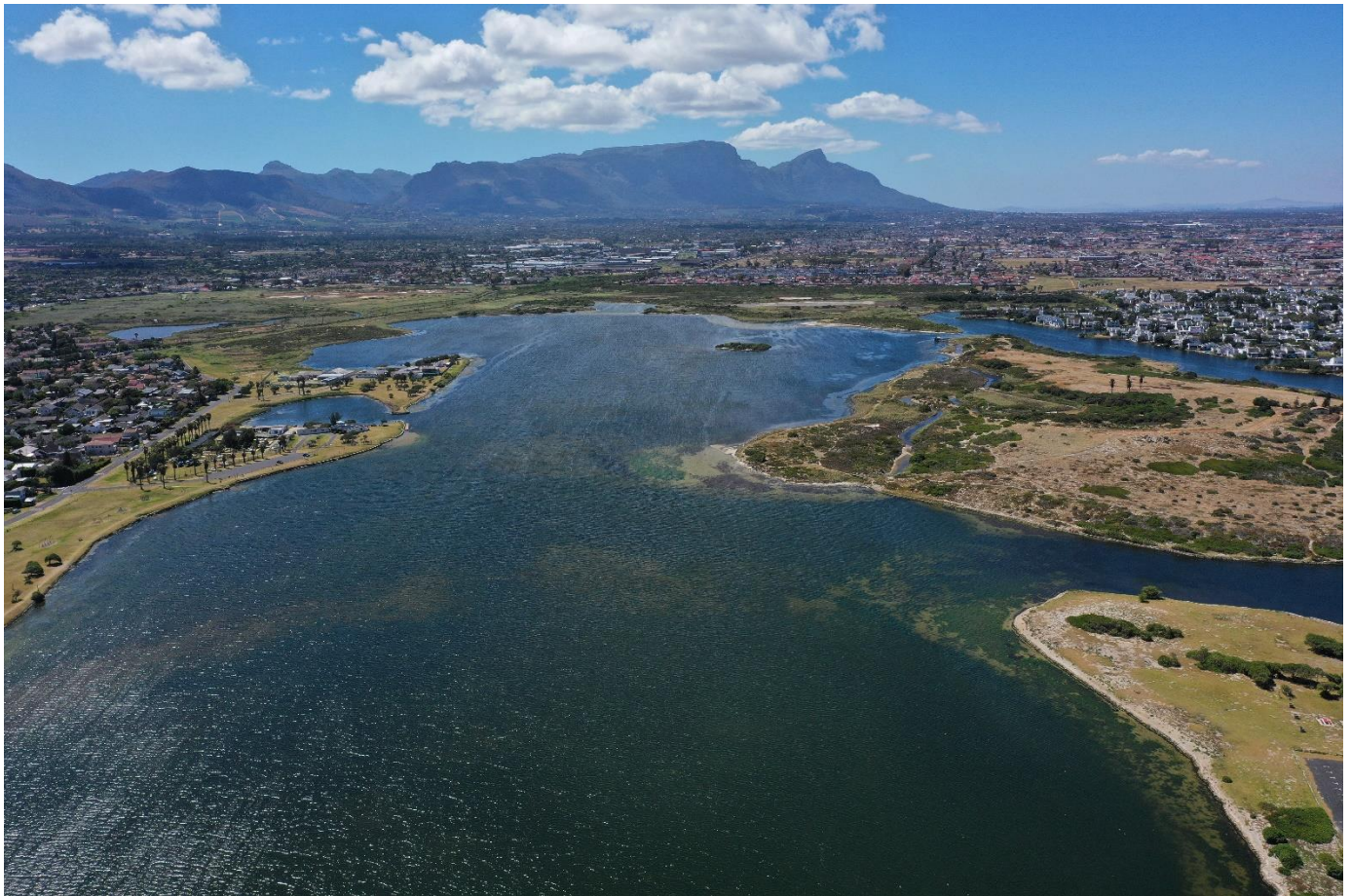




CITY OF CAPE TOWN
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CITY OF CAPE TOWN INLAND WATER QUALITY REPORT FOR THE PERIOD APRIL 2020 TO MARCH 2022 (2020 AND 2021 REPORTING PERIODS)



FINAL

MAY 2023

TECHNICAL REPORT

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READER GUIDE

Not everyone will have the time or inclination to read through all of the details of water quality analyses and interpretation that are presented in this report, and which are necessary to inform the contents of the simple summary overview report that is planned to follow, later in the year.

In the meantime, however, those interested in particular aspects of water quality and not wanting to read the report in detail should refer to the following Reader Guide to navigate the report more quickly:

- **Section 2** where **Figure 2.1** shows the locations of all of the subcatchments included in the CCT's area and referred to throughout this report;
- **Section 3** where **Section 3.7** provides an explanation of the water quality categories that are used in this report;
- **Section 4** for a discussion of rainfall data;
- **Section 5**, where the colour-coded compliance graphs give a quick visual overview of which subcatchments or listed vleis and other standing water areas had water quality that generally met or failed to meet Target criteria. These graphs are presented towards the end of each of the subsections on phosphate and nitrogen enrichment; ammonia; dissolved oxygen; chlorophyll-*a* and *E. coli*;
- **Section 6** for discussions around the condition of CCT's main recreational vleis, and their condition with regard to human health;
- **Section 7** for a brief overview of some of CCT's current and planned programmes to address water quality in the city and/or improve other aspects of watercourse condition;
- **Section 8** focuses on CCT's Priority Catchments, and provides brief, illustrated descriptions of the main factors affecting water quality in these catchments. Most usefully in this section are maps showing each priority catchment (and the surrounding area) with the locations of routine water sampling points in the map colour coded to represent the water quality category assigned to annual data for three key variables, namely phosphate (as PO₄-P), ammonia (as NH₃) and *E. coli*;
- **Section 9** summarises the main findings and recommendations of the report as a whole;
- **Appendix A** presents a table showing the locations and site codes for all of the sample points, in their different subcatchments;
- **Appendix C** presents summary annual data for key water quality variables for each sample point. These have been colour coded for ease of interpretation and allow readers to look up data relating to particular monitoring points of interest.

EXECUTIVE SUMMARY OF THE TECHNICAL REPORT

E1 INTRODUCTION

E1.1 Background

Water quality in rivers, wetlands and open waterbodies (vleis) reflects the condition of their catchments. In urban areas, water quality data for these ecosystems are therefore a useful indicator of the efficacy of a city's management strategies. Poor water quality in watercourses that are located in urban areas can have profound consequences for human health, tourism and recreational value, and biodiversity. This is the rationale for the City of Cape Town's (CCT) water quality monitoring programme, which monitors the quality of water in both inland and coastal waters.

The present report considers the quality of water in the CCT's inland watercourses— that is, in its rivers, major vleis, coastal lakes, and estuaries. The report focuses on water quality data for the period April 2020 to March 2021. In order to give these data context, they are analysed against a backdrop of data going back to April 2017.

E1.2 City catchments and the CCT's priority subcatchment areas

Cape Town's numerous watercourses drain 17 major subcatchment areas, as shown in **Figure E1**. The CCT manages these subcatchments through so-called Stormwater Planning Regions. There are four such regions, comprising a Northern, Southern, Eastern, and Central and Western region. Each region has a separate manager responsible for stormwater management in that region. Stormwater planning regions cut across subcatchments, with some subcatchments having up to three stormwater managers.

Based on previous monitoring data, six priority subcatchment areas have been identified by the CCT for focused interventions intended to improve river and wetland ecosystem function, and hence improve water quality.

The priority subcatchments are:

- The Lower Diep River (upstream of Milnerton Lagoon)
- The Soet River
- The Salt River
- The Kuils / Eerste Rivers
- The Hout Bay River
- The Big and Little Lotus Rivers (within the Zeekoe catchment)

The Sand subcatchment (upstream of Zandvlei) has recently been earmarked as an additional priority subcatchment, given the CCT's roll-out of river and wetland rehabilitation in that subcatchment and the sewage-related pollution problems that have been experienced in recent years in Zandvlei, which is an important recreational vlei in the city.

E1.3 Monitoring points in the CCT's Inland Water Quality Monitoring Programme

The CCT's water quality monitoring programme is designed primarily to monitor changes in watercourses where water quality is likely to be a cause for concern. Many of the monitoring points are therefore downstream of WWTW effluent discharge points, and in river reaches in catchments where runoff is likely to be contaminated. Some sampling points are located in watercourses that are used for religious rituals (e.g. baptisms) and/or recreational purposes (e.g. sailing, rowing, kayaking). Water quality data for such systems are used to provide information as to the fitness for use of these systems.

In total, the CCT's Inland Water Quality Monitoring Programme includes 162 routine monitoring points spread across most of the catchments in the city. These monitoring points are, made up of 10 canal sites, 4 artificial dam / impoundment sites, 3 detention ponds, 1 effluent outlet channel, 19 estuary sites, 92 river sites, 5 stormwater outlets and 28 vlei / wetland sites.

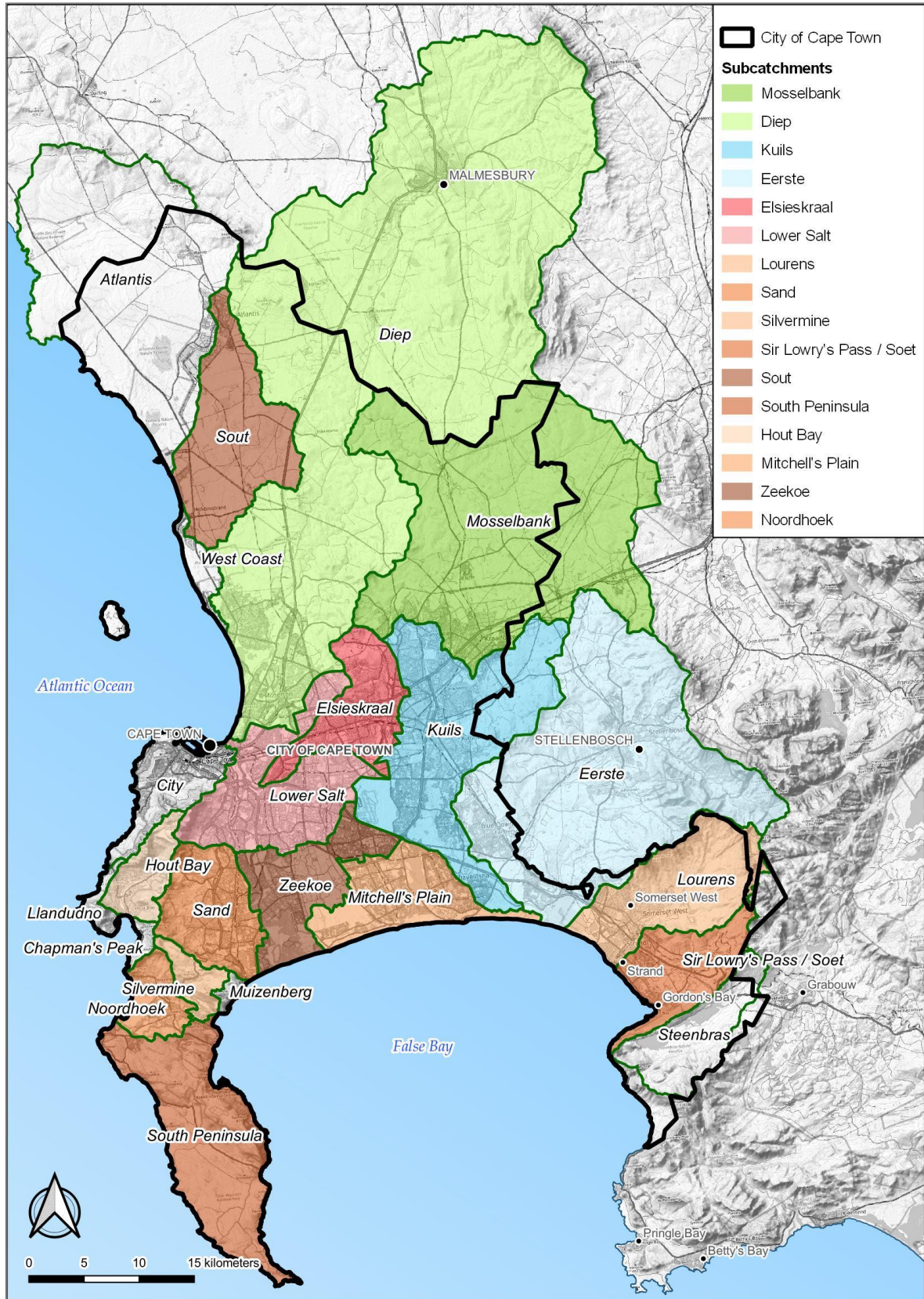


Figure E.1
Major subcatchments and watercourses in Cape Town

E1.4 Water quality variables and reporting periods considered in this report

Although the CCT analyses a wide range of water quality variables, only those considered the most important general indicators of urban aquatic ecosystem health and human health risk are assessed in the Inland Water Quality Report. These are:

- Major nutrients – phosphate (abbreviated PO₄-P) and Total Inorganic Nitrogen (TIN)
- Un-ionised (or 'free') ammonia (NH₃) (abbreviated as NH₃)
- Dissolved oxygen (DO)
- *Escherichia coli* bacteria (*E. coli*) and intestinal enterococci bacteria
- Microcystin concentration
- Chlorophyll-a (Chl-a)
- pH as an indicator of ammonia toxicity risk
- Electrical conductivity (EC) as a measure of salinity, specifically for vlei systems in the City that were delineated as estuaries in the Berg RQO study.

Annual water quality reporting periods comprise the period from 1 April to 31 March in any given cycle, and are given the YEAR identity at the start of the period. Data for the period 1 April 2020 to 31 March 2021 are accordingly referred to as the 2020 dataset.

This report focuses on the 2020 and 2021 datasets or reporting periods.

E1.5 Water quality thresholds to guide data interpretation

Water quality data are interpreted with regard to a number of thresholds for different states or categories of aquatic ecosystem condition and human health risk. These are presented in Tables E1.1-E1.5 for different groups of variables. The indices were developed for the 2020 Inland Water Quality Report and are based on thresholds used in the Gazetted Resource Quality Objectives (RQOs) for the Berg Catchment, the water resource management area into which Cape Town's watercourses fall (GN 1179 of November 2020). The ecological thresholds differ slightly between different watercourse types, and the CCT's data have been classified in terms of standing water systems (e.g. vleis, dams) and flowing water systems (e.g. rivers, stormwater channels).

Enterococci data thresholds, introduced for the first time in this report, have been taken from the coastal water quality monitoring report and DEA (2012).

Table E1.1

Rating ranges for variables considered in this assessment of water quality in rivers

Note: PO₄-P = phosphate phosphorus; TIN=Total inorganic nitrogen; DO=Dissolved oxygen; N:P= ratio of TIN:PO₄-P; NH₃ = un-ionised ammonia. Note also that the terms 'PO₄-P', 'NH₃' are abbreviations and are not the full chemical notation for these ionic compounds

City Water Quality Categories (CWQC)	Interpretation of CWQC	PO ₄ -P mg/l	TIN mg/l	DO mg/l	N:P	NH ₃ mg/l
GOOD	Target	< 0.025 (oligotrophic)	>0.25-0.70 (oligotrophic - mesotrophic)	> 6	>25	0.015-0.044
FAIR		>0.025-- 0.075 (mesotrophic)	>0.70-1.75 (mesotrophic)			>0.044 - 0.072
POOR	Poor	>0.075- 0.125 (eutrophic)	>1.75-3.00 (mesotrophic - eutrophic)	≥4 -6	10-25	>0.072-0.1
UNACCEPTABLE	Unacceptable	>0.125 (hypertrophic)	> 3.00 (eutrophic - concentrations > 10mg/L classified as hypertrophic)	< 4	< 10	>0.1

Table E1.2

Rating ranges for variables considered in this assessment of water quality in vleis and dams

Note: PO4-P = phosphate phosphorus; TIN=Total inorganic nitrogen; DO=Dissolved oxygen; N:P= ratio of TIN:PO4P; NH3 = un-ionised ammonia; Chl-a= Chlorophyll-a. Note also that the terms 'PO4-P', 'NH3' are abbreviations and are not the full chemical notation for these ionic compounds

City Water Quality Categories (CWQC)	Interpretation of CWQC	PO4-P mg/l	TIN	DO mg/l	N:P	NH3 mg/l	RUNNING MEAN ANNUAL Chl-a µg/l
GOOD	Target	≤ 0.005 (oligotrophic)	≤ 0.7	> 6	>25	< 0.015	≤ 5
FAIR		>0.005-- 0.015 (mesotrophic)	>0.7 -1			0.015-0.044	>5 - 10
POOR	Poor	>0.015 - 0.025 (eutrophic)	>1.0-4.0	≥4 -6	10-25	>0.044 - 0.072	>10 -20
UNACCEPTABLE	Unacceptable	>0.025 (hypertrophic)	> 4	< 4	<10	>0.072-0.1	> 20 - 30
						>0.1	> 30

Table E1.3

Approach to assessment of microbial data (faecal coliforms including *Escherichia coli*)

Note inclusion of Full Contact and Intermediate Contact thresholds

Interpretation	Inland systems ¹ Faecal Coliform Count (Including <i>E. coli</i>) ¹
TARGET for maximum acceptable risk for full contact recreation	≤ 400 cfu/100 ml
ACCEPTABLE RISK intermediate contact	1 001 – 2 500 cfu/100 ml
TOLERABLE Risk - intermediate contact	> 2 500 – 4 000 cfu/100 ml
UNACCEPTABLE Risk – intermediate contact	> 4 000 cfu/100 ml

¹ The concentrations of bacteria in water is usually expressed as numbers of colony-forming units (cfu) per 100 ml, which is a measure of the number of viable cells in a particular sample, where a colony represents an aggregate of cells derived from a single progenitor cell

Table E1.4

Approach to assessment of microbial data (intestinal enterococci counts)

Percentile data calculated using the Hazen Method. Water quality categories as used in the CCT's Coastal Water Quality Reporting . Single sample ratings from DEA (2012)

Interpretation	Descriptor in Coastal Water Quality Reporting	Estimated risk of illness per exposure ²	Enterococci (cfu/100 ml)	Enterococci (cfu/100 ml) - single samples
TARGET	Excellent	< .9% Gastrointestinal Illness (GI) risk	< 100 (95 th percentile)	
ACCEPTABLE RISK intermediate contact	Good	<5% Gastrointestinal Illness (GI) risk	< 200 (95 th percentile)	≤240
TOLERABLE Risk - intermediate contact	Sufficient	<8.5% Gastrointestinal Illness (GI) risk	< 185 (90 th percentile)	240 – 380
UNACCEPTABLE Risk - intermediate contact	Poor	>8.5% Gastrointestinal Illness (GI) risk	≥ 185 (90 th percentile)	>380

² 'Exposure' defined as 10 minutes of swimming with three head immersions

Table E1.5

Risk thresholds and corresponding concentrations for microcystin toxins for inland waters used for this report.

Note that WHO (2021) provides an updated GV Recreation (GVRECREATION) Threshold of 24 µg/L for microcystins, below which recreational water use should be within acceptable risk limits. This suggests that the lower threshold for Medium Risk in the table is slightly conservative (i.e. it could be higher)

Interpretation	Microcystin concentration
TARGET (acceptable)	≤ 20 µg/L
MEDIUM risk (unacceptable)	>20- 30 µg/L
HIGH risk (unacceptable)	>30-40 µg/L
EXTREME risk (unacceptable)	>40 µg/L

E1.6 Treatment of unreliable *E. coli* data

Between April 2021 and January 2022, the CCT's Scientific Services Branch (SSB) reported *E. coli* data that led to the closure of Rietvlei, Zeekoevlei and Zandvlei over various periods. Following testing of replicate water samples at independent laboratories, it was noted that there was a serious discrepancy in results, with *E. coli* concentrations being over-reported in the SSB data.

As a result of the above findings, the SSB has switched analytical methods, and now uses the Colilert system for *E. coli* analyses. Given these issues, the *E. coli* data for the entire 2021 reporting year could not be used in this report, and only the 2020 reporting year data are referenced. In addition, reporting on *E. coli* data over the 2020 reporting period included relatively large numbers of data reported as ">x" where "x" ranged between 200 and 100 000 000. Such reporting methods for relatively low *E. coli* counts are problematic in that they provide no gauge as to the scale of sewage pollution and do not allow useful comparisons between samples. As a result of these data issues, *E. coli* data were analysed mainly as compliance data rather than through the use of rigorous statistics.

E2 CURRENT STATE AND TRAJECTORIES OF CHANGE IN WATER QUALITY IN THE CCT'S MAJOR WATERCOURSES**E2.1 Major nutrients (phosphorus and nitrogen)****E2.1.1 Sources of nutrients**

Many of Cape Town's watercourses have been impacted by excessive nutrients, mainly phosphorus. The main sources of these nutrients are as follows:

- Inputs of treated sewage effluent from any of the CCT's 13 WWTWs that discharge treated effluent into inland watercourses or estuaries
- Overflows from sewage pump stations and/or low-lying sewer manholes into the stormwater system as a result of load-shedding, mechanical/electrical failures or blockages
- Runoff from catchment areas with high levels of backyard or informal settlements, where the stormwater system is used to dispose of and becomes contaminated with, human waste
- Illegal discharges into the stormwater system
- Runoff from fertilised gardens and parks
- Runoff from agricultural areas
- Recycling of decomposing sediments from bottom waters in lakes and dams.

E2.1.2 Phosphorus enrichment in Cape Town's watercourses

Assessment of the 2020 and 2021 water quality datasets showed that phosphate enrichment was probably the most significant factor impacting on the CCT's inland aquatic ecosystems over these reporting periods, with over 70% of water quality samples collected from both rivers / stormwater systems and vleis / detention ponds lying in the Unacceptable range for this variable. Phosphorus enrichment is likely to drive excessive plant growth and periodic algal blooms that threaten

recreational use of waterbodies and at times give rise to fish die-offs as a result of anoxic conditions associated with the rapid build-up of algae. Phosphorus enrichment also leads to high management costs, because of the need for removal of reeds and aquatic weeds from many waterbodies.

Data for the 2020 and 2021 reporting periods furthermore indicate a general increase in phosphorus enrichment over these periods in many subcatchments and standing waterbodies, indicating a trajectory of decline in ecosystem condition over this time. The data do, however, show a high degree of scatter in phosphate concentrations within subcatchments, pointing to both episodic point-source driven pollution as well as a range of watercourses in different condition within the subcatchments, with some more prone to receipt of severely contaminated water at times than others.

Arguably, subcatchments in a generally good condition (i.e. where target thresholds were usually met), should be safeguarded, with high attention paid to addressing sources of periodic pollutant inflows into these systems. Such an approach would at least ensure that some subcatchments remain in a relatively good condition. These include the Silvermine, Lourens, Hout Bay, South Peninsula and Sand subcatchments. None of these subcatchments receive WWTW effluent, and only the Hout Bay subcatchment receives significant runoff from poorly serviced informal settlements. The Silvermine and Lourens River subcatchments were consistently the least impacted subcatchments in monitored areas of the City.

The subcatchments subjected to the highest levels of phosphorus enrichment (with median values almost 50 times higher than the Unacceptable threshold value) comprised the Sout catchment in the 2021 reporting period, followed by the Lower Salt, Diep, Mosselbank, Eerste, Soet and Zeekoe subcatchments, in descending order of degradation. Land use in all of these subcatchments includes areas of poorly serviced informal settlement with high levels of disposal of raw sewage and other organic waste into watercourses, and/or receipt of at times inadequately treated sewage effluent from WWTWs.

E2.1.3 Nitrogen enrichment in Cape Town's watercourses

Slightly higher levels of compliance with the Target threshold were observed for Total Inorganic Nitrogen (TIN) concentrations than for phosphate concentrations during the 2020 and 2021 reporting years. Nevertheless, 60% of water quality samples from routinely monitored sites were rated Unacceptable in terms of TIN concentrations and, in at least some subcatchments, nitrogen enrichment was at ecologically highly problematic levels. Subcatchments where nitrogen enrichment was most pronounced comprised the Diep, Mosselbank, Kuils, Eerste, Lower Salt and Soet subcatchments, with samples from the latter always being in the Unacceptable range. This subcatchment has high levels of sewage inflows, and low levels of oxygenation. Under such conditions, important nitrification processes are often inhibited, and total ammonia can be the dominant form of nitrogen.

Thus, while phosphorus is considered more problematic than nitrogen in driving ecosystem responses to eutrophication (e.g. rapid plant growth including algae and reeds), nitrogen enrichment was also at levels of concern in many parts of the CCT's watercourses. Where nitrogen was primarily in the form of total ammonia (comprising ammonium ions and un-ionised ammonia), it could potentially also be problematic from the perspective of aquatic toxicity.

E2.2 Chlorophyll-a

Elevated chlorophyll-a concentrations, indicative of high algal concentrations typically as a result of nutrient enrichment (particularly by phosphates) can have serious consequences. Algae have rapid turnover rates and dead algal cells accumulate on lake bottoms, over time forming thick layers of organic sediments. Not only can the nutrients stored in these sediments become available to the waterbody again over time (e.g. if feeding carp or wind action stirs them up), but they also form very low quality, oxygen-depleted aquatic habitats. The algal blooms themselves are also problematic. High phosphate concentrations often support blue-green algae. In Cape Town, most blue-green algae is of the genus *Microcystis*, which produces a distinctive foul smell under bloom conditions. It can also release toxins under these conditions, affecting the fitness of the waterbodies for human recreational use, and affecting livestock and other animals that drink or swim in it.

The CCT monitors chlorophyll-*a* in many of its standing water systems. Analysis of these data resulted in the following key findings:

- The most problematic systems, where the risk of algal blooms would have been high during the 2020 and 2021 reporting periods, were Zeekoevlei and Wildevleivlei;
- Langevlei and Princessvlei were also problematic, with more than 70% of the samples in the Unacceptable category for Chl-*a* for all three reporting periods;
- Relatively high levels of non-compliance were also recorded for Rietvlei and Westlake in Reporting Year 2021, and for Die Oog in Reporting Year 2020;
- The situation was significantly worse in Princessvlei, Rondevlei and Zeekoevlei in Reporting Year 2021, compared to Reporting Year 2020, especially during summer in the case of Princessvlei and Rondevlei, and only during winter in the case of Zeekoevlei;
- The least problematic systems in terms of algal production were Glencairnvlei and the Elsiekraal dams, which are characterised by relatively low nutrient inputs;
- Relatively low chlorophyll-*a* concentrations predominated in Zandvlei and Little Princessvlei through most of the reporting period under consideration;
- There was a significant improvement in the situation at Die Oog in Reporting Year 2021 compared to previous years, especially during summer.

E2.3 Dissolved oxygen

Oxygen is critical for the respiration of all aerobic organisms and, in aquatic ecosystems, adequate supplies of dissolved oxygen are needed for the survival of all non-air-breathing organisms.

The dissolved oxygen (DO) data assessed in this report suggest that extremely low DO concentrations in the Unacceptable category were not as pervasive a problem as elevated nutrient concentrations in the CCT during the reporting periods, with 20-25% of the samples (from all flowing and standing water sites) being in the Unacceptable category for this variable. There are systems, however, which were characterised by low DO concentrations, either consistently or intermittently – these were generally rivers or channels, where water quality was typically more impacted than most of the large vleis / standing water systems.

For flowing systems, the results indicate generally poor water quality with respect to DO, with more than half the measurements collected over the five-year period from 2017 to 2021/22 consistently being reflective of Poor to Unacceptable conditions. Conditions in the Soet catchment were particularly bad in Reporting Year 2021 in terms of DO measurements, with approximately 65% of the samples falling within the Unacceptable category.

The least problematic subcatchments with respect to DO concentrations at monitored flowing water sites were, unsurprisingly, the more rural Elsiekraal subcatchment and the Lourens, Sir Lowry's Pass and Silvermine subcatchments, all of which include less-impacted upper river sites. For all the reporting periods considered in the current report, most of the DO measurements collected in these subcatchments were above the Target threshold. Other subcatchments with relatively good conditions were the Sand, Kuils, South Peninsula and Hout Bay subcatchments.

For standing water systems, the Mew Way and Mitchell's Plain detention ponds (DP) were in the worst condition, being characterised by a prevalence of very low dissolved oxygen concentrations, highlighting the need for oxygenation of these stormwater ponds to improve their functionality in dealing with nutrient-enriched inputs, in conjunction with catchment-scale clean-ups.

The standing waterbodies with the best conditions in terms of DO concentrations over the reporting periods considered in the current report were Rietvlei, Westlake, Princessvlei, Zeekoevlei, Zandvlei, Die Oog and Langevlei. For these systems, the DO concentrations were consistently in the Target category for all three reporting periods.

E2.4 Ammonia toxicity

In an aquatic environment, the relative proportion of un-ionised ammonia to ammonium ions in water is controlled primarily by pH and temperature. At pH >8, a significantly larger proportion of total ammonia ions are present in their un-ionised form (also called “free ammonia”), which may give rise to acute toxicity at concentrations as low as 0.1 mg N/L (DWAf 1996a). Low-oxygen conditions would tend to increase the availability of reduced nitrogen forms such as ammonia, rather than more stable nitrates.

Prolonged exposure to un-ionised ammonia at chronic toxicity levels (Poor category) could affect aquatic organism fecundity, general health and resilience, while exposure to elevated levels associated with acute toxicity (Unacceptable category) could result in the death of more sensitive organisms.

Free ammonia data (abbreviated in the report as NH₃) were analysed along with pH data. Key findings were as follows:

- Potentially toxic conditions from elevated NH₃ concentrations were more prevalent in flowing water systems than they were for standing water systems. Some 35% of samples for the former fell outside of the Target range versus approximately 20% of standing water samples for all of the assessed reporting periods. This is in part because of some dilution effect of large waterbodies and natural assimilation, uptake and nitrification processes in these systems, up to certain limits. However, the data mainly reflect standing waterbodies in relatively less polluted subcatchments;
- Ammonia toxicity would have been exacerbated further in the monitored flowing water systems because these systems were also generally more prone to low DO levels than the monitored standing water systems, thus limiting nitrification cycles;
- There were, however, a number of subcatchments for which ammonia toxicity was not an issue of concern for monitored flowing water systems, namely the Lourens, Sout, Hout Bay, Silvermine, Sir Lowry's Pass, Sand and South Peninsula subcatchments;
- Of the above, systems with naturally low pH (e.g. Hout Bay River) were somewhat buffered from ammonia toxicity, despite some river reaches with high total ammonia concentrations;
- There were also a number of monitored standing water systems for which ammonia toxicity was not an issue, namely Rietvlei, Rondevlei, Zandvlei, Die Oog, Glencairnvlei, Little Princessvlei, Princessvlei and the Elsieskraal dams;
- The most problematic subcatchment, in terms of the potential for ammonia toxicity, was again the Soet, where >80% of the samples collected in all three reporting periods had NH₃ concentrations in the Unacceptable category (increasing to >90% in Reporting Year 2020);
- All other monitored watercourses showed at least periodic episodes of ammonia toxicity, which would affect remnant sensitive fauna, if any remain.

E2.5 *Escherichia coli* as an indicator of sewage contamination

Escherichia coli measurements are used primarily as an indicator of human health risk, particularly for drinking or recreational use of a waterbody. However, the data also highlight point-sources of pollution into watercourses, where elevated *E. coli* is an indicator of contamination from untreated sewage, usually from overflows from manholes or sewage pump stations, or from inflows from backyard or informal settlements.

The report assessed both *E. coli* data (not available for the 2021 reporting period) and other evidence of sewage overflows, including the CCT's C3 sewage overflow complaint data and internal reporting data on sewage pump stations overflows / breakdowns. The latter, in particular, is a valuable new source of data that the CCT has started collating in a manner specifically designed to allow for analysis and interpretation at a subcatchment level.

Drawing on all of these sources of data, the report found that:

- Contamination of the City's rivers and stormwater channels by raw sewage is rife, with 48% of

river samples falling within the Unacceptable range for *E. coli* over the 2020 monitoring period, as was the case for the 2017-2019 monitoring period;

- Some of the affected systems are used for recreational purposes and in many of the poorest areas of the City, rivers and wetlands are used as play areas by children;
- The most polluted subcatchments comprised the Soet and Lower Salt subcatchments. These subcatchments should form the subject of intensive pollution abatement efforts by the CCT, focusing on both solid waste removal and the diversion and acceptable disposal of raw sewage before it enters watercourses;
- Only 46% of monitored watercourses fell within the Target range for *E. coli* over the 2020 monitoring period;
- The main sources of raw sewage seem to have comprised overflows from pump stations or low-lying manholes and disposal of sewage into stormwater drains or open channels in unserved informal settlements;
- Pump station overflows appear to have been most numerous in the Lower Salt, Zeekoe and Diep subcatchments, all of which received, in addition to frequent minor spills, between two and five major events, deemed likely to have resulted in significant pollution to sensitive receiving environments. Most pump station overflows in the period included in the dataset were the result of mechanical failure, mains supply faults, pump tripping and electrical failure. Load shedding accounted for just 4.7% of the 327 listed incidents over this period, and theft for 4.0%;
- Data for C3 reporting on sewage spills provided another estimate of areas most subject to sewage overflows. The areas mapped as 'hot spots' on this basis were mostly characterised by high levels of informal settlement and/or backyard dwellings, and accumulations of solid waste on streets and along channels. This could contribute to the frequency of sewer blockage, along with an increased likelihood of vandalism of sewers and pump stations as a result of a range of socio-economic and other issues;
- While data show that the City's river and stormwater systems were often polluted with raw sewage, *E. coli* bacteria were generally present in much lower concentrations in most monitored standing waterbodies (e.g. vleis and dams), with over 80% of standing waterbodies lying within the Acceptable risk range for this variable. This does, however, reflect both dilution by large waterbodies and the effect of increased detention time in allowing *E. coli* die-off in monitored vleis and dams, and does not necessarily indicate reduced sewage exposure in these systems;
- No reliable *E. coli* data were available for the 2021 reporting period, which is a significant gap in reporting history. However, on the basis of C3 data and pump station failure counts, it is evident that raw sewage overflows continued to be a major issue in the 2021 reporting year, and it is moreover known that vleis such as Zeekoevlei, Zandvlei, Milnerton lagoon and the Big Lotus River were among those systems known to have received large volumes of untreated sewage effluent at times. These are assumed to have contributed to ecosystem degradation;
- In order to improve confidence in *E. coli* monitoring data, it is recommended that the SSB submit replicate samples for 10% of water samples to at least three independent accredited laboratories, for analysis over the next 6 months, to show that the data lie within the same general range, noting that some differences between laboratories would be expected.

E3 CURRENT STATE OF RECREATIONAL WATERS

This section was included in the report to deal specifically with the current state of established recreational waterbodies in Cape Town from the perspective of the risk, if any, that they pose to human health. Five main waterbodies have been considered, namely:

- Rietvlei
- Milnerton Lagoon
- Princessvlei
- Zeekoevlei
- Zandvlei

With the exception of Princessvlei, these vleis and estuaries are used for various water sport activities, including sailing, kayaking, canoeing, fishing, kite-boarding, skiing, wind-surfing, rowing, and fishing. All of these activities expose users to some level of health risk if water quality is compromised.

The report considered two human health risk indicators (that is, *E. coli* and enterococci concentrations) and microcystin toxicity. The latter is a toxin produced at times by *Microcystis* algae under bloom conditions. All the assessments assume intermediate contact use only – that is, excluding swimming.

Drawing on these data, the report made the following findings:

- For the 2020 reporting period, assessed using *E. coli* data:
 - Faecal contamination tended to be greater in winter than summer, with all assessed recreational bodies showing fewer samples within the Target range for *E. coli* in winter than in summer. To some extent, this is assumed to reflect surface wash-off from contaminated terrestrial areas during rainfall events, with runoff from informal settlements in particular often flushing out accumulated waste in channels and drains. However, a more common cause of elevated *E. coli* in particular in winter stems from sewer and pump station overflows and surcharges, which are all more likely in the wet season, when many sewers have excess stormwater ingress;
 - Milnerton Lagoon was the worst-performing of the recreational waterbodies, showing a marked increase in samples rated as Unacceptable in winter 2020 (over 60%). Over the 2020 and 2021 reporting periods, the lagoon received water from a problematic upstream catchment, including inflows from a poorly performing WWTW, polluted surface flows from extensive areas of informal and backyard settlements, and repeated overflows of sewage from pump stations and low-lying manholes;
 - Zandvlei also showed an increase in periods of Unacceptable levels of *E. coli* contamination in 2020, in both summer and winter, with 15% and 35% of samples collected in summer and winter of reporting period 2020, respectively, being Unacceptable from a human health perspective. These data again most likely reflect an increased frequency of pump station overflows during that period, since the subcatchment has relatively limited areas of unserved informal settlement;
 - The other vleis were all subject to periodic sewage contamination that resulted in Unacceptable levels of *E. coli* contamination. These amounted to some 12% of samples in Zeekoevlei, in both the 2017-2019 and the 2020 reporting periods, and less than 10% of samples in the other recreational waterbodies. Zeekoevlei is routinely closed to most recreational use for much of the wet season in any case, as a result of annual draw-down of its water for management purposes;
 - Water quality improved in Princessvlei over the 2020 reporting period, with 100% of samples being within Target range;
- Overflows of sewage from pump stations and manholes affected all of the monitored vleis at some time over the 2020 and 2021 reporting periods;

- For the 2021 reporting period (based on enterococci data):
 - When analysed using the 95th and 90th percentiles for enterococci data, as recommended by WHO (2021), the results show very high levels of Unacceptability across all recreational vleis. This is in part driven by the impacts of (usually) short-term sewage overflows, which substantially extend the upper range of the data. Repeated sampling of waterbodies during and after sewage spills exacerbates this effect;
 - Milnerton Lagoon was the recreational waterbody worst impacted by sewage inflows, assumed to come from water flushed in from extensive informal settlements upstream, particularly in winter, as well as from blocked or overflowing sewage pump stations in the catchment;
 - Sewage contamination was again generally worse in winter, across all recreational waterbodies except Princessvlei;
- With regard to the risk of exposure to microcystin at toxic concentrations:
 - Rietvlei, Zandvlei and Zeekoevlei all experienced more frequent blue-green algal blooms in the 2021 reporting year than in the previous year, reflecting hypertrophic conditions as a result of phosphate enrichment;
 - Despite an increase in algal blooms in these three vleis, none appeared to experience microcystin toxins at levels likely to pose risks to human health, at least at the times and areas of sampling;
- Additional monitoring points for enterococci are recommended at RTV18 (Milnerton Lagoon) and in the Kuils River wetlands at the Khayelitsha Wetland Park, where the Khayelitsha Canoe Club is based. Ideally, enterococci should be monitored from all of the routine water quality monitoring points, so that a full enterococci dataset is available.

E4 CITY PROGRAMMES TO IMPROVE WATER QUALITY

In its Water Strategy, finalised in February 2020, the CCT made a commitment to facilitate Cape Town's transition by 2040 to a water-sensitive city with diverse water resources and water infrastructure, making optimal use of stormwater and urban waterways for flood control, aquifer recharge, water reuse and recreation, according to sound ecological principles. It stated that this would be done through new incentives and regulatory mechanisms, as well as through the way it invests in new infrastructure.

The overarching vision is that Cape Town will become a city that optimises and integrates the management of water resources to improve resilience, competitiveness and livability for the prosperity of its people. Achieving the vision will require a shift to water-sensitive urban design that encompasses all aspects of integrated urban water cycle management, including water supply, sewerage and stormwater management. Given that protecting water quality and natural ecosystems are fundamental principles of water-sensitive urban design, the CCT is obliged to take steps to address water pollution and rehabilitate waterways where possible.

Since the previous inland water quality report, the CCT has taken a number of initiatives, with a view to moving towards the above vision. The present report provides brief information on the following CCT programmes:

- The **Water Quality Improvement Programme (WQIP)**, which was formulated in 2020 and includes Pollution Abatement Strategies & Action Plans (PASAPS) that set out the strategies to address pollution and poor water quality on a river catchment or subcatchment basis, as well as Transversal Action Plans (TAPs) outlining short- to long-term interventions and projects across various directorates and work streams;
- The **Mayor's Priority Programme (MPP) on Sanitation and Inland Water Quality**, which will initially focus on six priority catchments that have been identified as having significant challenges with regards to water quality, namely the Diep River, Soet River, Salt River,

Eerste/Kuils River and Hout Bay River catchments, and the Big and Little Lotus Rivers of the Zeekoevlei catchment. The MPP includes the PASAPS of the WQIP under the MPP Work Stream: Pollution of Waterways. The four other Work Streams are: Sewer Network Spills, Pump Station Performance, Wastewater Treatment Capacity, and Communication and Partnership, each with their own sub-programmes and projects. The MPP is intended to improve the quality of life of the City's residents, reduce the impact of sewage spills and wastewater effluent on the environment, and improve reliability of infrastructure;

- The **Livable Urban Waterways (LUW) Programme**, which is a strategic and transversal programme developed by the CCT in response to the Water Strategy, Resilience Strategy and Environment Strategy. The programme will demonstrate how water sensitive design, waterway rehabilitation and a new approach to waterway management can achieve multiple benefits for society, the environment and the economy. The pilot phase of the LUW Programme focuses on the Sand River catchment, where several project sites, divided into five work packages, have been identified. These projects will be used to test different rehabilitation typologies and water sensitive design approaches, to develop and foster cross-departmental collaboration and planning within the CCT, and to co-design appropriate solutions with communities who live near the waterways or who use the space. Additional LUW projects are also in early planning stages on the Vygekraal River (Lower Salt subcatchment), and the Big and Little Lotus Rivers (Zeekoe catchment).

E5 WATER QUALITY IN PRIORITY CATCHMENTS ADDRESSED BY THE CCT'S WATER QUALITY IMPROVEMENT PROGRAMMES

The various CCT programmes to improve water quality and general watercourse condition focus on the six priority subcatchment areas listed above, as well as the Sand catchment following the commencement of the LUW programme in the latter. Water quality issues, concerns and interventions by the CCT are outlined for each of the seven focal catchments in the report, and were used to draw together the following key conclusions and recommendations:

- All of the MPP's priority catchments include runoff from informal settlements with poor access to sewerage systems. This means that water quality in stormwater systems is in many areas compromised, to levels where standard application of Sustainable Urban Drainage Systems (SUDS) and other stormwater quality polishing / improvement approaches are unlikely to be effective.
- The accumulation of solid waste is also rife in many areas of the City, particularly in low-income areas. This waste passes readily into stormwater systems, from where it is costly to remove. It also blocks or is used to vandalise sewage pipes and pump stations, resulting in added watercourse pollution. Addressing this issue through significantly ramped-up solid waste collection is strongly recommended;
- The LUW projects had just commenced or were in planning stages at the time of writing this report. Their impacts on water quality are not therefore reflected in the data reported on here, which only extend to March 2022. Those projects undertaken in less polluted priority catchments such as the Sand, which is not affected by high nutrient loading from any WWTWs or major informal settlements, could well show measurable water quality impacts as a result of improved water quality polishing, provided that issues such as pump station failure and sewer overflows are addressed in parallel, through ongoing pro-active sewer maintenance. LUW projects in areas challenged by more impacted water quality will need to be pragmatic and also consider linked issues such as solid waste and sources of raw sewage in the catchments if they are to achieve measurable water quality results;
- Implementation of the PASAPs and TAPs of the CCT's are most likely to result in measurable change in water quality in the priority subcatchments because they focus on the core issues affecting water quality through these areas – namely solid waste, runoff of black and grey water from informal and backyard settlements, and poorly performing WWTWs. The implementation of these action plans does, however, require interventions to be undertaken

across numerous CCT Directorates and therefore rests on adequate funding, effective communication, commitment and urgency across multiple CCT structures. Addressing these issues is likely to be complex and not achievable in the short-term;

- Actual roll-out and implementation of PASAPs and TAPs should, however, commence with more urgency if measurable impacts are to be achieved;
- The CCT's current stormwater management system results in some subcatchments extending across two or more Stormwater Planning Regions. This means that different Catchment Planners are responsible for different river reaches or catchment areas, making integration of projects and responsibilities difficult, and accountability for catchment condition unwieldy;
- Similarly, sewage reticulation activities are also not carried out on a (river) catchment basis – this again means that efforts in one part of a reticulation zone may be negated by a lack of co-ordination with upstream managers, or different strategies and level of effort in different areas;
- In non-priority catchments or parts of catchments that are not subject to high levels of sewage-impacted stormwater, the CCT is encouraged to implement or require implementation of SUDS-type interventions and implement pollution tracking when water quality deterioration is detected. These measures will help to maintain the current relatively good status of water quality in these subcatchments, namely:
 - The Silvermine subcatchment
 - The Lourens subcatchment
 - The South Peninsula subcatchment
 - The Liesbeek River catchment within the Lower Salt subcatchments.

E6 CONCLUSIONS AND RECOMMENDATIONS

E6.1 Overview of water quality in rivers and other waterbodies

Overall, analyses of water quality data and other complementary datasets highlighted the fact that, from an ecological perspective, **by far the most pervasive and problematic water quality issue almost throughout the CCT's monitored rivers and other watercourses was (and remains) phosphate enrichment**, with over 70% of all monitored systems being hypertrophic and in the range considered Unacceptable for this variable. More concerning still is the finding that, not only is phosphate enrichment a serious issue, but the 2020 and 2021 reporting periods saw a general increase in phosphorus concentrations in many subcatchments, indicating a trajectory of deterioration in ecosystem condition. In the 2021 reporting year, only 15% of the 2 287 samples analysed from river and stormwater channels fell within Target levels for phosphates.

In inland aquatic ecosystems, high phosphate availability results in excessive plant growth, promoting the growth of reeds, aquatic weeds (many of them invasive alien species) and algae. These come at high management costs, requiring ongoing removal or other management interventions, and affecting the fitness for use of some recreational waterbodies.

The most polluted subcatchments, characterised generally by high phosphate, ammonia and TIN concentrations and with low DO, without doubt comprised the Soet and Lower Salt subcatchments, both of which have deteriorated with regard to these key water quality variables since the 2017-2019 reporting period. Focusing on phosphate concentrations alone, other extremely poorly performing subcatchments comprised the Eerste, Kuils, Mosselbank, Diep and Sout, followed by the Zeekoe.

Nevertheless, some of the City's catchments were in relatively good condition with regards to water quality for aquatic ecosystems. These comprise (in order from least impacted) the Silvermine, Lourens and Hout Bay subcatchments, as well as the Liesbeek River catchment within the Lower Salt. The Hout Bay subcatchment is of particular interest from a management perspective. Most of its upper catchment monitoring points were in Target range for most key water quality variables assessed here. However, in its lower reaches, where the river is impacted by poor sanitation servicing in the extensive Imizamo Yethu settlement, water quality deteriorates rapidly to Unacceptable concentrations for

most variables, although naturally acidic waters reduce the threat of ammonia toxicity.

Of the monitored standing waterbodies, the most polluted (across all variables) comprised stormwater detention ponds in the Mitchell's Plain subcatchment, but large vleis (Zeekoevlei, Rietvlei and Wildevoelvlei) had consistently the worst performing water quality with regard to phosphate enrichment. Rietvlei showed serious deterioration over the 2020 and 2021 reporting periods. By contrast, Zandvlei at least showed improvement in most of its monitored variables over the 2020 reporting period.

A major contributor to the degradation of many of the City's watercourses was contamination with raw sewage. This assessment found that 48% of river samples were rated as Unacceptable for *E. coli* over the 2020 monitoring period – this was the same percentage as for the 2017-2019 monitoring period and reflects poor long-term city-wide compliance with water quality objectives.

E6.2 Key sources of pollution

The main drivers of aquatic ecosystem degradation, and phosphate enrichment in particular that persisted and in some cases worsened in the City's subcatchments over the 2020 and 2021 reporting period, appear to revolve primarily around the following:

- Inflows of treated effluent from WWTWs
- Periodic episodic overflows from sewage pump stations and surcharging manholes
- Runoff from informal settlements and housing areas with high levels of backyard dwelling and/or where there is poor attention paid to maintenance of existing infrastructure
- Accumulations of large volumes of solid waste

There are many other activities and landuses that contribute to cumulative water quality degradation in the City. The above are considered by far the most significant, and unless they can be addressed or their impacts mitigated, there is little likelihood that the CCT will be able to effect meaningful and measurable improvement in water quality in most of its managed subcatchments.

E6.3 The CCT responses to water quality issues

The above findings are not new. Similar findings were presented in the 2020 Inland Water Quality Report, and the MPP for Sanitation and Inland Water Quality as well as the WQIP all recognise and reference the urgent need to address the above complex issues.

The CCT's draft budget for 2023/24 to 2024/25 (CCT 2023b) furthermore itemises significant capital expenditure for the upgrading of WWTWs, maintenance and upgrading of sewer reticulation systems, repairing and upgrading of sewage pump stations and fitting of pump stations with emergency generators or UPS systems to deal with load-shedding.

E6.4 Key recommendations from this report

The report stressed that until the pervasive issues of pollution from WWTWs and informal settlements can be addressed, it is unlikely that there will be a significant turn-around in water quality in many areas. Recommendations are however made around a number of key issues.

E6.4.1 Focus on addressing over-riding pollution sources

Critical areas that need to be addressed comprise:

- Addressing pollution from major WWTWs
- Addressing pollution from informal settlements and suburbs with high levels of backyard settlement
- Addressing sewage overflows from pump station failure
- Reducing the passage of solid waste into stormwater systems and watercourses
- Making changes in stormwater and sewerage reticulation management structures
- Fast-tracking implementation of PASAPs
- Conservation of existing subcatchments in relatively good condition.

E6.4.2 Changes to the CCT's water quality monitoring programme

Recommendations for changes that would improve the efficacy of the current CCT water quality monitoring programme in being able to inform water quality data interpretation, water quality management and water quality improvement policy, as well as more effective implementation comprise:

- Inclusion of additional monitoring sites:
 - In the Khayelitsha Wetland Park, at a representative site for waterbodies utilised by the Khayelitsha Canoe Club
 - Downstream sites from all WWTW effluent outfalls into rivers or channels
- Monitoring of additional water quality variables:
 - Chloramine and COD testing at sampling points downstream of all WWTWs that discharge effluent directly or indirectly into rivers, vleis or estuaries
 - Periodic (every five years) analyses of heavy metal concentrations, with selection of heavy metals to be determined on the basis of subcatchment landuse characteristics
- Enterococci testing at all existing inland water quality monitoring points where *E. coli* counts are currently analysed, ideally with a view to moving from *E. coli* to enterococci testing or at least until there is higher confidence attached to the veracity of *E. coli* data
- Improving confidence in the CCT's *E. coli* data by a six-month period of submission of a subset of replicate water samples to three independent accredited laboratories for analysis, to show that the CCT's data lie within the same general range
- More consistent reporting of microbiological data, to higher concentrations
- Exclusion of enterococci data derived from event-driven, multiple sampling from routine monitoring datasets, to allow the use of risk-based summary statistical measurements
- Continued open public access to the CCT's water quality data via the online CCT Open Data Portal
- Use of water quality data to trigger focused pollution tracking and pollution abatement interventions on an ongoing basis, rather than simply monitoring ongoing pollution.

E6.4.3 Improvements in data quality or data availability from other CCT datasets

The following data should be collected or made available for water quality reporting:

- Reliable rainfall data across all subcatchments
- Reliable flow data for at least main stem rivers
- A co-ordinated log of PASAP and TAP interventions, showing intervention, date, subcatchment and location, to allow these interventions / efforts to be correlated with changes, if any, in water quality data
- Collation of ongoing pump station and manhole spill data should continue as at present, showing the subcatchment and ideally the logged co-ordinates of each spill.

E6.4.4 Water quality reporting

The terms of reference for this report were extensive and resulted in production of a lengthy document. It is recommended that much shorter annual reporting could be provided by a focus on changes in key water quality variables across all sampling sites. More detailed reporting that provides in-depth analysis of the various CCT priority programmes in key subcatchments could take place less frequently, potentially on a three- to five-yearly basis, when these programmes have had time to yield measurable results. This reporting would need to be informed by detailed reporting by the CCT as to which activities / interventions have been undertaken where and when.

E6.4.5 Undertake a study to assess the real socio-economic costs of vlei / estuary closure as a result of poor water quality

Closure of three of the CCT's recreational vleis during extended periods in the 2020-2021 reporting periods resulted in reported profound economic and social implications for businesses and users dependent on access to these waterbodies. It is recommended that the CCT should fund an independent study that investigates the actual socio-economic impacts of vlei closures, so that such interventions can be carried out in the future with full appreciation of the socio-economic consequences attached to measures aimed at reducing human health risk. Such a study should also try to identify means of mitigating against such impacts.

E6.5 What can residents do to improve water quality in the city's watercourses ?

Water quality in Cape Town's watercourses is not determined solely by the CCT's interventions. Residents also need to play a role in reducing sources of pollution into watercourses. This report includes ten priority steps that local residents can take which, if carried out by sufficient numbers, could achieve measurable change in at least some subcatchments (see Section 9.5).

ACRONYMS

BMB	Biodiversity Management Branch
CBD	Central Business District
CCPOA	Century City Property Owners' Association
CCT	City of Cape Town Metropolitan Municipality
CFF	C40 Cities Finance Facility
cfu	Colony forming units
Chl-a	Chlorophyll-a
COD	Chemical Oxygen Demand
CSRM	Catchment, Stormwater and River Management (Branch of CCT)
CWQC	City Water Quality Categories
DEA	Department of Environmental Affairs
DEADP	(Western Cape) Department of Environmental Affairs and Development Planning
DO	Dissolved oxygen
DWAF	Department of Water Affairs and Forestry (now DWS)
DWS	Department of Water and Sanitation
EFZ	Estuarine Functional Zone
<i>E. coli</i>	<i>Escherichia coli</i>
EC	Electrical conductivity
FLR	Friends of the Liesbeek River
FBNR	False Bay Nature Reserve
FOZR	Friends of Zeekoevlei and Rondevlei
GI	Green Infrastructure
GN	General Notice
HBRCF	Hout Bay River Catchment Forum
IUA	Integrated Unit of Analysis
LDC	Liz Day Consulting (Pty) Ltd
LUW	Liveable Urban Waterways (programme)
mamsl	metres above mean sea level
MAC	Milnerton Aquatic Club
MCC	Milnerton Canoe Club
Mplain	Mitchell's Plain
MPP	Mayoral Priority Programme
mS/m	milli-Siemens per metre (unit of measurement for conductivity)
NbS	Nature-based Solution
NH ₃	Abbreviation used in this report for free ammonia (NH ₃)
NH ₄ -N	Abbreviation used in this report for nitrogen in total ammonia (NH ₃ + NH ₄ ⁺)N

City of Cape Town

Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

NO3-N	Abbreviation used in this report for nitrogen component in nitrate salts
PASAPs	Pollution Abatement Strategy and Action Plan
PES	Present Ecological State
pH	Potential of hydrogen (a measure of how acidic or basic a substance is)
PO4-P	Abbreviation used in this report for phosphorus in phosphate
RQOs	Resource Quality Objectives
SABS	South African Bureau of Standards
SLPass	Sir Lowry's Pass
SSB	Scientific Services Branch (of the CCT)
SUDS	Sustainable Urban Drainage Systems
TAPs	Transversal Action Plans
TECs	Target Ecological Categories
TIN	Total inorganic nitrogen
ToR	Terms of Reference
Tot P	Total phosphorus
TSS	Total suspended solids
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WHO	World Health Organisation
WQIP	Water Quality Improvement Programme
WQMR	Water Quality Management Region
WTP	Water Treatment Plant
WWTW	Waste Water Treatment Works

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1 PREFACE AND INTRODUCTION

1.1 Background

The City of Cape Town (CCT) is responsible for the management of numerous rivers, wetlands and open water vleis systems, including estuaries and coastal lakes, within its municipal boundaries. These together are referred to as 'inland waters', largely in line with the South African classification system for aquatic ecosystems (Ollis et al. 2013).

In 2020, the CCT commissioned its first independent Inland Water Quality Report, which provided detailed analysis and discussion of water quality in Cape Town's inland aquatic ecosystems from the 1980s, when routine water quality analysis commenced, through to March 2020, but with the emphasis of data interpretation on the period April 2015 to March 2020. Since the 2020 report (Day et al. 2020), water quality monitoring has continued and the CCT has organised its monitoring system into different tranches, with routine monitoring points being separated out from ad hoc and project-driven monitoring. However, regular reporting on the results of water quality sampling is required in order to give meaning to these programmes, both to City managers and other interested parties / members of the public about the state of CCT's watercourses.

In February 2023, the CCT contracted Liz Day Consulting (Pty) Ltd to prepare the current 2022 Inland Water Quality Report, including an analysis of water quality data collected between April 2020 and end of March 2022, in the context of the medium-term trajectory of water quality over the past five years (i.e., as far back as April 2017).

1.2 Scope of Works

The Scope of Works for this project was outlined in the CCT's Request for Proposals for the project, which stipulated that the appointed consultants should compile a report on the water quality of Cape Town's waterways that:

- Follows the same format as the 2020 Inland Water Quality Report (i.e., Day et al. 2020);
- Utilises the same thresholds for interpretation of water quality data that were established in the 2020 Inland Water Quality Report;
- Analyses water quality data for a five-year period up until March 2022, with a particular focus on the months since the 2020 report (i.e., post April 2020) up until March 2022;
- Is scientifically defensible in its analyses and data interpretation and presentation;
- Uses language that is readily accessible by a wide-ranging and largely non-technical / scientific audience;
- Includes reporting on progress made in key City programmes that have a bearing on water quality in inland waters;
- Includes all data, analyses and graphics in spreadsheet format for subsequent use by the CCT.

1.3 Project Team

Liz Day Consulting (Pty) Ltd (LDC) is a private consulting company, specialising in river and wetland assessment, management and rehabilitation. The current project, carried out as an LDC consultancy, included the following team members:

- Dr Liz Day (LDC): project manager and water quality consultant
- Mr Dean Ollis (Inland Waters Consultancy): water quality consultant
- Ms Sonja Stock (LDC): project assistant for reporting in R
- Ms Sue Matthews: environmental science writer and editor, providing document review and

input into content

- Mr Ian Wilson (Spatial Mapping Solutions), providing GIS input and producing all GIS-based maps.

For the purposes of this report, reference to LDC includes acknowledgement of the full team of consultants listed above.

1.4 Client team

Input into this report was guided by the CCT's team from the Catchment Stormwater and River Management (CSRМ) Branch, comprising:

- Mr Andrew McDonald
- Mr Richard Nell
- Ms Nicole Garcia.

1.5 Audience

This report is intended to be accessible to a wide range of audiences, including people with both technical and non-technical / scientific backgrounds. Nevertheless, the data need to be presented in a scientifically defensible and rigorous manner, which means that some parts of the report are more technical than others. It is hoped that any difficulty in understanding this material, or limited time to go through it all in detail, is addressed in the summary sections at the end of each chapter, in the concluding sections, and in the Executive Summary.

1.6 Types of aquatic systems included

This report considers water quality data for Cape Town's inland and estuarine water quality monitoring sites only. It does not include data for any marine sites and includes only a few examples of artificial stormwater detention or attenuation ponds, where these provide useful indications of water quality issues in some key catchments. The report also excludes ad hoc or once-off sites, for which only a few data points exist.

1.7 Limitations

The following limitations apply:

- Large amounts of water quality data are available in the CCT's database. Of necessity, this project needed to summarise these data to draw out significant patterns and highlight particular areas of interest. This report thus focuses on a few key variables only, and does not consider data relating to every one of the water quality variables monitored by the CCT;
- Conversely, not all variables of concern are necessarily included in the CCT's monitoring programme and are not therefore covered in this report. Heavy metals, for example, are not routinely analysed by CCT, largely for budgetary reasons. Jackson et al. (2009) and Infinity & CCT (2022) have, however, noted significant concentrations of various heavy metals in the Diep and Eerste River estuaries, and other catchments might well be subject to similar issues (see also Day et al. 2022 for comment on heavy metals in the Zeekoe catchment);
- Although the CCT routinely collects phytoplankton samples for enumeration and identification of algal species, these data were not included in this assessment. Also, while water quality data for marine stormwater outfall sites clearly reflect pollution accruing in their upstream catchments, they were not included in the present report because:
 - They include only microbiological data relevant to human health (i.e., to their risk for coastal recreational users);
 - Their interpretation would need to be based on marine recreational guidelines;
 - They are already largely reported on in CCT's Coastal Water Quality report, with data up until November 2021 accessible from

https://resource.capetown.gov.za/documentcentre/Documents/City%20research%20reports%20and%20review/Know_Your_Coast_2021_Report.pdf.

- This report does not provide a synopsis of the ambient water quality in the rivers, canals, and open waterbodies across CCT because the analyses presented here are based exclusively on the sampling sites of particular concern that are routinely monitored by the Scientific Services Branch of the CCT – aquatic systems that are not affected by pollution issues are generally not monitored;
- No responsibility is taken by LDC for the accuracy of water quality data, which have all been derived from samples collected and analysed at the CCT's Scientific Services Branch (SSB), in Athlone;
- LDC distances itself from the implications of any future decisions taken to access any waterbodies for recreational purposes, on the basis of the data and assessments outlined here. These all refer to the past condition of these waterbodies, and no undertakings regarding future water quality or risk to human health is intended.

1.8 Report structure

This report has been structured as follows:

- **Section 1:** Preface and general introduction;
- **Section 2:** Background information on water quality, an introduction to the CCT's managed river catchments and stormwater regions, and a brief summary of the main findings and recommendations of the previous Inland Water Quality Report;
- **Section 3:** Introduction to the CCT's routine water quality monitoring programme and datasets; description of the water quality variables considered in this report; the water quality thresholds used to determine water quality classes and to set targets; an outline of data analysis and presentation approaches used in this report;
- **Section 4:** Consideration of rainfall data from sites within the CCT, to illustrate rainfall seasonality and patterns in annual rainfall that might have some bearing on water quality in Cape Town's watercourses;
- **Section 5:** Presentation of the assessment of long-term and current water quality data for river, stormwater and standing water sites across CCT, presented at a sub-catchment level, and discussed in terms of each of the key variables selected. This section includes compliance-type graphs and summary boxplots for all of the key variables included;
- **Section 6:** Presentation of water quality data pertaining to the condition of the key recreational vleis in the CCT, with regard to water quality risks to human health. This section focuses on variables with a direct bearing on human health during recreational activities, hence: *E. coli*, enterococci, and microcystin toxin data;
- **Section 7:** An overview of the key programmes established by the CCT in an effort to address water quality issues in particular;
- **Section 8:** A summary of water quality conditions and concerns in the CCT's seven priority catchments, including comment on measures undertaken in each to try to address these;
- **Section 9:** Summary of key issues, with recommendations and conclusions;
- **Appendices:** These include a list of sites for which data have been accessed for this report; a brief review of the information used to define water quality thresholds of acceptability; and detailed data tables showing summary annual data for each of the key variables selected, for each site, for each year between April 2020 and March 2022, and the full statistical boxplots for variables presented in **Section 5**. Readers with a particular interest in water quality at a particular site can access more detailed site specific information in these tables.

1.9 Acknowledgements

Useful comments and feedback and ongoing input into the project were provided by the following officials from the CCT's CSR Branch: Water and Sanitation Department; Water and Waste Directorate:

- Mr Richard Nell
- Mr Andrew Mc Donald
- Ms Nicole Garcia
- Ms Kristin Botes
- Mr Fahad Aziz
- Catchment managers:
 - Mr Abdulla Parker
 - Mr Ben De Wet
 - Mr Johann Terblanche and
 - Mr Franz Von Moltke.

Scientific Services Branch is also thanked for providing the datasets, and for comments regarding the collection and analysis of water quality samples. In particular, comment from Mr Robert Siebritz and Dr Swastika Surujlal-Naicker is appreciated.

Ms Suretha Dorse (CCT Biodiversity Management Branch), Mr Gregg Oelofse and Mr Darryl Colenbrander (CCT Coastal Management Branch) provided valuable input into the setting of thresholds for intestinal enterococci data in Inland waterbodies.

The Century City Property Owners' Association (CCPOA) is also thanked for making their rainfall data available for this study.

2 WATER QUALITY IN AN URBAN CONTEXT

2.1 A history of changes to watercourses in Cape Town

Prior to Cape Town's urbanisation, the area likely had extensive permanent wetlands, identifiable today only by remnant peat deposits; seasonal and/or temporary wetlands that were inundated for a few months of each year; mainly seasonally flowing and a few permanent (or perennial) rivers; and several estuaries along the Table Bay or False Bay coastlines.

The most significant of the estuaries would have been those of the Eerste, Sand and Diep Rivers. Under natural conditions, the Diep River estuary was the combined outlet of the Liesbeek, Black, Salt and Diep River systems, which flowed into Table Bay via a broad wetland marsh in the general region of today's Paarden Eiland (Brown and Magoba 2009).

Perennial (i.e., permanently flowing) rivers were those that rose in the mountains, with the main perennial systems being the Silvermine and Else Rivers, tributaries of the Diep, Keyzers and Liesbeek Rivers, Lourens, Sir Lowry's Pass and Eerste Rivers.

Most of the rivers that flowed through the vast, sandy Cape Flats, by contrast, were seasonal and often associated with groundwater-fed wetlands, which would have been inundated when the primary (surface) aquifer rose above the level of surrounding surface depressions. These wetlands supported communities of small crustaceans and insects that were adapted to surviving life in seasonal systems, often using hibernation or diapause strategies, or having eggs able to withstand long periods of dryness.

A long history of urban development has resulted in the loss and/or near complete change of many of these systems within the CCT's boundaries. Low-lying seasonal wetlands and rivers have been the most severely impacted, mainly through:

- Drainage and/or infilling of wetlands;
- Diversions, channelisation and canalisation of rivers and valley-bottom wetlands;
- Passage of treated sewage effluent into naturally seasonal rivers, creating perennial, nutrient-enriched systems with different plant and animal communities, different responses to drought and floods, and different management requirements as a result (see **Box 2.2**);
- The creation of canals and drainage channels to lower the water table and/or the floodline to allow development to encroach into naturally seasonally inundated areas, areas with a high water table, and areas prone to flooding (e.g. the Big and Little Lotus Rivers in the Zeekoe catchment).

2.2 Water course classification

CCT includes a number of different kinds of watercourse, ranging from rivers, through wetlands and coastal lakes, to estuaries, as well as artificial or highly modified dams and vleis. Since natural water quality can vary widely between different systems, it is important to understand the system it is reflecting.

The 'Classification System for wetlands and other Aquatic Ecosystems in South Africa' of Ollis et al (2013) is currently used in the CCT's data for differentiating between various watercourses. This system is a hierarchical one, which distinguishes first between marine, estuarine and inland systems. The present report deals only with inland and estuarine ecosystems.

2.2.1 Inland systems

There are three broad types of Inland Systems, namely:

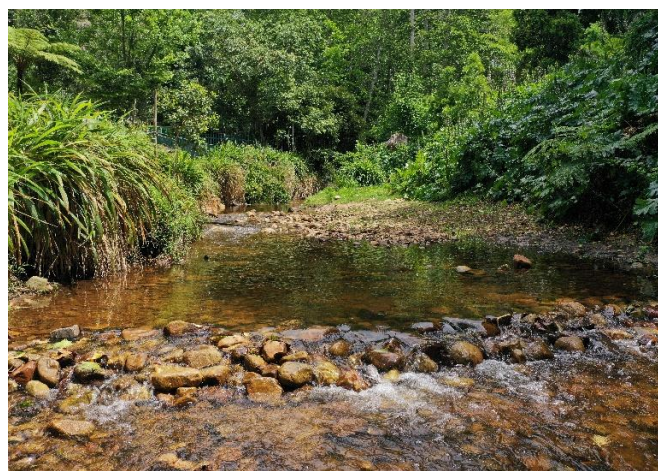
- **Rivers**, which are flowing water systems, where water is concentrated in distinct channels. Five river types can be identified within Cape Town's waterbodies:
 - **Mountain stream** reaches flowing off steep mountain gradients, and tending to occur on the outskirts of CCT and to lie outside of the urban edge;

- **Upper (or Cobble) foothill** reaches, which occur on the steep mountain foothills, and which, where they pass through the CCT's boundaries, tend to run mainly through farms, smallholdings or low-density residential areas and nature reserves;
- **Lower (or gravel) foothills** which, with a few exceptions, run through highly developed urban areas, including residential suburbs, commercial and industrial zones;
- River reaches classified in the CCT's database as 'transitional', but which are more accurately classified in terms of Ollis et al (2013) as **valley-bottom wetlands**, and which dominate the naturally seasonal flat, low-lying Cape Flats area; and
- **Lowland rivers**, which meander across broad floodplains and generally pass into the estuarine zone of the river.

Table 2.1
Examples of river types in Cape Town



Cobble Foothills
(Hout Bay River)



Gravel foothills
Liesbeek subcatchments (Photo: CCT)



Lowland River
(bermed Eerste River)



Valley-bottom wetland / 'wetland transitional' stream
Channelised and partially diverted Keyesers River

- **Open waterbodies**, which are permanently inundated waterbodies where standing water is the main habitat– open waterbodies with water greater than 2 m in depth are also called lake (or limnetic) systems;
- **Wetlands**, which are characterised by permanently, seasonally or temporarily saturated soils, sometimes covered with shallow water and vegetated with plants that are adapted to life in saturated soils or standing water.

Of the above inland systems, this report considers only rivers, artificial stormwater channels and canals that *de facto* are comparable to 'rivers' in their various forms; and the main 'open water' bodies that are routinely monitored by the CCT. The latter include both natural and artificial waterbodies (e.g. stormwater detention ponds).

In addition, there are artificial stormwater canals and channels – these are included with the river (i.e., flowing water) systems for the purposes of this report.

2.2.2 Estuaries

Before urbanisation, Cape Town's rivers all ultimately passed into the sea via estuaries or coastal lagoons. There are 10 estuaries within the CCT's boundaries, namely the Diep River (Milnerton Lagoon), Hout Bay, Wildevleivlei, Bokramspruit, Schuster, Silvermine, Zandvlei, Eerste, Lourens and Sir Lowry's Pass estuaries. The Sout and Salt systems would also have formed estuaries / coastal lagoons under natural conditions, but these have long lost all natural estuarine function as a result of upstream changes including canalisation up to the seashore.

Many of the remaining estuaries have also been highly modified, their river outlets having been converted into concrete canals (e.g. the Salt and Sir Lowry's Pass Rivers), and with none of the salt flux and tidal exchange necessary to meet the criteria for an estuary. Zandvlei and the Diep River Estuary (Milnerton Lagoon) are the only remaining systems that, despite significant levels of impact, particularly in the case of Milnerton Lagoon (see **Section 6**), retain real estuarine functionality. The Eerste River Estuary has been severely impacted by large volumes of low salinity wastewater discharges, and the Lourens River and Silvermine River estuaries have been impacted by urban development and (in the case of the former) significant upstream abstraction.

Other naturally seasonal coastal lakes, which opened periodically to the sea during particularly wet periods (e.g. Rondevlei and Zeekoevlei) have today been connected to the sea via artificial channels and canals (Brown and Magoba 2009). These channeled outlets do not, however, have any estuarine function.

In this report, Milnerton Lagoon (downstream of Otto Du Plessis Drive) and Zandvlei have been treated as functional estuaries. The other estuaries are either not routinely monitored at their outlets or their outlets are too altered to be expected to have any estuarine characteristics.

Box 2.1

Open waterbodies

Rietvlei, Zeekoevlei and Wildevleivlei are all lake-like open waterbodies. Of these, Rietvlei and Zeekoevlei have both been artificially modified to provide near-permanent standing water for recreational purposes.



View of Rietvlei

Box 2.2

What is an estuary ?

Estuaries are legally defined as 'a body of surface water— (a) that is permanently or periodically open to the sea; (b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the body of surface water is open to the sea; or (c) in respect of which the salinity is higher than fresh water as a result of the influence of the sea, and where there is a salinity gradient between the tidal reach and the mouth of the body of surface water' (definition from The National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008 (as amended 2015))).



Photo: Zandvlei outlet

Photo credit: Kyran Wright

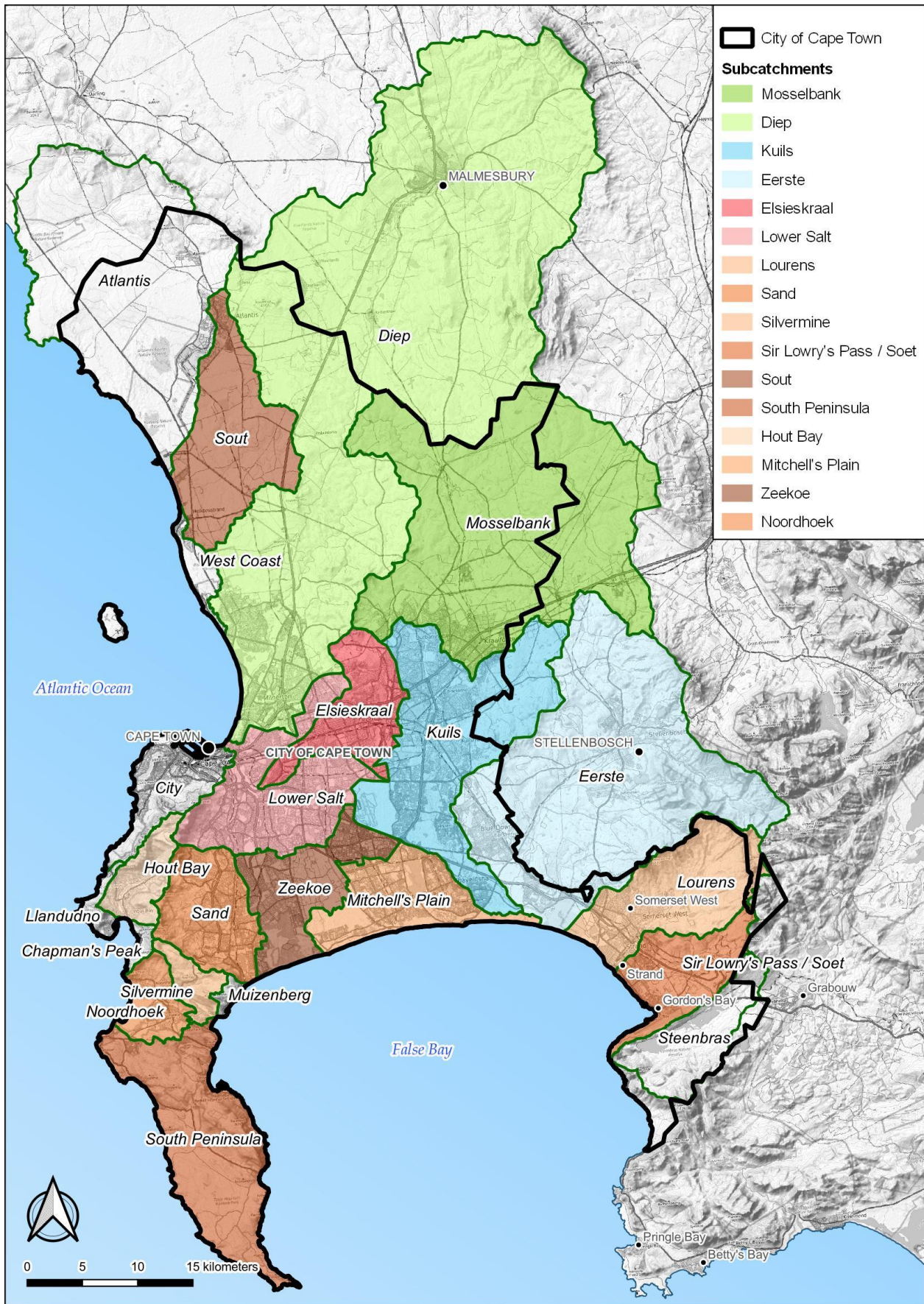


Figure 2.1
Major subcatchments and watercourses of Cape Town

2.3 Urban watercourses and people

Urban watercourses can play important roles in a city, and their overarching condition can have significant indirect impacts on issues such as human health, property value, security, amenity opportunities, flood risk, and maintenance and management costs such as litter and sediment removal. For example, while properties in proximity to well-managed watercourses in good condition may benefit from enhanced property value, those in proximity to watercourses that are in poor condition, subject to litter, odour or aquatic plant invasion (including algal growth in standing waterbodies), are likely to experience a decline in property value (de Wit et al. 2009).

Among the most profound issues affecting water quality in Cape Town, as well as in many other urban centres, is the impact of waste. Treated and untreated sewage waste that enters Cape Town's watercourses is a particular cause of problems.

Under ideal conditions, domestic and industrial waste is conveyed to waste water treatment works (WWTWs), where it is treated to an acceptable standard and then either released back into the environment (usually into rivers or the sea), re-used in industry or for irrigation, or in some areas treated further for human consumption. In practice, however, the management and treatment of human waste is often fraught with problems, particularly in developing countries. Key issues relevant to waste management in Cape Town are:

- Informal settlements with inadequate or no sanitation, resulting in waste being discharged into roads or directly into stormwater systems;
- Informal settlements in marginal land considered unsuitable for housing – such land is often in low-lying areas, in or near to seasonally inundated wetlands. The disposal of waste from residents is thus often directly into these areas, resulting in rapid pollution and degradation of sometimes important seasonal wetlands;
- Repeated sewer leaks and overflows from aging infrastructure in dense urban areas – these are often older areas, where infrastructure is now failing;
- Overflows from sewers as a result of pump failure, often caused by power outages due to 'load-shedding' or illegal dumping into the sewage system;
- Poorly treated effluent discharged from WWTWs into rivers, contributing to significant enrichment and often low levels of oxygen and elevated ammonia, affecting river habitat quality and downstream systems such as vleis and other wetlands. Without dilution by the receiving waterbody, even effluent that is treated to comply with legal standards (e.g. General Effluent Limits, as specified by the National Department of Water and Sanitation (DWS)), is likely to contain high levels of nutrients, as well as ammonia, and could also lead to poorly oxygenated waters as a result of high levels of organic decomposition;
- Illegal connections in industrial or residential areas, allowing waste that should be discharged into sewers to be passed instead into the stormwater systems – a common source of pollution in many more affluent residential areas is the passage of water backwashed from swimming pools into streets or the stormwater system, where it can result in the formation of persistent toxins (e.g.

Box 2.3

Watercourses defined

The National Water Act (Act 36 of 1998) defines a 'watercourse' as -

- (a) a river or spring;
- (b) a natural channel in which water flows regularly or intermittently;
- (c) a wetland, lake or dam into which, or from which, water flows; and
- (d) any collection of water which the Minister may, by notice in the Gazette, declare to be watercourse, and a reference to a watercourse includes, where relevant, its bed and banks.

The 'regulated area' of a watercourse (i.e. that area that is considered in the legislation) is further defined in Government Notice (GN) 509 of 2016 as the area within the 1:100 year floodline of the watercourse.

The City of Cape Town considers the river floodplain as the area below the 1:100 year floodline – this has relevance to the application of its policy for development in floodprone areas, which requires new developments to be set back from rivers and its stormwater quality policy, which regulates the treatment of runoff from new developments, into watercourses.

chloramines);

- Poor levels of solid waste collection and high levels of illegal waste dumping, resulting in the accumulation of waste along roads and open spaces, from where plastics and organic waste can wash into the stormwater system.

2.4 Ecological importance of urban watercourses

From an ecological perspective, urban watercourses can act as corridors of relatively natural habitat through increasingly sterile urban landscapes and, in Cape Town's case, connect mountainous habitats with the coast. They also provide aquatic habitat and, in some areas, are of great biodiversity importance. The city lies in the heart of the Cape Fynbos Biome, and some of its aquatic ecosystems, support species of plants and/or animals that occur in a restricted area and nowhere else in the world.

2.5 City catchments

Cape Town lies within the Berg River catchment, which forms part of the Berg-Olifants Water Management Area. The city's numerous watercourses drain 17 major catchment areas, shown in **Figure 2.1**. Some of these major catchments in fact include a number of relatively small catchments that are lumped together for management purposes. These include the 'South Peninsula' catchment, comprising several discrete river systems such as the Bokramspuit River and the Schusters River, and the Sir Lowry's Pass River system, which includes the hydrologically separate but adjacent Soet River system, itself almost wholly an artefact of stormwater management.

It should be noted that the City Bowl and adjacent Sea Point and Camps Bay areas do not have any remaining natural rivers. Both natural and artificial drainage is diverted into underground systems, which can nevertheless affect coastal water quality if polluted.

By contrast, the Mitchell's Plain catchment, shown in **Figure 2.1**, would not have included any natural rivers prior to urbanisation. Rainwater falling in this part of the Cape Flats probably infiltrated through the sand or formed shallow, largely isolated wetlands. Today, however, the area is highly urbanised, and runoff from the hardened surfaces is collected in large artificial detention ponds and conveyed to the sea through stormwater pipes and drains (**Photo 2.1**)

Other catchments (Atlantis, Steenbras, Llandudno, Chapmans Peak and Muizenberg catchments) do not have major rivers and do not currently include any monitoring points. These catchments have not been color-coded in **Figure 2.1** and are not referenced further in this report, although clearly activities in these catchments, as in all catchments, have an impact on the quality of water entering the coastal zone.

Three catchments are significantly larger than others, namely the Diep, Eerste and Salt catchments. For the purposes of this report, these catchments have been further divided into subcatchments (Diep and Mosselbank; Kuils and Eerste; Elsieskraal and Lower Salt). These subcatchments are shown in **Figure 2.1**, and all of the delineated areas in that figure are hereafter referred to as 'subcatchments'. These might, as already outlined, include several minor discrete river systems and their catchments (e.g. South Peninsula subcatchment); an entire river catchment (e.g. Hout Bay), or a discrete portion of large catchment (e.g. Kuils) (see also **Section 3.8.3**).

The (small) Soet and adjacent Sir Lowry's Pass River subcatchments are managed by the CCT as one

Box 2.4

Lost Watercourses

Most of the streams that drain off Table Mountain and the Twelve Apostles range into the City Bowl and Sea Point / Camps Bay areas have been piped underground, and pass into Table Bay and the coastline along the Atlantic seaboard as stormwater. CCT's Green Point Park makes use of some of this water resource to supply the artificial wetlands and streams and to irrigate the Biodiversity Showcase and other gardens.



Photo 2.2: The Platteklouf River, which is passed under the City Bowl in covered, brick-lined culverts

unit and referred to as the Sir Lowry's Pass / Soet subcatchment.

2.6 CCT's priority subcatchment areas

Six priority subcatchment areas have been identified by the CCT for focused interventions, intended to improve river and wetland ecosystem function, and through this, an improvement in water quality. An additional subcatchment, the Sand, has also been identified for significant rehabilitation measures. All of these interventions are described in **Section 7** of the report, and form the focus of three major City programmes, namely the CCT's Water Quality Improvement Programme (WQIP); the Liveable Urban Waterways (LUW) Programme and the Mayor's Priority Programme (MPP) on Sanitation and Inland Water Quality.

The subcatchments are:

- The Lower Diep River (upstream of Milnerton Lagoon)
- The Sir Lowry's Pass and Soet River
- The Salt River
- The Kuils / Eerste Rivers
- The Hout Bay River
- The Big and Little Lotus Rivers (within the Zeekoe catchment)
- The Sand catchment (upstream of Zandvlei).

Progress in these three programmes, with particular regard to interventions aimed at improving water quality within the priority subcatchment areas, is reported on in **Section 7**, and the condition and trajectory of water quality in each of the priority subcatchments is considered in **Section 8**.

2.7 Quantification of Cape Town's watercourses

The natural watercourses (including estuaries) that are described above are included in the CCT's stormwater management system. This system, covering the entire city (some 2 445 km²), includes:

- 16 630 km of pipes and culverts¹
- 890 detention ponds
- 236 stormwater treatment wetlands
- 1 880 km of natural rivers and streams²
- Around 567 km of lined and unlined open channels and canals
- 4 164 'natural and semi natural' wetlands, including 'vleis' and estuaries³.

CCT's Inland Water Quality Monitoring Programme includes routine monitoring points in many of the above. This programme is outlined in detail in **Section 3**.

2.8 Stormwater management regions

While Cape Town's rivers and other watercourses lie within catchments, defined by topography and separated by watershed, the CCT manages them through so-called Stormwater Planning Regions. There are four such regions, comprising a Northern, Southern, Eastern, Central and Western region (see **Figure 2.2**). Each region has a separate manager, responsible for stormwater management across the whole region. The delineation of the regions does not take any account of the 18 major river subcatchments, but in many cases cut through subcatchments, assigning sections of a river and its tributaries in some cases to two different managers.

This means that effectively it is difficult to manage stormwater and its associated water quality issues from a catchment perspective, which would be a more logical starting point. This issue is returned to in **Section 9**.

¹ Data from <http://www.capetown.gov.za/family%20and%20home/transport-and-vehicles/road-safety/our-stormwater-system>

² Data kindly supplied by Ms Kristin Botes, City of Cape Town

³ Data from City of Cape Town (2017) wetland layer

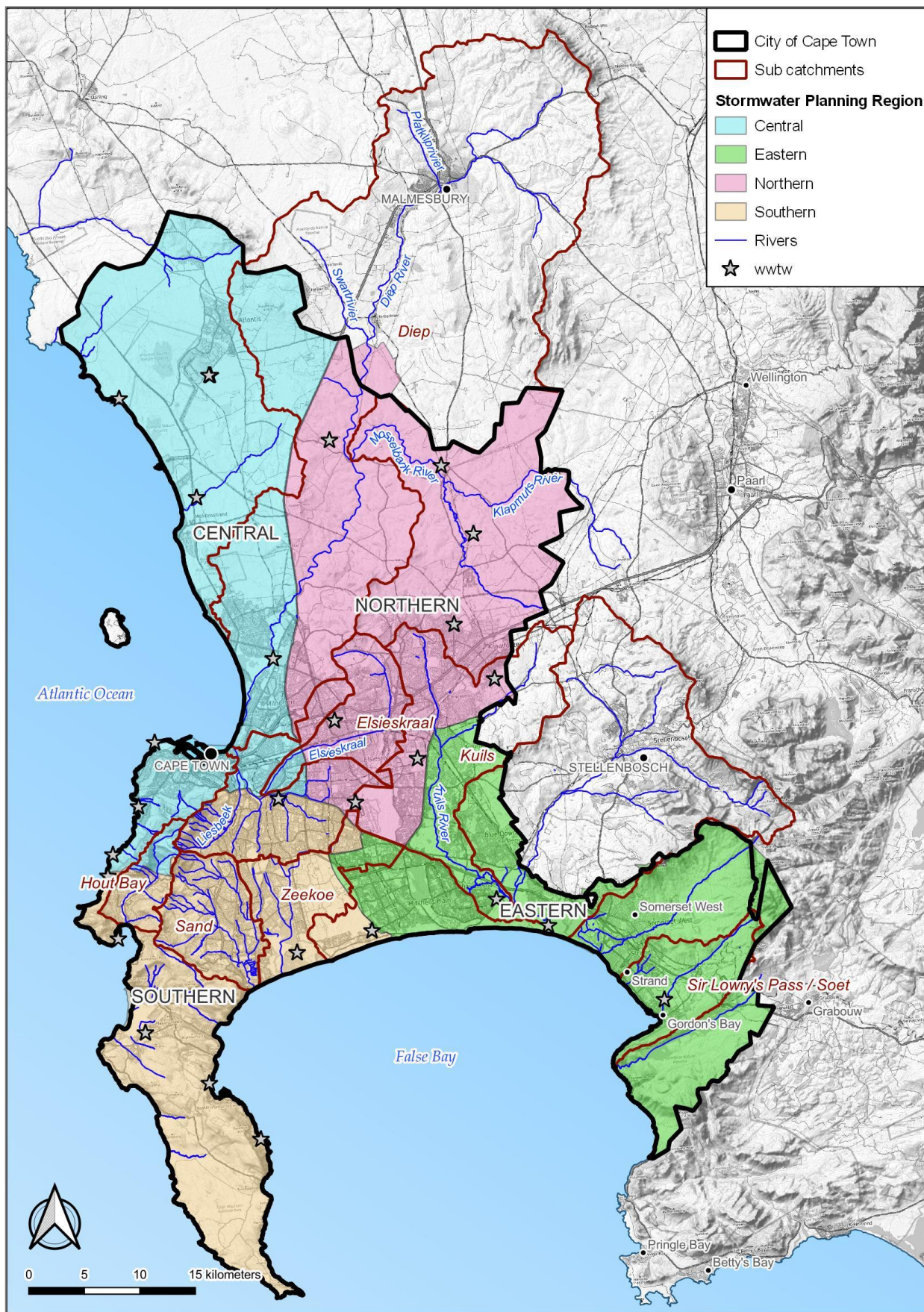


Figure 2.2
Relationship between the CCT's Stormwater Planning Regions and Cape Town's river catchments

2.9 Key findings and recommendations of the previous (2020) Inland Water Quality Report

The previous Inland Water Quality Report (Day et al. 2020) concluded with the following broad findings and recommendations:

- The biggest water quality issue afflicting most of the city's watercourses was elevated phosphorus, which drives eutrophic and hypertrophic conditions (see **Section 5.1.4**), resulting in increased maintenance costs (vegetation growth) and health risks (microcystin toxins from cyanobacteria, also called blue-green algae);
- The main sources of phosphorous loading within Cape Town's catchments were assumed to be treated effluent from WWTWs, discharges of raw sewage from leaking or overflowing infrastructure (also pump failure during load-shedding), and water contaminated with sewage and domestic waste (e.g. cooking and washing water) from informal/ poorly serviced areas. Together these waste streams would have been associated with significant bacterial contamination and could have constituted serious health risks when encountered in settlements, stormwater channels, receiving rivers, and to a lesser extent vleis and dams;
- The impacts of failing to address such contamination sources would include decreased human health and dignity, and significant costs associated with the resultant need for reactive and symptomatic management, including clearing of invasive aquatic plants and other vegetation encroaching into nutrient-enriched and shallowing waterbodies; the need for removal or dredging of organic sediments and sludges; litter removal; interventions such as cutoff drains and low-flow diversions for the redirection of contaminated stormwater into sewers; and emergency closure of recreational waterbodies in response to algal blooms and/or sewage spills;
- It was thus recommended that the CCT needs to focus on reducing contamination of runoff into and through its watercourses, by improving sewage management, solid waste removal, and stormwater treatment and conveyance;
- Despite the above concerns affecting many of Cape Town's watercourses, water quality in some, such as the Silvermine and the Lourens River systems, was still in a relatively natural condition, while others such as the Hout Bay River were significantly contaminated only in their lower reaches (due to inadequate servicing of informal settlements);
- The report noted that water quality monitoring was an essential activity, needed to inform the CCT as to where to focus attention on implementation of pollution abatement measures and to identify areas posing high risks to human health. It further recommended that such data should be made freely available to the public, in order to drive constructive discussion about implementation of remediation measures;
- Gaps in monitoring were identified in the report, with the need for monitoring of *E. coli* / other human health risk indices in the lower Kuils River through the Khayelitsha Wetland Park being flagged as a particular concern, given the use of these river reaches by local communities for kayaking.

Finally, it was also recommended that 'ambient' water quality data should be collected periodically to provide a more holistic view of the general condition of Cape Town's watercourses, rather than the current focused assessment of pollution-prone systems. A five-yearly assessment of key water quality variables collected annually in spring from the downstream node of all 2nd/3rd order streams and all natural standing water wetlands above a threshold size was proposed, as a potential tool to track the CCT's long-term efficacy in managing its watercourses.

3 APPROACHES TO WATER QUALITY MONITORING, DATA ANALYSIS AND INTERPRETATION⁴

3.1 What is water quality?

The concept of 'water quality' considers the combined effects of the physical, chemical, and biological attributes of a sample of water on a particular user. It is a measure of the condition of water relative to the requirements of one or more species, or to any human need or purpose – that is, its 'fitness for use'.

Water quality is usually interpreted with regard to standards or guidelines, developed around the specific effects of different aspects of water quality on a particular user group or purpose. These may include guidelines for human drinking water; aquaculture, industrial use, domestic animal drinking water; irrigation water; recreational use of water (e.g. swimming or watersports) and guidelines as to the effects of different water quality ranges on aquatic plants and animals.

Since assessing water quality from a human health and/or ecological perspective requires data representing a range of physical, chemical, and biological attributes, people with expertise in the fields of freshwater ecology, water chemistry and microbiology should ideally be tasked with interpreting the data.

3.2 Purpose of water quality monitoring in urban watercourses

Water quality monitoring, if carefully structured and rigorously carried out, can provide valuable insights into the long-term trajectory of water quality in waterbodies, including rivers and lakes/vleis. This is important for informing decisions about the risk water quality may pose to different user groups (for example, are vleis generally fit for recreational uses such as swimming, rowing, sailing, or canoeing?). It also provides information about the ecological health of these systems and, where long-term data are available, can provide an indication of the trajectory of different ecosystems – that is, whether their condition is improving or deteriorating over time. Such information can and should be used to inform planning around the need for engineering or other interventions to address deterioration in any watercourses. They can also be used to assist catchment managers in planning strategically, around where to focus efforts to achieve maximum returns.

Water quality data can also 'red flag' sudden onsets of pollution (caused, for example, by sewage leaks or illegal discharges), inform pollution-tracking efforts along watercourses and provide evidence for compliance with licensing or permit conditions.

Box 3.1

Ambient water quality

'Ambient water quality' refers to the quality of water in natural watercourses, as opposed to treated or piped water quality. The term is used to describe the state or condition of systems, derived from holistic monitoring of whole systems. By contrast, CCT's Inland Water Quality reports focus on water quality data collected from specific points, usually identified as problem areas, and thus do not provide an overall idea of ambient water quality in CCT. In fact, because the focus of monitoring is on poorly performing systems, the water quality data assessed in this report arguably exaggerate the level of watercourse pollution in CCT.

It is, however, reasonable that water quality monitoring effort should focus on problem areas, **provided that such effort is accompanied by focused pollution abatement efforts.**

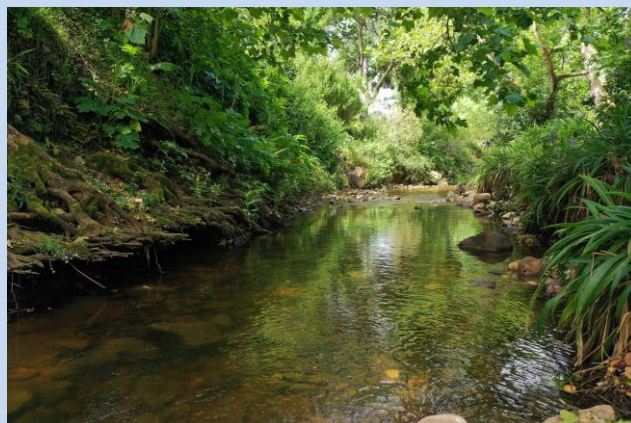


Photo: Clean stream in Cape Town – photo courtesy CCT

⁴ While most of this report has been updated entirely to reflect new thinking, data and interpretation since the 2020 report of Day et al. (2020), this section has been edited only where necessary, to reflect minor changes, but essentially the assessment and reporting methodologies outlined here remain (as a specific requirement of the Terms of Reference for this contract) as per those of the 2020 approach.

3.3 The CCT's Inland Water Quality Monitoring Programme

The CCT's water quality database goes back to the late 1970s for at least some monitoring points along its main rivers and wetlands/vleis. The previous (2020) Inland Water Quality Report analysed and discussed the full historical record of water quality data included in this extensive database.

The present report deals only with data generated from water quality monitoring over the past five years. These monitoring points are located in main rivers and stormwater outflows into watercourses, as well as key wetlands, dams and detention ponds.

Since 2020, the CCT has rationalised its water quality monitoring data, so as to differentiate between data from routine sampling, reflecting data from samples collected from the same monitoring points on a regular, long-term basis; ad hoc samples, collected to inform specific once-off or short-term questions around pollution type, magnitude or sources in particular watercourses; and project specific data, collected as part of specific programmes such as for pollution tracking or to inform stormwater master planning.

The present report considers only data from **routine** sampling.

Figure 3.1 shows the locations of all the current inland routine monitoring points utilised in this study. Note that these exclude the 23 sampling points located at stormwater outfalls along the coast. This is because, although the quality of water passing out of these points reflects the condition of their upstream stormwater catchments, these outflows are considered in the CCT's coastal water quality report, the most recent of which (Know Your Coast, 2021) covered data up until November 2021. In addition, samples from these sites are analysed only for intestinal enterococci. *Enterococcus* and *Escherichia coli*, which would in any case need to be interpreted with regard to their implications for marine rather than inland (freshwater) ecosystems and human health, as discussed in **Section 3.7**.

The water quality sampling sites included in this report comprise a total of 162 routine monitoring sites, made up of 10 canal sites; 4 artificial dam / impoundment sites; 3 detention ponds; 1 effluent outlet channel; 19 estuary sites, 92 river sites; 5 stormwater outlets and 28 vlei / standing water wetland sites (see **Figure 3.2**). Note that these data differ from those presented in the previous (2020) report. This is because the latter presented sites from the full historical dataset.

Box 3.2

Public access to water quality data

Following years of agitation from concerned members of the public and various organisations regarding their need to access the CCT's water quality data to allow for independent data evaluation and comment, the CCT announced in April 2022 that these data would be available for public download from its data portal [<https://odp-cctegis.opendata.arcgis.com/documents/inland-water-quality/about>]. These data include most but not all of the monitored water quality variables from inland and estuary systems.

Box 3.3

Limitations of water quality data

Water quality data show only what the quality of water was like at the time of sampling and at the specific location where the sample was collected. It cannot be used to infer future water quality (for example whether a waterbody is fit for swimming a day or even an hour after sampling, or to show what it was like immediately before sampling. 'Plugs' of pollution, for example, may be missed, or accidentally targeted by the timing of sampling. Furthermore, where watercourses are seriously contaminated, point-source pollution streams may be difficult to identify, because of the high level of general contamination.

It also only provides information about the constituents that were actually measured – there may also be other kinds of pollutants in the water. For example, CCT's routine water quality monitoring does not include analyses of heavy metals, hydrocarbons, or contaminants of emerging concern (CECs).

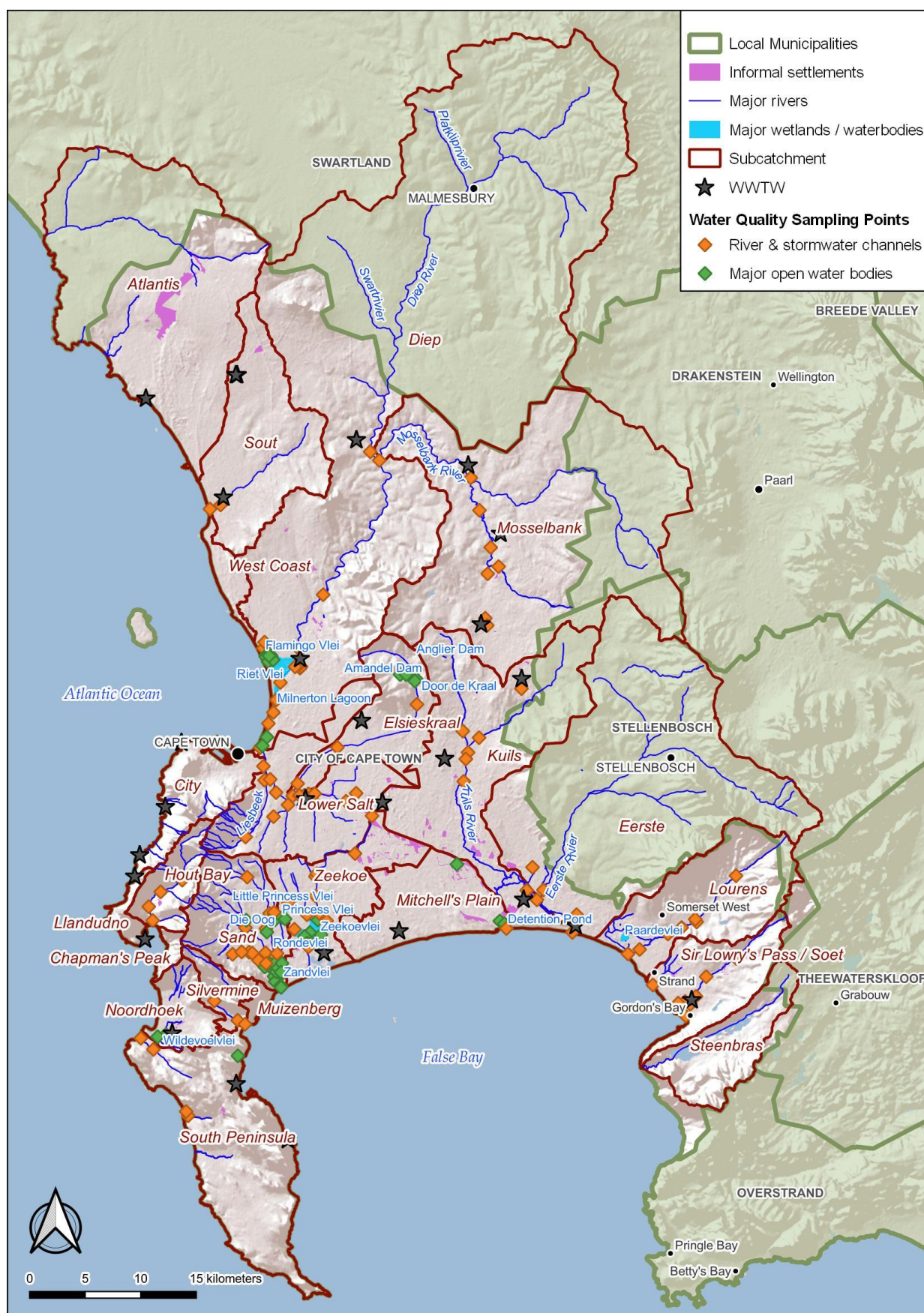


Figure 3.1

City subcatchments, showing river and stormwater channels and canals and standing water (vlei and dam) water quality sampling point locations

A range of chemical, algal and bacterial constituents are measured from water samples collected at these sites, and the data are interpreted and reported on by the CCT's Catchment, Stormwater and River Management (CSRM) Branch.

Figure 3.3 shows the number of water quality monitoring points in each of the CCT's subcatchments. These data show that the largest number of routine monitoring points are located in the Sand subcatchment (35); followed by the Diep (25); and Zeekoe and Lower Sand subcatchments (17 each). However, the largest catchments by area are the Diep, Mosselbank Eerste and Kuils subcatchments (**Table 3.2**)– of these, a large proportion of the Diep, Mosselbank and Eerste subcatchments in fact lie outside of the CCT's boundary (see **Figure 3.1**). Listings of the actual locations of each monitoring point in each subcatchment are provided in **Appendix A**.

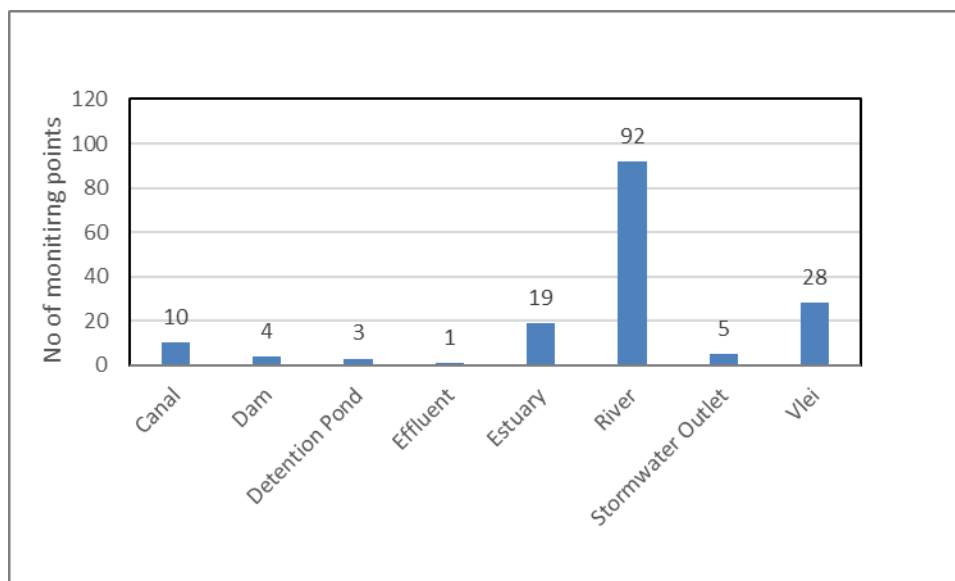


Figure 3.2

Summary of types and numbers of sample points for which data have been included in the present report

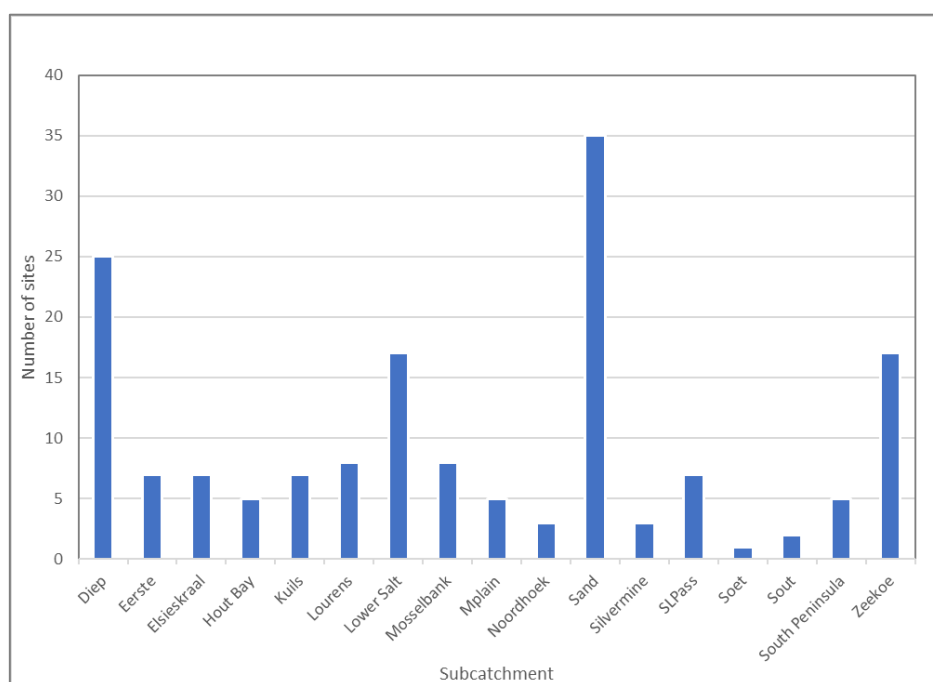


Figure 3.3

Summary of numbers of sites in each subcatchment for which data have been included

Table 3.1
Subcatchment area and number of routine water quality monitoring sites per subcatchment

Subcatchment name	No. of water quality monitoring points	Area (ha)
Lower Diep	25	108 704 (whole subcatchment) 40 889 (in the CCT boundary)
Eerste	7	43 489 (whole subcatchment) 7 150 (in the CCT boundary)
Elsieskraal	7	7 927
Hout Bay	5	3 774
Kuils	7	23 381
Lourens	8	12 458
Lower Salt	17	13 486
Mosselbank	8	46 236 (whole subcatchment) 30 527 (in the CCT boundary)
Mplain	5	9 065
Noordhoek	3	3 471
Sand	35	8 420
Silvermine	3	2 273
SLPass	7	6 510
Soet	1	1 066
Sout	2	14 196
South Peninsula	5	16 725
Zeekoe	17	9 302
Total	162	330 483 (whole subcatchment) 246 959 (in the CCT boundary)

3.4 Objectives of the CCT's water quality monitoring programme

The CCT's water quality monitoring programme is designed to monitor changes in watercourses where water quality is likely a cause for concern. Many of the monitoring points are therefore downstream of WWTW effluent discharge points, and in river reaches in catchments where runoff is likely to be contaminated. Some sampling points are located in watercourses that are used for religious rituals (e.g. baptisms) and/or recreational purposes (e.g. sailing, rowing, kayaking). Water quality data for such systems are thus used to provide information as to the fitness for use of these systems.

An important outcome of this approach is that, rather than being a structured programme that generates an overall understanding of the condition of all of Cape Town's watercourses, the data focus on problem areas and rather provide information about long-term trends and trajectories of water quality in these systems.

This is not necessarily a criticism of the monitoring programme, since it would be both very expensive and logistically unfeasible to conduct full-scale long-term monitoring of all watercourses in Cape Town. It is, however, an important point that should be borne in mind when considering the water quality data that are available.

3.5 Context in the Berg Resource Quality Objectives study

Cape Town falls within the Berg-Olifants Water Management Area. In 2020, the Department of Water and Sanitation (DWS) published a Gazette outlining the proposed Water Resource Classification and Resource Quality Objectives (RQOs) for Priority (water) Resource Units in the Berg Catchment, along with a number of smaller catchments within the Cape Town Metropolitan Area, on the Cape Peninsula and along the West Coast (see Government Notice 1179 of 6 November 2020). The following Priority Resource Units fall within the CCT's boundaries:

- Two river nodes in the Diep River, as well as the Diep River Estuary and Rietvlei;
- Two river nodes in the Peninsula, and Wildevoevlei as an estuary node;
- One river node in the Cape Flats; and Zandvlei as an estuary node;
- Two river nodes in the Eerste River catchment, and the Eerste River estuary;
- Three river nodes in the Sir Lowry's Pass / Lourens River catchment areas, the Lourens River Estuary, the Steenbras Reservoir, and the Upper Steenbras Dam.

The resource classification and associated determination of RQOs are intended to inform management of water resources in the greater Berg catchment. The Gazetted RQOs were based on meeting defined Target Ecological Categories (TECs) for each Integrated Unit of Analysis (IUA) (usually particular river reaches or specified estuaries). The TECs comprised hierarchical categories A to F, for the following components:

- Water quantity (flow regime/hydroperiod)
- Water quality
- Aquatic habitat and
- Aquatic biota.

The water quality categories used in both the 2020 and the present Inland Water Quality Reports are compatible with those of the Berg RQOs, although there are some differences in the classification of estuaries between the two (see **Box 3.4** above). For the vlei systems within the City that have been delineated as estuaries in the Berg RQO study, an assessment of compliance with the RQOs that were set for salinity has been included in the current report (**Section 5.6**) to highlight some of the issues with the misclassification of some of these systems as estuaries in the Berg RQO study.

Note that the Water Resource Classification as presented in the Gazette relates only to rivers and estuaries, with the classification of wetlands and setting of wetland RQOs not yet finalised.

Box 3.4

RQOs and Estuaries

The Berg Water Resource Classification system assigned Resource Quality Objectives to river and estuary systems in the Berg Water Management Area, including those in CCT. It is important to note that this study defined estuaries as all areas below 5 m above mean sea level (mamsl). This area in fact relates to the legislated Estuarine Functional Zone (EFZ). It is based on Listing Notice 3 of Government Notice (GN) 324 of 2017, which defines an EFZ as *'the area in and around an estuary which includes the open water area, estuarine habitat (such as sand and mudflats, rock and plant communities) and the surrounding floodplain area, as defined by the area below the 5 m topographical contour (referenced from the indicative mean sea level)'*.

Under this definition, many non-estuarine watercourses such as Langvlei, Rondevlei and Zeekoevlei have been classified as estuarine, and assigned estuarine rather than Inland standing water RQOs.

3.6 Water quality variables considered in this report

3.6.1 Key variables considered

Although the CCT analyses a wide range of water quality variables, only those considered the most important general indicators of urban aquatic ecosystem health and human health risk are assessed in the Inland Water Quality Report, as determined in Day et al. (2020). The following variables have been included (abbreviations used to refer to them in this report are shown in brackets):

- Major nutrients – phosphate (PO₄-P) and Total Inorganic Nitrogen (TIN)
- Un-ionised (or 'free') ammonia nitrogen (NH₃)
- Dissolved oxygen (DO)
- *Escherichia coli* bacteria (*E. coli*) and intestinal enterococci bacteria
- Microcystin concentration
- Chlorophyll-*a* (Chl-*a*) and
- pH as an indicator of ammonia toxicity risk; and
- Electrical conductivity (EC) as a measure of salinity, specifically for vleis systems in the City that were delineated as estuaries in the Berg RQO study.

In addition, to the above, which were included in the 2020 inland water quality report, enterococci data, not available for many sites in 2020, were also considered in the present report, for recreational waterbodies.

3.6.2 Analysis of pH and electrical conductivity

No detailed analyses of pH or EC were undertaken for the current study, other than (for pH) to inform interpretation of ammonia data, and (EC) to inform discussions around the EC of vlei systems that have been delineated as estuaries in the Berg RQO study. The absence of detailed analyses of EC and pH data was due to a lack of trends having been found for these parameters in the long-term (1980-2020) analyses that were completed for river sites in the previous report (Day et al. 2020). In the previous report, no analyses of pH or EC were completed for standing water sites because of a lack of 'reference data' for the expected ranges of values in minimally impacted systems of this nature in the Cape Town area.

Summary boxplots for pH are nevertheless included in **Appendix D**, for reference with regard to ammonia toxicity analyses and discussions.

3.7 Water quality thresholds to guide data interpretation

3.7.1 Thresholds to interpret ecosystem condition with regards to water quality

Tables 3.2 and **3.3** outline the ranges in concentrations of key water quality variables considered in this report, with regard to their implications for **ecosystem condition**. The criteria used to derive these (currently nationally acceptable) thresholds are outlined in **Appendix B** along with the link between these categories and the various terminologies used in different DWS reporting (e.g. DWS (2008) A-F categories and DWAF (2011) Ideal – Unacceptable descriptors).

The ranges and thresholds distinguish between **flowing water systems** (rivers, channels and canals) and **open water systems** (dams, vleis, detention ponds and coastal lakes). The rationale behind these thresholds is also outlined in **Appendix B**, after Day et al. (2020), while trophic thresholds that underpin some of these thresholds are presented in **Appendix E**.

Table 3.2

Rating ranges for variables considered in this assessment of water quality in City rivers

See Appendix B for derivation of threshold values.

Note: PO₄-P = phosphate phosphorus; TIN=Total inorganic Nitrogen; DO=Dissolved oxygen; N:P= ratio of TIN:PO₄-P; NH₃ = un-ionised ammonia. Note also that the terms 'PO₄-P', 'NH₃' are abbreviations and are not the full chemical notation for these ionic compounds

City Water Quality Categories (CWQC)	Interpretation of CWQC	PO ₄ -P mg/l	TIN mg/l	DO mg/l	N:P	NH ₃ mg/l
GOOD	TARGET	< 0.025 (oligotrophic)	>0.25-0.70 (oligotrophic - mesotrophic)	> 6	>25	0.015-0.044
FAIR		>0.025-- 0.075 (mesotrophic)	>0.70-1.75 (mesotrophic)			>0.044 - 0.072
POOR	POOR	>0.075- 0.125 (eutrophic)	>1.75-3.00 (mesotrophic -eutrophic)	≥4 -6	10-25	>0.072-0.1
UNACCEPTABLE	UNACCEPTABLE	>0.125 (hypertrophic)	> 3.00 (eutrophic - concentrations > 10mg/L classified as hypertrophic)	< 4	< 10	>0.1

Table 3.3

Rating ranges for variables considered in this assessment of water quality in City Vleis and Dams

See Appendix B for derivation of threshold values.

Note: PO₄-P = phosphate phosphorus; TIN=Total inorganic Nitrogen; DO=Dissolved oxygen; N:P= ratio of TIN:PO₄-P; NH₃ = un-ionised ammonia; Chl-a= Chlorophyll-a. Note also that the terms 'PO₄-P', 'NH₃' are abbreviations and are not the full chemical notation for these ionic compounds

City Water Quality Categories (CWQC)	Interpretation of CWQC	PO ₄ -P mg/l	TIN	DO mg/l	N:P	NH ₃ mg/l	RUNNING MEAN ANNUAL CHL-A µg/l
GOOD	TARGET	≤ 0.005 (oligotrophic)	≤ 0.7	> 6	>25	< 0.015	≤ 5
FAIR		>0.005-- 0.015 (mesotrophic)	>0.7 -1			0.015-0.044	>5 - 10
POOR	POOR	>0.015 - 0.025 (eutrophic)	>1.0-4.0	≥4 -6	10-25	>0.072-0.1	>10 -20
UNACCEPTABLE	UNACCEPTABLE	>0.025 (hypertrophic)	> 4	< 4	<10	>0.1	> 20 - 30

3.7.2 Thresholds to interpret water quality risks to human health

Tables 3.4 to 3.6 present the thresholds used to determine risk to human health on the basis of monitoring of three key variables, namely *Escherichia coli* bacteria, enterococci bacteria and microcystin toxins associated with cyanobacteria (also called blue-green algae). Concentrations of all of these are evaluated with respect to the level of risk they pose to people undertaking 'intermediate contact' recreational activities, such as canoeing, kayaking, fishing, sailing, rowing, kite-boarding and wind-surfing. Although people undertaking such activities are likely to come into contact with water and possibly ingest some, they are less at risk than people undertaking 'full-contact' recreational activity (swimming).

Note that the CCT does not manage any of its waterbodies with the target of their being fit for full contact recreation. This is not considered a realistic target under the present circumstances.

The criteria used to derive these thresholds are outlined in **Appendix B**. Note that enterococci data were not available at the time of preparation of the previous (2020) Inland Water Quality Report, and the criteria used to define their thresholds have been prepared as part of the current reporting input, in discussion with CCT officials.

Finally, the WHO (2021) guidelines for management of water quality in recreational waterbodies stress important points, namely that most generic guideline values are derived from studies involving healthy adult recreational water users. They may not apply to children, the elderly or people who are immunocompromised, who may have lower immunity and might require a greater degree of protection. In addition, risks are also likely to be greater in areas with higher carriage rates or prevalence of diseases that could be transmitted through recreational water contact. These warnings are probably relevant to many low-income and particularly informal settlement areas in Cape Town, where immune systems may be compromised by chronic exposure to pathogens and poor nutrition and access to basic health structures.

Table 3.4

Approach to assessment of microbial data (faecal coliforms including *Escherichia coli*)

See **Appendix B** for derivation of threshold values.

Note inclusion of Full Contact and Intermediate Contact thresholds and expansion of UNACCEPTABLE range to show different scales of pollution. This expanded scale was not however used in this report, given issues of reporting on ">" values, as discussed in Section 3.8.6.

Interpretation	Inland systems ¹ Faecal Coliform Count (Including <i>E. coli</i>) ¹
TARGET FOR MAXIMUM ACCEPTABLE RISK FOR FULL CONTACT RECREATION	≤ 400 cfu/100 ml
ACCEPTABLE RISK INTERMEDIATE CONTACT	1 001 – 2 500 cfu/100 ml
TOLERABLE RISK - INTERMEDIATE CONTACT	> 2 500 – 4 000 cfu/100 ml
UNACCEPTABLE RISK - INTERMEDIATE CONTACT– LEVEL 1	> 4 000 – 10 000 cfu/100 ml
UNACCEPTABLE RISK - INTERMEDIATE CONTACT– LEVEL 2	> 10 001 - 100 000 cfu/100 ml
UNACCEPTABLE RISK - INTERMEDIATE CONTACT– LEVEL 3	> 100 000 cfu/100 ml

¹ The concentrations of bacteria in water is usually expressed as numbers of colony-forming units (cfu) per 100 ml, which is a measure of the number of viable cells in a particular sample, where a colony represents an aggregate of cells derived from a single progenitor cell

Table 3.5
Approach to assessment of microbial data (intestinal enterococci counts)

Percentile data calculated using the Hazen Method
Water quality categories as used in the CCT's Coastal Water Quality Reporting⁵
Single sample ratings from DEA (2012)
See **Appendix B** for derivation of threshold values.

Interpretation in this report	Descriptor in Coastal Water Quality Reporting	Estimated risk of illness per exposure ²	Enterococci (cfu/100 ml)	Enterococci (cfu/100 ml) - for single samples
TARGET	EXCELLENT	< .9% Gastrointestinal Illness (GI) risk	< 100 (95 th percentile)	
ACCEPTABLE RISK INTERMEDIATE CONTACT	GOOD	<5% Gastrointestinal Illness (GI) risk	< 200 (95 th percentile)	≤240
TOLERABLE RISK - INTERMEDIATE CONTACT	SUFFICIENT	<8.5% Gastrointestinal Illness (GI) risk	< 185 (90 th percentile)	240 – 380
UNACCEPTABLE RISK - INTERMEDIATE CONTACT	POOR	>8.5% Gastrointestinal Illness (GI) risk	≥ 185 (90 th percentile)	>380

² 'Exposure' defined as 10 minutes of swimming with three head immersions

Table 3.6

Water quality grades and corresponding threshold concentrations for microcystin toxins for inland waters adopted for this project.

Guideline levels are based on those published by the WHO (2003). Note that WHO (2021) provides an updated GV Recreation (GV_{RECREATION}) Threshold of 24 µg/L for microcystins, below which recreational water use should be within acceptable risk limits. This suggests that the Medium Risk values in the table are slightly conservative. See **Appendix B** for derivation of threshold values.

Interpretation	Microcystin concentration
TARGET (ACCEPTABLE)	≤ 20 µg/L
MEDIUM RISK (UNACCEPTABLE)	>20- 30 µg/L
HIGH RISK (UNACCEPTABLE)	>30-40 µg/L
EXTREME RISK (UNACCEPTABLE)	>40 µg/L

3.8 Data analysis

3.8.1 Sampling sites included in the analyses

Only sites in the CCT's routine monitoring network have been included in this assessment. All sites are sampled monthly, and samples analysed for basic water chemistry variables and microbiology (*E. coli*). In addition, recreational vleis (Rietvlei, Milnerton Lagoon, Zeekoevlei, Princessvlei and Zandvlei) are sampled roughly twice monthly for *E. coli* and (less regularly) intestinal enterococci.

3.8.2 Dealing with seasonal variability

A number of water quality variables are subject to significant seasonal variability, largely related to differences in rainfall between the wet and dry seasons. An attempt has thus been made to explicitly take seasonal variability into account in the current assessment by assigning one of two seasons to

⁵ (<https://www.capetown.gov.za/explore%20and%20enjoy/nature-and-outdoors/our-precious-biodiversity/coastal-water-quality>)

the data, as follows:

- Winter (typically the 'wet season' in Cape Town) = April to September
- Summer (typically the 'dry season' in Cape Town) = October to March

These seasons were based on the four seasons assigned by Dallas et al. (1998) in the development of regional guidelines for water quality assessment in South Africa, with the 'winter' referred to here, starting mid-way through the Dallas et al. autumn season (i.e., April) and 'summer' starting mid-way through the Dallas et al. spring season.

Each sampling record in the dataset was pre-assigned to one of the two above-mentioned seasons before conducting the data analyses. The dataset used in the report concludes in March 2022 (end of dry season).

3.8.3 Spatial groupings of data

Sites within the water quality dataset were classified in terms of subcatchment, using the areas identified in **Figure 3.1**. The assignment of different sites to subcatchments is indicated in the sites table in **Appendix A**. The subcatchments used as the basis for data analysis are as listed below, noting that in some cases the 'subcatchments' comprise whole river catchments (e.g. Hout Bay River), while in others the main catchments have been split into different subcatchments (e.g. Mosselbank and (lower) Diep subcatchments of the Diep River). Other 'subcatchments' in fact comprise a number of different river systems in adjacent catchments, considered sufficiently similar in terms of land use to warrant lumping together by area (e.g. South Peninsula, comprising the Else, Bokramspuit and Schusters rivers). This was done to reduce the total number of subcatchments in this report to more manageable numbers. The groupings were as follows for catchments and subcatchments with water quality data:

- Diep
 - Mosselbank
 - Diep
- Eerste
 - Kuils (to Baden Powell Drive)
 - Lower Kuils and Eerste
- Salt
 - Lower Salt
 - Elsieskraal
- Hout Bay
- Lourens
- Mosselbank
- Mitchell's Plain (Mplain)
- Noordhoek
- Sand
- Silvermine
- Sir Lowrys Pass (SLPass)
 - Sir Lowrys Pass (SLPass)
 - Soet (managed as part of the Sir Lowry's Pass catchment)
- Sout
- South Peninsula
- Zeekoe.

Note that of these systems, the Mitchell's Plain subcatchment does not include any natural river systems, but it generates large volumes of runoff from hardened urban areas. Two stormwater attenuation pond sample sites have been used to represent water quality in this subcatchment, runoff from which is also represented in a number of coastal sample sites, which include stormwater outlets onto the beaches of False Bay.

The coastal sites are not considered here, as water quality data from these sites have already been assessed in the CCT's 'Know your Coast 2021' coastal report.

It should also be noted that not every catchment in Cape Town is represented in the monitoring programme. Some catchments that are not considered problematic from a water quality perspective, or which do not have significant river systems (e.g. the Atlantis subcatchment), or where natural rivers have been entirely piped into the stormwater system (e.g. City Bowl) do not have any monitoring sites (see also **Section 2.3**).

3.8.4 Calculations to provide additional water quality variables

The following additional water quality variables were obtained for analysis in this report, by calculation from existing data:

- Total Inorganic Nitrogen (TIN) – through addition of NH₄-N and (NO₃+NO₂)-N
- NH₄:TIN – the ratio of NH₄-N:TIN
- TIN: PO₄P – as a ratio of TIN to PO₄-P
- PO₄-P:Total phosphorus (PO₄-P:TotP), expressed as a ratio (note that in some cases this ratio exceeded 1, suggesting analytical error / inaccuracy, and in such cases the data were excluded).

3.8.5 Date nomenclature and time series considered in this report

The annual reporting period comprises the period from 1 April to 31 March in any given cycle and is given the YEAR identity at the start of the period. Data for the period 1 April 2020 to 31 March 2021 are accordingly referred to as the **2020** dataset.

This report is required to focus on the two reporting periods that followed the previous Inland Water Quality Report, which reported on water quality data up to 31 March 2020 (i.e. the 2019 reporting period). **The present report thus focuses on data for the 2020 and 2021 reporting periods** (1 April 2020 to 31 March 2022).

In order to be able to report meaningfully on at least short- to medium-term water quality trajectories, data for the 2020 and 2021 reporting periods are, however, assessed in the light of data over a five-year period. **Thus, the report includes data from 1 April 2017 through until 31 March 2022.**

In future, it is this team's understanding that the CCT's Inland Water Quality Report will be generated on an annual basis and will assess data from the last reporting period against the previous four years' of data on a rolling basis.

3.8.6 Treatment of unreliable *E. coli* data

Between April 2021 and January 2022, the CCT's Scientific Services Branch (SSB) reported *E. coli* data that appeared out of sync with observed conditions in many waterbodies, and led to the closure of Rietvlei, Zeekoevlei and Zandvlei, over various periods. Following testing of replicate water samples at independent laboratories, it was noted that there was a serious discrepancy in results, with *E. coli* concentrations being over-reported in SSB data. This was confirmed in independent testing carried out in both Rietvlei and Zeekoevlei.

An investigation into the SSB processes was carried out by SABS in May 2022. This investigation concluded that the Hicrome MTEC agar that SSB had started using in April 2021 was problematic, in that it allowed the growth of both *E. coli* and another faecal coliform bacteria, *Klebsiella pneumoniae*, which has a similar colony form, making differentiation of the two difficult (Memorandum from SSB to CSRM, 7 February 2023).

As a result of the above findings, the SSB has switched analytical methods, and now uses the Colilert system for *E. coli* analysis.

Given these issues, the *E. coli* data for the entire 2021 Reporting Year could not be used in this report, and only the 2020 Reporting Year data are referenced.

In addition to the above, reporting of *E. coli* data by SSB includes a number of samples that, for reasons of over-dilution or under-dilution, cannot be assigned actual numbers of *E. coli* colony forming units, but which are rather reported as '<x' or '>x' (where x= the level of resolution that has been attained by the laboratory for that sample). While this method of reporting is normal laboratory

practice, over the 2020 reporting period for which *E. coli* data are assumed to be reliable, there was both an increase in the percentage of such reporting, as well as an increase in the reporting of samples as '>' values that were either still below the Unacceptable threshold for this variable, or above the lower threshold, but within relatively low concentrations for known highly polluted scenarios. For example, reporting at >24 196 cfus for samples in a system where *E. coli* counts frequently exceed 1 000 000 cfus does not allow for pollution tracking or for detection of areas where pollution appears to be greater and closer to source. Such practices also make meaningful statistics difficult.

For this reason, *E. coli* data were analysed only in terms of Compliance-type reporting of the percentage of samples falling within different categories of acceptability. Data reported as '>' any number below the Unacceptable threshold was automatically rated as Unacceptable. Similarly, (less frequent) reporting as '<' any number within the Unacceptable range was also rated Unacceptable. This is a risk-averse strategy to deal with data uncertainty and could result in some over-estimation of Unacceptable data.

Figure 3.4 presents a summary of the number of data points reported as '>' and '<', excluding those in the 2021 reporting year, which have already been excluded from the dataset. Only 5% of all data reported in the 2017-2019 (three-year) period were thus reported, while 14.6% of data in the 2020 reporting year alone were affected. Data for samples reported on as '>' for levels below ten million cfu/100 ml at least were considered problematic, as they do little to assist in pollution tracking or catchment-scale interpretation.

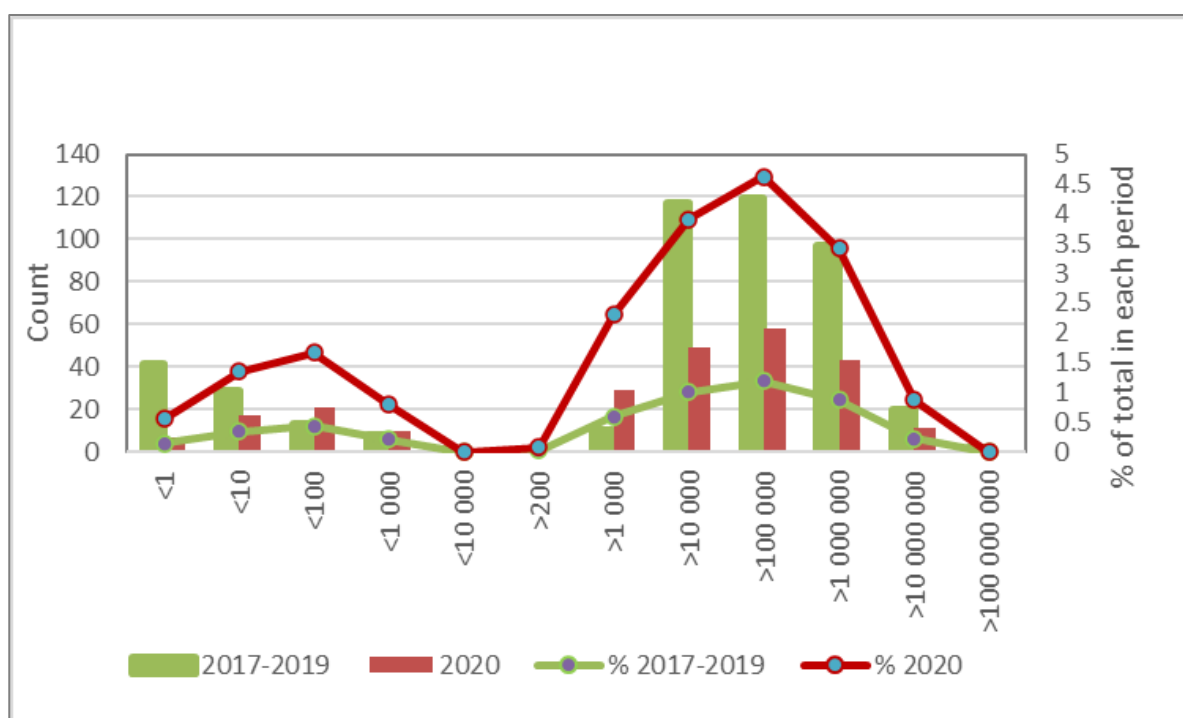


Figure 3.4

Frequency histogram showing numbers and percentages of *E. coli* data reported on as '<' or '>', categorised by reporting year. Data for 2021 monitoring period excluded.

3.8.7 Data categorisation

- Seasons were allocated as described in **Section 3.8.2**;
- Subcatchments were used as the unit of analysis, as already described;
- Sites were analysed separately according to watercourse type, i.e., standing water (vleis, dams and detention ponds) and flowing water (rivers and stormwater channels);

- Functional estuaries⁶ were classified as to whether they were standing water or flowing systems – e.g. water quality data for the Diep River Estuary / Milnerton lagoon were classified as from a flowing water system, and included, while Zandvlei was classified as a standing water system – note that these classifications applied only to water quality variables such as DO, PO₄-P, TIN, N:P ratios, and enterococci concentrations, the interpretation of which did not differ between estuarine and freshwater systems. *E. coli* assessments did, however, distinguish between estuaries and other aquatic ecosystems since different standards are applicable to estuarine and freshwater systems.

3.8.8 Analysis of data for the current reporting period

For the purposes of this report, the 'current' reporting period is defined as the last two years of the monitoring record – that is, April 2020 to March 2022 - and the data from this period have been treated as follows:

- In order to provide broad summaries of 'performance' (that is, the proportion of data for each selected key variable from monitoring points across each subcatchment over any reporting period), compliance-type graphs were created, plotting the percentage of data falling into each of the Target, Poor and Unacceptable categories listed in **Tables 3.2-3.6** for ecological variables, *E. coli*, intestinal enterococci counts and microcystin toxicity. In this regard:
- In the case of *E. coli* data, the CCT has set itself a 'target' that at least 60% of samples in any catchment should meet the defined Target thresholds. *E. coli* compliance graphs thus also show this 60% threshold – **Section 4.6** provides comment on this practice;
- Boxplots were developed for all of the selected data, and presented for discussion, comparing the current (2020 and 2021) datasets (separately) with data from the previous three years (2017 – 2019) – these data are presented relative to the interpretation categories for aquatic ecosystem health and human health (*E. coli*) shown in **Tables 3.2 – 3.5**;
- Median annual data per site per variable (mean data for *E. coli* and Chlorophyll-*a*) were also presented (**Appendix D**), with data colour-coded for ease of reference as to its water quality category;
- Truncated summary boxplot data are presented in **Section 5** for ease of reference – the full boxplot datasets including outliers is presented in **Appendix E**.

Box 3.5 provides an explanation of the interpretation of boxplots as a guide to readers unfamiliar with this form of data presentation.

⁶ Note that the DWS (2018) classification of all areas below the 5 mamsl contour line as estuarine was not considered in this assessment, and only systems known to comply with the legal definition of an estuary (see **Section 7.2**) were assessed using Estuarine rather than Inland thresholds for *E. coli*

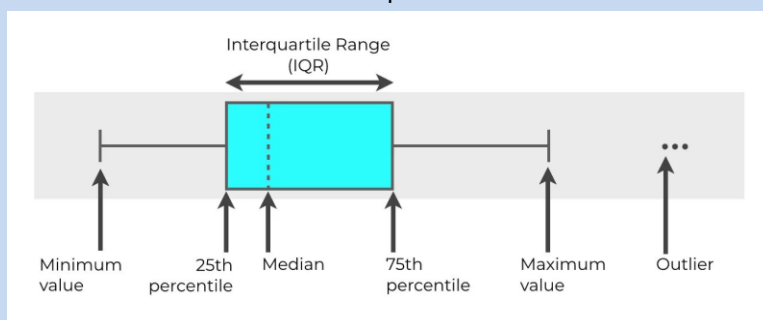
Box 3.5**Explanation of boxplots, also known as box-and-whisker plots**

A boxplot, or box-and-whisker diagram, is a standardised type of graph for visually depicting the central tendency and variability of a dataset, as well as the distribution (or skewness) of the data and the presence of outliers. It does this by dividing the range of a dataset into quarters, or quartiles, with each quartile containing 25% of the data points. There are thus the same number of data points in each quartile. A boxplot typically consists of three parts: a box (usually split into two portions), a set of lines perpendicular to the box ('whiskers') and point markers beyond the whiskers depicting outliers, as shown in the diagram below. Sometimes, the full range of a dataset is shown as part of the whiskers, in which case there will be no outliers.

The box represents the range of values from the first/lower quartile ($Q_1 = 25\text{th percentile}$) of a dataset to the third/upper quartile ($Q_3 = 75\text{th percentile}$), with the middle value in the dataset ($Q_2 = \text{median or } 50\text{th percentile}$) indicated by a line dividing the box into two quartiles. The box thus shows the range of values within which the central half (50%) of the data points of a dataset fall, extending from Q_1 to Q_3 and known as the Inter-quartile Range (IQR).

The whiskers of a boxplot extend outwards from ends of the box, which represent the lower and upper quartiles (Q_1 and Q_3 , respectively), to the minimum and maximum values of the dataset. For a boxplot, the minimum and maximum values are typically derived from the IQR (i.e., $Q_3 - Q_1$) to set a boundary beyond which any observations would be considered outliers. The maximum is taken as the largest observed value of a dataset that falls within 1.5 times the IQR added to Q_3 , while the minimum is taken as the smallest observed value falling within 1.5 times the IQR subtracted from Q_1 . The whiskers either simply terminate at the minimum and maximum values or short lines are drawn perpendicular to the whiskers at these points (as in the diagram below). It is important to remember that, even though 1.5 times the IQR is the same for both sides of the box, the whisker lengths are often unequal because the whiskers must end at an observed data point. In some cases, the minimum (and boundary of the lower whisker) is simply taken as the smallest observed value of the data set, and the maximum (boundary of the upper whisker) as the largest observed value of the data set.

All data points outside the boundary of the whiskers (i.e., less than the derived minimum or greater than the derived maximum values) are considered to be outliers. Outliers are plotted as individual data points on the boxplot.



3.8.9 Assessment of the current state of water quality in terms of human health risks at major recreational sites

For the assessment of the current state of Cape Town's inland water quality, the last five reporting years of available data (2017 – 2021) were used, and the same seasonal cycles and year nomenclature were used as presented in **Section 3.8.8**.

Data focused on Cape Town's main recreational vleis / waterbodies, namely:

- Princessvlei
- Zeekoevlei
- Rietvlei

- Milnerton lagoon
- Zandvlei.

Although inclusion of a section of the lower Kuils River, from which the Khayelitsha Canoe Club operates, was also planned for inclusion, there are no sample points that adequately reflect water quality in this area.

Assessment of human health risk at each waterbody entailed an analysis of the percentage of samples that exceeded the target value for safe intermediate contact recreation in terms of *E. coli*, enterococci and microcystin concentrations (see **Section 3.6** for an explanation of the relevant criteria).

E. coli data for the 2021 reporting period were not used, given issues around the reliability of these data (see **Section 3.8.6**).

Enterococci data, available for most recreational waterbodies for the 2021 reporting period were categorised in the database using the single sample criteria recommended by DEA (2012) (see Table 3.5). These criteria were used to generate comparative compliance graphs for rivers in different subcatchments and for grouped sites in standing waterbodies.

90th and 95th percentile data were also calculated for annual enterococci data for the 2021 reporting period, using the Hazen method of statistical analysis. Spreadsheet-based formulae provided by McBride and Payne (2009) were utilised to calculate these percentiles. The Hazen method provides a 'middle of the road' estimate of the percentile value in contrast to other common methods of calculation (McBride and Payne 2009). These data are presented in Appendix C (Table C3).

3.8.10 Assessment of the trajectory of water quality in priority subcatchments

- Median annual and seasonal data were calculated separately for the two current reporting years (2020 and 2021) and compared against the combined year sets for the 2017 to 2019 reporting periods for all key variables, except Chlorophyll-*a*, *E. coli* and enterococci. Arithmetic mean data were calculated for the former; geometric mean data were calculated for *E. coli*; and the 95th and 90th percentiles were calculated for annual enterococci data, using the Hazen Method as recommended by WHO (2021), and interpreted as per **Table 3.5**;
- Data showing changes in median annual and seasonal data per variable between 2021 data and 2020 data were plotted on GIS maps, with a map produced per Priority Subcatchment;
- The data were colour-coded per site for each variable considered, using the thresholds for Target to Unacceptable as shown in **Tables 3.2-3.6**, for median data for the 2021 reporting period. In order to provide an indication of trajectory of change, data points were also coded to indicate improvement, degradation, or no real change. Significant 'change' was determined as an increase or decrease of 25% or more, compared to the 2020 dataset. These maps were produced for the water quality variables believed to be most indicative of catchment quality – PO4-P; NH3; NH4-N; TIN; and *E. coli*;
- Since reliable *E. coli* data were not available for the 2021 period, only 2020 data are included in the maps, and were compared with data for the period 2017-2019 to derive trajectories. The *E. coli* data are presented as geometric means, rather than median values, this being the more appropriate way of treating these data (see **Box 3.6**);
- Enterococci data, only available for the 2021 reporting period, were also provided for the limited sites for which these data are available, to provide a longer term indication of sewage contamination issues.

Box 3.6

Geometric versus arithmetic means

The Geometric Mean (GM) is a type of average, which is often used as a measure of central tendency for bacteria concentrations and other datasets with a large range of variability. While the arithmetic mean finds the average by summing the values and dividing by the number of observations, the GM finds the average by multiplying and then taking a root of the product. The GM is mathematically defined as the **nth root of the product of n numbers**, with the following formula:

$$\sqrt[n]{X_1 X_2 \dots X_n}$$

GM =

Where:

X = the values of a variable; and

n = the number of values in the dataset.

What this formula means is that you multiply the values by one another and then take the nth root, where n is the number of values in the dataset. This is the same as taking the average of the logarithmic values of a dataset and converting this back to a base 10 number, which implies that the geometric mean (sometimes referred to as the log mean) is really a log-transformation of a dataset.

The GM tends to dampen the effect of very high or low values to a greater degree than the arithmetic mean. It is always less than the arithmetic mean, except where all the values of the dataset are the same, in which case the two means are equal.

If the variable of interest has a log-normal distribution, the GM is the same as the median for that dataset (Vogel 2020), although random differences can be expected in practice, depending on the number of samples and the sampling frequency (DWAf 1996). It is important to be aware that the GM is extremely sensitive to both the underlying distribution of a dataset and its skewness, as well as differences in sample size (Vogel 2020). This measure should thus be used with caution when comparing datasets that have significantly different sample sizes.

4 RAINFALL PATTERNS IN CAPE TOWN

4.1 Reasons for assessing rainfall

Rainfall data are included to provide background understanding of rainfall patterns in different subcatchments of the city, both over the current reporting period and to get context over a longer term period (e.g. whether it was a drought year). Tight correlations of rainfall events with individual sample point data is not however possible, as sample collection is not (and is not intended to) align with rainfall events.

4.2 Approach

Rainfall data were provided by the CSRm for 38 rain-gauging stations across Cape Town, spanning the period April 2017 to March 2022 (i.e., Reporting Years 2017 through to 2021). Unfortunately, the datasets provided had numerous 'no data' entries for most of the stations during the relevant reporting periods (as shown on the graph in **Figure 4.1**, below). **Figure 4.2** shows the locations of the gauging stations.

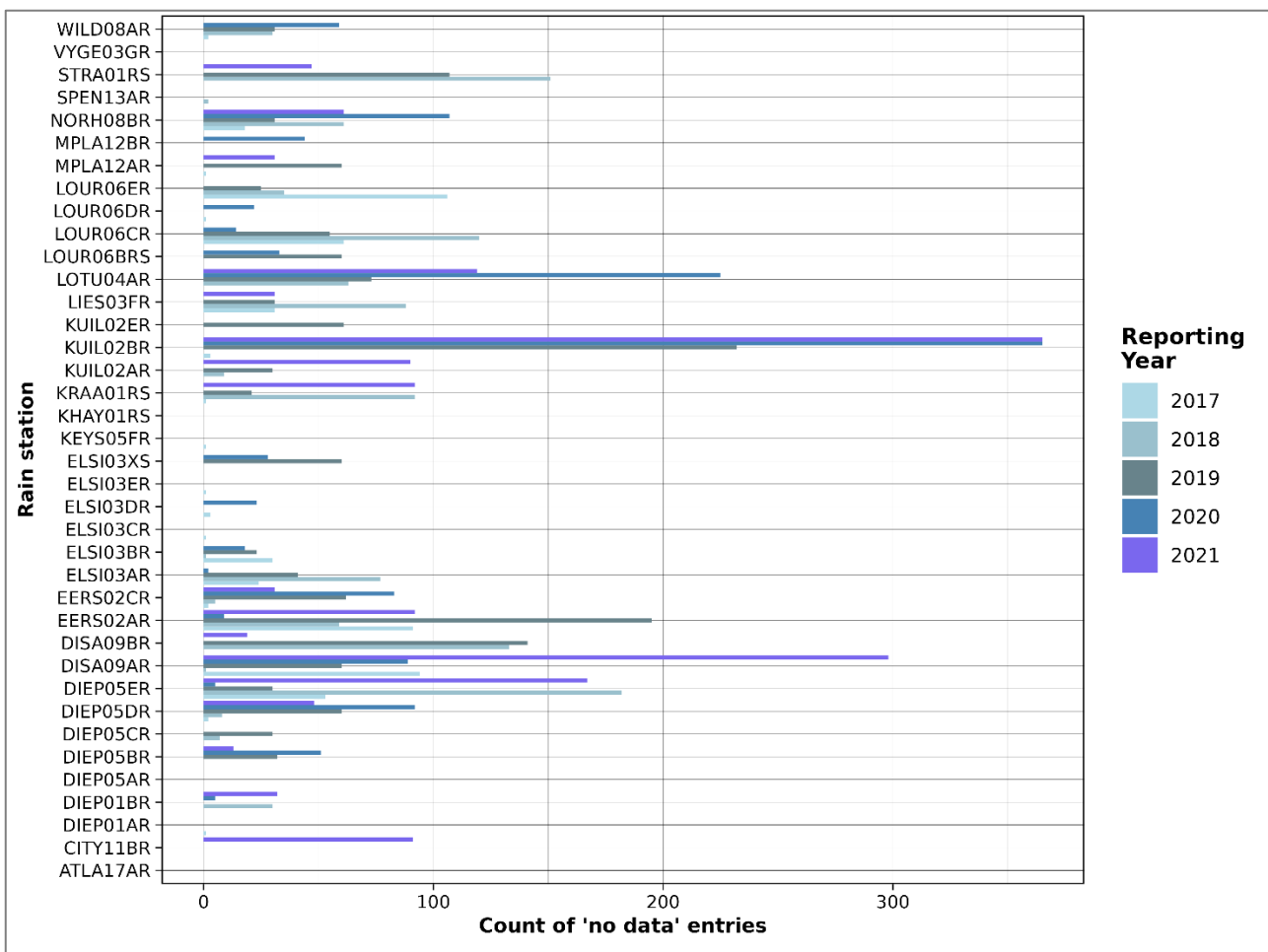


Figure 4.1
Histogram showing number of 'no data' entries at CCT rain-gauging stations (Apr 2017 to Mar 2022)

In the end, the rainfall analyses completed for the current project involved the use of monthly rainfall data from only eight rain-gauging stations with no missing data (or only one 'no data' entry during a period when no or very little rainfall was recorded at other rain-gauging stations). The eight stations that were selected are spread across seven of the CCT's subcatchments (see list in **Table 4.1** and map in **Figure 4.2**).

Table 4.1
List of eight CCT rain-gauging stations used in the rainfall analyses, indicating which catchment and subcatchment each station is located within

Rain station	Description	Catchment	Subcatchment
ATLA17AR	Atlantis WWTW	Atlantis	Atlantis
DIEP01AR	Potsdam WWTW	Diep	Diep
ELSI03CR	Tygerberg Reservoir	Salt	Elsieskraal
ELSI03ER	Pinelands Roads Depot		
VYGE03GR	Athlone WWTW		Lower Salt
DIEP05AR	Kendal Water Works Depot	Sand	Sand
KHAY01RS	Khayelitsha Roads Depot	M-Plain	M-Plain
SPEN13AR	Brooklyn WTP, Red Hill, Simonstown	South Peninsula	South Peninsula

To gain a better understanding of the rainfall patterns in the study area during the time period of analysis in relation to longer term trends, a long-term dataset for a rain-gauging station at Intaka Island (Century City) was obtained. For the current study, 20 years of rainfall data were extracted from this additional dataset for the period April 2002 to March 2022.

For the rainfall analyses, monthly rainfall totals were derived from daily rainfall figures. The monthly totals were grouped into 'hydrological years' or 'reporting years' (April to March), as opposed to calendar years, and into 'winter' (April to September) and 'summer' (October to March) seasons using the seasonal categorisation explained previously (see **Section 3.8.2**). For the CCT's dataset, rain-gauging stations were grouped into subcatchments for some of the analyses. It should be noted that the Intaka Island rain-gauging station is located within the Diep subcatchment.

The following summaries were produced from the two rainfall datasets:

- Intaka Island gauging station:
 - Total annual rainfall for each year, compared against the mean annual rainfall over the April 2002 – March 2022 period; and
 - Mean monthly rainfall (and standard deviation) by season per reporting year, compared against the mean monthly winter rainfall for the 20-year period.
- CCT gauging stations:
 - Monthly rainfall at each of the eight selected stations for the April 2017 – March 2022 reporting period;
 - Total annual rainfall at each station for each reporting year (2017-2022), grouped by subcatchment, compared against the mean annual rainfall at Intaka Island over the 20-year period;
 - Mean annual rainfall (and standard deviation) across all gauging stations per reporting year for the five-year reporting period (2017-2021), compared against the 20-year mean annual rainfall at Intaka Island; and

Mean monthly rainfall (and standard deviation) by season and year at each of the eight stations for the five-year reporting period, compared against the 20-year mean monthly winter rainfall at Intaka Island.

The rainfall patterns are discussed separately, below, for the 20-year period preceding the end of the current reporting period (**I.E.**, March 2022), based on the Intaka Island dataset (**Section 4.3**), and for the five-year period up to the end of the current reporting period, based on the CCT's rain-gauge data (**Section 4.4**). The long-term average, derived from the 20-year Intaka Island dataset, is shown as a point of comparison in some of the analyses for the recent five-year period.

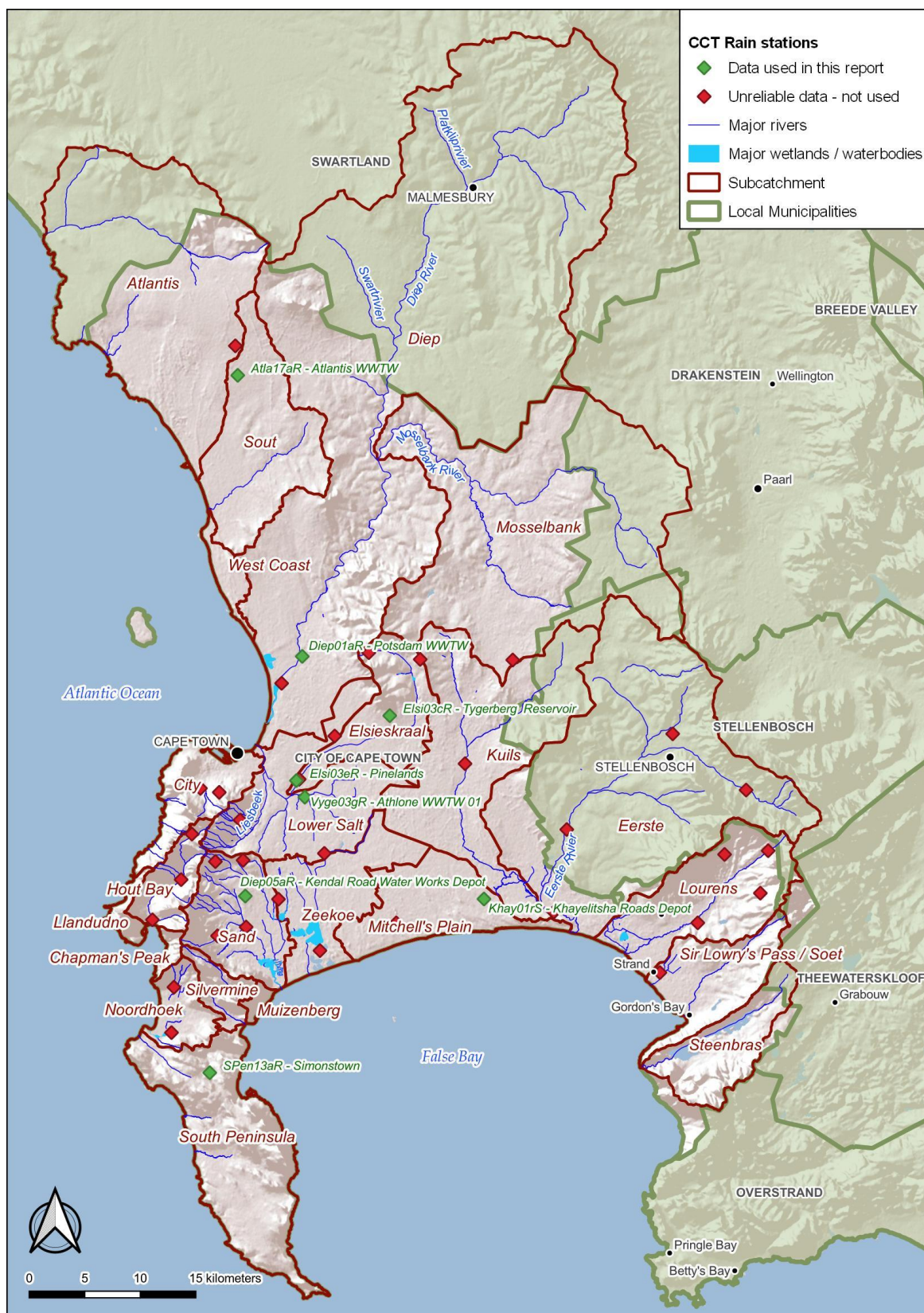


Figure 4.2

Map of CCT rain-gauging stations, in relation to subcatchments, distinguishing between the eight stations which had no missing data for the period Apr 2017 to Mar 2022 and the others

4.3 Intaka Island 20-year dataset

The mean annual rainfall at Intaka Island over the 20-year period of analysis (Apr 2002 – Mar 2022) was 575 mm (see **Figure 4.3**). The drought of 2015-2017, with less <450 mm per annum (dropping to <350 mm for Reporting Year 2017), is clearly visible on the bar graph and it is apparent that Reporting Year 2019 was a similarly dry year (<400 mm annual rainfall). Going back further, the previous dry period (with <450 mm of annual rainfall), was a much shorter spell in Reporting Year 2010. The annual rainfall recorded at Intaka Island during the focal period for the current report (i.e., Reporting Years 2020 and 2021) was still significantly below the 20-year average, at 450-500 mm per annum. The most recent wet period observed at Intaka Island was in Reporting Years 2012 and 2013, when more than 700 mm of rain was recorded per annum.

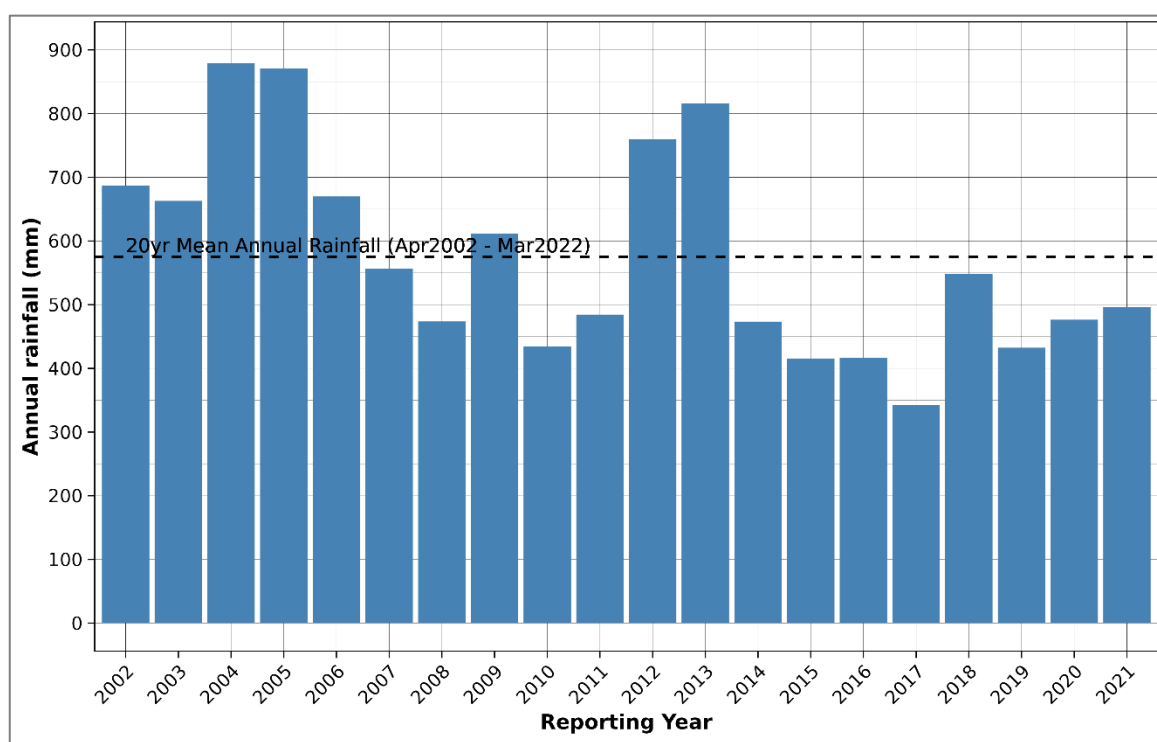


Figure 4.3

Total annual rainfall at Intaka Island for the 20-year period Apr 2002 – Mar 2022, showing the mean annual rainfall over this period

Interrogation of the mean monthly rainfall per season for each year over the last 20 years at Intaka Island (see **Figure 4.4**) shows that the mean monthly rainfall during the winter months was significantly less than the long-term (20-year) winter average (approximately 70 mm) in Reporting Years 2015, 2017 and 2019, at close to or less than 50 mm per month. The mean monthly rainfall during winter of Reporting Year 2018, at approximately 80 mm, was greater than the long-term winter average. Prior to this, above-average monthly winter rainfall was most recently recorded at Intaka Island in Reporting Years 2012, 2013 and 2014. The mean monthly rainfall recorded in winter at Intaka Island during the focal period for the current report (i.e., Reporting Years 2020 and 2021) was approaching but still below the long-term 20-year average for winter months, at 55-65 mm per month.

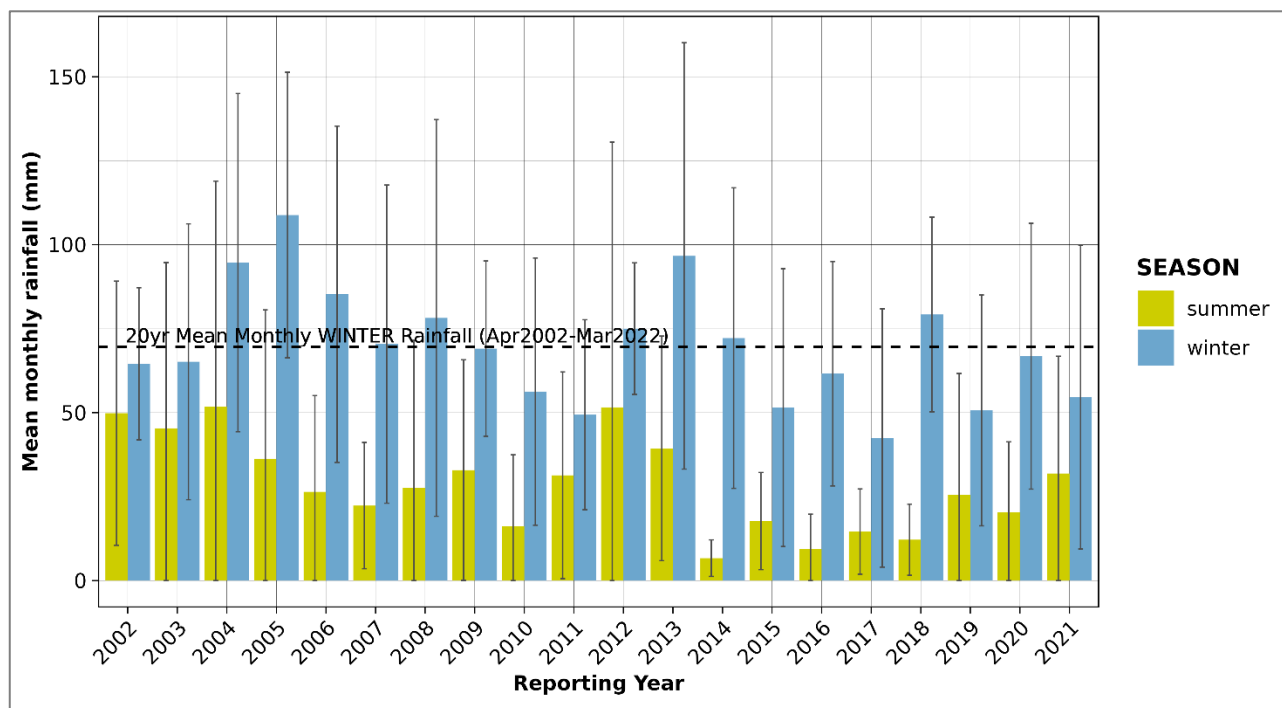


Figure 4.4

Mean monthly rainfall (and standard deviation) at Intaka Island during summer and winter for each reporting year between 2002 and 2021, in relation to the mean monthly rainfall during winter for the full 20-year period

4.4 Five-year period (Apr 2017- Mar 2022) at the CCT's rain-gauging stations

The graph of total annual rainfall at the CCT's rain-gauging stations for the 2017-2021 period (**Figure 4.5**) shows that there was a significant amount of variability between gauging stations across Cape Town in each year, with the highest cumulative rainfall for each year typically being recorded at rain stations DIEP05AR (in the Sand subcatchment) and SPEN13AR (in the South Peninsula subcatchment). At all the rain stations, however, significantly less rain was consistently recorded for 2017 and 2019 compared to Reporting Years 2018, 2020 and 2021. This pattern is also shown very clearly in the graph of mean annual rainfall (and standard deviation) per year across all gauging stations (**Figure 4.6**), confirming that Reporting Years 2017 and 2019 were particularly dry years across all parts of Cape Town. For Reporting Years 2018, 2020 and 2021, the mean annual rainfall across all CCT-operated rainfall stations included in the analysis was still well below the long-term (20-year) MAP of just under 600 mm derived from the Intaka Island dataset.

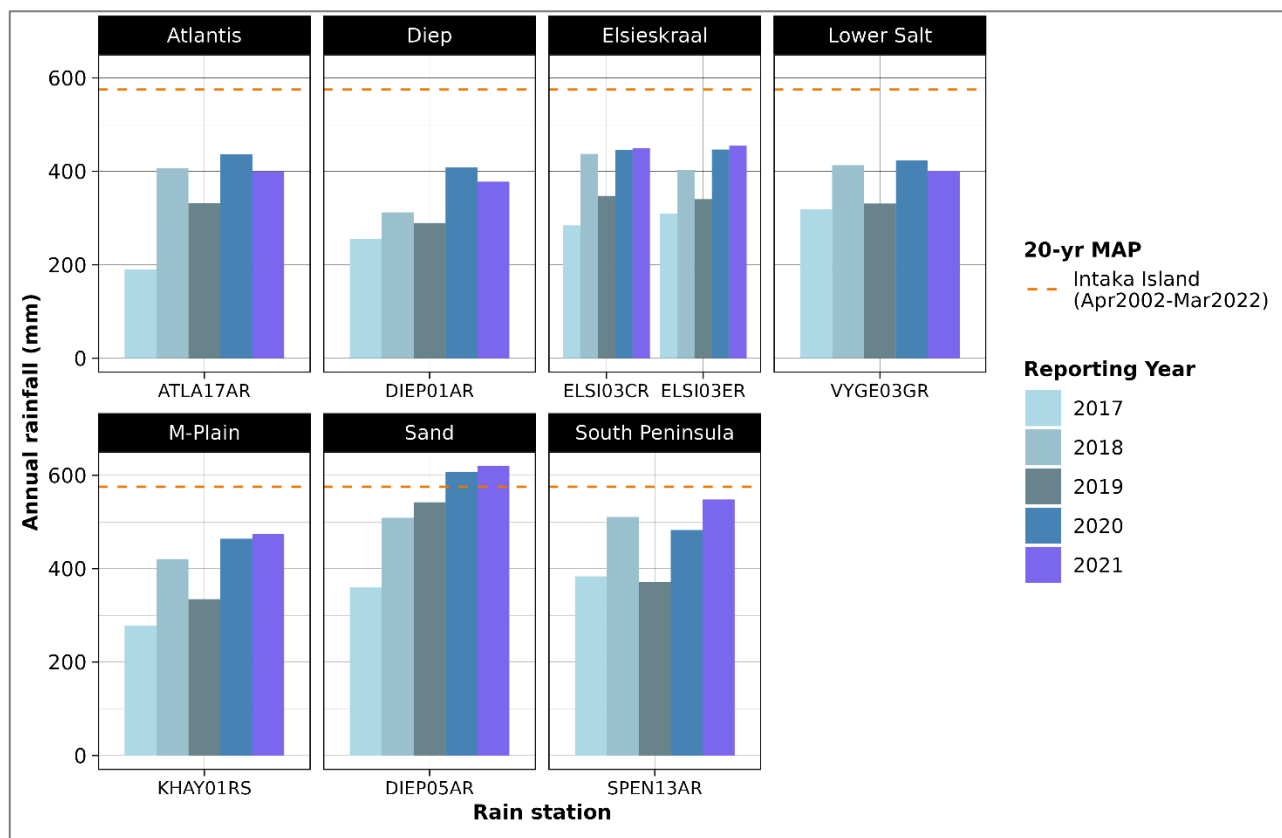


Figure 4.5

Total annual rainfall (Reporting Years 2017-2021) at each of the CCT-operated rain-gauging station that was selected for the rainfall analyses, grouped by subcatchment, showing the long-term (20-year) MAP at Intaka Island

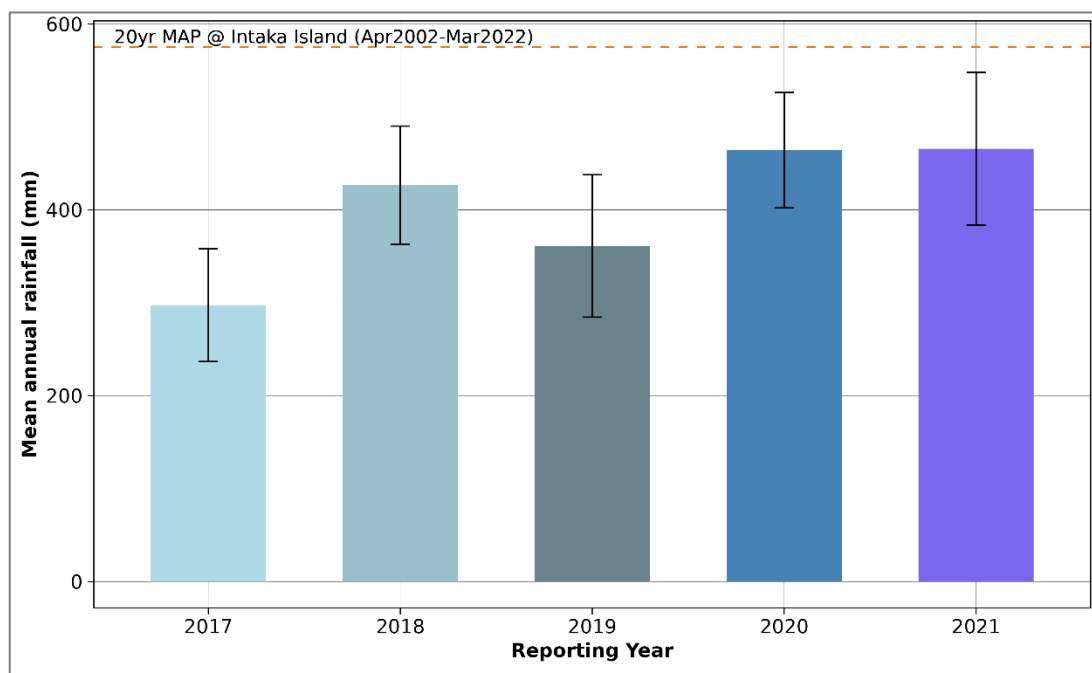


Figure 4.6

Mean annual rainfall (and standard deviation) per year across all of the CCT-operated rain-gauging stations that were selected for the rainfall analyses (Reporting Years 2017-2021)

The above-mentioned rainfall patterns are not so clearly evident in the bar graphs of cumulative monthly rainfall at each of the selected CCT-operated rain-gauging stations over the April 2017 to March 2022 period (see **Figure 4.5**), highlighting the importance and value of more interrogative data analysis.

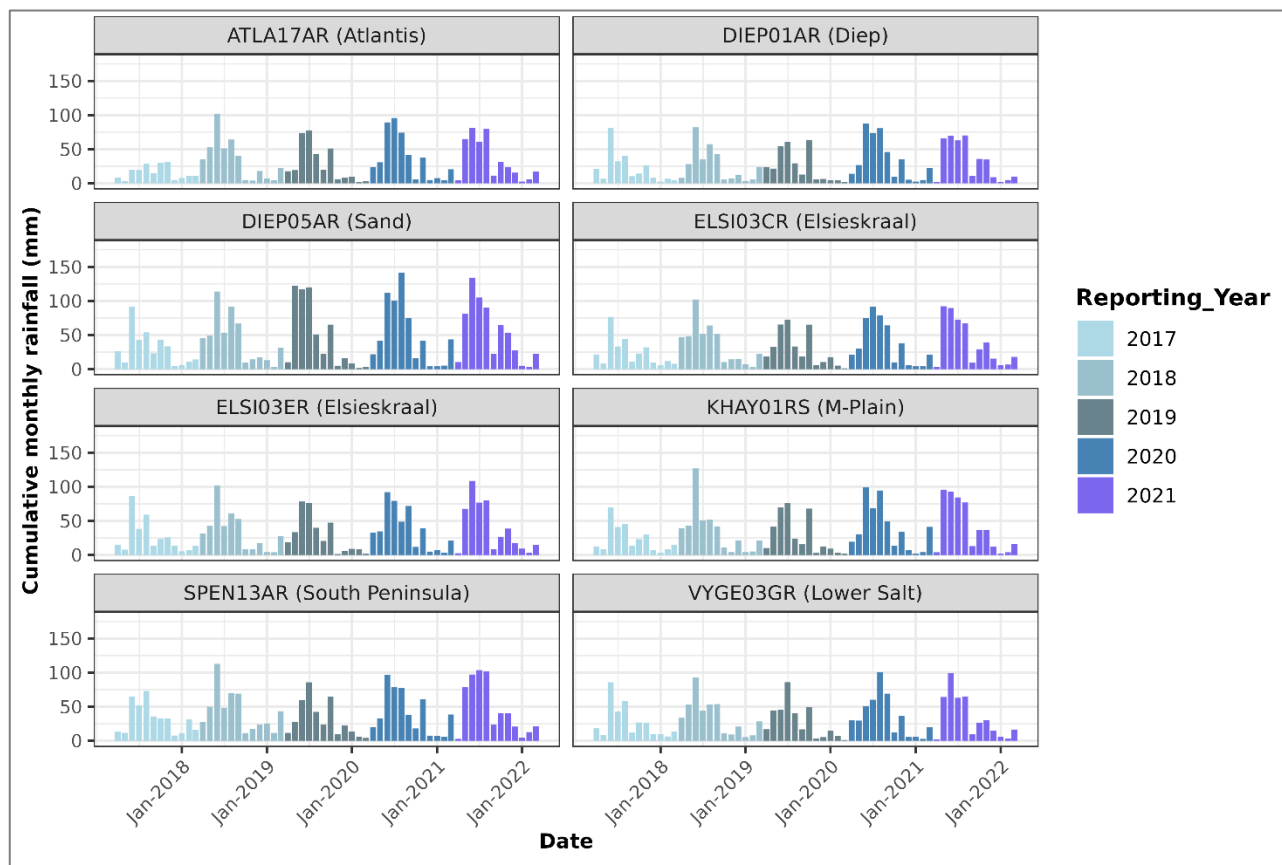


Figure 4.7

Cumulative monthly rainfall at each CCT-operated rain-gauging station that was selected for the rainfall analyses (Reporting Years 2017-2021), indicating the subcatchment (in brackets behind the station name)

The analysis of mean monthly rainfall per season per Reporting Year at each of the selected CCT-operated rain-gauging stations, for the five-year period from April 2017 to March 2022 (**Figure 4.8**), shows that the summer rainfall is significantly lower than the winter rainfall at all stations, as was the case for the Intaka Island 20-year dataset (**Figure 4.4**). This confirms that the seasons, as classified for the current project, very clearly reflect a 'dry season' (summer) and a 'wet season' (winter) and can thus be used to aid interpretation of the results of the water quality data analyses. The graphs of average monthly rainfall by season for the selected CCT gauging stations also show that, with the exception of gauging station DIEP05AR (in the Sand subcatchment), the average monthly rainfall during winter was below the 20-year long-term average derived from the Intaka Island dataset at all the stations in all reporting years from 2017 to 2021, but especially in Reporting Years 2017 and 2019, similar to the pattern observed at Intaka Island. For gauging station DIEP05AR, located at the Kendal Water Works Depot (within the suburb of Bergvliet) in the Sand subcatchment, the mean monthly rainfall during winter was similar to or greater than the long-term winter average at Intaka Island in four of the five years of analysis, only being below the long-term average in Reporting Year 2017 (during the Cape Town drought). It is not clear why this station has a significantly higher average monthly rainfall during winter, compared to the other stations, because it is not located in a high-lying mountainous area where the rainfall is typically greater.

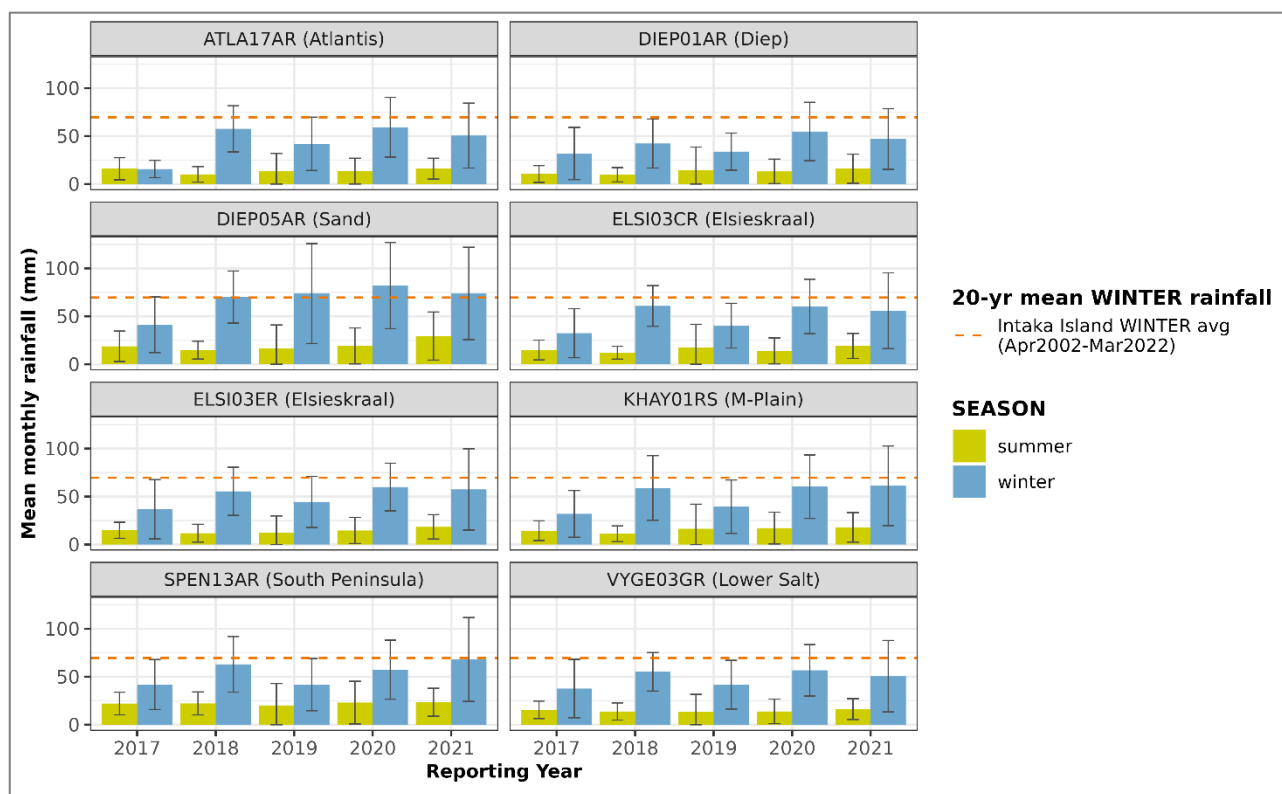


Figure 4.8

Mean monthly rainfall (and standard deviation) at the CCT-operated rain-gauging stations per season for each reporting year from 2017 to 2021, compared with the 20-year mean winter rainfall figure derived from the Intaka Island dataset

4.5 Recommendations

The large number of 'no data' entries in the electronic spreadsheets used to capture and store the rainfall data for the CCT's rain-gauging stations was a major limitation for the rainfall analyses undertaken for the current reporting period, as explained in **Section 4.2**, and shown graphically in **Figure 4.1**. Besides having missing data, a number of other issues were encountered with the CCT's monthly rain-gauge spreadsheets, including inconsistencies in the recording of 'no data' entries (**E.G.** blank cells vs. text vs. highlighted cells), the use of different templates for capturing the data over different time periods, and a lack of consistency in the format of the spreadsheet files (switching between .csv and .xls formats). Metadata, in the form of plain text files, usually accompanied the rain-gauge spreadsheet files (in the relevant folder), but the information in these documents (including details about missing data and/or non-functional gauges over the month of monitoring) was not always captured correctly or in a consistent manner for the monitoring period considered for the current report.

The following recommendations are made to improve the collation of rain-gauging data by the CCT:

- Rain-gauging stations that are regularly non-functional for long periods of time should be decommissioned;
- A smaller set of rain-gauging stations should be used *than in* the present situation (approximately 40 stations), with resources invested to ensure that all the stations are properly maintained and fully functional;
- Valuable long-term rainfall datasets such as that at Paardevlei, previously maintained by AECI and then Paardevlei properties, should be re-instated and included in the monitoring programme;

- A master dataset should be set up to store all the rain data for all the stations, instead of individual spreadsheet files for each month, although monthly spreadsheets could be used for initial data capture each month;
- More consistent metadata records should be kept, preferably using tables with the same information captured each time (e.g. in CSV format) instead of plain text files with different information recorded on each occasion;
- A consistent approach should be adopted for the recording of 'no data' entries, for example using NULL; and
- The use of blank cells should be avoided, for both 'no data' entries and 'no rainfall' entries, with zeros to be entered when there is no rainfall.

5 CURRENT STATE AND TRAJECTORIES OF CHANGE IN WATER QUALITY IN CAPE TOWN'S MAJOR WATERCOURSES

5.1 Major nutrients (phosphorus and nitrogen)

5.1.1 Role of nutrients

All ecosystems require nutrients to support growth. In aquatic ecosystems, the major nutrients are phosphorus and nitrogen, which occur in various different forms. These two nutrients play a particularly important role in determining the rate of plant growth, and so are sometimes referred to as 'growth-limiting' nutrients. In freshwater ecosystems, phosphorus is the main growth limiting nutrient, as some plants can access sufficient nitrogen from the air for growth. Other nutrients are also important for healthy growth, and these include sulphur, magnesium, potassium, calcium, iron, and many others, often required only in very small amounts.

This section deals only with phosphorus and nitrogen nutrients, which play a major role in determining aquatic ecosystem condition.

5.1.2 Forms of phosphorus and nitrogen in aquatic ecosystems

Both phosphorus and nitrogen occur in various forms in aquatic ecosystems, some of which are available for uptake by plants.

Phosphorus, for example, occurs in both inorganic and organic forms, and may be present in water as particulate or dissolved species. Phosphate species (H_2PO_4^- and HPO_4^{2-}) are the only forms of soluble inorganic phosphorus that can be utilised directly by plants (DWAf 1996a). In this report they are referred to generally as phosphates, and with regard to the data, which reflect the concentration of phosphorus in phosphate only, as the abbreviation PO₄-P.

Total phosphorus (Tot-P) is a measure of all the chemical species of phosphorus present in the water column. It includes dissolved forms, insoluble particulate forms and phosphorus already incorporated into phytoplankton (Malan and Day 2005). Total phosphorus is useful for understanding the nutrient (or trophic) status of aquatic ecosystems because it represents all the phosphorus potentially available for incorporation into active biomass.

Phosphorus is reactive under oxidizing conditions, forming relatively insoluble compounds with cations (e.g. Al^{3+} (aluminium), Fe^{3+} / Fe^{2+} (iron), which precipitate out of the water. By contrast, low-oxygen conditions may cause the release of phosphorus back into the water column (DWAf 1996a).

In aquatic ecosystems, **nitrogen** occurs both as organic nitrogen and as inorganic nitrogen, in the form of nitrate (NO_3^-) and nitrite (NO_2^-) ions, as well as total ammonia, comprising ionised (NH_4^+) and un-ionised (NH_3) forms. Un-ionised (or 'free') ammonia can be toxic to some aquatic organisms, even at very low concentrations (DWAf 1996a and DWAf 2008). This aspect is discussed in **Section 5.4**.

The present section focuses on the role and availability of inorganic nitrogen as a nutrient, available as NO_3^- and NH_4^+ for plant uptake.

5.1.3 The effects of nutrient enrichment on aquatic ecosystems

In inland aquatic ecosystems, high concentrations of nutrients, and phosphate in particular, promote rapid plant growth. This growth may be in the form of rooted plants such as reeds and sedges in shallow areas of watercourses, vleis and lakes; floating or rooted plants in the water column or on the water surface; or algae suspended in the water column or floating on the water surface as scums or algal mats.

Rooted plants such as pondweed play important roles in aquatic ecosystems, as they both take up nutrients and store them in plant tissue, and oxygenate the water column, through photosynthesis. Such plants do, however, rely on light penetration for photosynthesis to take place. In deep waters, or where aquatic weeds or algae inhibit light penetration, they may not have access to sufficient

light. Under such conditions, with high phosphate concentrations providing an abundance of nutrients, there may be a shift in plant type, with phytoplankton and/or floating aquatic macrophyte plants dominating the system instead. Blue-green algae (or cyanobacteria) often prevail in these circumstances, in part because they are able to access nitrogen from the air, in response to high phosphate availability.

As algal cells die off and fall to the lake or vlei floor, they start to decompose. Decomposition requires oxygen – and if abundant nutrients have promoted eutrophic to hypertrophic conditions, then the oxygen demands of decomposition may be very high, particularly in summer, when warm temperatures promote decomposition and algal growth, and when dissolved oxygen concentrations are in any case lower, because of temperature.

Under such conditions, or when there are additional inflows of organic enrichment (e.g. raw sewage), oxygen demand may well exceed oxygen supply, resulting in anoxic or low-oxygen conditions, which may result in sudden fish die-off and death of other aquatic organisms that depend on the availability of dissolved oxygen in the water column.

In the Western Cape, floating non-algal aquatic plants are all alien to this area, and likely to proliferate under conditions of elevated nutrients. The most problematic floating plant species include water hyacinth (*Pontaderia crassipes*), duck weed (*Lemna gibba*) and *Ceratophyllum demersum* (water hornwort). These can create serious management problems. Water hyacinth in particular blocks channels and open waterbodies, leading to flooding and affecting their suitability for recreational uses such as sailing, rowing, and kayaking.



Photo 5.1.1
The CCT's False Bay Nature Reserve officials remove
invasive water hyacinth from Zeekoevlei

5.1.4 Categorising nutrient levels as trophic states

The nutrient (or 'trophic') status of freshwater ecosystems allows them to be broadly classified into one of four trophic categories - oligotrophic, mesotrophic, eutrophic, and hypertrophic – respectively associated with low, moderate, high and extremely high levels of nutrients (mainly phosphorus and nitrogen nutrients) (see **Box 5.4**).

In standing waterbodies such as vleis or lakes, these conditions can translate into the following broad habitat types, where:

- **Oligotrophic** waterbodies typically have clear waters and a rocky or sandy shoreline. Both planktonic and rooted plant growth are sparse;
- **Mesotrophic** waterbodies represent intermediate trophic states between oligotrophic and eutrophic, and often share characteristics between the other two;
- **Eutrophic** waterbodies are typically shallow with a soft, silty bottom. Rooted plant growth is abundant along the shores and out into the lake, and algal blooms are not unusual. Water clarity is usually poor. If deep enough to thermally stratify, the bottom waters are often devoid of or low in oxygen;
- **Hypertrophic** waterbodies may have similar habitat types to eutrophic systems, but bottom-level anoxia is more common and the systems are prone to blooms of blue-green as well as green algae.

Appendix E presents the range of nitrogen and phosphorus concentrations associated with different trophic states in South African freshwater ecosystems. These are also indicated in **Tables 3.1** and **3.2**, in relation to the threshold ranges used there. Flowing water (i.e., river) systems are somewhat less sensitive to elevated nutrient concentrations than standing water systems, and this is reflected in higher threshold concentrations for rivers than for standing water systems (as recommended in DWAF 2011).

5.1.5 Sources of nutrients

The main sources of nutrients into Cape Town's watercourses are as follows:

- Inputs of treated sewage effluent from any of the CCT's 13 WWTWs that discharge treated effluent into inland watercourses or estuaries. These discharges do not always meet licensing conditions, and even if they do so, the volumes of effluent discharged, compared to the volumes of river water, mean that they still give rise to significant nutrient enrichment downstream. This is particularly likely in summer, when treated effluent makes up the entire run-of-river flow in some naturally seasonal systems (e.g. the Black, Kuils and Mosselbank Rivers and Milnerton Lagoon);
- Overflows from sewage pump stations and/or low-lying sewer manholes into the stormwater system as a result of load-shedding or sewer line blockage;
- Runoff from catchment areas with high levels of backyard or informal settlements, subject to poor levels of sewage and stormwater servicing;
- Illegal discharges into the stormwater system in industrial and commercial areas (e.g. fertiliser factories; car washes; markets; informal butcheries and meat markets);
- Runoff from fertilised gardens and parks;
- Runoff from agricultural areas (e.g. Philippi Horticultural Area);
- Recycling of decomposing sediments from bottom waters in lakes and dams, as a result of low-oxygen conditions that cause re-activation of phosphorus; and also, as a result of stirring up of sediments from wind- or boat-induced wave action.

5.1.6 Phosphorus enrichment of Cape Town's watercourses

Phosphorus data are presented in this report in the forms of:

- Compliance-type data, showing the percentage of river / stormwater / 'flowing' samples in each subcatchment (**Figure 5.1.1**) or major vlei / dam (**Figure 5.1.2**) that met Target conditions for this variable, versus falling within the range for Poor or Unacceptable concentrations. Target concentrations imply mesotrophic to oligotrophic conditions with regards to this nutrient (see **Section 5.1.4** and **Appendix E**), while Unacceptable concentrations suggest hypertrophic conditions (at least in terms of this variable);
- Boxplots presenting summary statistical data for PO₄-P – these are shown as seasonal plots in **Figures 5.1.3** and **5.1.4** for flowing water systems and vleis / dams respectively, and in **Appendix D** (**Figures D1.1** and **D1.2**).

Box 5.4

Nutrients under natural conditions

Under natural (or 'reference') conditions prior to human-induced change, the upper reaches of Cape Town's rivers would have been naturally low in nutrients, especially those that passed through catchments dominated by ancient well-leached and thus nutrient-poor Table Mountain Sandstones. With distance downstream, even natural rivers tend to accumulate low levels of nutrients, as they are exposed to larger areas of catchment and its runoff.

By contrast, even under pre-development conditions, many wetlands would probably have been more nutrient enriched – particularly those that were not linked to channeled outflows, and thus accumulated plant material over time. Shallow, seasonally inundated wetlands used as feeding areas by birds could become highly nutrient-enriched over time, supporting rich 'soups' of invertebrates.

Today, most if not all of the aquatic ecosystems in CCT have been severely impacted by the receipt of additional nutrients, particularly phosphorus.

Median annual PO₄-P concentrations at individual monitoring points in each subcatchment can be seen in **Appendix C**, as well as (for priority catchments), in the maps in **Section 8**.

The data suggest that:

- For **rivers / flowing water systems**:

- The best-performing subcatchments monitored were clearly the Lourens and Silvermine subcatchments, both of which showed few (< 10%) samples that did not meet Target criteria. In the Silvermine subcatchment, periodic overflows of sewage from problem manholes in the lower river reaches is likely to be at least a contributor to elevated phosphate at times, as would seepage inflows from the adjacent golf course. In the Lourens River subcatchment, sewage inflows are also likely on occasion as is nutrient enrichment from residential gardens and upstream agricultural areas;
- The above notwithstanding, both of these subcatchments showed reduced annual compliance between the 2020 and 2021 reporting periods, with an increase in the number of samples falling into the Unacceptable Category. This could correlate with an increase in sewer and pump station overflows; in the Silvermine subcatchment, these issues would apply primarily to the lower reaches;
- The Hout Bay, South Peninsula, Sand and Elsieskraal river systems were the next least impacted subcatchments over the 2020 and 2021 reporting periods, in that order. Of these, the Hout Bay subcatchment saw a substantial increase in Unacceptable samples from 20% in the 2020 reporting period to 62% in the 2021 reporting period. By contrast, the number of samples falling within Target thresholds increased substantially (40-60%) in the Sand subcatchment and slightly (by <5%) in the 2021 reporting period for the South Peninsula and Elsieskraal subcatchments over the same time periods;
- The Sir Lowry's Pass and Zeekoe subcatchments were the only other subcatchments that showed >10% of annual samples falling within the Target range for this variable – and both of these showed a >10% deterioration in the number of samples meeting Target criteria between the 2020 and 2021 reporting periods, reflecting a significant increase in phosphate concentrations in these subcatchments. In the case of the Zeekoe subcatchment at least, samples falling with Target range were located mainly along the Little Lotus River and Southfield Canal areas;
- Of the remaining subcatchments, the (lower) Diep River, Lower Salt River, Eerste and Kuils River subcatchments showed consistently high levels of phosphorus enrichment, with >90% of samples falling within the Unacceptable range over both the 2020 and the 2021 reporting periods, and an increase in the percentage of Unacceptable samples in all four subcatchments between these two reporting periods;
- The worst-performing subcatchments, and those potentially requiring significant rectification to improve water quality with regard to reducing phosphates, were the Mosselbank, Sout and Soet subcatchments, for which the data show that 100% of samples taken within the 2020 and 2021 reporting periods fell within the Unacceptable range for this nutrient. Of these subcatchments, the Mosselbank and Sout are both fed by WWTWs, and monitoring points have been selected around monitoring of the effect of these inflows. The Soet subcatchment has high levels of informal settlements and build-up of solid waste and dumping is evident in its broader catchment area;
- These poorly performing subcatchments were followed by the Diep and Eerste subcatchments, where very low numbers (<5%) of samples fell within Target ranges;
- Seasonal data, shown as boxplots in **Figures 5.1.3**, provide further insights into patterns of phosphate pollution in Cape Town's watercourses. This is in part because the data indicate not only the levels of data compliance with specified targets, but also the magnitude of non-compliance. These data show that:
 - Subcatchments that receive treated effluent inflows from WWTWs showed markedly elevated median and maximum phosphate concentrations – these

subcatchments comprise the Diep, Eerste, Kuils, Lower Salt, Mosselbank, Sout and Zeekoe catchments. Most of the sample points in the Zeekoe catchment, however, lie upstream of the WWTW inlet, and phosphate concentrations in this subcatchment rather reflect upstream inflows in the form of contaminated solid waste, untreated sewage inflows and polluted stormwater from poorly serviced urban spaces. This is a similar scenario to the (much smaller) Soet subcatchment, which also showed elevated median and maximum concentrations, and which has high levels of informal settlement in its catchment;

- Generally, all subcatchments showed an increase in phosphate contamination in the 2021 reporting period, compared to the 2020 and three prior reporting years (2017-2019). Exceptions to this were the Eerste, Lower Salt and Mosselbank subcatchments, both of which showed slight improvement, at least in summer. This is possibly linked to upgrades at the Zandvliet WWTW, just upstream of the Eerste River monitoring points;
- As noted in the 2020 Inland Water Quality Report, water quality data consistently showed that phosphorus concentrations were highest in summer, although this pattern was most marked in the subcatchments that receive treated WWTW effluent. Such patterns were far less pronounced in subcatchments that do not receive treated effluent inflows, i.e., the (monitored portion of) Zeekoe, South Peninsula, Silvermine, Lourens, Elsieskraal, Hout Bay and Sand subcatchments. This pattern possibly reflects the fact that most of the systems showing worsening impacts in summer were naturally seasonal, drying out in summer. Their summer flows today probably comprise mostly treated sewage effluent, which even when it complies with general effluent limits, lies well above hypertrophic concentrations.

Overall, most of Cape Town's monitored rivers and other stormwater systems were significantly contaminated and well above the Unacceptable range for phosphorus over the full reporting period considered in this report, with only the Silvermine subcatchment lying almost always below Unacceptable enrichment levels.

- Summary data presented in **Appendix D (Figure D1.1)** do show a high degree of scatter in phosphate concentrations within subcatchments, pointing to both episodic point-source driven pollution as well as a range of water courses in different condition within the subcatchments, with some more prone to receipt of severely contaminated water at times than others;
- Median and inter-quartile range data were highest (median values almost 50 times higher than the Unacceptable threshold value) in the Sout catchment in the 2021 reporting period, followed by the Lower Salt, Diep, Mosselbank, Eerste, Soet and Zeekoe subcatchments, in descending order.
- **For standing water systems (vleis, dams, detention ponds)**, shown in **Figures 5.1.2 and 5.1.4**, the data suggest that:
 - The monitored waterbodies with the lowest levels of phosphate enrichment city-wide generally comprised smaller wetlands / dams that are not linked to active WWTWs and lie in subcatchments that are largely free of informal settlements;
 - The best-performing waterbodies comprised Glencairnvlei, in which the number of samples within Target range increased to 83% and 92% respectively for the 2020 and 2021 reporting periods, compared to 67% for the previous three reporting years; Princessvlei (for which the 2021 reporting period unfortunately showed an increase in Unacceptable samples; Die Oog (with fewer Unacceptable samples in the 2021 reporting period, albeit with fewer samples meeting Target as well; and the three Elsieskraal dams, which showed a slight increase in samples within Target range and a reduction in the number of samples falling within the Unacceptable range;
 - A higher proportion of samples from Zandvlei fell within the Target range for phosphorus

over the 2020 and 2021 reporting periods than in the 2017-2019 periods – however compliance remained at very low levels (45% in the 2020 reporting period, dropping to 33% in the 2021 period) and indicate that elevated phosphate remained a serious problem in this system;

- o Phosphorus enrichment in Little Princessvlei reduced over the reporting period, but again from a low base of only 20% within Target in the 2017-2019 period, to only 46% for the 2021 reporting period – nevertheless a substantial improvement;
- o Phosphorus enrichment was consistently high in Rondevlei (< 10% of samples within Target throughout the assessed periods) and the Westlake wetlands, where enrichment increased in the 2021 period;
- o Generally, however, the larger vleis (Rietvlei, Wildevoelvlei and Zeekoevlei) showed consistently high levels of phosphorus enrichment, almost always within the range of Unacceptable, reflecting hypertrophic systems fed by polluted catchments and/or WWTW inflows (Wildevoelvlei);
- o Water quality data from smaller detention ponds (Mew Way and Mitchell's Plain) also showed permanent Unacceptable levels of phosphorus nutrients, again reflecting upstream catchments characterised by high levels of pollution;

Overall, in the 2021 reporting period, just 20% of samples from monitored standing water bodies fell within the Target range for phosphate, with over 75% lying in the Unacceptable range. This indicates a city with high levels of phosphorus in its watercourses, likely to reflect in high costs for the control of reeds, aquatic weeds, and algae, discussed in later chapters.

- o Seasonal data, shown as boxplots in **Figure 5.1.4**, provide further insights into patterns of phosphate pollution in Cape Town's standing waterbodies. Again, these graphs are useful because they reflect the magnitude of non-compliance. The data show that:

- By far the highest levels of consistent phosphorus enrichment in standing waterbodies over the 2020 and 2021 reporting periods, based on median and inter-quartile ranges, was Wildevoelvlei, followed by the Mew Way Detention Ponds, Zeekoevlei, the Mitchell's Plain detention pond and Zoarvlei – such hypertrophic conditions are likely to be linked to excessive plant growth including algae, invasive alien plants such as water hyacinth and reeds;
- Of the other monitored standing waterbodies, the only ones where phosphate phosphorus concentrations fairly consistently lay below hypertrophic (Unacceptable) thresholds were Glencairn Vlei and Princessvlei. The former showed some improvement in nutrient enrichment since the 2017-2019 reporting periods, while summer phosphate concentrations increased marginally at Princessvlei over the 2021 reporting period;
- As would be expected, summer concentrations were generally higher than winter concentrations in all standing water systems, reflecting a combination of evapoconcentration; reduced inflows from (cleaner) groundwater into some systems; and elevated summer concentrations in the rivers and stormwater channels feeding many of these systems.

Box 5.7

During dry periods, flows in urban stormwater channels usually reflect pollution sources such as irrigation, illegal pool and industrial waste discharges, and treated or untreated sewage effluent – all of which tend to be more diluted in winter by rainfall and stormwater runoff over a cleaner (more recently flushed) catchment.

Box 5.7

Reed growth in Zeekoevlei

Recent analyses of changes in reedbed extent in Zeekoevlei showed a 105% increase in reedbed extent between 2009 and 2021 (Day et al. 2022).

Interestingly, summary data in **Appendix D (Figures D1.1 and D1.2)** show that, while phosphorus enrichment is clearly a problem throughout the CCT's monitored watercourses, concentrations in its rivers and stormwater channels generally far exceeded those in monitored standing waterbodies.

Table 5.1.1 assists in interpreting this issue, showing that median values for the 2021 reporting period for river / stormwater channel subcatchments ranged between 0.013 mg P/L (Silvermine) and 4.9 mg P/L (Sout), versus 0.005 mg P/L (Glencairnvlei and Die Oog) and 4.353 mg P/L (Wildevoevllei) for monitored standing water / vlei systems. However, excluding Wildevoevllei, all other monitored standing water systems had median phosphate values <1.5 mg P/L, compared with the Mitchell's Plain, Mosselbank, Soet, Diep, Eerste, and Lower Salt subcatchments, which all showed 2021 median value > 1.5 mg P/L. These data help to explain the difference between overall phosphorus enrichment in standing waterbodies and that of rivers and stormwater systems. With the exception of Rietvlei and Zoarvlei, in the Diep subcatchment, none of the other standing waterbodies that are monitored by the CCT lie within any of the worst-performing subcatchments. Neither Rietvlei nor Zoarvlei in fact receives direct runoff from the main channel of the Diep River outside of major flood events, and otherwise receive mostly localised (and at times highly polluted) stormwater runoff via the Bayside canal (Infinity 2022, Rose et al., 2023).

Nevertheless, phosphorus concentrations were far too high in all of the standing waterbodies assessed.

Note that maps showing rated annual median phosphate concentrations at all sample points in the priority catchment areas can be accessed in **Section 8**.

Table 5.1.1
Summary Median data for reporting periods 2020 and 2021 – phosphate and TIN data only showing subcatchments and vlei names

System type	Subcatchment name	Vlei name	2020		2021	
			PO4-P	TIN	PO4-P	TIN
			mg P/L	mg N/L	mg P/L	mg N/L
River dataset	Diep	-	2.130	4.900	2.100	6.492
	Eerste	-	2.550	16.700	2.200	10.900
	Elsieskraal	-	0.120	2.066	0.147	1.459
	Hout Bay	-	0.033	0.232	0.037	0.407
	Kuils	-	1.200	7.279	1.300	6.197
	Lourens	-	0.021	0.549	0.018	0.366
	Lower Salt	-	3.310	13.876	2.700	10.918
	Mosselbank	-	1.600	8.340	1.600	6.900
	Mplain	-	1.165	15.625	1.534	15.915
	Sand	-	0.092	0.712	0.062	0.686
	Silvermine	-	0.012	0.104	0.013	0.107
	SLPass	-	0.100	0.918	0.106	1.091
	Soet	-	1.630	19.652	2.021	17.340
	Sout	-	4.000	0.943	4.900	1.450
	South Peninsula	-	0.163	1.185	0.128	1.230
	Zeekoe	-	0.405	5.509	0.628	8.130
Standing water (vleis, ponds and dams)	Diep	Rietvlei	0.182	0.185	0.162	0.138
		Zoarvlei	0.368	0.880	0.227	0.754
	Elsieskraal	Elsieskraal dams	0.013	0.272	0.013	0.168
	Kuils	Mew Way DP	2.110	19.125	1.460	14.115
	Mplain	Mplain DP	1.150	13.238	1.487	15.140
	Noordhoek	Wildevleivlei	3.760	20.417	4.353	21.765
	Sand	Die Oog	0.005	0.359	0.005	0.202
		Langevlei	0.117	1.066	0.046	0.447
		Little Princessvlei	0.025	0.280	0.017	0.240
		Princessvlei	0.005	0.131	0.010	0.118
		Westlake	0.043	0.429	0.060	0.257
		Zandvlei	0.020	0.255	0.033	0.177
	South Peninsula	Glencairn vlei	0.008	0.126	0.005	0.102
	Zeekoe	Rondevlei	0.077	0.652	0.062	0.203
		Zeekoevlei	0.734	0.802	0.406	1.158



Figure 5.1.1

Percentage of phosphate (PO₄-P) samples falling within each rated category for this variable, per subcatchment. Thresholds for rated categories as defined in Table 3.2. Data for river / 'flowing' water monitoring points in each subcatchment. Subcatchments as shown in Figure 2.1. Total number of samples considered shown in bars in bottom right plot ('All rivers / stormwater systems').

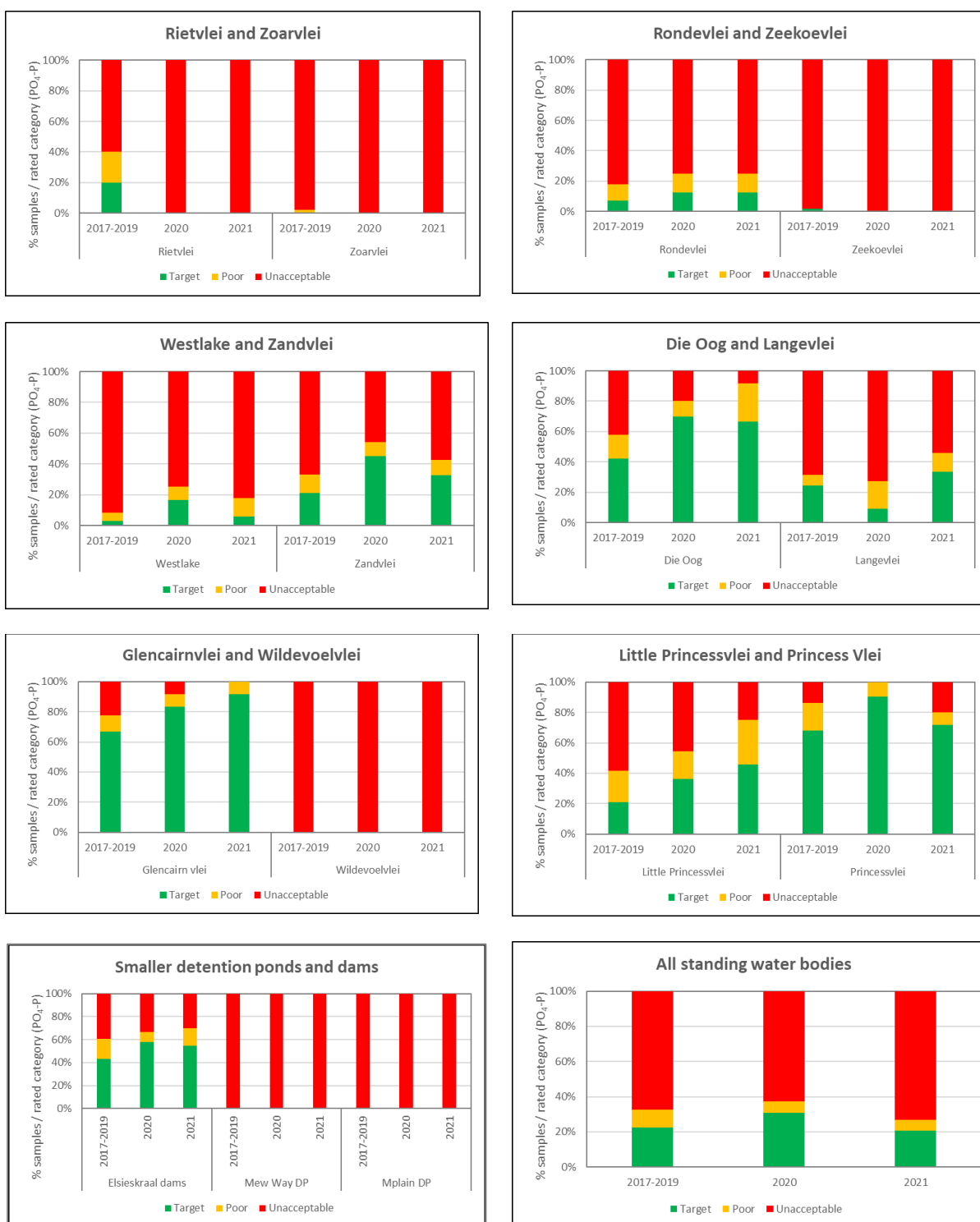


Figure 5.1.2

Percentage of phosphate (PO₄-P) samples falling within each rated category for this variable, per monitored standing water system. Thresholds for rated categories as defined in Table 3.3. Data for sample points in standing waterbodies / vleis and detention ponds. Total number of samples considered shown in bars in bottom right plot ('All standing waterbodies').

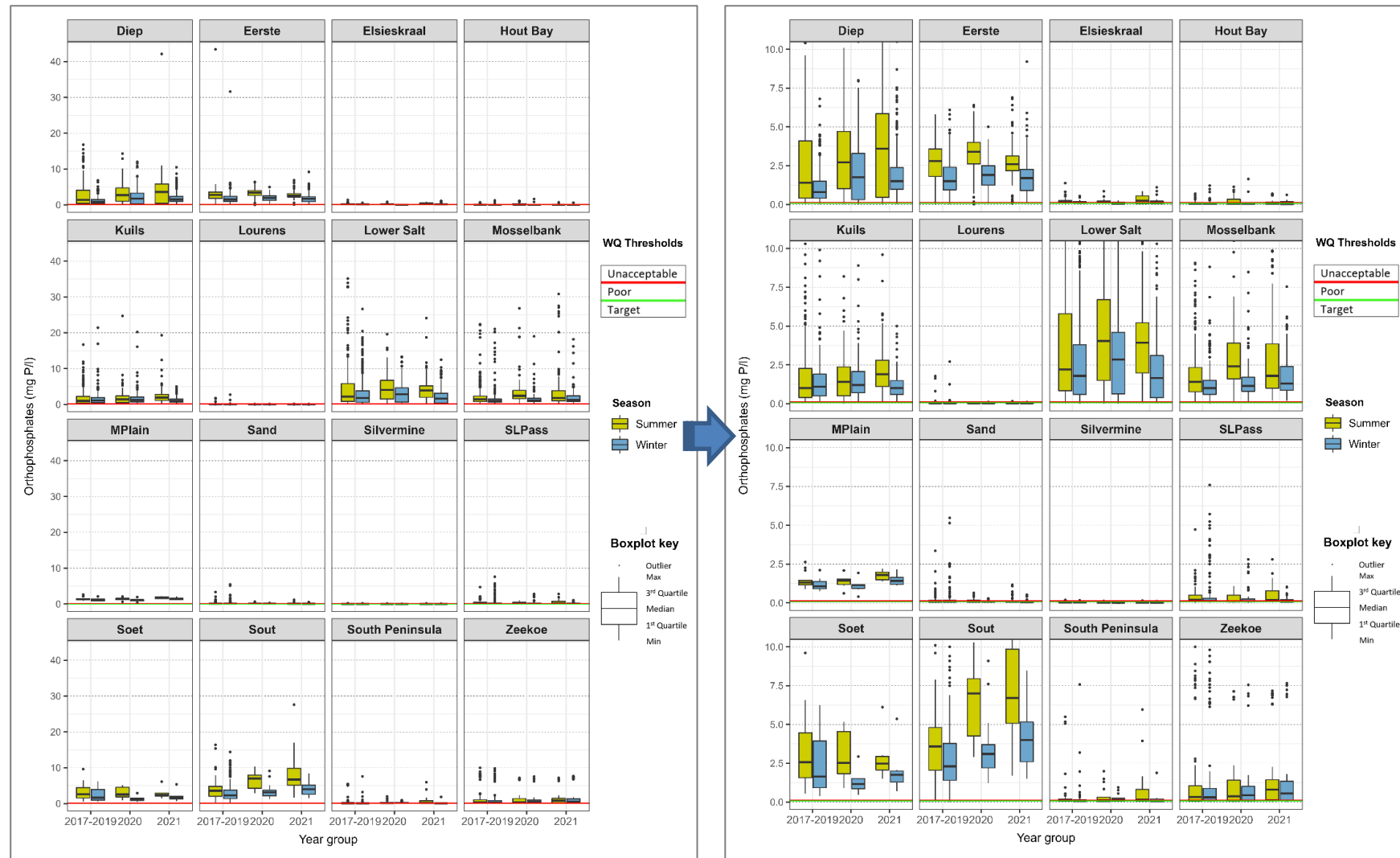


Figure 5.1.3

Comparison of phosphate (PO₄-P) data for flowing systems (rivers and stormwater channels) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Data analysed as summer and winter datasets. Marked thresholds as per Table 3.2. Closer view (reduced y-axis) shown in right hand figure.

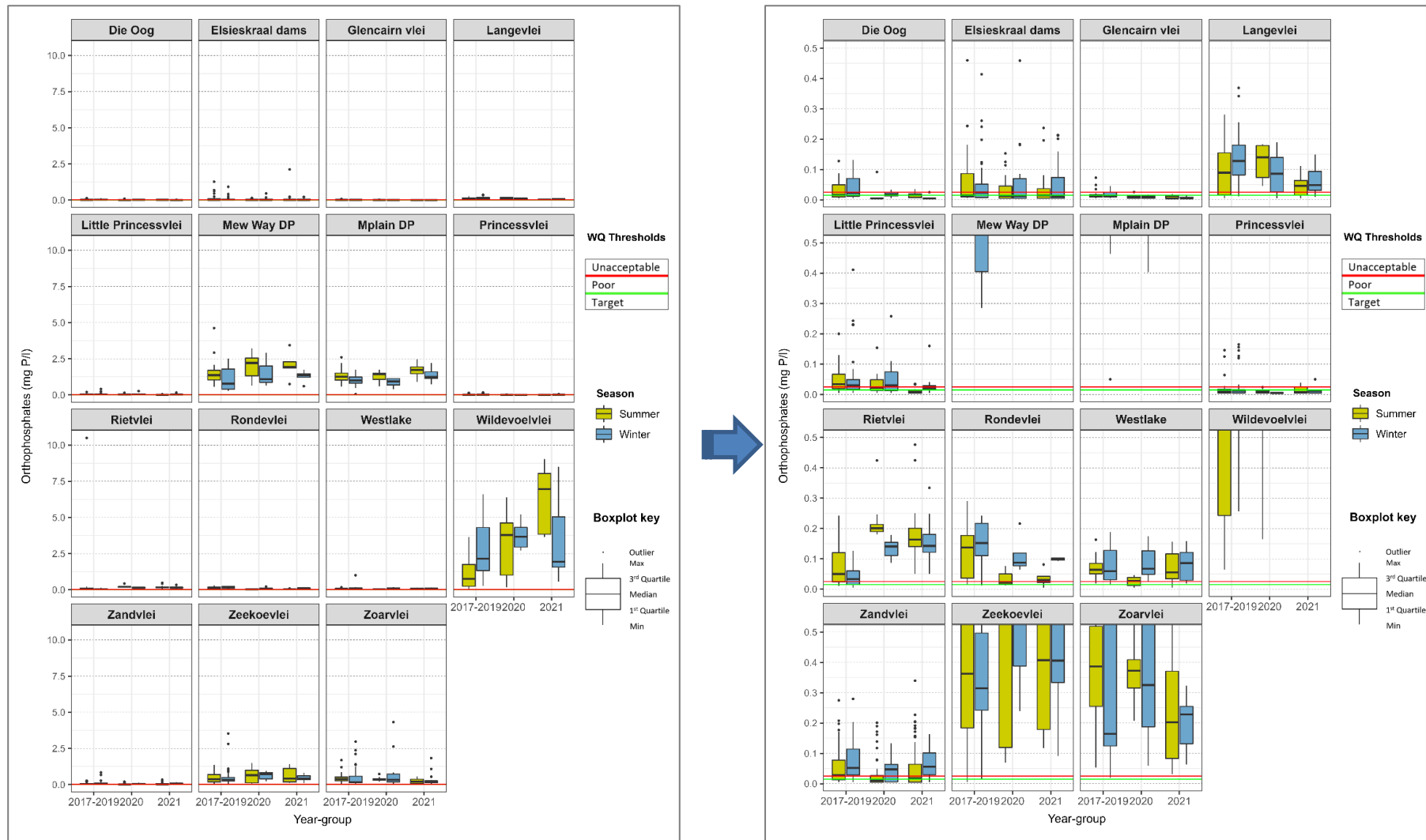


Figure 5.1.4

Comparison of phosphate (PO₄-P) data for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Data analysed as summer and winter datasets. Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in right hand figure.

5.1.7 Nitrogen enrichment of Cape Town's watercourses

As for phosphate reporting, nitrogen enrichment data (reported on as Total Inorganic Nitrogen / TIN) are presented as both compliance-type data (proportion of samples in various categories that fall within the Target range, or are rated as 'Poor' or 'Unacceptable', using the criteria listed in **Tables 3.1 and 3.2**), and as boxplots, which show statistical data for all analysed watercourse groups and categories, allowing consideration of the magnitude of TIN concentrations, in addition to compliance. These data are presented separately for flowing water systems (rivers and stormwater channels) (**Figures 5.1.5 and 5.1.7**, as well as **Figure D1.3 in Appendix D**) and for standing water systems (vleis, dams and detention ponds) (**Figures 5.1.6 and 5.1.8**, as well as **Figure D1.4 in Appendix D**).

The data show that:

- In general, nitrogen was a much less problematic nutrient in the CCT's watercourses over the 2020/2021 reporting periods than was phosphorus, with both river / stormwater channel and standing water systems showing far higher levels of compliance with Target thresholds;
- Nevertheless, the data do indicate that at least in some subcatchments, nitrogen enrichment was at ecologically problematic levels, as is unpacked in the following sections;
- For **rivers / flowing water systems**:
 - The best-performing subcatchments over the past two reporting periods were clearly the Lourens and Silvermine subcatchments, both of which showed 100% compliance with TIN Target thresholds, indicating 'clean' catchments with few sources of nitrogen enrichment. This corresponds with similar findings with regard to phosphate data and is despite periodic sewer overflows in the lower Silvermine catchment;
 - The next best-performing subcatchments with regard to TIN were Hout Bay (> 80% within Target thresholds, despite two of the three sample points lying downstream of significant sources of pollution from informal settlement), and the South Peninsula, Sand and Sir Lowry's Pass subcatchments, all of which showed TIN concentrations that were > 60% within Target thresholds. The Sir Lowry's Pass subcatchment improved significantly in the 2020 and 2021 reporting periods, while there was a slight deterioration in South Peninsula compliance levels compared with the 2017-2019 reporting periods;
 - The Elsieskraal and Soet subcatchments both performed poorly, with only 40-60% compliance with TIN targets. Nevertheless, the Soet subcatchment did show an improvement over the 2017-2019 reporting periods, in both the 2020 and 2021 periods;
 - By contrast, TIN enrichment increased in the Zeekoe subcatchment over the same reporting period, with the proportion of samples within the Target range dropping from 37% in the 2017-2019 period to 28% in the 2021 period, while the proportion of samples rated as Unacceptable increased from 56% to 79% over the same period. This catchment was plagued by numerous raw sewage overflows during this period (see Day et al. 2022);
 - The subcatchments where nitrogen enrichment was most pronounced were the Diep, Mosselbank, Kuils, Eerste, Lower Salt and Soet subcatchments, with samples from the latter subcatchment always being in the Unacceptable range. Such subcatchments are likely to have high levels of sewage inflows, and potentially low levels of oxygenation, so that nitrogen cycling is inefficient;
 - Overall, the data showed that, for the 2020 and 2021 reporting periods, 60% of water quality samples from routinely monitored sites were rated Unacceptable with regard to their TIN concentrations. This indicates that, while phosphorus is considered more problematic than nitrogen in driving ecosystems responses to eutrophication (e.g. rapid plant growth including algae and reeds), nitrogen enrichment is also at levels of concern in many parts of Cape Town's watercourses;
 - Seasonal TIN data, shown as boxplots in **Figure 5.1.7** for routinely monitored sample sites, allow more quantitative interpretation of TIN data, and indicate that:

- The Eerste and Soet subcatchments showed the greatest levels of enrichment, with median summer TIN concentrations always above 20 mg N/L, with the exception of the 2021 reporting period, where the Diep subcatchment showed some improvement;
 - Median concentrations in the Mosselbank, Diep, Kuils, Lower Salt, Zeekoe and Mitchell's Plain subcatchments were also elevated well above the lower Unacceptable threshold for this nutrient, with data moreover showing high levels of elevated TIN at times, resulting in inter-quartile ranges extending in most cases at least three times the Unacceptable threshold of 3 mg N/L (see **Table 5.1**);
 - The Sout subcatchments showed lower levels of nitrogen enrichment, albeit still mostly above the Unacceptable threshold, while median TIN data from the Elsiekraal, Hout Bay, Lourens, Sand and Sir Lowry's Pass subcatchments all fell below Unacceptable thresholds, and all showed reduced scatter and reduced upper inter-quartile range values than in the 2017-2019 reporting period;
 - An increase in summer inter-quartile range data for the South Peninsula subcatchment was evident in the 2020 and 2021 reporting period datasets – these suggest an increase in nitrogen sources in contributing water courses in this subcatchment, comprising several different actual topographic catchments.
- **For standing water systems (vleis, dams, detention ponds)**, shown in **Figures 5.1.6, 5.1.8** and (for ratios of total ammonia nitrogen to TIN) **Figure 5.1.9**, the data suggest that nitrogen enrichment was less problematic in these systems than in the flowing water systems, with the following more specific observations applying:
 - Over 60% of samples from most of the monitored standing water systems fell within the Target range for this variable;
 - Exceptions to the above were:
 - Westlake and Langevlei wetlands in the 2020 reporting period, when the number of samples rated as 'Poor' increased substantially, and (for Westlake samples) remained higher than in the 2017-2019 period and in 2021 – the latter was prone repeated sewage overflows in 2020 (Kotze 2020);
 - Zeekoevlei, at only 40% Acceptable, with a decrease in compliance since the 2017-2019 reporting period;
 - Wildevoelvlei showed a marked deterioration in TIN compliance over the 2020 and 2021 reporting periods compared with the 2017-2019 periods, with no samples falling within Target thresholds in either year, although the 2021 period saw a reduction in Unacceptable samples and an increase in samples rated as Poor;
 - 100% of samples from the Mitchell's Plain and Mew Way detention ponds were rated Unacceptable, reflecting stormwater runoff from polluted catchments with poor capacity for nitrogen assimilation and denitrification. **Figure 5.1.9** shows that in these systems, most of this nutrient was in the form of ammonia-nitrogen, and with limited opportunities for assimilation by plants and poor nitrification efficiency, nitrogen enrichment remained at high levels in all assessed samples.
 - Seasonal TIN data, shown as boxplots in **Figure 5.1.8** for routinely monitored sample sites, again allow more quantitative interpretation of TIN data, and indicate that:
 - Median TIN data for standing water courses only exceeded Target thresholds at Wildevoelvlei and at the Mitchell's Plain and Mew Way detention ponds;
 - At these three waterbodies, TIN was significantly in excess of the threshold for Unacceptable conditions, suggesting significant nitrogen enrichment;
 - The detention ponds function primarily in winter, and thus the summer seasonal data are of little value in these graphs;

- However, **Figure 5.1.9** is of more value and indicates that TIN in the Mitchell's Plain and Mew Way detention ponds consists primarily of total ammonia rather than oxidized nitrites or nitrates – oxygenation of these waterbodies would be beneficial in increasing nitrification and thus the oxidation of ammonia to nitrite and nitrate, from where denitrification (transformation of nitrate-nitrogen into nitrogen gas) would be more efficient;
- By contrast, TIN at Wildevleivlei generally comprised a lower proportion of total ammonia nitrogen than at the detention ponds, although the proportion of total ammonia nitrogen increased substantially over the 2020 / 2021 reporting periods, compared to the 2017-2019 periods (see **Figure 5.1.9**). This suggests a possible decline in the efficacy of effluent processing at the Wildevleivlei WWTW over the 2020 and 2021 reporting periods and suggests that oxygenation of water from the WWTW and within Wildevleivlei would potentially also be beneficial.
- Overall, summary median data shown in **Table 5.1.1** suggest that:
 - Median TIN concentrations in flowing water systems (rivers and stormwater channels) ranged between 0.107 mg N/L (Silvermine subcatchment) and 17.340 mg N/L (Soet subcatchment), in the 2021 reporting period, compared with a range of 0.102 mg N/L (Glencairnvlei) to 21.765 mg N/L (Wildevleivlei). However, only three of the 15 monitored standing water systems had median TIN values above the Unacceptable threshold for this variable ((4 mg N/L) whereas for the river / stormwater systems, eight of the 16 subcatchments had median TIN values in excess of the Unacceptable threshold of 3 mg N/L for these systems;
 - The above discussion suggests that, as in the case of phosphorus enrichment, nitrogen enrichment is more significant in rivers and stormwater channels than in standing water systems, where increased residence time allows for nutrient uptake and nitrification and denitrification processes, but also again points to the fact that the majority of monitored standing waterbodies in Cape Town are located in generally less polluted subcatchments.

5.1.8 Implications of nitrogen-to-phosphorus ratios

Finally, the ratios of nitrogen (as TIN) to phosphorus (as PO₄-P) data are presented in **Figure 5.1.10** for standing waterbodies only (as individual vleis, dams and detention ponds). These ratios are considered important, because they provide some hint of likely ecosystem responses to different degrees of nutrient enrichment. Aquatic ecosystems that have low N:P ratios (that is, a lot of phosphorus in comparison to nitrogen availability) are more likely to be dominated by plants that are able to extract nitrogen from the air, rather than relying on nitrogen in dissolved compounds in the water. The most common of these include cyanophyte (or 'blue-green') algae.

The data are presented only for standing waterbodies, where these relationships are more likely to exist than in flowing rivers and stormwater systems, where flow rates mean that algal growth is often not an issue with low uptake rates as a result of flow velocities.

The data suggest that:

- Generally, standing waterbodies were characterised by low N:P ratios, in the range most likely for these systems to be dominated by blue-green algae rather than rooted plants or other less problematic algal groups;
- In particular, low ratios well below Target values were evident in Rietvlei, Wildevleivlei, Zeekoevlei, Zoarvlei, Rondevlei (outside of summer in the 2021 reporting period) and the Mew Way and Mitchell's Plain detention ponds, suggesting that all of these systems are likely to be affected at least at times by blue-green algal growth. This is discussed further in **Section 6**;
- Waterbodies that showed more ecologically desirable N:P ratios were Die Oog, the Elsieskraal Dams, Glencairn vlei, Little Princessvlei, Princessvlei, and Zandvlei, with strong seasonal differences in some vleis (Langevlei, Rondevlei and Princessvlei). At Langevlei and Princessvlei,

T:P ratios were consistently improved in the winter (wet season). Algal growth is, however, inhibited in winter by light and low temperatures, and these patterns would probably not have impacted on algal growth in winter.

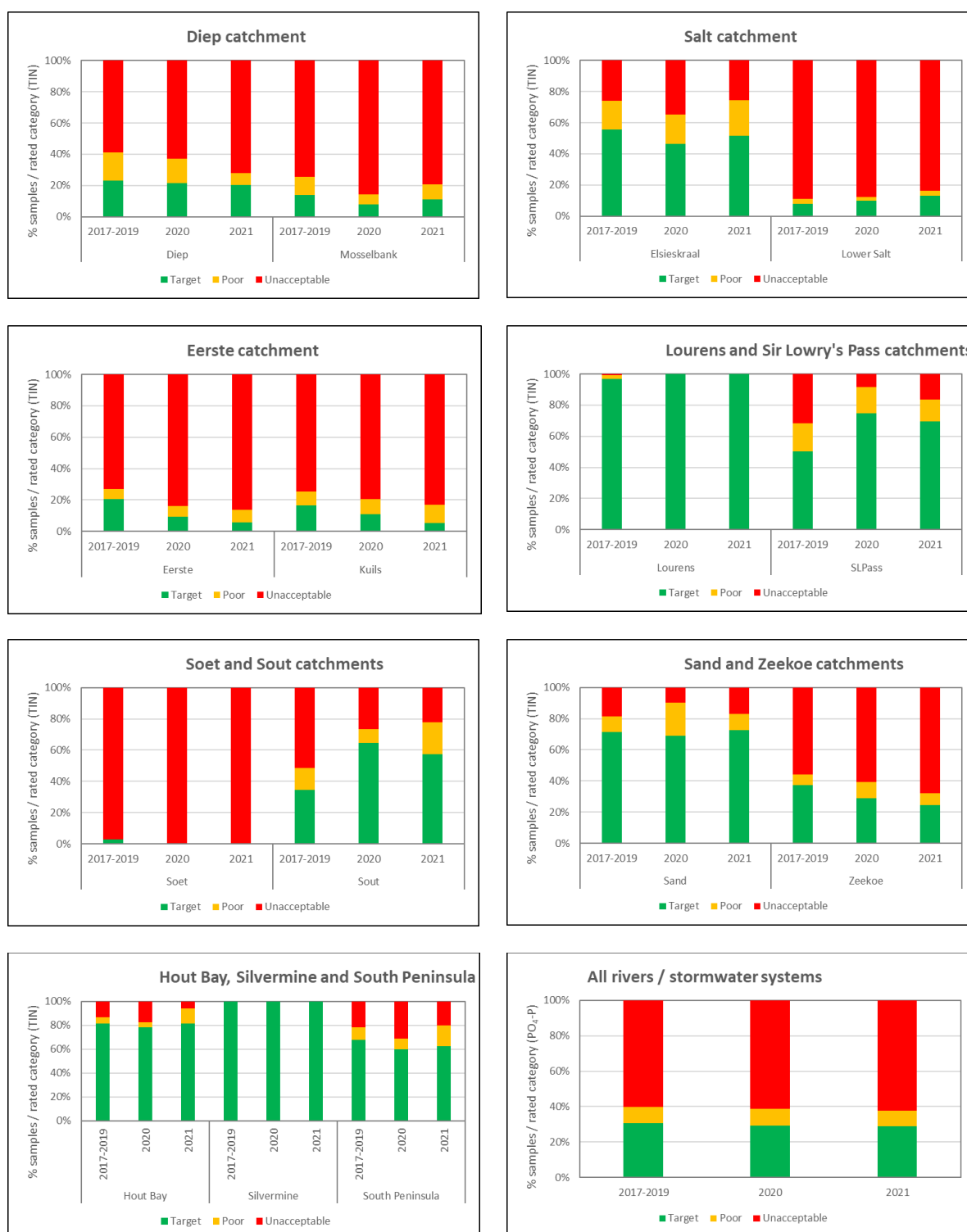


Figure 5.1.5

Percentage of Total Inorganic Nitrogen (TIN) samples falling within each rated category for this variable, per subcatchment. Thresholds for rated categories as defined in Table 3.2. Data for river / 'flowing' water monitoring points in each subcatchment. Subcatchments as shown in Figure 2.1. Total number of samples considered shown in bars in bottom right plot ('All rivers / stormwater systems').



Figure 5.1.6

Percentage of Total Inorganic Nitrogen (TIN) samples falling within each rated category for this variable, per monitored standing water system. Thresholds for rated categories as defined in Table 3.3. Data for sample points in standing waterbodies / vleis and detention ponds. Total number of samples considered shown in bars in bottom right plot ('All standing waterbodies').

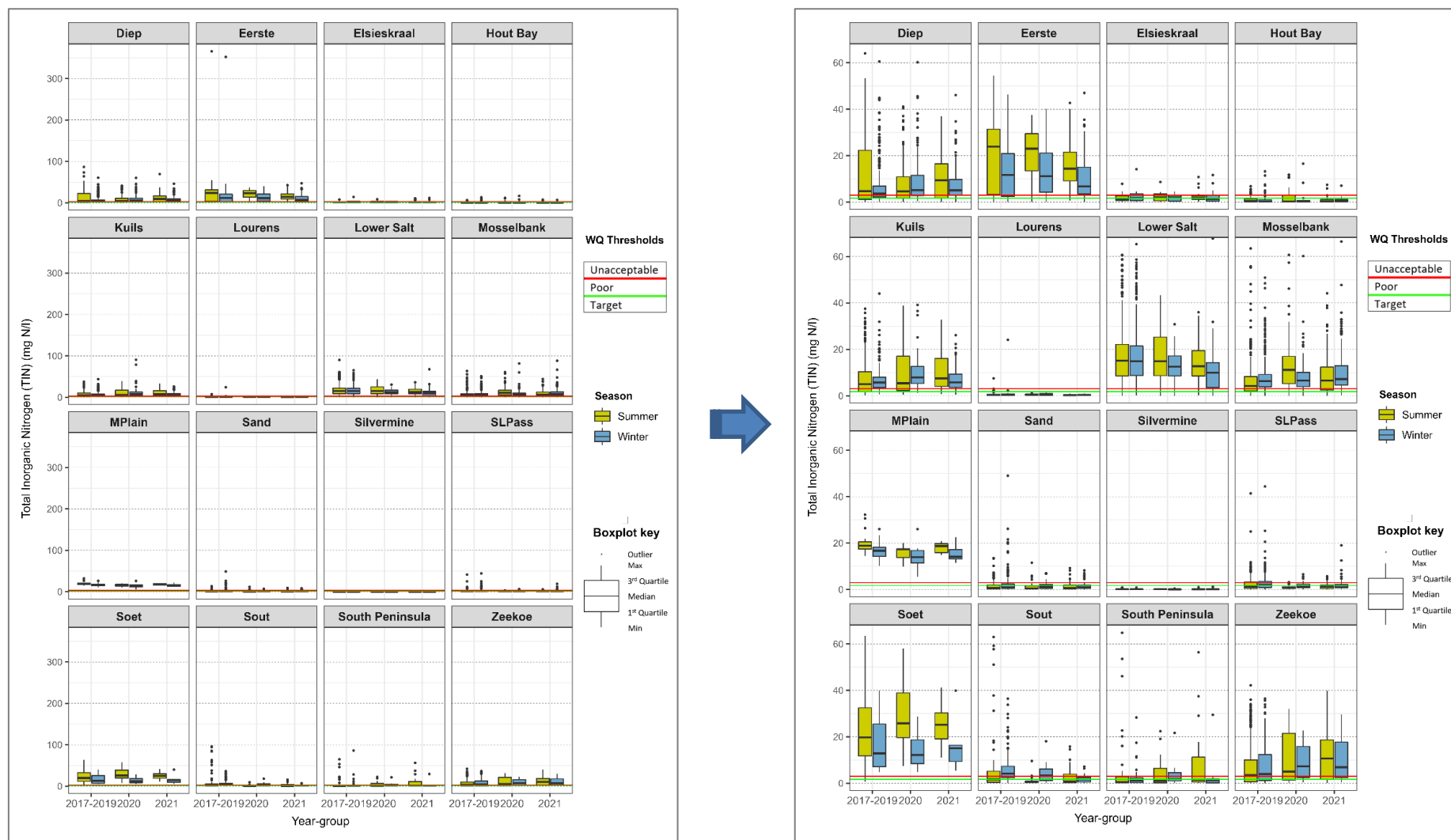


Figure 5.1.7

Comparison of Total Inorganic Nitrogen (TIN) data for flowing systems (rivers and stormwater channels) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Data analysed as summer and winter datasets. Marked thresholds as per Table 3.2. Closer view (reduced y-axis) shown in right hand figure (arrowed).

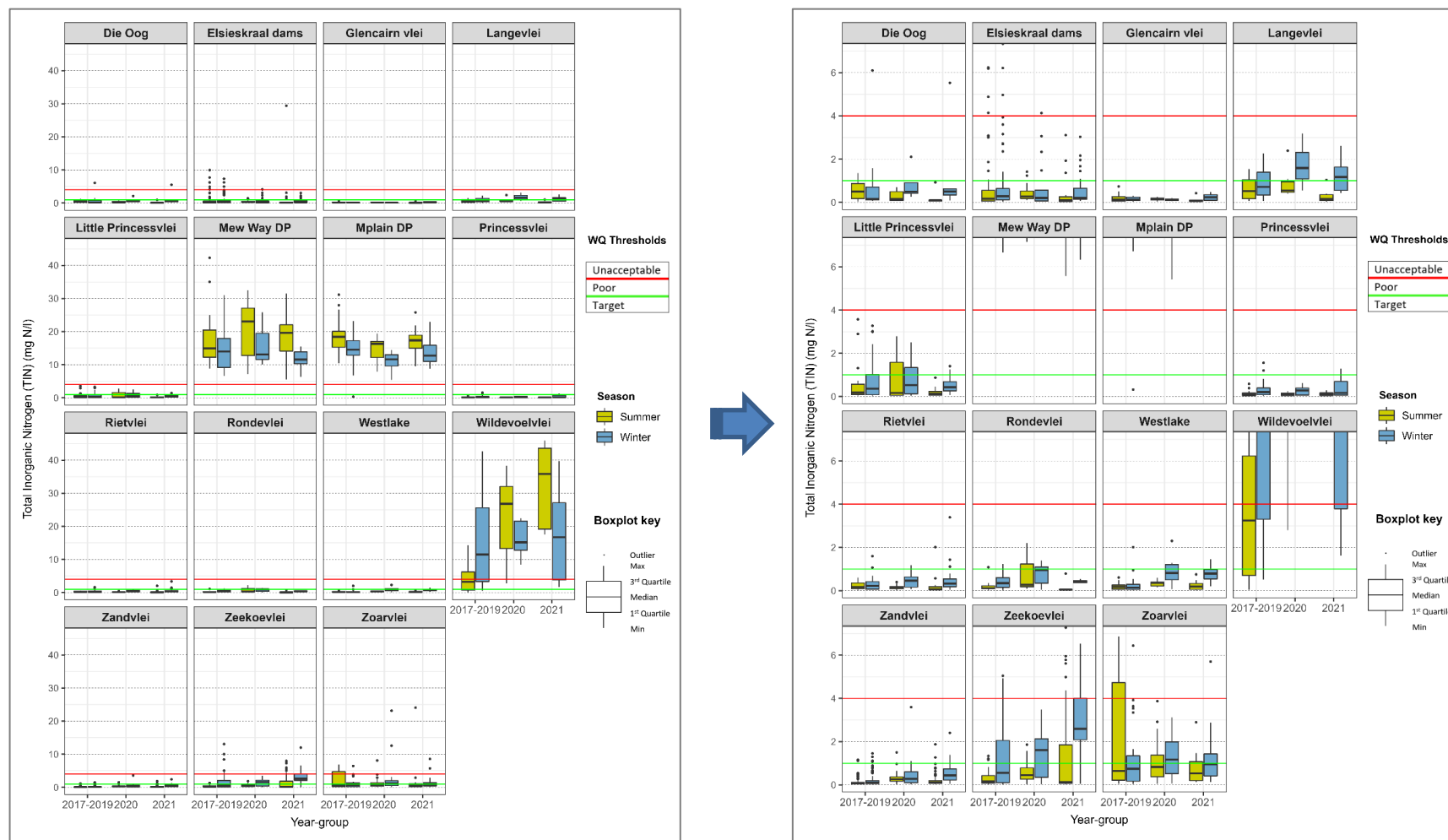


Figure 5.1.8

Comparison of Total Inorganic Nitrogen (TIN) data for standing water systems (vlei, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Data analysed as summer and winter datasets. Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in right hand figure.

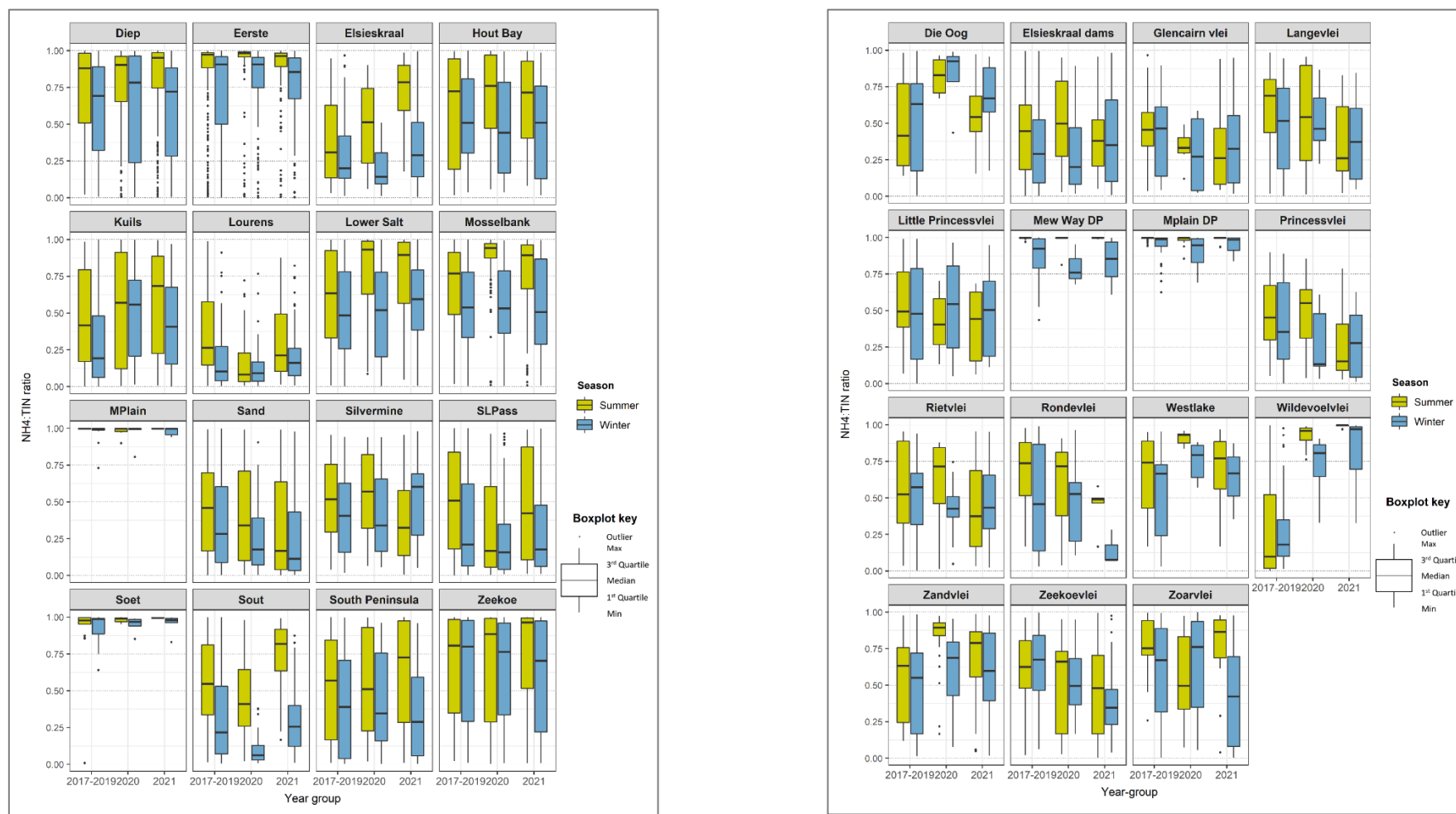


Figure 5.1.9

Comparison of ratios of total ammonia nitrogen (NH₄-N) to Total Inorganic Nitrogen (TIN) for flowing systems (rivers and stormwater channels) (left hand boxplots) and standing water systems (vleis, dams and detention ponds) (right hand boxplots) from the 2021 reporting period, with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Data analysed as summer and winter datasets. Marked thresholds as per Tables 3.2 and 3.3.

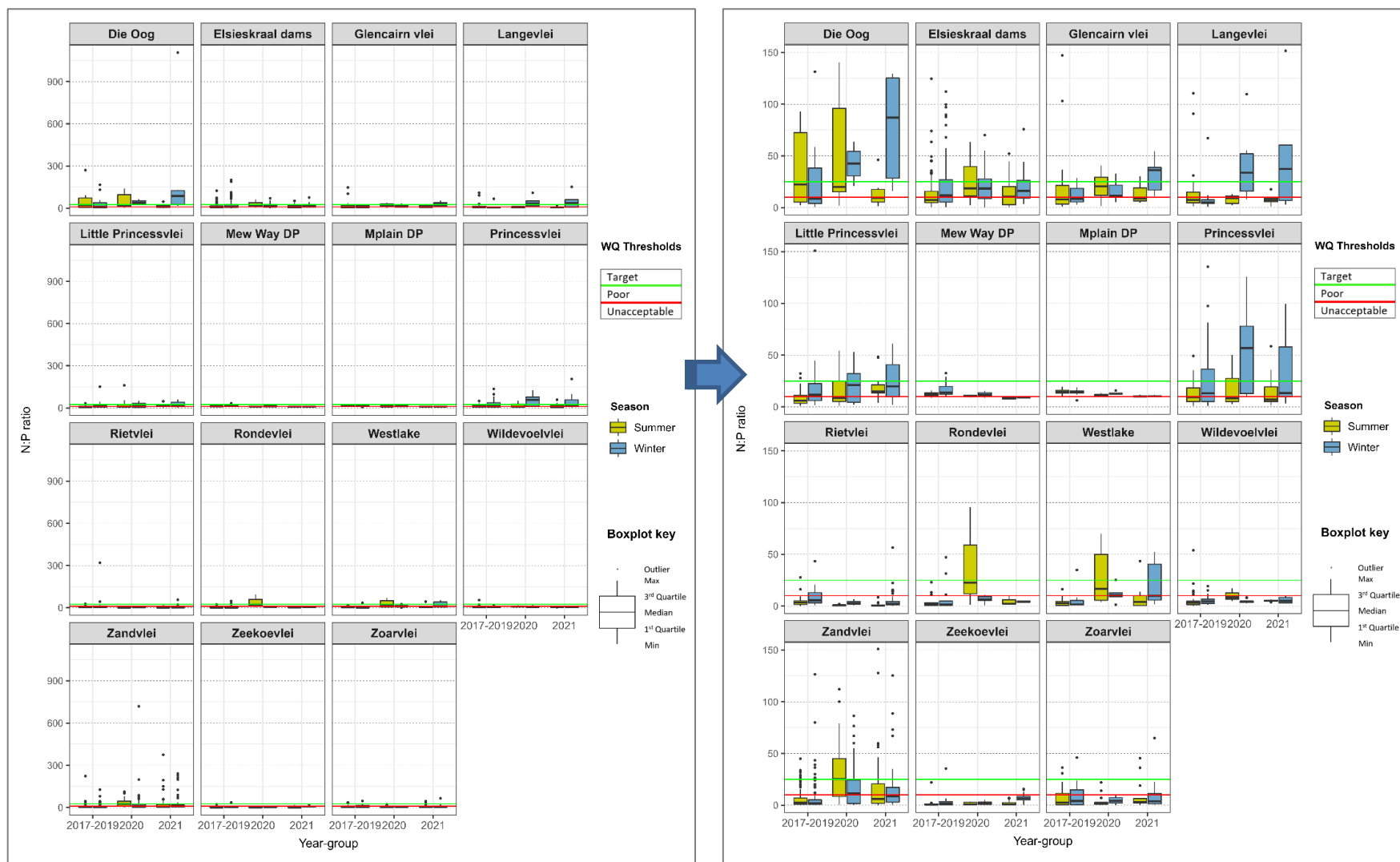


Figure 5.1.10

Comparison of ratios of Total Inorganic Nitrogen (TIN) to phosphate phosphorus (PO₄-P) for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period, with those from 2020 and the previous three years (2017 to 2019) combined. Data analysed as summer and winter datasets. Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in right hand figure. Marked thresholds as per Table 5.2.

5.1.9 Key take-away points from assessment of nutrient data

Phosphate enrichment was probably the most significant factor impacting on Cape Town's inland aquatic ecosystems over the reporting periods considered here, with over 70% of water quality samples collected from both rivers / stormwater systems and vleis / detention ponds lying in the Unacceptable range for this variable. Phosphorus enrichment is likely to drive excessive plant growth and periodic algal blooms that threaten recreational use of waterbodies and at times give rise to fish die-offs as a result of anoxic conditions associated with the rapid build-up of algae in vlei and other standing waterbodies. Phosphorus enrichment also results in high management costs, as a result of the need for plant management (e.g. reed clearing and water hyacinth removal from many waterbodies).

Data for the 2020 and 2021 reporting periods furthermore indicate a general increase in phosphorus enrichment over these periods in many subcatchments and standing waterbodies, indicating a trajectory of decline in ecosystem condition over this time.

The data do, however, show a high degree of scatter in phosphate concentrations within subcatchments, pointing to both episodic point-source driven pollution as well as a range of water courses in different condition within the subcatchments, with some more prone to receipt of severely contaminated water at times than others. Arguably, subcatchments in a generally good condition (i.e., where target thresholds were usually met), should be safeguarded, with high attention paid to addressing sources of periodic pollutant inflows into these systems. Such an approach would at least ensure that some subcatchments remain in a relatively good condition. These subcatchments include (in descending order) the Silvermine, Lourens, Hout Bay, South Peninsula, and Sand subcatchments. None of these subcatchments receive WWTW effluent, and only the Hout Bay subcatchment receives significant runoff from poorly serviced informal settlements. The Silvermine and Lourens River subcatchments were consistently the least impacted subcatchments in monitored areas of the city, at least with regard to phosphorus enrichment.

The subcatchments subjected to the highest levels of phosphorus enrichment (with median values almost 50 times higher than the Unacceptable threshold value) comprised the Sout catchment in the 2021 reporting period, followed by the Lower Salt, Diep, Mosselbank, Eerste, Soet and Zeekoe subcatchments, in descending order of degradation.

Land use in all of these subcatchments includes areas of poorly serviced informal settlement with high levels of disposal of raw sewage and other organic waste into watercourses, and/or receipt of at times poorly treated sewage effluent from WWTWs.

Nitrogen enrichment was a much less problematic nutrient in Cape Town's watercourses over the 2020/2020 reporting periods than was phosphorus, with both river / stormwater channel and standing water systems (vleis, detention ponds etc.) showing far higher levels of compliance with Target thresholds. Nevertheless, the data do indicate that at least in some subcatchments, nitrogen enrichment was still at ecologically problematic levels. Subcatchments where nitrogen enrichment was most pronounced comprised the Diep, Mosselbank, Kuils, Eerste, Lower Salt and Soet subcatchments, with samples from the latter always being in the Unacceptable range. This indicates a subcatchment with potentially high levels of sewage inflows, and low levels of oxygenation, likely to promote nitrification and then denitrification processes.

Overall, the data showed that, for the 2020 and 2021 reporting periods, 60% of water quality samples from routinely monitored sites were rated Unacceptable with regard to their TIN concentrations – this indicates that, while phosphorus is considered more problematic than nitrogen in driving ecosystem responses to eutrophication (e.g. rapid plant growth including algae and reeds), nitrogen enrichment was also at levels of concern in many parts of Cape Town's watercourses. Where nitrogen was primarily in the form of total ammonia, it could also have been problematic from the perspective of aquatic toxicity, as is discussed in **Section 5.4**.

5.2 Chlorophyll-a

Chlorophyll-a is a pigment that occurs in green plants and is one of the primary pigments used in photosynthesis. In water quality assessments, it is used as a measure of algal growth, specifically of phytoplankton abundance.

The CCT monitors chlorophyll-a in many of its standing water systems. This section considers these data from the perspective of its value as an indicator of ecosystem health.

5.2.1 Relevance in water quality monitoring

Under conditions of nutrient enrichment, particularly of phosphorus, chlorophyll-a often increases, reflecting an increase in algal growth rates in response to increased nutrients. If nutrient-enriched systems are dominated by macrophytes (that is, more complex plants than single-celled or filamentous algae, such as pondweed or other plants), they are less likely to be dominated by algae or give rise to algal blooms.

The sudden growth and subsequent die-back or simple turnover of phytoplankton blooms can have significant negative ecological impacts, as bloom decomposition may create anoxic conditions that may result in fish deaths. Anoxia also promotes the release of phosphorus from sediments, as well as hydrogen sulphide in the case of estuaries.

Blooms of blue-green algae (also called cyanobacteria or cyanophytes) are usually associated with very high nutrient concentrations. In large concentrations, they form thick, unsightly scums, which may be odorous and at times can produce toxins that cause skin irritations on contact with water, or vomiting, acute gastroenteritis and impaired liver function if ingested (DWAF 2006b).

Severely elevated chlorophyll-a concentrations, indicative of bloom conditions, have a range of implications for waterbody management. Not only do they contribute to the accumulation of nutrients, organic sludges (requiring periodic dredging) and low-oxygen water in bottom waters, but they can also be associated with odour and aesthetic problems. *Microcystis*, for example, which is the dominant blue-green algal species in some of Cape Town's waterbodies, produces a distinctive foul smell under bloom conditions. The visible presence of green algal scums is also unpleasant, and persistent bloom conditions in waterbodies can affect property value and the suitability of the waterbody for different kinds of recreational uses. This issue is discussed in **Section 6**.

5.2.2 Current state and recent trajectory of change

Chlorophyll-a (Chl-a) data for standing waterbodies are presented as both compliance-type data (proportion of samples from the reporting years under consideration that fall within the Target range, or are rated as 'Poor' or 'Unacceptable', according to the toxicity criteria listed in **Tables 3.1 and 3.2**), and as boxplots (explained in **Box 3.1**). Truncated seasonal boxplots are shown in this section, while the annual boxplots and untruncated seasonal boxplots are provided in **Appendix D**.

Box 5.10

Note that mean annual Chl-a concentrations at individual monitoring points in each waterbody can be seen in **Appendix C**, as well as (for priority catchments) in the maps in **Section 7.3**.

The compliance graphs for Chl-a concentrations in **standing water systems** (at vlei, dam and detention pond sites) (**Figure 5.2.1**) suggest that:

- Considering all the data from standing water systems together (graph in bottom right panel), it can be seen that there was a decrease of approximately 10% in the proportion of samples within the Target range for Chl-a (i.e., <20 µg/L) in Reporting Year 2021, from close to 50% compliance in the previous 2017-2019 and 2020 reporting years;
- The least problematic system was Glencairnvlei, where 100% of the samples had Chl-a readings within the Target range in reporting years 2020 and 2021, with close to 100% compliance also in the 2017-2019 reporting period;
- Relatively good conditions in terms of algal productivity, as indicated by Chl-a measurements,

were also present in the Elsieskraal dams, Zoarvlei, Zandvlei and Little Princessvlei, where close to 60% or more of the samples were in the Target category in all three reporting periods, although there was a reduction in the proportion of compliant samples in Reporting Year 2021 compared to previous years for all of the above except for Zandvlei;

- Relatively high levels of compliance (>60% in Target category for Chl-a), but only in some of reporting periods, were also recorded for Rietvlei in Reporting Year 2020, Rondevlei in the 2017-2019 and the 2020 reporting periods (rising to >80% compliance in Reporting Year 2020 before decreasing to only approximately 50% in Reporting Year 2021) and Die Oog in Reporting Year 2021;
- The most problematic systems, where the risk of algal blooms would have been high during the reporting periods being considered, were Zeekoevlei and Wildevleivlei, both with 100% or close to 100% of the samples that were collected in all three reporting periods falling into the Unacceptable category for Chl-a (i.e., >30 µg/L);
- Langevlei and Princess Vlei were also problematic, with more than 70% of the samples in the Unacceptable category for Chl-a for all three reporting periods, while similar levels of non-compliance were recorded for Rietvlei and Westlake in Reporting Year 2021, and for Die Oog in Reporting Year 2020.

The seasonal boxplots for Chl-a in **Figure 5.2.2** (and the annual boxplots in **Appendix D**) provide the following additional insight in relation to the potential for algal blooms in standing waterbodies during the reporting periods under consideration:

- The only systems with Chl-a levels consistently below the threshold for Unacceptable (as indicated by the inter-quartile ranges on the boxplots) were Glencairnvlei, the Elsieskraal dams and Zoarvlei, with the exception of Zoarvlei in the summer season of Reporting Year 2021, when the upper end of the inter-quartile range extended well above the Unacceptable threshold;
- The situation was significantly worse in Princess Vlei, Rondevlei and Zeekoevlei in Reporting Year 2021, especially compared to Reporting Year 2020, with the upper end of the inter-quartile range for Chl-a boxplots extending noticeably higher, but this was only observed for the summer season in the case of Princess Vlei and Rondevlei, and only during winter in the case of Zeekoevlei;
- There was a significant improvement in the situation at Die Oog in Reporting Year 2021 compared to previous years, especially during summer;
- No clear seasonal patterns were observed, which was somewhat surprising because algal production is generally lower during the colder winter months and should result in mostly lower Chl-a measurements compared to those recorded in summer.



Figure 5.2.1

Percentage of chlorophyll-a (Chl-a) samples falling within each rated category for this variable, per monitored standing water system. Thresholds for rated categories as defined in Table 3.3. Data for sample points in standing waterbodies / vleis and detention ponds. Total number of samples considered shown in bars in bottom right plot ('All standing waterbodies').

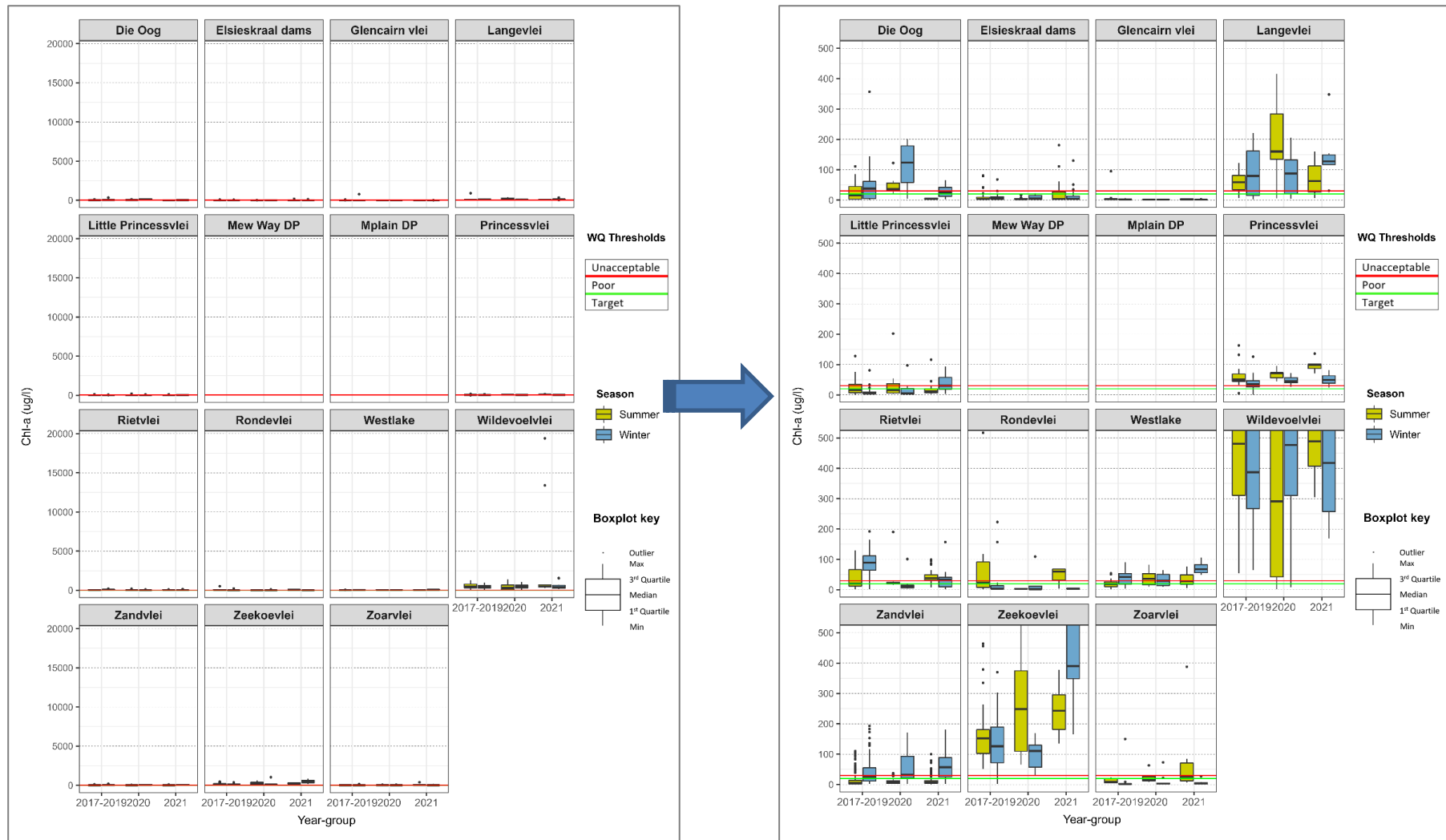


Figure 2.2.2

Comparison of chlorophyll-a data for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Data analysed as summer and winter datasets. Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in right hand figure. Note that there are no data for Mew Way DP and Mplain DP

5.2.3 Key take-away points from assessment of Chlorophyll-a data

The main findings in terms of algal productivity, as reflected in chlorophyll-a measurements recorded for the selection of standing waterbodies in Cape Town during the reporting periods under consideration, were:

- The most problematic systems, where the risk of algal blooms would have been high during the reporting periods being considered, were Zeekoevlei and Wildevoelvlei;
- Langevlei and Princess Vlei were also problematic, with more than 70% of the samples in the Unacceptable category for Chl-a for all three reporting periods;
- Relatively high levels of non-compliance were also recorded for Rietvlei and Westlake in Reporting Year 2021, and for Die Oog in Reporting Year 2020;
- The situation was significantly worse in Princess Vlei, Rondevlei and Zeekoevlei in Reporting Year 2021, compared to Reporting Year 2020, especially during summer in the case of Princess Vlei and Rondevlei, and only during winter in the case of Zeekoevlei;
- The least problematic systems in terms of algal production were Glencairnvlei and the Elsieskraal dams, which are characterised by relatively low nutrient inputs, as well as Zoarvlei, except in the summer season of Reporting Year 2021 when a number of samples exceeded the Unacceptable threshold for Chl-a;
- Relatively good conditions were also present in Zandvlei and Little Princessvlei through most of the reporting period under consideration;
- There was a significant improvement in the situation at Die Oog in Reporting Year 2021 compared to previous years, especially during summer.

5.3 Dissolved oxygen

5.3.1 Relevance in water quality monitoring

Oxygen is critical for the respiration of all aerobic organisms, and, in aquatic ecosystems, adequate supplies of dissolved oxygen are needed for the survival of all non-air-breathing organisms. In aquatic ecosystems, it is sourced from atmospheric oxygen which dissolves in water, particularly if there is turbulent flow or wind-generated waves. It is also generated by submerged aquatic plants and algae during photosynthesis.

Low oxygen availability, particularly if combined with high temperature, can compound impacts on aquatic organisms, and can increase the toxicity of certain toxic substances such as various heavy metals (e.g. zinc, lead, copper) as well as sulphides and ammonia (DWAf 1996a). In conditions where dissolved oxygen is limited, important nutrient cycling may be retarded – for example, oxidation of ammonia (NH_3) to Nitrite (NO_2^-) and then Nitrate (NO_3^-) may occur only very slowly, resulting in the accumulation of potentially toxic unionised ammonia. This is especially problematic for aquatic systems that are polluted with nitrogen-rich contaminants such as sewage. In standing waterbodies (e.g. vleis and dams), oxygen concentrations are also important in determining phosphorus release from sediments. At low oxygen concentrations, phosphorus can be released as biologically available phosphates, contributing to ongoing cycles of increased plant productivity (Cooke et al. 2005).

Dissolved oxygen concentrations vary with temperature and salinity/conductivity. Variations in photosynthesis through the day means that concentrations of dissolved oxygen also vary on a daily basis, with the highest concentrations occurring in mid-afternoon and lowest concentrations usually occurring near dawn. Consequently, the measurement of dissolved oxygen in water quality monitoring programmes should be carried out at the same time of day if data between sites or over time are to be comparable. Since the CCT's sampling programme follows a strict order of sampling, it is assumed that samples are indeed collected at approximately the same time in each sampling cycle.

Exposure to water with very low dissolved oxygen concentrations can trigger immediate death for some non-air-breathing organisms, as in the case of some fish kill incidents. Continuous exposure to water with non-lethal but sub-optimal concentrations may also be very harmful to aquatic organisms, including impacts on fish fecundity and/or mortality (DWAf 1996a).

5.3.2 Current state and recent trajectory of change

In this section, dissolved oxygen is considered from the perspective of the degree to which suppressed dissolved oxygen concentrations are likely to have contributed to aquatic ecosystem degradation at sampling sites. The next section (Section 5.4) considers ammonia toxicity as a potential issue in Cape Town's waterbodies. Total ammonia concentrations are directly affected by dissolved oxygen concentrations. This is because, with low DO availability, nitrification processes are slow to non-existent, and decomposing organic nitrogen remains as total ammonia nitrogen and does not oxidise readily to nitrites or nitrates.

Figures 5.3.1 and 5.3.2 present data for dissolved oxygen concentrations in terms of the percentage of samples per subcatchment and standing waterbody, respectively, that met or did not meet the minimum threshold of ecological acceptability – that is, a threshold concentration of 4 mg/l, below which DWAf (1996) suggests acute effects of oxygen scarcity would be expected, if such conditions persisted for a day or more. The graphs also show the percentage of samples that were in the target range for dissolved oxygen concentration (i.e., >6 mg/l), as well as the remaining percentage of samples considered to be representative of poor conditions in terms of dissolved oxygen (i.e. concentrations of 4-6 mg/l).

The graphs for river and stormwater channel sites (**Figure 5.3.1**), grouped by subcatchment, suggest that:

- In the most recent year of analysis (Reporting Year 2021), very low levels of DO were prevalent in the Lower Salt, Eerste, Soet and Zeekoe subcatchments, with close to 40% or more of the samples

collected during the year falling within the Unacceptable category;

- Conditions in the Soet catchment were particularly bad in Reporting Year 2021, with approximately 65% of the samples falling within the Unacceptable category;
- Low to very low DO levels were also prevalent in the Diep, Mosselbank and Sout subcatchments during Reporting Year 2021, with close to 50% or more of the samples falling into the Poor and Unacceptable categories combined;
- During the 2020 reporting year, very low levels of DO were prevalent in the Lower Salt, Eerste, Soet and Zeekoe subcatchments, with close to 40% or more of the samples collected during the year falling within the Unacceptable category, as in Reporting Year 2021, but the percentage of samples in the Unacceptable range was more than that in the 2021 reporting year in the case of the Lower Salt and Eerste subcatchments, and less for the Soet subcatchment;
- Very low DO levels were more prevalent in the Diep, Mosselbank and Sout subcatchments during Reporting Year 2020, compared to 2021, with the proportion of samples in the Unacceptable category approaching or exceeding 40%;
- The worst-performing subcatchment in Reporting Year 2020, in terms of DO concentrations, was the Lower Salt, with more than 70% of the samples below the Poor threshold and nearly 60% of the samples within the Unacceptable category;
- High DO levels within the Target range (reflective of good conditions) were recorded in 90% or more of the samples collected from the Elsieskraal and Lourens subcatchments during Reporting Years 2020 and 2021;
- High DO levels within the Target range were also recorded in 90% or more of the samples collected from the SL Pass subcatchment during Reporting Year 2020, where the percentage of samples in this category dropped to 75% in 2021;
- High DO levels within the Target range were recorded in approximately 70% of the samples collected from the Kuils and Sand subcatchments during Reporting Year 2020, and in the Hout Bay, Silvermine and South Peninsula subcatchments in the same year, but the proportion of samples in this category dropped to close to or less than 60% in 2021 in the case of the Kuils, Hout Bay and Silvermine subcatchments (remaining similar to the previous year in the Sand and increasing to close to 80% for the Silvermine subcatchment in Reporting Year 2021);
- The conditions in the most recent year of analysis (Reporting Year 2021) improved compared to Reporting Years 2017-2019, in terms of DO concentrations, in the Mosselbank, Eerste, Sout and Sand subcatchments, and slightly in the Silvermine and South Peninsula subcatchments, where the proportion of samples in the Unacceptable category decreased and the proportion within the Target category increased;
- Conditions in the Sir Lowry's Pass, Hout Bay and, especially, Soet catchments deteriorated from Reporting Years 2017-2019 to Reporting Year 2021, with an increase of samples in the Poor to Unacceptable category and a decrease of the proportion of samples in the Target category;
- Taking all the data for flowing systems in all the monitored subcatchments across Cape Town together (bottom right panel in **Figure 5.3.1**), the proportion of sampling sites with DO measurements within the Target category remained at 50-55% throughout the 2017-2021 reporting period, while the proportion of sampling sites with DO measurements in the Unacceptable category decreased from approximately 30% in the 2017-2019 and 2020 reporting years to approximately 25% in Reporting Year 2021. These results are indicative of a generally poor state of water quality with respect to DO levels in flowing systems across Cape Town, with

Box 5.11

Dissolved oxygen in open waterbodies

In shallow standing water systems, dissolved oxygen concentrations can be reduced (i.e. made worse) by:

- re-suspension of anoxic sediments as a result of wind-induced turbulence;
- the presence of oxidisable organic matter (e.g. decaying plant matter);
- high concentrations of suspended material, especially phytoplankton.

more than half the measurements collected over the five-year period from 2017 to 2021/22 consistently being reflective of Poor to Unacceptable conditions.

Standing waterbodies are generally more vulnerable to the development of low-oxygen or even anoxic conditions than riverine systems. The data for vleis, dams and detention ponds (graphs in **Figure 5.3.2**) suggest that:

- The Mew Way and Mitchell's Plain detention ponds were characterised by a prevalence of very low dissolved oxygen concentrations, highlighting the need for oxygenation of these stormwater ponds to improve their functionality in dealing with nutrient-enriched inputs, although the proportion of samples in the Target category did increase from the previous years to approximately 10% in Reporting Year 2021 for the Mew Way DP, and to 20-40% for the Mitchell's Plain DP in 2020 and 2021;
- In Reporting Year 2021, very low levels of DO were prevalent in Zoarvlei and Rondevlei, with close to 40% or more of the samples collected during the year falling within the Unacceptable category;
- Low to very low DO levels were also prevalent in Glencairnvlei, Wildeveolvlei, Little Princessvlei and the Elsiekraal dams during Reporting Year 2021, with 40% or more of the samples falling into the Poor and Unacceptable categories combined (although no samples were in the Unacceptable category in the case of Glencairnvlei);
- High DO levels within the Target range (reflective of good conditions) were recorded in all the samples collected from Rietvlei, Westlake, and Princessvlei during Reporting Year 2021;
- High DO levels were also prevalent in Zeekoevlei, Zandvlei, Die Oog and Langvlei during Reporting Year 2021, with close to 80% or more of the samples within the Target range;
- There has been a trajectory of improvement at Zoarvlei, from Reporting Year 2017-2019 to Reporting Year 2020 and again from 2020 to 2021, with an increase in the percentage of DO measurements in the Target category and a concomitant decrease in the percentage of samples in the Unacceptable and Poor categories;
- At Rondevlei, there was an increase in the percentage of samples in the Target category in 2021 (to almost 40%), compared to previous years, but there was also an increase in the percentage of samples in the Unacceptable category from Reporting Year 2020 to 2021;
- There was also an increase in the percentage of samples in the Target category at Zeekoevlei and Westlake in 2021, compared to previous years (to 20% and 100%, respectively);
- There was a decrease in the percentage of samples in the Target category at Glencairnvlei in 2020 and 2021, compared to Reporting Years 2017-2019, from close to 80% to below 50%, although the percentage of samples in the Unacceptable category reduced to zero in this system in Reporting Year 2021;
- There appears to be a declining trajectory in terms of DO concentrations at Wildeveolvlei and in the Elsiekraal dams over the recent five-year period, with an increase in the percentage of samples in the Unacceptable category and a concomitant decrease in the percentage of samples in the Target category in Reporting Year 2021 compared to previous years;
- Considering the data for all the monitored standing water systems across CCT together (bottom right panel in **Figure 5.3.2**), the proportion of sampling sites with DO measurements within the Target category was significantly higher than that for flowing systems, at 65-70% for the 2017-2019 and 2020 reporting years, increasing to approximately 75% for Reporting Year 2021 (versus 50-55% throughout the reporting period for flowing systems). The proportion of standing water samples with DO measurements in the Unacceptable category was concomitantly lower than that for flowing systems, decreasing from ~20% in the 2017-2019 reporting period to ~15% in 2020, and even further to <10% in Reporting Year 2021. These results are somewhat unexpected, with standing water systems, which lack the turbulence allowed by flow, generally assumed to be less oxygenated than flowing systems. The results were however probably skewed by the large number of flowing water sites in the monitoring database that were selected specifically due to

the presence of pollution problems (explained in Sections 3.3 & 3.4) and the presumed collection of water samples in standing water systems from near the water surface, as opposed to from deeper into the water column and closer to the bottom.



Figure 5.3.1

Percentage of Dissolved Oxygen (DO) falling within each rated category for this variable, per subcatchment. Thresholds for rated categories as defined in Table 3.2. Data for river / 'flowing' water monitoring points in each subcatchment. Subcatchments as shown in Figure 2.1. Total number of samples considered shown in bars in bottom right plot ('All rivers / stormwater systems').



Figure 5.3.2

Percentage of Dissolved Oxygen (DO) samples falling within each rated category for this variable, per monitored standing water system. Thresholds for rated categories as defined in Table 3.3. Data for sample points in standing waterbodies / vleis and detention ponds. Total number of samples considered shown in bars in bottom right plot ('All standing waterbodies').

Figure 5.3.3 presents boxplots of DO data for Reporting Years 2020 and 2021 compared to data from the previous three-year period (2017-2019), separated into summer and winter seasons, for river / stormwater channels (left panel) and dams / vleis (right panel). These graphs show that, for river and stormwater channel sites, there was a tendency for conditions to be worse (lower DO concentrations) in summer compared to winter, as expected. There was also a tendency, at least over the three reporting periods analysed here, for the range of variability to be greater during summer than in winter at the sites representative of flowing systems. This was also to be expected due to the wider range of temperature fluctuations in flowing water systems during summer compared to winter. Exceptions to this tendency were, however, observed through all three reporting periods in the Eerste, Lower Salt, Sout and Zeekoe subcatchments (with similar summer and winter inter-quartile ranges), all of which receive WWTW inflows (or stormwater inflows that are contaminated with sewage input in the case of the Zeekoe subcatchment), regulating the flows and (to less extent) water temperatures in the systems, thus dampening seasonal DO variations. This was also the case for the Mosselbank subcatchment (which also receives WWTW inflows) in Reporting Year 2021, the Mitchells Plain subcatchment in Reporting Years 2020 and 2021 (significantly larger range in winter than summer), the Sand and Soet subcatchments in the 2017-2019 reporting years, all of which receive sewage-contaminated inflows in portions of the subcatchments, and the Silvermine subcatchment in Reporting Year 2020 (where periodic sewage inputs were experienced in the lower portion of the subcatchment). The Sir Lowry's Pass subcatchment was the only subcatchment with a consistently wider range of riverine DO levels recorded during winter than in summer, as indicated by a wider inter-quartile range (i.e., the box of the boxplots) for all three reporting periods.

The above-mentioned patterns, in terms of summer versus winter differences, are not apparent in the data for the vlei, dam and detention pond sites (see right panel compared to left panel in **Figure 5.3.3**). The main reasons for this lack of strong seasonal variability lie in the fact that:

- Standing water systems are generally not exposed to strong seasonal variation (other than in Zeekoevlei and Rondevlei, which are both managed by seasonal draw-down of water level, with Zeekoevlei water levels being drawn down in winter and Rondevlei's water levels being drawn down in summer);
- More stable temperature regime compared to flowing systems, due to a lack of flows and a deeper water column;
- The presence of a much greater volume of water with a larger surface area, exposed to atmospheric oxygen as well as wind-induced turbulence and mixing.

The only standing waterbody with a consistent seasonal pattern was the Mew Way detention pond, where DO levels recorded during summer were lower than those recorded during winter and, in contrast to the majority of flowing water sites, the range of recorded values was greater in winter than in summer for all three reporting periods. This is the smallest of all the monitored standing waterbodies and typically has very low water levels in summer with significantly fluctuating water levels during the wet winter season, which would explain the observed seasonal DO pattern that is not obvious for any of the other, significantly larger waterbodies. The DO values recorded in this shallow, hypertrophic artificial stormwater system are always very low, with the summer and winter median values for all three reporting periods being below the threshold for the Unacceptable category. While some of the other standing waterbodies also had median DO values that were lower in summer than in winter for all three reporting periods (i.e., Glencairnvlei, Mitchells Plan detention pond, Rietvlei, Westlake and Wildevoelvlei), there was a lot more overlap in the range of DO measurements recorded in these cases than there was for the Mew Way detention pond.

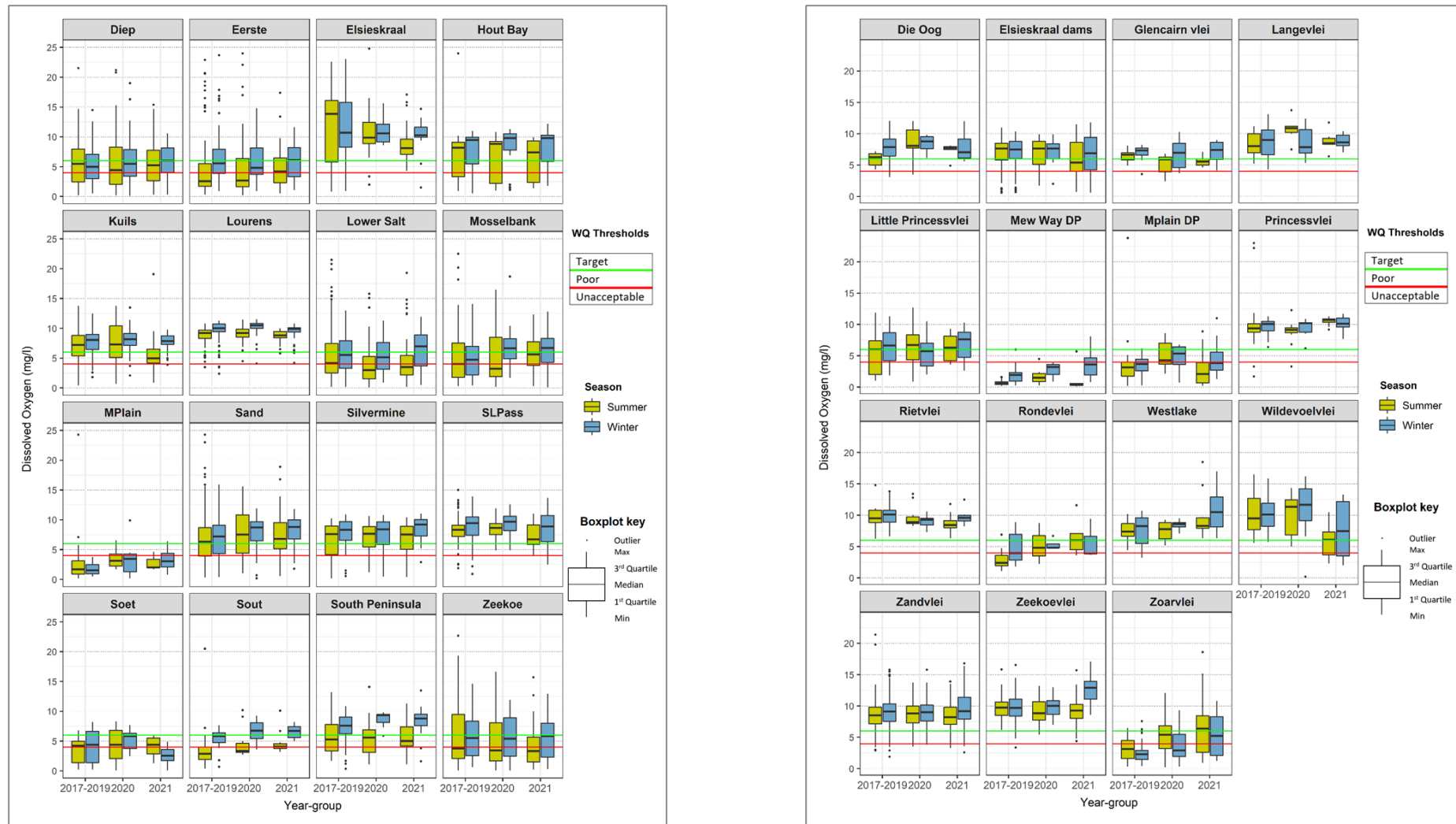


Figure 5.3.3

Comparison of dissolved oxygen for flowing systems (rivers and stormwater channels) (left hand boxplots) and standing water systems (vleis, dams and detention ponds) (right hand boxplots) from the 2021 reporting periods, with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Data analysed as summer and winter datasets. Marked thresholds as per Tables 3.2 and 3.3.

5.3.3 Key take-away points from assessment of dissolved oxygen data

The main findings with respect to dissolved oxygen levels in the monitored waterbodies across the city were as follows:

- Extremely low DO concentrations in the Unacceptable category were not as pervasive a problem as elevated nutrient concentrations during the reporting periods considered in the current report, although there were systems characterised by low DO concentrations, either consistently or intermittently;;
- As observed for nutrient concentrations, the level of non-compliance in relation to the Target range of values for DO concentrations was more problematic for the monitored flowing water sites than it was for standing water sites, but this could be largely a result of the majority of the monitored standing water systems being located in less polluted subcatchments, whereas many of the flowing system sites are purposefully located immediately downstream of known pollution sources.
- For flowing systems, the results are indicative of a generally bad state of water quality with respect to DO levels at the monitored sites within the city, with more than half the measurements collected over the five-year period from 2017 to 2021/22 consistently being reflective of Poor to Unacceptable conditions;
- Conditions in the Soet subcatchment were particularly bad in Reporting Year 2021 in terms of DO measurements, with approximately 65% of the samples falling within the Unacceptable category compared to just over 40% during the previous 2020 reporting year, probably at least partly attributable to polluted stormwater runoff from informal settlements in the subcatchment;
- The least problematic subcatchments with respect to DO concentrations at monitored flowing water sites were, unsurprisingly, the more rural Elsieskraal subcatchment and the Lourens, SL Pass and Silvermine subcatchments containing less impacted upper river sites;
- For river and stormwater channel sites, there was a tendency for conditions to be worse (lower DO concentrations) in summer compared to winter, and for the range of variability to be greater during summer than in winter, although exceptions to this latter tendency were observed in subcatchments which receive WWTW inflows and/or or stormwater inflows that are contaminated with sewage input (e.g. from informal settlements or leaking sewerage infrastructure) including the Eerste, Lower Salt, Sout, Mitchell's Plain and Zeekoe subcatchments;
- For standing water systems, the Mew Way and Mitchell's Plain detention ponds (DP) were in the worst condition, being characterised by a prevalence of very low dissolved oxygen concentrations, highlighting the need for oxygenation of these stormwater ponds to improve their functionality in dealing with nutrient-enriched inputs;
- Conditions appear to have improved in Zoarvlei and Rondevlei during Reporting Years 2020 and 2021, compared to the 2017-2019 reporting years, with most DO samples being in the Poor to Target categories in the more recent reporting years compared to many DO measurements being in the Unacceptable category for 2017-2019 (although there was also an increase in the percentage of samples in the Unacceptable category from Reporting Year 2020 to 2021 at Rondevlei);
- There was also a trajectory of improvement in DO concentrations at Zeekoevlei and Westlake, where an increase in the percentage of samples in the Target category (to 20% and 100%, respectively) was observed in 2021, compared to previous years;
- On the other hand, there appeared to be a declining trajectory of change in terms of DO concentrations at Wildevolevlei and in the Elsieskraal dams over the recent five year period, with an increase in the percentage of samples in the Unacceptable category and a concomitant decrease in the percentage of samples in the Target category in Reporting Year 2021 compared to previous years;
- Standing waterbodies with the highest DO concentrations over the 2020 to 2021 reporting periods were Rietvlei, Westlake, Princessvlei, Zeekoevlei, Zandvlei, Die Oog and Langevlei.

5.4 Ammonia toxicity

As explained in Section 5.1.2, inorganic nitrogen in aquatic ecosystems occurs in the form of nitrate and nitrite ions, and as total ammonia. There are two forms of ammonia, namely ionised ammonia (NH_4^+), also known as ammonium, and un-ionised ammonia (NH_3). Un-ionised (or 'free') ammonia can be toxic to some aquatic organisms, even at very low concentrations (DWAf 1996a and DWAf 2008).

The present section focuses specifically on the potential for ammonia toxicity as a result of elevated unionised ammonia concentrations at the CCT's water quality sampling points, both in flowing and standing water systems.

5.4.1 Relevance in water quality monitoring

In an aquatic environment, the relative proportion of un-ionised ammonia to ammonium ions in water is controlled primarily by pH and temperature. The CCT measures the 'total ammonia nitrogen' concentration in a water sample and calculates the proportion of this that is likely to be in the potentially toxic un-ionised form, taking into account pH, temperature and EC (for salinity in estuarine waters). At $\text{pH} > 8$, a significantly larger proportion of total ammonia ions are present in the un-ionised form, which may give rise to acute toxicity at concentrations as low as 0.1 mg N/L (DWAf 1996a).

Concentrations of un-ionised ammonia above Target levels (see **Tables 3.1 and 3.2**) would increase the risk of ammonia toxicity in sensitive fauna, especially fish. The presence of low oxygen conditions would tend to increase the availability of reduced nitrogen forms such as ammonia, rather than more stable nitrates. Oxygen levels are thus also an important consideration when assessing the threat posed to aquatic ecosystems by ammonia toxicity.

Prolonged exposure to un-ionised ammonia at chronic toxicity levels (Poor category in **Tables 3.1 and 3.2**) could affect aquatic organism fecundity, general health and resilience, while exposure to elevated levels associated with acute toxicity (Unacceptable category in **Tables 3.1 and 3.2**) could result in the death of more sensitive organisms.

5.4.2 Current state and recent trajectory of change

Un-ionised ammonia data (abbreviated hereafter as NH_3) are presented as both compliance type data (proportion of samples from the reporting years under consideration that fall within the Target range, or are rated as 'Poor' or 'Unacceptable', according to the toxicity criteria listed in **Tables 3.1 and 3.2**), and as boxplots, which show statistical data for all analysed watercourse groups and categories (as explained in **Box 3.1**).

Box 5.12

Note that median annual NH_3 concentrations at individual monitoring points in each subcatchment can be seen (as NH_3) in **Appendix C**, as well as (for priority catchments) in the maps in **Section 7.3**.

These data are presented separately for flowing water systems (rivers and stormwater channels) and for standing water systems (vleis, dams and detention ponds). The compliance graphs and seasonal boxplots are shown in this section, while the annual boxplots are provided in **Appendix D**.

The compliance graphs for NH_3 concentrations at **river and stormwater channel sites** (**Figure 5.4.1**), grouped by subcatchment, suggest that:

- Considering all flowing water sites across all subcatchments together (graph in bottom right panel), 25-30% of the samples from all three reporting periods had elevated un-ionised ammonia concentrations in the Unacceptable category, representing potential acute toxicity conditions at the times these samples were collected, whereas approximately 65% of the samples from all three reporting periods had NH_3 concentrations within the Target range of values;
- There was a low risk of ammonia toxicity, especially over the past two reporting periods, in the Lourens, Sout, Hout Bay and Silvermine subcatchments, with 100% or close to 100% compliance in relation to the Target threshold for un-ionised ammonia in these mostly relatively unpolluted

subcatchments (with the exception of the Sout, which is characterised by high EC values that would reduce the proportion of un-ionised to ionised ammonia);

- There was also a relatively low risk of ammonia toxicity over all three reporting periods in the SL Pass, Sand and South Peninsula subcatchments, where close to or more than 80% of the samples had NH₃ concentrations lower than the Target threshold;
- The most problematic subcatchment, in terms of the potential for ammonia toxicity, was the Soet where >80% of the samples collected in all three reporting periods had NH₃ concentrations in the Unacceptable category (increasing to >90% in Reporting Year 2020), representing conditions conducive to acute toxicity for aquatic fauna;
- Potentially toxic conditions were also prevalent in the Lower Salt and the Eerste subcatchments in all three reporting periods, and in the Mosselbank, Elsieskraal and Zeekoe subcatchments in the 2020 and 2021 reporting years, with NH₃ concentrations above the Target threshold recorded in close to or more than 50% of the samples that were collected in all these cases;
- Potentially toxic conditions do also occur at times in the Diep and Kuils subcatchments, where 60-75% of the samples collected in all three reporting periods were within the Target category for un-ionised ammonia, implying that concentrations indicative of conditions conducive to chronic or acute ammonia toxicity were recorded in 25-40% of the samples from these subcatchments.

The compliance graphs for NH₃ concentrations in **standing water systems** (at vlei, dam and detention pond sites) (**Figure 5.4.2**) suggest that:

- Considering all the data from standing water systems together (graph in bottom right panel), ammonia toxicity was generally less of a problem for these systems than it was for flowing water systems, with approximately 80% of the standing water samples from all three reporting periods being in the Target category for un-ionised ammonia concentrations;
- There was a particularly low risk of ammonia toxicity in Rietvlei, Rondevlei, Zandvlei, Die Oog, Glencairnvlei, Little Princessvlei, Princess Vlei and the Elsieskraal dams in all three reporting periods, and in Westlake (excluding Reporting Year 2021) and Langevlei (excluding Reporting Year 2020), with 100% or close to 100% compliance in relation to the Target threshold for NH₃ recorded;
- Potentially toxic conditions were particularly prevalent in Wildevoelvlei in the 2020 and 2021 reporting years, when the recorded NH₃ concentrations were above the Unacceptable threshold (indicating acute toxicity) in 100% of the samples;
- Potentially toxic conditions were also prevalent in the Mew Way and, especially, Mitchell's Plain detention ponds in all three reporting periods, with the Target for NH₃ reached in less than 20% and 10% of the samples that were collected from these artificial stormwater systems, respectively, indicative of an ongoing high risk of at least chronic toxicity (rising to a risk of acute ammonia toxicity in 60-80% of the samples collected from the Mew Way pond and in 70-90% of the samples collected from the Mitchells Plain pond in each reporting year);
- Potentially toxic conditions were often present in Zeekoevlei during all three reporting periods, with NH₃ concentrations above the Target threshold (indicative of a high risk of at least chronic ammonia toxicity) recorded in close to or more than 50% of the samples that were collected.

The seasonal boxplots for un-ionised ammonia in **Figure 5.4.3 and 5.4.4** (and the annual boxplots in **Appendix D**) provide the following additional insight in relation to the potential for ammonia toxicity:

- The range of recorded NH₃ values was noticeably greater in subcatchments and standing water systems with lower levels of compliance, as shown by wider boxes (representing the inter-quartile range) and longer whiskers (representing the range, excluding outliers) on the boxplots;
- The risk of toxicity associated with high levels of un-ionised ammonia is clearly generally greater in the monitored flowing water systems than it is in the monitored standing water systems, with the exception of the poorly performing standing water systems (i.e., Wildevoelvlei and the artificial Mew Way and Mitchells Plain detention ponds);

- If the subcatchments and standing waterbodies with very high levels of compliance in terms of un-ionised ammonia are excluded, all the other flowing water sites and standing water sites showed a greater range of values in summer compared to winter, and generally (but not always) higher median values (and thus more risk of non-compliance) in summer than in winter. This is the expected pattern for ammonia toxicity, the risk of which increases at higher temperatures.

5.4.3 pH values and risk of ammonia toxicity at sampling points

As explained in Section 5.4.1 particular attention should be paid to raised pH levels because of the relationship between pH, water temperature and the ratio of ammonium ions to un-ionised ammonia (DWAf, 1996a). Here, as a rough guideline, pH >8 is considered to be a potential trigger for ammonia toxicity when associated with elevated total ammonia concentrations. Boxplots of the pH values recorded at CCT sampling sites during the three reporting periods considered in this report are presented in **Appendix C4**, with separate plots for the flowing water and standing water sites. It is important to note that the focus of the analysis here is to assess the degree of ammonia toxicity risk as a result of high pH values, and not the degree to which pH has been altered from the presumed natural reference range (this aspect was discussed in Section 3.6.1).

For river and stormwater channel sites, grouped by subcatchment, the relevant boxplot of recorded pH values in **Appendix D** suggests the following in relation to the risk of ammonia toxicity:

- The Elsiekraal subcatchment is the most at risk of ammonia toxicity, with median pH values of >8 in all three reporting periods and few pH measurements being less than just below 8 (the 1st quartile ranged between 7.7 and 7.8);
- Maximum pH values approaching close to 11 were recorded in the Elsiekraal subcatchment in the 2017-2019 and 2020 reporting periods, with the maximum measurement decreasing to 9.7 in Reporting Year 2021;
- The subcatchments least at risk of ammonia toxicity because of low pH values are the Hout Bay and Silvermine subcatchments, where in all three reporting periods median pH values were <7, the 75th percentile (3rd quartile) was <7.15 and the maximum values were ≤8.1 (<7.5 in the case of the Hout Bay subcatchment);
- All other subcatchments had median pH values ranging between 7.1 and 7.7, with the 75th percentile generally <8 (the only exception being the Mosselbank catchment in the 2020 and 2021 reporting years, when the 75th percentile was 8.1 and 8, respectively), suggesting a generally low risk of ammonia toxicity unless ammonia concentrations were exceedingly high and/or there were particularly warm water temperatures;
- Maximum pH values of >9, indicating intermittent spikes of high ammonia toxicity risk related to pH, were recorded for Reporting Years 2020 and/or 2021 in the Eerste, Lower Salt, Mosselbank, Sand, South Peninsula and Zeekoe subcatchments;
- For standing water (vlei and wetland) sites, grouped by waterbody, the relevant boxplot of recorded pH values in **Appendix D** suggests the following in relation to the risk of ammonia toxicity:
 - There was relatively high risk of ammonia toxicity as a result of median pH values >8 in the Langevlei, Princess Vlei, Rietvlei, Wildevoelvlei, Zandvlei and Zeekoevlei waterbodies during all three reporting periods, and during Reporting Year 2021 in the Westlake Wetland;
 - A relatively high risk was most prevalent in Langevlei, Rietvlei, Wildevoelvlei, Zandvlei and Zeekoevlei in all three reporting periods, and in the Westlake Wetland in Reporting Year 2021, with the 25th percentile (1st quartile) for recorded pH values approaching or exceeding 8;
 - During the 2020 and 2021 reporting years, maximum pH values ≥9, indicating periods of particularly high risk of ammonia toxicity, were recorded in the Elisekraal dams (2020), Langevlei (2020 and 2021), Princess Vlei (2021), Rondevlei (2021), Westlake Wetland (2021), Wildevoelvlei (2020 and 2021), Zandvlei (2020 and 2021), Zeekoevlei (2020 and 2021) and

Zoarvlei (2020 and 2021).

5.4.4 Key take-away points from assessment of un-ionised ammonia data

The main findings with respect to the potential for toxic conditions for aquatic fauna in monitored aquatic ecosystems across the City resulting from elevated levels of un-ionised ammonia were:

- Potentially toxic conditions associated with elevated NH₃ concentrations were more prevalent in flowing water systems than they were for standing water systems, with concentrations outside the Target range for approximately 35% of the samples from flowing water systems versus approximately 20% of the standing water samples for all three reporting periods, partly attributable to the dilution effect of large standing water bodies;
- There were a number of subcatchments for which ammonia toxicity was not an issue of concern for monitored flowing water systems during the 2017-2019, 2020 and 2021 reporting periods, namely the Lourens, Sout, Hout Bay and Silvermine, Sir Lowry's Pass, Sand and South Peninsula subcatchments;
- There were also number of monitored standing water systems for which ammonia toxicity was not an issue of concern during the 2017-2019, 2020 and 2021 reporting periods, namely Rietvlei, Rondevlei, Zandvlei, Die Oog, Glencairnvlei, Little Princessvlei, Princess Vlei and the Elsiekraal dams, as well as Westlake in the 2017-2019 and 2020 reporting years (but not in Reporting Year 2021) and Langevlei in the 2017-2019 and 2021 reporting years (but not in Reporting Year 2020);
- The most problematic subcatchment, in terms of the potential for ammonia toxicity, was the Soet where >80% of the samples collected in all three reporting periods had NH₃ concentrations in the Unacceptable category (increasing to >90% in Reporting Year 2020);
- Other problematic subcatchments (with NH₃ concentrations above the Target threshold recorded in close to or more than 50% of the samples collected) included the Lower Salt and Eerste subcatchment in all three reporting periods, and the Mosselbank, Elsiekraal and Zeekoe subcatchments in the 2020 and 2021 reporting years;
- The most problematic standing water system, especially in Reporting Years 2020 and 2021, was Wildevoelvlei, where the recorded NH₃ concentrations were above the Unacceptable threshold (indicating acute toxicity) in 100% of the samples;
- Other problematic standing water bodies, where potentially toxic conditions were prevalent in all three sampling periods, were the Mew Way and, especially, Mitchell's Plain detention ponds, where the Target for NH₃ was recorded in less than 20% and 10% of the samples that were collected from these artificial stormwater systems, respectively;
- Potentially toxic conditions were also often present in Zeekoevlei during all three reporting periods, with NH₃ concentrations above the Target threshold recorded in close to or more than 50% of the samples that were collected;
- There was generally a greater range of values in recorded un-ionised ammonia levels in summer compared to winter, for all watercourses (flowing and standing water systems) that did not have very high levels of compliance in terms of the Target range for NH₃ concentrations, and the median NH₃ concentration was generally (but not always) higher in summer, indicating a greater risk of toxic conditions than in winter;
- Most of the problematic subcatchments had sporadically but not consistently high pH values indicative of increased ammonia toxicity risk, with the exception of the Soet and the Elsiekraal, suggesting that the problems in the Soet subcatchment in particular are being driven by excessively high ammonia concentrations and not elevated pH values;
- Standing water systems with a relatively high risk of ammonia toxicity as a result of median pH values >8 were Langevlei, Princess Vlei, Rietvlei, Wildevoelvlei, Zandvlei and Zeekoevlei during all three reporting periods, and Westlake Wetland during Reporting Year 2021.



Figure 5.4.4

Percentage of un-ionised ammonia (NH₃) samples falling within each rated category for this variable, per subcatchment. Thresholds for rated categories as defined in Table 3.2. Data for river / 'flowing' water monitoring points in each subcatchment. Subcatchments as shown in Figure 2.1.



Figure 5.4.5

Percentage of un-ionised ammonia (NH₃) samples falling within each rated category for this variable, per monitored standing water system. Thresholds for rated categories as defined in Table 3.3. Data for sample points in standing waterbodies / vleis and detention ponds.

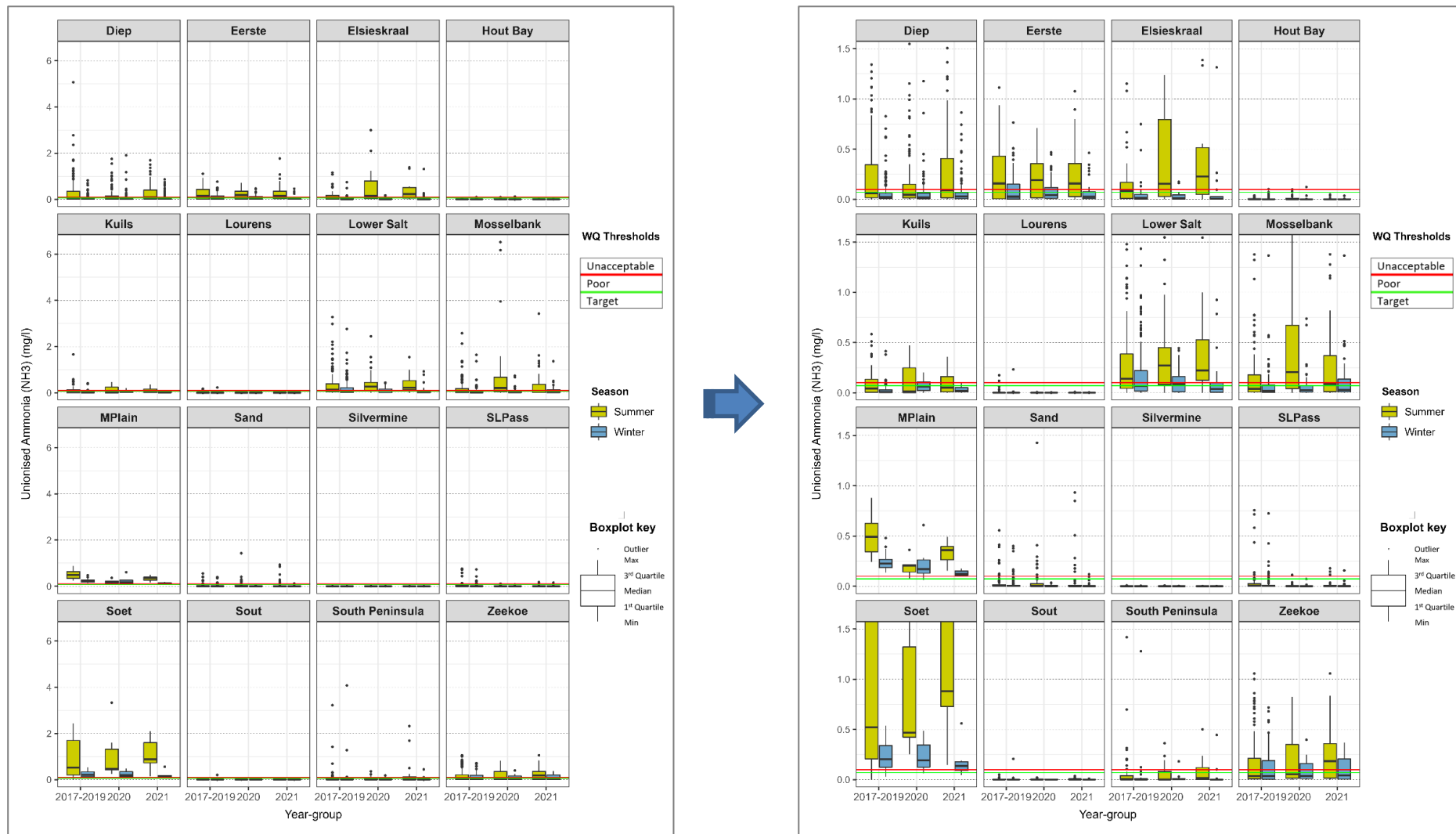


Figure 5.4.6

Comparison of un-ionised ammonia for flowing systems (rivers and stormwater channels) from the 2021 reporting period, with those from 2020 and the previous three years (2017 to 2019) combined. Data analysed as summer and winter datasets. Subcatchments as shown in Figure 2.1. Marked thresholds as per Table 3.2. Closer view (reduced y-axis) shown in right hand figure.



Figure 5.4.4

Comparison of un-ionised ammonia for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period, with those from 2020 and the previous three years (2017 to 2019) combined. Data analysed as summer and winter datasets. Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in right hand figure.

5.5 *Escherichia coli* as an indicator of sewage contamination

5.5.1 Relevance

Escherichia coli measurements are used primarily as an indicator of human health risk, particularly for drinking or recreational use of a waterbody. Consideration of this parameter is, therefore, of most relevance to Cape Town's established recreational vlei systems, where a range of watersports and/or other water-based activities are known to take place (i.e., Zandvlei, Zeekoevlei, Rietvlei, Milnerton Lagoon and Princessvlei) as well as the lower Kuils River, which is used by the Khayelitsha Canoe Club. This issue is dealt with extensively in Section 5.

The current section has however been included in this report to evaluate the potential recreational fitness-for-use of a broader array of rivers and vlei systems within Cape Town – not necessarily all major / established recreational waterbodies. The data referenced here also highlights point-source pollution into watercourses, where elevated *E. coli* is an indicator of contamination from untreated sewage, either from overflows from manholes or sewage pump stations, or from inflows from poorly serviced backyard or informal settlements with inadequate access to sewer networks.

Box 5.13

Escherichia coli (abbreviated *E. coli*) is a species of faecal coliform bacteria that is commonly found in the lower intestine of warm-blooded organisms (birds and mammals). Most *E. coli* strains are harmless, but some can cause serious food poisoning in humans. Their presence in the water is used as an 'indicator' of faecal contamination of avian or mammalian origin, and therefore are indicative of other pathogens that may be present in faeces.

5.5.2 Risk levels

The recreational risk ratings applied in the current assessment include *E. coli* thresholds for intermediate contact (e.g. canoeing, sailing), as explained in Section 3.7.2 (see **Table 3.4**). Ranges are provided for 'Target' (acceptable risk), 'Poor' (tolerable risk) and 'Unacceptable' (high risk). Although **Table 3.4** also provides for an additional two levels of 'Unacceptable', to aid in the identification of areas where there is extreme exceedance of the high-risk threshold for *E. coli*, these were not applied in this assessment. This was due to issues with reporting of *E. coli* data, making tighter determinations difficult over the 2020 reporting period (see Section 3.8.7). No reliable *E. coli* data were moreover available for the 2021 reporting period (again see Section 3.8.7).

5.5.3 Sources of sewage contamination based on *E. coli* data

Sources of sewage contamination in Cape Town's subcatchments include:

- Periodic sewer blockages and overflows that enter the stormwater system and thus pass into watercourses (**Photo 5.5.1**);
- Overflows from sewage pumpstations (or from low-lying manholes downstream of pump stations) as a result of blockages, pump station failure; and, increasingly in the 2021 reporting period and going forward, from load-shedding power outages;
- Contaminated stormwater runoff from poorly serviced informal settlements, where sewage is disposed of into canals and stormwater drains for want of alternative disposal options or because access to options to dispose of waste to sewers is unsafe (e.g. at night) or unhygienic (because of a build-up of solid waste and/or faecal waste) (**Photo 5.5.2**);
- Runoff from urban areas with high levels of homeless people without alternative waste disposal options;
- Inputs from wildlife (baboons and birds);
- Input from livestock (e.g. feedlots in agricultural areas in and draining into rivers or other watercourses);
- Runoff from pavements, parks etc. accessed by domestic animals (e.g. dogs), but this is likely to

be a relatively minor input in most areas.



Photo 5.5.1
Attending to a major sewage spill at the Cape Flats
WWTW in July 2021, when raw effluent entered
Zeekoevlei – a Ramsar wetland



Photo 5.5.2
Dry-season runoff of sewage-contaminated flows
from the Kleine Stink River, through the Dunoon
informal settlement (Diep subcatchment)

5.5.4 Frequency of sewage spills into Cape Town's subcatchments

The CCT keeps records of both pump station overflows and public reporting of sewage manhole overflows.

Of these, **pump station overflow data** have been captured so as to include the stormwater catchment in which each overflow occurred, with effect from July 2020 (CCT's 2020/2021 Financial Year). This is an important development in data capture, because it allows tracking of problematic catchments, as well as identification of problem pump stations that affect more sensitive watercourses (e.g. recreational vleis; Ramsar wetlands in the False Bay Nature Reserve; Zandvlei estuary; the Rietvlei saltmarshes; and Milnerton Lagoon). Data for the period July 2020 to October 2021 were available for this report and are summarised in **Figure 5.5.1**. It should be noted that these data do not correspond with any specific reporting water quality periods, and in fact overlap the 2020 and 2021 reporting periods. They are thus indicative only, although future Inland Water Quality reports should be able to access data that correspond with specific reporting periods. The data also include categorised reasons for pump overflows.

The data have been further categorised by the CCT in terms of the magnitude / impact significance of each spill incident, as shown in **Table 5.5.1**. The data in **Figure 5.5.1** suggest that:

- Subcatchments experiencing the highest number of pump station overflows comprises the Lower Salt, Zeekoe and Diep (in descending order), with all of these subcatchments receiving in excess of 25 overflows, of which between two and five events were classified as 'Major' events, defined in **Table 5.1** as 'uncontrollable and likely to drain to a local sensitive environment' and/or where the volume of sewage is high with regard to the volume and flow of the receiving waters or where the overflow reaches land or watercourses where public exposure risk will be high;
- The Mosselbank and Mitchell's Plain subcatchments were also exposed to major sewage overflows. The former drains into the Diep subcatchment, highlighting the extent of upstream exposure of the Milnerton Lagoon (Diep River estuary) to significant pollutant sources;
- Both the Kuils and the Sand subcatchments were also exposed to a number of sewage spills, of up to Moderate levels, and thus likely to have some impact on the downstream receiving environment and recreational user groups;
- Most pump station overflows in the period included in the dataset were the result of mechanical failure, mains supply faults, pump tripping and electrical failure. Stormwater ingress, clogging of pumps with foreign objects and ultrasonic (i.e., remote sensing) failure also contributed to

overflows. Load shedding accounted for 4.7% of the 327 listed incidents over this period, and theft for just 4.0%.

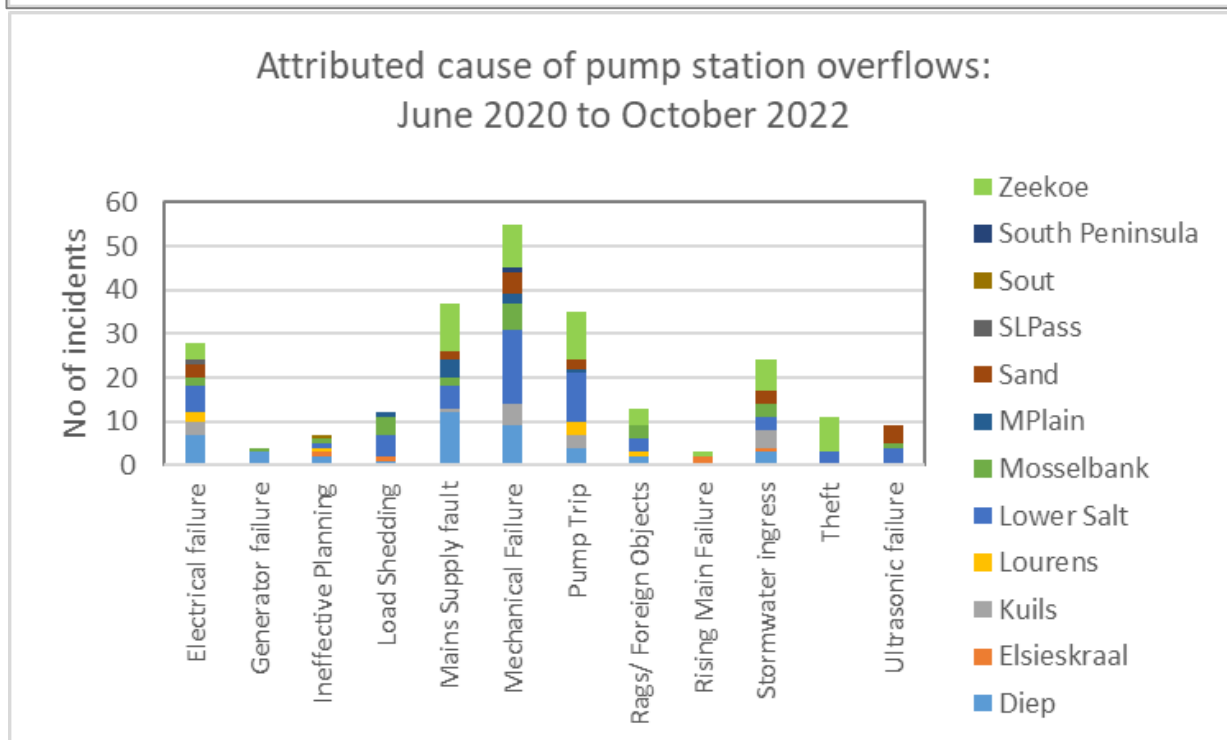
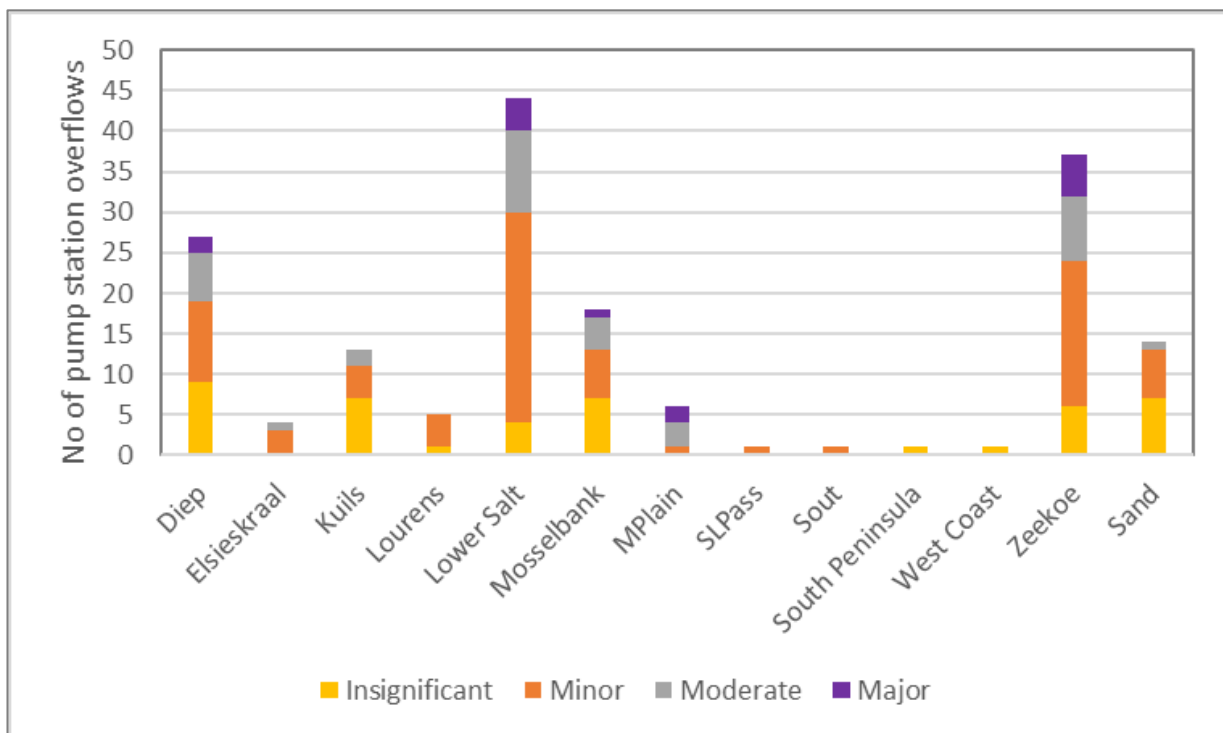


Figure 5.5.1

Number of reported pump station overflows in Cape Town's subcatchments. Data provided by the CCT for the period July 2020 to end of June 2021. Data categorised as per Table 5.5.1

Table 5.5.1
Classification of Sewage Pollution Incidents.
Classification supplied by the CCT

Level	Classification	Description
1	Minor (No reporting)	The overflow <u>is/will be contained and not drain</u> to a local sensitive environment* and/or - Where the overflow reaches waters, the volume of sewage likely to enter the waterway may be insignificantly small with regard to the volume and flow of receiving waters or, - Where the overflow reaches land, it is contained in an area where public exposure is minimal given the maximum response time**.
2	Moderate (Responsible Person to report internally Alarm report and IIR)	The overflow <u>may not be contained and/or could drain</u> to a local sensitive environment* and/or - Where the overflow reaches waters, the volume of sewage likely to enter the water way is insignificant with regard to the volume and flow of receiving waters, or - Where the overflow reaches land or watercourse, it may travel to an area where public exposure is low within the maximum response time**.
3	Major (Responsible Person to report internally & externally – alarm report and 14 days EIR)	The overflow <u>is uncontrollable and likely to drain</u> to a local sensitive environment* and/or - Where the overflow reaches waters, the volume of sewage likely to enter the waterway is high with regard to the volume and flow of the receiving waters, or - Where the overflow reaches land or watercourse, the public exposure risk will be high given the maximum response time**.
4	Catastrophic (Responsible Person to report internally & externally – alarm report and 14 days EIR)	The overflow <u>drains to</u> a local sensitive environment* and - Where the overflow discharges to waters, the volume of sewage entering the water is very high with regard to the volume and flow of receiving waters, or - Where the overflow discharges to land or watercourse, the public exposure risk is very high given the maximum response time**.

*A sensitive environment includes:

- A drinking water catchment or domestic groundwater source, or
- Protected waterbodies, ecological communities or conservation areas as defined by Local Government, National Conservation Authorities, or
- Waterways used for recreation (non-contact), or
- A recreational area or other area with high public exposure or associated health risk

**Maximum response time should be based on the length of time taken for the relevant official to detect the overflow or for the overflow to be reported, and the time taken for the relevant official to attend to the site and secure against public contact.

***Overflow = raw untreated overflow

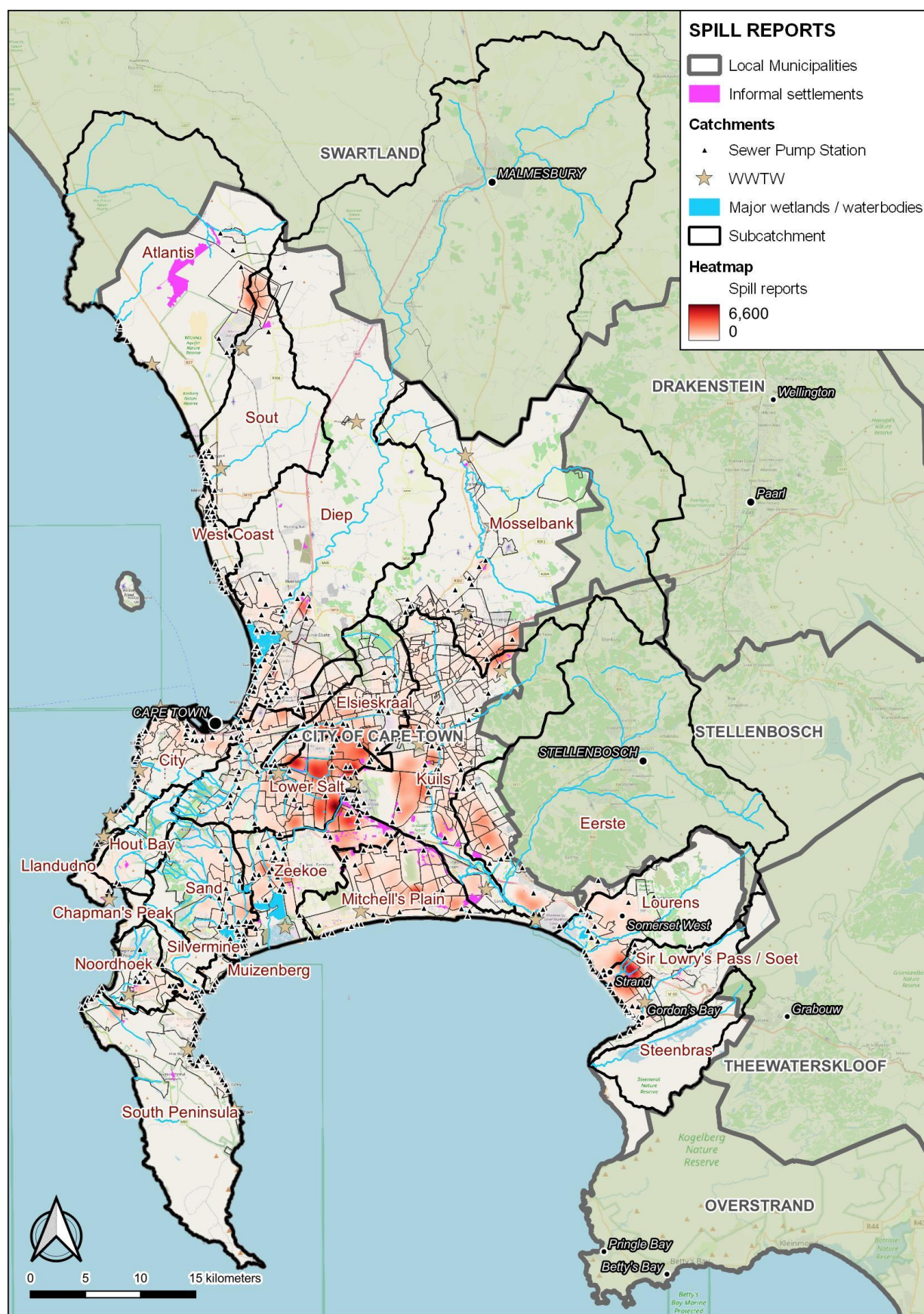


Figure 5.5.2

'Heat map' showing the number of C3 complaints filed for sewage spills in Cape Town over the 2020 and 2021 reporting periods (April 2020 to 31 March 2022).

Sorted C3 data provided in subcatchment format by Infinity Consulting

Another measure of sewage spill frequency in Cape Town is provided by records of reporting on sewage spills by members of the public. This is done on-line using the CCT's C3 reporting forms. **Figure 5.5.2** provides a coarse spatial overview of the distribution of C3 data for the period 1 April 2020 to 31 March 2022 (data sorted courtesy Infinity Consulting using City C3 data). The data are presented as a 'heat map', which shows the intensity of C3 reporting in different areas of Cape Town.

These data indicate that, over the 2020-2021 reporting periods:

- The hotspots for sewage overflows, based on reported incidents, lay in the Lower Salt subcatchment, with the Bonteheuvel, Ruytewacht, Kewtown and Manenberg areas being worst affected;
- Other significantly affected subcatchments included:
 - The Zeekoe subcatchment – with particularly problematic areas in the Manenberg, Crossroads / Gugulethu areas; and (seemingly to a lesser reported extent) in the area immediately downstream of Gugulethu; along the Woodlands canal; and in the Parklands and Grassy Park areas;
 - The Kuils River, in its Delft and Rotterdam areas
 - The Eerste River in its Faure and Macassar areas
 - The Mosselbank in the Wallacedene and Belmont Park areas
 - The Diep River in the Dunoon area
 - Mitchell's Plain subcatchment in the Portland Park area
 - The Soet River portion of the Sir Lowry's Pass / Soet subcatchment.

Of the above, most of these are areas with high levels of informal settlement and/or backyard dwellings and the subcatchments themselves are characterised by an accumulation of solid waste that is likely to contribute to the frequency of sewer blockage, along with an increased likelihood of vandalism of sewers and pump stations as a result of a range of socio-economic and other issues.

A caveat to the data presented in **Figure 5.5.2** is however that the original data source does not indicate volumes of sewage spilled or overflowing, or the time over which the spill occurred before being addressed. In addition, the data reflect only areas in which sewage spills were reported – in some areas, residents might be more vigilant in reporting problems than in others, and some reports might also reflect relatively short-lived incidents versus major spills. In addition, repeat-reports of the same incident are also likely to cloud the data.

5.5.5 Assessment of available *E. coli* data

Figures 5.5.3 and **5.5.4** present the results of analyses of samples from routine water quality monitoring points in rivers/ stormwater channels and standing water systems (vleis / detention ponds etc.) respectively. The data are compared over the 2017-2019 and 2020 reporting periods only. Data from the 2021 reporting period have been excluded, as a result of analytical irregularities, discussed in Section 3.8.7.

The data suggest that (for the limited data period available):

- For **rivers / flowing water systems**:
 - Only 46% of monitored water courses fell within the Target range for *E. coli* over the 2020 monitoring period;
 - 48% of monitored water courses fell within the Unacceptable range for *E. coli* over the 2020 monitoring period – this was the same percentage as for the 2017-2019 monitoring period and reflects very poor city-wide compliance with water quality objectives;
 - While the above may not be problematic from a human health perspective, in that Cape Town's rivers are not overtly managed for recreational use, the fact remains that some **are** used on a recreational basis (e.g. Kuils River past the Khayelitsha canoeing club and the Milnerton Lagoon) and these data show very low overall levels of compliance with basic human health standards – this issue is accentuated in a society where there are in

fact much higher levels of human usage of these waterbodies than is implied in the water quality thresholds;

- The subcatchments that showed the lowest levels of compliance with regard to *E. coli* thresholds were the Soet and Lower Salt subcatchments, with the latter showing some deterioration over the 2020 monitoring period compared to the 2017-2019 period, with 100% of water samples falling within the Unacceptable range;
- Of the remaining subcatchments, the following showed some **improvement** in levels and frequency of *E. coli* contamination over the 2020 reporting period compared to the previous three years:
 - The Mosselbank
 - The Lower Salt
 - The Sir Lowry's Pass
 - The Kuils and Eerste
 - The Sout and
 - The Sand.
- By contrast, the following subcatchments showed a **deterioration** (i.e., an increase) in concentrations and an increase in the frequency of *E. coli* contamination over the 2020 reporting period:
 - Hout Bay
 - Silvermine
 - South Peninsula
 - Diep River
 - Lourens River

For rivers receiving effluent from treated WWTWs, elevated *E. coli* counts could also be linked to poor effluent quality. Potsdam WWTW, for example, achieved only 9% in the 2021 Green Drop Report of DWS (2021), despite the WWTW achieving an overall Green Drop score of 90-89%.

In many of the cases of deteriorating river condition, the main issue lies in just a few sites (e.g. lower reaches of Hout Bay and Silvermine Rivers) rather than throughout the river systems.

- **For standing water systems (vleis, dams, detention ponds)**, shown in **Figures 5.1.2** and **5.1.4**, the data suggest that, for the limited period of reliable data that can be drawn on here:
 - *Escherichia coli* bacteria were generally measured at lower concentrations than in flowing water systems, with over 80% of standing waterbodies lying within the Acceptable risk range for this variable, compared with < 45% in the case of monitored rivers / stormwater channels – this largely reflects the effect of increased retention time in monitored vleis and dams, with *E. coli* being impacted by prolonged exposure to sunlight in near-standing water conditions, as well as the effect of dilution with passage into large water bodies. Lower *E. coli* levels do not necessarily indicate reduced sewage exposure in these systems;
 - Standing water systems that were least impacted by *E. coli* contamination, and in fact showed improvement (to 100% Target compliance) compared with data from the 2017-2019 reporting periods, comprised Rondevlei; Die Oog; Glencairnvlei; and Princessvlei;
 - Other waterbodies that showed improvement in compliance with Target conditions, albeit not to 100% compliance, were Rietvlei; Zoarvlei; Langevlei; Wildevoelvlei; and the Elsieskraal dams;
 - The frequency and magnitude of contamination of Zeekoevlei increased slightly over the 2020 reporting period – this vlei was also affected by repeated sewage inflows from both the upstream Big Lotus River and the adjacent WWTW over the following (2021) reporting period (thus not reflected in *E. coli* monitoring data);
 - Contamination of both the Westlake wetlands and Zandvlei also increased significantly over the 2020 monitoring period, with Zandvlei Target compliance levels dropping from

- >90% in the 2017-2019 reporting period to 72% in the 2020 period, reflecting a high frequency of overflows from problem pump stations or overflowing manholes in the catchment;
- o Finally, the available data show that water quality in the Mew Way and Mitchell's Plain detention ponds was always in the Unacceptable category over the assessed period – and the reporting of *E. coli* data by SSB using '>' notation (see Section 3.8.7) means that it is difficult to unpack whether these highly polluted systems deteriorated or improved in water quality over the assessed periods;
 - o The Mew Way and Mitchell's Plain detention ponds were the worst performing in the CCT's routinely monitored standing water systems and reflect upstream catchments with high levels of raw sewage inflows.

5.5.6 CCT's *E. coli* targets

In the case of *E. coli* data, the CCT has set itself a 'target' that at least 60% of samples in any catchment should meet the defined Acceptable thresholds of $\leq$ cfu /100 ml (as per **Table 3.4**). *Escherichia coli* compliance graphs thus also show this 60% threshold as a dotted line across the data. The rationale for an additional 'target' for meeting minimum Acceptable standards from a human health perspective is, however, questioned in this report. The Target values, as defined in Table 3.4, indicate *E. coli* counts that would be considered 'safe' or of low / acceptable risk for uses engaging in intermediate contact recreational activities only – that is, with assumed low exposure to sewage-associated contaminants in the waterbody. In practice, many waterbody users engaging in these relatively 'safe' activities are in fact already exposed to a greater degree of risk than what is implied by 'intermediate' recreational exposure. Sailing, rowing, kayaking, and kite-surfing, for example, are all popular sports engaged in within Cape Town's inland recreational waterbodies. These all in fact expose participants to full immersion at times in the waterbodies.

The CCT's 60% target for meeting Acceptable risk levels seems counter-productive in this regard – **and a target of 100% for meeting Acceptable standards in Cape Town's recreational waterbodies would be a strongly recommended way forward.**

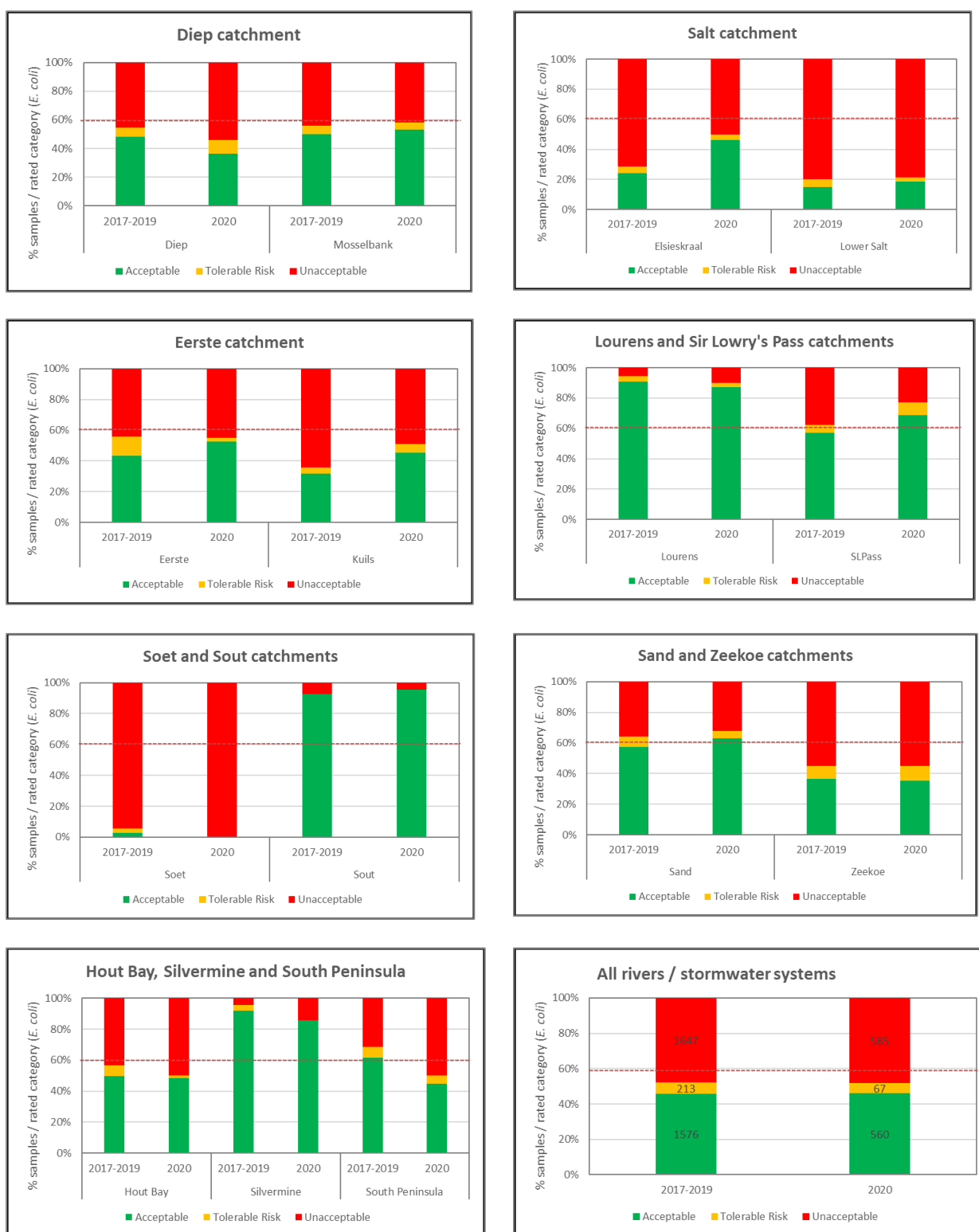


Figure 5.5.3

Percentage of *Escherichia coli* samples falling within each rated category for this variable, per subcatchment.

Thresholds for rated categories as defined in Table 3.4. Data for river / 'flowing' water monitoring points in each subcatchment. Subcatchments as shown in Figure 2.1. Total number of samples considered shown in bars in bottom right plot ('All rivers / stormwater systems').

Dotted red line indicates City's '60% Target' for meeting *E. coli* targets.

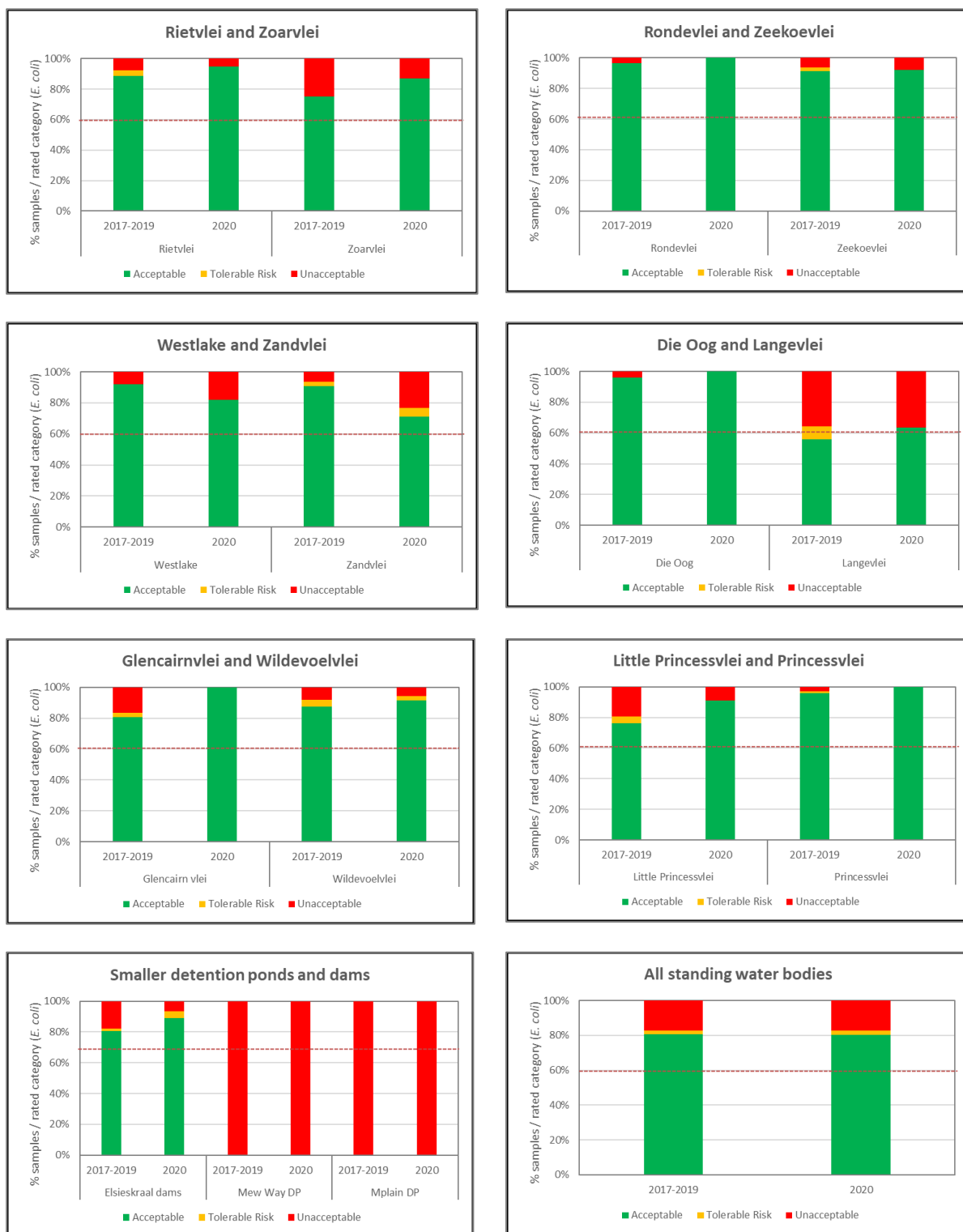


Figure 5.5.4

Percentage of *Escherichia coli* samples falling within each rated category for this variable. Thresholds for rated categories as defined in Table 3.4. Data for sample points in standing waterbodies / vleis and detention ponds. Total number of samples considered shown in bars in bottom right plot ('All standing waterbodies')

5.5.7 Intestinal enterococci data

The 2020 Inland Water Quality report recommended that intestinal enterococci should be monitored in inland waterbodies. This was based on a recommendation in WHO (2003) and is reiterated in WHO (2021). Although the SSB has now commenced intestinal enterococci monitoring, it is carried out on samples from only a few standing water monitoring bodies (Rietvlei and Milnerton lagoon (Diep subcatchment), Zeekoevlei (Zeekoe subcatchment), Zandvlei and Princessvlei (Sand subcatchment) and the monitored Michell's Plain detention ponds, as shown in **Figure 5.5.5**.

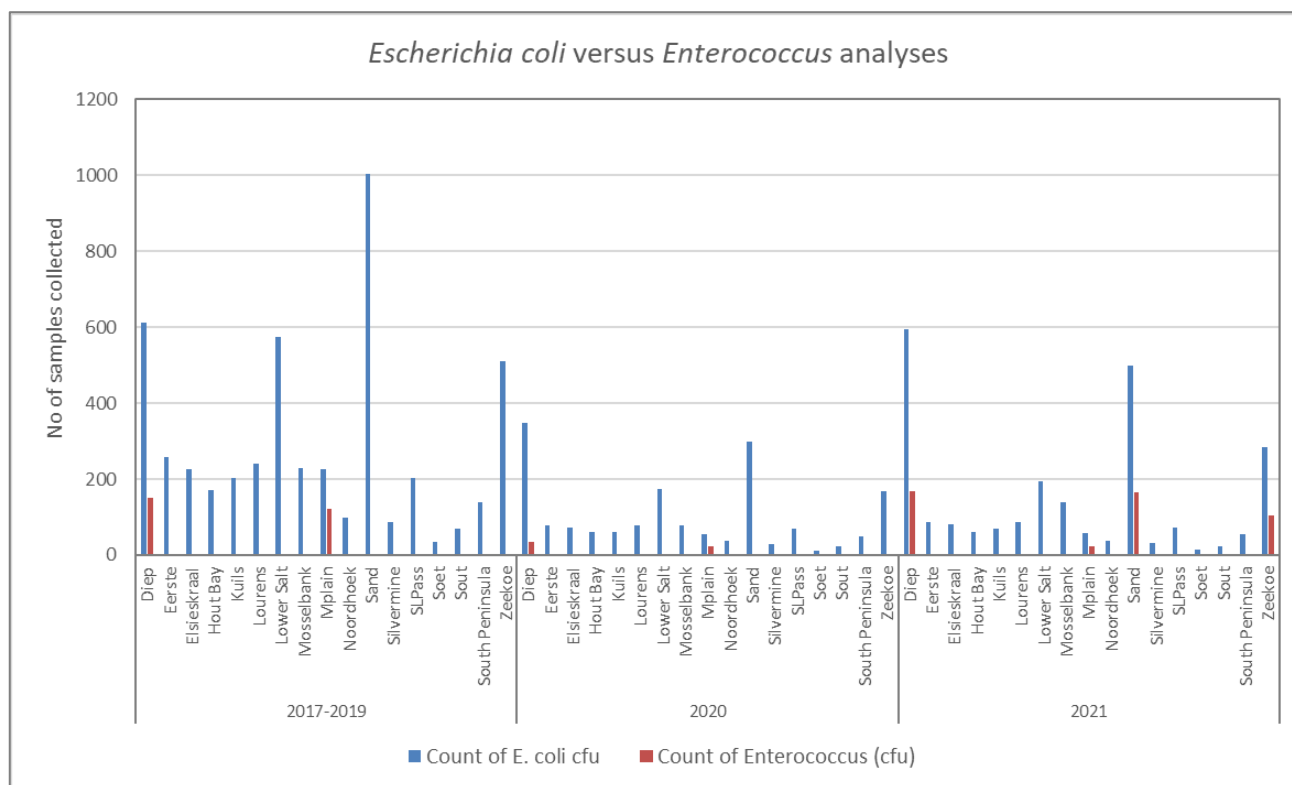


Figure 5.5.5

Frequency of measurements of *Enterococcus* and *E. coli* from samples in different subcatchments

Since the 2020 Inland water quality report, WHO (2021) have further recommended monitoring of intestinal enterococci only, rather than intestinal enterococci and/or *E. coli*, on the basis that no statistical relationship has been established for *E. coli* that can support a dose-response guideline value.

E. coli data do however still provide evidence of sewage leakage issues in the broader catchments, rather than simply being useful as indicators for human recreational safety.

5.5.8 Key take-away points from assessment of *E. coli* data and other indicators of sewage contamination

- Contamination of the city's rivers and stormwater channels by raw sewage is rife, with 48% of river samples falling within the Unacceptable range for *E. coli* over the 2020 monitoring period – this was the same percentage as for the 2017-2019 monitoring period and reflects very poor long-term city-wide compliance with water quality objectives;
- Some of the affected systems are used for recreational purposes and in many of the poorest areas of the city, rivers and wetlands are used as play areas by many children;
- The most polluted subcatchments comprised the Soet and Lower Salt subcatchments, and these subcatchments should form the subject of intensive pollution abatement efforts by the CCT, focusing on both solid waste removal and the diversion and acceptable disposal of raw sewage before it enters watercourses;

- Only 46% of monitored water courses fell within the Target range for *E. coli* over the 2020 monitoring period;
- The main sources of raw sewage seem to have comprised overflows from pump stations or low-lying manholes and disposal of sewage into stormwater drains or open channels in unserved informal settlements;
- Pump station overflows appear to have been most numerous in the Lower Salt, Zeekoe and Diep subcatchments, all of which received, in addition to frequent minor spills, between two and five major events, deemed likely to have resulted in significant pollution to sensitive receiving environments. Most pump station overflows in the period included in the dataset were the result of mechanical failure, mains supply faults, pump tripping and electrical failure;
- Data for C3 reporting on sewage spills provided another estimate of areas most subject to sewage overflows. The areas mapped as 'hot spots' on this basis were mostly characterised by high levels of informal settlement and/or backyard dwellings, and accumulations of solid waste on street and along channels – this could contribute to the frequency of sewer blockage, along with an increased likelihood of vandalism of sewers and pump stations as a result of a range of socio-economic and other issues;
- While data show that the city's river and stormwater systems were often polluted with raw sewage, *E. coli* bacteria were generally present in much lower concentrations in most monitored standing waterbodies (e.g. vleis and dams), with over 80% of standing waterbodies lying within the Acceptable risk range for this variable – this does however reflect the effect of increased detention time in allowing *E. coli* die-off monitored vleis and dams, and does not necessarily indicate reduced sewage exposure in these systems;
- No reliable *E. coli* data were available for the 2021 reporting period – this is a significant gap in reporting history. However, on the basis of C3 data and pump station failure counts, it is evident that raw sewage overflows continued to be a major issue in the 2021 reporting year, and it is moreover known that vleis such as Zeekoevlei, Zandvlei, Milnerton lagoon and the Big Lotus River were among those systems known to have received large volumes of untreated sewage effluent at times (e.g. Day et al., 2022 and Rose et al., 2023). These are assumed to have contributed to ecosystem degradation (e.g. Day et al., 2022);
- This project team recommends (as previously for the 2020 Inland Water Quality Report) that the CCT should migrate its human health monitoring systems to intestinal enterococci monitoring, at least in the main recreational bodies in line with global monitoring approaches and as recommended by WHO (2021);
- In order to improve confidence in *E. coli* monitoring data, it is recommended that SSB submit replicate samples for 10% of water samples to at least three independent accredited laboratories, for analysis over the next 6 months, to show that the data lie within the same general range, noting that differences between laboratories would be expected.

5.6 Electrical conductivity of vleis in relation to Gazetted Resource Quality Objectives

In November 2020, a Notice was published by the national Department of Water and Sanitation relating to 'Determination of Classes of Water Resource and associated Resource Quality Objectives for the Berg Catchment' (Government Notice No. 1179 in *Government Gazette* No. 43872 of 6 November 2020). This Notice contains RQOs for prioritised (water) Resource Units within the study area, including rivers, estuaries, dams, and groundwater, but excluding inland wetlands and standing waterbodies. The following vleis within the City were delineated as estuaries, as they fall within the legislated Estuarine Functional Zone (EFZ) defined to include the 'area below the 5 m topographical contour (referenced from the indicative mean sea level)' (as explained in the 'RQOs and Estuaries' in **Box 3.4** in **Section 3.5**):

- Milnerton Lagoon and Rietvlei (both delineated to form part of the 'Rietvlei/Diep Estuary')
- Wildevoelvlei
- Zandvlei
- Zeekoevlei and Rondevlei (both delineated to form part of the 'Zeekoevlei Estuary').

Through the water resource classification study for the Berg Catchment, Estuarine RQOs were set for the above four estuaries, which comprise six of the vlei systems distinguished in the current report. Of these, Rietvlei, Rondevlei and Zeekoevlei do not however have any present estuarine function, although they lie within the EFZ. Van Niekerk *et al.* (2020) define an estuary as an area that is subject to tidal action, salinity penetration or back-flooding under closed mouth conditions. This aligns with the legal definition of an estuary in terms of the National Environmental Management: Integrated Coastal Management Act (Act No. 24 of 2008), whereby an estuary is '*a body of surface water— a) that is permanently or periodically open to the sea; b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the body of surface water is open to the sea; or in respect of which the salinity is higher than fresh water as a result of the influence of the sea, and where there is a salinity gradient between the tidal reach and the mouth of the body of surface water.*'

Salinity was one of the parameters for which Estuarine RQOs were set for the above systems (see **Table 5.6.1**). In the analysis undertaken for the current report, the salinity values (in dimensionless Practical Salinity Units) were converted to EC values (in mS/m) to allow for a comparison with the data collected from these systems by the CCT. The conversion was done by making use of an online 'salinity unit calculator' (<https://reefapp.net/en/salinity-calculator>), which applies algorithms based on UNESCO (1983).

Table 5.6.1
Salinity RQOs for estuaries in the City from the Berg Catchment water resource classification study

Estuary name	Vlei name/s	Salinity RQOs		Derived EC RQOs	
		Average	Max	Average	Max
Rietvlei/Diep	Milnerton Lagoon	>20	<35	>3210 mS/m	<5310 mS/m
	Rietvlei				
Wildevoelvlei	Wildevoelvlei	>2	n/a	>380 mS/m	n/a
Zandvlei	Zandvlei	>15	<35	>2470 mS/m	<5310 mS/m
Zeekoevlei	Zeekoevlei	>10	<35	>1700 mS/m	<5310 mS/m
	Rondevlei				

The boxplots in **Figures 5.6.1 and 5.6.2** provide a statistical summary of the EC data for the above-mentioned vlei systems by reporting period in relation to the average and maximum salinity/EC thresholds that have been Gazetted as Estuarine RQOs through the water resource classification study for the Berg Catchment. These plots show that:

- EC never exceeded the maximum RQO threshold of 5310 mS/m (equivalent to a salinity of 35) in any of the systems during the full 2017-2021 reporting period, indicating that hypersalinity is not a problem in any of them;
- In the case of the Milnerton Lagoon portion of the Diep/Rietvlei Estuary, for all three reporting periods the median EC (ranging between 500 and 1000 mS/m) was well below the minimum required threshold for average salinity in this system should remain above according to the relevant RQO (i.e., 3210 mS/m), and the third quartile for all three reporting periods was also below the target EC of the RQO. The upper limit of the range of recorded EC values did, however, extend above the RQO target for average salinity in Reporting Years 2020 and 2021, implying limited compliance with the RQO at times during these years (but not during the 2017-2019 reporting period). As Milnerton Lagoon (i.e., the section of the Lower Diep River below Otto Du Plessis Drive) remains a functional estuarine system, these results suggest that there may be a 'freshening' of the estuary, partly due to significant non-saline inflows from the Potsdam WWTW and stormwater runoff;
- In the case of the Rietvlei portion of the Diep/Rietvlei Estuary, it is not clear whether this vlei system formed part of what was referred to as 'the lower estuary (Milnerton lagoon)' in the RQOs. From the relevant plot in **Figure 5.6.1** (middle panel), it is clear that this is an inland water system with salinity/EC values that were consistently way below the lower salinity threshold of the Estuary RQO during all three reporting periods. It is interesting to note, however, that the median EC for this vlei system (400-500 mS/m for the three reporting periods) was similar to that for Milnerton Lagoon and that the first quartile and the lower limit of the range for EC values recorded in Rietvlei was *higher* than that for Milnerton Lagoon in all three reporting periods, highlighting the periodic problem of significant 'freshening' of Milnerton Lagoon, presumably related to stormwater and WWTW inflows;
- Zandvlei (bottom panel in **Figure 5.6.1**) shows good compliance with the Estuarine RQOs for salinity/EC in all three reporting years, with all recorded values below the maximum threshold (salinity of 35) and the median for each reporting period (EC of 2200-3000 mS/m) being close to the average salinity lower threshold that was set for this system (2470 mS/m). These results confirm that Zandvlei is functioning like a true estuary and the Estuarine RQOs for salinity are, therefore, applicable;
- The median EC value ranged between 140 and 150 mS/m for Wildevoelvlei, and between 90 and 150 mS/m for Zeekoevlei and Rondevlei in all three reporting years, while the upper limit of the inter-quartile range and, in most cases, the full range of EC values in all three of these systems did not exceed 250 mS/m in any of the reporting periods considered (see **Figure 5.6.2**). Although the EC values recorded in Wildevoelvlei are closer to the average salinity lower RQO threshold that was set for this system (380 mS/m), which is significantly less than the threshold that was set for Zeekoevlei and Rondevlei (1700 mS/m), the Estuarine RQO thresholds for salinity far exceed the range of EC values typically measured in all three of these systems. These results suggest that none of these inland water systems are influenced by saline intrusion from a connection to the sea, especially in the case of Zeekoevlei and Rondevlei. None of these three systems are influenced by tidal fluctuations either, so they are not true estuaries, rendering evaluation against the Gazetted Estuarine RQOs for salinity a meaningless exercise because the specified objectives are not relevant;
- On this basis it is recommended that the only vlei systems in the City that should be evaluated against the Gazetted Estuarine RQOs for salinity and other estuarine variables, as part of the ongoing monitoring of water quality, are Milnerton Lagoon (excluding Rietvlei) and Zandvlei because these are the only currently functional estuarine systems;
- It is noted that the 2020 Estuary Management Plan for the Diep River Estuary confirms that estuary water quality RQOs should be applicable only to the Milnerton Lagoon downstream of Otto Du Plessis Drive (CCT and Infinity 2021).

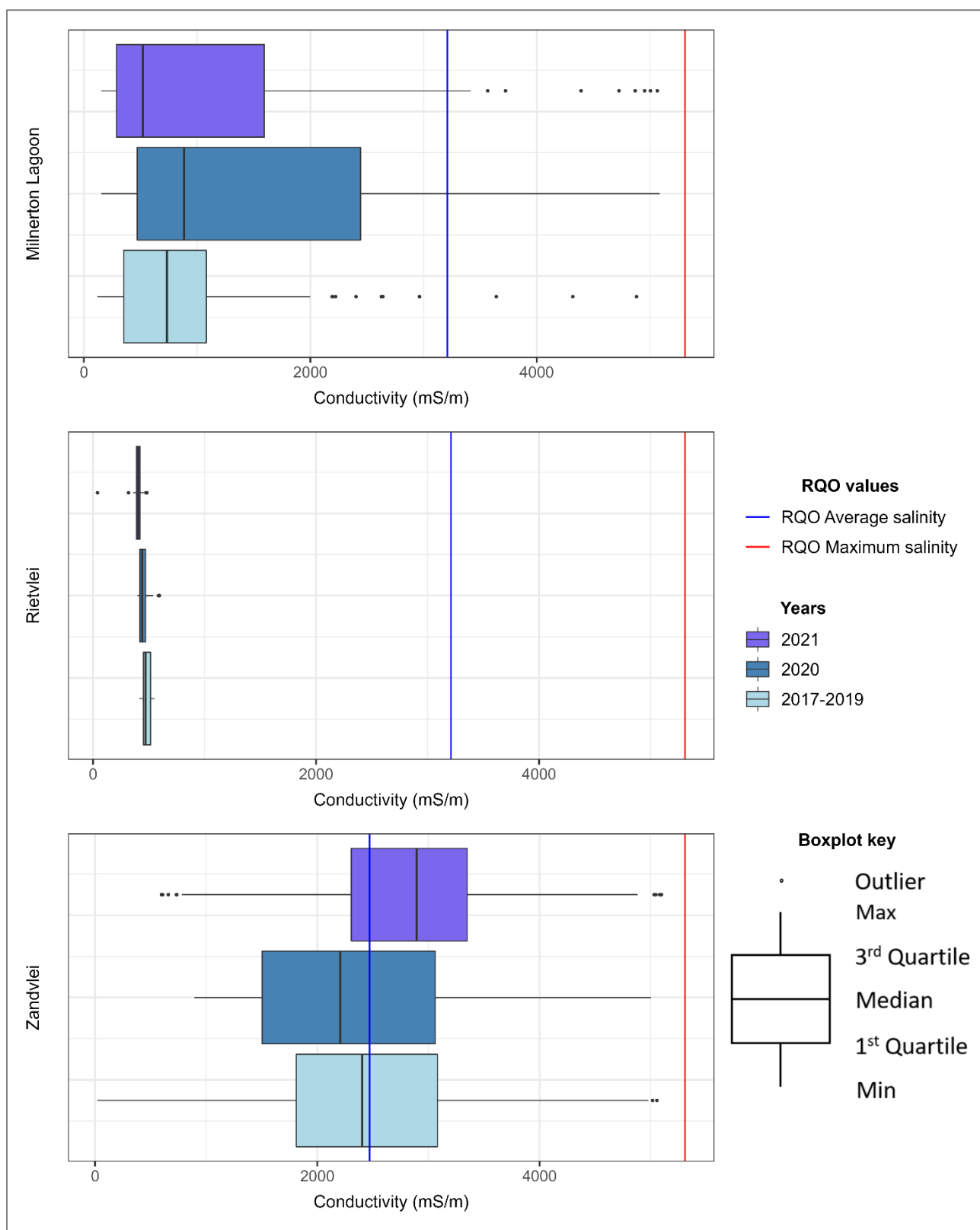


Figure 5.6.1

Comparison of electrical conductivity in Milnerton Lagoon, Rietvlei and Zandvlei from the 2021 reporting period, with those from 2020 and the previous three years (2017 to 2019) combined. Marked salinity thresholds from the Gazetted Estuarine RQOs.

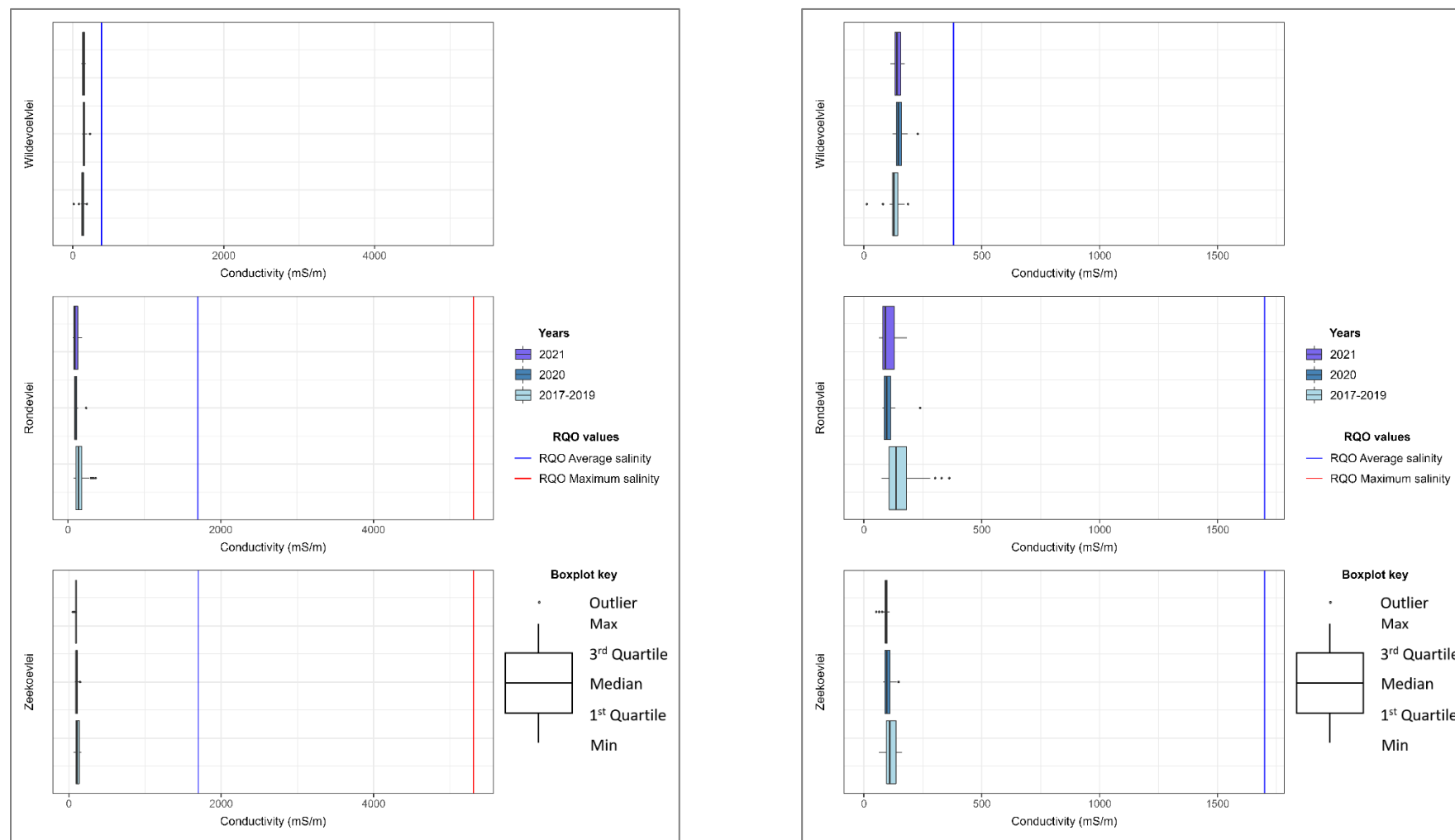


Figure 5.6.2

Comparison of electrical conductivity in Wildevleivlei, Zeekoevlei and Rondevlei from the 2021 reporting period, with those from 2020 and the previous three years (2017 to 2019) combined. Marked salinity thresholds from the gazetted Estuarine RQOs. Closer view (reduced y-axis) shown in right hand figure.

6 CURRENT STATE OF CAPE TOWN'S RECREATIONAL WATERS

6.1 Background

This section has been included to deal specifically with the current state of Cape Town's established recreational waterbodies from the perspective of the risk, if any, that they pose to human health. Five main waterbodies have been considered (as identified in consultation with the CCT):

- Rietvlei
- Milnerton Lagoon
- Princessvlei
- Zeekoevlei
- Zandvlei.

With the exception of Princessvlei, these vleis and estuaries are used for various water sport activities, including sailing, kayaking, canoeing, fishing, kite-boarding, skiing, wind-surfing, rowing, and fishing. All of these activities expose users to some level of health risk if water quality is compromised.

Princessvlei is not used recreationally. It is however used periodically for baptism ceremonies, requiring full immersion.

6.2 Human health risk thresholds

The data presented here have been assessed with regard to the rated water quality thresholds presented in **Tables 3.4-3.6**.

It is however noted that the CCT does not purport to manage any of its inland waterbodies for full contact recreation, but rather sets 'Target', 'Tolerable Risk' and 'Unacceptable' thresholds, based on risks posed by intermediate contact only (CCT 2023a).

6.3 Data used to assess risks to human health

Available water quality data for all of the above waterbodies have already been analysed and broadly discussed in Section 5 of this report. That section includes both compliance assessments (i.e., the proportion of data falling within the different rated categories (Target, Poor or Unacceptable)) and summary statistical data (median, range and inter-quartile spread), presented as boxplots.

These data indicate that of the above waterbodies, all have been impacted by high levels of phosphate enrichment, high total ammonia with at times elevated free ammonia at levels of concern and low DO at least at times. Zeekoevlei and Rietvlei were most impacted by phosphate enrichment, with almost all samples collected lying in the Unacceptable range for this variable.

The present section considers only those variables that relate directly to human health, rather than to ecosystem condition. These comprise indicators of sewage contamination (i.e., *E. coli* and enterococci data) and data reflecting concentrations of toxins associated with blue-green algal blooms (i.e. microcystin concentrations).

What is intermediate contact recreational use?

CCT (2023) defines this as 'All forms of water based recreation but excluding full-body water contact activities such as swimming or diving. Intermediate contact activities may involve a high degree of water contact, such as water skiing, wind surfing and canoeing'. DEA (2012) does not distinguish between full contact and intermediate contact uses, but notes that exposure (and therefore risk) differs between activities.

Full-immersion baptism is short-term, and once-off, but nevertheless is arguably a full-contact use, rather than an intermediate contact use (see DWAF 1996). The CCT does not endorse full-contact use of its inland waterbodies,

6.4 Indicators of sewage contamination

6.4.1 *Escherichia coli*

6.4.1.1 Background

Escherichia coli (abbreviated *E. coli*) is a species of faecal coliform bacteria that is commonly found in the lower intestine of warm-blooded organisms (birds and mammals). It is generally present in greater numbers than intestinal enterococci in fresh excreta (WHO 2021). Most *E. coli* strains are harmless, but some (generally < 1%) can cause significant diarrhoea and other illness (WHO 2021). The presence of *E. coli* in water is used as an indicator of faecal contamination of avian or mammalian origin, and therefore is indicative of other pathogens that may also be present in faeces. These include other bacteria, nematode cysts and viruses.

See Section 5.5 for *E. coli* data in the CCT waterbodies as a whole and for discussion around issues with *E. coli* analysis and reporting.

6.4.1.2 *E. coli* data and recreational vlei closures

During the 2021 reporting period, *E. coli* data were compromised, and have been excluded from assessment in this report (see Section 5.5). On the basis of these compromised data, Zandvlei, Zeekoevlei and Rietvlei were however closed for recreational use over extended periods in the 2021 reporting year.

These vlei closures had in some cases profound economic and social implications for users of these waterbodies, including loss of training facilities (which affected local, previously disadvantaged athletes in particular, with no alternative venues to turn to (e.g. Grassy Park Rowing Club, operating from Zeekoevlei); and income for sports clubs and their associated service providers, including small-scale catering service vendors and other service industries (e.g. boat repair and servicing companies).

6.4.1.3 *E. coli* data for recreational waterbodies

Figure 6.1 presents the results of *E. coli* analyses for water samples from the recreational waterbodies outlined in Section 6.1. These data were available only for reporting periods 2017-2019 and 2020. The *E. coli* data have already been presented in Section 5.5, along with data for other open waterbodies and rivers.

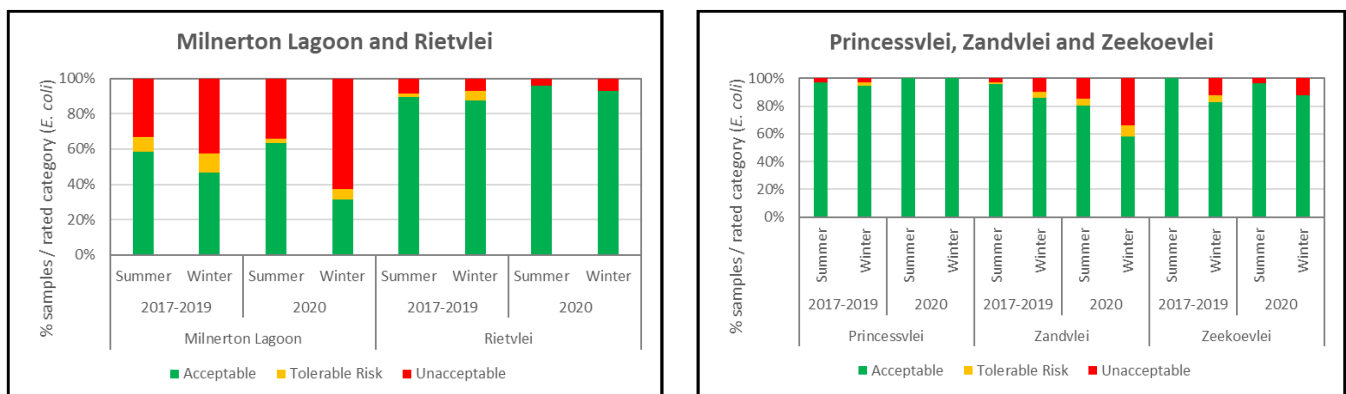


Figure 6.1

Percentage of *E. coli* samples falling within each rated category for this variable for each recreational waterbody

The data in the above figure are presented as compliance graphs, showing separate summer and winter samples. The data show that:

- Faecal contamination tended to be greater in winter than summer, with all assessed recreational bodies showing fewer samples within the Target range for *E. coli* in winter than in summer. To some extent this is assumed to reflect surface wash-off from contaminated terrestrial areas during rainfall events, with runoff from informal settlements in particular often flushing out accumulated waste in channels and drains (e.g. ICE 2009). However, a more common cause of elevated *E. coli* in winter stems from sewer and pump station overflows and surcharges, which are all more likely in the wet season, when many sewers have

excess stormwater ingress;

- Milnerton Lagoon was the worst-performing of the recreational waterbodies, showing a marked increase in samples rated as Unacceptable in winter 2020 (over 60%). The lagoon receives water from a problematic upstream catchment. During summer, almost all of its flows stem from the Potsdam WWTW and (to a much lesser degree) contaminated dry-weather flows of stormwater from informal settlements, mainly in the Joe Slovo area. The latter pass into the lagoon via the Erica Road stormwater outlet, in the upper reaches of the lagoon. During the winter, and following heavy rainfall events, the lagoon also receives flows from the (generally seasonal) Diep River upstream of Blauwberg Road. Extensive informal settlement has been established in the Diep River 1:100 year floodplain between Malibongwe Drive and the railway bridge, and during rainfall events, polluted water is flushed into the river from these areas (e.g. ICE 2009 and Rose et al. 2023);
- **Section 5.5.4** indicates that the Dunoon area of the Lower Diep subcatchment was also a hotspot for reported sewage overflows, and the Lower Diep had the third highest number of reported pump station failures for the period July 2020 to end of June 2021, including at least two major ones (see **Figure 5.5.1**). Known problem pump stations at that time included the Koeberg Road pump station, just south-east of the WWTW and the Table View West pump station (comment from Mr B. De Wet, Catchment Planner, Central Region);
- Geometric means for *E. coli* data in Milnerton Lagoon as a whole in the 2020 reporting period were 3064 cfu/100 ml, with data per site comprising 7 115 cfu/100 ml at RTV18 (just downstream of the Erica Road outlet); 3 585 cfu/100 ml (at RTV09 at Woodbridge Island bridge); and 5 122 cfu/100 ml near the mouth (all units cfu/100 ml) (see **Table C3** in **Appendix C**). These values all lie well within the CCT's Unacceptable range for *E. coli*;
- Zandvlei also showed an increase in periods of Unacceptable levels of *E. coli* contamination in 2020, in both summer and winter, with 15% and 35% respectively of samples collected in summer and winter of reporting period 2020 being Unacceptable from a human health perspective. These data again most likely reflect an increased frequency of pump station overflows during that period, since the subcatchment has relatively limited areas of unserved informal settlement;
- The other vleis were all subject to periodic sewage contamination that resulted in Unacceptable levels of *E. coli*. These amounted to some 12% of samples in Zeekoevlei, in both the 2017-2019 and the 2020 reporting periods and less than 10% of samples in the other recreational waterbodies. Zeekoevlei is however routinely closed to most recreational use for most of the wet season in any case, as a result of annual draw-down of its water for management purposes;
- Water quality improved in Princessvlei over the 2020 reporting period, with 100% of samples being within Target range.

Reliable *E. coli* data were not available to allow interpretation of the state of any of the recreational vleis over the 2021 reporting period. Nevertheless, a number of severe sewage overflows did occur in the catchments of all of the vleis over that reporting period (see Section 5.5.4), and faecal contamination and its associated risks would have been likely at times in this period.

Enterococci data are considered for the 2021 reporting period, in Section 6.4.3.

6.4.2 *E. coli* by site

In order to provide some spatial information about *E. coli* concentrations in different parts of the main recreational vleis, geometric mean *E. coli* data for the 2020 reporting period have been colour coded, using the **Table 3.4** threshold data as a guide, and plotted as individual monitoring sites in **Figures 6.2** and **6.3**, which show Zandvlei, Zeekoevlei and Princessvlei; and Rietvlei and Milnerton Lagoon respectively.

These data highlight what the compliance data have already indicated, namely:

- During the 2020 reporting period, all sampling points showed mean annual *E. coli* levels within Target values for this variable in the main waterbodies of Zandvlei and Princessvlei, although sample points in the canals leading into both vleis showed highly polluted flows (Unacceptable);
- Zandvlei data showed generally Acceptable conditions, but indicated significant deterioration

compared to the 2017-2019 period;

- Zeekoevlei's internal sample points were all within Target range over this period, with the exception of site ZEV2S, located close to the mouth of the Lotus River. Given that both the Big and the Little Lotus River downstream channel sites were rated Unacceptable over this period, the elevated Poor rating at ZEV2S suggests that water quality is probably contaminated on a long-term basis close to the river mouths, after which *E. coli* levels reduce, both as a result of dilution in a large water body, and exposure to sunlight. The nutrients and some of the other pathogens associated with sewage inflows would however be retained in the system;
- Monitored sample points in Rietvlei were all rated as within Target range – but the upstream catchment (Bayside channel) is clearly problematic and rated as Unacceptable;
- Sample points in Milnerton Lagoon were all rated as Unacceptable as far as RTV09, reflecting inflows from a severely contaminated catchment to the east;
- Some improvement in water quality was shown near the Woodbridge Island bridge, where sample points were rated as Tolerable Risk and (at the Milnerton Canoe Club) Acceptable. *E. coli* levels increased to pass into the Unacceptable range at RTV10.

It should be noted that summary *E. coli* data are complicated, in that even using geometric means, the data include in some cases a wide range of variables, between spill and non-spill periods, and even those sites rated green (Target) in the figures below may have experienced sewage spills at times.

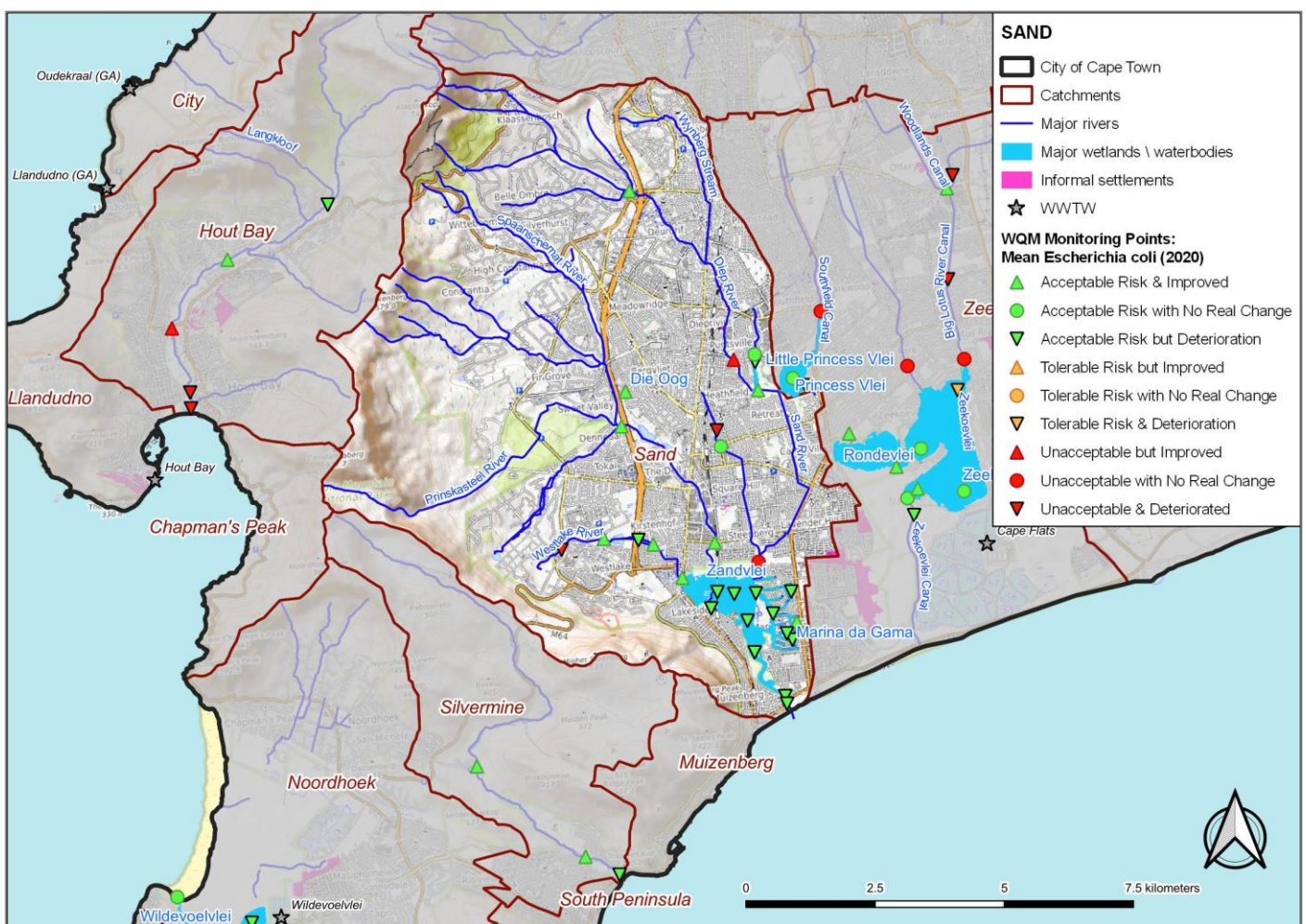


Figure 6.2

Geometric mean annual *E. coli* data, focusing on Zandvlei, Zeekoevlei and Princessvlei.

Data compare mean *E. coli* (geometric means) for the 2020 monitoring period with means for the 2017-2019 periods.
Data coded as described in Section 3.8.10

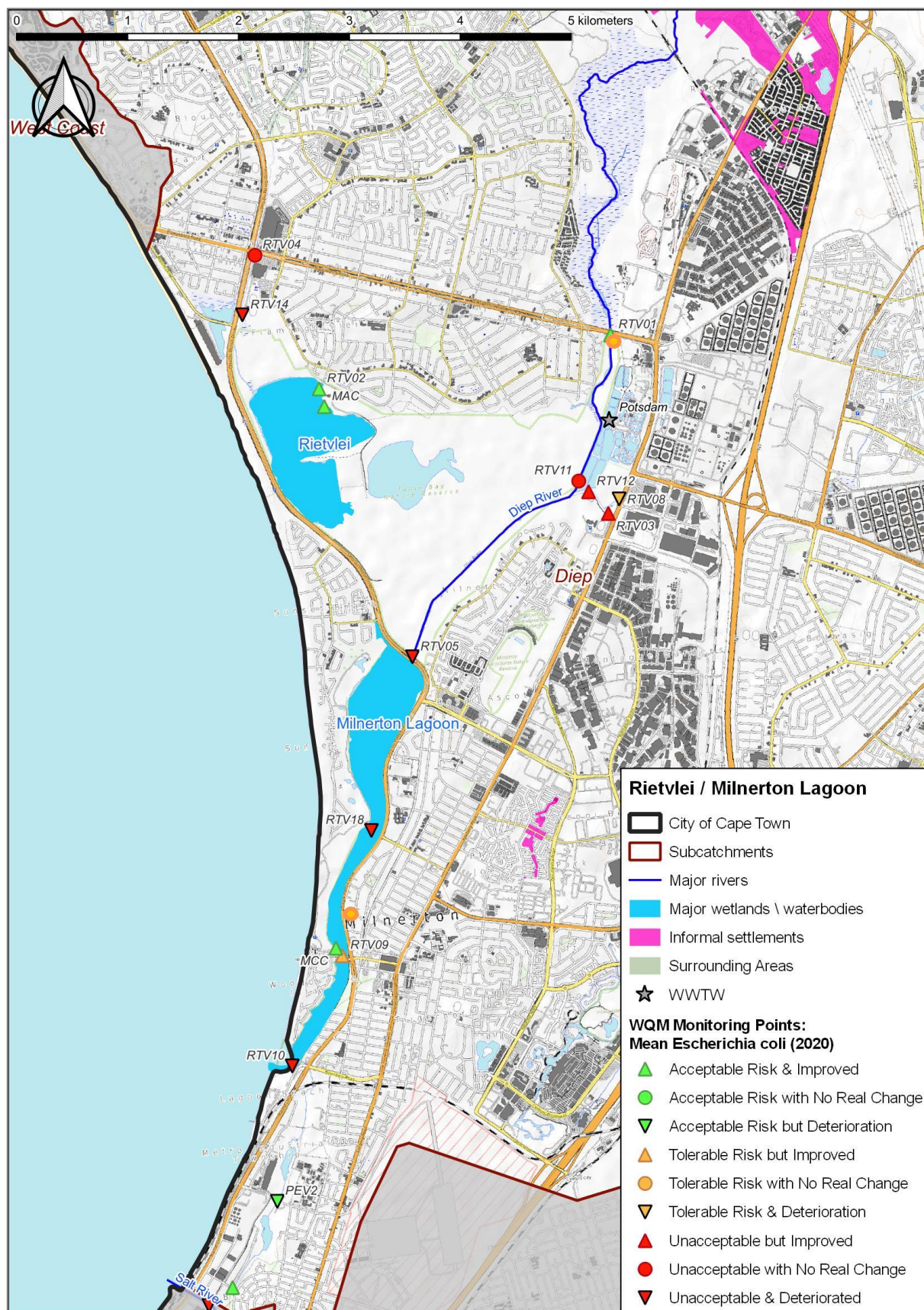


Figure 6.3

Geometric mean annual *E. coli* data, focusing on Rietvlei and Milnerton Lagoon.

Data compare mean *E. coli* (geometric means) for the 2020 monitoring period with means for the 2017-2019 period.
Data coded as outlined in Section 3.8.10.

6.4.3 Intestinal enterococci

6.4.3.1 Background

Enterococci are a group of bacteria that occur in the intestines of warm-blooded animals and like *E. coli* are used as indicators of faecal pollution including human sewage. WHO (2021) suggests that there is better dose-dependent correlation between enterococci counts and gastro-intestinal disease than in the case of *E. coli*. It should however be remembered that, as with all indicator organisms, their presence is used to assume a range of other pathogens potentially associated with faecal contamination. This is an important point. Data from WWTWs that disinfect their treated effluent so as to eliminate indicator *E. coli* and enterococci bacteria may show final data with low enterococci (or *E. coli*) counts, while other unmonitored pathogens survive (e.g. viruses, various protozoa and intestinal helminths).

Historically, the CCT has relied primarily on *E. coli* analyses to monitor sewage contamination in its inland watercourses, with limited enterococci analyses. The CCT's coastal monitoring programme, by contrast, relies on enterococci monitoring rather than *E. coli*.

During the 2021 reporting period, the CCT increased the number of samples analysed for enterococci substantially, so as to include all of its key recreational waterbodies, as well as some problematic river sites (e.g. lower Lotus River) and detention ponds known to be pollution hot-spots in Mitchell's Plain. This increase in monitoring effort commenced from July 2021. This means that data for the 2021 reporting year are limited, and exclude 25% of the reporting year, which started in April 2021.

Data for the CCT's recreational waterbodies are analysed and discussed in this section and used to allow more quantitative comment on the performance of these systems from a human health perspective.

6.4.3.2 Assessment of enterococci data for recreational waters

Enterococci data are presented here as compliance-type graphs in **Figures 6.4** and **6.5**, both for separate recreational bodies considered as a whole, and for individual waterbodies, showing performance at individual sites. The latter allow for identification of the most problematic sites.

Table C4 in **Appendix C** presents summary annual data for each site, analysed as outlined in **Table 3.5**. The methodology recommended for the interpretation of these data means that 90% and 95% of all data for each site or assessed water body need to be below the thresholds indicated in **Table 3.5**, for each rating category to apply. Outlier enterococci counts from sites exposed to major sewage spills, even if only occurring periodically, can result in the 95th and 90th percentiles being very high for a particular dataset, and well above geometric mean values.

When 90th and 95th percentile data are calculated for the 2021 reporting year dataset, all of the recreational vleis are rated as in an Unacceptable condition. This is shown in **Table 6.1**. These results are however driven by relatively few but very high sewage inflows, as shown in the compliance graphs below. They are moreover skewed by repeated, more-frequent sampling under sewage overflow conditions. This means that highly polluted samples are more likely to be included in the dataset than least-impacted samples.

For this reason, it is considered more useful for the purposes of reporting here, that attention is focused on the compliance graphs and reporting, rather than on the annual percentile-based approach. The approach outlined in DEA (2012) has thus been used, as reproduced in **Figure 6.6**, which is based on rated data for individual samples.

Table 6.1

Summary 95th and 90th percentile enterococci data for the CCT's recreational waterbodies in the 2021 reporting period.

Data coded Target to Unacceptable as indicated in Table 3.5

Note that this approach is skewed by higher sampling frequency under sewage spill conditions

Recreational waterbody	90 th percentile	95 th percentile	Interpretation
Rietvlei	200	369	Unacceptable
Milnerton Lagoon	2 820	3 785	Unacceptable
Zandvlei	555	1 085	Unacceptable
Zeekoevlei	634	928	Unacceptable
Princess Vlei	595	680	Unacceptable

The enterococci data illustrated in **Figures 6.4** and **6.5** suggest the following:

- **Milnerton Lagoon** was the worst-performing recreational waterbody in both the 2020 and 2021 reporting periods – these data support the 2020 *E. coli* data presented in **Section 6.4.1**. More specifically:
 - In the 2020 winter, no samples fell within the Acceptable range for enterococci;
 - The 2021 summer data showed deterioration compared with the 2020 summer, with 40% of samples within the Unacceptable range and just under 50% being Acceptable;
 - Winter 2021 data were marginally improved over winter 2020 data. Nevertheless, 68% of samples fell within the Unacceptable range.
- Data in **Figure 6.5** allow a closer look at the lagoon data, and show that:
 - 60% of samples from RTV09 and RTV10, lying closest to the lagoon mouth, were rated Unacceptable;
 - Samples from the Milnerton Canoe Club area (MCC) showed marginally better compliance with 55% of samples rated as Unacceptable. This site was however sampled more frequently than the other two, and the data are not exactly comparable.
- No samples from RTV18 were analysed for enterococci – this is unfortunate, as RTV18 lies just downstream of the Erica Road stormwater outfall and is a known source of long-term sewage contamination from its upstream Joe Slovo catchment (Rose et al. 2023);
- Other at-times major sources of sewage pollution are likely to include pump station overflows as well as, at times, poorly treated effluent from the WWTW itself;
- **Rietvlei** enterococci data were relatively well-performing over the 2021 reporting period, compared with both the 2020 and the 2017-2019 reporting periods, with over 90% of samples falling within the Acceptable range in both summer and winter. This is ironic, in that Rietvlei was closed for several months during the 2021 reporting period on the basis of unreliable *E. coli* data;
- Data in **Figure 6.5** show that only five Rietvlei samples fell within the Unacceptable range in the 2021 reporting period, variously from MAC, RTV17 and RTVBUOY1. This is of interest, since these sites lie close to the Milnerton Aquatic Club jetties and launch areas, whereas RTV19 (at the outlet of the Bayside Canal into the vlei) showed 100% Acceptable conditions in all samples taken. These data suggest that periodic overflows from the pump stations at the aquatic club might have taken place – but the low sample numbers generally mean that such interpretation is highly speculative. The variability in number of samples collected at different sites means, however, that percentage compliance per site should generally be treated cautiously, although the data do still indicate sites prone to pollution;
- Enterococci data for **Princessvlei** showed that, by contrast with most other vleis showing generally elevated winter enterococci concentrations, more summer samples were rated as Unacceptable than in winter (38% versus 0%). **Figure 6.5** however shows the limited numbers of samples for this water body – again highlighting the need to exercise caution in deducing trends and patterns from a very small dataset;

- It seems most likely that the Unacceptable summer data in Princessvlei were driven by local sewage overflows, potentially triggered by load-shedding;
- **Zandvlei** data show that samples with enterococci concentrations in the Unacceptable range varied between 12% and 20% for summer and winter in the 2021 reporting period respectively;
- Site-specific data for Zandvlei, presented in **Figure 6.5**, show that the sites most prone to elevated enterococci above Unacceptable thresholds were ZA01, ZA02, ZA07, ZA11 and ZA12, all of which had between 25 and 30% of samples rated Unacceptable. These sites lie in the central vlei (ZA01, ZA02, ZA07) and in the north-eastern part of the Marina da Gama canals. It is assumed that sources of sewage inflows were mainly from pump station failures and overflowing manholes in the upstream catchment (e.g. along the Keyzers and Westlake Rivers) and areas abutting the Marina and upper estuary (e.g. Clifton Road pump station). The best-performing sites were all located in the lower estuary and southern end of the Marina and are assumed to lie furthest from the source of inflow at the time of sampling;
- Although Zandvlei was closed for extended periods in the 2021 reporting period on the basis of *E. coli* data, the enterococci data suggest water that was clearly at times contaminated and of high risk to human health, but Acceptable during at least 75% of the times when samples were taken;
- **Zeekoevlei** data show that 12% and 20% respectively of all samples analysed for enterococci in summer and winter of the 2021 reporting period were rated Unacceptable. Known major sewage overflows into Zeekoevlei occurred in July 2021, when enterococci monitoring commenced, and major and minor sewage inflows also occurred within the Big Lotus River, which feeds into Zeekoevlei (Day et al. 2022);
- Site-specific compliance data shown in **Figure 6.4** show that:
 - ZEV2S was the worst performing site over this time – this site lies near the mouth of the Big Lotus River, and these data support previous reporting (e.g. Day et al. 2022) that, apart from a major sewage overflow at the inlet to the WWTW in July 2021, most sewage inflows into the vlei are via the Big Lotus River. 48% of samples analysed from ZEV2S were rated as Unacceptable. This highlights the fact that these upper reaches of the vlei are highly prone to sewage contamination and should be used for intermediate contact recreational activities with great caution;
 - 21% of samples from ZEV4s were also in the Unacceptable range over the 2021 reporting period. This site is located in the downstream reaches of the vlei, some 2.8 km downstream of ZEV2S. Given that enterococci are likely to exhibit die-off in sunlight (Sinton et al. 2002) it is surprising that elevated enterococci persisted as far down as ZEV4S, and moreover that such data were not reflected in data for the nearby weir site (ZEWEIR).
- Overall, enterococci data over the 2021 reporting period generally appear to show patterns that are consistent with observed and /or correlative information relating to these watercourses. While the data clearly show that severe sewage contamination did occur at times in all of the recreational waterbodies, affecting their fitness for recreational use, such events were unlikely to have persisted over months and should not have prompted long-term waterbody closure, at least in Rietvlei, Zandvlei and Zeekoevlei.

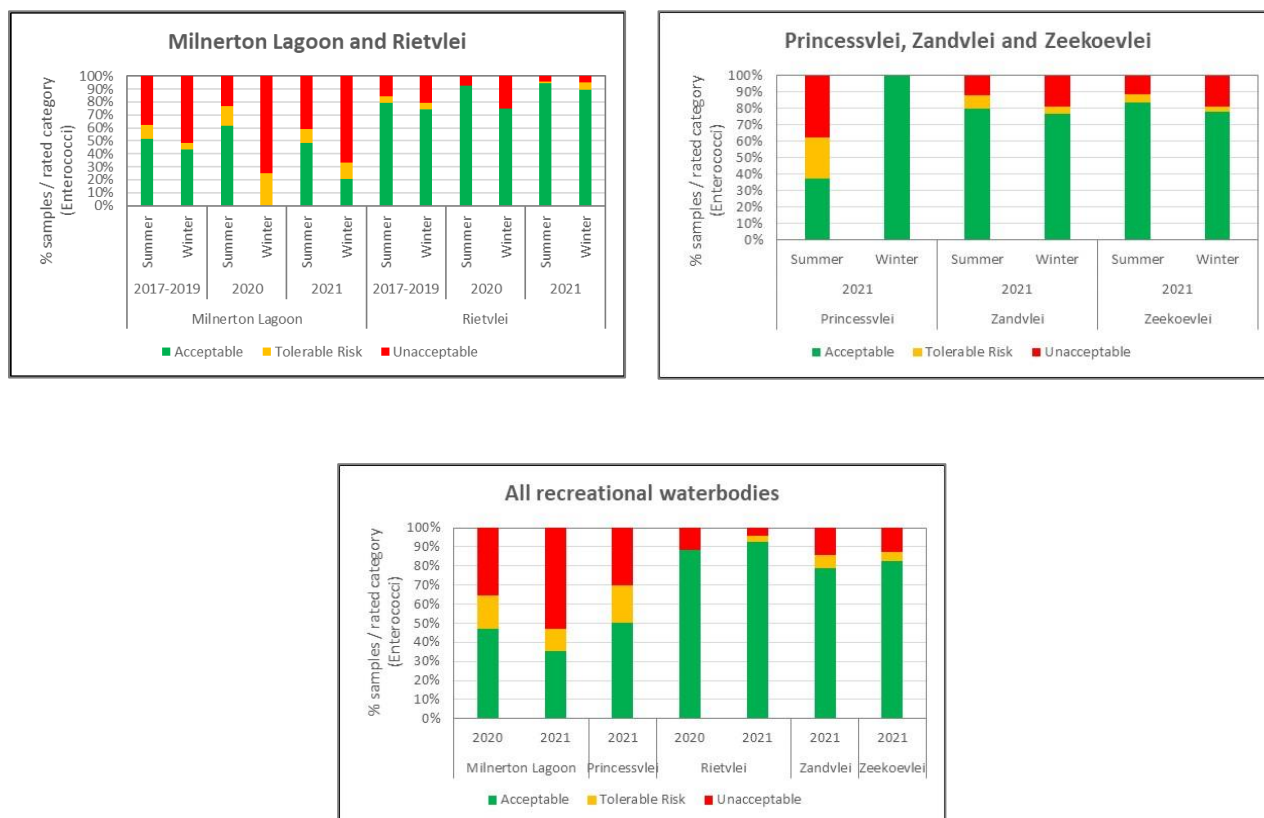


Figure 6.4

Percentage of enterococci samples falling within each rated category for each recreational waterbody. Top graphs show summer and winter data separately. Bottom graph shows seasons combined. Data coded as per Table 3.5 for single samples.

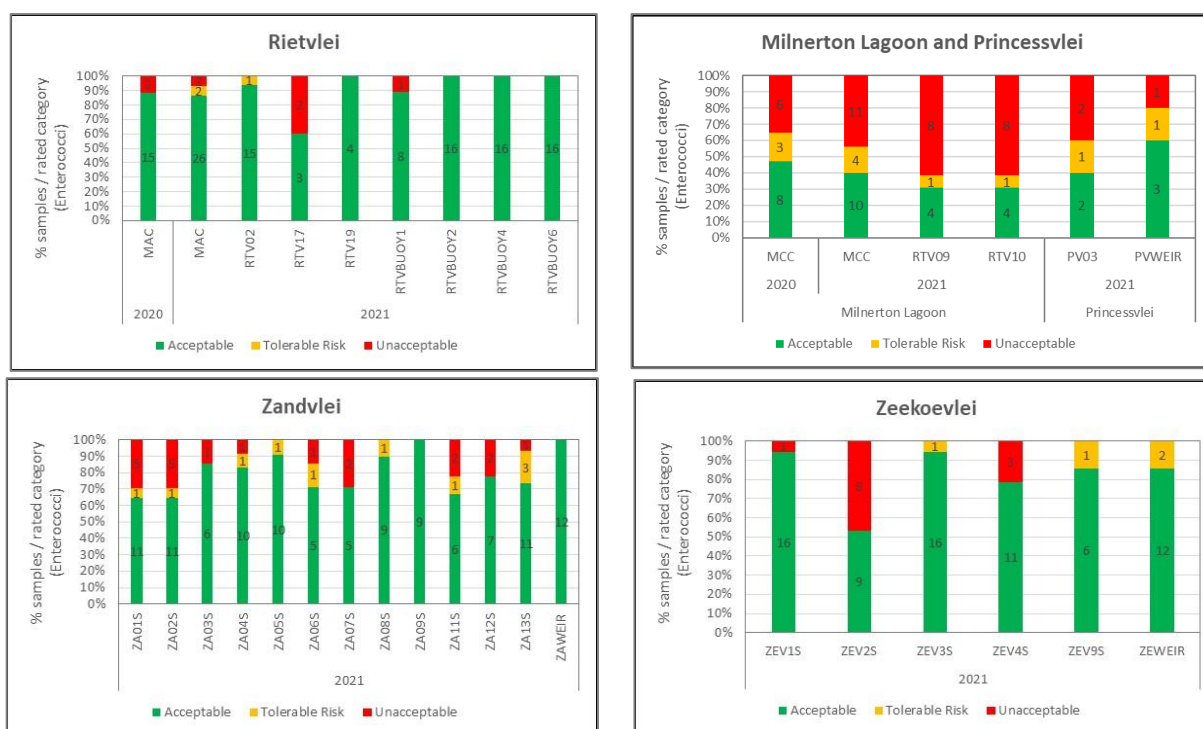


Figure 6.5

Percentage of enterococci samples falling within each rated category for individual sites at each recreational waterbody. 2021 reporting period only. Data coded as per Table 3.5 for single samples. Number of samples labelled in each category.

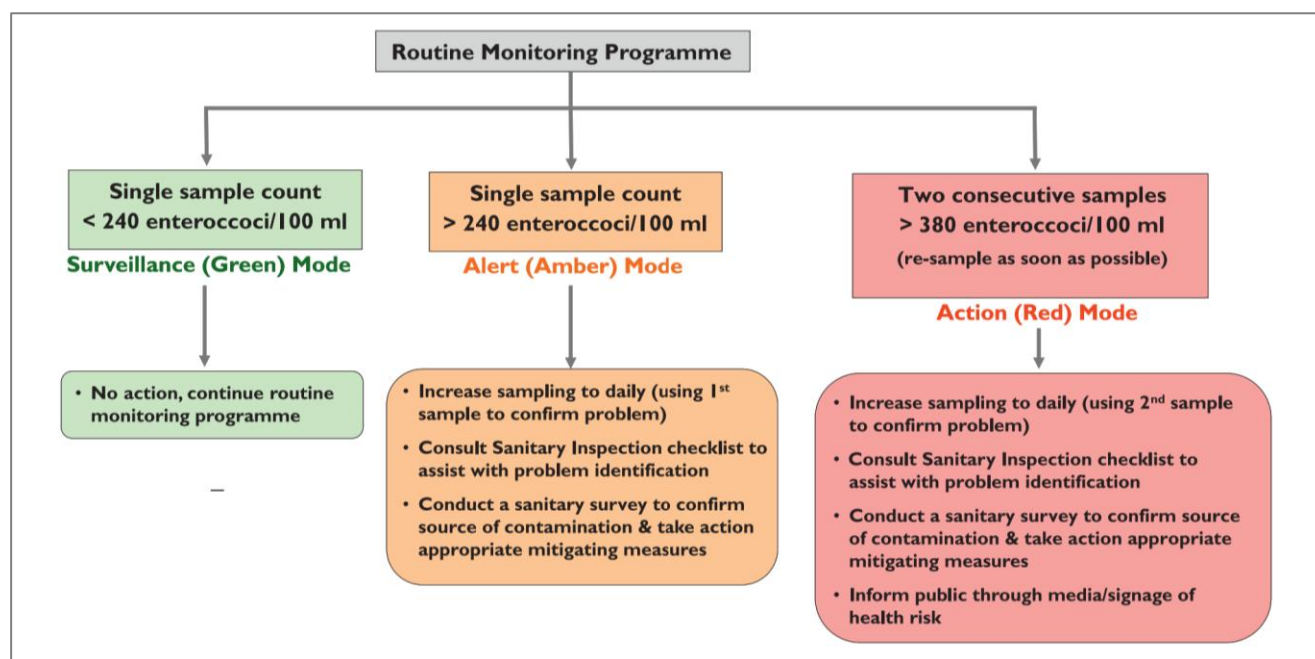


Figure 6.6

Proposed operational management process for enterococci data in South Africa. Figure after DEA (2012) for marine waters but applicable to freshwater systems too (WHO 2021).

6.5 Microcystin risks

6.5.1 Background

Cyanobacteria (or blue-green algae) are a common and naturally occurring component of most recreational water environments (WHO 2003). They are of potential public health concern because some types may, under certain conditions, produce a group of secondary metabolites known as microcystins, some of which are toxic.

Since microcystin toxin testing is expensive, it is not routinely included in the CCT's water quality tests but is instead undertaken when blue-green algal blooms have been detected. A 'bloom' is defined by the SSB as a cell count > 20 000 cells/ml. However, when field evidence suggests that bloom conditions are obvious (e.g. blue-green algal slicks), microcystin tests are carried out immediately, without the delay necessitated by microscopic enumeration of algal cells.⁷

Why blue-green algae?

Blue-green algae (a division of algae also referred to as cyanophytes or cyanobacteria) produce green surface scums under bloom conditions. The algal cells also contain a blue pigment (phycocyanin), which is mostly visible when algal cells in bloom conditions die and rupture, releasing the pigment into the water. This sometimes appears as if turquoise-coloured paint has been spilled into the water body (adapted from WHO 2021)

6.5.2 Assessment of microcystin toxin data and sampling frequency

Figure 6.7 presents the results of analyses of water samples from Cape Town's recreational waterbodies for microcystin toxins.

The data show that, although blue-green algal blooms were clearly present on numerous occasions over the 2020 and 2021 reporting periods covered in this report, none of the samples analysed were found to contain microcystins at concentrations of any concern, and 100% of all samples analysed were within the Acceptable range for this variable.

This means that, despite periodic blue-green algal blooms, Cape Town's recreational watercourses were assumed to be relatively safe for human use over the 2020 and 2021 reporting periods, from the perspective of exposure during intermediate contact use to microcystin toxins in water from these systems.

⁷ Mr R. Siebritz, SSB, Emailed comment to Liz Day (24.3.2023)

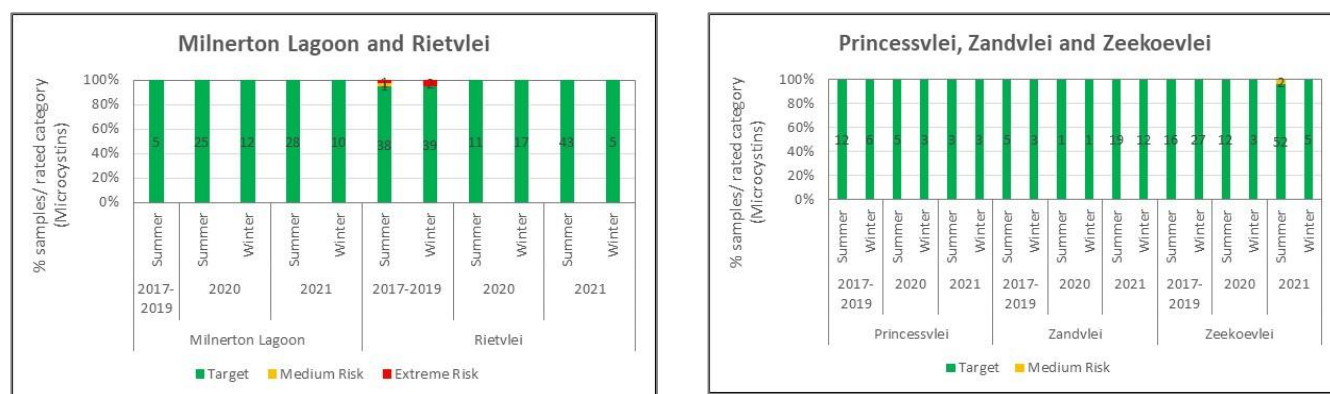


Figure 6.7

Percentage of microcystin samples falling within each rated category for this variable, per subcatchment. Thresholds for rated categories as defined in Table 3.6

Figure 6.8 presents a slightly different picture. This graph plots the frequency of samples that were analysed for the presence of microcystins, over the 2017-2019, 2020 and 2021 reporting periods. Since the trigger for microcystin analysis of any sample is the presence of visible blue-green algal blooms or algal count data indicating bloom conditions, the data can also be used as a gauge of blue-green algal bloom frequency, even where this is not accompanied by microcystins at toxic concentrations. On this basis it can therefore be loosely deduced that:

- There was a marked increase in the number of algal blooms in Milnerton Lagoon over the 2020 and 2021 reporting periods, compared to the preceding 2017-2019 period (spanning three reporting years);
- Princessvlei appeared to experience a reduced number of algal blooms in 2021, compared to 2020;
- Rietvlei experienced high numbers of blooms in the 2017-2019 reporting period, some of which included microcystins at toxic concentrations (see Figure 6.7);
- Rietvlei, Zandvlei and Zeekoevlei all experienced much more frequent blue-green algal blooms in the 2021 reporting year than the 2020 reporting year – this reflects hypertrophic conditions as a result of phosphate enrichment in all of these waterbodies, which were able to support high levels of phytoplankton productivity. Blue-green algae are moreover able to access nitrogen through the air (Kadlec 2020) as well as through the waterbody, so in conditions of elevated phosphate, they have a competitive advantage over many other taxa.

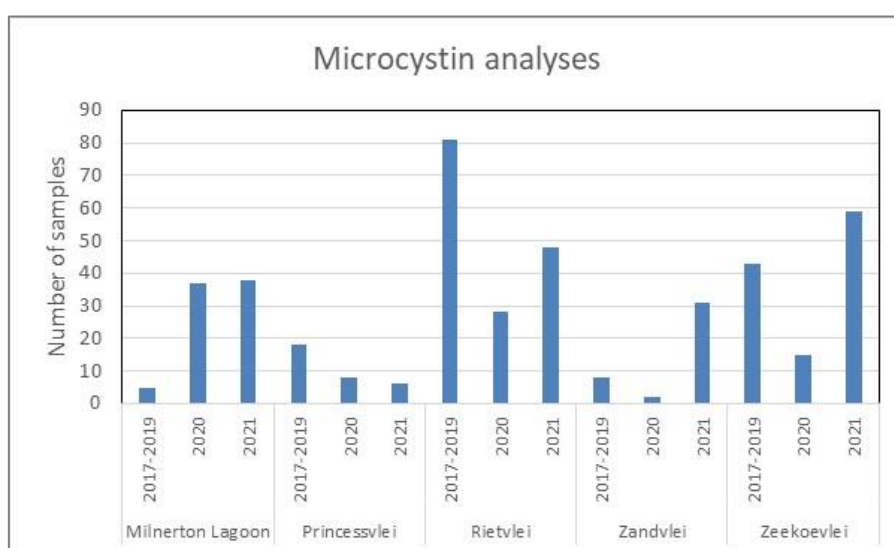


Figure 6.8

Number of samples analysed for the presence and concentration of microcystins

6.6 The Kuils River at the Khayelitsha Wetland Park

The Khayelitsha Canoe Club operates from the Khayelitsha Wetland Park, located on what is presumed to have been a backwater of the Kuils River, but is now a stormwater detention pond (see **Figure 6.9**). The club's operations are hampered by ongoing land invasion into the wetland park (see also **Box 8.1** in **Section 8.1.5**) as well as by invasion of open waterbodies by water hyacinth. These plants are cleared manually by the Canoe Club members⁸, and their rate of growth reflects the high levels of nutrient availability in the Kuils River subcatchment, and phosphorus availability in particular, in its phosphate form.

Canoeing or kayaking in these sections of the river, as well as water hyacinth clearing, exposes members of the club to potential health risks, stemming from exposure to inflows of raw sewage or other sources of pollution. Although the Kuils River main stem is monitored at the Baden Powell Bridge, this sample point is considered unrepresentative of conditions at the Khayelitsha Canoe Club venue itself, where water backs up in a ponded area and point source inflows from adjacent areas impact on local water quality.

Without data, the fitness of this waterbody for intermediate contact recreational use cannot be commented on. It is however recommended that the CCT create an additional routine monitoring point within the Khayelitsha Wetland Park, in the reaches utilised by the canoe club, to provide some input into health risks imposed at different times by exposure to polluted waters.

At the same time, it is recommended that this section of the Kuils River subcatchment should be highlighted for specific interventions (e.g. stormwater diversion to sewer and aquatic alien plant clearing by the CCT), to support community-based initiatives such as the Khayelitsha Canoe Club.



Figure 6.9

Khayelitsha Canoe Club location (arrowed) in Khayelitsha Wetland Park (yellow polygon) showing the location of the nearest routine water quality monitoring point (EK08) on the main Kuils River channel downstream (Baden Powell Road).

⁸ Comment From Mr Siya Sopangisa (Khayelitsha Canoe Club) to Liz Day via phone on 28 April 2023

6.7 Key take-away points

- The absence of reliable *E. coli* data from the dataset over the 2021 reporting period limited the degree to which trends and trajectories in contamination of recreational watercourses by raw sewage could be investigated. Interpretation of sewage-based human health risks over this period was therefore based on limited enterococci data;
- The CCT's recent increase in the number of sampling points now monitored for enterococci is supported and is in line with global recommendations for enterococci data to be used as indicators of sewage contamination in both fresh and marine waters;
- Additional monitoring points for enterococci are recommended at RTV18 (Milnerton Lagoon) and in the Kuils River wetlands at the Khayelitsha Wetland Park, where the Khayelitsha Canoe Club is based. Ideally, enterococci should in fact be monitored from all of the routine water quality monitoring points, so that a full enterococci dataset is available;
- Overflows of sewage from pump stations and manholes affected all of the monitored vleis at some time over the 2020 and 2021 reporting periods. These events are assumed to have been triggered mainly by load-shedding, although the Zeekoe and Diep subcatchments in particular are also prone to blockages from vandalism and solid waste (Rose et al. 2023 and Day et al. 2022);
- Enterococci data, when analysed using 95th and 90th percentile data as recommended by WHO (2021), show large numbers of samples in an Unacceptable condition across all recreational vleis – this is in part driven by the impacts of (usually) short-term sewage overflows, which substantially extend the upper range of the data. Repeated sampling of water bodies during and after sewage spills exacerbates this effect;
- Milnerton Lagoon was the recreational waterbody worst impacted by sewage inflows, assumed to come from water flushed in from extensive informal settlements upstream, particularly in winter, as well as from blocked or overflowing sewage pump stations in the catchment;
- Sewage contamination was generally worse in winter across all recreational waterbodies except Princessvlei. Many sewers and pump stations are more prone to blockage and overflows under wet conditions, when stormwater ingress into some systems adds significantly to the volume conveyed;
- Rietvlei, Zandvlei and Zeekoevlei all experienced more frequent blue-green algal blooms in the 2021 reporting year than in the previous year – this reflects hypertrophic conditions as a result of phosphate enrichment. Despite an increase in algal blooms, none appeared to experience microcystins at levels likely to have posed risks to human health, at least at the times and areas of sampling.

7 CITY PROGRAMMES TO IMPROVE WATER QUALITY

7.1 Background

In its Water Strategy finalised in February 2020, the City made a commitment to facilitate Cape Town's transition by 2040 to a water-sensitive city with diverse water resources and water infrastructure, making optimal use of stormwater and urban waterways for flood control, aquifer recharge, water reuse and recreation, according to sound ecological principles. It stated that this would be done through new incentives and regulatory mechanisms, as well as through the way the City invests in new infrastructure.

The overarching vision is that Cape Town will become a city that optimises and integrates the management of water resources to improve resilience, competitiveness, and liveability for the prosperity of its people. Achieving the vision will require a shift to water-sensitive urban design that encompasses all aspects of integrated urban water cycle management, including water supply, sewerage, and stormwater management. Given that protecting water quality and natural ecosystems are fundamental principles of water-sensitive urban design, the City is obliged to take steps to address water pollution and rehabilitate waterways where possible.

Box 7.1

Cape Town as a Ramsar Wetland City

In 2015 the City of Cape Town's False Bay Nature Reserve was designated as South Africa's 22nd Wetland of International Importance under the Ramsar Convention. More recently, the City of Cape Town became South Africa's first city to be accredited as a Ramsar Wetland City. The announcement that Cape Town was one of the successful applicant cities was made in May 2022 by the Independent Advisory Committee on Wetland City Accreditation, with certificates presented on 10 November 2022 at the 14th Meeting of the Convention's Conference of the Contracting Parties (COP14), held in Geneva, Switzerland. The accreditation acknowledges the best-practice work that the City has undertaken in implementing innovative policies and plans to ensure Cape Town's wetlands are protected, rehabilitated and restored.

The voluntary accreditation scheme was approved in 2015 at COP12, where Contracting Parties were invited to propose cities that are located close to Ramsar Sites or other significant wetlands for accreditation, providing they met specific criteria. The scheme was conceptualised in recognition of the importance of urban wetlands and the fact that more than 50% of the Earth's population now resides in cities, towns and urban settlements. It was developed to encourage cities to highlight and strengthen a positive relationship with wetlands through increased public awareness and participation in municipal planning and decision-making. It also promotes the conservation and wise use of wetlands, as well as sustainable socio-economic benefits for local people. The first batch of 18 Wetland Cities were recognised at COP13 in 2018, with another 25 recognised at COP14 in 2022.

7.2 Water Quality Improvement Programme

During 2020, draft Terms of Reference (ToR) for a Water Quality Improvement Programme (WQIP) were therefore developed by the CCT's Water and Sanitation Department. The WQIP was conceptualised as a strategic intervention integrating short-term priority responses with a medium- and long-term programme, with the overall objective of progressively improving water quality in the rivers and waterbodies of Cape Town.

The WQIP comprised Pollution Abatement Strategies & Action Plans that set out the strategies to address pollution and poor water quality on a river catchment or sub-catchment basis. They included detailed Transversal Action Plans (TAPs) outlining short- to long-term interventions and projects across various directorates and work streams. Since the TAPs needed to be developed with a clear understanding of the causes of pollution, relative significance of pollution sources, anticipated effects of interventions, as well as costs and timeframes, they would be compiled by Tasks Teams made up of key roleplayers within those catchments or sub-catchments. They included aspects such as monitoring of capital improvements at WWTW plants, infrastructure audits, improved sewer spill response times, proactive maintenance of sewage infrastructure, river maintenance programme implementation, litter-boom, and river warden project partnerships, as well as engagement with catchment forums and other interest groups.

Subsequent to the development of the draft WQIP ToR, public and political attention on water quality issues increased as a result of sewage spill incidents due to load-shedding, pump station failures and pipeline blockages, in addition to temporary closure of the city's vleis for recreational activities because of high levels

of faecal bacteria. On his first day in office on 19 November 2021, the new Mayor, Geordin Hill-Lewis, inspected sewage problems in Khayelitsha and Phoenix and noted that he had long been concerned about sewage spills in the city. He requested officials to provide short-term solutions to alleviate the sanitation issues and to clean up the city's waterways.

7.3 Mayor's Priority Programme on Sanitation and Inland Water Quality

In response to the request by Mayor Hill-Lewis, the Water and Sanitation Department developed a Charter for the Mayor's Priority Programme (MPP) on Sanitation and Inland Water Quality. As a part of this development, the WQIP transitioned into the MPP. This meant that the WQIP and its associated PASAPs were accorded both greater budget allocations and stronger political will behind their various initiatives.

The WQIP and its PASAPs will initially focus on six priority catchments that the City identified as having significant challenges with regards to water quality, namely Diep River, Soet River, Salt River, Eerste/Kuils River, Hout Bay River, and the Big and Little Lotus Rivers of the Zeekoevlei catchment. TAPs have already been compiled for the Lower Diep River and the Soet River and both are being implemented, although the former is being revised to address the pollution issues in Milnerton Lagoon. In addition, TAPs are under development for the Mosselbank River tributary of the Diep River and the four other priority catchments. The Salt River TAP focuses on the Vygekraal River tributary and the Eerste/Kuils River TAP focuses on the Bottellary River.

Implementation of the TAPs is expected to yield improvements in ambient water quality, although the rate of change will depend on the actual interventions and actions, their timing and scale, as well as the City's ability to address sources of diffuse pollution from grey water and unserved informal settlements.

However, the MPP's scope goes well beyond Pollution Abatement Strategies & Action Plans, which are just one component of a sub-programme on Ambient Water Quality Improvement within the Work Stream: Pollution of Waterways. The MPP also includes four other Work Streams on Sewer Network Spills, Pump Station Performance, Wastewater Treatment Capacity, and Communication and Partnership, each with their own sub-programmes and projects (**Figure 7.1**). Once fully implemented, the MPP will improve the quality of life of the City's residents, reduce the impact of sewage spills and wastewater effluent on the environment, and improve reliability of infrastructure.

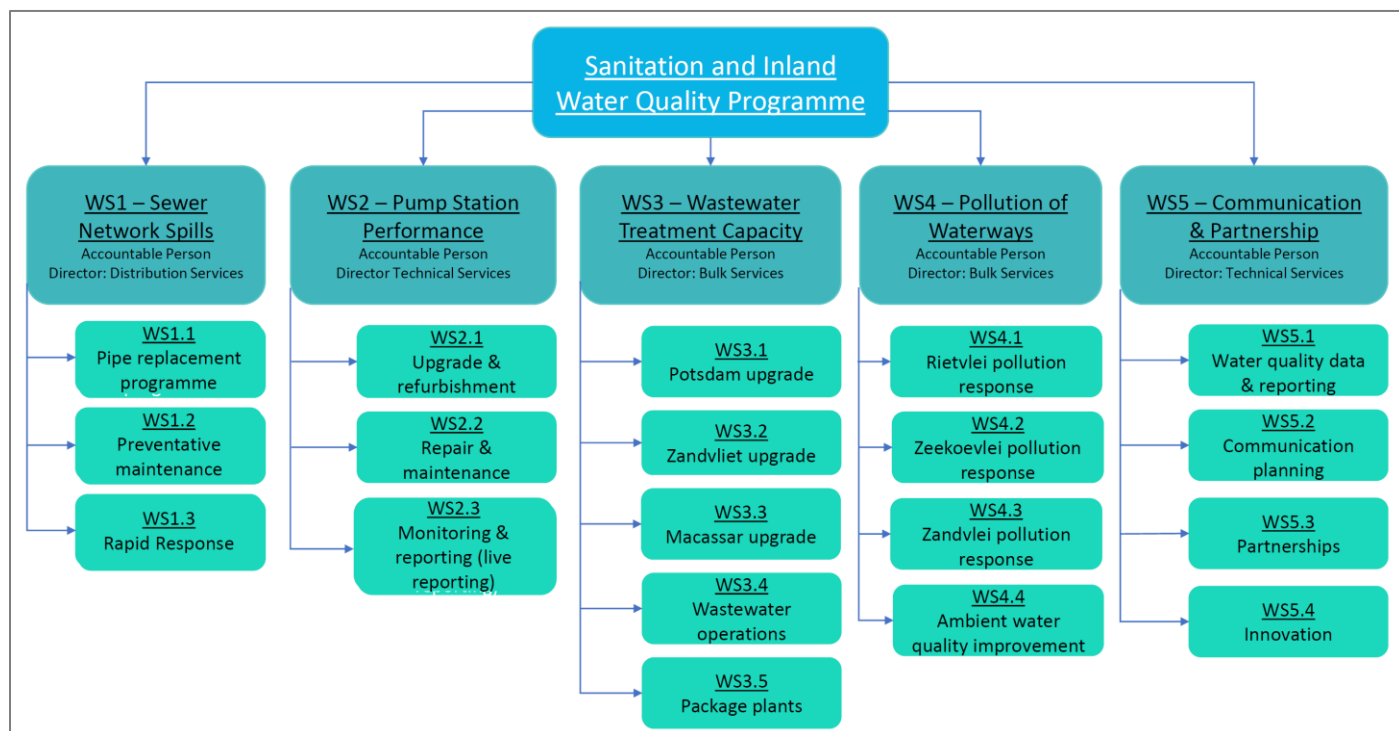


Figure 7.1

The Mayor's Priority Programme (MPP) on Sanitation and Inland Water Quality is structured around five Work Streams, each comprised of a number of sub-programmes.

More detail on the MPP's five Work Streams is provided below:

- Sewer Network Spills:** This Work Stream aims to reduce the frequency, duration, and impact of sewer network spills through preventative maintenance and a pipe replacement programme, as well as faster response in addressing such spills. Preventative maintenance involves proactive cleaning of critical sewer networks, together with regular cleaning of pump station wet wells to reduce overflows. In addition, investigations to identify illegal connections between sewer and stormwater systems will be conducted to prevent both stormwater ingress into the sewer system and illegal discharge of sewage into the stormwater system;
- Pump Station Performance:** This Work Stream will improve reliability and performance of pump stations, which have electrical-mechanical equipment that is subject to wear and tear, requires ongoing maintenance and has a life span limited to 10 to 15 years. The aim is to reduce the frequency and duration of spills from pump stations, and hence their impact on the environment and on the recreational use of Rietvlei, Zandvlei and Zeekoevlei. Apart from strategic interventions involving upgrades, refurbishment, repairs and maintenance, the Work Stream has a monitoring and reporting component that will improve near real-time monitoring via telemetry systems and a manned operational control room;
- Wastewater Treatment Capacity:** This Work Stream will increase the capacity of the three wastewater treatment works (Potsdam, Zandvliet and Macassar WWTW) currently constraining development in their respective catchment areas and will also bolster training for operators at all WWTW, which will improve the overall quality of treated wastewater and reduce operational incidents that result in poor effluent quality. Furthermore, the viability of package plants in addressing capacity constraints will be investigated (in partnership with GreenCape) to provide guidance to the City on how to manage decentralised wastewater treatment to enable development;
- Pollution of Waterways:** This Work Stream deals with addressing the causes of pollution of Cape Town's rivers and vleis, as well as short- and longer-term remediation measures to ensure that the vleis are managed and maintained in a healthy ecological state. The overall objective is to improve water quality of City catchment areas and ensure that Rietvlei, Zandvlei and Zeekoevlei remain open for recreational use. The Kader Asmal Integrated Catchment Programme (a job creation and skills development programme) will be scaled up, and since it includes the appointment of river wardens, visibility on the river corridors will improve. Strategic interventions include canal and weir upgrades, deployment of litter booms, vlei dredging and weed removal, and review of estuary management plans, among others;
- Communication and Partnerships:** This Work Stream will facilitate the development and implementation of a programme to effectively communicate and partner with residents on issues related to environment pollution, including water quality, the causes of poor water quality, and community actions to improve water quality outcomes. Learning initiatives will be implemented and innovation supported to raise awareness within communities and to formulate solutions for pollution problems, including those emanating from diffuse sources. These activities will support a shift in communications by the City, with a focus on openness, acknowledgment of challenges and shortfalls in City operations, and the promotion of community stewardship. Existing forums and groups, such as Protected Area Advisory Committees, Friends groups and ratepayers associations, will be engaged with, and catchment forums established for the Sand, Zeekoe and Diep catchments.



Photo 7.1
Rubble and other waste dumped in sewers
contributes to blockages and overflows
Photo courtesy CCT (Mr A. Taylor)

7.4 Liveable Urban Waterways Programme

The Liveable Urban Waterways (LUW) Programme is a strategic and transversal programme developed by the CCT in response to the Water Strategy, Resilience Strategy and Environment Strategy. The programme will demonstrate how water sensitive design, waterway rehabilitation and a new approach to waterway management can achieve multiple benefits for society, the environment, and the economy.

The CCT recognises that creating liveable waterways can help build adaptability to the uncertainties of climate change while transitioning to a water-sensitive city. It defines a liveable waterway as one that has acceptable water quality, makes space for water, has a functioning ecology, connects the waterway to the water table and the floodplain, connects communities by shared use and enjoyment, and provides a range of ecosystem services as well as economic and social benefits.

Seven core principles are intended to guide the LUW Programme and its individual projects:

- Collaboration and partnering
- Identification of waterways as connectors and catalysts
- Designing with nature
- Designing for many users
- Building in resilience
- Designing for attractive and usable public places
- Allowing for post project care and maintenance.

The pilot phase of the LUW Programme focuses on the Sand River catchment, where several project sites, divided into five work packages, have been identified. These projects will be used to test different rehabilitation typologies and water sensitive design approaches, to develop and foster cross-departmental collaboration and planning within the CCT, and to co-design appropriate solutions with communities who live near the waterways or who use the space.

The projects commenced in early 2022, after which a multidisciplinary team of consultants conducted specialist studies to provide a body of knowledge on which the concept designs would be based. In the second half of the year, a series of public engagement sessions took place, with more than 150 people attending the introductory meetings held in Constantia, Muizenberg and Westlake in July. This was followed in August–September by three co-design workshops attended by more than 75 people, who shared their ideas and local knowledge. In November, the concept designs developed by the multidisciplinary team and informed by the co-design workshops were presented in the last three public engagements, with feedback and comments invited. Implementation of the projects is expected to start in 2024, once internal approval processes and detailed design have been finalised and the required water use, environmental and heritage authorisations from National and Provincial government obtained.

The projects will all involve some degree of river channel and bank reshaping, management of bed and bank erosion, creation of new wetlands and riparian habitats, enhancing public open space, and installing new amenity facilities. Some improvement in water quality might be envisaged as a result- the degree to which this would be measurable would depend on the magnitude of intervention and the level of water quality impairment. The projects fall within the five work packages as follows:

- **Sand and Langevlei Canals:** At the confluence of the Sand and Langevlei Canals, sections of concrete canal will be broken out and a wetland created for the treatment of stormwater before it enters Zandvlei. New litter- and sediment-traps will be installed upstream of the wetland, and laterite pathways and seating areas established alongside the waterway to encourage recreational use;
- **Keysers River:** One project focuses on a narrow corridor where the river flows through the Steenberg industrial area, and a second on a drainage channel behind the Blue Route Mall. In both projects, steep embankments will be reshaped and planted with low-growing wetland species, and recreational nodes with pathways, bridges and seating areas created to provide lunch-break areas for factory workers and shop assistants.
- **Westlake River:** The Westlake River Upper project seeks to upgrade the walkway and pedestrian bridge

that provide access around an extensive reedbed between Westlake Village and the nearby shopping centre, and to establish a variety of recreational and 'outdoor classroom' facilities. The Westlake Lower project focuses on the Kirstenhof greenbelt, where the existing pathways will be upgraded, and the wetland areas rehabilitated to provide an increased range of wetland habitat types and improved stormwater treatment;

- **Spaanschemat and Prinskasteel River:** This work package comprises three project sites within the Constantia–Tokai greenbelt along the Spaanschemat River, including the Silverhurst Trail and Sillery in the upper reaches, the confluence with the Grootboschkloof River, and the confluence with the Prinskasteel River further downstream. The interventions at all three sites will primarily focus on river and wetland rehabilitation, with upgrading of pathways and bridges where appropriate;
- **Grootboschkloof River:** One project focuses on the river reach on both sides of Nova Constantia Road, where the river flows through dense reedbeds within a grassed corridor. The rehabilitation work will include the installation of a sediment trap, weirs, and swales, while recreational use will be encouraged by providing pedestrian movement routes along both banks. The second project further downstream, within the well-used Grootboschkloof River Walk greenbelt below Spaanschemat Road, will include installation of gabion weirs to reduce erosion and re-wet the surrounding wetland, among other interventions. A new multi-use pathway will be constructed in the uppermost 'paddocks' area, and other pathways upgraded where needed.

An additional LUW project has been initiated on the Salt catchment's Vygekraal River, where it flows through Nantes Park (see **Figure 7.3**). Furthermore, the awarding of a technical donation of approximately R10 million by the C40 Cities Finance Facility (CFF) for the CCT's 'Green Infrastructure Options for Improved Waterway and Catchment Management Project' will allow other potential sites to be identified in the Zeekoe catchment as well as the Diep (South Peninsula)⁹ section of the Sand catchment. The project will develop a masterplan for implementing waterway rehabilitation, green infrastructure (GI) and nature-based solutions (NbS) through the LUW Programme and the CCT's Green Infrastructure Programme. As part of the project, various technical studies will be conducted to inform a climate change vulnerability and ecosystem goods and services assessment. The GI and NbS interventions will then be designed to provide adaptation to the anticipated climate change impacts (such as flooding and deteriorated water quality), while improving the ecological status and functioning of waterways, where possible, and providing additional socio-economic benefits. The Diep (South) study area focuses on the Diep (South) River and its minor tributaries, Wynberg Stream, Mocke River, Little Princessvlei, Sand River Canal, Langevlei and Langevlei Canal, while the Zeekoe study area includes the Big Lotus River, Little Lotus River, and Woodland Canal. The wetlands and open spaces of all these waterway corridors are also an integral part of the study.

What is Green Infrastructure?

Green infrastructure can be defined as a strategically planned, designed and managed network of multifunctional natural open spaces and 'engineered' ecological systems, with other environmental features, that provide ecological, community and infrastructure services.

A section of the Vygekraal River, which forms part of the Lower Salt River subcatchment, as well as small sections of the Blomvlei and Jakkalsvlei rivers, where they converge with the Vygekraal River, have recently been added to the LUW Programme (see **Figure 7.3**). The proposed scope of this project includes river channel and bank shaping, management of bed and bank erosion, creation of new wetland habitat, enhancing public open space and installing new amenities (e.g. a pedestrian footbridge) (Lukhozi 2023).

⁹ Note that this river is not the main stem Diep River entering Milnerton Lagoon – this Diep River forms part of the Sand River catchment and rises on the Constantiaberg mountain range.

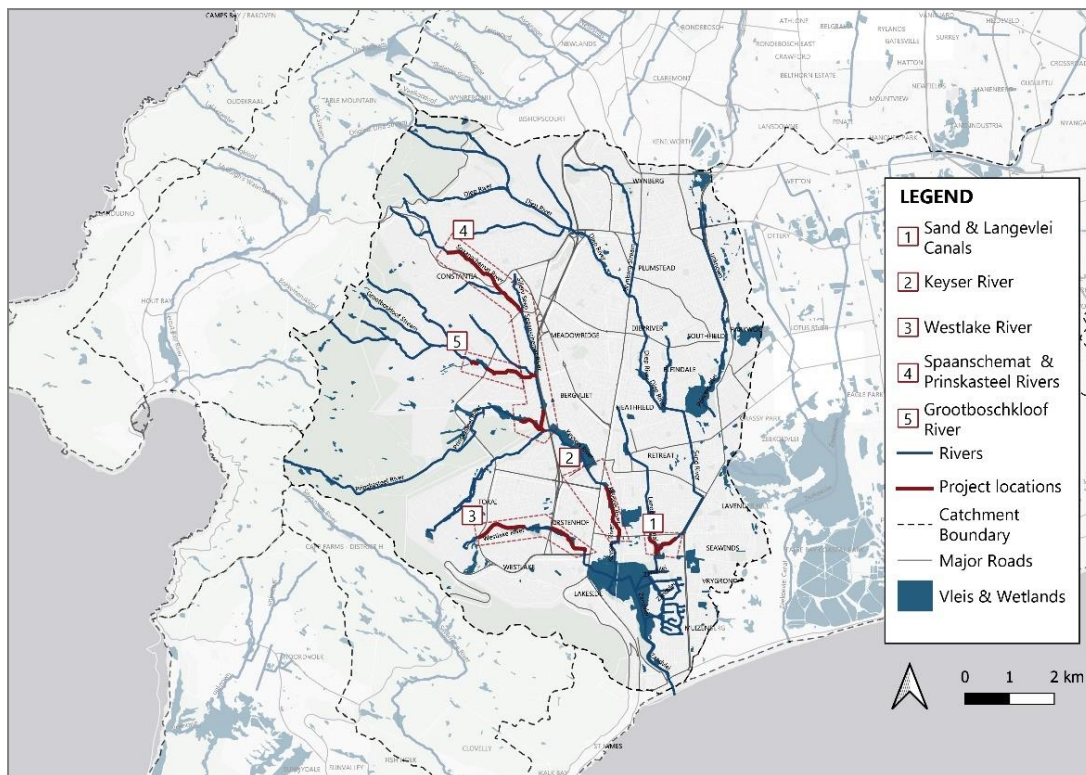


Figure 7.2

The pilot projects in the Sand River catchment are grouped into five work packages.
Figure courtesy ARLA Consulting

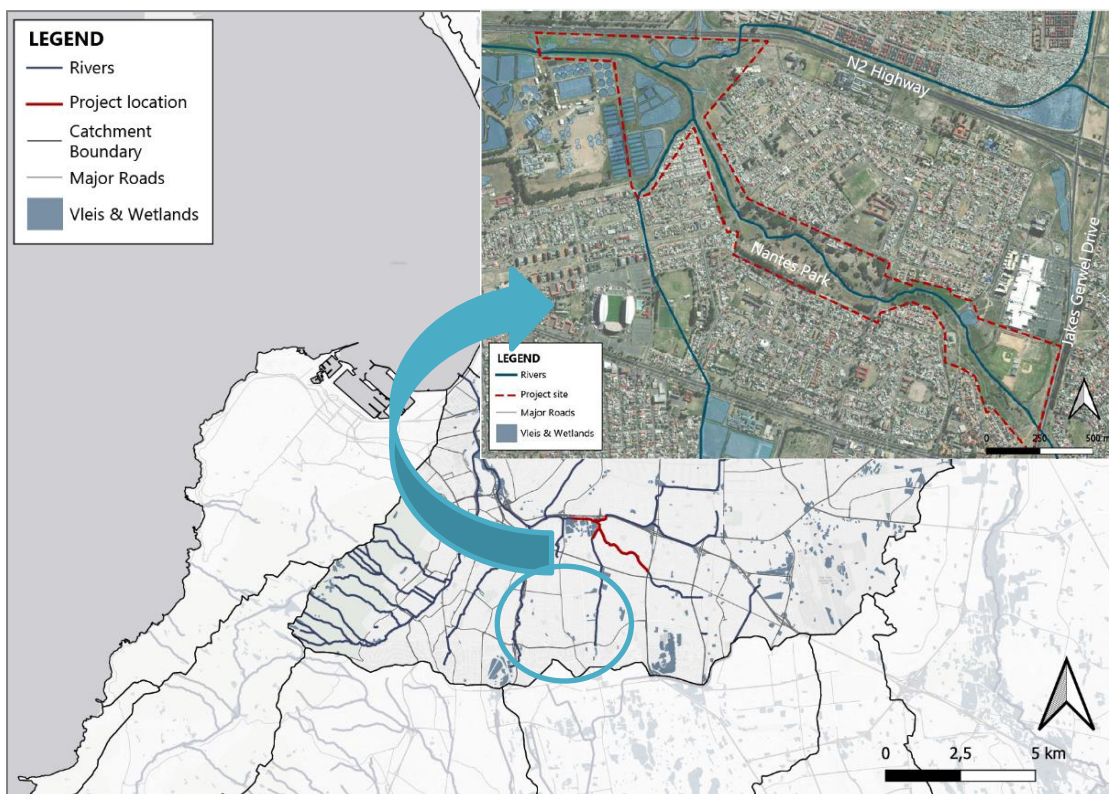


Figure 7.3

The proposed Nantes Park project in the Lower Salt River subcatchment
Map courtesy ARLA Consulting. Inset taken from Lukhozi (2023)

8 WATER QUALITY IN PRIORITY CATCHMENTS ADDRESSED BY THE CCT'S WATER QUALITY IMPROVEMENT PROGRAMMES

8.1 Context

The various CCT programmes to improve water quality and general watercourse condition (see **Section 7**) focus in particular on the six priority subcatchments already mentioned in **Section 2.6**, as well as the Sand subcatchment. These subcatchments are looked at in a little more detail in this section, which presents water quality data for individual monitoring points in each priority subcatchment, and highlights where possible particular interventions that are planned or have been implemented in different areas. This allows interested readers to home in on water quality issues in particular parts of each priority subcatchment. Note however that only key interventions relevant to improving inland water quality are highlighted here –more detailed information regarding the CCT's current and planned interventions can be sourced through an analysis of the draft budget for the 2023-24 and 2024-25 financial years (CCT 2023b).

The seven subcatchments considered in this section are indicated in **Figure 8.1**.

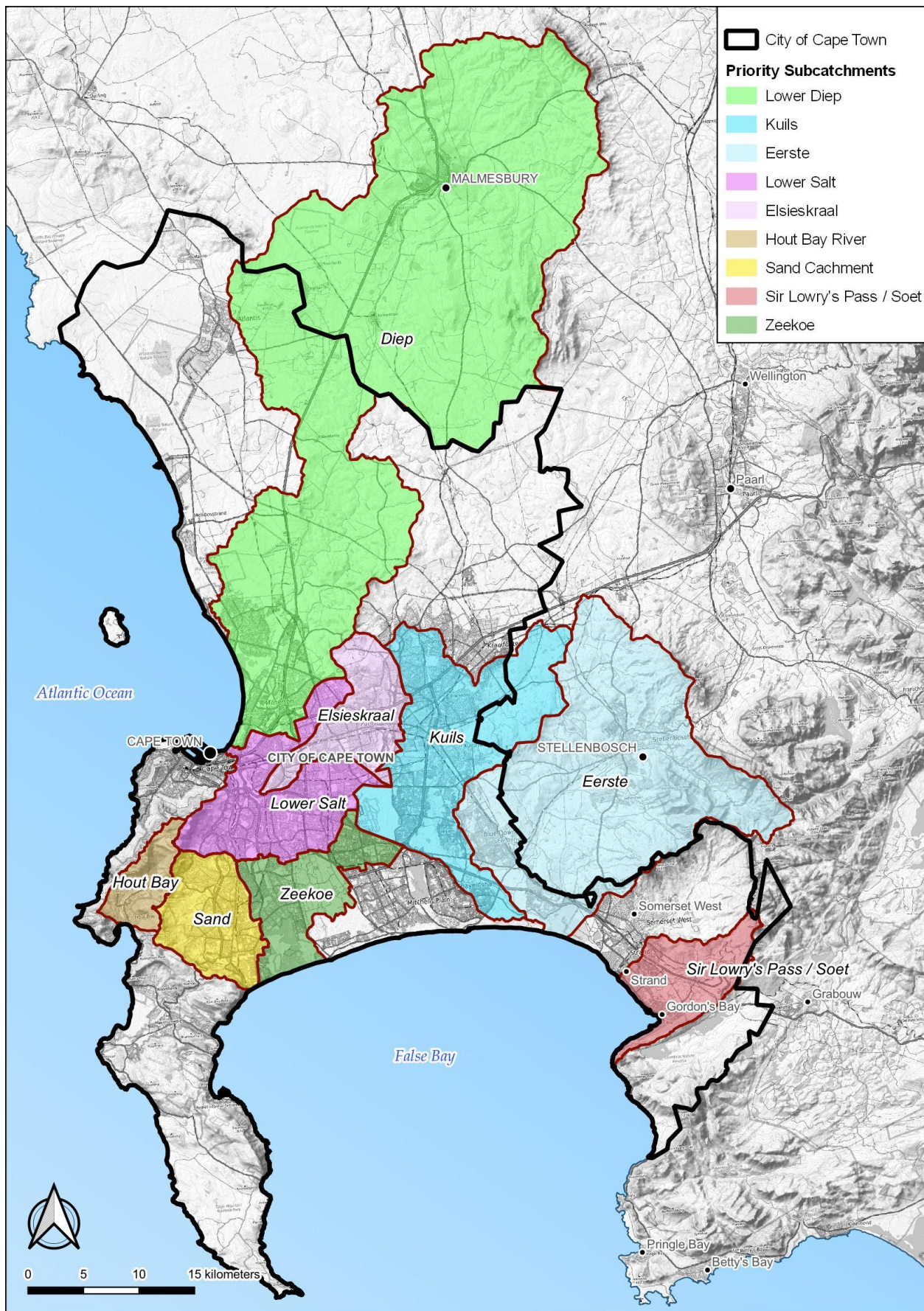


Figure 8.1
The CCT's priority subcatchments

8.2 Diep River

8.2.1 Catchment overview

This priority catchment comprises the Diep River subcatchment, from upstream of Milnerton Lagoon. Rehabilitation and remediation of the Lagoon itself is currently being dealt with separately, through other MPP projects (e.g. Rose et al 2023).

The Diep River catchment extends far north and east of the boundary of the City of Cape Town and includes parts of the Swartland Local Municipality (West Coast District) as well as portions of the Drakenstein and Stellenbosch Municipalities (Cape Winelands District). The Diep River itself rises in the Riebeek Kasteel mountains north of the town of Malmesbury and flows through agricultural areas (mainly vineyards and wheat) before passing through Malmesbury, where it receives treated effluent from the Malmesbury WWTW. Downstream of the town, the river flows through primarily agricultural areas, where its condition is impacted by abstraction from numerous on- and off-channel dams, poor water quality from crops and feed-lots and extensive invasion of its banks by alien vegetation (both eucalyptus and various invasive acacia species) (Rose et al 2023).

The river is joined in the Philadelphia area by its largest tributary, the Mosselbank River, which flows in from the east, rising in the Kraaifontein area of Cape Town and passing through mainly residential and urban / peri-urban areas in its upper reaches and then mainly farms and smallholdings including agricultural feedlots in its lower reaches (ICE 2009). The Mosselbank River is a naturally seasonal, low-nutrient river system that does however now receive perennial effluent inflows from the Kraaifontein and Fisantekraal WWTWs.

Downstream of the Malibongwe Drive / M12 road bridge, the river passes into a burgeoning urban environment. Although formal settlement lies largely outside of the wide 1:100 year floodplain, invasion of the floodplain by informal settlements in the Dunoon area has expanded significantly in the past decade (Rose et al 2023). Most of the informal settlements within the floodplain occur in the area between Malibongwe Drive and the railway bridge and extend well into the floodplains of both the Diep River and its minor tributary, the Kleine Stink River, which enters the Diep River within this zone, passing under Malibongwe Drive some 780 m south east of the Diep River crossing.

Downstream of the Blaauwberg Road bridge, the remnant waterbodies and surrounding undeveloped areas form a broad triangle, included as part of the CCT-managed Table Bay Nature Reserve, and comprising reedbeds and extensive saltpans, as well as Rietvlei, which is made up of a (northern) recreational standing water portion and a (southern) bird sanctuary portion. Rietvlei itself is the product of excavation of natural estuarine saltmarsh and sand dune mosaic habitat in the 1970s to provide infill for development of Cape Town Harbour's Duncan Dock area (Brown and Magoba 2009).

Under pre-development conditions, the Diep River is believed to have flowed through these wetlands, outletting at times into the sea via an estuary mouth in the north, close to today's Dolphin Beach area, as well as from its current position in the south (Scott and Millard 1954). Today however, outside of flood conditions, the Diep River bypasses these wetlands in a diversion channel along the eastern edge of the wetland. This channel receives treated effluent from the Potsdam WWTW as well as stormwater inflows from the Theo Marais channel, just downstream of the WWTW inflows. The channel passes under Theo Marais Drive and enters Milnerton Lagoon. Flows from the diversion canal make up the main source of water from the upstream catchment into the lagoon, outside of flood conditions (Rose et al 2023). Downstream of Otto Du Plessis Drive, various stormwater channels from the eastern catchment also discharge into the lagoon. Of these, the Erica Road outlet is most problematic, as it discharges grey- and black-water, mainly generated in the Jo Slovo settlement, with its high levels of backyard dwellings, the occupants of which often have no alternatives but to discharge sewage and domestic waste into the stormwater system.

While inflows from the Potsdam WWTW result in perennial flows in the lower Diep River today, early literature suggests (e.g. Scott and Millard 1954) that the Diep River and its tributaries were naturally seasonal, with the Diep River and Rietvlei wetlands drying up completely in summer, when the river stopped flowing, around December.

Since then, the hydrological functioning within the catchment has been subject to significant human-induced change. Flows entering the estuary from the upstream catchment are estimated to have been reduced by up to 38% as a result of agricultural abstraction of water (Clark 2018). However, the estuary receives

supplementary flows in the form of treated wastewater from the Potsdam WWTW, which currently offset upstream abstraction (Rose et al 2023), although if effluent quality could be managed, the volume of treated effluent that could be sold for industrial, agricultural or other uses is likely to increase significantly.



Photo 8.2.1
Informal settlement in Dunoon on the Diep River floodplain



Photo 8.2.2
Diep River at the railway crossing downstream of Dunoon – standing water only in summer 2022



Photo 8.2.3
Theo Marais channel upstream of WWTW inflows

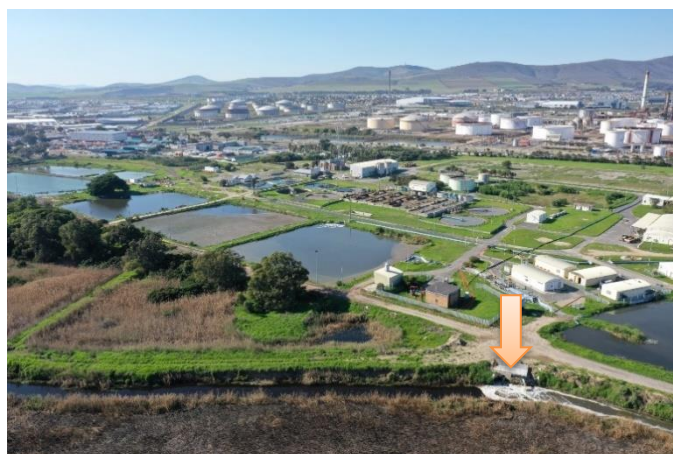


Photo 8.2.4
Aerial view of Potsdam WWTW, effluent outlet (arrowed) and bypass channel. Photo courtesy J. Rose.

8.2.2 River water quality through the catchment – condition and trajectory

At the time of writing this report, Milnerton Lagoon (i.e., the Diep River estuary from downstream of the Otto Du Plessis Road bridge) was rated as an estuary in a state of severe ecosystem collapse, attributed primarily to prolonged inflows of water with high Chemical Oxygen Demand, high levels of (mainly organic) suspended sediments and high total ammonia concentrations from the Potsdam WWTW. The impacts of these inflows are compounded by smaller volumes of polluted inflows mainly from the Jo Slovo area. These pass into the estuary via the Erica Road stormwater outlet¹⁰ into the lagoon, downstream of Otto Du Plessis Drive. During winter and in large rainfall events, polluted water is also flushed in from the Dunoon settlement upstream.

Figures 8.2.1-8.2.3 present summary annual water quality data for phosphate (as $\text{PO}_4\text{-P}$), free ammonia (NH_3) and E. coli data, with actual analyses as outlined in **Section 3.8.10** of this report.

These figures, viewed in conjunction with data already presented in **Sections 5** and **6**, suggest that:

- Water quality entering Milnerton Lagoon is compromised by activities throughout its catchment.

¹⁰ Note that the influence of the Erica Road outlet on lagoon water quality is represented in this report by data for water monitoring point RTV18, in the lagoon downstream of the stormwater inlet.

Phosphate concentrations shown in **Figure 8.2.1** show that river water is phosphate-enriched to Unacceptable (hypertrophic) concentrations even upstream of the CCT boundary, where it is affected by agriculture, including feedlots along both the Diep and the Mosselbank Rivers; inflows from the Malmesbury WWTW and two CCT WWTWs in the Mosselbank subcatchments. High levels of summer time abstraction as well as the impacts of alien vegetation along the riparian area reduce natural summer flows in particular, preventing dilution of polluted inflows. **Figure 8.2.2** also shows high levels of ammonia (within the Poor range) in the Mosselbank River, suggesting low oxygenation compared to chemical and biological oxygen demands;

- Phosphate data comparing median concentrations in the upper Diep and Mosselbank Rivers between the 2020 and 2021 reporting periods nevertheless indicate a >25% reduction in PO₄-P concentrations over this period in the Diep River main stem, upstream of the CCT's boundary;
- Data for the 2021 reporting period show that phosphate concentrations remained in an Unacceptable condition and/or increased by more than 25% in the Diep River mainstem reaches within the CCT boundary, as far as Milnerton Lagoon, and continued on a deteriorating trajectory through the lagoon;
- Ammonia concentrations similarly showed deteriorating conditions through these river reaches, although inflows into the Diep River Diversion channel as well as within the main channel upstream of the Blaauwberg Bridge were in fact still within the Target range for this variable. They deteriorated to the Unacceptable range downstream of the Potsdam WWTW inflows;
- *E. coli* data within the CCT's boundary in the Diep subcatchment showed that *E. coli* concentrations in the Diep River were generally within Target range for this indicator of faecal pollution, but deteriorated to Poor within the reaches upstream of Blaauwberg Road and then deteriorated further to Unacceptable, which levels were sustained through the Milnerton Lagoon. These data indicate high levels of raw sewage that enter the river from informal and backyard settlements in the Dunoon and Jo Slovo settlements;
- It is important to note that the water quality data presented in this report can be misleading, in that they denote concentrations of key water quality variables but not loading. Concentrations are important in understanding the quality of a waterbody for particular user groups including aquatic ecosystems and their flora and fauna. However, loading (which reflects the volume and concentration of water from a pollution or upstream source) is very important for understanding the impacts of pollution sources on downstream receiving bodies. For example, receipt of low volumes of highly polluted water from a particular source may be less important than the receipt of large volumes of less concentrated pollutants. Rose et al (2023) showed that the loading of TSS, total ammonia and COD from the Potsdam WWTW into Milnerton Lagoon by far exceeds polluted inflows from the upstream catchment throughout most of the year. In fact, the Diep River upstream of Blaauwberg Bridge flows as trickle flow to no flow through most of summer. This means that while inflows from Dunoon via direct channels and the Kleine Stink River, which runs through Dunoon, have high concentrations of PO₄-P, NH₃, total ammonia and *E. coli*, these tend to dissipate in summer into pools within the floodplain. During winter, they are flushed downstream. Flows from the WWTW, however, pass continually into the diversion channel and thence into the lagoon, or overflow and pass into the Theo Marais channel and thence into the Milnerton Lagoon. They result in permanent loading of the lagoon with high levels of organic sediment and nutrients with high CODs;
- Data for Rietvlei indicate that this system lay within the Unacceptable range for phosphate in the 2021 reporting period, but nevertheless showed some improvement (i.e., decrease) over median 2020 phosphate concentrations;
- Water quality in the Bayside Canal, which discharges directly into Rietvlei, was rated as Poor and deteriorating with regard to phosphate concentrations in the 2021 reporting period compared with 2020, and within Target range, but deteriorating with regard to ammonia. *E. coli* data showed that the Bayside Canal inflows were rated as Unacceptable for the 2020 reporting period. This channel receives overflows of sewage from blocked pump stations and low-lying manholes in the Bayside area, and from the Table View West pump station in particular (Mr B. De Wet, CCT, pers. comm. To Liz Day, Jan 2023).

8.2.3 Focus areas of the CCT's current remediation programmes

The CCT has been aware of the above sources of pollution into Milnerton Lagoon for well over a decade, having commissioned a pollution-abatement strategy in 2009 (reported on in ICE 2009). Since then, water quality in the subcatchment has deteriorated substantially, as highlighted in the present report.

The following recent pollution and/or aquatic ecosystem remediation studies have however been undertaken in the subcatchments:

- Remediation plan for Rietvlei¹¹ (Infinity 2022), which recommended focused management of pondweed habitat in the vlei, mitigation of upstream pollution sources (mainly in the Bayside canal) and future (but not immediate) dredging of vlei sediments;
- Water quality remediation plan for Milnerton Lagoon (Rose et al 2023), which recommended a number of interventions to address water quality in the Lagoon, including measures to address pollution from the WWTW and Erica Road outlets.

The CCT's 2023/24 to 2024/25 draft financial budgets moreover recognise the urgency of addressing the significant deterioration in condition of the Milnerton Lagoon as a result of catchment level pollution, and the following direct interventions to improve water quality are planned and/or are in the process of being implemented within the subcatchment:

- Remediation of contaminated maturation ponds at the Potsdam WWTW, which have significantly impacted on effluent quality since May 2022 (see Rose et al 2023);
- Upgrading of the Potsdam WWTW to include ultrafiltration of treated effluent for the new works, and improved filtration systems for the existing (upgraded) works – this project commenced in April 2023;
- Remediation of contaminated reedbeds downstream of the WWTW maturation and outlet ponds, to remove contaminated sediments and allow these to be redesigned in part as short-term holding ponds for contaminated effluent, pending repumping back into the WWTW, and (separately) for possible stormwater filtration (as per Rose et al 2023);
- Upgrading of the Koeberg sewage pumpstation, to include screening and a bypass pond for effluent storage during breakdown or load-shedding periods;
- Installation of a new major sewer line through the Montague Gardens area, which will allow maintenance / repairs to the existing major line to the Koeberg pump station;
- Construction of a flood attenuation pond with allowance for water quality filtration through a reedbed wetland between Rietvlei and the Bayside Canal, to address polluted inflows from this point source;
- Active pumping of effluent from the Erica Road stormwater outlet into the adjacent sewer at the Otto Du Plessis Drive stormwater outlet from this system – this was taking place at the time of this report. However, the CCT plans to implement a permanent gravity-fed low flow diversion to the stormwater system on the upstream side of Otto Du Plessis Drive;
- Interventions in the stormwater system in the vicinity of Milky Way, just downstream of the Jo Slovo settlement, to:
 - Include pumped offtakes of contaminated low flows to the adjacent Phoenix pump station;
 - Include screens to capture rags, and other solid waste upstream of the pump station and so reduce the frequency of blockages;
 - Potential construction /re-design of ponds as holding areas for sewage overflows to allow back-pumping;
 - Potential implementation of stormwater biofiltration systems in this area (as per Rose et al 2023).
- Purchase and deployment of a weed harvester for Rietvlei, to allow improved management of pondweed in the wetland, from the perspective of both water quality improvement and recreational use

¹¹ Note that "Rietvlei" in the cited report refers to the greater reedbed and saltmarsh area and the area referred to in the current report as Rietvlei is referred to in the cited report as Flamingo Vlei

(as per Infinity 2022).

8.2.4 Recommendations going forward

Urgent implementation of the above measures is recommended.

Rose et al (2023) noted that one of the reasons for the apparent collapse of the Milnerton Lagoon estuarine ecosystem in 2022 / 2023 was the long delay (10 months) in accessing a pump to allow partially treated effluent at the Potsdam WWTW to bypass the contaminated maturation ponds, and allow remediation of these systems. The CCT needs to establish systems that allow it to escalate procurement of essential equipment needed to address serious problems such as this with the urgency required. This issue, which appears to cut across multiple CCT branches and affects the CCT's ability to address many significant pollution issues, should be addressed at a policy level.

The issue of polluted runoff from informal and backyard settlements is also a complex one, and has implications for human health and dignity within these areas as well as for water quality into downstream areas, and the fitness of these for recreational and other uses. As a short-term intervention, diversions of polluted low flows from these areas to sewers is recommended. One measure that might improve the efficacy of such diversions, by controlling the volume of flows requiring diversion, would be the possible diversion of the Kleine Stink River upstream of Dunoon, so that upstream river flows do not add to the volume of water from Dunoon that needs to be diverted. Kleine Stink River flows could possibly instead be diverted north and into the Diep River.

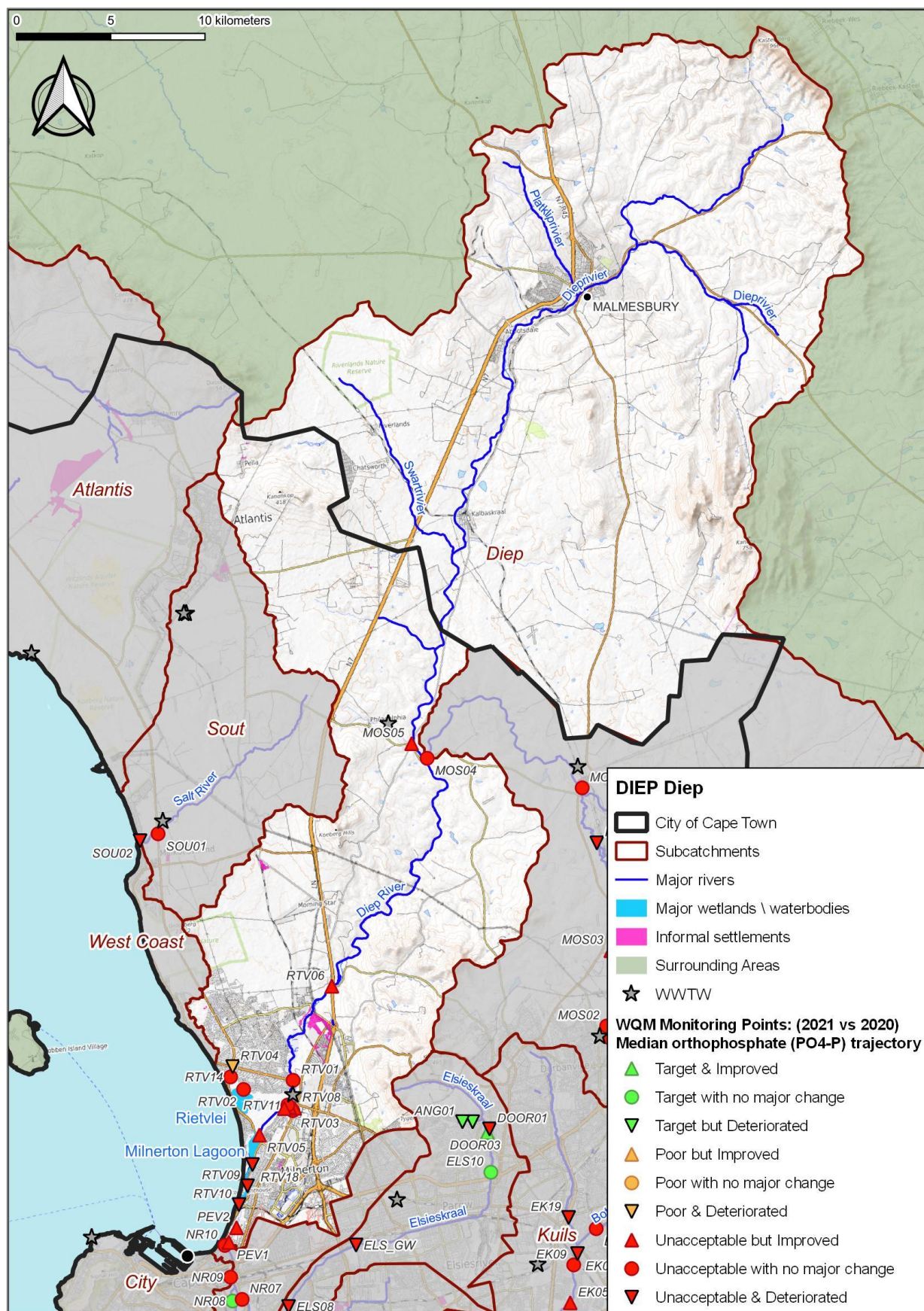


Figure 8.2.1

Median annual phosphate (PO4-P) concentrations, focusing on the DIEP subcatchment
Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020

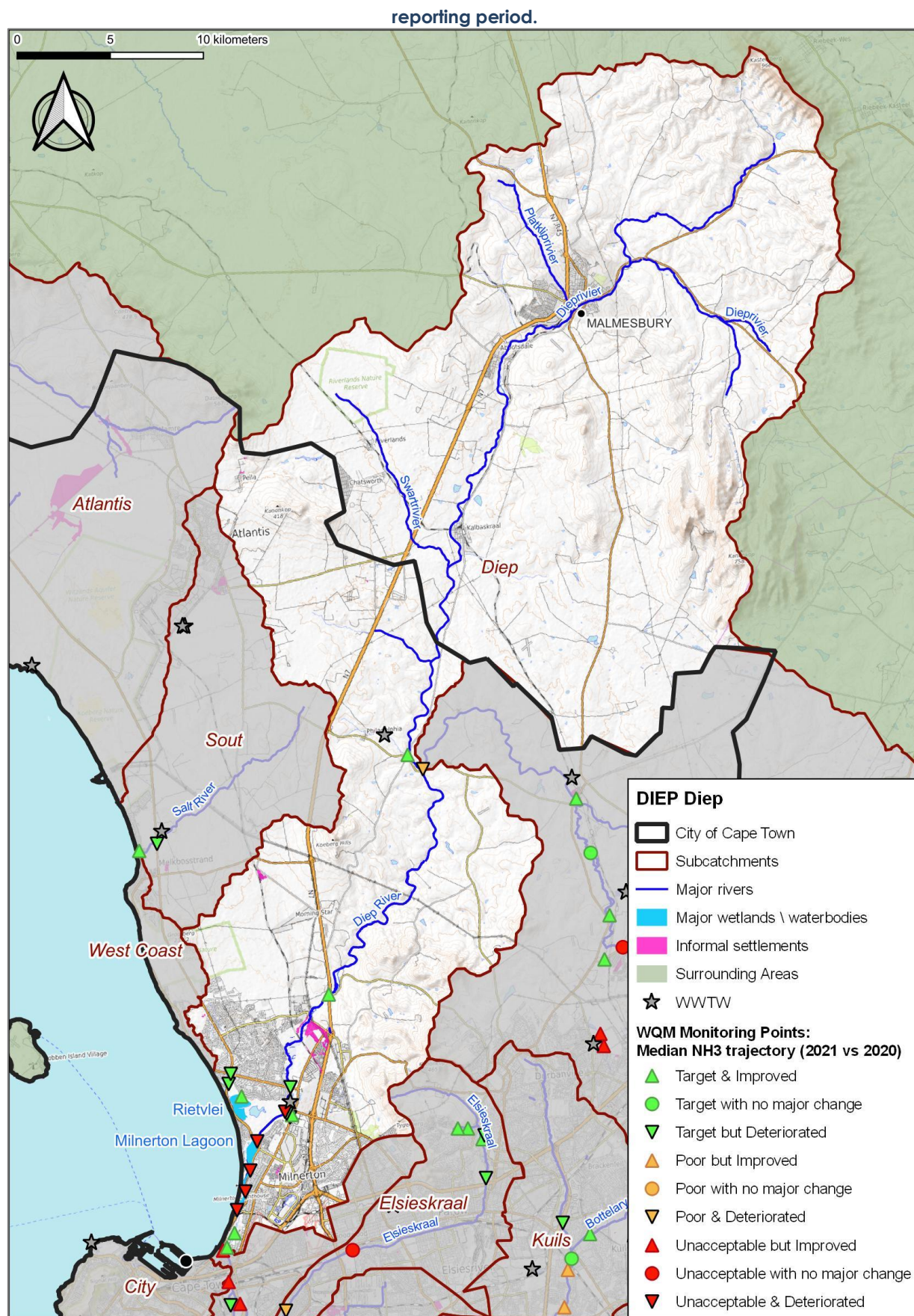


Figure 8.2.2

Median annual free ammonia (NH₃) concentrations, focusing on the DIEP subcatchment.
Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020

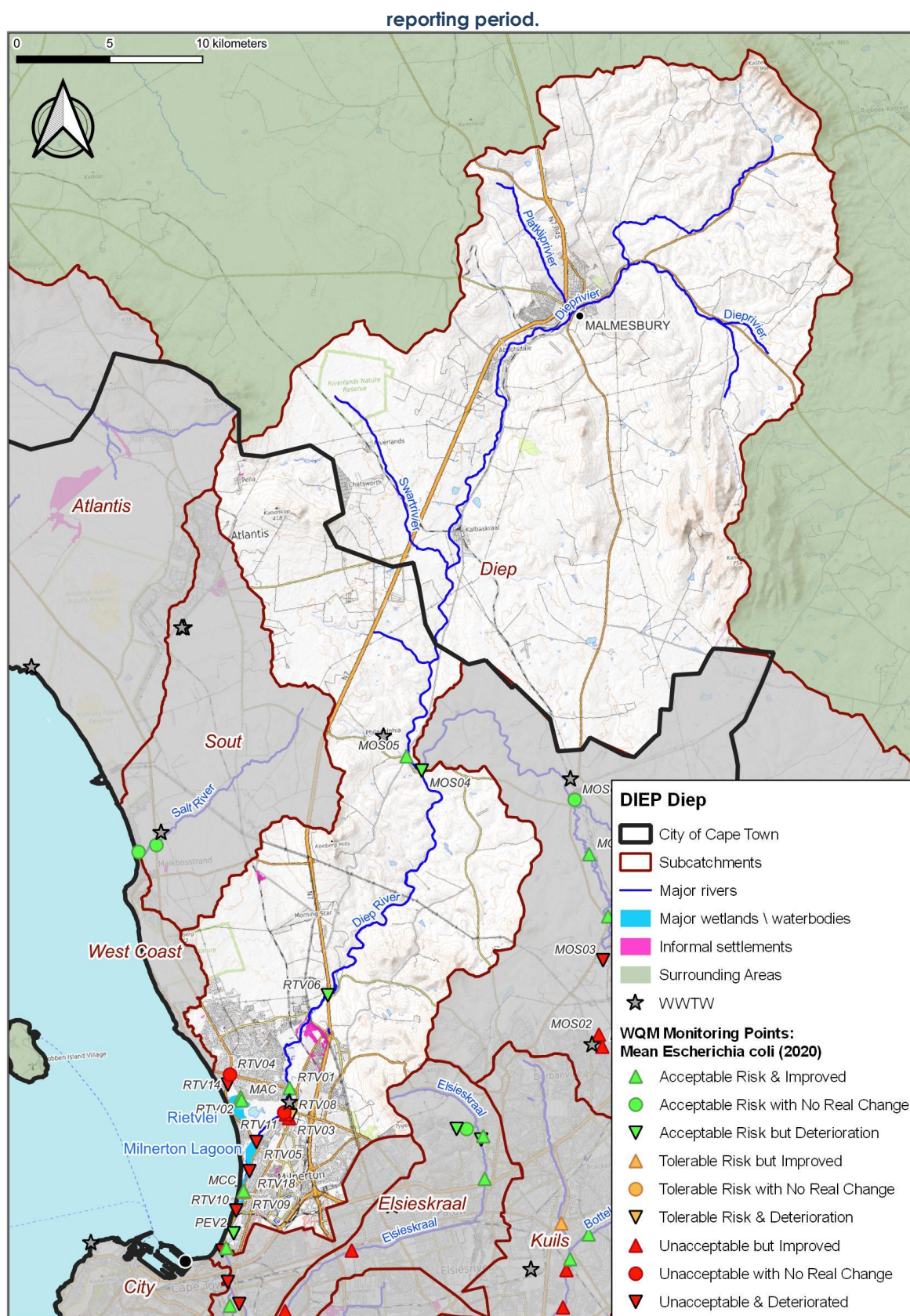


Figure 8.2.3

Mean *E. coli* data (geometric means), focusing on the DIEP subcatchment.

Data coded as to human health risk (see Table 3.5). No reliable data available for the 2021 reporting period, so 2020 data shown in relation to mean data for the 2017-2019 reporting years.

Trajectories calculated and coded as per Section 3.8.10.

8.3 Soet River

8.3.1 Catchment overview

The Soet River (also referred to as the 'Soete River' in some maps and documents) is a small stream that rises in the Schapenberg hills above the suburb of Dennegeur in Somerset West, forming a small catchment wedged between the Lourens and Sir Lowry's Pass River catchments. A number of minor tributaries feed it from the hillslopes, and it passes through a number of large housing developments, including Heritage Park, where these stream flows as well as stormwater generated on the estate are managed in a series of large detention ponds. Upstream erosion results in significant sedimentation at times in catchpits both upstream of the estate and in the detention ponds immediately upstream of the N2. Prior to urban development in this area, the gently sloping foothills of the Schapenberg included extensive hillslope seep wetlands, most of which were destroyed by agriculture.

The other main Soet tributaries lie some 500 m further southeast, and are conveyed downslope east of Chris Nissen Village and under the N2, where they pass through Asanda and Nomsamo – a high-density suburb with large numbers of informal settlements and backyard dwellings. Accumulation of solid waste in open space areas is high.

A small remnant wetland, conserved to offset upslope developments and their associated wetland loss (Ractliffe 2004), remains between the N2 and Asanda Village. This wetland was subject to ongoing infilling, dumping of solid waste including abattoir waste, and encroachment by informal settlement, urban agriculture and livestock. In early 2021, the CCT initiated a community-driven rehabilitation project in the wetland (see below).

The Asanda wetland is fed mainly by one of the Soet tributaries, channeled along the edge of Heritage Park. Downstream of the wetland, these flows are piped through Asanda and Nomsamo, as are the other stream flows. They emerge downstream of these settlements and converge to flow within a single wide, mainly earth, canal between more formal developments. In these reaches, the open channel is visibly polluted with high levels of organic waste, raw sewage from the informal settlement upstream as well as from overflowing manholes, and high levels of solid waste. It is piped from Naomi Street, daylighting again as a polluted stream downstream of the R44, to flow into False Bay.

Data from C3 complaint forms and CCT sewage overflow records for the period July 2020 to July 2021 indicate that the Soet catchment was one of the hotspots for pollution by raw sewage. (see **Figure 5.5.2** in **Section 5.2**).



Photo 8.3.1

Fast flows from a steep erosion-prone catchment bring sediment via the upper Soet, depositing it in stormwater ponds and channels (inset)



Photo 8.3.2

Prior to its 2021 rehabilitation, the Asanda wetland was used as a dump site, and had visibly poor water quality



Photo 8.3.3
Solid waste in the Soet catchment



Photo 8.3.4
Soet River downstream of Asanda and Nomsamo

8.3.2 River water quality through the catchment – condition and trajectory

The CCT includes only one routine water quality monitoring point in this catchment (SOE02). Data presented spatially in **Figures 8.3.1-8.3.3** show that:

- Phosphate and ammonia concentrations were all in the Unacceptable range in both the 2020 and the 2021 reporting periods, and *E. coli* data were in the Unacceptable range for the 2020 period, indicating a system that was hypertrophic, with high aquatic ecosystem toxicity and constituting a high risk to human health for intermediate recreational use. Since many people in the upstream settlements are forced to walk through stormwater flows on a daily basis in the wet season (e.g. Asanda wetland), such human health risks extend well beyond recreational users;
- The above data are in line with the summary data presented in **Section 5** for the Soet catchment, with compliance graphs showing that 100% of TIN and phosphate samples were in the Unacceptable Range throughout 2020 and 2021; DO concentrations declined in the latter period, from 45% of samples within Target range in the 2020 period and 35% Unacceptable, to 0% Acceptable and 65% Unacceptable; >80% of the samples collected in all three reporting periods had ammonia concentrations in the Unacceptable category (increasing to >90% in Reporting Year 2020); and *E. coli* samples always fell very far into the Unacceptable range, and deteriorated between the 2017-2019 and 2020 reporting periods (mean *E. coli* concentrations of 224 812 cfu versus 802 251 between these periods (see **Table C3** in **Appendix C**).

8.3.3 Focus areas of the CCT's current remediation programmes

The following activities have been implemented by the CCT to improve water quality in this catchment:

- Rehabilitation of the Asanda wetland to incorporate it into a community wetland park: This is a LUW project. Project planning commenced in 2014, with detailed community stakeholder engagement. Actual project implementation commenced in 2021, and included removal of large volumes of solid waste and other fill from the wetland; installation of a pedestrian walkway across the wetland, where pedestrians previously had to walk through polluted water in winter; clearing of waste from, and repairs to, the catchpit at the outlet from the wetland into the downstream Soet River; construction of litter and sediment traps downstream of the N2; and the construction of a pathway as well as play and amenity areas along the wetland edge. Construction was nearing completion at the time of submission of this report, although management of dumping and removal of an illegal goat kraal were ongoing challenges;
- Removal of solid waste from the Soet River channel downstream of Asanda / Nomsamo – accumulation of solid waste is however an ongoing issue in this subcatchment.



Photo 8.3.5

Removal of fill and waste and the construction of a pedestrian causeway, play areas and footpaths at Asanda Wetland Park. Planning for this project commenced in 2014 and construction commenced in 2021 as part of the LUW programme



Photo 8.3.6

Construction of a gabion weir across the Asanda wetland to spread stormwater inflows from upstream stormwater inflows. Earth and rubble fill as well as alien vegetation were removed at the same time

8.3.4 Recommendations going forward

Large areas of unserviced dwellings, with associated disposal into the stormwater system of black and grey water as well as dumped solid waste that causes frequent overflows from sewage pump stations and manholes, mean that management of the Soet catchment is challenging for the CCT.

That said, the frequency of solid waste removal from streets, pavements and open spaces is clearly out of line with the volume of waste generated in settlements with little space for storage of waste on-site between collection periods. An increase in the frequency and volume of solid waste collected from areas downstream of the N2, in particular, is strongly recommended.

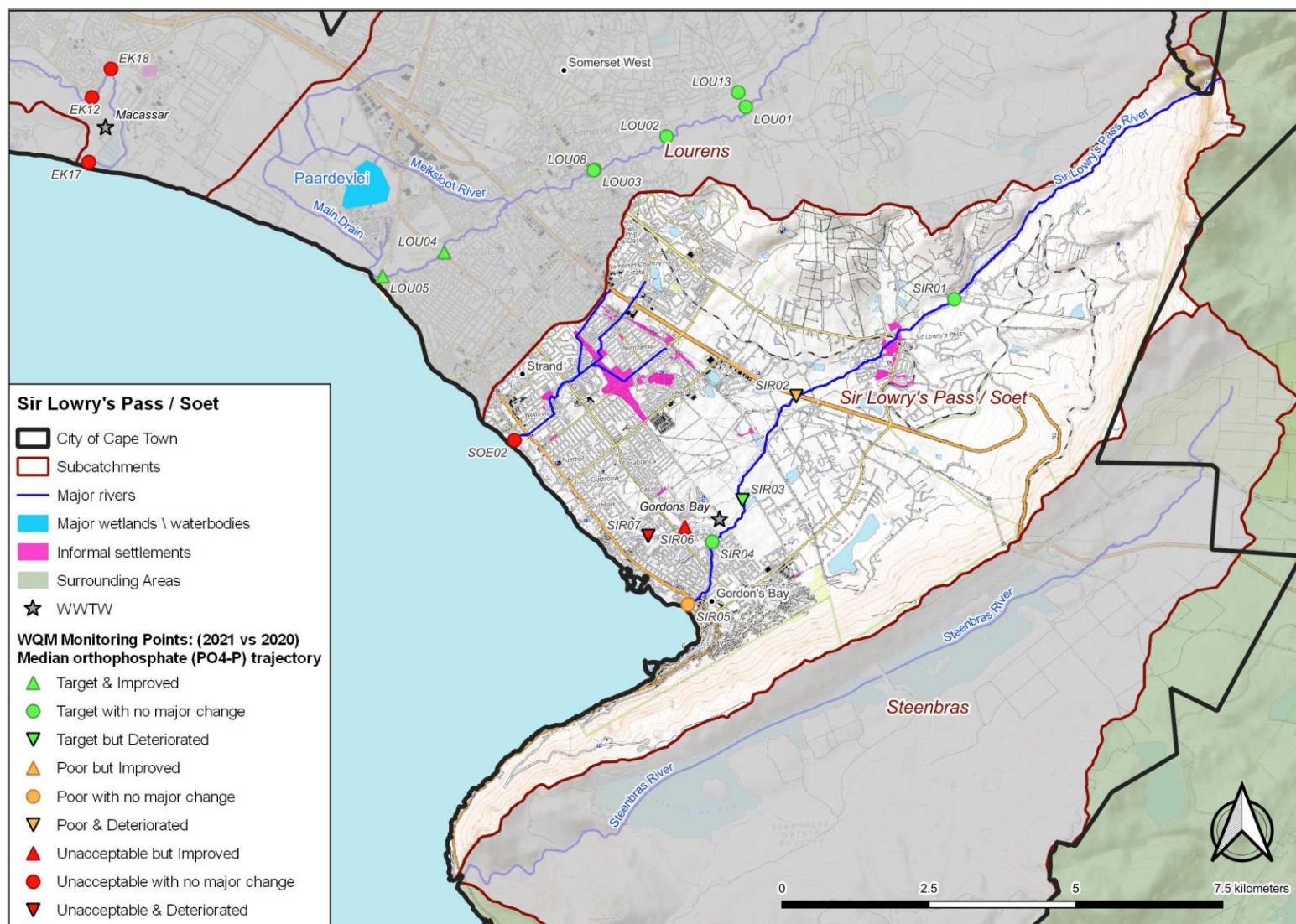


Figure 8.3.1

Median annual phosphate (PO4-P) concentrations, focusing on the SOET RIVER in the Sir Lowry's Pass / Soet subcatchment.
 Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

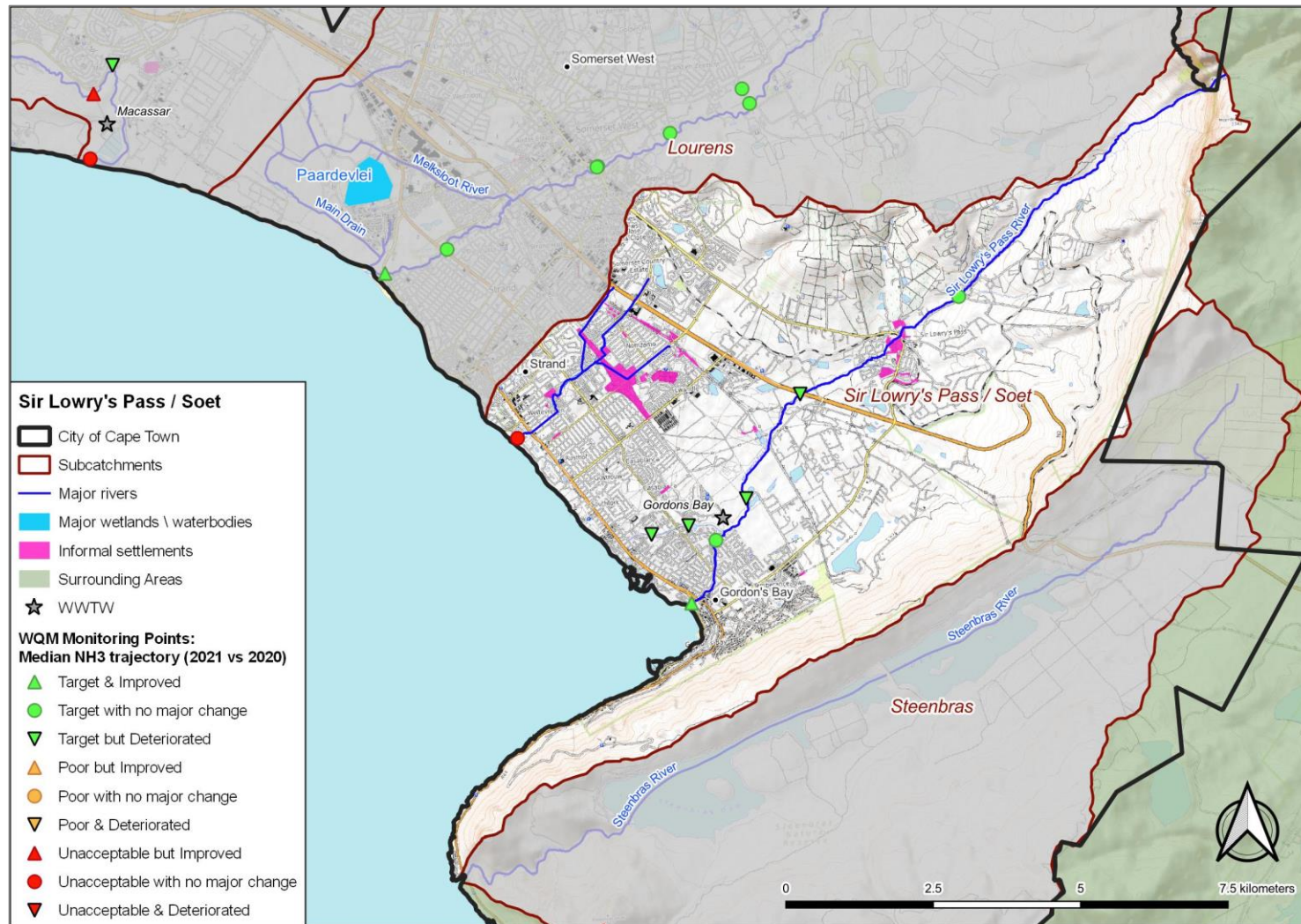


Figure 8.3.2

Median annual free ammonia (NH3) concentrations, focusing on the SOET RIVER in the Sir Lowry's Pass / Soet subcatchment. Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

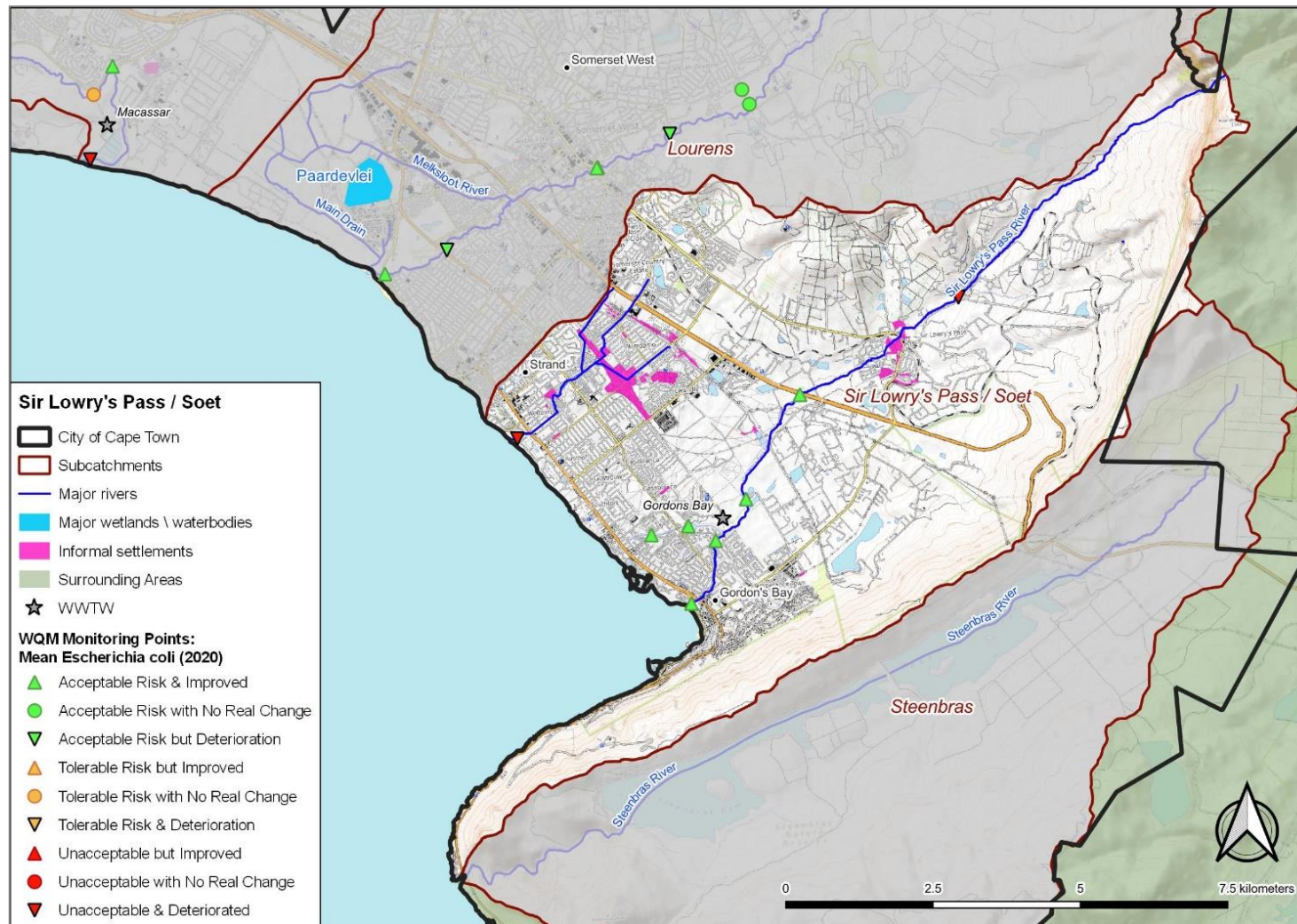


Figure 8.3.3

Mean *E. coli* data (geometric means), focusing on the SOET RIVER in the Sir Lowry's Pass / Soet subcatchment.

Data coded as to human health risk (see Table 3.5). No reliable data available for the 2021 reporting period, so 2020 data shown in relation to mean data for the 2017-2019 reporting years. Trajectories calculated and coded as per Section 3.8.10.

8.4 Lower Salt River subcatchment

8.4.1 Catchment overview

The Lower Salt River subcatchments is relatively large, ranked 6th by area of the 17 major subcatchments within the CCT's boundary. It overlaps three of the four CCT Stormwater Planning Regions (Central, Northern and Southern regions), meaning that three different CCT Catchment Managers are responsible for different sections (see **Figure 3.1**).

The subcatchment is highly developed to the north, east and south, and most of the 'rivers' (see **Figure 8.8** and **Figures 2.1 and 3.1**) are in fact concrete canals constructed to drain the Cape Flats' high water table (Brown and Magoba 2009). An exception to this is the Vygekraal River, which flows within an earth channel through at least some of its reaches, including through the Nantes Park area (the site for one of the CCT's LUW projects).

Many of these low-lying rivers pass through socio-economically challenged suburbs with high levels of crime and gang activity, affecting both local communities and the ability of the CCT to conduct routine monitoring and implement effective interventions. In places, public open spaces, roadsides and pavements have high levels of solid waste, some of which subsequently blocks sewers and causes sewage overflows. **Section 5.5.4** presents data for pump station overflow frequency and C3 complaints about sewage overflows. These data suggest that these parts of the Lower Salt subcatchment experience among the highest frequency and severity of sewage overflows, which are likely to have significant negative impacts on water quality. This is exacerbated by high levels of informal settlement and/or backyard settlements, particularly in the suburb of Langa and surrounds, and the north-western edge of KTC. Although portable toilets are provided for these residents, the toilets themselves in many areas are lined up along the top bank of the river channels, and can readily be drained into the watercourses.

These rivers all join the Black River in the vicinity of the N2, and flow from there until just downstream of the confluence with the Liesbeek River in Observatory. Permanent flows of nutrient-enriched water support the growth of water hyacinth, which requires ongoing management by the CCT. Downstream of the railway bridge, the river channel is canalised to its outlet into Table Bay, and is referred to as the Salt River canal.

Rivers draining into the subcatchment from the west and north form part of the Liesbeek River's catchment, and this enters the Black River in the downstream reaches of the Lower Salt. These rivers drain the eastern slopes of Table Mountain. Their upper reaches lie within the Table Mountain National Park, where they flow as mountain streams first through relatively unimpacted fynbos in the areas above former forestry plantations, Kirstenbosch Botanical Gardens and high-lying affluent suburbs on the lower mountain slopes. The rivers in these reaches are impacted primarily by local surface and groundwater abstraction, affecting the concentrations of pollutants that are passed into the rivers. Fertilisers from lawns and extensive gardens are likely to impact on water quality in the upper river reaches. With distance downstream into densely urbanised areas such as Newlands, Claremont and Rondebosch, most of the rivers are canalised or in some cases piped. Unlined reaches are threatened by development encroachment and vulnerable to erosion. An active Friends Group (Friends of the Liesbeek River) partners with the CCT in alien plant and litter clearing along the Liesbeek River.

In addition to all of the potential water quality impacts relating to the above land uses and issues, the Lower Salt subcatchment also includes the Borchard's Quarry WWTW and Athlone WWTW. Of these, the former discharges treated effluent into a channel flowing immediately north of and along the N2, through the southern edge of Langa, before joining with the Elsieskraal River opposite the Athlone WWTW, and passing under the N2. Treated effluent from the latter is also passed into the channel, which is then known as the Black River. Apart from treated effluent, the Black River is subject to high levels of solid waste as well as inflows of raw sewage from adjacent settlements.



Photo 8.4.1

Eroding channel of the upper Liesbeek River, with still relatively unimpacted water quality



Photo 8.4.2

Informal housing built right over the edge of the Jakkalsvlei Canal, along the N2 past Langa

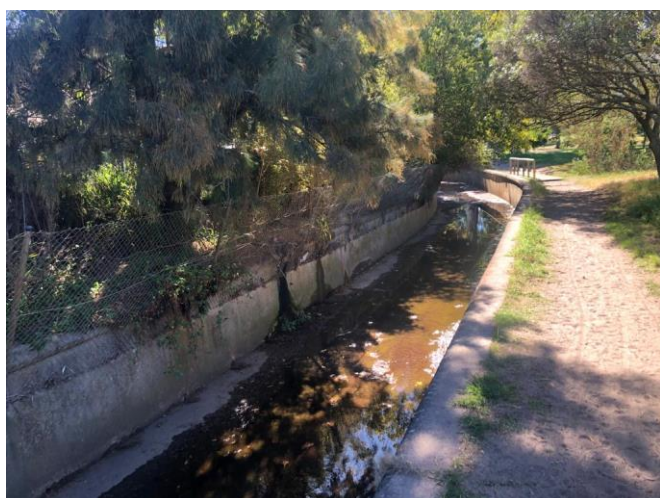


Photo 8.4.3

The canalized Black River upstream of the N2, through Keurboom Park



Photo 8.4.4

Kromboom Canal just upstream of the Black River confluence near the N2. Access to the canal off side streets allows dumping into the canal

8.4.2 River water quality through the catchment – condition and trajectory

Figures 8.4.1 and **8.4.2** illustrate spatial patterns and trends in phosphate enrichment and exposure to free ammonia in the subcatchment for the 2020 and 2021 reporting periods, while **Figure 8.4.3** shows spatial patterns in *E. coli* concentrations in the 2020 period only. The figures highlight the following, interpreted with reference to the catchment descriptions in the previous section:

- The Liesbeek River catchment was in relatively good condition, with the few sites in the catchment lying within the target range for phosphates, ammonia and *E. coli* (2020). Nevertheless, water quality at the most upstream monitoring point (NR22) showed a deteriorating trajectory in the 2021 reporting period for both phosphates and ammonia, while median ammonia concentrations increased at the downstream site NR08 too. The upper catchment includes parts of Bishopscourt and Kirstenbosch Botanical Gardens, which are all potential sources of nutrients, albeit still at relatively low levels. In the lower catchment, an increase in free ammonia is probably correlated with increased sewage spills in the catchment, often linked to load-shedding;

- Throughout the rest of the Lower Salt subcatchment, water quality was severely compromised and in the Unacceptable range for all of the mapped variables (phosphates, ammonia and *E. coli*) at all but one of the sample points (NR24 on the Black River channel in Rondebosch). More specifically, the mapped data show that:
 - Between the 2020 and 2021 reporting periods, median phosphate concentrations either remained unchanged (i.e., Unacceptable) or declined further within this range (in the Blomvlei/Jakalskraal, main stem Black River and Kromboom canals);
 - Improvement in phosphate concentrations, although still well within the Unacceptable range, was evident in the channel downstream of Borcherd's Quarry and the Vygekraal River;
 - The Black River channel at NR24, upstream of the Kromboom and Vygekraal inflows, was the only sample point outside of the Liesbeek catchment that showed median annual phosphate concentrations better than Unacceptable but within the range of Poor;
 - Ammonia concentrations were in the Acceptable range for samples in the (upper) Black River, Black River downstream of the Kromboom River inflows and in the Blomvlei Canal, but in all these cases showed a deteriorating trajectory, with increasing median concentrations. This is likely to reflect, at least in part, increased sewage spills in the catchment, as a result of load-shedding;
 - E. coli* concentrations in the 2020 reporting period were always in the Unacceptable range in these river reaches, other than in the Black River immediately downstream of the confluence of the Kromboom River (*E. coli* in the Tolerable Risk range);
 - Ammonia concentrations (albeit in the Poor range) nevertheless improved in the 2021 reporting period downstream of the treated effluent discharge point from Borcherd's Quarry. This, combined with similarly improved median phosphate concentrations at the same site (NR26) might reflect remediation works completed at Borcherd's Quarry in April 2020 and aimed at improving WWTW efficiency (<https://www.civils2000.co.za/project/borchers-quarry-wwtw-cape-town/>);
 - The data shown in **Figure 8.4.2** do illustrate the role of a few minor catchments in better condition than adjacent ones, in moderating water quality downstream. For example, with regard to ammonia concentrations, Target (but deteriorating) inflows from the Blomvlei channel in 2021 diluted Unacceptable (and deteriorating) inflows from the upstream Jakkalsvlei / Borcherd's Quarry systems, achieving a Poor rating, upstream of the Athlone WWTW, whereafter water quality dropped again to Unacceptable for this variable.



Photo 8.4.5

Dredging organic sludges and solid waste from the Black River
Photo courtesy CCT¹²



Photo 8.4.6

Vygekraal River near Nantes Park at site of proposed pedestrian bridge and near park to be upgraded as part of the LUW Programme

¹² Photo from article by Wesley Ford, 17 February 2022. southernsuburbstatler.co.za/news/dredging-part-of-black-river-clean-up-b0d5991a-bcfb-4194-9b92-22217e3756c5

8.4.3 Focus areas of the CCT's current remediation programmes

Remediation by the CCT to date in this subcatchment appears to have revolved around:

- Ongoing removal of solid waste from the river / stormwater channels – the visible build-up of solid waste in the channels suggests, however, that solid waste removal at a catchment level is inadequate compared to the scale of the problem (see **Photo 8.4.4**);
- A large-scale intervention to dredge sediment from the lower reaches of the Black River, in the latter parts of the 2021 reporting year, resulting in excavation of some 5 000m³ of organic sludges and solid waste from a 2 km stretch of the river (see **Photo 8.4.5**);
- Initiation of a LUW project in the Nantes Park area of the subcatchment, just south of the N2 (see **Figure 7.3**) - this project aims to improve, among other goals, channel and wetland aquatic habitat quality and amenity value. These objectives are all lauded – but realistically the project is unlikely to achieve measurable improvement in water quality in downstream reaches. That said, reduced ammonia concentrations might well be achieved by extended detention of water in wetlands and aeration, and the creation of nodes / islands of aquatic biodiversity in an urban area would be a positive ecological impact regardless of the level of impact on water quality at a subcatchment scale;
- Initiation of the Manenberg canal rehabilitation project – this CSRM project is investigating improved solid waste management in the Manenberg area, particularly in the vicinity of open canals, which include the Vygekraal and Blomvlei canals;
- Increasing provision of back-up generators and UPS systems for pump stations to reduce sewage overflow frequency as a result of load-shedding.

8.4.4 Recommendations going forward

- The absence of any significant informal settlements / backyard dwellings and of WWTWs in the Liesbeek River catchment mean that this small section of the greater Lower Salt subcatchment has water quality issues that result from real stormwater-driven urban runoff only, and not to the untenable mixing of sewage and stormwater in many other areas of the City. This suggests that water quality in the Liesbeek River and its tributaries would probably respond well to SUDS treatment interventions, designed for water quality polishing and removal of low pollution loads. Opportunities to include such measures should be actively sought in this catchment, in order to retain its current Good condition rating. Focus areas for such measures should be reaches showing signs of water quality degradation;
- The most significant polluters of the Lower Salt subcatchment in terms of loading are assumed to be the two WWTWs and inflows from residential areas in the northern, eastern and south-eastern parts of the subcatchment. Attention to the following (highly challenging) aspects is most likely to give rise to measurable improvement in water quality and aquatic ecosystem condition in these areas, and through this, improvement in human living conditions:
 - Load-shedding is likely to contribute to deteriorating water quality in this and other catchments. Ongoing roll-out of back-up generators or UPS power supplies for problem pump stations should remain a CCT priority;
 - WWTWs need to comply with their licensing conditions – in summer, inflows from WWTWs, untreated sewage and grey water discharges from informal settlements, sewage overflow and other mainly illegal discharges into the stormwater system comprise 100% of the flow in the Black River, which was a naturally seasonal river prior to urban development;
 - Attention must be focused on increasing the efficiency or frequency of solid waste collection so that solid waste does not accumulate in urban watercourses, from where its collection is more expensive and less efficient. Solid waste collection must be ramped up to meet the volume of waste produced in these catchments, bearing in mind that many residents do not have space to store waste on their premises for a week between collection periods;
 - The current system of aligning portable toilets along watercourse banks must be revisited, and these toilets should either be relocated elsewhere or bunded to reduce passage of effluent directly into the watercourses;

- Given that the impact on stormwater in many of these areas is the result of inadequate infrastructure to transport sewage and grey water to WWTWs, where pollution streams of raw sewage and grey water exist, these should be diverted into sewers, at least under low flow conditions. It is recognised that this is an inefficient process – but is essential from the perspective of management of water quality in open waterways from a human health and ecological perspective;
- Like many of the CCT's catchments, the Lower Salt is managed by multiple Catchment Planners – it is recommended, as stated elsewhere in this report, that this system should be rationalised into one that is catchment-based, to facilitate more holistic management and responsibility within CCT structures.

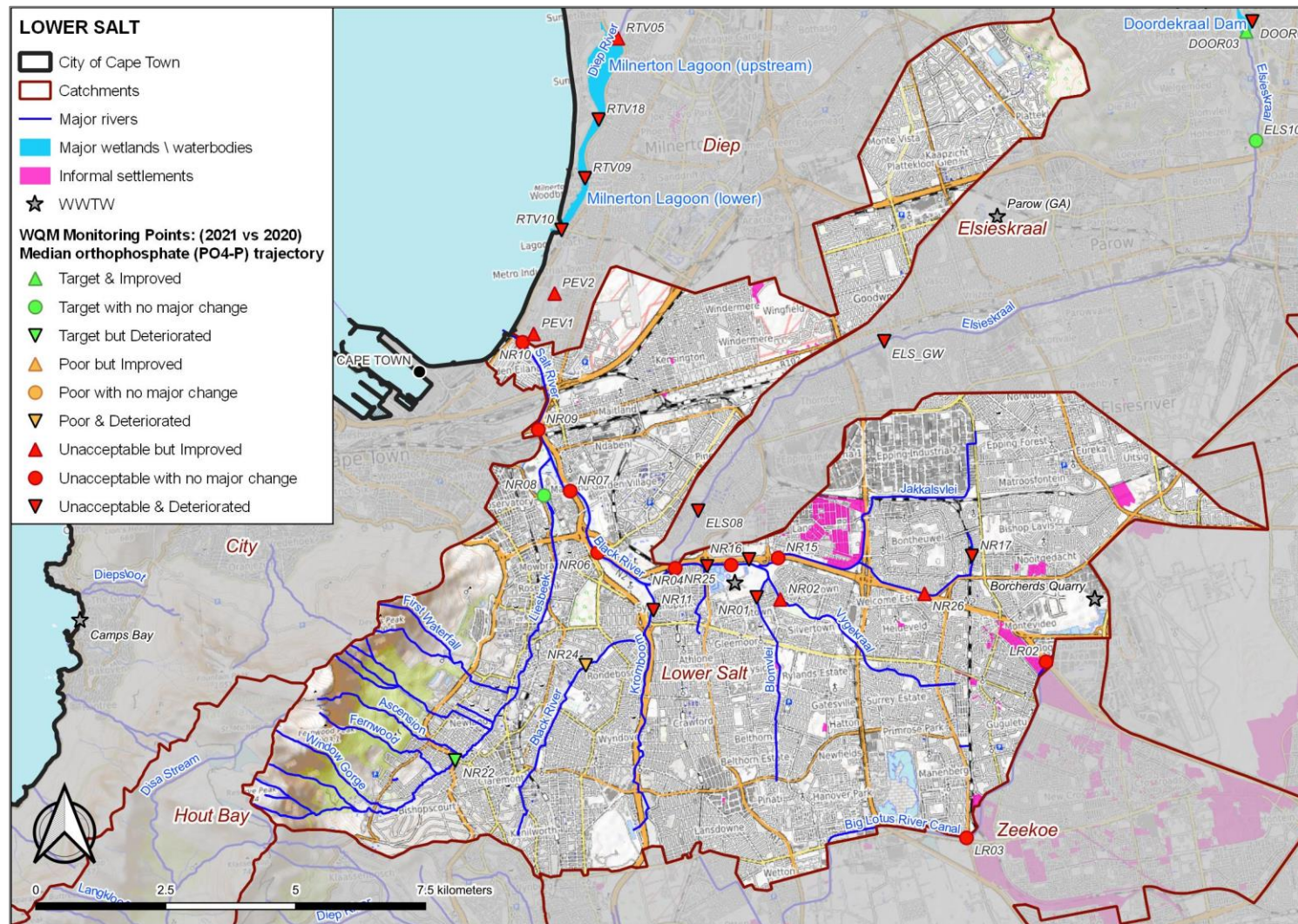


Figure 8.4.1

Median annual phosphate (PO₄-P) concentrations, focusing on the LOWER SALT subcatchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

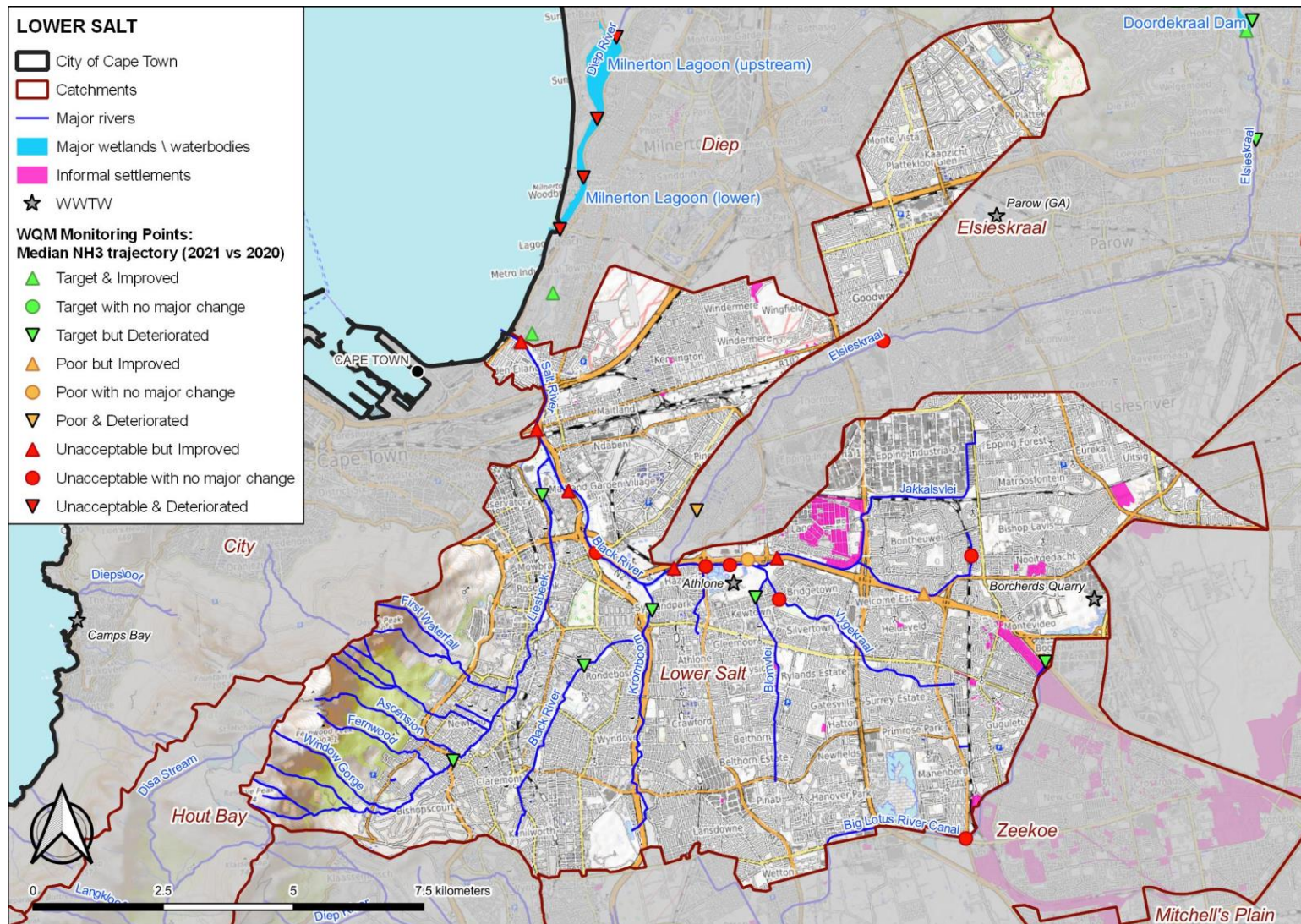


Figure 8.4.2

Median annual free ammonia (NH₃) concentrations, focusing on the LOWER SALT subcatchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

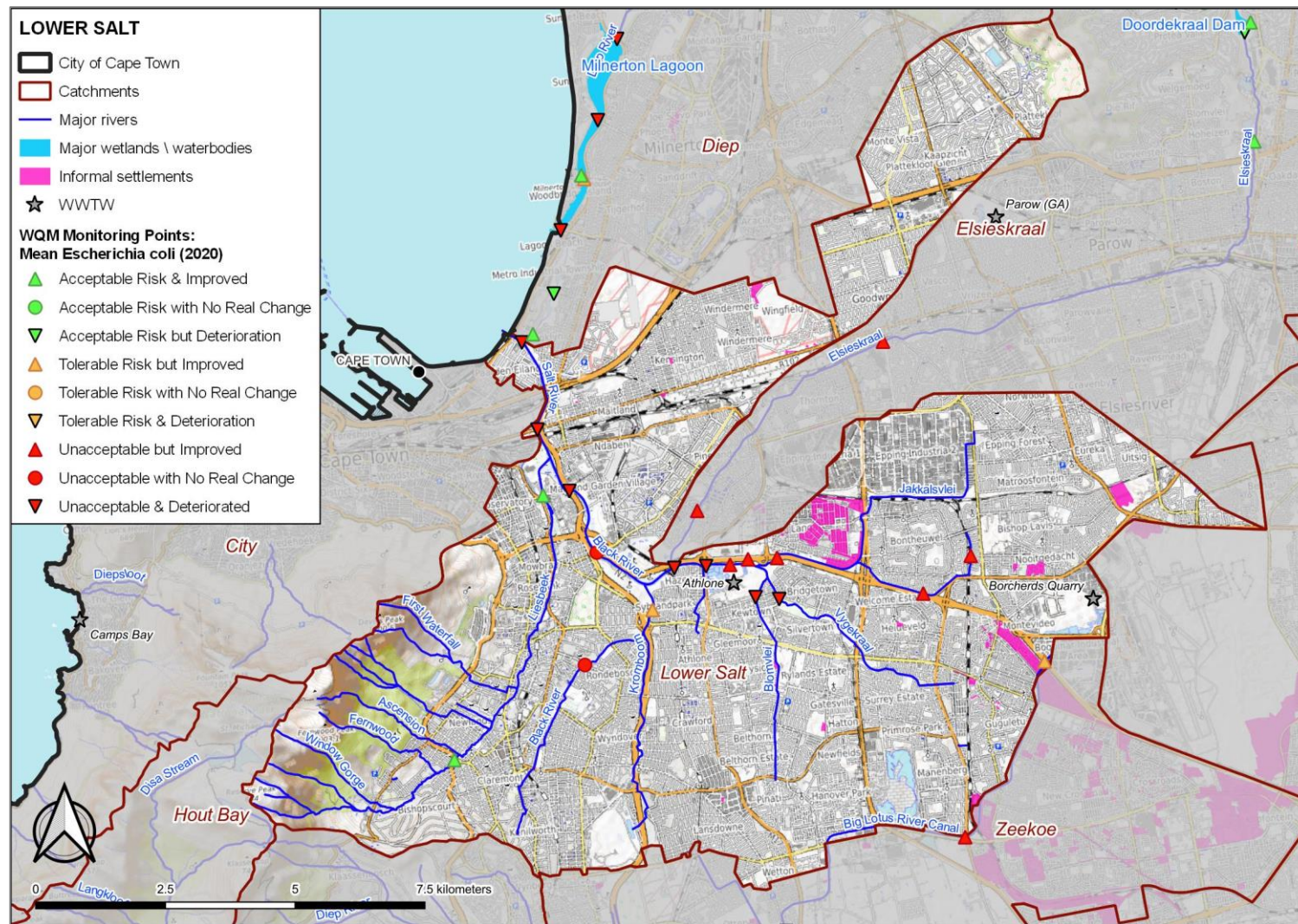


Figure 8.4.3

Mean *E. coli* data (geometric means), focusing on the LOWER SALT subcatchment.

Data coded as to human health risk (see Table 3.5). No reliable data available for the 2021 reporting period, so 2020 data shown in relation to mean data for the 2017-2019 reporting years. Trajectories calculated and coded as per Section 3.8.10.

8.5 Kuils / Eerste River

8.5.1 Catchment overview

This large priority catchment includes the Kuils and the downstream Eerste River subcatchments. Most of the Kuils River and its tributaries lie within the CCT boundary, while most of the Eerste subcatchment lies in the Stellenbosch Municipal area, only entering the CCT boundary in its lower reaches just upstream of the N2 road crossing. Three municipal WWTWs are in operation in the Kuils River subcatchment, and one (the Macassar WWTW) in the Eerste River subcatchment. Of these, the Zandvliet works has recently undergone a major upgrade to increase treatment capacity and improve effluent quality.

Land use in the Kuils subcatchment is primarily urban, and it includes major industrial and commercial areas such as Bellville CBD, Brackenfell, Stikland and Kuilsrivier areas, likely to reflect in stormwater quality typical of these land uses. An exception is the north-eastern corner of the subcatchment in the vicinity of the Scottsdene WWTW indicated in **Figure 8.5.1**, which includes some agricultural land use (mainly wine estates) and more open spaces including golf courses. With distance south through the catchment, land use moves to primarily residential, with high density, low-cost housing predominating downstream of the Stellenbosch Arterial. Discussion in previous sections of this report highlighted relatively high incidences of reported sewage spills in the Delft and Rotterdam areas of the Kuils River in these reaches, as well as high levels of logged pump station overflows (**Section 5.5** and **Figures 5.5.1** and **5.5.2**).

Since the last Inland Water Quality Report (Day et al. 2020), land invasions in the southern parts of the subcatchment have increased exponentially, with the Cape Nature managed Driftsands Nature Reserve just north of the N2 having been deproclaimed in 2022 as a result of land invasions triggered during the 2020 Covid lockdown. These invasions have resulted in loss of important wetlands. In nearby CCT-owned land, similar land invasions have resulted in marked expansion of informal and unserviced areas into wetlands, resulting in the loss of important remnant duneslack wetlands. **Box 8.1** illustrates land invasion along the lower Kuils River in the Khayelitsha Park between 2011 and 2023.

These unserviced areas, and high levels of crime and poor access into burgeoning informal and backyard developments, also result in at-times prolonged sewage overflows and other point-source inflows into the stormwater system and from there, directly, or indirectly into wetlands and rivers (see **Photos 8.5.1** and **8.5.2**).

Box 8.1

Land invasion along the southern boundary of Khayelitsha wetland Park since 2011. Yellow polygon plots Park boundary; red line is the southern Kuils subcatchment boundary. Most notable infill areas arrowed.

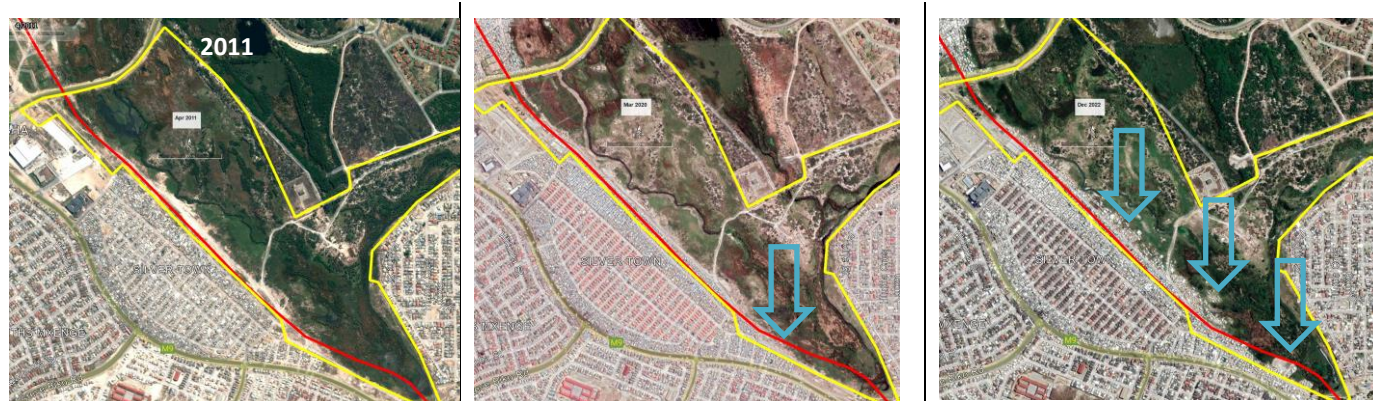




Photo 8.5.1

Out of sight, out of mind – blocked stormwater pipe to Kuils River, Bardale



Photo 8.5.2

Dry weather (Dec 2022) flows in Mfuleni suggest pollution sources

8.5.2 River water quality through the catchment – condition and trajectory

Figures 8.5.1-8.5.3 present summary annual water quality data for phosphate (as $\text{PO}_4\text{-P}$), free ammonia (NH_3) and *E. coli* from routine sample sites in the Kuils and Eerste subcatchments, within the CCT boundaries. Methods of data analysis are as outlined in **Section 3.8.10**.

These figures show that:

- **Phosphorus** enrichment (as measured by median annual data per site) was consistently unacceptable (and in the hypertrophic range) throughout both the Kuils and the Eerste subcatchments in the 2021 reporting period;
- These high levels of enrichment occurred even at the Kuils River main stem monitoring point upstream of both the Bellville WWTW and inflows from the Bottelary River, which receives treated effluent from the Scottsdene WWTW. This suggests sources of phosphorus-enriched runoff in the Bellville CBD and upstream, and would include runoff from inner city areas with high levels of homeless communities as well as inflows from suburban gardens (e.g. Durbanville) and other sources;
- Generally, most sites showed little change in the 2021 reporting period compared to the previous year. The upstream main stem Kuils River site described above did, however, show an increase in phosphorus enrichment, which was carried on to the next site downstream;
- Point source inflows into the Bottelary River from the De Novo Stream, downstream of the effluent discharge point from the Scottsdene WWTW and various local farming activities, showed deterioration in water quality, with median phosphorus concentrations of 2.06 and 2.09 mg P/L in the two reporting periods listed in **Appendix C, Table C3**), and over an order of magnitude higher than the threshold for Unacceptable;
- **Figure 8.5.3** indicates that this site showed higher levels of *E. coli* (in the range of Poor) than either the Bottelary site or the downstream Kuils River site, and if this was repeated into the 2021 reporting period, this might explain elevated phosphorus concentrations too;
- High phosphorus concentrations have long characterised the Kuils and Eerste subcatchments, and have contributed to the abundant growth of reeds and alien aquatic vegetation (e.g. water hyacinth) in the lower river reaches in particular;
- **Ammonia** concentrations, shown in **Figure 8.5.2**, suggest that the upstream catchment of the Kuils River was unlikely to be impacted by ammonia toxicity over the 2020 and 2021 reporting periods, with

monitoring points upstream of the Bellville WWTW all being within the Target range. This despite deterioration in the upstream mainstem Kuils River site, consistent with previous comments that its exposure to raw sewage was elevated in the 2020 period;

- Threats to aquatic ecosystems posed by ammonia toxicity increased downstream of the Bellville WWTW inflow, with the two closest sites downstream of this point being rated as Poor for the 2021 period – their water quality nevertheless showed improvement over the previous reporting year. Increased ammonia concentrations indicate likely much higher TIN concentrations, with a high proportion of NH₄:TIN, reflecting high CODs and low DO downstream of the point of effluent discharge. This is borne out by median data for individual sites, presented in **Table C2** in **Appendix C**. The table shows that median NH₄N:TIN ratios at the site downstream of the Bellville WWTW (EK05) varied between 76% and 75% in the 2020 and 2021 reporting periods respectively, indicating that over 75% of the nitrogen load was in a reduced form (i.e., total ammonia nitrogen), with a portion comprising the free ammonia discussed here;
- Ammonia concentrations remained in the Poor range through the extensive areas of informal settlement in the lower Kuils River, as far as Baden Powell Drive. The lack of improvement in this variable with distance downstream points to high loading from upstream WWTW inflows, continued inflows from informal settlements and backyard dwellings, and a generally 'dirty' downstream catchment;
- Ammonia concentrations increased downstream of inflows from the Zandvliet WWTW, falling into the Unacceptable range, indicating probable sustained acute toxicity impacts to aquatic organisms. Notwithstanding, all sites downstream of these inflows did show improvement over the 2021 reporting period, indicating possible early impacts associated with upgrading of the WWTW, which commenced in 2018;
- *E. coli* data for the 2020 reporting period suggest poor functioning at least at times at the Bellville WWTW, with samples within the Unacceptable Range from this point downstream;
- Despite passage of the Kuils River through extensive areas of informal settlement in its lower reaches, *E. coli* concentrations were within the Target range by the Baden Powell Bridge, and remained within Target range as far as the Macassar WWTW, whereafter they increased to within the Unacceptable range, suggesting poor performance at the latter plant with regard at least to disinfection;
- Inflows into the Kuils River from the (artificial) Kleinvlei Canal were within the Unacceptable Range for all three variables mapped for this section – this canal is characterised by high levels of dumped organic and solid waste and the reflected data tally with the observed situation.

8.5.3 Focus areas of the CCT's current remediation programmes

Over the actual reporting period considered here, there were few direct interventions by the CCT to address water quality in these socially and economically complex, large subcatchments (the Kuils subcatchment is the 4th largest by area in the city).

However, PASAPs (see **Section 7.2**) have been developed for the upper Bottelary River, and their implementation could reduce pollution incidents and magnitude in this area, where inflows from the Scottsdale WWTW are considered a significant pollution source, on the basis at least of PO₄-P.

A number of low-cost housing projects are being planned and some are under construction in the Mfuleni area, amongst others. Some of these will occur in areas subject to high levels of land invasion into wetlands, and it is arguable that formalisation of housing and sewage services there could at least ameliorate downstream pollution streams from alternative expansion of unserviced settlement. This argument applies only if formal development is accompanied by high levels of clearing of solid waste before it enters watercourses; focused attention on maintenance of stormwater management systems; and attention to localised point source effluent streams within housing areas.

8.5.4 Recommendations going forward

Taking account of the notes and comments above, the following recommendations apply – although they are not applicable only to this subcatchment, but to all areas of the city subject to expanding informal settlement:

- A sustained and measurable increase in solid waste collection effort is required to prevent the build-up of organic, plastic and other waste in the catchment. This requires significantly increased focus on the frequency and volume of removal of solid waste at source;
- Pollution tracking within new and existing high-density housing areas is recommended to identify pollution streams and sources – where these stem from unserviced backyard or informal housing elements, diversion of lowflow pollution streams to sewer should be considered as a resource protection measure. Regular pollution tracking through these areas would also help to identify areas of blocked or vandalised infrastructure, often linked with pollution streams;
- Interventions to provide sewage and stormwater servicing to the rapidly expanding informal and backyard settlements in the area need to be implemented;
- Inclusion of an additional monitoring point at the river crossing on Old Faure Road is moreover recommended as a potentially useful means of providing water quality information about the contribution of this part of the catchment to downstream nutrient loading, measured at the Baden Powell Road crossing only.

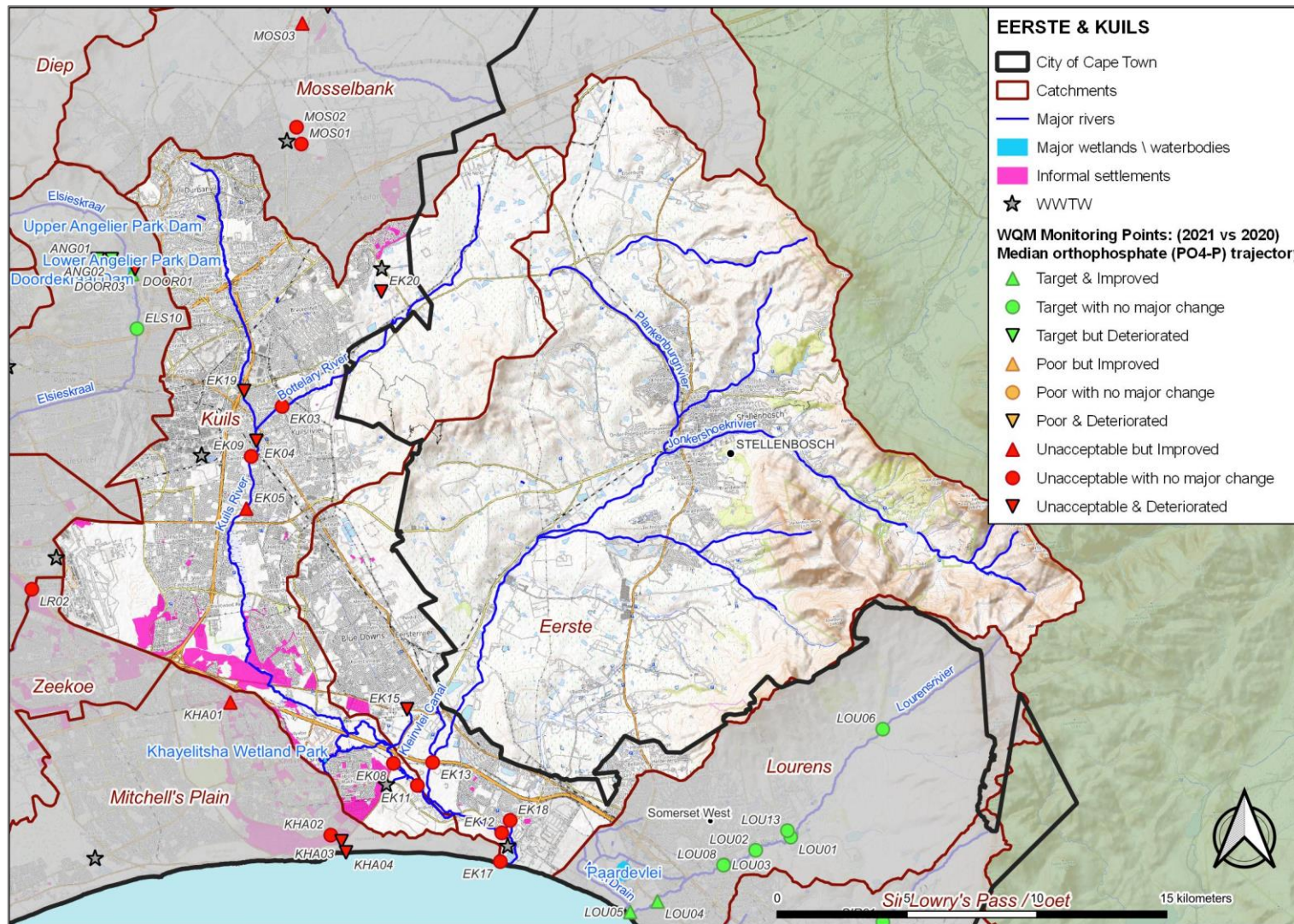


Figure 8.5.1

Median annual phosphate (PO₄-P) concentrations, focusing on the KUILS /EERSTE subcatchments.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

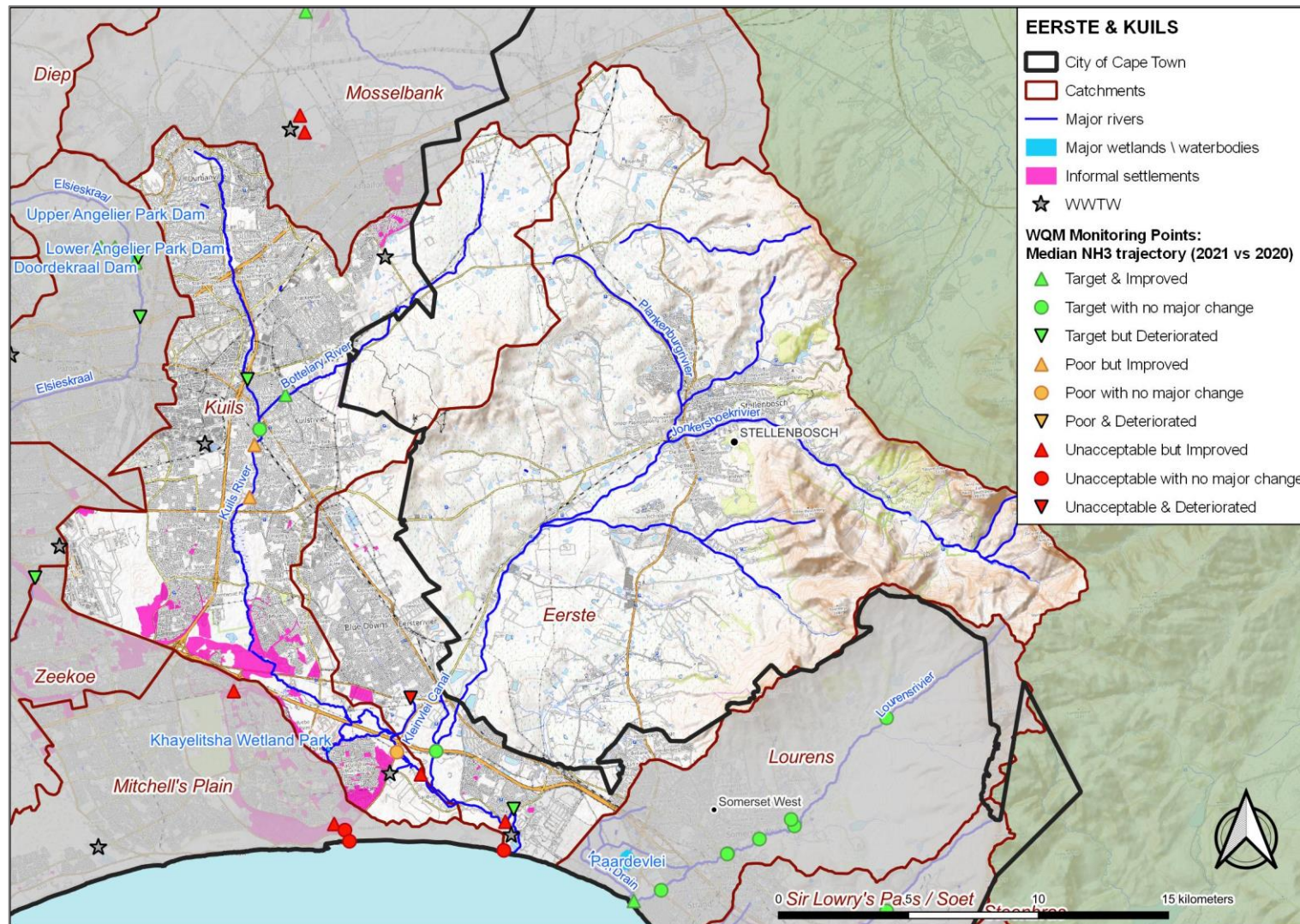


Figure 8.5.2

Median annual free ammonia (NH3) concentrations, focusing on the KUILS /EERSTE subcatchments.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

City of Cape Town

Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

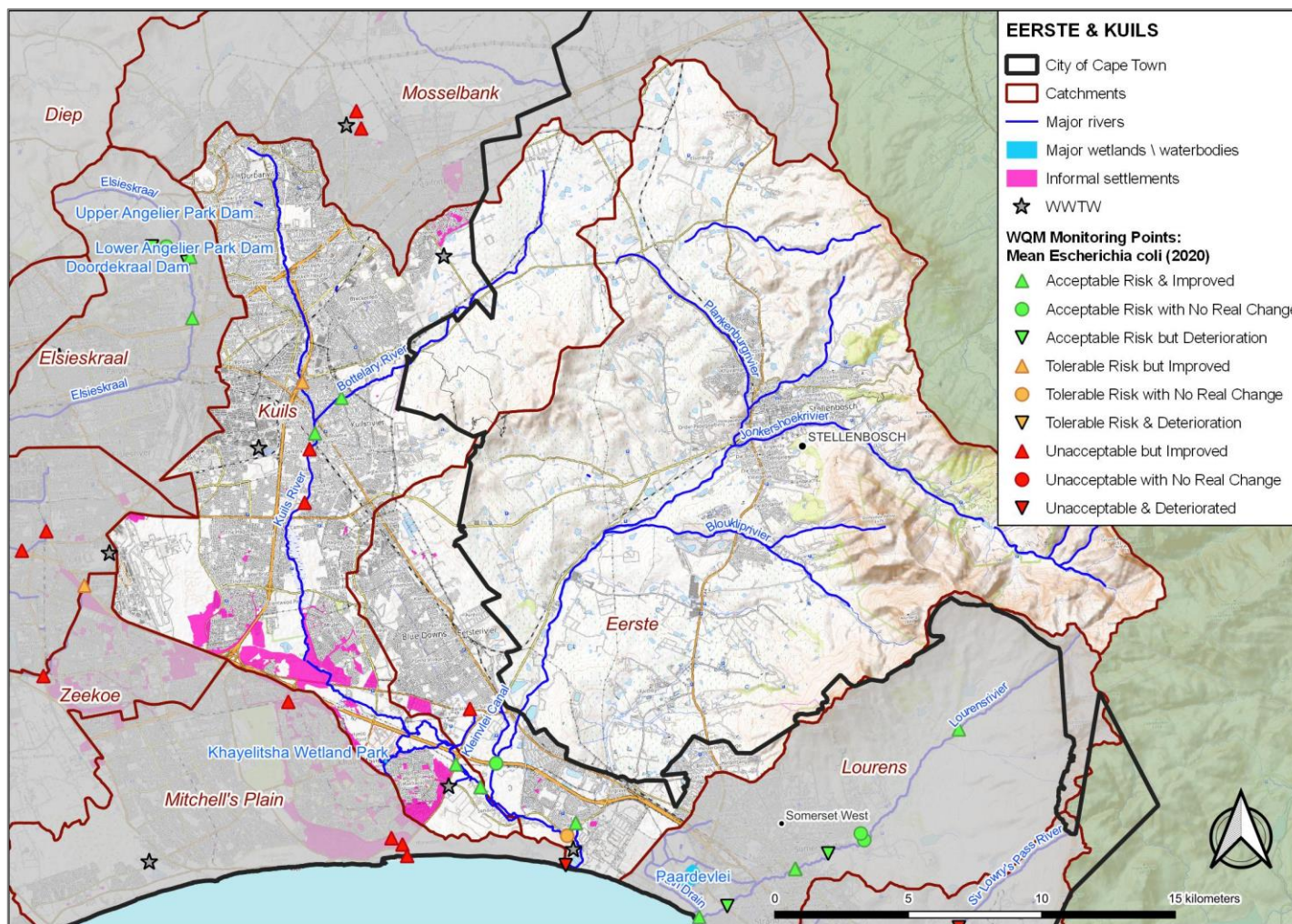


Figure 8.5.3

Mean *E. coli* data (geometric means), focusing on the KUILS /EERSTE subcatchments.

Data coded as to human health risk (see Table 3.5).

No reliable data available for the 2021 reporting period, so 2020 data shown in relation to mean data for the 2017-2019 reporting years.

Trajectories calculated and coded as per Section 3.8.10.

8.6 Hout Bay River

8.6.1 Catchment overview

Most of this contextual information is taken from the State-of-Rivers Report prepared by the River Health Programme (RHP, 2003). The Hout Bay River catchment is a relatively small catchment (approximately 40 km² in areal extent), with the entire upper catchment located within the Table Mountain National Park consisting mostly of natural areas. The middle to lower portions of the catchment are, however, dominated by urban, peri-urban, and commercial land-uses, occupying approximately 20% of the catchment area. There is a relatively large (especially in relation to the catchment size) informal settlement (Imizamo Yetho) in the lower reaches of the catchment. A number of domestic water supply dams in the upper catchment (see **Box 8.1**) have significantly affected the flows of the Hout Bay River.

The Disa and the Original Disa tributaries originate on Table Mountain at an altitude of 720 m AMSL. These streams join to form the Hout Bay River in the access-controlled Orange Kloof section of the Table Mountain National Park, which contains a relatively large, intact area of Afromontane forest. The Hout Bay River is approximately 12 km long, with steep and fast-flowing, naturally acidic waters in the more natural upper to middle reaches. The river meanders through farmlands and residential areas in the lower reaches, where extensive reed beds flank the river channel, before it widens into a small lagoon which discharges into the sea on Hout Bay beach.

The name Hout Bay refers to the abundance of indigenous trees that once occurred in the middle to upper reaches of the catchment ("hout" is the Afrikaans word for wood). The lower reaches of the Hout Bay River originally consisted of a naturally braided channel flowing through an extensive palmiet (*Prionium serratum*) and reed wetland area. Large-scale harvesting of the indigenous forest in the upper catchment and removal of palmiet and reed beds in the naturally wide floodplain resulted in severe erosion along the middle and lower reaches of the Hout Bay River, which was addressed by the construction of the rather extensive concrete Longkloof weir that had its own negative impacts on the ecological functioning of the downstream reaches of the river.

Other impacts in the middle to lower reaches of the Hout Bay River include the encroachment of invasive alien vegetation along the riverbanks (e.g. see **Photo 8.5.1**), channel straightening, dredging of sediments from the channel and construction of levees to prevent flooding of riverside properties. There are no WWTWs that discharge wastewater into rivers in the Hout Bay catchment because primary treated wastewater from the area is released into Hout Bay via a deep-sea outfall. There are, however, sewage pipelines in the catchment, as well as septic tanks and the informal settlement of Imizamo Yethu, which cause sewage-related pollution problems and the proliferation of algae, reeds and other alien instream vegetation in the middle to lower reaches of the Hout Bay River (e.g. see **Photo 8.5.2**).

Box 8.1

Dams in the upper Hout Bay catchment

The Hout Bay River was an important water resource for Cape Town over 100 years ago, with some of the earliest domestic water supply dams for the city having been constructed in the upper reaches of the catchment (on top of Table Mountain). There are five in-stream dams, namely:

- **Woodhead Dam** (built in 1897) and **Hely-Hutchinson Dam** (built in 1904) on the Disa tributary; and
- **Alexandra and Victoria Dams** (built in 1903), and **De Villiers Dam** (built in 1907) on the Original Disa tributary.

The total storage volume of the five dams is approximately 2.5 Mm³, representing 24% of naturalised MAR of the catchment (RHP, 2003). These dams now supply less than 15% of Cape Town's water requirements.



Photo 8.6.1

Example of the transformed lower reaches of the Hout Bay River, significantly affected by encroachment of invasive alien vegetation along the channel banks



Photo 8.6.2

Close-up shot showing the visibly polluted lower reaches of the Hout Bay River, where there is a proliferation of algal growth and instream alien vegetation

8.6.2 River water quality through the catchment – condition and trajectory

Figures 8.6.1-8.6.3 present summary annual water quality data for phosphate (as $\text{PO}_4\text{-P}$), free ammonia (NH_3) and *E. coli* data, with analyses undertaken as outlined in **Section 3.8.10** of this report.

These figures show that, for the Hout Bay River:

- Water quality was generally good upstream of the more urbanised portion of the catchment (above site DR06 at Bethel Road);
- Water quality deteriorated significantly in the middle to lower reaches, which are dominated by residential land-use including the informal settlement of Imizamo Yethu;
- At the upstream sites that were sampled, median $\text{PO}_4\text{-P}$ and NH_3 concentrations were within Target in both the 2020 and 2021 reporting years, while the mean *E. coli* concentrations in Reporting Year 2021 was also within the Target range at these sites;
- At the sites that were sampled downstream of Imizamo Yethu (i.e., at and below DR02 at Victoria Road), median $\text{PO}_4\text{-P}$ and mean *E. coli* concentrations were in the Unacceptable range in Reporting Year 2021, indicating phosphate enrichment and sewage contamination in these lower reaches of the river;
- There was an increase in the median $\text{PO}_4\text{-P}$ concentration at site DR02 immediately downstream of Imizamo Yethu from Reporting Year 2020 to Reporting Year 2021, indicating a deterioration in the river here in terms of phosphate enrichment;
- While median NH_3 concentrations were within the Target range at the lower sites, there was a deterioration at site DR02 immediately below Imizamo Yethu, suggesting an increasing risk of ammonia toxicity although the generally low pH values (all <7.5 with an average of <7) recorded at all sites along the Hout Bay River in the 2020 and 2021 reporting years (and prior to that) mitigate the risk of ammonia toxicity in this river at present;
- The eutrophication and bacterial contamination of the middle to lower reaches of the Hout Bay River is largely attributable to inflows of untreated sewage from the Imizamo Yethu informal settlement into the stormwater network and sewer overflows as a result of blocked pipes, exacerbated by significantly reduced river flows during summer from dams and other abstraction in the catchment.

8.6.3 Focus areas of the CCT's current remediation programmes

Over the reporting period considered here, there were few water quality related interventions by the CCT in the Hout Bay catchment, although the Hout Bay River Catchment Forum (HBRCF) has been active since May

2016, together with the Friends of the Rivers of Hout Bay. These community-based groups have been working in partnership with the CCT to address some of the water quality and sanitation issues in the catchment (Ellis 2016).

Subsequent to the reporting period considered in the current report, the CCT has however undertaken sewer pipe cleaning work along the Hout Bay River (April – July 2022), to prevent the blocking and surcharging of sewer pipes (**E.G.** see **Photo 8.5.3**).



Photo 8.6.3

Debris cleared from sewer pipes in the Hout Bay catchment (April 2022)
[photo credit: Andrew Taylor, City of Cape Town]

8.6.4 Recommendations going forward

The main water quality issues in the Hout Bay catchment are associated with a lack of adequate sanitation in the Imizamo Yethu informal settlement and the subsequent inflows of untreated sewage into the stormwater network that discharges into the lower reaches of the Hout Bay River.

The following recommendations are made, to facilitate improvement in the water quality of the middle to lower reaches of the Hout Bay River catchment:

- An urgent focus on interventions to provide sewage and stormwater servicing to the Imizamo Yethu informal settlement;
- Improved solid waste management in Imizamo Yethu;
- More frequent cleaning of blocked sewer pipes throughout the catchment;
- Diversion of contaminated stormwater to the sewerage network and/or provision of decanting points for the disposal of waste water into the sewer line at Imizamo Yethu, to prevent or at least reduce the discharge of “black water” from the informal settlement to the river; and
- Continuing active engagement with the HBRCF to understand where the most urgent problem areas are and to formulate solutions together.

Although the Hout Bay catchment is split into two CCT stormwater management regions (see **Section 2.8** and **Figure 2.2**), the portion of the catchment that falls within the Central region is almost all within the mostly unpolluted Table Mountain National Park, while the portion that falls within the Southern region includes the middle to lower portions of the catchment where there are serious water quality issues that need to be addressed. As such, the problem of fragmented management of water quality due to the stormwater management regions not aligning with topographical catchments is less of an issue in the case of the Hout Bay catchment than it is for other “split” catchments in the city.

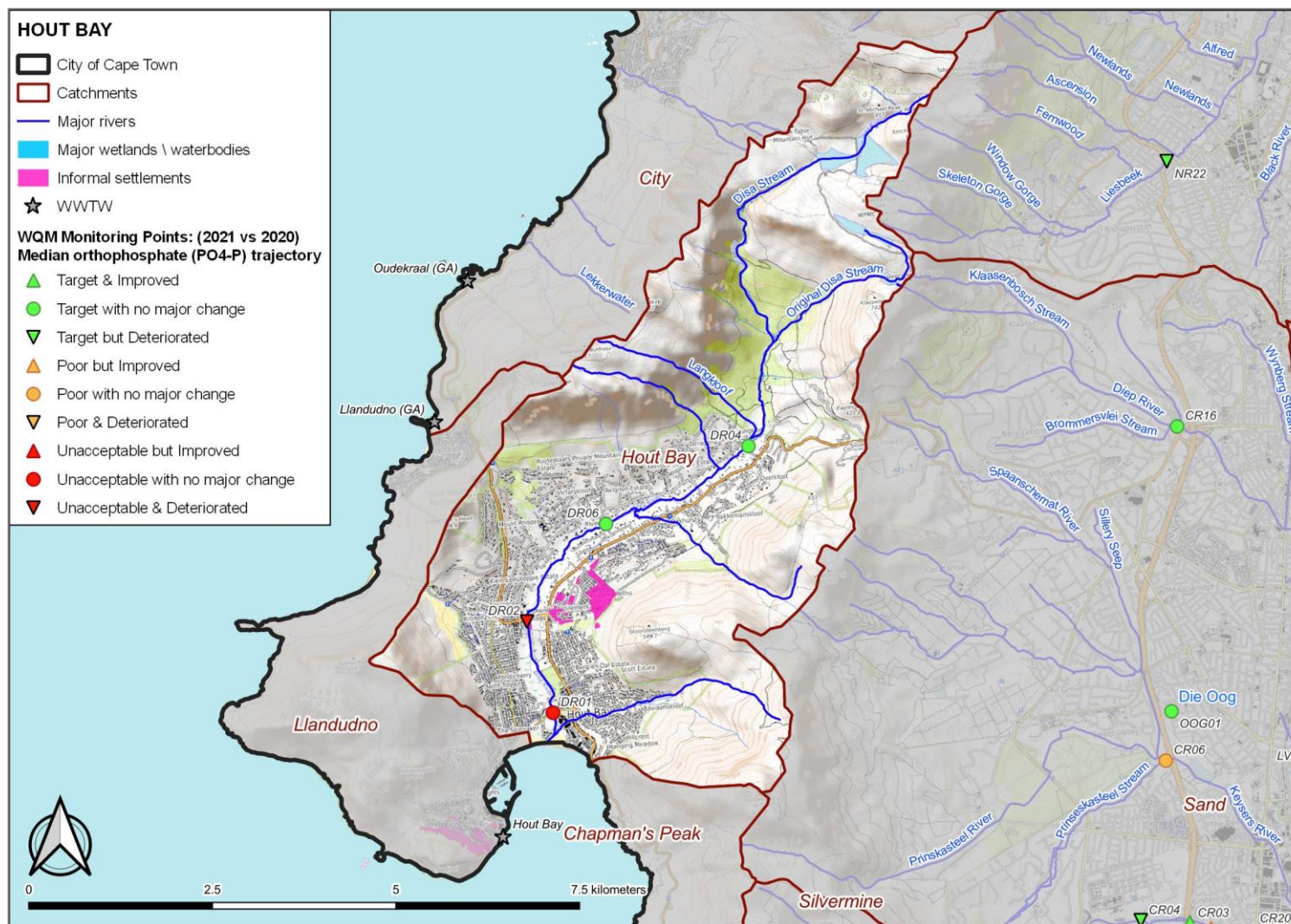


Figure 8.6.1

Median annual phosphate (PO₄-P) concentrations, focusing on the HOUT BAY catchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

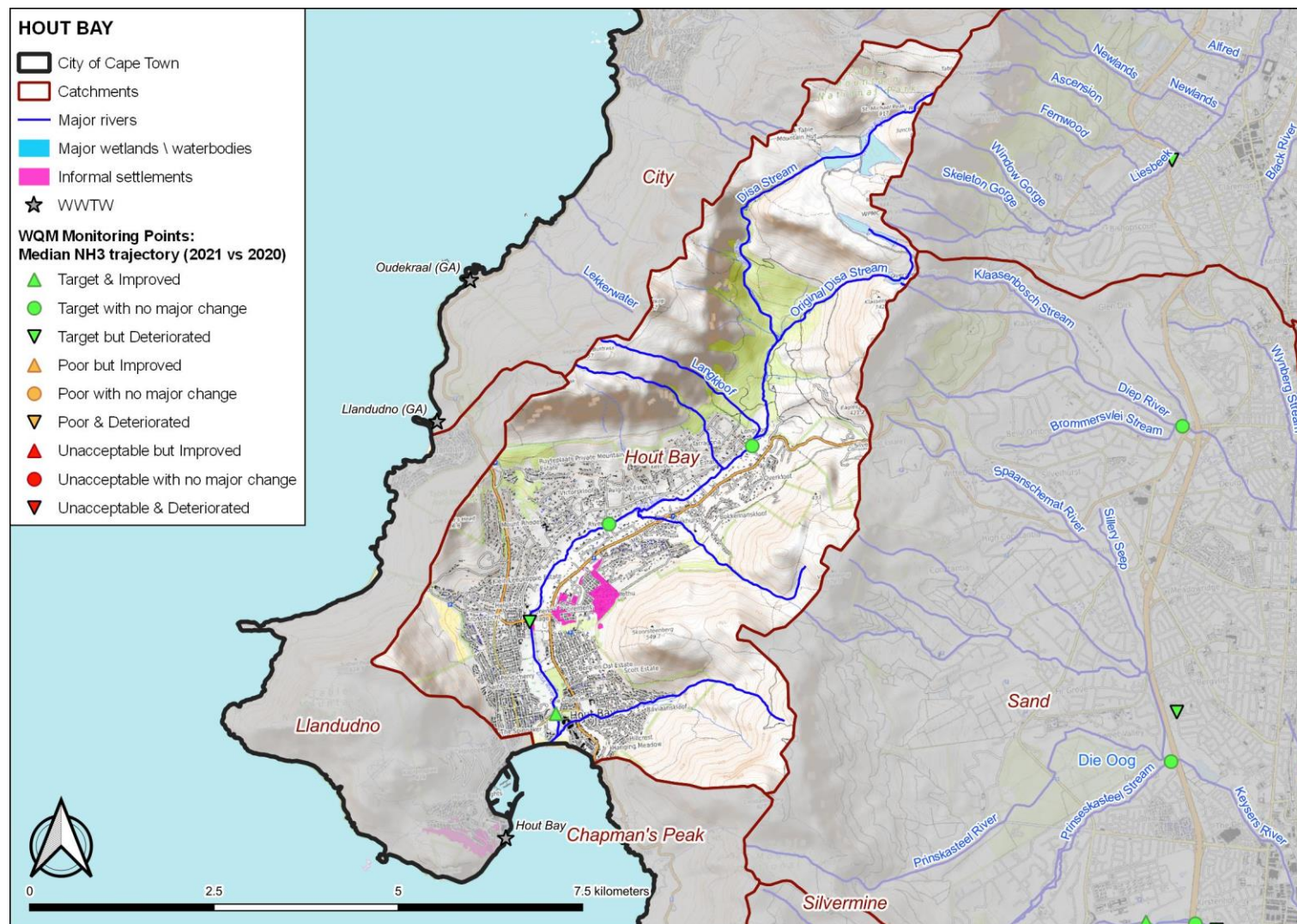


Figure 8.6.2

Median annual free ammonia (NH₃) concentrations, focusing on the HOUT BAY catchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

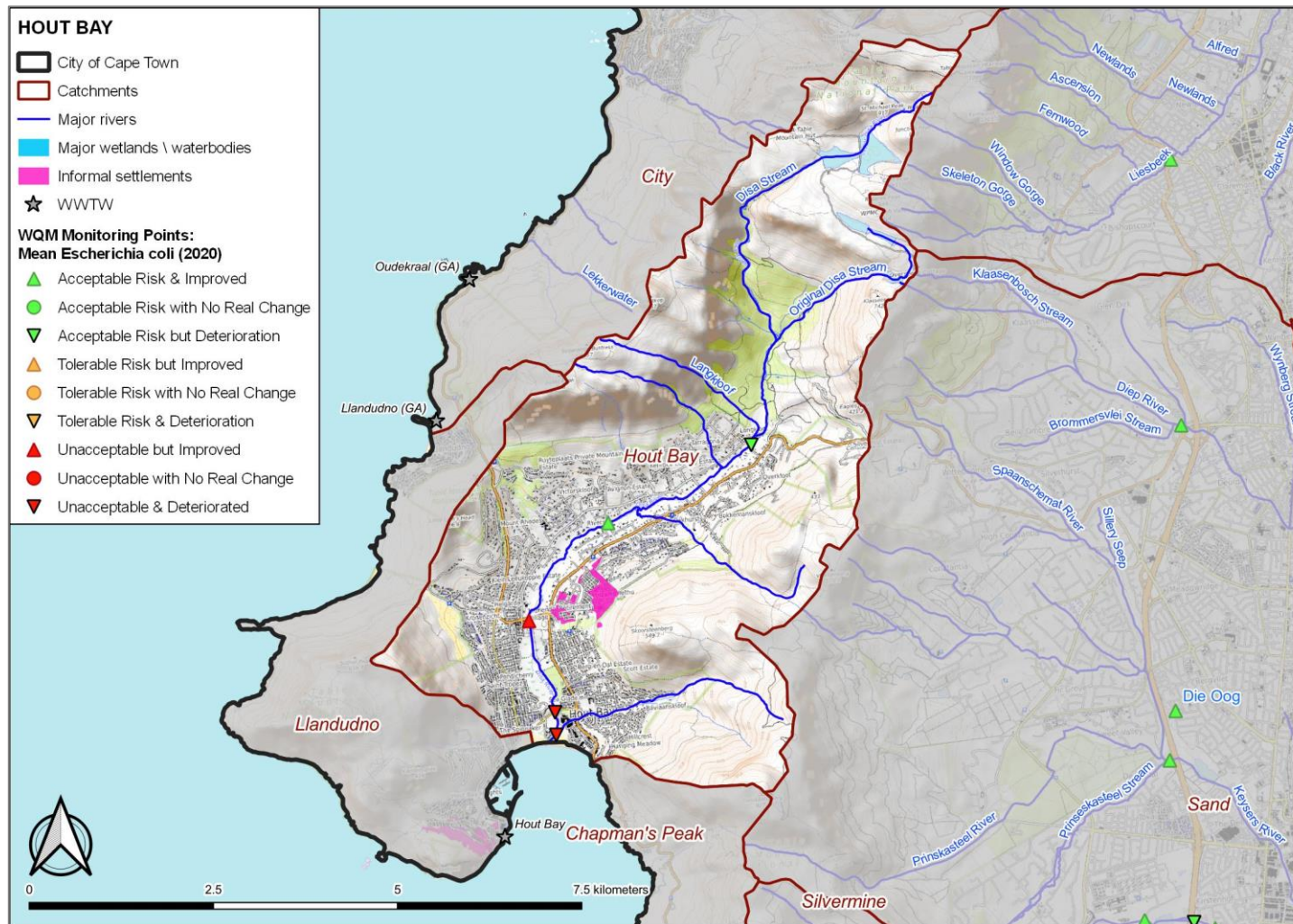


Figure 8.6.3

Mean *E. coli* data (geometric means), focusing on the HOUT BAY catchment.

Data coded as to human health risk (see Table 3.5).

No reliable data available for the 2021 reporting period, so 2020 data shown in relation to mean data for the 2017-2019 reporting years.

Trajectories calculated and coded as per Section 3.8.10.

8.7 Sand catchment

The Sand catchment is not one of the six priority catchments forming the focus of the Mayor's Priority Programme on Sanitation and Inland Water Quality (see **Section 7.3**). It has been included in this chapter of the report because the pilot phase of the LUW Programme focuses on the Sand River catchment (as explained in **Section 7.4**).

8.7.1 Catchment overview

There are no WWTWs or major informal settlements in the Sand catchment. Zandvlei, which is one of two estuarine vleis in Cape Town that are major recreational waterbodies, is however located in this catchment.

Zandvlei drains into False Bay at Muizenberg beach and receives the bulk of its fresh water from three river systems originating on the east-facing slopes of the Table Mountain - Constantiaberg mountain chain. These are the Sand/Diep, Keyzers and Westlake Rivers.

The Sand River is a canal that flows southwards and then in a south-westerly direction from the outlet of Little Princessvlei, which is in turn fed by the Mocke and Diep Rivers. The Diep River and two of its tributaries (the Klaassenbosch and Cecilia Forest Streams) rise on the east-facing slopes of Table Mountain above Constantia, in a natural area forming part of the Table Mountain National Park. The river then flows south-eastwards through a series of greenbelts and public open spaces within the residential suburb of Constantia before crossing under the M3 freeway. Downstream of the freeway, it winds through residential, commercial and industrial land-uses in Plumstead, Diep River and Heathfield, into Little Princessvlei. Approximately 4 km downstream of the outlet from Little Princessvlei, the Langvlei canal (which drains southward from the Langvlei waterbody) joins the Sand River, after flowing through the relatively high-density residential suburbs of Retreat and Steenberg. The Sand River enters the wetland area on the northern fringes of Zandvlei after flowing along the edge of Marina da Gama. It has been estimated that approximately 75% of the ~15 km long Sand/Diep River system is canalised (RHP 2005).

The Keyzers River rises on the east-facing slopes of the Constantiaberg mountain as a series of small streams, the most significant of these being the Spaanschemat, Grootboschkloof, and Prinskasteel Rivers. The upper reaches of the Grootboschkloof and Prinskasteel Rivers are located within the undeveloped Table Mountain National Park. Upstream of the M3 freeway, the tributaries of the Keyzers River flow through forestry, agricultural (vineyards) and residential land-uses in Constantia and Tokai. From the confluence of all the tributaries just to the west of the freeway, the Keyzers River flows south-eastwards under the freeway and through urban open space (old farmland) in Dreyersdal until it reaches Main Road where commercial land-use dominates. After going under Main Road, the river turns southwards and flows through an industrial area and a portion of the high-density residential suburb of Steenberg before reaching the wetland area on the north-western fringes of Zandvlei.

The Westlake River has its source on the lower slopes of the Constantiaberg mountain, within an agricultural estate below Silvermine Nature Reserve. Steenberg. It flows through the gardens of the Norval Foundation, under Steenberg Road and past a commercial node (Steenberg Village shopping centre), before turning eastward and flowing alongside the Westlake low-income settlement and then through the agricultural fields of Polsmoor Prison into the Polsmoor Dam. Downstream of the dam, the Westlake River flows under the M3 freeway and then south-eastwards through the residential suburb of Kirstenhof via the Kirstenhof Wetlands Park before turning (unaturally) sharply southwards to flow via a canal under Steenberg Road. Downstream of Steenberg Road, the river turns south-eastward again and flows under Main Road, straight into the wetland area on the north-western fringes of Zandvlei.

The entire Sand catchment ultimately drains into Zandvlei, which means that the vlei is particularly susceptible to water quality problems emanating from the catchment. The water level in the estuary is

Box 8.1:

Standing waterbodies in the Sand catchment

There are a number of standing waterbodies in the Sand catchment. The main vleis, besides Zandvlei, are Little Princessvlei, Langvlei and Die Oog. There are also extensive wetland areas, including the Westlake Wetland, the Kirstenhof Wetlands Park and the Keyzers River wetlands. In addition, there are a number of dams (artificial open waterbodies), including Pollsmoor Dam.

artificially controlled by a rubble weir and a sand bar, which is periodically opened. The estuary has benefited from the artificial opening of its mouth because this allows saline water from the sea to flow into the estuary, ensuring that the system is able to function more naturally and remain in a more healthy ecological state.

Nutrient inputs from agricultural, industrial and residential areas are a problem for Zandvlei, as are inputs of oil, heavy metals and other toxicants from the increasingly urbanised catchment. Sewage spills, however, remain the most significant contributor to poor water quality in the vlei, with a number of significant closures to recreational use since 2018 (pers. comm., Kyron Wright, CCT; Kotze, 2020; Human, 2021). The longest closure to date was May 2021- February 2022. Sewage spills contribute to nutrient enrichment of the vlei, exacerbating the incidence of algal blooms and the prolific growth of problem plants in the vlei. Sedimentation of Zandvlei from forestry and agricultural land-uses in the upper catchment areas is also a major problem, having resulted in a decrease in the depth of the vlei by approximately 0.5 m (pers. comm., Kyron Wright, CCT) and probably being a significant source of particle-bound phosphorus into the system, thus contributing to the nutrient enrichment.



Photo 8.7.1
Sewage spilling into Zandvlei [photo credit: Kyron Wright, City of Cape Town]



Photo 8.7.2
Aerial photograph showing an algal bloom in Zandvlei [photo credit: Kyron Wright, City of Cape Town]

8.7.2 River and vlei water quality through the catchment – condition and trajectory

Figures 8.7.1-8.7.3 present summary annual water quality data for phosphate (as PO₄-P), free ammonia (NH₃) and *E. coli* data, with analyses undertaken as outlined in **Section 3.8.10** of this report.

- In terms of phosphate concentrations (**Figure 8.7.1**), the main findings for the Sand catchment were as follows:
 - Phosphate enrichment was a major problem in the main part of Zandvlei and Westlake Wetland, with median PO₄-P concentrations in the Unacceptable range for all sampling sites in these areas during both the 2020 and 2021 reporting periods, representing eutrophic conditions that would have been conducive to the formation of algal blooms and excessive weed growth in the vlei;
 - Phosphate enrichment was not as much of a problem in the Marina da Gama canals, where median PO₄-P concentrations for the 2021 reporting year were in the Target range and remaining the same as the previous year or improving (at sites ZA08S and ZA09S), or they were in the Poor (but not Unacceptable) category and deteriorating compared to the 2020 reporting year (at sites ZA12S and ZA13S);
 - Elevated median PO₄-P concentrations, in the Poor category, were recorded for all three sampling sites on the main stem of the Keyzers River for which data were collected (i.e., at sites CR06, CR20 and CR22);
 - An elevated median PO₄-P concentration, in the Poor category (although improving from the previous year), was also recorded in the Westlake River where it flows through Kirstenhof (at site

CR02) for Reporting Year 2021, but not at the sampling sites on the river upstream or downstream of this (i.e., CR01 and CR03), where median concentrations were in the Target range;

- Phosphate enrichment was a problem in the Langevlei, with median PO₄-P concentrations at the two sampling points in the Poor and Unacceptable categories during Reporting Year 2021 but improving relative to the previous year;
- An elevated but improving median phosphate concentration was recorded at the outlet of Little Princessvlei (sampling site LPVS) during Reporting Year 2021, while median concentrations at the upper end of the vlei (LPVN) and in the Mocke River inflow (LPVMR) were in the Target range for PO₄-P;
- Rather unexpectedly, the median PO₄-P concentration in the Sand River a short distance downstream of the confluence with the Langvlei River (at sampling site CR21) remained in the Target range during both the 2020 and 2021 reporting years;
- Median PO₄-P concentrations were in the Target range at Die Oog, on the Westlake River where it flows through the Pollsmoor Prison grounds (at sampling site CR04), and on the two sampling points for which data were available on the Diep River.

In terms of un-ionised ammonia, the median NH₃ concentrations in the Sand catchment were all within the Target range during the reporting period (**Figure 8.7.2**), despite relatively high pH values >8.5 being recorded quite frequently at a number of the sampling sites within the catchment. This suggests that there is a low risk of ongoing ammonia toxicity within the catchment or Zandvlei. It is important to bear in mind, however, that occasional spikes in NH₃ concentrations (into the Poor and Unacceptable categories) are recorded at certain sites within the catchment, so ammonia toxicity could at times be a problem in certain areas, especially with the high pH values that have been measured at some sites.

In terms of *E. coli* mean values from reporting year 2020 (**Figure 8.7.3**), the main findings were as follows:

- All the sampling sites in Zandvlei were shown to be within the Target range;
- Mean *E. coli* measurements from Little Princessvlei and Die Oog were also within the Target range;
- The mean value at the inlet to Langevlei was in the Unacceptable category, while the mean value at the outlet of the vlei was in the Target range possibly showing some assimilation within the vlei;
- All three sampling sites on the Keyzers River had mean *E. coli* values within the Target range;
- All the sampling sites on the Westlake River were within the Target range, with the exception of the site in the Pollsmoor Prison grounds (CR04) where the mean *E. coli* value was in the Unacceptable category, presumably as a result of a significant sewage inputs from broken sewer pipes leaking into the river in this area during the reporting year (2020);
- Mean *E. coli* measurements were in the Unacceptable category in the Sand River below the confluence with the Langvlei River (at sampling site CR21) and further upstream in the Diep River section of the river at sampling site DRRSC (Roscommon Road);
- Overall, as indicated previously (see **Section 5.5**), the Sand catchment showed some improvement in the levels and frequency of *E. coli* contamination over the 2020 reporting period compared to the previous three years.

Analysis of the enterococci data for Zandvlei (see **Section 6.3.2**) showed that, for Reporting Year 2021 (the only year for which these data were available for this vlei), approximately 80% of the enterococci measurements collected from Zandvlei were within the Target range. Closer examination of the data by sampling site within the vlei revealed that there was a slight trend of increasing levels of compliance from the upper estuary sites (northern section of the vlei) to the lower estuary sites (southern section of the vlei).

It is important to note that, despite the “averaged out” findings presented above, there were at certain times very high *E. coli* measurements (above the Unacceptable threshold) recorded from a number of sampling sites within the Sand catchment during both the 2020 and 2021 reporting years. These spikes of elevated *E. coli*, which sometimes lasted several weeks to months, were typically associated with sewage spill incidents that ultimately flowed into Zandvlei, usually resulting in closure of the vlei for recreational use (e.g. see Kotze 2020; Human 2021; CCT 2021). For example, the vlei was directly impacted by significant pollution incidents

associated with failures of the Clifton Road pump station in May 2021 and the Keyser River pump station in July 2021, both attributable to infrastructure that had been severely damaged by solid objects in the sewer line (CCT 2021).

8.7.3 Focus areas of the CCT's current remediation programmes

Some of the active interventions undertaken by the CCT in the Sand catchment during the reporting period included, *inter alia*:

- Cured-in-Place Pipe (CIPP) lining of leaking and/or old sewer pipes at a number of locations in the catchment;
- Cleaning out of sewer pipes in the Lavender Hill and Overcome Heights areas (May – November 2021) (pers. Comm., Andrew Taylor, CCT);
- Repair of damaged sewage infrastructure as soon as possible when incidents occurred, and investment by the Water and Sanitation Department in measures to prevent the high volumes of dumped materials (rags, rubble, etc.) from entering the pump stations, which is one of the leading causes of failure and spillage (CCT, 2021);
- Extensive engagement with the Zandvlei Protected Advisory Action Committee through the City's Stormwater and Biodiversity Management branches (CCT, 2021);
- Collection and clearing of litter from the waterways that flow into Zandvlei (e.g. see **Photo 8.7.3**).



Photo 8.7.3

Litter trapped in nets for removal from one of the canals in the Sand catchment that flows into Zandvlei [photo credit: Kyran Wright, City of Cape Town]

A number of important interventions have been initiated for the Sand catchment subsequent to the reporting period/s considered in the current report. These include:

- Relaunching of the Sand River Catchment Forum by the CCT in November 2022 in the hope of driving collaborative water governance to address the issues in the catchment (Engel, 2022);
- Repairs and upgrades to the sewerage reticulation network (pers. Comm., Kyran Wright, CCT);
- Initiation of the following five pilot projects within the Sand catchment through the Living Urban Waterways (LUW) Programme (see **Section 7.4**):
 - Grootboschkloof River Corridor Rehabilitation and Public Space Enhancements

- Spaanschemat, and Prinskasteel River Corridor Rehabilitation and Public Space Enhancements
- Sand and Langevlei Canal Rehabilitation
- Westlake River Corridor Rehabilitation and Public Space Enhancements
- Keyser River Corridor Rehabilitation and Public Space Enhancements.

The LUW Programme aims to, amongst other things, achieve acceptable water quality by focusing on improving the quality and function of the aquatic, riparian, and wetland environments through water-sensitive design and an integrated approach to waterway management (Lukhozi, 2022). In the Sand catchment, the implementation of this programme will hopefully lead to general water quality improvement in the broader catchment and a reduction in the nutrient loading of Zandvlei.

8.7.4 Recommendations going forward

A number of actions have already been initiated to improve water quality and the general ecological state of Zandvlei and the aquatic ecosystems in the Sand catchment, as described above. Some of these actions have already resulted in improvements in the ecological health of the estuary such as more effective saline intrusion and tidal interchange through better management of the estuary mouth, and a subsequent increase in the diversity of indigenous fish species as well as expansion in the area of occurrence of sand prawns (pers. Comm. Kyran Wright, CCT). The relatively good water quality of Zandvlei compared to many other aquatic ecosystems in Cape Town, outside of sewage spill incidents, is largely attributable to a relatively unpolluted catchment area, with no WWTW inflows and limited areas of informal settlement. The assignment of the entire Sand catchment to one CCT Stormwater Management Region (namely the Southern Region, as shown in **Section 2.8** and **Figure 2.2**) is also likely to help to achieve more effective water quality management across the catchment.

Notwithstanding the above positives, there are still a number of water quality concerns for Zandvlei and in the Sand catchment, as indicated in **Section 8.7.2**. The following recommendations are made to facilitate improvement in the water quality in Zandvlei and its catchment:

- Problematic sewers and pump stations should be repaired and/or upgraded as a matter of urgency, to prevent future failures that could lead to significant sewage spill events like those that have occurred at times over the past few years;
- Pro-active lining and clearing of sewer pipes in the catchment is supported and should continue as required;
- Improvement in the frequency and volume of solid waste collection in open spaces in some parts of the catchment is urgently required, to prevent the passage of solid waste into watercourses. The Sand and Langevlei Canals are particularly vulnerable to dumping of solid waste, which accumulates along the canal banks and bed;
- Dredging of the main portion of Zandvlei, which is currently being planned, should be implemented as a priority action in this catchment as this should help to lower nutrient levels (especially phosphate concentrations), raise DO levels and improve the hydrological functioning of the estuary;
- Land management in the upstream areas of the catchment should be improved to reduce erosion as a source of sediment, and ultimately reduce the frequency of future dredging requirements in the estuary going forwards. This means that the CCT should engage with landowners, particularly in agriculture and with SANParks, regarding addressing erosion in these areas;
- The projects forming the pilot phase of the LUW Programme should be carefully and strategically implemented so that they can contribute towards the reduction of sediment and pollution inputs into Zandvlei, and additional funding should be acquired to supplement and/or enhance these projects;
- Implementation of SUDS approaches should be encouraged throughout the catchment, as these interventions might achieve measurable impacts at least in moderately impacted systems such as the Westlake and Keyser's River systems and their upstream reaches in particular;
- More frequent monitoring of enterococci levels at sampling sites in Zandvlei should be carried out (e.g.

weekly sampling at carefully selected sites throughout the year) so that the data can be more effectively used to assess the risk of recreational use of the vlei;

- The CCT should continue to actively engage with the recently re-established Sand River Catchment Forum, to understand where the most urgent problem areas are and to formulate solutions together.

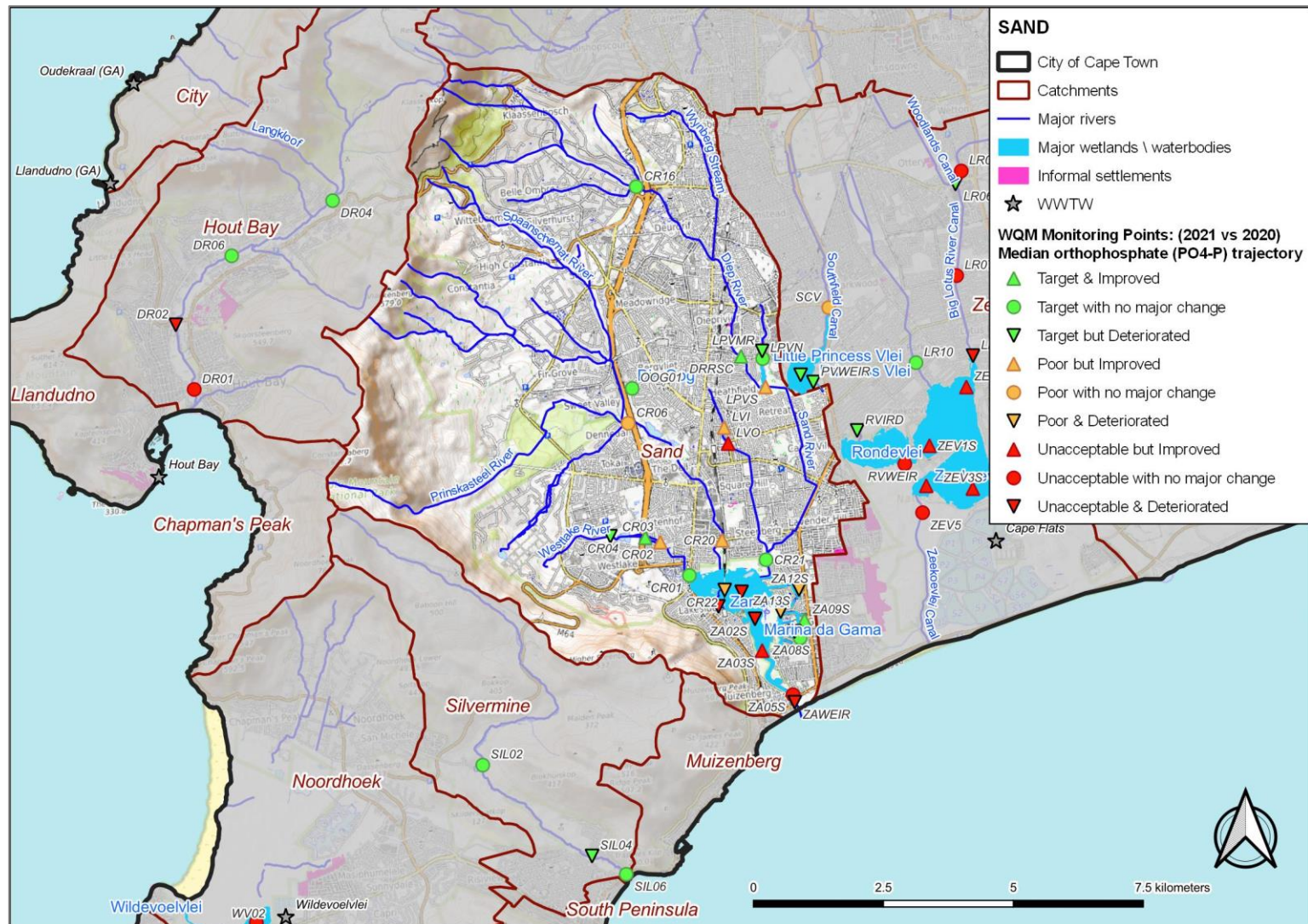


Figure 8.7.1

Median annual phosphate (PO₄-P) concentrations, focusing on the SAND catchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

City of Cape Town

Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

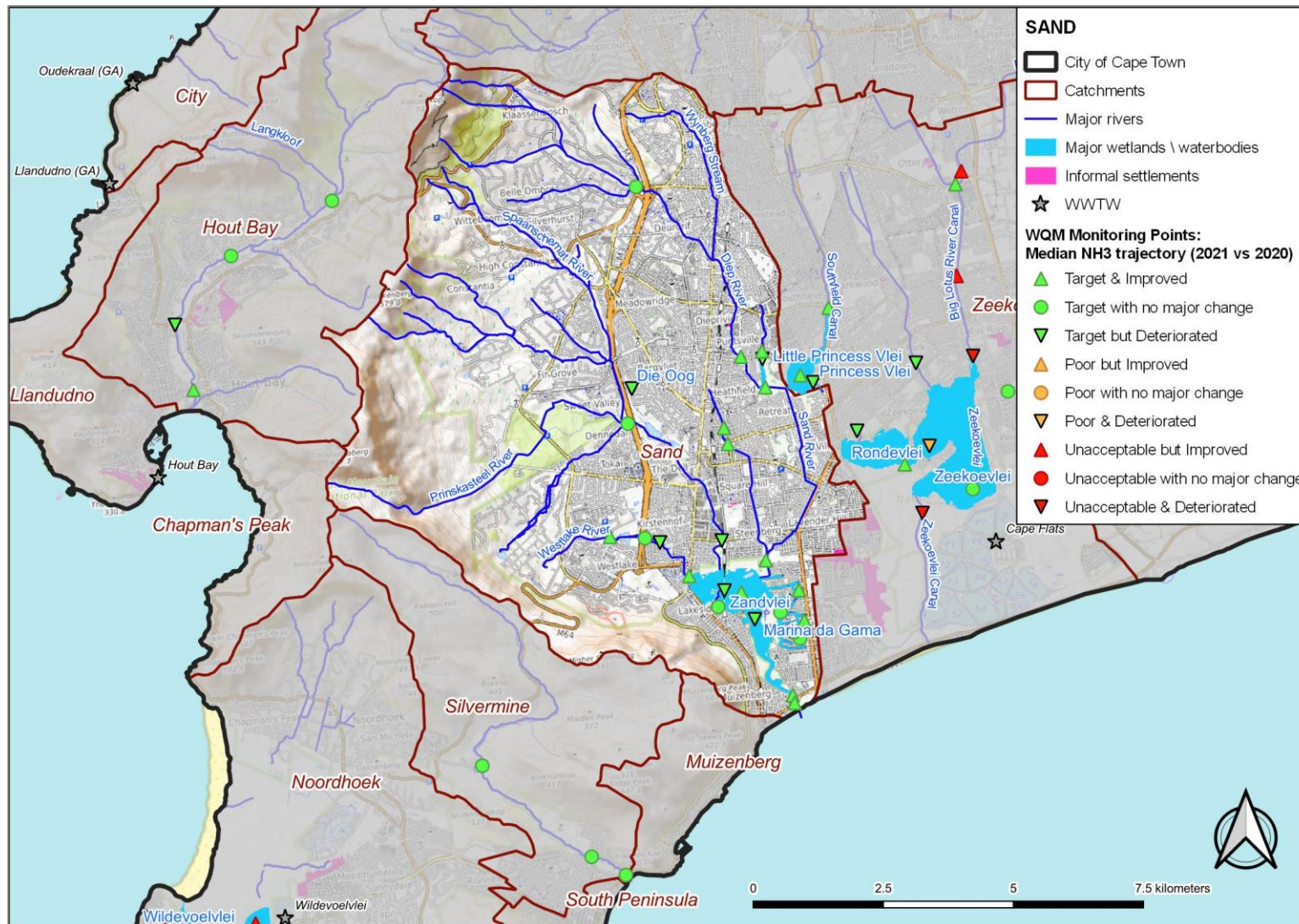


Figure 8.7.2

Median annual free ammonia (NH₃) concentrations, focusing on the SAND catchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

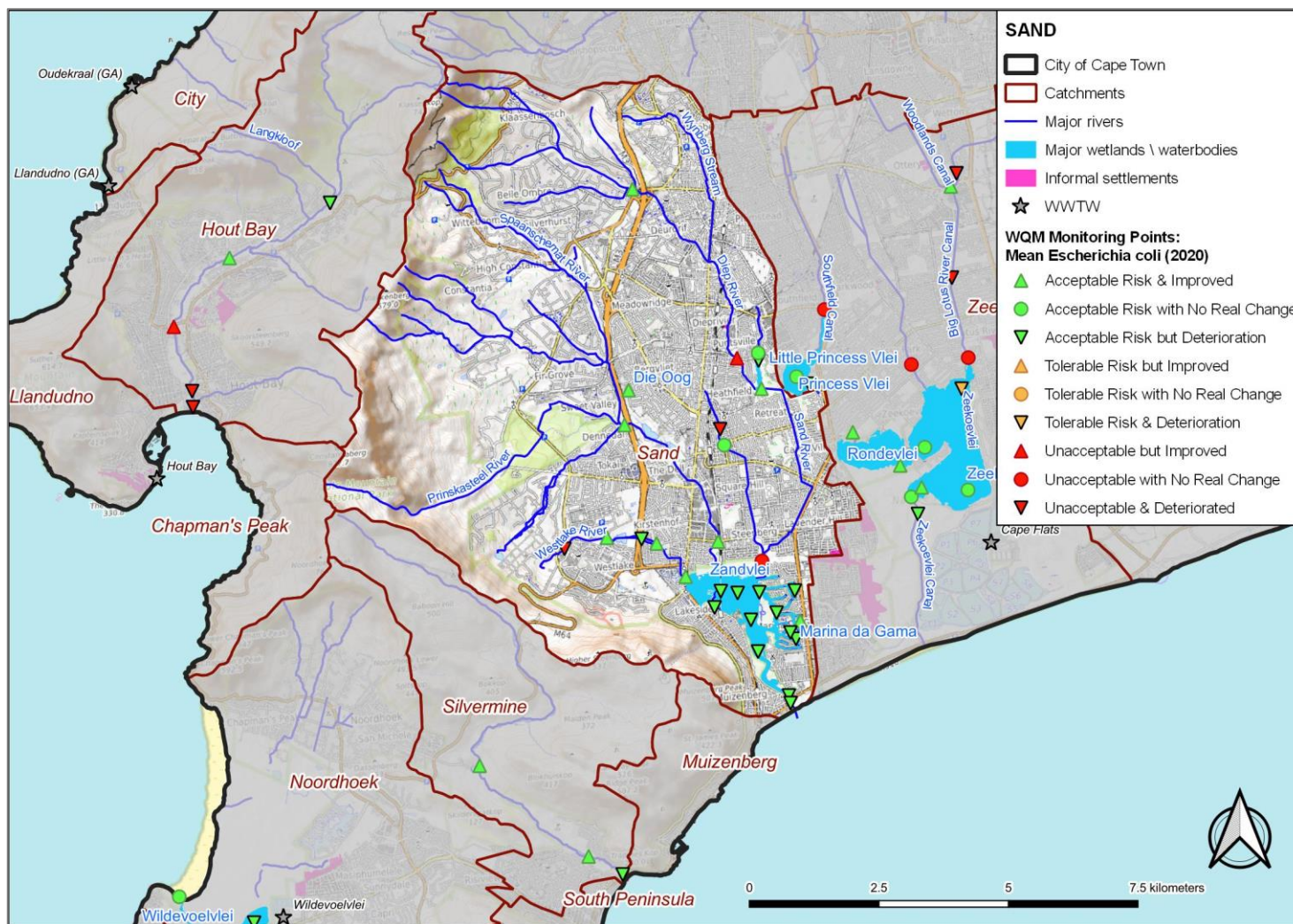


Figure 8.7.3

Mean *E. coli* data (geometric means), focusing on the SAND catchment.

Data coded as to human health risk (see Table 3.5).

No reliable data available for the 2021 reporting period, so 2020 data shown in relation to mean data for the 2017-2019 reporting years.

Trajectories calculated and coded as per Section 3.8.10.

8.8 Big and Little Lotus River catchments

8.8.1 Catchment overview

The Big and Little Lotus Rivers are the main sources of surface flow into Zeekoevlei, and the False Bay Nature Reserve (FBNR) (see **Figures 8.8.1-8.8.3** for context). Of these, the Big Lotus River has a far larger catchment, starting as a small stormwater channel just north of the N2, through the airport industrial area. Immediately downstream of the N2, it flows through parts of Nyanga, Gugulethu and New Crossroads, in places as a lined canal. These are all densely populated areas with high levels of backyard and other informal settlement, before passing along the southern edges of Manenberg and Hanover Park. Many of these areas have significant socio-economic problems and high levels of crime and gang violence, which challenge effective catchment management activities.

The Big Lotus swings south just east of Wetton and passes through parts of the Philippi Horticultural Area, where agriculture as well as associated manure and composting forms the main land use. In these river reaches, a lowflow diversion (the Springfield Diversion) diverts a portion of lowflows from the river to the nearby Cape Flats WWTW, in an effort to reduce downstream water quality impacts on Zeekoevlei. From here, the river flows still as an open channel through residential and commercial land uses in Ottery and is joined by the Woodfield Canal just east of the remnant and important Bamboesvlei seasonal wetland. It flows through parts of the residential areas of Lotus River and Grassy Park, before entering Zeekoevlei, just south of Fisherman's Walk.

The Big Lotus River has been subjected to numerous inflows of raw sewage from blocked manholes and failed pump stations over the past few years, contributing to the progressive decline in water quality and wetland ecosystem quality in Zeekoevlei (Day et al. 2022).

The Little Lotus River drains a smaller and less impacted catchment than the Big Lotus River. It rises just south of Ottery Road (east of the Royal Golf Course) and flows through the mainly residential areas of Parklands and Grassy Park, mainly as a lined canal, before entering Zeekoevlei, south of the Big Lotus River confluence. The river is generally less vulnerable to raw sewage inflows and solid waste accumulation than the Big Lotus River, but nevertheless experiences periodic pollution episodes (Day et al. 2022).

Local community / CCT partnerships have facilitated and funded litter fences at the outlet of both the Big and the Little Lotus Rivers into Zeekoevlei, in an effort to control the vast volumes of solid waste that wash into the vlei, particularly from the Big Lotus River (Day et al. 2022).

Box 8.1:

Natural watercourses in the Zeekoe catchment

Typical of many areas of the Cape Flats, the Zeekoe catchment is characteristically sandy, with a high wet season water table in many areas. This feature gave rise, under natural circumstances, to an abundance of seasonal, groundwater-fed wetlands across low-lying areas of the catchment. In some areas, localised lenses of calcrete have also given rise to perched, seasonally inundated wetlands, many of which have high biodiversity importance.

The Big and Little Lotus Rivers are not natural rivers, but were both constructed to drain water from areas with a high water table and so allow expansion of urban development.



Photo 8.8.1

Litter in the Big Lotus River near Hanover Park

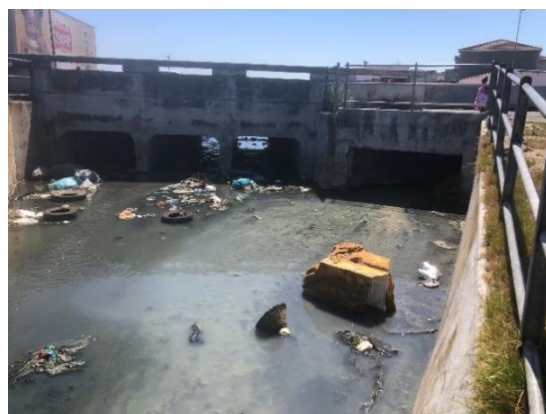


Photo 8.8.2

Visible pollution streams into the Big Lotus River in Gugulethu

8.8.2 River water quality through the catchment – condition and trajectory

Figures 8.8.1-8.8.3 present summary annual water quality data for phosphate (as $\text{PO}_4\text{-P}$), free ammonia (NH_3) and *E. coli* data, with actual analyses as outlined in **Section 3.8.10** of this report.

These figures show that, for the Big and Little Lotus Rivers (i.e., priority catchment areas) that drain into Zeekoevlei:

- Phosphate enrichment was pervasive in the Zeekoevlei catchment over the assessed reporting periods, with inflows from the Big Lotus River being always well within the Unacceptable levels for this nutrient;
- More particularly:
 - Although the data shown in **Figure 8.8.1** show that all sample points from the Big Lotus River source to Zeekoevlei lay within the 'unacceptable' range, data (presented in **Section 5.1.6** and **Table C1 Appendix C**) show that phosphate concentrations in fact increased significantly downstream of the N2. It is assumed on visual flow evidence (but without supporting data) that loading of all contaminants also increased dramatically downstream of the N2;
 - Median phosphate concentrations in the Little Lotus River and in the Woodlands Canal, both discharging into the Big Lotus River, were usually within target range for this variable, pointing to relatively 'clean' catchments with low levels of inflows of organic waste associated with no WWTW inflows and limited inflows from informal and/or backyard settlements;
 - There was generally no change in rated phosphate enrichment category at monitoring points in the Big Lotus River between the 2020 and 2021 reporting periods – but the levels of phosphorus enrichment were excessively high at a subcatchment scale, as discussed in **Section 5.1.6**, and there was an increase in enrichment throughout Zeekoevlei itself and at the most downstream of the Big Lotus River monitoring points (LR08) in the 2021 reporting period. This was assumed to relate to the large number of sewage overflows into the river in the 2021 reporting year (Day et al. 2022);
- Plotted ammonia (NH_3) data showed that:
 - Upstream of the N2, median annual ammonia concentrations were within Target concentrations, but showed a deterioration over the 2021 reporting period reflecting (on the basis of other water quality variables) a polluted system on a deteriorating trajectory in 2021;
 - With distance downstream, ammonia concentrations increased to well above the Unacceptable threshold – data presented in Day et al., 2022 from targeted pollution tracking in these reaches showed that this deterioration occurs in the canal from its reaches immediately downstream of the N2;
 - Ammonia remained in the Unacceptable range all the way to Zeekoevlei, although

concentrations were somewhat improved in the reaches through Ottery and Grassy Park in the 2021 reporting period;

- Ammonia concentrations in the Little Lotus River and Woodlands Canal were within Acceptable limits, although on a deteriorating trajectory in the former.
- *E. coli* data available for the 2020 reporting period only showed that:
 - All sites downstream of the N2 were always in an Unacceptable condition in both the Big and the Little Lotus Rivers, with only the small and seasonal Woodlands Canal showing minimal faecal contamination. These data reflect a catchment subject to high levels of inflow from backyard and informal settlements, as well as a high frequency of sewage and pump station overflows – Day et al, (2022) reported on *E. coli* concentrations from limited data not analysed by the CCT in the 2021 reporting period and showed similar patterns in that year, with *E. coli* concentrations often well into the millions and several orders of magnitude above the Unacceptable threshold.
- Solid waste is a serious issue throughout the catchment, contributing to frequent blockages of both stormwater and sewer systems, including the Springfield diversion system, and resulting in both unsightly and unhygienic conditions within the upstream catchment, and the need for ongoing expensive clean-ups of Zeekoevlei in the FBNR, by local communities, Friends groups and the CCT's BMB.

8.8.3 Focus areas of the CCT's current remediation programmes

Over the actual reporting period considered here, there were few active interventions by the CCT in this highly impacted catchment, other than reactive (and often delayed) repairs to blocked or collapsed sewers, vandalised or stolen pumps at pump stations, and in July 2021, emergency repairs following failure of the screw pumps leading into the Cape Flats WWTW, which resulted in surcharging of one of the three bulk sewer mains.

However, there has since been some focus on addressing some of the issues that plague water quality in the upstream catchment, with the following activities:

- Focused strategic cleaning of sewers in the southern part of the catchment (downstream of Strandfontein Road) by Waste Water Conveyance (Region 1) – this is a pro-active response to reduce sewer blockages and overflows into the stormwater system, and in fact commenced in the Lotus River suburbs in May 2021 (2021 reporting period) and continued into the Grassy Park area from February to October 2022;
- Commissioning of an assessment of, and plans for remediating the effects of, long-term pollution in the catchment and its impact on Zeekoevlei and Rondevlei (Day et al. 2022). Remediation of water quality in Zeekoevlei through implementation of some of the required measures is included in Work Stream 4.2 of the MPP on Sanitation and Inland Water Quality;
- The CCT is currently undertaking upgrading of the Cape Flats WWTW, repairs / upgrades to its inlet systems and bulk sewer mains systems (see CCT 2023b);
- Passing of a 'Motion of exigency' by the CCT sub-council at its meeting of 17/11/2022, for the establishment of the Zeekoevlei Catchment Forum – the forum itself has not yet been set up;
- Pollution tracking up the Big Lotus River by teams from CSRM and Water Pollution Control between March and April 2022, intended to identify point source pollution inflows into the river;
- Improved liaison between CSRM, the CCT's BMB, and community activists including the Friends of Zeekoevlei and Rondevlei (FOSR) in working together for solutions to problems of litter and pollution in the downstream environment. These include litter clean-ups and monitoring and management of litter fences;
- Securing CFF funding (March 2022) for investigations to identify opportunities within the Big and Little Lotus River catchments for non-structural interventions and green infrastructure (GI), including sustainable drainage systems (SuDS) and nature-based solutions (NbS) (see **Section 7.4**).

The only one of the above interventions that could have impacted positively on water quality over the current monitoring period was the pro-active cleaning of sewers in parts of the catchment in the 2021 reporting period. There were, however, no *E. coli* data for the 2021 reporting period to illustrate this. Improved ammonia

concentrations in the Grassy Park area over the 2021 reporting period could well reflect a reduced occurrence of sewage overflows.

Repairs to sewer bulk infrastructure and the WWTW should also start to yield results in reduced spill frequency and risk, while rehabilitation measures in Zeekoevlei should improve water quality in that downstream system.

The effects of the other activities listed above are unlikely on their own to result in measurable changes in water quality in this catchment unless planning, pollution tracking, and assessment are followed with active interventions.



Photo 8.8.3

CCT staff clearing solid waste from the new litter fence installed on the Big Lotus River in 2022



Photo 8.8.4

CCT work teams clearing solid waste from the Big Lotus River

8.8.4 Recommendations going forward

The main water quality issues in the Big and Little Lotus River are associated with the Big Lotus River, and its impacts on important downstream waterbodies (Zeekoevlei). Faecal pollution is a threat to the health and dignity of local communities in the Big Lotus catchment, as well as to users of Zeekoevlei and the beaches along the False Bay coastline adjacent to the Zeekoe canal outlet.

The following measures should be focused on by the CCT, if there is to be any measurable improvement in water quality in the Big and Little Lotus River catchments, and by implication in Zeekoevlei downstream:

- Significantly increased focus on the frequency and volume of removal of solid waste at source;
- Attention to diverting existing known sources of effluent into the canal, to sewers;
- A focus on interventions to provide sewage and stormwater servicing to the rapidly expanding informal and backyard settlements in the area;
- A focus on provision of improved bunding and short-term storage of effluent at all sewage pump stations, but particularly those abutting the FBNR and the Big and Little Lotus River canals;
- Implementation of the CCT's existing plans for upgrading of the Cape Flats WWTW and ongoing rehabilitation and upgrading of the sewers in the catchment;
- A change in the CCT's regional structure, so as to align with hydrological (major river) catchments, rather than with the current stormwater management regions (see **Section 2.8**) and sewage reticulation management regions, which do not relate to surface runoff and do not facilitate strategic pollution abatement at a catchment level, since different managers have responsibility for different parts of the catchment. For example, at present, two Senior Professional Officers oversee different sections of the Zeekoe Catchment – one upstream of Strandfontein Road and one downstream, with the result that the downstream officer has no control on inputs or efforts from the upstream area.

It is also noted that there are no routine monitoring points between the N2 and Govan Mbeki Road downstream of Jakes Gerwel Drive. This means that point-source pollutants between these points cannot be

identified without focused pollution tracking. Additional routine monitoring sites within this pollution hotspot should be included to assist in pollution tracking, and pollution tracking itself should be followed up by active interventions to address identified pollution sources.

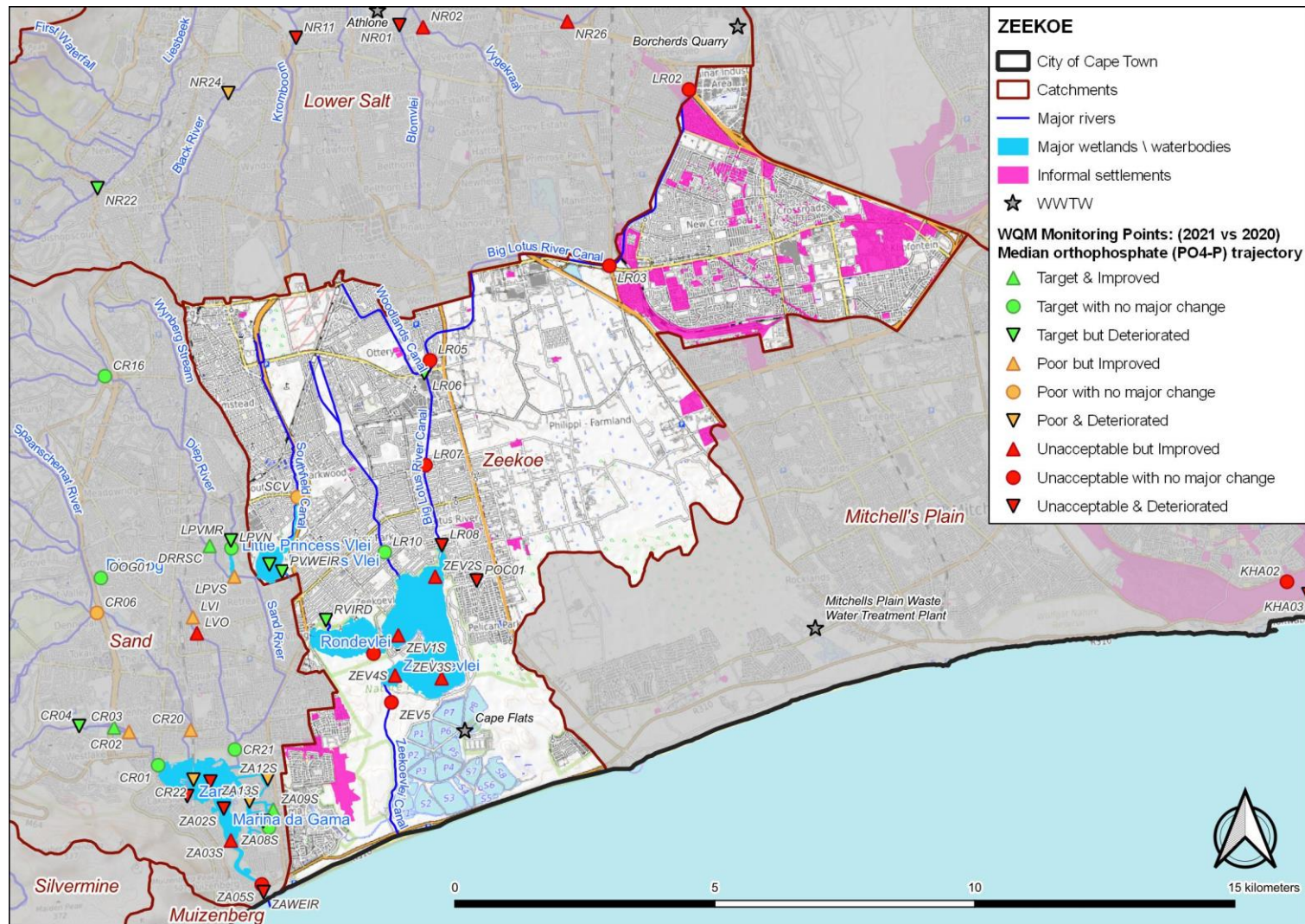


Figure 8.8.1

Median annual phosphate (PO₄-P) concentrations, focusing on the ZEEKOE catchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

City of Cape Town

Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

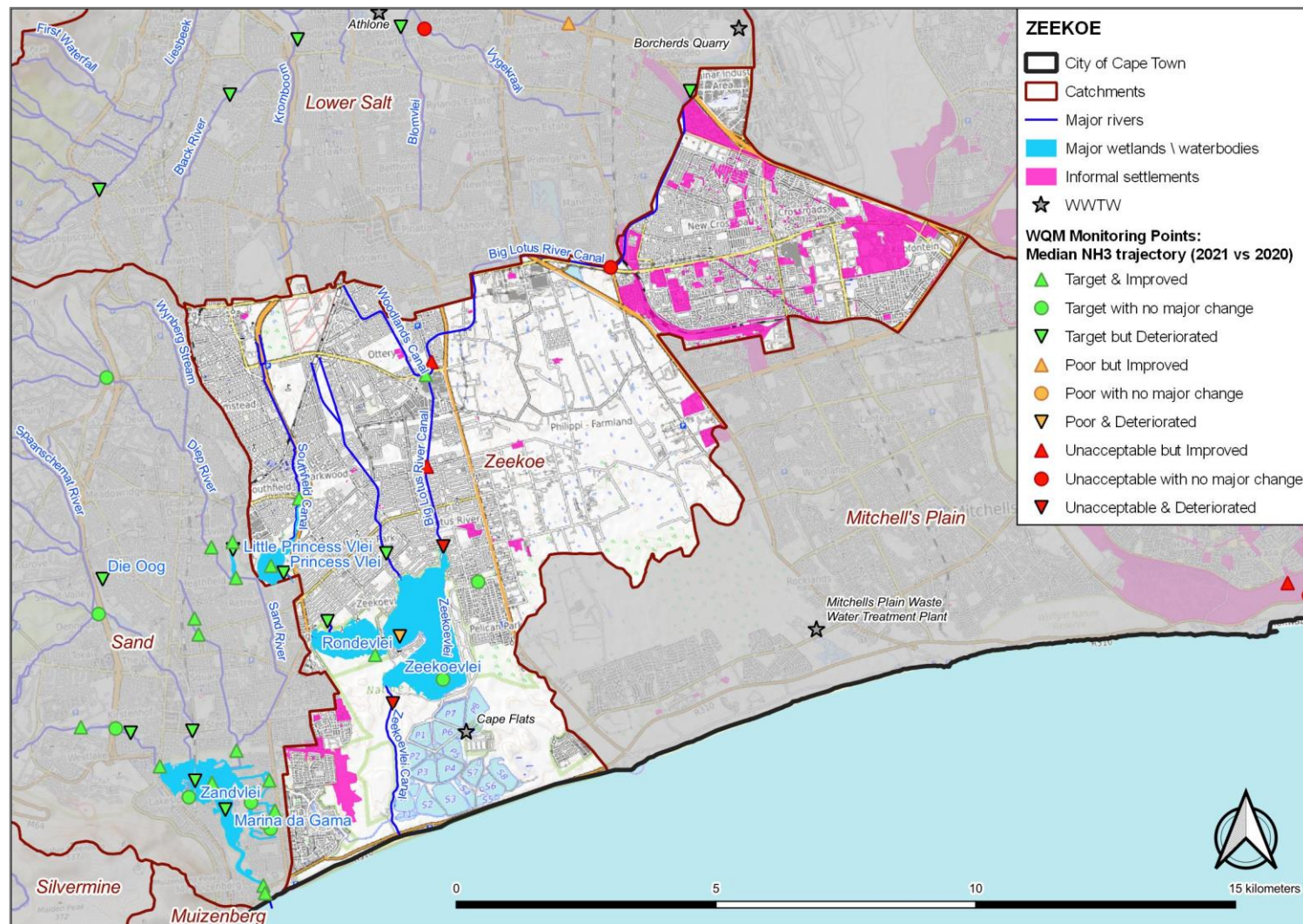


Figure 8.8.2

Median annual free ammonia (NH₃) concentrations, focusing on the ZEEKOE catchment.

Data coded as to level of change in the 2021 reporting period, compared with median annual data for the 2020 reporting period.

City of Cape Town

Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

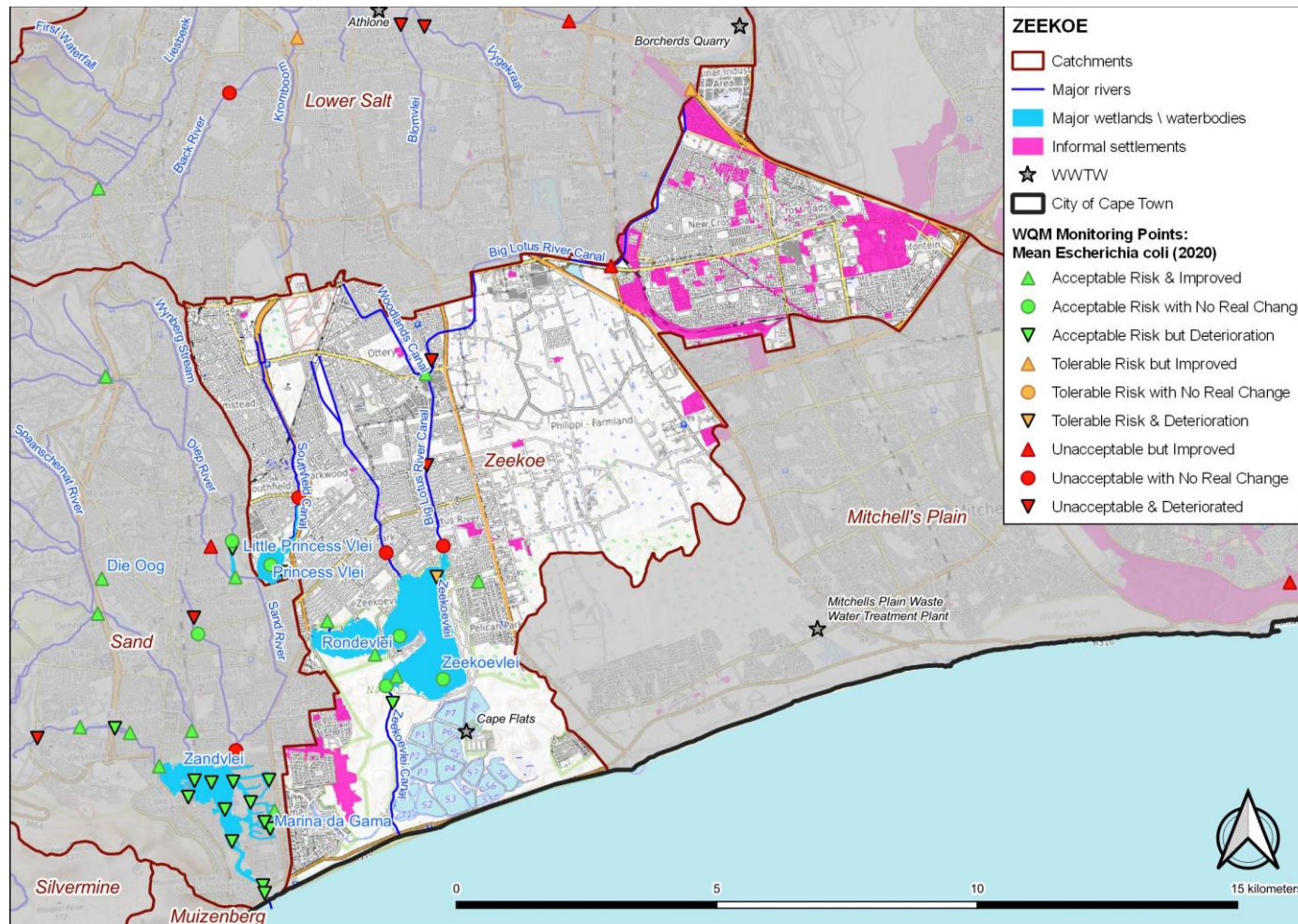


Figure 8.8.3

Mean *Escherichia coli* data (geometric means), focusing on the ZEEKOE catchment.

Data coded as to human health risk (see Table 3.5).

No reliable data available for the 2021 reporting period, so 2020 data shown in relation to mean data for the 2017-2019 reporting years.

Trajectories calculated and coded as per Section 3.8.10.

8.9 What of non-priority catchment areas?

Effective catchment management measures that prevent pollution of CCT's waterways and downstream receiving environments is as important in non-priority catchments as in priority catchments. The priority catchments addressed in this report include, however, all of the worst-performing, most problematic catchments in the CCT boundary. The exception to this is the Sir Lowry's Pass River catchment, which ought also to be included as an additional priority catchment. This system has severe upstream pollution issues, stemming at least in part from poor servicing of expanding backyard and informal settlements. In its reaches downstream of the N2, the CCT is commencing a major river works project, that will result in channelisation of the river to provide space for floodplain development. If water quality problems from upstream persist, the required ecological mitigation measures that made this project ecologically acceptable will not be realised.

The remaining subcatchments were, at least over the reporting periods considered here, in generally better condition from a water quality perspective. It is, however, very important that water quality in these systems does not deteriorate, and should ideally improve further. For this reason, it is strongly recommended that ongoing attention be paid to data for key indicative water quality parameters from sites in these systems, and any persistent (i.e., more than two consecutive months, or a once-off but large-scale) deterioration in any of the monitored variables should be followed up by pollution tracking to identify likely pollution sources, followed up with interventions to address identified issues.

Input from local residents, Friends groups, and other organisations relating to water quality concerns and known pollution 'hotspots' should be facilitated by the CCT.

8.10 Key take-away points

The following key points emerge from the above discussions:

- All of the CCT's priority catchments include runoff from informal settlements with poor access to sewerage systems. This means that water quality in stormwater systems is in many areas compromised, to levels where standard application of SUDS and other stormwater quality polishing / improvement approaches are unlikely to be effective;
- In areas not subject to high levels of sewage-impacted stormwater, the CCT is encouraged to implement or require implementation of SUDS-type interventions and implement pollution tracking when water quality deterioration is detected. These measures will help to maintain the current relatively good status of water quality in these subcatchments. These subcatchments comprise:
 - The Silvermine subcatchment
 - The Lourens subcatchment
 - The South Peninsula subcatchment and
 - The Liesbeek River catchment within the Lower Salt subcatchment.
- The accumulation of solid waste is also rife in many areas of the city, particularly in low-income areas. This waste passes readily into stormwater systems, from where it is costly to remove. It also blocks or is used to block sewage pipes and pump stations, resulting in added watercourse pollution. Addressing this issue through significantly ramped-up solid waste collection is strongly recommended;
- The LUW projects had just commenced or were in planning stages at the time of writing this report. Their impacts on water quality are not therefore reflected in the data reported on here, which extend to March 2022 only. Those projects undertaken in less polluted priority catchments such as the Sand, which is not affected by high nutrient loading from any WWTWs, could well show measurable water quality impacts as a result of improved water quality polishing, provided that issues such as pump station failure and sewer overflows are addressed in parallel, through ongoing pro-active sewer maintenance. LUW projects in areas challenged by more impacted water quality will need to be pragmatic and also consider linked issues such as solid waste and sources of raw sewage in the catchments if they are to achieve measurable water quality results. This is not to say that other important aspects such as public amenity and the creation of nodes of wetland habitat are not also important goals;

- The CCT's current stormwater management system results in some subcatchments extending across two or more Stormwater Planning Regions. This means that different Catchment Planners are responsible for different river reaches or catchment areas, making integration of projects and responsibilities difficult, and accountability for catchment condition difficult and unwieldy;
- Similarly, sewage reticulation activities are also not carried out on a (river) catchment basis – this again means that efforts in one part of a reticulation zone may be negated by a lack of co-ordination with upstream managers, or different strategies and level of effort in different areas.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Overview of water quality in rivers and other waterbodies

This report was required to focus on the CCT's water quality data for the 2020 and 2021 reporting periods, against a baseline of data from the previous three years (2017 to 2019 reporting periods). Other data such as rainfall data, sewage pump station overflow data and sources of information gathered from CCT officials and others regarding planned interventions to address water quality going forwards, and those highlighted for the seven priority catchments in particular, were also considered, and drawn into various discussions in the report. This has made for a long and in places technical report. Its key findings and recommendations have however been pulled out relatively simply in this section.

Overall, the analyses highlighted the fact that, from an ecological perspective, by far the most pervasive and problematic water quality issue almost throughout the CCT's monitored rivers and other watercourses was (and remains) **phosphate enrichment**, with over 70% of all monitored systems being hypertrophic and in the range considered Unacceptable for this variable. More concerning still is the finding that, not only is phosphate enrichment a serious issue, but the 2020 and 2021 reporting periods saw a general increase in phosphorus concentrations in many subcatchments, indicating a trajectory of deterioration in ecosystem condition. In the 2021 reporting year, only 15% of the 2 287 samples analysed from river and stormwater channels fell within Target levels for phosphate.

In inland aquatic ecosystems, high phosphate availability results in excessive plant growth, promoting the growth of reeds, aquatic weeds (many of them invasive alien species) and algae. These come at high management costs, requiring ongoing removal or other management interventions, and affecting the fitness for use of at least some recreational waterbodies.

Analysis of chlorophyll-*a* data (a measure of algal productivity) in this report confirmed that chlorophyll-*a* concentrations increased substantially in Princess Vlei, Rondevlei and Zeekoevlei over the 2021 reporting period, and the number of samples rated as Unacceptable for this variable increased in all monitored standing water systems throughout the city, with the exception of Zandvlei and Die Oog in 2020 and 2021 data, compared with the previous three years. Similarly, microcystin data showed a marked increase in the number of **blue-green algal blooms** in Milnerton Lagoon over the 2020 and 2021 reporting periods, as was the case for Rietvlei, Zandvlei and Zeekoevlei in the 2021 reporting year. Microcystins were not however measured at concentrations of concern from a human health perspective, which is a positive outcome.

Analysis of other ecologically important variables highlighted concerns that often go hand-in-hand with eutrophication. Concentrations of **dissolved oxygen** (DO) (a variable essential for most aquatic life), were within the critical range for this variable, with more than 50% of monitored sites having DO concentrations in Poor or Unacceptable categories. DO concentrations often reduce when bottom decomposition rates are high (e.g. when hypertrophic conditions promote rapid algal growth with high turnover rates, resulting in a 'rain' of dead algal cells onto the lake or wetland floor). Inflows of water with high chemical oxygen demand (COD) can also reduce DO concentrations in water bodies.

Linked with low DO concentrations in many systems were high levels of total ammonia, which included potentially toxic 'free' ammonia. **Ammonia** concentrations in samples from hypertrophic vleis such as Wildevleivlei and Zeekoevlei (the latter characterised by deep anoxic sediments in some areas) were almost always in the range of acute aquatic ecosystem toxicity (i.e. rated Unacceptable).

The most polluted **subcatchments**, characterised generally by high phosphate, ammonia and TIN concentrations and with low DO, without doubt comprised the Soet and Lower Salt subcatchments, both of which have deteriorated with regard to these key water quality variables since the 2017-2019 reporting period. Focusing on phosphate concentrations alone, other extremely poorly performing subcatchments comprise the Eerste, Kuils, Mosselbank, Diep and Sout, followed by the Zeekoe subcatchments.

Nevertheless, some of the city's subcatchments were in relatively good ecological condition with regards to water quality. These comprised (in order from least impacted) the Silvermine, Lourens and Hout Bay subcatchments, as well as the Liesbeek River catchment within the Lower Salt. The Hout Bay subcatchment is of particular interest from a management perspective. Most of its upper catchment monitoring points were in Target range for most key water quality variables assessed in this report. However, in its lower reaches, where the river is impacted by poor sanitation servicing in the extensive Imizamo Yethu settlement, water

quality deteriorates rapidly to Unacceptable concentrations for most variables, although naturally acidic waters reduce the threat of ammonia toxicity.

Of the monitored standing water bodies, the most polluted (across all variables) comprised stormwater detention ponds in the Mitchell's Plain subcatchment, but large vleis (Zeekoevlei, Rietvlei and Wildevoelvlei) had consistently the worst performing water quality with regard to phosphate enrichment. Rietvlei showed major deterioration over the 2020 and 2021 reporting periods. By contrast, Zandvlei at least showed improvement in most of its monitored variables over the 2020 reporting period.

A major contributor to the degradation of many of the city's watercourses is contamination with raw sewage. This assessment found that 48% of river samples were rated as Unacceptable for *E. coli* over the 2020 monitoring period – this was the same percentage as for the 2017-2019 monitoring period and reflects poor long-term city-wide compliance with water quality objectives. This issue, which has profound implications for both ecosystem condition and human health, is unpacked below.

9.2 Identification of key pollution sources

The main drivers of the aquatic ecosystem degradation, and phosphate enrichment in particular that persisted and in some cases worsened in the city's subcatchments over the 2020 and 2021 reporting period, appear to revolve primarily around the following:

1. **Inflows of treated effluent from WWTWs** across the city result at best (if licensing requirements are met) in permanent flows of nutrient-enriched¹³ effluent into sometimes seasonal or small river systems, and downstream vleis or estuaries. However, not all WWTWs meet General Effluent Limits and some of the CCT's major WWTWs produce effluent that has high CODs, high levels of suspended (organic sediments); high total ammonia concentrations; and bacteria and other (unmeasured) contaminants (see Rose et al. 2023). Downstream water quality impacts may also be exacerbated by unanticipated impacts of disinfection. Where chlorination is used to disinfect effluent with high total ammonia concentrations, persistent potentially toxic chloramines may be formed and passed into downstream receiving waterbodies.
2. Periodic **episodic overflows from sewage pump stations and surcharging manholes** result in overflows that pass either directly into watercourses or enter them via the stormwater system. These result in plugs of effluent with high COD, elevated total ammonia concentrations, high phosphate concentrations, high organic loading and often high levels of solid waste passing into downstream watercourses. Data from the CCT's records of pump station overflows summarised in **Figure 9.1** (and shown in more detail in **Section 5.5**) show that most pump station overflows in the period included in the dataset were the result of mechanical failure, mains supply faults, pump tripping and electrical failure. Stormwater ingress, clogging of pumps with foreign objects and ultrasonic (i.e., remote sensing) failure also contributed to overflows. Load shedding accounted for 4.7% of the 327 listed incidents over this period, and theft for just 4.0%.
3. **Runoff from informal settlements** and housing areas with high levels of backyard dwelling and/or where there is poor attention paid to maintenance of existing infrastructure result in permanent, generally low level but highly contaminated waste streams passing out of informal settlements and into the city's watercourses. Not only do these outflows constitute a severe health risk for children and other residents of local communities who live, play and have to cross through these areas, but they also can significantly impact on water quality in downstream rivers and other receiving waterbodies, and can negate river rehabilitation activities in these reaches.
4. **Accumulations of large volumes of solid waste** characterise many areas of the city's open spaces, roadways and pavements. This waste enters watercourses, where it may contribute harmful pollutants to the aquatic ecosystem (e.g. cans containing oil and other waste; old nappies and other organic waste) and also blocks stormwater drains. If it is disposed of into the sewer system, it can block pipelines and pumps at sewage pump stations. This issue stems largely from solid waste collection, particularly in less affluent areas, that is simply inadequate compared with the volume of waste generated.

¹³ The DWS' General Effluent Limits for phosphate (as PO₄-P) in effluent discharge are 10 mg P/l. That is, two orders of magnitude above the threshold for hypertrophic conditions.

There are many other activities and landuses that contribute to cumulative water quality degradation in the city. The above are considered by far the most significant, and unless they can be addressed or their impacts mitigated, there is little likelihood that the CCT will be able to effect meaningful and measurable improvement in water quality in most of its managed subcatchments.

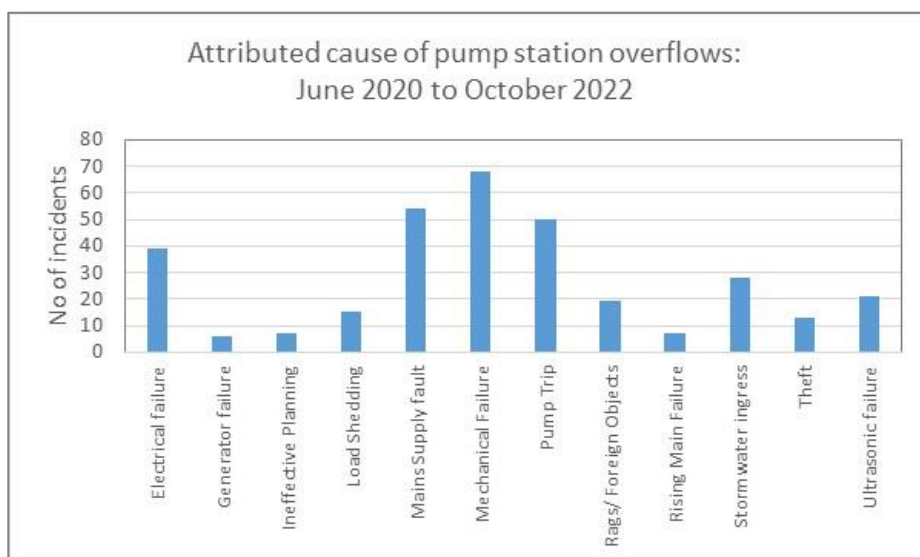


Figure 9.1

Summary data showing causes of sewage pump station overflows between June 2020 and October 2022, for the subcatchments included in the present assessment report only. Data provided by the CCT. Data show number of reported incidents and not percentage

9.3 Responses by the CCT to water quality issues

The above findings are not new – similar findings were presented in the 2020 Inland Water Quality Report, and the MPP for Sanitation and Inland Water Quality as well as the WQIP (see **Section 7**) all recognise and reference the urgent need to address the above complex issues.

The CCT's draft budget for 2023/24 to 2024/25 (CCT 2023b) furthermore itemises significant capital expenditure for the upgrading of WWTWs, maintenance and upgrading of sewer reticulation systems, repairing and upgrading of sewage pump stations and fitting of pump stations with emergency generators or UPS systems to deal with loadshedding.

9.4 Key recommendations from this report

Recommendations to address water quality at a municipal level in a city where water quality is severely compromised could constitute a study on its own, and incorporate measures from major interventions to best practices that should result in water quality improvement if rolled out at scale. This section rather highlights the key interventions and/ or activities that stem from this assessment.

Upfront it must be stated that until the pervasive issues of pollution from WWTWs and informal settlements can be addressed, it is unlikely that there will be a significant turn-around in water quality in many areas.

9.4.1 Addressing pollution from major WWTWs

The CCT's current focus on pollution abatement through investment in WWTW and sewage reticulation infrastructure (indicated in CCT 2023b) is strongly supported. Nevertheless, it is clear (see Rose et al. 2023 and Day et al. 2022) that some WWTWs that discharge treated effluent into the city's rivers and vleis have been poorly maintained over several years, and have contributed substantially to ongoing ecological degradation. Implementation of major works to rehabilitate these and other wetlands severely impacted by decades of water quality abuses should be prioritised – it is acknowledged that the CCT's 2023/24-2024/25 year draft

budget does include some significant vlei rehabilitation interventions, including dredging of Zeekoevlei and Milnerton Lagoon.

It is however relatively meaningless to rehabilitate these ecosystems if they remain the receiving areas for large-scale pollution, and measures to address WWTW performance are critically important. Rapid access to basic equipment for management of WWTWs under emergency / breakdown conditions appears to be a serious limitation in the CCT's current management structures, with long delays in procurement of pumps and other equipment required to effect repairs or remediation of contaminated areas. In the case of the Milnerton Lagoon at least, these resulted in prolonged exposure to high levels of effluent that clearly did not meet its required standards and contributed substantially to the collapse, in 2022, of an important estuarine ecosystem (see Rose et al. 2023).

A system for fast-tracking procurement of, or keeping in stock, equipment that is likely to be required on an emergency basis for all WWTWs should be investigated, noting the opportunities for graft that such systems could also enable.

It is further recommended that CSRM should include final effluent water quality and discharge volumes from all WWTWs in its data base, to allow for more integrated interpretation of water quality data in receiving water bodies.

9.4.2 Addressing pollution from informal settlements and suburbs with high levels of backyard settlement

It is clear that there is an urgent need to address access to adequate sewerage and stormwater services within all CCT managed settlements. From a water quality perspective, there is however no time to wait for such an eventuality and in the interim it is recommended that the CCT pursue less-ideal measures such as diversions of polluted low stormwater flows to WWTWs via existing or new sewers.

The rapid and uncontrolled expansion of informal settlements in many areas of the city also needs to be addressed. Addressing this issue falls outside of the scope of this report but remains highly relevant to water quality concerns.

9.4.3 Addressing sewage overflows from pump station failure

Figure 9.1 highlights the fact that the main reasons for pump station overflows, at least over the CCT's 2020/21 financial year, appeared to be rooted in mechanical and equipment failure, rather than from load-shedding, although load-shedding impacts have probably increased since the 2021 reporting period, with increased frequency of power outages. Ensuring availability of spare parts, proactive maintenance and strategic upgrading of pump stations should be prioritised.

Pump station upgrades should include allowance for additional bunding as well as inclusion of grids to reduce ingress by foreign objects, which clearly play a role in periodic pump station failure.

9.4.4 Reducing the passage of solid waste into stormwater systems and watercourses

Collection of solid waste must be upscaled in the city to reduce the high levels of waste that accumulate in many areas. Subcatchments that are particularly prone to the build-up of solid waste include the Soet, upper Sir Lowry's Pass, lower Kuils, Lower Salt, Diep, lower Hout Bay, north-eastern Sand and upper Zeekoe subcatchments.

Pro-active measures to improve waste management in solid waste hotspots should include the provision of skips or dedicated waste disposal areas at access points to known dumping areas, as well as increased frequency of collection of solid waste (daily if necessary) from areas where residents are unlikely to have space for refuse storage over extended periods of time.

9.4.5 Making changes in stormwater and sewerage reticulation management structures

An important recommendation from this report is for a change in the CCT's regional management structures, across both sewerage reticulation areas and stormwater management regions, so as to align management areas and responsibilities with hydrological (major river) catchments, rather than with the current stormwater management regions (see **Section 2.8**) and sewerage reticulation management regions, which do not relate to surface runoff and do not facilitate strategic pollution abatement at a catchment level, since different

managers have responsibility for different parts of the catchment.

9.4.6 Fast-tracking implementation of PASAPs

While it is understood that PASAPs have been developed for several areas of the city to date, their details were not available at the time of this report. It is however strongly recommended that implementation of the PASAPs be fast-tracked, so that measurable improvement in pollution abatement can be tracked.

It is also recommended that additional PASAPs should be compiled and implemented for other key pollution hotspots, including the lower Kuils River, the upper Sir Lowry's Pass River, the upper Sand River through Retreat and the Diep River subcatchments at least.

9.4.7 Changing targets for interpreting sewage contamination in water quality data

The CCT currently has a 60% target for meeting Acceptable *E. coli* Risk levels in any subcatchment. This low target seems counter-productive and it is strongly recommended that a target of 100% Acceptable samples would be more appropriate. This is particularly so because many of the CCT's citizens are regularly exposed to contact with water in watercourses that are not managed for recreational use.

9.4.8 Conservation of existing subcatchments in relatively good condition

Water quality data reported on in this document highlighted the fact that some subcatchments and portions of subcatchments were in a generally good condition (i.e., target thresholds for key ecological and human health variables were usually met). These subcatchments should be safeguarded, with high attention paid to addressing sources of periodic pollutant inflows into these systems. Such an approach would at least ensure that these subcatchments remain in a relatively good condition within the CCT boundaries. These include (in descending order) the Silvermine, Lourens, (upper) Hout Bay, South Peninsula and Sand subcatchments. None of these subcatchments receive WWTW effluent, and only the Hout Bay subcatchment receives significant runoff from poorly serviced informal settlements.

Problem manholes and pump stations in these areas should be attended to as a matter of urgency.

9.4.9 Inclusion of the Sand subcatchment as a priority catchment

The Sand subcatchments includes Zandvlei – one of the city's important recreational waterbodies. This subcatchment is not currently included among the six priority catchments, although it has been included in this report among these, because of the extent of work currently being carried out in the catchment through the LUW programme. It is however recommended that the Sand subcatchments should be formally included as a priority catchment within the MPP. This recommendation recognizes the importance of the catchment; its vulnerability to frequent sewage overflows and pump station failures; and the high levels of recreational use of the Zandvlei estuary and its associated wetlands.

9.4.10 Undertake a study to assess real socio-economic costs of vlei / estuary closure as a result of poor water quality

Closure of three of the CCT's recreational vleis during extended periods in the 2020-2021 reporting periods resulted in reported profound economic and social implications for businesses and users dependent on access to these waterbodies. It is recommended that the CCT should fund an independent study that investigates the actual socio-economic impacts of vlei closures, so that such interventions can be carried out in the future with full appreciation of the socio-economic consequences attached to measures aimed at reducing human health risk. Such a study should also try to identify means of mitigating against such impacts.

9.4.11 Changes to the CCT's water quality monitoring programme

The recommendations made in this section relate specifically to changes that would improve the efficacy of the current CCT water quality monitoring programme in being able to inform water quality data interpretation, water quality management and water quality improvement policy and implementation.

9.4.11.1 Sample sites

Additional monitoring sites should be provided as follows:

- In the Khayelitsha Wetland Park, at a representative site for the water bodies utilised by the Khayelitsha Canoe Club;
- Downstream monitoring sites for all WWTW effluent outfalls into rivers or channels (that is, all non-marine discharge points).

9.4.11.2 Water quality variables

Monitoring of the following additional variables is recommended:

- At existing or new sampling points downstream of all WWTWs that discharge effluent into directly or indirectly into rivers, vleis or estuaries:
 - Chloramine and COD testing in receiving waters downstream of WWTWs;
 - Heavy metal analyses, with heavy metals to be determined with regard to subcatchment landuse characteristics.
- At all existing inland water quality monitoring points, where *E. coli* counts are currently analysed:
 - Enterococci testing should be allowed for as well, with a view to moving from *E. coli* to enterococci testing or at least until there is higher confidence attached to the veracity of *E. coli* data.

9.4.12 Safe-guarding the integrity of water quality analyses

Poor confidence in *E. coli* analyses carried out at the SSB resulted in no *E. coli* data being included for the whole 2021 reporting period. This is a significant data gap that has compromised the ability of this report to comment accurately on trends in sewage contamination of Cape Town's waterways over this period. Although enterococci analyses were carried out on additional sites over this time, they allowed only recreational vleis to be considered in any detail, and without recourse to a longer data record.

In order to improve confidence in *E. coli* monitoring data, it is recommended that SSB submit replicate samples for 10% of water samples to at least three independent accredited laboratories, for analysis over the next 6 months, to show that the data lie within the same general range, noting that differences between laboratories would be expected.

Until such time as that is achieved, it is recommended that enterococci analyses should take place for all inland water quality samples, in addition to *E. coli*.

9.4.13 Reporting water quality data

The system for reporting of *E. coli* and other bacteriological data must be standardised to allow for better statistical analyses of these data. It is important that data reflecting samples that have not been analysed to an actual count are at least taken as close to that number as possible, through multiple laboratory dilutions, facilitated by the Colilert system currently being used by SSB. In particular, ">" annotation should not be used to reflect counts that are less than the threshold for Unacceptable. Moreover, in highly polluted watercourses, data simply reflecting ">x", where x is above the Unacceptable limit but still relatively low relative to the degree of pollution, such data do not allow pollution tracking or the identification of likely zones of increasing contamination. It is recommended that samples should be diluted to levels where at least reporting up to 10 000 000 cfu/100ml is possible. SSB should be engaged with in this regard, to set consistent rules for data dilution and reporting.

9.4.14 Reporting on enterococci data

One of the issues highlighted in this report was that of repeated sampling of sites where sewage spills have taken place or are suspected. This results in multiple potentially highly contaminated water samples, the data from which can skew Hazen assessments of long-term data, by increasing the 90th and 95th percentiles considerably. Such issues need to be considered carefully in the interpretation of long-term data with high potential event-driven variability. It is recommended (1) that criteria for once-off samples should be used for event-based monitoring; and (2) that regular monitoring should be carried out at problem sites, whether or not there are sewage spills, to build up a big enough dataset to allow for proper risk assessment based on percentiles.

9.4.15 Water quality data availability

The CCT's allowance in early 2022 for open public access to water quality data from its routine monitoring programme through the CCT data portal is fully supported and should continue.

9.4.16 The need to link water quality data to pollution control interventions

The CCT's routine water quality monitoring produces an extensive ongoing dataset. However, without using these data to trigger further investigations or to design and carry out specific interventions to address sources of pollution or police identified polluters, the CCT is simply producing a record of water quality deterioration. It is recommended that targeted short-term pollution tracking projects should be set up in all of the priority catchments, and the findings of these programmes used to design appropriate interventions, with a view to using water quality data to make sound management decisions and interventions.

9.4.17 Improvements in data quality or data availability from other CCT datasets

9.4.17.1 Rainfall data

Reliable rainfall data were available for only eight rain-gauging stations across the city. This did not provide an adequate spread of data with which to make useful links to water quality data. This report has provided (in **Section 4.5**) recommendations for improving rainfall data collection and collation for future reporting.

9.4.17.2 Flow data

Water quality data on their own do not allow calculations of loading on downstream ecosystems. This means that the impact of high concentrations from small discharge sources may be over-estimated, while significant impacts resulting from large discharges of less polluted effluent may be missed.

The CCT currently collects flow data from some routine monitoring points. These data are not however collected at the same time as water quality samples, making calculations of loading impossible. Furthermore, the datasets themselves are problematic, with many missing datapoints.

It is recommended that regular flow measurements should be taken from selected points in all of the CCT's major rivers, at the same time as water samples are collected. Flow measurement approaches could be technology driven with recording devices, or (more practically) carried out using depth measurements at controlled areas (e.g. culverts), where the cross-section can be surveyed and discharge curves calculated.

9.4.17.3 Tracking interventions

The CCT is currently undertaking numerous interventions across the city, carried out by various departments, branches and sections within the Water and Waste Directorate. It is recommended that a coordinated log of these interventions should be kept, showing intervention, date, subcatchment and location, to allow these interventions / efforts to be correlated with changes, if any, in water quality data.

9.4.18 Capturing spill data per catchment

The CCT has commenced logging data for sewage pump station overflows. These data now include locations tagged to subcatchments and are a valuable source of information for water quality data interpretation and to guide repair and maintenance effort. These datasets should be maintained and should form part of water quality assessments going forward.

9.5 What can residents do to improve water quality in Cape Town's watercourses ?

Water quality in Cape Town's watercourses is not determined solely by the CCT's interventions. Residents also need to play a role in reducing sources of pollution into watercourses.

The following are the top ten changes that could lead to a measurable improvement in water quality in many systems, if they are consistently applied by enough residents:

1. Household waste should be binned, recycled or composted, depending on the type. Do not throw it down the stormwater drain or into the sewer network, as it either blocks the system and causes localised flooding or sewer overflows, or ends up in and pollutes our waterways. If household waste is

not collected often enough, then contact the CCT or your Ward Councillor.

2. Don't flush nappies, sanitary products, wipes, earbuds, condoms, hair, rags or newspapers into toilets or into the sewer network. These block the sewer network, which result in overflows of raw sewage into the environment.
3. Dirty household wastewater, swimming pool backwash, bin washing water and other polluted water should be disposed of in the sink or toilet so that it enters the sewer network and travels to WWTWs for treatment, rather than the stormwater system. If such wastewater reaches the stormwater system instead, it is destined for our waterways and, ultimately, the ocean, where it will pollute and harm these ecosystems.
4. Report sewage spills or sewage pump overflows in any areas to the CCT's "Report a fault" (C3 notification) system by phoning 0860 103 089 or going online to:
www.capetown.gov.za/servicerequests.
5. Join local river clean-up groups and help prevent waste from getting into waterways in the first place.
6. Restaurants should clean out grease traps regularly, as a build-up of fats in the sewer system is a major cause of blockages and sewer overflows.
7. Don't wash vehicles on hard surfaces near a drain, as the chemicals in the greywater will run directly into the stormwater system. Rather wash your vehicle on a soft surface, where the greywater gets absorbed into the soil. Also make sure that your local car wash facility takes steps to prevent runoff of dirty detergent-laden wastewater.
8. Dispose of used oil, paint and other products that contain harmful chemicals at a City-approved drop-off facility, and not into the stormwater system or sewer network.
9. Use eco-friendly products in gardens and for cleaning vehicles. When it rains, chemicals in fertilisers, pest control and cleaning products end up in the stormwater system, harming our rivers, streams, wetlands and the ocean.
10. Make a concerted effort to use low-phosphate detergents and other products, wherever possible, to help reduce the phosphate load on rivers, vleis and wetlands, and to help transition Cape Town towards a phosphorus-free city.

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APPENDIX A: WATER QUALITY SAMPLING SITES AND MONITORING RECORD

Table A.1
Frequency of samples per site in each subcatchment for the 2020 and 2021 Reporting Periods

Subcatchment	Type	Site	Description of sample point location	Assessment Year	
				2020	2021
Diep	River dataset	MCC	Milnerton Canoe Club (Diep River)	17	31
		MOS05	Diep River u/s Mosselbank River confluence	16	24
		RTV01	Diep River at Blauwberg Road bridge	90	97
		RTV03	Stormwater canal from Theo Marais Park (Montagu Gardens)	54	51
		RTV04	Stormwater channel from Bayside Mall (into Rietvlei)	41	55
		RTV05	Outlet from Rietvlei at Otto du Plessis Drive bridge	87	106
		RTV06	Diep River downstream of N7 road bridge	33	45
		RTV08	Duikersvlei Stream u/s of confluence with Theo Marais canal	42	51
		RTV09	Diep River estuary at Woodbridge Island (Loxton Rd)	77	82
		RTV10	Diep River estuary at mouth	78	82
		RTV11	Diep River d/s of Potsdam WWTW	94	95
		RTV12	Canal d/s confluence TM & Duikersvlei	63	48
		RTV14	Stormwater channel next to Bayside Mall d/s of Blaauwberg Rd	26	34
		RTV18	Rietvlei north of island opp Broad Rd	18	65
		THEO_MARAIS_D_STREAM	100m d/s of TM Park STW system	29	63
	Standing water	MAC	Rietvlei in front of Milnerton Aquatic Club	18	62
		PEV1	Zoarvlei (south end) at corner of Vrystraat and Grey St	46	50
		PEV2	Zoarvlei (centre) at Wemmys road footbridge	45	41
		RTV02	Rietvlei at jetty	68	95
		RTV17	Water Sport Area middle; Rietvlei		29
		RTV19	Rietvlei north west near Bayside Canal inlet		32
		RTVBUOY1	Rietvlei Waterbody@Bouy1	1	40
		RTVBUOY2	Rietvlei Waterbody@Bouy2	2	57
		RTVBUOY4	Rietvlei Waterbody@Bouy4	1	56
		RTVBUOY6	Rietvlei Waterbody@Bouy6	1	56
Mosselbank	River dataset	MOS01	Maastricht Canal u/s WWTW	75	100
		MOS02	Maastricht Canal d/s WWTW	71	100
		MOS03	Mosselbank trib d/s Fisankraal	20	50
		MOS04	Mosselbank River u/s Diep River confluence	22	24
		MOS06	Mosselbank River nr Klipheuvel	12	16
		MOS07	Mosselbank River u/s Fisankraal WWTW	46	67
		MOS08	Mosselbank River d/s Fisankraal WWTW	56	62
		MOS09	Mosselbank tributary d/s Fisankraal settlement	22	42
Eerste	River dataset	EK08	Kuils River d/s of Baden Powell Drive bridge	76	76
		EK11	Kuils River d/s of Zandvliet discharge (dirt road bridge)	76	76
		EK12	Eerste River u/s of Macassar WTW (d/s of Kuils confluence)	76	74
		EK13	Eerste River on N2 Freeway (u/s of Kuils confluence)	20	24
		EK15	Kleinvlei canal	20	24
		EK17	Eerste River estuary	76	75
		EK18	Moddergatspruit River at Macassar Rd	20	24
Kuils	River dataset	EK03	Bottelary River at Amandel Rd	20	24

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Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

Subcatchment	Type	Site	Description of sample point location	Assessment Year	
				2020	2021
		EK04	Kuils River at Carinus street bridge	73	74
		EK05	Kuils River in canal u/s of Stellenbosch Arterial Rd	18	24
		EK09	Kuils River d/s Belville WWTW discharge at Rietvlei Rd	74	74
		EK19	Kuils River d/s R300 off old bridge	20	24
		EK20	River d/s of Scottsdene WWTW	50	49
	Standing water	KHA01	Pond in Site C on Mew Way	18	22
Hout Bay	River dataset	DR01	Hout Bay River at Princess St	24	24
		DR02	0	25	24
		DR04	Hout Bay River at Longkloof Rd	23	24
		DR05	0	12	12
		DR06	Disa River at Bethal Rd	22	24
Lourens	River dataset	LOU01	Lourens River at Vergelegen Estate	24	25
		LOU02	Lourens River in P.O.S., Hillcrest Rd	20	25
		LOU03	Lourens River at Main Rd - Somerset West	20	25
		LOU04	Lourens River at Broadway Rd	20	25
		LOU05	Lourens River on Beach Road	24	24
		LOU06	Lourens River in Lourensford Estate at ‘Red Bridge’	20	23
		LOU08	Lourens River between Old Bridge and Main Rd Bridge	20	25
LOU13	Stormwater outlet from wetland on Vergelegen Rd	10	11		
Mplain	River dataset	KHA04	Outlet from Khayelitsha stormwater system to sea	24	22
	Standing water	CS23	Mitchell's Plain West STW Drain	24	25
		KHA02	Canal inlet to detention pond near litter device	20	22
		KHA03	Detention pond near outlet on Baden Powell Drive	20	22
Noordhoek	Standing water	WV02	Centre of EAST vlei	40	36
		WV05	Centre of WEST vlei	40	36
		WV08	Wildevoelvlei mouth to sea	11	12
Elsieskraal	River dataset	ELS_GW	Elsieskraal River near Grandwest and Goodwood Station	20	24
		ELS08	Elsieskraal River at Nightingale Way	20	24
		ELS10	Elsieskraal at Carl Cronje Rd	12	22
	Standing water	ANG01	Angelier Park upper dam near Van Riebeeckshof Rd	36	36
		ANG02	Angelier Park lower dam near Van Riebeeckshof Rd	30	33
		DOOR01	Doordekraal Dam at large stormwater outlet on Angelier Stre*	22	22
DOOR03	Doordekraal Dam at south end next to dam wall	36	36		
Lower Salt	River dataset	NR01	Blomvlei Canal at Koodoo Street u/s of Vygekraal River conf*	20	22
		NR02	Vygekraal River at Cornflower Street u/s of Blomvlei Canal *	20	22
		NR03	Vygekraal River u/s of Athlone WTW	28	22
		NR04	Vygekraal River d/s Athlone WTW	24	22
		NR06	Black River at Raapenberg Road bridge	20	24
		NR07	Black River on Footbridge to Alexandra Institute	20	24
		NR08	Liesbeek River downstream of Lake weir opp. Hartleyvale	20	24
		NR09	Salt River Canal at Voortrekker Road bridge	20	24
		NR10	Salt River Canal at Marine Drive Bridge - Paarden Eiland	24	24
		NR11	Black River in Rdbosch Golf Course	20	22
		NR15	Jakkalsvlei Canal at N2	68	76

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Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

Subcatchment	Type	Site	Description of sample point location	Assessment Year	
				2020	2021
		NR16	Langa Canal on N2	20	24
		NR17	Kalksteenfontein Canal nr Netreg Stn	19	22
		NR22	Liesbeek River on Paradise Road	14	14
		NR24	Black River at Sandown Road	11	12
		NR25	Vygekraal d/s of Athlone WWTW at Jan Smuts Drive	27	24
		NR26	Kalksteen Canal at corner Robert Subukwe and N2	72	75
Sand	River dataset	CR01	Westlake River cnr Main and Chenel Roads	20	22
		CR02	Westlake River at Orange St - Kirstenhof	2	14
		CR03	Westlake River Altenburg Rd - Kirstenhof	3	12
		CR04	Westlake River in Pollsmoor Prison grounds	2	10
		CR05	Westlake River at Steenberg Rd	1	12
		CR06	Prinskasteel River in greenbelt off Lismore Rd (close to M3)	20	20
		CR16	Diep River at Alphen Rd in canal d/s of CR15	14	22
		CR20	Keysers River at Military Rd	22	24
		CR21	Sand River at Oudevlei Road (d/s conf Langvlei & Sand)	24	21
		CR22	Downstream of Westlake and Keysers River near railway line	20	20
		CR29	Sand River at Coniston Rd (u/s of litter trap)		14
		DRRSC	0	20	24
		LPVMR	Mocke River inflow to Little Princessvlei	20	24
		LVI	Langevlei - canal at vlei inlet	20	24
		SCV	Southfield Canal at Victoria Road	20	26
	Standing water	LPVN	Little Princessvlei - north	30	36
		LPVS	Little Princessvlei - south	36	36
		LVO	Langevlei - vlei outlet	36	36
		OOG01	Die Oog at Midwood Avenue, Bergvliet	30	36
		PV03	Princessvlei - centre	33	38
		PVWEIR	Princessvlei near outlet weir	20	24
		ZA01S	Zandvlei - north, surface	36	75
		ZA02S	Zandvlei - centre (opp Imperial Yacht Club), surface	40	75
		ZA03S	Zandvlei- south (opposite Playwaters), surface	4	21
		ZA04S	Outlet channel - midway to mouth, surface		49
		ZA05S	Outlet channel near Royal Road bridge, surface	32	52
		ZA06S	South entrance to Marina da Gama canals, surface		33
		ZA07S	North entrance to Marina da Gama canals, surface	2	37
		ZA08S	Marina da Gama canal near 'The Anchorage', surface	37	53
		ZA09S	Marina da Gama canal, surface	30	52
		ZA10S	Westlake Wetland opposite Rutter Rd (old WLW)	35	51
		ZA11S	Marina da Gama canal East Lake (old BM20), surface	30	51
		ZA12S	Marina da Gama canal Baalen Way (old BM22), surface	33	51
		ZA13S	Marina da Gama canal Park Island Bridge (old BM23), surface	33	66
		ZAWAIR	Zandvlei outlet channel at Rubble Weir, surface	33	55
SLPass	River dataset	SIR01	Sir Lowrys Pass River at Wedderwill Farm	20	24
		SIR02	Sir Lowrys Pass River d/s N2	20	24
		SIR03	Sir Lowrys Pass River at Gustrouw Rd	19	20

City of Cape Town

Water Quality of Rivers and Vleis for the period April 2020 to March 2022 (2020 and 2021 Reporting Periods)

Subcatchment	Type	Site	Description of sample point location	Assessment Year	
				2020	2021
		SIR04	Sir Lowrys Pass River (original river channel) at Dolphin Rd	10	6
		SIR05	Sir Lowrys Pass River (original river channel) Hendon Park	24	26
		SIR06	Sir Lowrys Pass River d/s of WWTW (diversion canal)	72	74
		SIR07	Sir Lowrys Pass River at Hibiscus Rd (diversion canal)	24	22
Soet	River dataset	SOE02	Soet River u/s of Greenways Rd	24	25
Silvermine	River dataset	SIL02	Silvermine River near Sunbird Environmental Centre	16	24
		SIL04	Silvermine River a wooden bridge near Winkle Rd - Clovelly	14	16
		SIL06	Silvermine River at Bridge on Main Rd, Clovelly	25	24
Sout	River dataset	SOU01	Sout River at R27	69	70
		SOU02	Sout River at Otto du Plessis Drive	24	24
South Peninsula	River dataset	BOK02	Bokramspruit River upstream of Slangkop Road	21	25
		BOK03	Bokramspruit River a short distance d/s of Flamingo Rd	23	23
		SCH02	Schusters River at Schusterskraal Reserve entrance	16	22
		SCH04	Pound canal (stormwater)	13	15
	Standing water	GC02	Glencairn vlei centre - at concrete berm	35	36
Zeekoe	River dataset	LR02	Lotus River on (N2) 500m from Airport Approach Rd	20	26
		LR03	Lotus River at corner Duinefontein and Lansdowne Roads	20	27
		LR05	Lotus River at entrance to Council Depot on Old Strandfontein Road	20	27
		LR06	Woodlands Canal at New Ottery Road (near Ottery Hypermarket)	20	22
		LR07	Lotus River at Klip Road	19	27
		LR08	Lotus River at Fisherman's Walk bridge (just u/s of vlei)	28	30
		LR10	Little Lotus River at Eighth Avenue	24	26
		POC01	Phillipi stormwater outlet upstream site	20	26
		RVIRD	Italian Rd canal leading to Rondevlei	20	26
	Standing water	RVWEIR	Rondevlei at weir	24	23
		ZEV1S	Zeekoevlei Home Bay in front of Zeekoevlei Yacht Club	34	67
		ZEV2S	Opposite inlet of Big Lotus River	13	54
		ZEV3S	Zeekoevlei in front of Cape Peninsula Aquatic Club	41	70
		ZEV4S	SW corner approx. 200m from weir	10	45
		ZEV9S	Zeekoevlei Eastern shore near stormwater outlet from picnic area at traffic circle		32
		ZEWEIR	Zeekoevlei near weir	4	49

APPENDIX B: THRESHOLD VALUES USED IN DATA INTERPRETATION

B Threshold values to aid in data interpretation

B1 Thresholds for the interpretation of ecosystem condition

The City of Cape Town is included in the Berg Catchment and many of its watercourses have been assigned specific Resource Quality Objectives (RQOs) through the Berg Classification (see Section 5.6). It is thus important that the rating ranges and rating terminology used in assessments of the CCT water quality data should align with those of the Berg RQOs, and be readily referenceable to these gazetted requirements. This approach also ensures that any ecological categorisation of water quality for the CCT aligns to the categories of water quality condition employed at a national level in South Africa and in particular to the methods for determining the water quality component of the Ecological Reserve for rivers. These methods, used in the Berg Classification of DWS (2018), are referred to as Resource Directed Measures (RDM) and assign estuaries and river reaches or systems to a range of water quality categories, which are aligned to categories used in the assessments of Present Ecological State (PES).

The range of values included in these categories have been variously described as Natural to Poor or¹⁴Ideal to Unacceptable (DWAF 2011), and ranked A to F. They can be semi-quantified in terms of percentage deviation from natural (reference) conditions, with 100% scores indicating completely natural conditions, and scores of 0 representing extreme (complete) change from natural conditions with respect to water quality (DWAF 2008). They are compared in **Table B1**.

In the previous CCT inland water quality report (Day et al. 2020), a simpler approach, with fewer but still comparable categories was utilised, for ease of interpretation by a wide range of users. The rating scale included in **Table B1** was thus adopted, with its ratings of Good, Fair, Poor and Unacceptable, with the desired threshold (break point) being "Fair".

Table B1
Relationship between Present Ecological State (PES) water quality categories A-F and scores, showing % deviation from natural conditions, as defined in DWAF (2008) for river Water Quality Resource Directed Measures, as well as the rating categories and their simplified interpretation, compared with the Ideal to Unacceptable categories used in DWAF (2011) and the Berg RQOs

This project:		DWS Ecological Categories (PES) / RDM terminology	PES% score range	DWAF (2011)
City Water Quality Categories	Interpretation of City Water Quality Categories – this report			
GOOD	TARGET	A: Natural / no change	90-100%	Ideal
		B: Largely natural, with few modifications / small change	80-89%	
FAIR		C: Moderately modified / moderate change	60-79%	Acceptable
POOR	POOR	D: Largely modified / large change	40-59%	Tolerable
UNACCEPTABLE	UNACCEPTABLE	E: Seriously modified / serious change	20-39%	Unacceptable
		F: Critically modified / extreme change	0-19%	

¹⁴ **Ideal** – the use of water is not affected in any way; 100% fit for use by all users at all times; desirable water quality (TWQR); **Acceptable** – slight to moderate problems encountered on a few occasions or for short periods of time; **Tolerable** – moderate to severe problems are encountered; usually for a limited period only; and **Unacceptable** – water cannot be used for its intended use under normal circumstances at any time (DWAF 2006)

Rating ranges differentiate between standing water bodies (in this case, the main recreational vleis and dams included in the City's inland monitoring programme) and flowing water systems (that is, rivers), with different variables and sometimes concentrations applicable to different watercourse types, as identified in **Tables B2** and **B3**.

Table B2
Rating ranges for variables considered in this assessment of water quality in City Rivers

City Water Quality Categories (CWQC)	Interpretation of CWQC	¹⁵ PO ₄ -P mg/l	¹⁶ TIN mg/l	¹⁶ DO mg/l	¹⁶ NH ₃ mg/l
GOOD	TARGET	≤ 0.005	≤ 0.25	> 6	< 0.015
		>0.005-0.025	>0.25-0.70		0.015-0.044
FAIR		>0.025-- 0.075	>0.70-1.75		>0.044 -0.072
POOR	POOR	>0.075- 0.125	>1.75-3.00	≥4 -6	>0.072-0.1
UNACCEPTABLE	UNACCEPTABLE	>0.125	> 3.00	< 4	>0.1

Table B3
Rating ranges for variables considered in this assessment of water quality in City Vleis and Dams

City Water Quality Categories (CWQC)	Interpretation of CWQC	¹⁷ PO ₄ -P mg/l	¹⁸ TIN	¹⁹ DO mg/l	¹⁶ NH ₃ mg/l	RUNNING MEAN ANNUAL CHL-A µg/l
GOOD	TARGET	≤ 0.005	≤ 0.7	> 6	< 0.015	≤ 5
					0.015-0.044	>5 - 10
FAIR		>0.005-- 0.015	>0.7 -1		>0.044 -0.072	>10 -20
POOR	POOR	>0.015 - 0.025	>1.0-4.0	≥4 -6	>0.072-0.1	> 20 - 30
UNACCEPTABLE	UNACCEPTABLE	>0.025	> 4	< 4	>0.1	> 30

¹⁵ Based on DWAF (2011) and used in Berg RQOs (DWS 2018)

¹⁶ Based on DWAF (2008) and used in Berg RQOs (DWS 2018)

¹⁷ Based on DWAF (2002) and used in Berg RQOs (DWS 2018)

¹⁸ Based on DWAF (2002) and used in Berg RQOs (DWS 2018)

¹⁹ Based on DWAF (1996a) guideline and used In Berg RQOs (DWS 2018)

B2 Thresholds for the interpretation of water quality risks to recreational users

B2.1 General

Human health risk ratings for *Escherichia coli* data were also based on those used in the Berg RQOs study. Day et al. 2020 used an expanded version of these thresholds, to identify examples of extreme exceedance of these thresholds (as developed by the CCT in routine reporting), as shown in **Table B4**, while Microcystin toxin thresholds were based on those included in the CCT's Recreational Use Water Quality Index. These are slightly more conservative than those used in WHO (2021).

The ratings include both full contact (i.e., swimming) and intermediate contact (e.g. canoeing, sailing) for *E. coli*.

Note however that, given issues around reporting of ">" data over the 2020 reporting period, in the present report, the expanded range of values was not utilised. It has been included in this appendix for future possible application.

B2.2 Microbial indicators

The most frequent adverse health outcome associated with exposure to water contaminated with faecal material is enteric illness (WHO 2021).

Historically, two different bacterial indicators have been used as a measure of the risk posed by the presence of pathogens in water - faecal coliforms and *Escherichia coli*, both typically reported as the number of organisms (or colony forming units / cfu) present per 100 ml of water.

Faecal coliforms are a group of bacteria that include genera (such as *Escherichia*) that are able to survive in the guts of animals (including humans) and also occur in their faeces.

Escherichia coli (abbreviated *E. coli*) is a species of faecal coliform bacteria that is commonly found in the lower intestine of warm-blooded organisms (birds and mammals). Most *E. coli* strains are harmless, but some can cause serious food poisoning in humans. Their presence in the water is used as an "indicator" of faecal contamination of avian or mammalian origin, and therefore are indicative of other pathogens that may be present in faeces.

While faecal coliforms (including *E. coli*) are still considered to be good indicators of the presence of other pathogens in freshwater, research over the last 10 years has shown that faecal coliforms tend to die off faster than other pathogens in seawater, and can result in an underestimate of the risk to beach bathers when only faecal coliform concentrations are monitored. As a result, microbial assessments of coastal waters has shifted to measurements of **intestinal enterococci** as an indicator of public health risks. Worldwide, there has been a general shift to the use of intestinal Enterococci as a standard indicator of public health risks in inland recreational water bodies as well (WHO 2003; 2018; 2021; Australian Government National Health and Medical Research Council 2008).

While there are guidelines for the interpretation of *E. coli* in waters used for full contact recreation (e.g. EU), most authorities who do consider intermediate contact uses now have begun to rely on intestinal Enterococci guidelines.

In South Africa, DWAF (1996b) provides guidelines for both Full Contact and Intermediate Contact recreational use. Of these, the former are based on non-exceedance of maximum ***E. coli*** concentrations, noting that there is "insufficient information for the development of criteria for *E. coli* in water used for intermediate contact recreation purposes" while the latter are based on non-exceedance of maximum **faecal coliform** bacteria concentrations.

The CCT's historical inland water quality database includes both faecal coliform and *E. coli* data. However, all current water microbial assessments include only *E. coli* data²⁰. This means that

²⁰ This was due to a change in microbial analytical methodology (media change) where there is no longer a presumptive faecal coliform count followed by a confirmatory count for *E. coli*. Instead, the *E. coli* count is determined immediately after incubation (see Day et al. 2020).

evaluations of the implications of these data for human health must be carried out on the basis of *E. coli* concentrations alone. Accordingly, the CCT generally interprets the suitability of its inland waters for recreational purposes according to an adaptation of the intermediate contact South African Water Quality Guidelines for Recreational Use (DWAF 1996b) – see **Table B4**. A limitation of this guideline, when used with *E. coli* data alone, however, is that it potentially under-estimates risk, in that *E. coli* concentrations make up just one component of the total faecal bacterial count.

Table B4
Generic water quality limits for Recreational Use: Intermediate Contact
Faecal coliforms
Values extracted from DWAF (2006) as used in Berg RQOs

GRADE	FAECAL COLIFORM COUNT (INCLUDING <i>E. COLI</i>) ¹
TARGET (IDEAL)	≤ 1 000 CFU/100 ML
ACCEPTABLE	1 001-2 500 CFU/100 ML
TOLERABLE	>2 500-4000 CFU/100 ML
UNACCEPTABLE	>4000 CFU/100 ML

Table B5

Approach to assessment of microbial data in this study, based on DWAF (1996b) and the Berg RQOs and applied to *E. coli* concentrations as per CCT's *E. coli* specific target for full contact recreation, as per DWAF (1996b). The table below indicates additional ranges for *E. coli* beyond the "Unacceptable" threshold, to indicate very high levels of pollution in some cases.

GRADE	FAECAL COLIFORM COUNT (INCLUDING <i>E. COLI</i>) ¹
TARGET FOR MAXIMUM ACCEPTABLE RISK FOR <u>FULL CONTACT RECREATION</u>	≤ 400 ²¹ CFU/100 ML \
ACCEPTABLE <u>RISK INTERMEDIATE CONTACT</u>	≤ 2 500 CFU/100 ML
TOLERABLE RISK - INTERMEDIATE CONTACT	> 2 500-4000 CFU/100 ML
UNACCEPTABLE RISK - INTERMEDIATE CONTACT	>4000 CFU/100 ML

"UNACCEPTABLE" CATEGORIES	INDICATIVE <i>E. COLI</i> RANGE (COUNT/100ML)	COMMENT / STRATEGIC MANAGEMENT RESPONSE
LEVEL 1	4001 – 10 000	- WQ <u>trends</u> in this range may be reflective of general urban diffuse runoff rather than a major point source of pollution - Address using stormwater / catchment management measures. - Ensure sewer spill responses are adequate and timely. - Continue to monitor to determine if additional pollution abatement intervention is necessary.
LEVEL 2	10 001 – 100 000	- WQ <u>trends</u> in this high range are likely indicative of chronic pollution possibly from multiple source/s. - If results are in this range for a single month / only during the rainy season it is possible that catchment wash-off (first flush) or surcharging sewers were causal factors. - Transversal approach to pollution abatement is necessary. - Extra budget may be required.
LEVEL 3	> 100 000	WQ <u>trends</u> in this extreme range likely indicate chronic

²¹ The concentrations of bacteria in water is usually expressed as numbers of colony-forming units (cfu) per 100 ml, which is a measure of the number of viable cells in a particular sample, where a colony represents an aggregate of cells derived from a single progenitor cell

"UNACCEPTABLE" CATEGORIES	INDICATIVE <i>E. COLI</i> RANGE (COUNT/100ML)	COMMENT / STRATEGIC MANAGEMENT RESPONSE
		ongoing pollution from multiple sources &/or extreme incidents.* - Urgent management intervention to address the source/s of contamination. - Transversal approach to pollution abatement is necessary. - Significant funding likely to be required

Enterococci data were interpreted using the same thresholds used by the CCT for its coastal enterococci evaluations, which are drawn from the national guidelines of DEA (2012) WHO (2021) confirm that the same thresholds can be applied to both marine and inland (fresh) waters.

Guidelines for the interpretation of single sample data have been used in this report for compliance type reporting. These guidelines are provided in DEA (2012) as well. The latter report does note however that single sample interpretation is not ideal, as it does not allow reasonable determination of Risk for water users. However, in the present reporting context, it does allow evaluation of suitability of water for intermediate contact use over a number of sampling periods.

One of the issues also highlighted in this report was that of repeated sampling of sites where sewage spills have taken place or are suspected. This results in multiple potentially highly contaminated water samples, the data from which can skew Hazen assessments of long-term data, by increasing the 90th and 95th percentiles considerably. Such issues need to be considered carefully in the interpretation of long-term data with high potential event-driven variability.

Table B6

Approach to assessment of microbial data (intestinal enterococci counts)

Percentile data calculated using the Hazen Method

Water quality categories as used in the CCT's Coastal Water Quality Reporting²²

Single sample ratings from DEA (2012)

See **Appendix B** for derivation of threshold values.

Interpretation	Descriptor in Coastal Water Quality Reporting	Estimated risk of illness per exposure ²	Enterococci (cfu/100 ml)	Enterococci (cfu/100 ml) - for single samples
TARGET	EXCELLENT	< .9% Gastrointestinal Illness (GI) risk	< 100 (95 th percentile)	
ACCEPTABLE RISK INTERMEDIATE CONTACT	GOOD	<5% Gastrointestinal Illness (GI) risk	< 200 (95 th percentile)	≤240
TOLERABLE RISK - INTERMEDIATE CONTACT	SUFFICIENT	<8.5% Gastrointestinal Illness (GI) risk	< 185 (90 th percentile)	240 – 380
UNACCEPTABLE RISK - INTERMEDIATE CONTACT-- LEVEL 1	POOR	>8.5% Gastrointestinal Illness (GI) risk	≥ 185 (90 th percentile)	>380

² 'Exposure' defined as 10 minutes of swimming with three head immersions

²² (<https://www.capetown.gov.za/explore%20and%20enjoy/nature-and-outdoors/our-precious-biodiversity/coastal-water-quality>)

B2.3 Microcystin toxins

Cyanobacteria (or blue-green algae) are a common and naturally occurring component of most recreational water environments (WHO 2021). They are of potential public health concern because some types may under certain circumstances produce toxins that can have a harmful effect on recreational water users.

The City of Cape Town also monitors its water bodies for microcystin toxins. The thresholds for interpretation shown in Table B6 are used by the CCT, and were developed for use in its Recreational Water Quality Index (Day and Clark 2012). These thresholds are based on the WHO (2003) guidelines for full and intermediate contact recreation. Note that WHO (2021) provides an updated GV Recreation ($GV_{RECREATION}$) Threshold of 24 $\mu\text{g/L}$ for microcystins, below which recreational water use should be within acceptable risk limits. This suggests that the Medium Risk values in **Table B7** are slightly conservative

Table B7

Water quality grades and corresponding threshold concentrations for Microcystin toxins for inland waters adopted for this project. Guideline levels are based on those published by the WHO (2003).

Interpretation	Microcystin Toxin Concentration
TARGET (ACCEPTABLE)	$\leq 20 \mu\text{G/L}$
MEDIUM RISK (UNACCEPTABLE)	$>20-30 \mu\text{G/L}$
HIGH RISK (UNACCEPTABLE)	$>30-40 \mu\text{G/L}$
EXTREME RISK (UNACCEPTABLE)	$>40 \mu\text{G/L}$

APPENDIX C: SUMMARY VALUES FOR KEY VARIABLES

Table C.1

Summary data for key variables per subcatchment for reporting period 2020 and 2021 – for flowing water systems (rivers and stormwater channels)
Data presented as median values for all variables except *E. coli*, for which data are presented as geometric means

Subcatchment	2020						2021					
	<i>E coli</i> (cfu/100 ml)	NH3 (mg/L)	PO4-P (mg/L)	TIN (mg/L)	NH4: TIN	DO (mg/L)	NH3 (mg/L)	PO4-P (mg/L)	TIN (mg/L)	NH4: TIN	DO (mg/L)	
Diep	5 479	0.032	2.13	4.90	0.88	5.10	0.040	2.10	6.49	0.85	5.45	
Eerste	2 763	0.085	2.55	16.70	0.96	4.10	0.059	2.20	10.90	0.92	4.95	
Elsieskraal	4 562	0.055	0.12	2.07	0.27	10.15	0.029	0.15	1.46	0.53	9.90	
Hout Bay	4 995	0.001	0.03	0.23	0.58	9.02	0.001	0.04	0.41	0.58	8.90	
Kuils	4 833	0.035	1.20	7.28	0.56	7.90	0.034	1.30	6.20	0.54	6.95	
Lourens	204	0.001	0.02	0.55	0.08	9.80	0.001	0.02	0.37	0.18	9.50	
Lower Salt	60 577	0.154	3.31	13.88	0.74	3.65	0.096	2.70	10.92	0.69	4.75	
Mosselbank	3 068	0.054	1.60	8.34	0.82	5.40	0.049	1.60	6.90	0.75	6.40	
Mplain	2 226 789	0.200	1.17	15.63	1.00	3.45	0.161	1.53	15.92	1.00	2.40	
Sand	1 218	0.002	0.09	0.71	0.25	8.30	0.001	0.06	0.69	0.13	8.15	
Silvermine	129	0.001	0.01	0.10	0.45	8.20	0.001	0.01	0.11	0.46	8.40	
SLPass	899	0.001	0.10	0.92	0.17	8.75	0.001	0.11	1.09	0.25	8.45	
Soet	224 812	0.404	1.63	19.65	0.98	5.80	0.376	2.02	17.34	0.99	3.30	
Sout	267	0.002	4.00	0.94	0.22	5.10	0.001	4.90	1.45	0.52	5.35	
South Peninsula	5 277	0.002	0.16	1.19	0.47	7.30	0.001	0.13	1.23	0.44	7.40	
Zeekoe	10 491	0.052	0.41	5.51	0.78	4.23	0.114	0.63	8.13	0.90	4.25	

Table C.2
Summary data for key variables per subcatchment for reporting period 2020 and 2021 – for standing water systems (vleis and lakes/ dams)
Data presented as median values for all variables except *E. coli*, for which data are presented as geometric means

Subcatchment	Vlei name	2020						2021				
		<i>E. coli</i> (cfu/100 ml)	NH3 (mg/L)	PO4-P (mg/L)	TIN (mg/L)	NH4:TIN	DO (mg/L)	NH3 (mg/L)	PO4-P (mg/L)	TIN (mg/L)	NH4:TIN	DO (mg/L)
Diep	Rietvlei	19	0.011	0.18	0.19	0.54	8.99	0.005	0.16	0.14	0.39	8.60
	Zoarvlei	234	0.005	0.37	0.88	0.55	4.00	0.003	0.23	0.75	0.67	5.40
Elsieskraal	Elsieskraal dams	132	0.004	0.01	0.27	0.35	7.60	0.001	0.01	0.17	0.37	5.80
Kuils	Mew Way DP	3 167 381	0.254	2.11	19.13	1.00	1.60	0.117	1.46	14.12	1.00	1.70
Mplain	Mplain DP	570 187										
	Mplain DP	2 984 354	0.185	1.15	13.24	0.99	4.75	0.132	1.49	15.14	1.00	3.05
Noordhoek	Wildevleivlei	223	1.586	3.76	20.42	0.88	11.36	0.863	4.35	21.76	0.99	6.65
Sand	Die Oog	101	0.001	0.01	0.36	0.88	8.09	0.001	0.01	0.20	0.63	7.75
	Langevlei	452	0.039	0.12	1.07	0.46	10.41	0.009	0.05	0.45	0.26	8.50
	Little Princessvlei	141	0.001	0.03	0.28	0.48	6.35	0.001	0.02	0.24	0.47	6.85
	Princessvlei	67	0.001	0.01	0.13	0.37	9.30	0.002	0.01	0.12	0.17	10.50
	Westlake	330	0.013	0.04	0.43	0.86	8.53	0.015	0.06	0.26	0.75	9.40
	Zandvlei	368	0.011	0.02	0.26	0.84	9.00	0.010	0.03	0.18	0.76	8.35
S. Peninsula	Glencairn vlei	222	0.001	0.01	0.13	0.33	5.90	0.001	0.01	0.10	0.26	5.90
Zeekoe	Rondevlei	19	0.003	0.08	0.65	0.57	4.80	0.001	0.06	0.20	0.37	5.25
	Zeekoevlei	88	0.032	0.73	0.80	0.53	9.29	0.033	0.41	1.16	0.42	9.75

Table C.3

Median values for key variables per subcatchment for flowing water systems (river and stormwater channels) and standing water systems (vleis and lakes / dams) for each site.
Data presented as median values for all variables except *E. coli*, for which data are presented as geometric means

Subcatchment	Site	Type	Vlei name	2020						2021				
				<i>E. coli</i> cfu/100ml	NH3 (mg/L)	PO4-P (mg/L)	TIN (mg/L)	NH4:TIN	DO (mg/L)	NH3 (mg/L)	PO4-P (mg/L)	TIN (mg/L)	NH4:TIN	DO (mg/L)
Diep	MAC	Standing water	Rietvlei	31						0.003	0.152	0.055	0.193	8.650
	MCC	River dataset	Milnerton Lagoon	776										
	MOS05	River dataset	N/A	888	0.029	1.980	1.737	0.628	4.950	0.010	1.280	1.489	0.554	7.150
	PEV1	Standing water	Zoarvlei	201	0.015	0.340	0.993	0.509	5.550	0.010	0.160	1.155	0.673	6.500
	PEV2	Standing water	Zoarvlei	297	0.002	0.405	0.626	0.875	2.100	0.001	0.245	0.372	0.692	2.150
	RTV01	River dataset	N/A	548	0.007	2.500	5.600	0.836	5.800	0.012	2.643	6.481	0.864	4.300
	RTV02	Standing water	Rietvlei	14	0.011	0.182	0.185	0.542	8.990	0.005	0.163	0.138	0.405	9.150
	RTV03	River dataset	N/A	7 439	0.007	0.137	2.098	0.270	5.350	0.012	0.132	1.734	0.340	6.900
	RTV04	River dataset	N/A	42 863	0.016	0.076	2.191	0.339	6.650	0.024	0.099	1.711	0.507	7.950
	RTV05	River dataset	N/A	15 437	0.063	4.100	8.835	0.954	3.200	0.104	3.035	10.350	0.938	2.800
	RTV06	River dataset	N/A	1 367	0.012	3.865	1.042	0.727	2.950	0.005	2.205	0.745	0.474	4.100
	RTV08	River dataset	N/A	3 091	0.113	2.430	17.938	0.936	4.950	0.060	0.452	6.907	0.358	6.700
	RTV09	River dataset	Milnerton Lagoon	3 585	0.078	1.815	4.405	0.887	7.900	0.116	3.305	7.860	0.928	6.850
	RTV10	River dataset	Milnerton Lagoon	5 122	0.043	1.135	3.774	0.899	9.100	0.101	2.058	5.203	0.919	9.750
	RTV11	River dataset	N/A	9 296	0.099	3.200	9.950	0.915	3.900	0.143	3.184	11.553	0.950	3.650
	RTV12	River dataset	N/A	19 530	0.043	0.857	4.464	0.766	4.100	0.059	0.415	4.903	0.683	5.850
	RTV14	River dataset	N/A	24 691	0.010	0.155	1.703	0.354	7.000	0.029	0.140	1.419	0.660	4.500
	RTV17	Standing water	Rietvlei							0.006	0.184	0.040	0.367	8.400
	RTV18	River dataset	Milnerton Lagoon	7 115	0.036	2.330	4.832	0.901	2.700	0.178	4.101	11.386	0.981	4.300
	RTV19	Standing water	Rietvlei							0.004	0.180	0.111	0.373	8.300
	RTVBUOY1	Standing water	Rietvlei							0.028	0.160	0.102	0.447	8.150

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	RTVBUOY2	Standing water	Rietvlei							0.006	0.158	0.203	0.372	8.400
	RTVBUOY4	Standing water	Rietvlei							0.008	0.157	0.225	0.428	8.200
	RTVBUOY6	Standing water	Rietvlei							0.005	0.157	0.187	0.407	8.200
	THEO_MARAIS_D_STREAM	River dataset	N/A	4 300		4.850	8.781	0.950		0.052	1.580	7.369	0.815	4.100
Eerste	EK08	River dataset	N/A	970	0.085	2.700	9.350	0.927	1.500	0.098	2.300	8.552	0.955	1.800
	EK11	River dataset	N/A	1 887	0.303	2.800	22.400	0.955	3.150	0.179	2.300	14.300	0.920	3.600
	EK12	River dataset	N/A	2 718	0.260	2.500	21.100	0.966	2.400	0.165	2.050	12.299	0.894	3.900
	EK13	River dataset	N/A	642	0.002	0.463	1.651	0.079	7.705	0.002	0.557	1.833	0.061	7.750
	EK15	River dataset	N/A	41 632	0.050	0.062	3.499	0.187	14.250	0.125	0.220	3.480	0.608	9.700
	EK17	River dataset	Eerste Estuary	17 837	0.386	3.190	27.500	0.983	2.700	0.314	3.400	23.600	0.971	5.500
	EK18	River dataset	N/A	476	0.001	0.137	0.445	0.111	5.350	0.007	0.145	0.815	0.586	5.950
Elsieskraal Hout Bay	ANG01	Standing water	Elsieskraal dams	51	0.003	0.005	0.192	0.382	6.900	0.001	0.014	0.173	0.340	6.000
	ANG02	Standing water	Elsieskraal dams	104	0.003	0.005	0.239	0.308	8.400	0.001	0.010	0.106	0.335	7.400
	DOOR01	Standing water	Elsieskraal dams	977	0.002	0.085	1.236	0.275	7.500	0.010	0.196	1.928	0.526	4.300
	DOOR03	Standing water	Elsieskraal dams	67	0.007	0.013	0.191	0.463	6.550	0.001	0.008	0.113	0.380	5.550
	ELS_GW	River dataset	N/A	6 928	0.169	0.161	3.384	0.247	11.435	0.193	0.283	2.656	0.547	10.050
	ELS08	River dataset	N/A	16 999	0.055	0.128	2.260	0.266	11.940	0.077	0.252	2.017	0.589	10.350
	ELS10	River dataset	N/A	254	0.001	0.041	0.281	0.226	8.600	0.003	0.044	0.255	0.328	9.600
	DR01	River dataset	N/A	72 867	0.010	0.226	2.776	0.988	2.155	0.004	0.246	1.669	0.877	2.700
	DR02	River dataset	N/A	18 383	0.001	0.058	0.669	0.916	4.605	0.003	0.127	1.021	0.865	3.400
	DR04	River dataset	N/A	390	0.001	0.014	0.080	0.486	10.000	0.001	0.014	0.099	0.510	9.750
	DR05	River dataset	N/A	25 648										

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	DR06	River dataset	N/A	156	0.001	0.017	0.156	0.333	9.700	0.001	0.015	0.182	0.263	9.300
Kuils	EK03	River dataset	N/A	523	0.031	2.065	8.130	0.418	6.050	0.021	2.093	8.564	0.304	5.000
	EK04	River dataset	N/A	1 883	0.011	0.820	4.927	0.250	10.550	0.012	1.100	4.862	0.229	8.150
	EK05	River dataset	N/A	39 971	0.148	2.100	12.836	0.758	7.700	0.087	1.437	7.757	0.753	6.200
	EK09	River dataset	N/A	23 263	0.163	2.100	14.500	0.807	8.400	0.082	1.900	12.463	0.842	7.150
	EK19	River dataset	N/A	3 139	0.001	0.150	1.767	0.062	7.500	0.003	0.197	2.551	0.116	6.600
	EK20	River dataset	N/A			0.600	5.400	0.636			1.200	5.850	0.528	
	KHA01	Standing water	Mew Way DP	3 167 381	0.254	2.110	19.125	0.998	1.600	0.117	1.460	14.115	0.996	1.700
Lourens	LOU01	River dataset	N/A	76	0.001	0.020	0.755	0.040	10.100	0.001	0.017	0.413	0.083	9.800
	LOU02	River dataset	N/A	459	0.001	0.019	0.619	0.066	9.760	0.001	0.020	0.444	0.171	9.700
	LOU03	River dataset	N/A	276	0.001	0.018	0.544	0.040	10.150	0.001	0.017	0.461	0.223	9.700
	LOU04	River dataset	N/A	1 055	0.001	0.022	0.614	0.067	9.635	0.001	0.016	0.267	0.149	9.500
	LOU05	River dataset	N/A	940	0.001	0.031	0.584	0.222	9.700	0.001	0.022	0.449	0.228	8.700
	LOU06	River dataset	N/A	7	0.001	0.020	0.084	0.256	10.400	0.001	0.022	0.088	0.408	10.000
	LOU08	River dataset	N/A	249	0.001	0.019	0.576	0.049	10.100	0.001	0.016	0.293	0.164	9.500
	LOU13	River dataset	N/A	122	0.001	0.054	0.121	0.339	6.500	0.001	0.044	0.132	0.250	6.050
Lower Salt	NR01	River dataset	N/A	203 459	0.010	0.186	3.585	0.728	3.150	0.019	0.314	2.184	0.958	2.500
	NR02	River dataset	N/A	172 318	0.158	1.260	12.386	0.922	2.750	0.129	0.542	7.140	0.916	6.600
	NR03	River dataset	N/A	400 239	0.174	2.750	11.502	0.701	1.800	0.135	2.250	8.980	0.768	3.200
	NR04	River dataset	N/A	247 878	0.214	3.190	21.798	0.938	2.300	0.147	2.970	16.737	0.887	4.100
	NR06	River dataset	N/A	126 981	0.213	2.665	20.486	0.964	1.900	0.193	2.953	15.285	0.885	3.650
	NR07	River dataset	N/A	183 451	0.290	3.000	20.694	0.976	1.600	0.148	3.071	14.539	0.947	2.400
	NR08	River dataset	N/A	400	0.001	0.036	0.515	0.345	5.300	0.002	0.045	0.595	0.641	7.900
	NR09	River dataset	N/A	97 565	0.275	3.080	17.727	0.962	1.800	0.104	2.544	12.417	0.970	2.300
	NR10	River dataset	N/A	52 790	0.346	2.895	14.714	0.970	5.125	0.140	2.542	12.568	0.970	5.700

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	NR11	River dataset	N/A	2 723	0.008	0.066	1.526	0.196	10.650	0.015	0.210	1.332	0.479	11.700
	NR15	River dataset	N/A	952 693	0.150	5.100	13.700	0.680	4.150	0.112	4.250	12.850	0.679	4.350
	NR16	River dataset	N/A	180 847	0.071	0.431	5.392	0.856	3.750	0.084	1.013	6.504	0.922	4.900
	NR17	River dataset	N/A	121 486	0.282	0.714	11.640	0.667	5.395	0.336	1.151	11.540	0.966	6.900
	NR22	River dataset	N/A	412	0.001	0.037	0.053	0.280	10.500	0.001	0.050	0.104	0.213	10.800
	NR24	River dataset	N/A	6 358	0.001	0.063	1.713	0.008	10.300	0.003	0.085	1.327	0.268	9.650
	NR25	River dataset	N/A	401 370	0.214	2.390	22.234	0.897	3.950	0.171	3.209	12.964	0.860	4.150
	NR26	River dataset	N/A	82 086	0.150	6.600	14.376	0.562	4.850	0.080	4.100	12.500	0.432	5.100
Mosselbank	MOS01	River dataset	N/A	15 324	0.485	1.475	12.100	0.863	9.925	0.223	1.300	10.500	0.753	9.550
	MOS02	River dataset	N/A	12 522	0.301	1.205	9.951	0.857	8.450	0.109	1.100	7.500	0.776	8.200
	MOS03	River dataset	N/A	6 922	0.078	1.382	12.699	0.917	3.150	0.031	0.627	5.444	0.798	4.400
	MOS04	River dataset	N/A	781	0.016	1.490	1.556	0.636	5.700	0.091	1.500	3.305	0.783	6.050
	MOS06	River dataset	N/A	1 628	0.013	1.430	3.350	0.303	4.150	0.009	1.744	4.291	0.336	4.200
	MOS07	River dataset	N/A	368	0.018	2.200	5.862	0.806	2.470	0.011	2.900	5.300	0.769	2.000
	MOS08	River dataset	N/A	924	0.007	1.985	5.100	0.710	5.450	0.008	2.634	4.600	0.679	5.400
	MOS09	River dataset	N/A	5 595	0.190	11.300	38.695	0.642	2.600	0.186	14.400	24.458	0.895	6.100
Mplain	CS23	Standing water	N/A	570 187										
	KHA02	Standing water	Mplain DP	2 754 974	0.213	1.060	12.670	0.959	4.900	0.117	1.210	11.525	0.983	4.200
	KHA03	Standing water	Mplain DP	3 232 831	0.151	1.155	13.925	0.997	4.700	0.142	1.621	16.010	0.998	2.300
	KHA04	River dataset	N/A	2 226 789	0.200	1.165	15.625	0.998	3.450	0.161	1.534	15.915	0.998	2.400
Noordhoek	WV02	Standing water	Wildevleivlei	200	2.627	3.665	20.758	0.913	11.400	1.039	4.303	21.765	0.989	6.800
	WV05	Standing water	Wildevleivlei	156	1.078	3.770	18.547	0.842	9.600	0.737	4.763	21.871	0.992	6.650
	WV08	Standing water	Wildevleivlei	411										
Sand	CR01	River dataset	N/A	396	0.002	0.064	1.904	0.138	7.350	0.001	0.058	1.649	0.033	6.400

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	CR02	River dataset	N/A	390	0.001	0.170	1.011	0.005	9.500	0.001	0.087	1.065	0.070	6.300
	CR03	River dataset	N/A	1323	0.001	0.132	1.027	0.005	9.800	0.001	0.073	1.705	0.016	7.650
	CR04	River dataset	N/A	480	0.004	0.047	1.195	0.341	5.800	0.001	0.068	1.037	0.040	7.600
	CR05	River dataset	N/A	27 000						0.001	0.047	0.231	0.129	8.300
	CR06	River dataset	N/A	241	0.001	0.140	0.229	0.184	6.150	0.001	0.116	0.393	0.098	6.200
	CR16	River dataset	N/A	452	0.001	0.039	0.429	0.070	9.300	0.001	0.036	0.447	0.067	9.400
	CR20	River dataset	N/A	161	0.001	0.170	0.329	0.499	2.500	0.001	0.103	0.643	0.262	6.200
	CR21	River dataset	N/A	11 576	0.014	0.068	1.862	0.224	9.800	0.007	0.053	2.400	0.091	9.600
	CR22	River dataset	N/A	260	0.003	0.095	0.344	0.468	7.950	0.007	0.120	0.787	0.700	6.700
	CR29	River dataset	N/A							0.007	0.039	1.869	0.086	10.900
	DRRSC	River dataset	N/A	19 175	0.045	0.150	1.847	0.585	11.170	0.004	0.046	0.876	0.167	10.680
	LPVMR	River dataset	N/A	100	0.001	0.013	0.172	0.465	5.950	0.001	0.016	0.127	0.233	4.730
	LPVN	Standing water	Little Princessvlei	44	0.001	0.012	0.073	0.312	6.740	0.001	0.014	0.151	0.643	7.350
	LPVS	Standing water	Little Princessvlei	368	0.003	0.050	1.393	0.552	4.980	0.001	0.019	0.392	0.214	4.650
	LVI	River dataset	Langevlei	4 665	0.013	0.178	1.541	0.447	7.400	0.004	0.103	0.563	0.757	6.450
	LVO	Standing water	Langevlei	452	0.039	0.117	1.066	0.463	10.405	0.009	0.046	0.447	0.262	8.500
	OOG01	Standing water	Die Oog	101	0.001	0.005	0.359	0.882	8.090	0.001	0.005	0.202	0.629	7.750
	PV03	Standing water	Princessvlei	45	0.003	0.005	0.130	0.375	10.200	0.002	0.010	0.102	0.167	10.300
	PVWEIR	Standing water	Princessvlei	103	0.001	0.005	0.150	0.323	8.665	0.002	0.009	0.143	0.208	10.800
	SCV	River dataset	N/A	19 774	0.011	0.082	5.600	0.080	10.100	0.004	0.081	4.751	0.025	10.050
	ZA01S	Standing water	Zandvlei	1 138	0.029	0.018	0.335	0.889	10.170	0.012	0.042	0.288	0.748	7.650
	ZA02S	Standing water	Zandvlei	302	0.007	0.034	0.162	0.775	9.600	0.017	0.048	0.234	0.813	8.050
	ZA03S	Standing water	Zandvlei	493		0.050	0.459	0.218		0.025	0.030	0.225	0.838	7.000
	ZA04S	Standing water	Zandvlei							0.004	0.062	0.189	0.772	6.700
	ZA05S	Standing water	Zandvlei	592	0.011	0.099	0.456	0.769	8.480	0.003	0.117	0.137	0.752	8.200

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	ZA06S	Standing water	Zandvlei							0.027	0.005	0.178	0.860	7.500
	ZA07S	Standing water	Zandvlei	565						0.019	0.008	0.151	0.801	7.300
	ZA08S	Standing water	Zandvlei	161	0.013	0.011	0.184	0.849	9.815	0.014	0.010	0.121	0.757	9.200
	ZA09S	Standing water	Zandvlei	32	0.018	0.011	0.232	0.835	9.370	0.007	0.005	0.111	0.540	9.700
	ZA10S	Standing water	Westlake	330	0.013	0.043	0.429	0.862	8.530	0.015	0.060	0.257	0.749	9.400
	ZA11S	Standing water	Zandvlei	118	0.022	0.005	0.180	0.857	8.705	0.020	0.015	0.137	0.778	7.900
	ZA12S	Standing water	Zandvlei	739	0.028	0.005	0.278	0.856	8.285	0.015	0.021	0.109	0.648	9.900
	ZA13S	Standing water	Zandvlei	602	0.021	0.008	0.354	0.900	8.700	0.017	0.017	0.183	0.778	9.400
	ZAWAIR	Standing water	Zandvlei	878	0.008	0.065	0.240	0.806	8.100	0.003	0.112	0.122	0.756	8.200
Silvermine	SIL02	River dataset	N/A	21	0.001	0.014	0.089	0.425	9.800	0.001	0.013	0.114	0.323	9.850
	SIL04	River dataset	N/A	48	0.001	0.012	0.092	0.577	8.600	0.001	0.017	0.112	0.530	8.500
	SIL06	River dataset	N/A	682	0.001	0.012	0.163	0.375	5.350	0.001	0.012	0.073	0.541	5.750
SLPass	SIR01	River dataset	N/A	6 047	0.001	0.033	0.371	0.096	9.700	0.001	0.038	0.259	0.156	9.650
	SIR02	River dataset	N/A	1 780	0.001	0.063	1.101	0.147	9.250	0.001	0.086	0.828	0.159	8.260
	SIR03	River dataset	N/A	1 575	0.001	0.054	0.710	0.078	9.100	0.003	0.070	0.717	0.231	9.100
	SIR04	River dataset	N/A	805	0.001	0.052	0.359	0.058	7.900	0.001	0.040	0.830	0.064	3.700
	SIR05	River dataset	N/A	998	0.002	0.072	0.799	0.070	8.600	0.001	0.086	0.530	0.065	7.050
	SIR06	River dataset	N/A	172	0.002	0.300	1.300	0.321	6.900	0.002	0.200	1.500	0.417	6.200
	SIR07	River dataset	N/A	336	0.002	0.112	0.935	0.041	11.100	0.008	0.163	1.250	0.097	10.400
Soet	SOE02	River dataset	N/A	224 812	0.404	1.630	19.652	0.983	5.800	0.376	2.021	17.340	0.993	3.300
Sout	SOU01	River dataset	N/A	118	0.001	4.200	1.200	0.222	4.850	0.003	4.700	1.750	0.468	4.900
	SOU02	River dataset	N/A	528	0.002	3.610	0.260	0.360	5.100	0.001	5.404	0.150	0.598	7.050
South Peninsula	BOK02	River dataset	N/A	101 297	0.098	0.659	5.757	0.812	8.700	0.074	0.224	2.482	0.492	8.900
	BOK03	River dataset	N/A	5 123	0.011	0.209	2.219	0.426	7.300	0.002	0.128	1.326	0.305	8.200
	GC02	Standing water	Glencairn vlei	222	0.001	0.008	0.126	0.333	5.900	0.001	0.005	0.102	0.260	5.900

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	SCH02	River dataset	N/A	188	0.001	0.017	0.136	0.582	7.350	0.001	0.020	0.116	0.687	5.200
	SCH04	River dataset	N/A	2 418	0.001	0.210	1.251	0.090	5.750	0.001	0.252	1.162	0.075	5.700
Zeekoe	LR02	River dataset	N/A	2 575	0.012	0.319	1.117	0.720	3.950	0.016	0.291	1.049	0.659	5.800
	LR03	River dataset	N/A	2 045 650	0.273	1.065	20.987	0.977	1.410	0.259	0.921	16.761	0.991	1.300
	LR05	River dataset	N/A	362 773	0.259	1.310	17.856	0.993	1.900	0.184	1.166	16.066	0.989	1.940
	LR06	River dataset	N/A	1 898	0.008	0.050	1.225	0.556	9.450	0.006	0.066	1.504	0.465	5.690
	LR07	River dataset	N/A	296 700	0.303	1.017	15.095	0.985	4.700	0.190	1.262	16.565	0.994	2.200
	LR08	River dataset	N/A	26 477	0.148	0.892	11.242	0.970	3.880	0.209	1.123	11.306	0.944	1.530
	LR10	River dataset	N/A	9 104	0.020	0.051	1.854	0.411	11.210	0.038	0.056	1.177	0.430	10.000
	POC01	River dataset	N/A	1 046	0.030	0.174	5.785	0.254	4.780	0.026	0.243	5.679	0.142	5.800
	RVIRD	River dataset	N/A	2 050	0.002	0.025	1.530	0.057	7.150	0.004	0.065	3.106	0.047	5.700
	RVWEIR	Standing water	Rondevlei	19	0.003	0.077	0.652	0.566	4.800	0.001	0.062	0.203	0.373	5.250
	ZEV1S	Standing water	Zeekoevlei	29	0.026	0.512	0.493	0.444	10.345	0.085	0.348	1.784	0.409	11.000
	ZEV2S	Standing water	Zeekoevlei	3 120		0.836	2.922	0.729		0.129	0.461	2.872	0.596	9.100
	ZEV3S	Standing water	Zeekoevlei	59	0.041	0.765	1.504	0.543	8.650	0.037	0.403	1.651	0.414	9.750
	ZEV4S	Standing water	Zeekoevlei	13		0.856	1.157	0.384		0.012	0.450	0.978	0.407	9.400
	ZEV5	River dataset	Zeekoevlei	13	0.231	6.830	22.707	0.987	2.600	0.357	6.960	27.236	0.992	2.500
	ZEV9S	Standing water	Zeekoevlei							0.025	0.337	0.087	0.499	9.150
	ZEWEIR	Standing water	Zeekoevlei	26						0.008	0.397	0.638	0.246	10.300

Table C.4

Summary enterococci data per site for the 2021 reporting period.

Data interpreted per site as per Table 3.5 with percentiles calculated using the Hazen method, calculated from McBride and Payne (2009)'s spreadsheet-based formulae.

Subcatchment	Site	Monitoring period	Enterococci 90th percentile	Enterococci 95th percentile	Rating
Diep	MAC	2021	289	452.5	Unacceptable
	MCC	2021	2280	3520	Unacceptable
	RTV02	2021	80	165	Acceptable
	RTV04	2021	9001.4	9501.2	Unacceptable
	RTV09	2021	2360.2	3020	Unacceptable
	RTV10	2021	2586	4360	Unacceptable
	RTV14	2021	9001.9	9501.45	Unacceptable
	RTV17	2021	714	802	Unacceptable
	RTV19	2021	149	174.5	Acceptable
	RTVBUOY1	2021	356	668	Unacceptable
	RTVBUOY2	2021	49.5	67.5	Acceptable
	RTVBUOY4	2021	40	87.5	Acceptable
	RTVBUOY6	2021	39	50	Acceptable
Mplain	CS23	2021	236000	501000	Unacceptable
Sand	PV03	2021	604	642	Unacceptable
	PVWEIR	2021	430	470	Unacceptable
	SCV	2021	27400.4	33200.2	Unacceptable
	ZA01S	2021	2740	3820	Unacceptable
	ZA02S	2021	504	1232	Unacceptable
	ZA03S	2021	394	592	Unacceptable
	ZA04S	2021	244	403	Unacceptable
	ZA05S	2021	220	260	Unacceptable
	ZA06S	2021	360	390	Unacceptable
	ZA07S	2021	2006	2603	Unacceptable
	ZA08S	2021	139	224.5	Tolerable
	ZA09S	2021	96	148	Acceptable
	ZA10S	2021	1126	1763	Unacceptable
	ZA11S	2021	1660.8	2980.4	Unacceptable
	ZA12S	2021	464	612	Unacceptable
	ZA13S	2021	314	437	Unacceptable
	Zaweir	2021	230	230	Unacceptable
Zeekoe	LR03	2021	90000	90000	Unacceptable
	LR05	2021	78000	78000	Unacceptable
	LR07	2021	67000	67000	Unacceptable
	LR08	2021	136000.1	138000.05	Unacceptable
	POC01	2021	690	805	Unacceptable
	ZEV1S	2021	120	300	Tolerable
	ZEV2S	2021	13800	43600	Unacceptable
	ZEV3S	2021	150	220	Tolerable
	ZEV4S	2021	988	1840	Unacceptable

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	ZEV9S	2021	168	249	Tolerable
	ZEWEIR	2021	286	347	Unacceptable

APPENDIX D: BOXPLOTS OF ANNUAL DATA FOR KEY VARIABLES

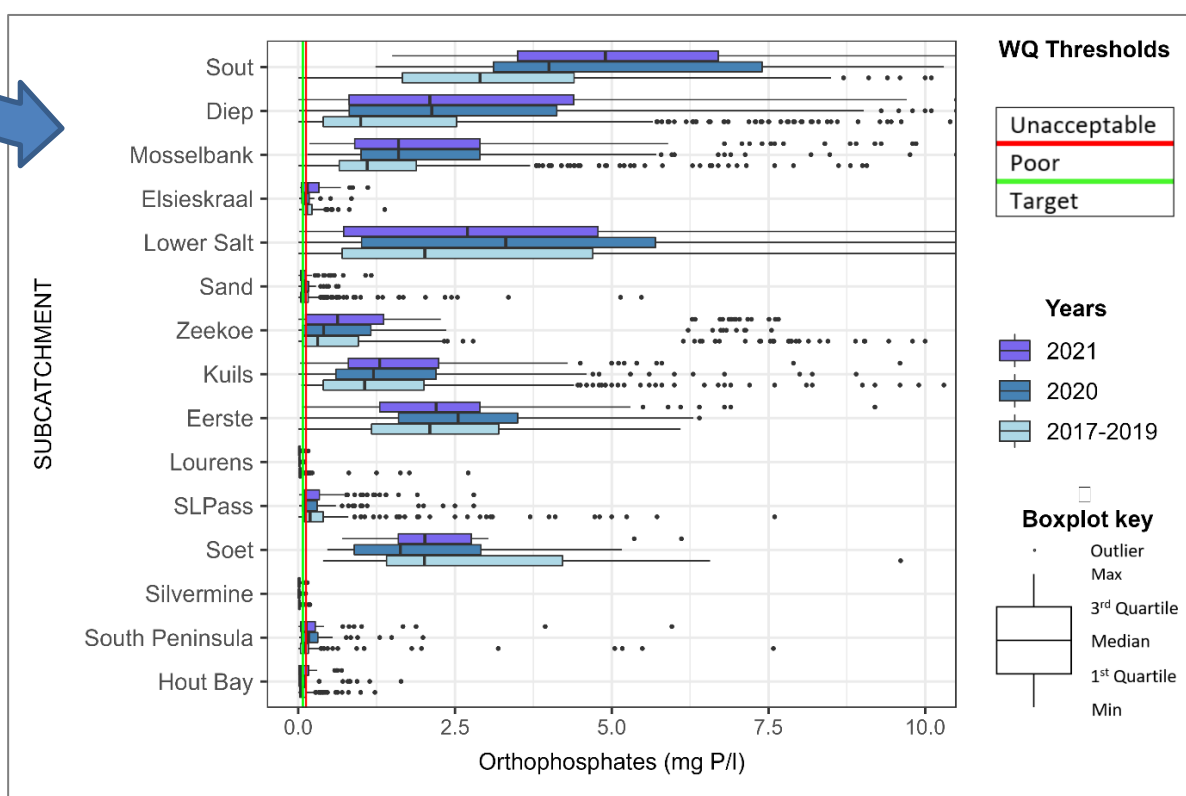
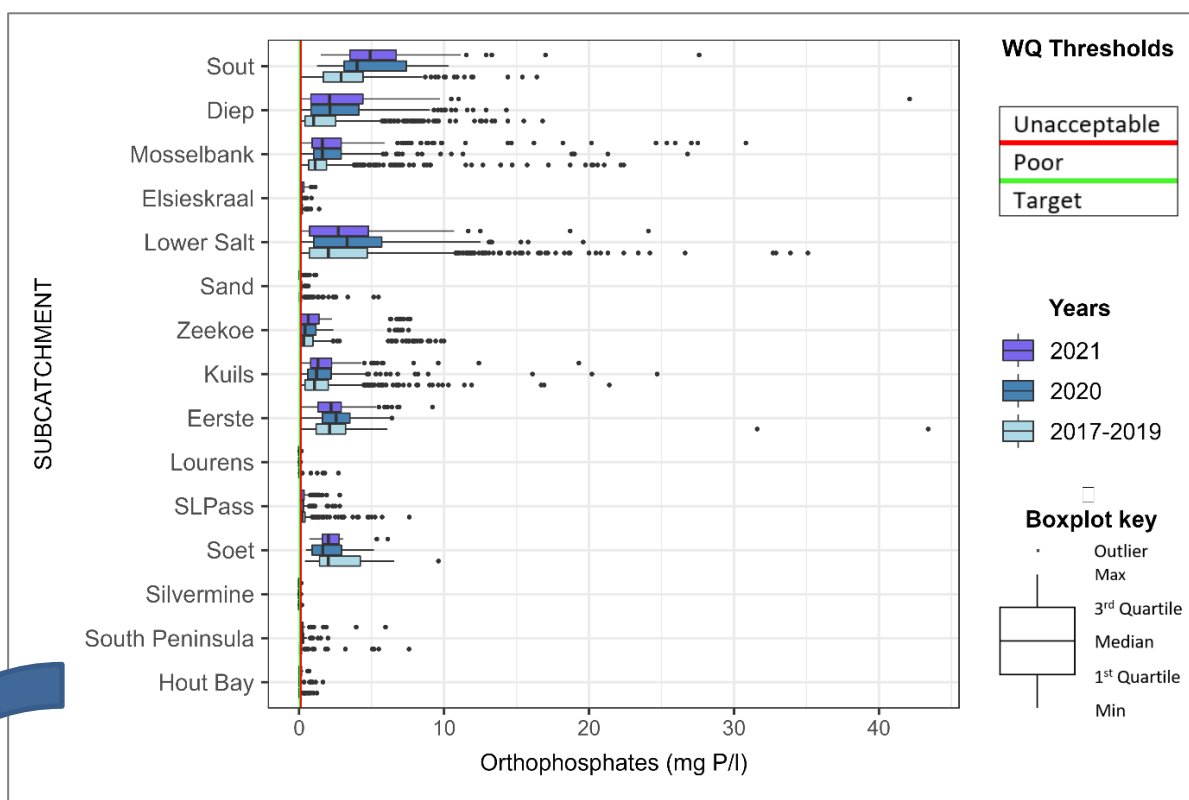


Figure D1.1

Comparison of phosphate (PO₄-P) data for flowing water systems (rivers and stormwater channels) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Marked thresholds as per Table 3.2. Closer view (reduced y-axis) shown in bottom figure (arrowed)

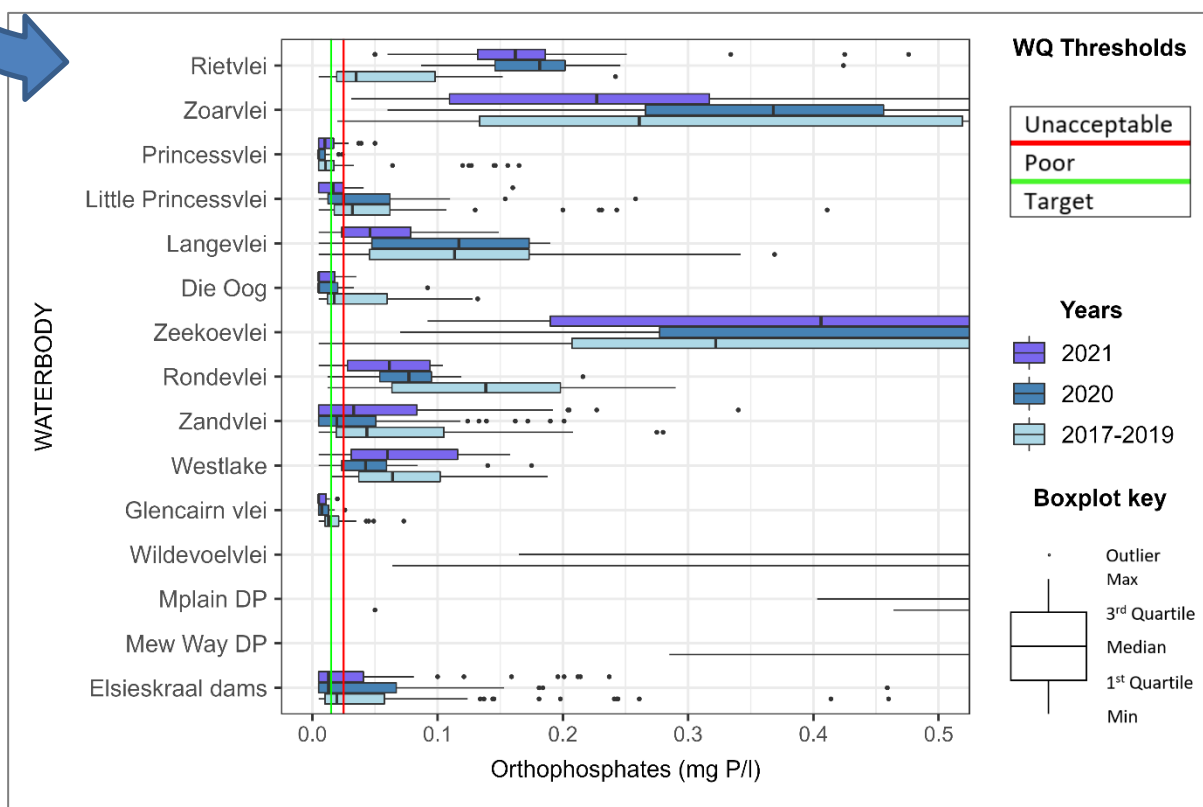
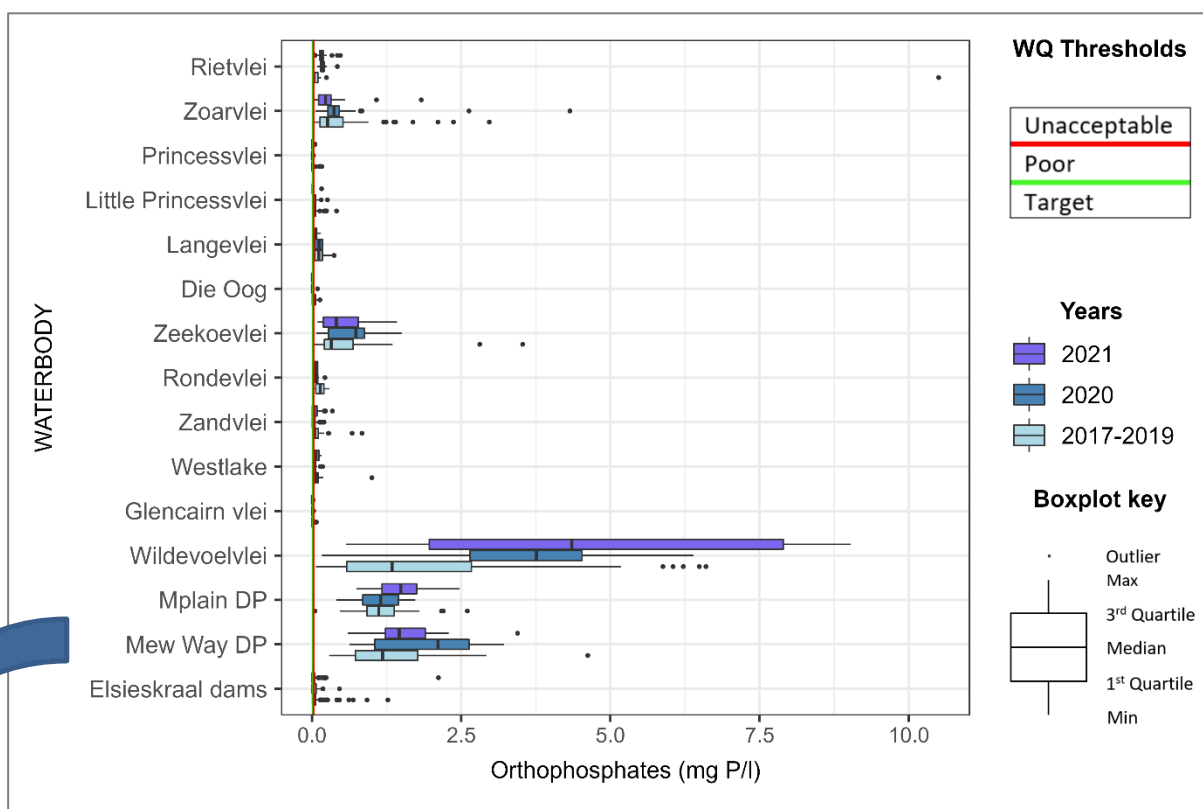


Figure D1.2

Comparison of phosphate (PO₄-P) data for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in bottom figure (arrowed)

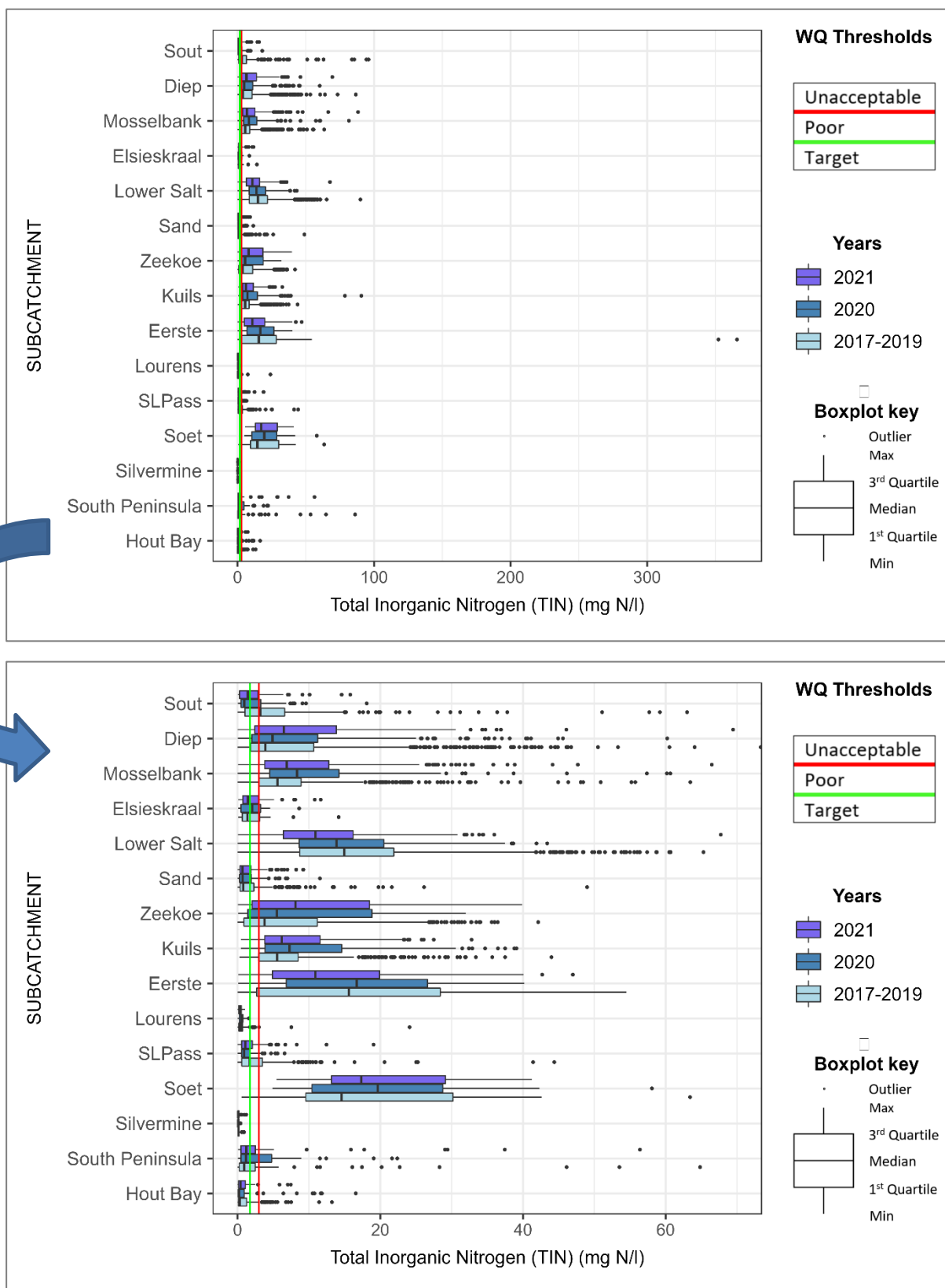


Figure D1.3

Comparison of Total Inorganic Nitrogen (TIN) data for flowing water systems (rivers and stormwater channels) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined.

Subcatchments as shown in Figure 2.1. Marked thresholds as per Table 3.2.

Closer view (reduced y-axis) shown in bottom figure (arrowed)

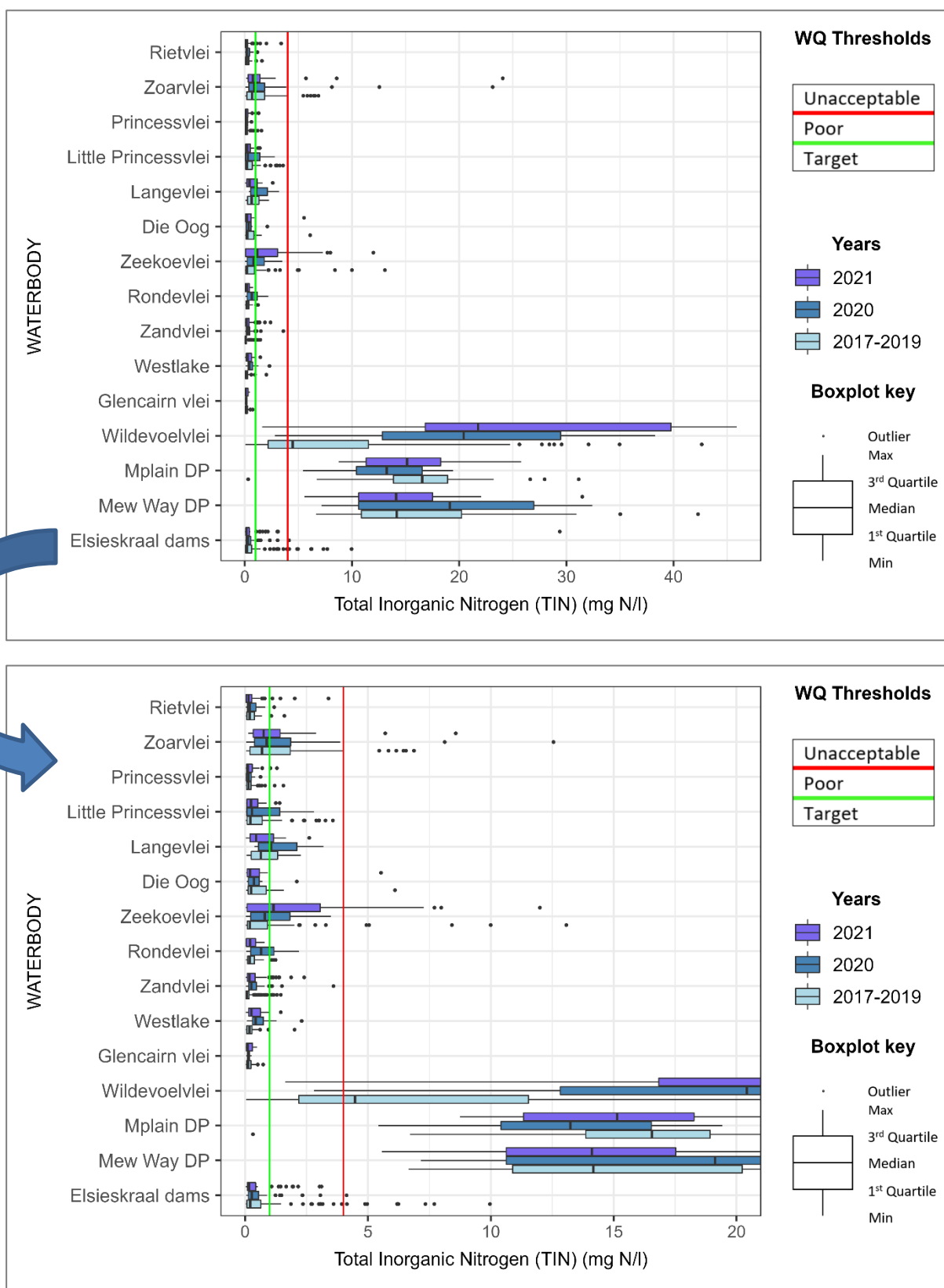


Figure D1.4

Comparison of Total Inorganic Nitrogen (TIN) data for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined.

Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in bottom figure (arrowed)

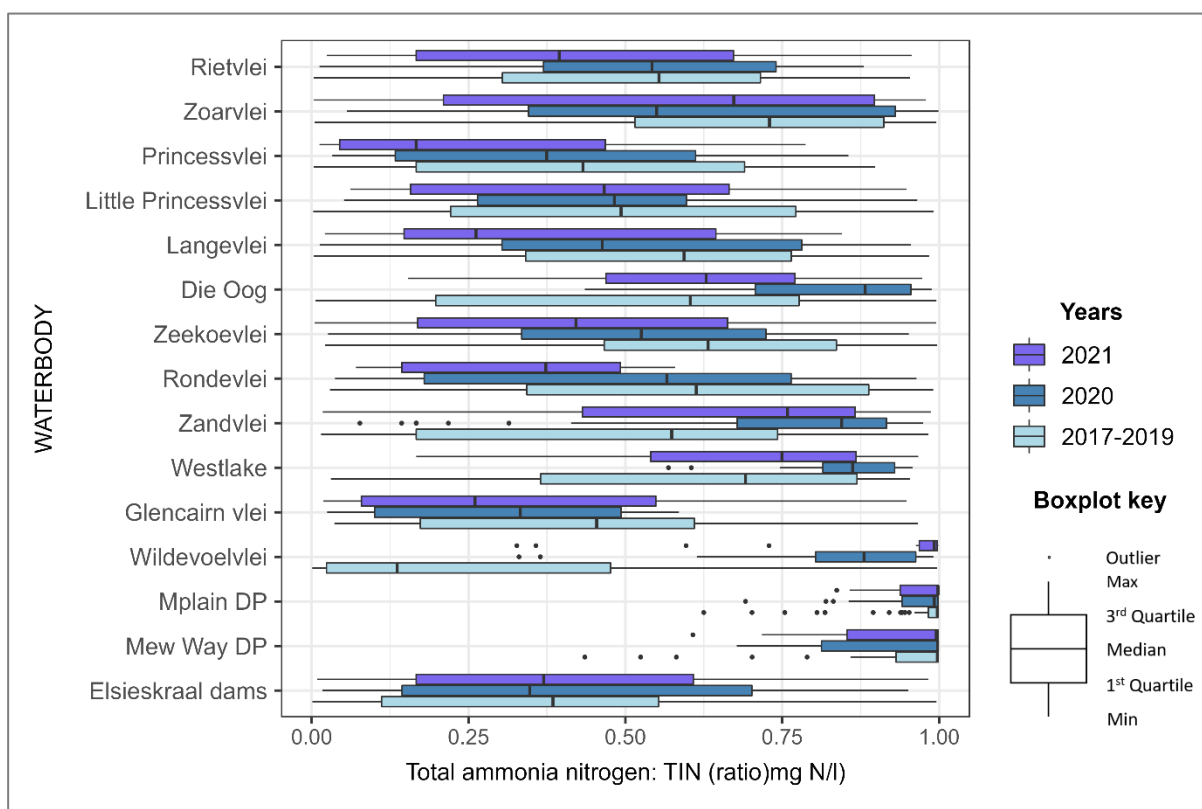
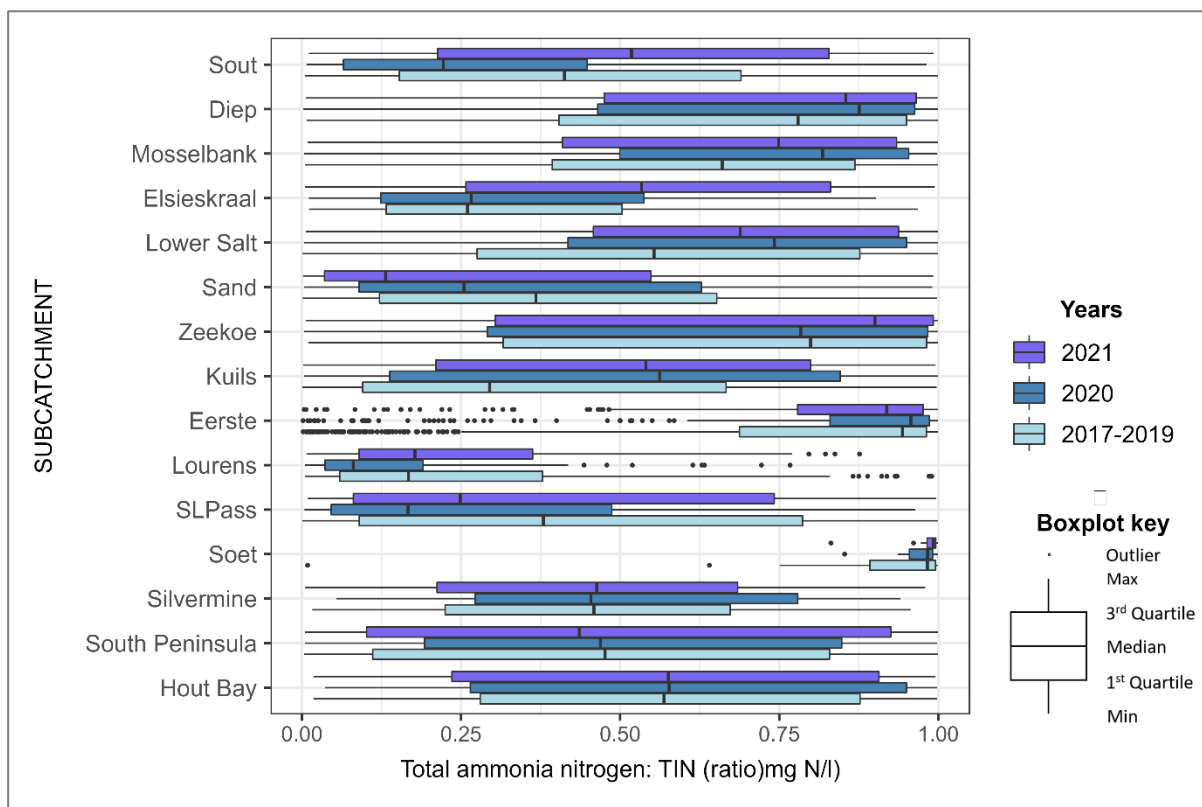


Figure D1.5

Comparison of ratios of total ammonia nitrogen (NH₄-N) to Total Inorganic Nitrogen (TIN) for flowing systems (rivers and stormwater channels) (top) and standing water systems (vleis, dams and detention ponds) (bottom) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Marked thresholds as per Table 3.2 and 3.3.

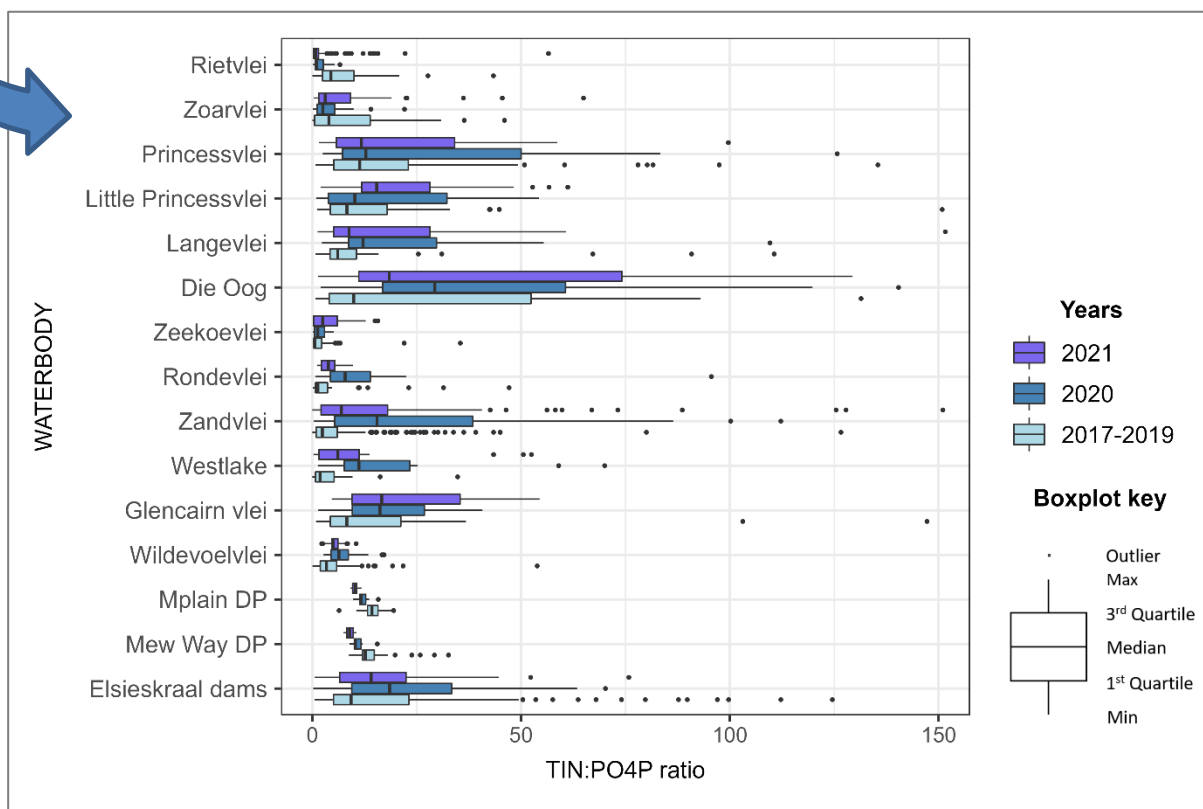
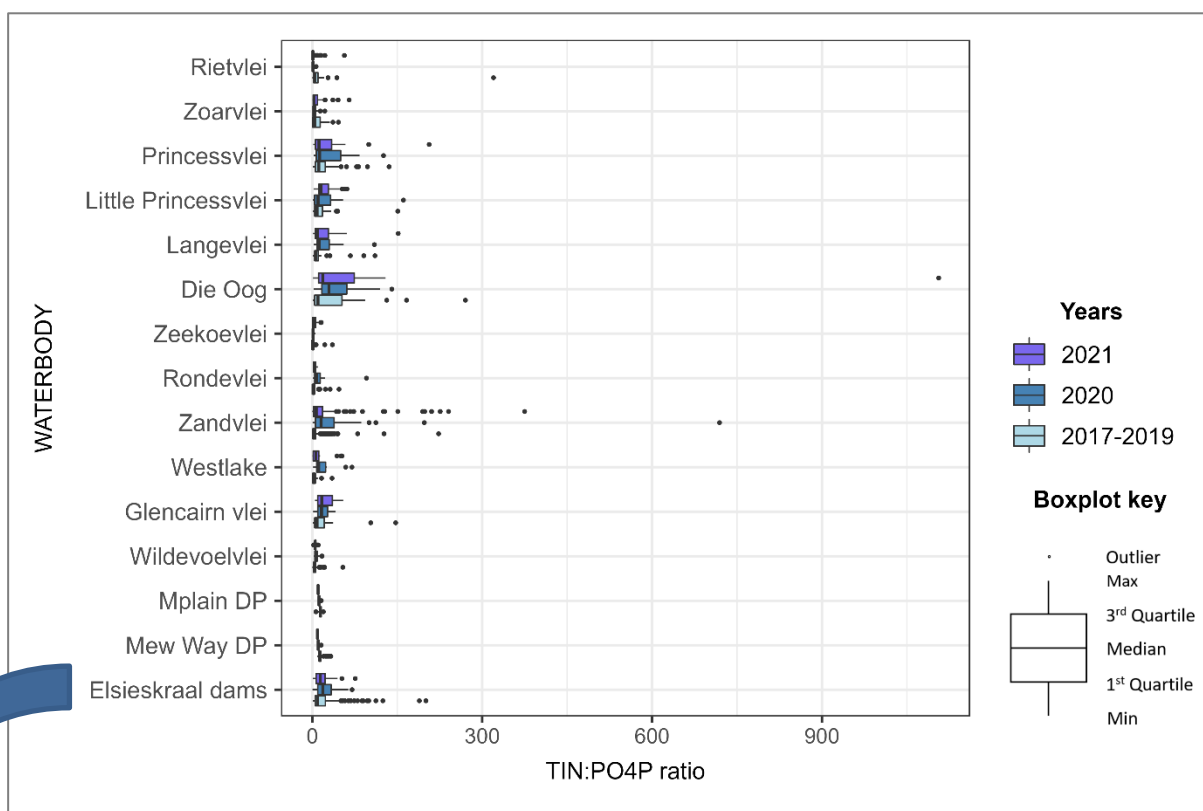


Figure D1.6

Comparison of ratios of Total Inorganic Nitrogen (TIN) to phosphate (PO₄-P) for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Marked thresholds as per Table 3.2. Closer view (reduced y-axis) shown in bottom figure (arrowed).

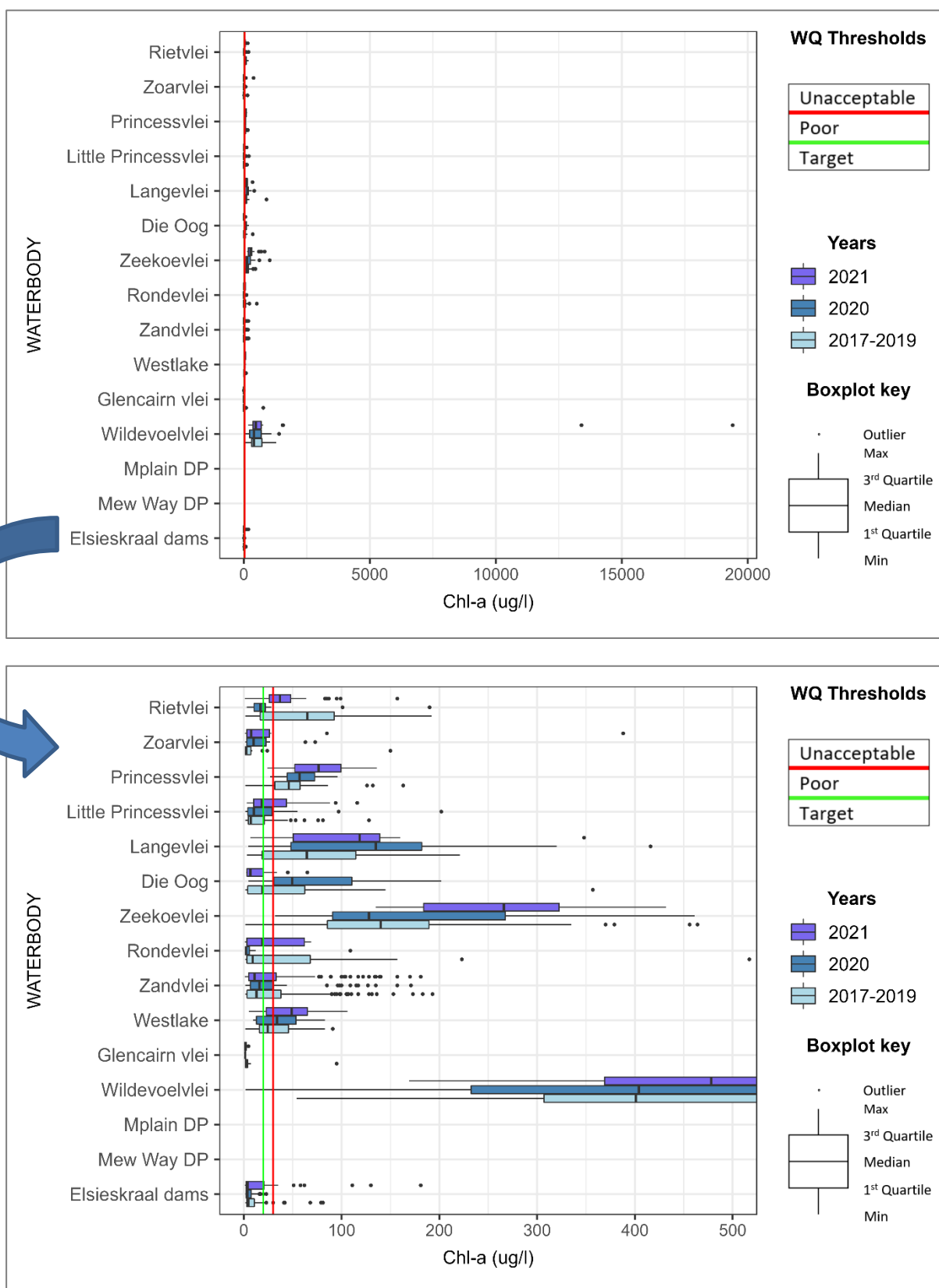


Figure D2.1

Comparison of chlorophyll-a data for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Marked thresholds as per Table 3.2. Closer view (reduced y-axis) shown in bottom figure (arrowed).

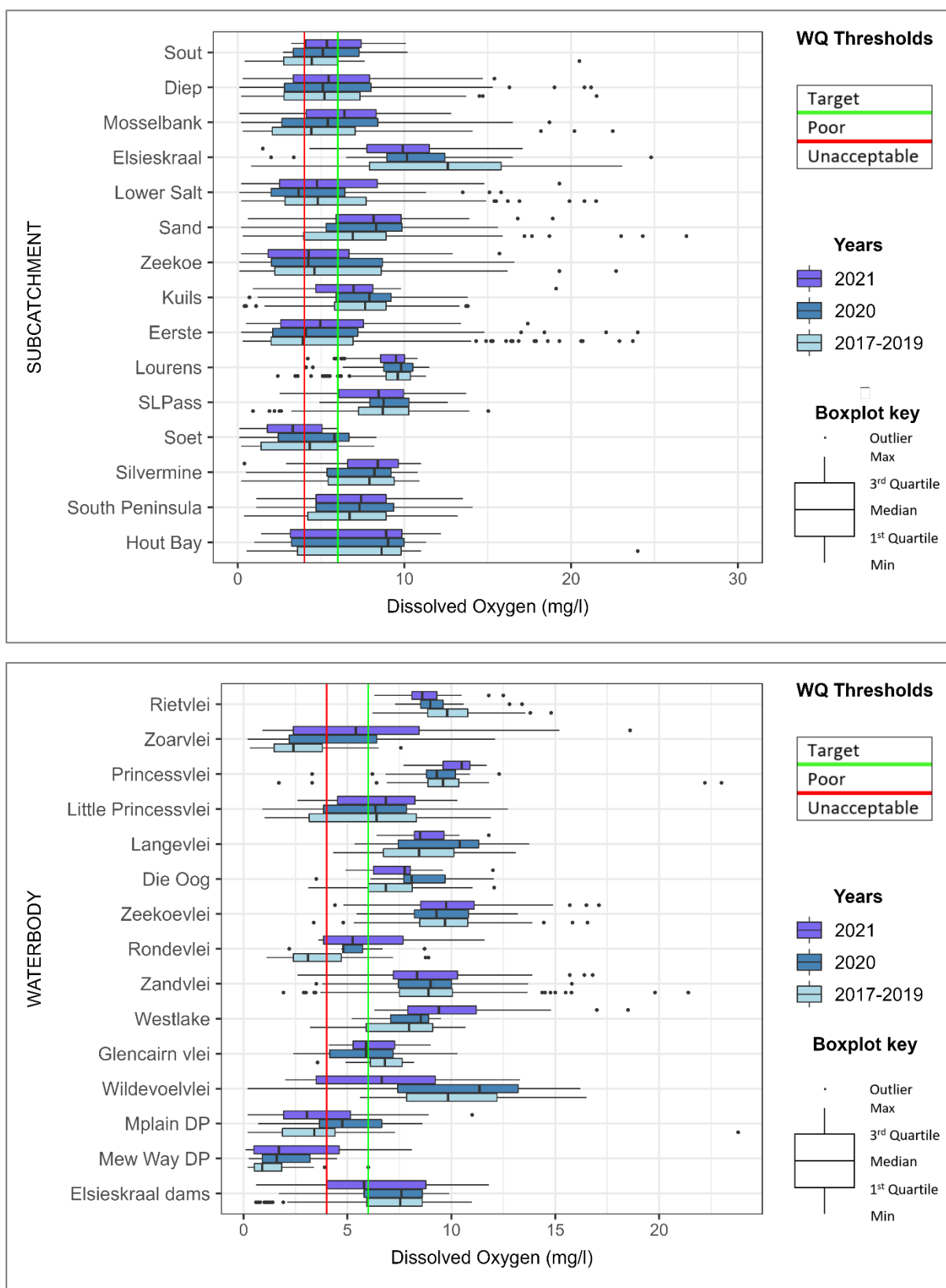


Figure D3.1

Comparison of Dissolved Oxygen for flowing systems (rivers and stormwater channels) (top) and standing water systems (vleis, dams and detention ponds) (bottom) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Marked thresholds as per Table 3.2 and 3.3.

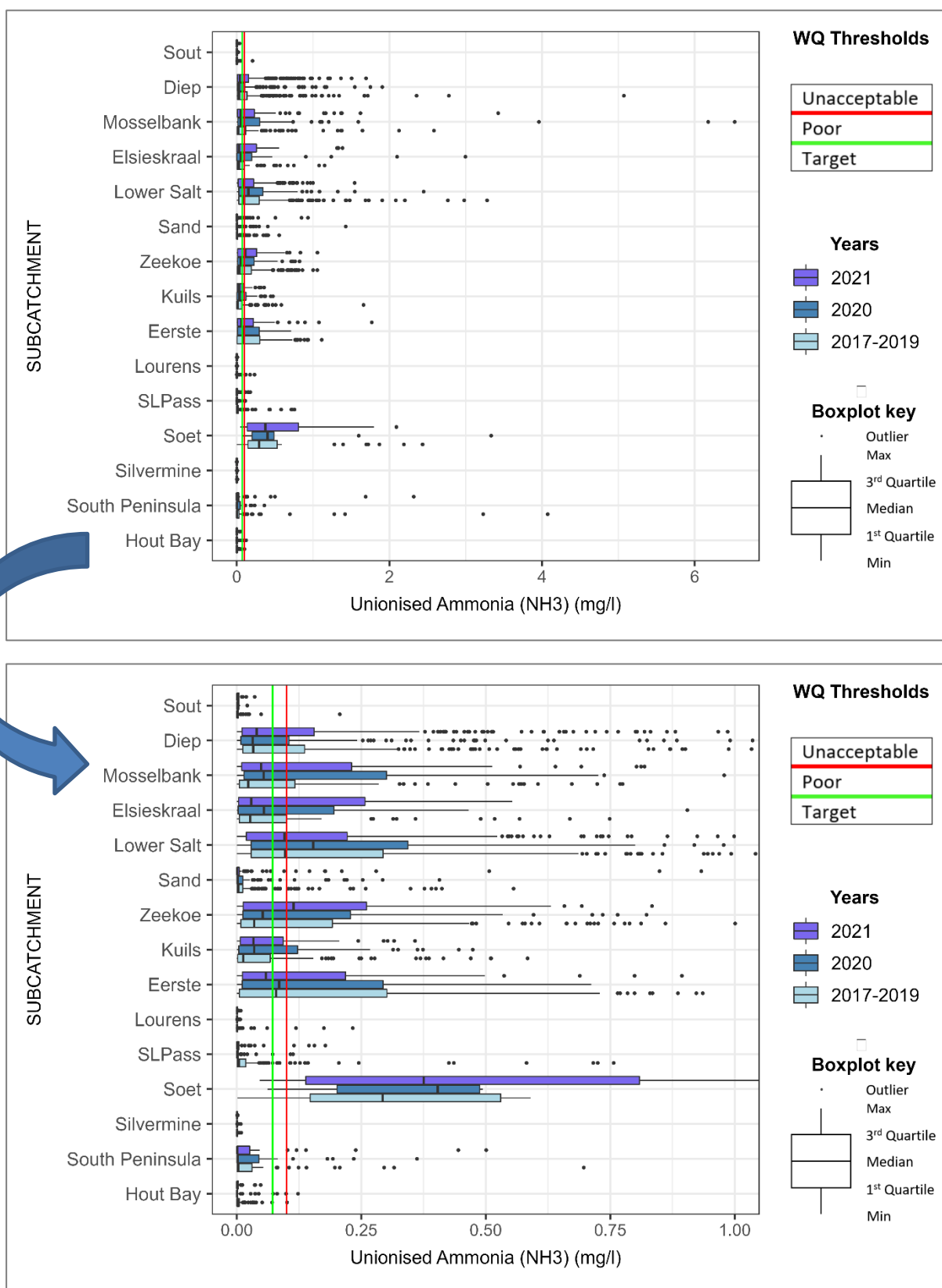


Figure D4.1

Comparison of un-ionised ammonia for flowing systems (rivers and stormwater channels) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Subcatchments as shown in Figure 2.1. Marked thresholds as per Table 3.2. Closer view (reduced y-axis) shown in bottom figure (arrowed).

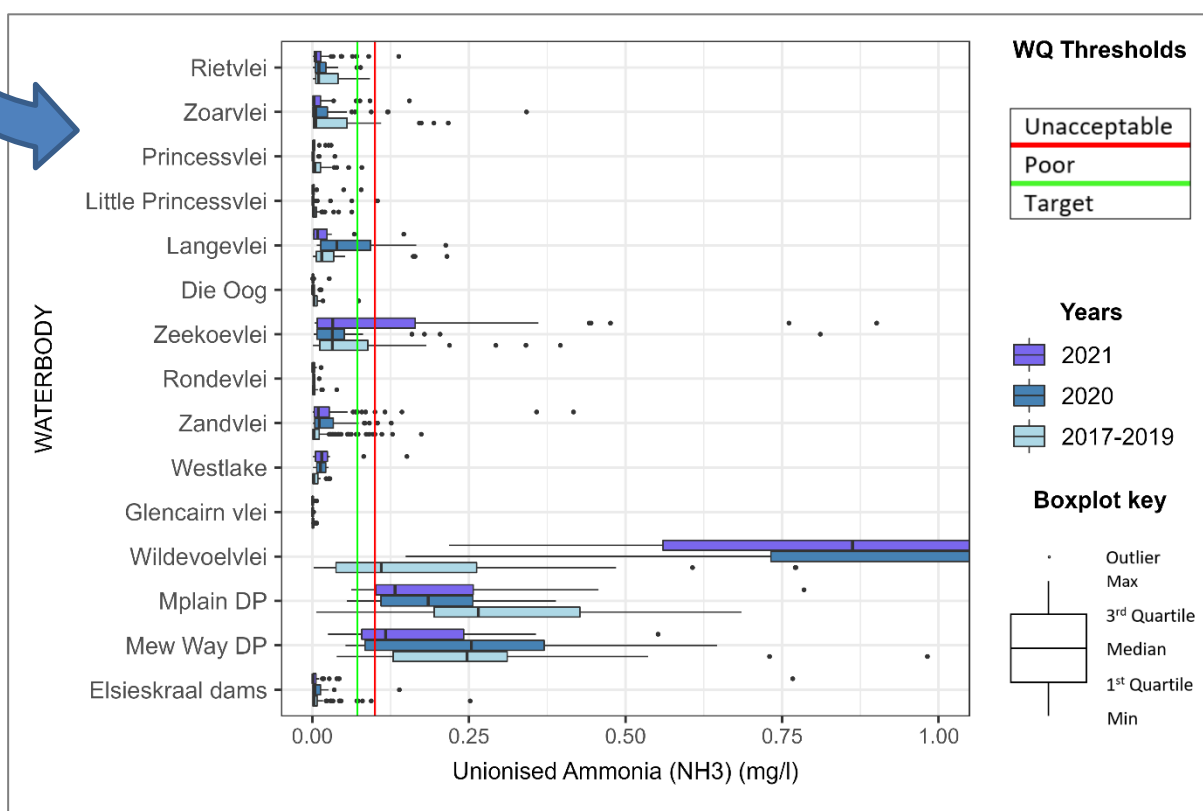
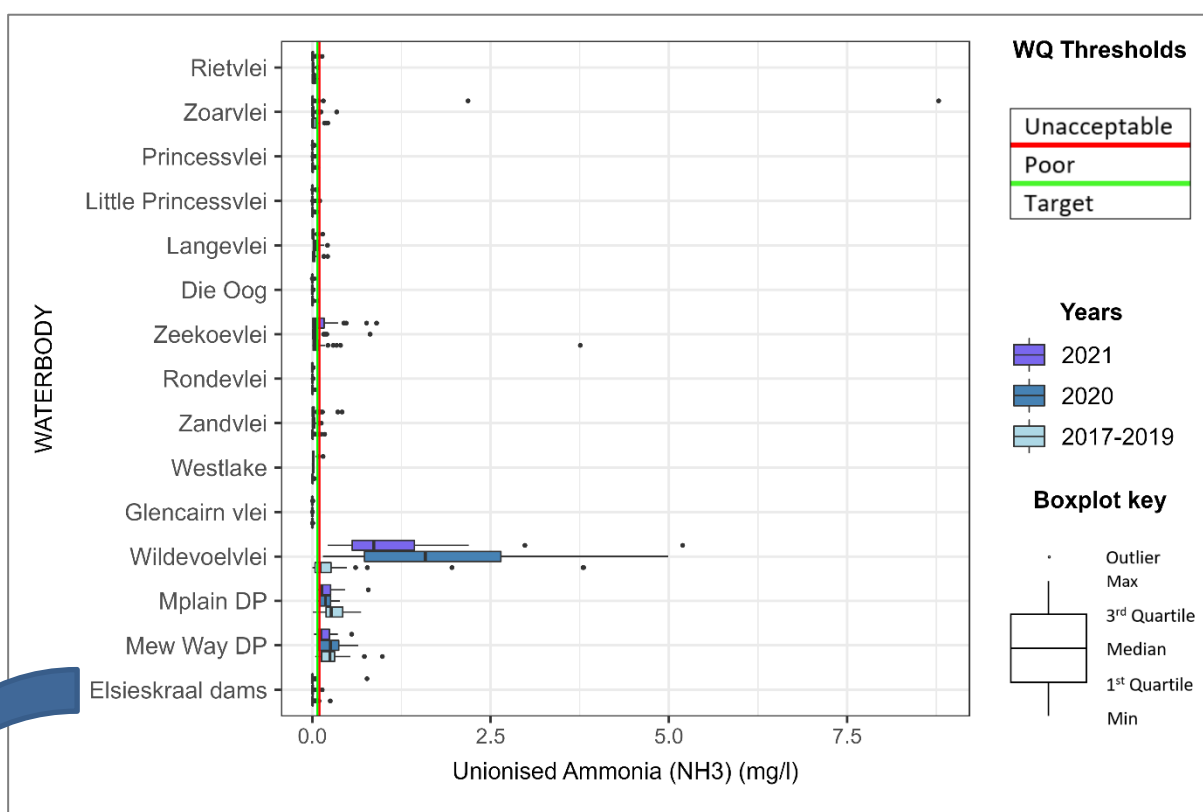


Figure D4.2

Comparison of un-ionised ammonia for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Marked thresholds as per Table 3.3. Closer view (reduced y-axis) shown in bottom figure (arrowed).

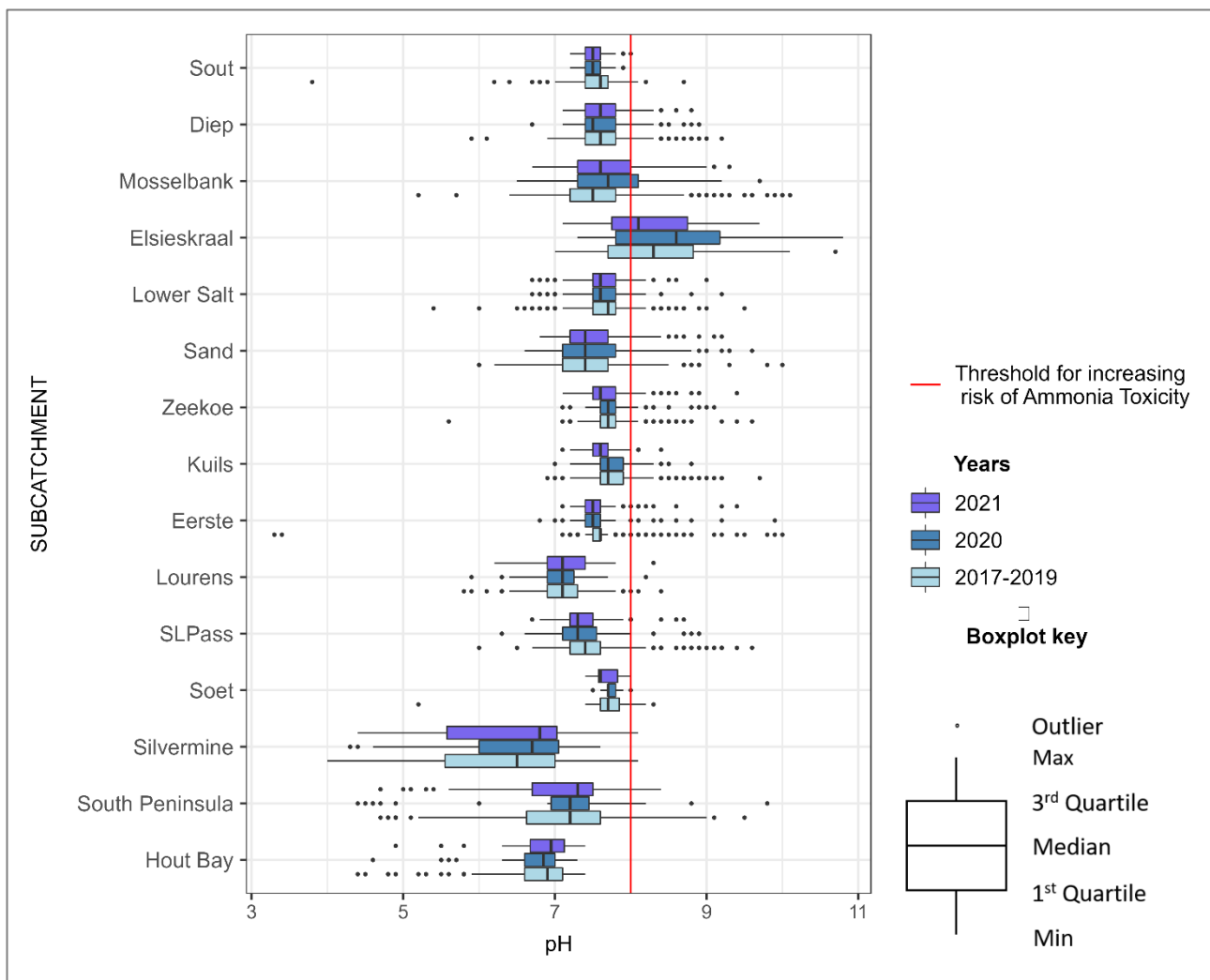


Figure D5.1

Comparison of pH for flowing systems (rivers and stormwater channels) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Marked thresholds show pH > 8, used in this report to indicate increased risk of ammonia toxicity in samples with elevated total ammonia

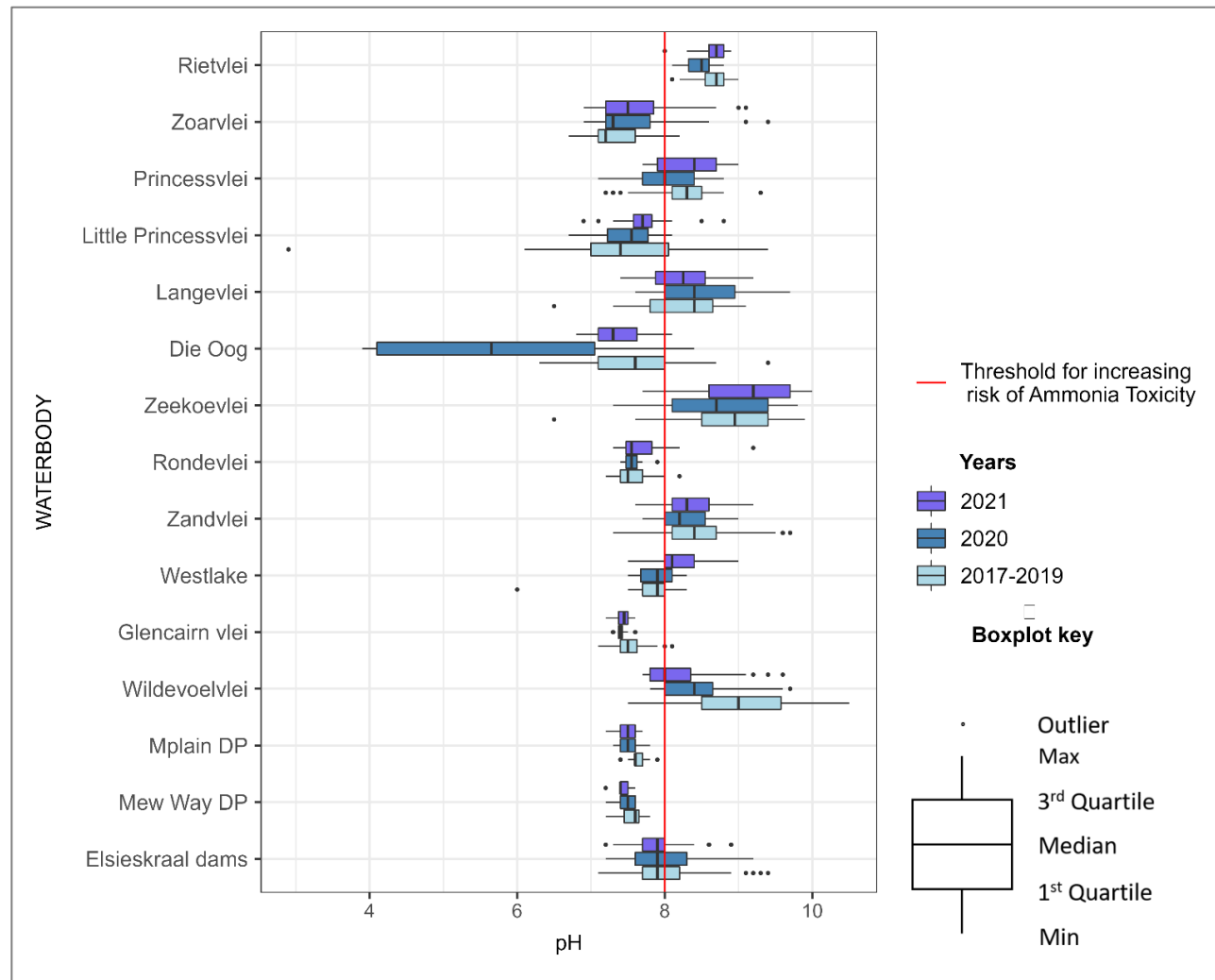


Figure D5.2

Comparison of pH for standing water systems (vleis, dams and detention ponds) from the 2021 reporting period with those from 2020 and the previous three years (2017 to 2019) combined. Marked thresholds show pH > 8, used in this report to indicate increased risk of ammonia toxicity in samples with elevated total ammonia

APPENDIX E: NITROGEN AND PHOSPHOROUS RANGES FOR DIFFERENT TROPHIC STATES

Table E.1

Summary of ranges of phosphorus and/or nitrogen based nutrients associated with different trophic conditions in flowing (rivers and stormwater channels) and standing (vleis, dams and detention ponds) water ecosystems.

Standing water nitrogen and phosphorus ranges from DWAF (1996a) as modified by DWAF (2002 and 2011);

Flowing water ranges taken from DWAF (1996a), with modifications from (DWAF 2008) and DWAF (2011).

Trophic State	Effects	Average summer inorganic nitrogen (TIN) concentrations (mg/l)	Average summer inorganic phosphorus concentrations (PO ₄ -P) (mg/l)	
		Rivers and standing water	Standing water	Rivers
Oligotrophic	Moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or the presence of blue-green algae	< 0.25	≤ 0.015	≤ 0.005
Mesotrophic	Usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic	0.25 -1.00	> 0.015 – 0.047	> 0.005 – 0.025
Eutrophic	Usually low levels of species diversity; usually highly productive systems; nuisance growths of aquatic plants and blue-green algae, algal blooms may include species that are toxic to man, livestock and wildlife	> 1.00 – 10.00	> 0.047 – 0.130	> 0.025 – 0.125
Hypertrophic	Usually very low levels of species diversity; usually very highly productive systems; nuisance growths of aquatic plants and blue-green algae, algal blooms may include species that are toxic to man, livestock and wildlife	> 10.00	> 0.130	> 0.125