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Ecological outcomes of wastewater discharges in contrasting receiving environments

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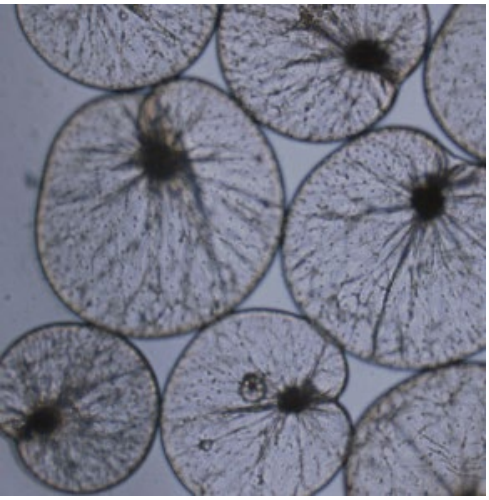

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This report is available on the NESP Marine and Coastal Hub website: www.nespmarinecoastal.edu.au

Table of Contents

List of Tables

Appendix B: Data from the WWTP A outfall

Appendix C: Data from the WWTP B outfall

Appendix D: Data from the WWTP C outfall

List of Figures

Appendix B: Data from WWTP A outfall

Appendix C: Data from WWTP B outfall

No table of figures entries found.

Appendix D: Data from WWTP C outfall

List of Abbreviations

CAS	Chemical Abstracts Service
CEC	Contaminant of Emerging Concern
DGV	Default Guideline Value
EPA	Environmental Protection Authority
ESI	Electrospray Ionisation
FWC	Freshwater channel
HLB	Hydrophilic Lipophilic Balanced
NOD	National Outfalls Database
NTU	Nephelometric Turbidity Unit
PCA	Principal component analysis
PFAS	Per- and poly-fluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
ppb	Parts per billion
ppm	Parts per million
PSU	Practical Salinity Units
SD	Standard deviation
SPE	Solid Phase Extraction
VLP	Virus-like Particle
WAX	Weak Ion Exchange
WWTP	Wastewater Treatment Plant

Executive summary

In Australia, 192 wastewater treatment plants (WWTPs) discharge treated effluent into coastal waters. Since effluent contains residual concentrations of contaminants, outfalls are a point source of complex pollution into marine ecosystems, including nutrients and metals. These can accumulate in the environment and reduce water quality. Emerging contaminants are also found in effluent, but their environmental fate after discharge, and their potential ecological effects, are relatively unstudied.

Globally, the approach governing the management of WWTP effluent is that “the solution to pollution is dilution”. This paradigm relies on seawater in the receiving environment rapidly diluting effluent and reducing the concentration of contaminants to background levels. However, many contaminants of emerging concern are toxic even at low concentrations, and their resistance to degradation means that they can accumulate in the environment. Further, the complex mixture of contaminants present in effluent poses a relatively unknown risk to ecosystems because little is understood about the potentially synergistic effects of these pollutants.

Microbes are often the first organisms to respond to pollution. Assemblages of viruses, bacteria and microscopic algae live in seawater and marine sediments, and their short life cycle makes them ideal early indicators of pollution-induced changes in the environment. Microbes are also highly relevant indicators: since they drive oceanic nutrient cycles and primary production, pollution-induced changes to microbial assemblages can alter the provision of ecosystem services that are crucial for maintaining healthy environments. WWTP effluent has been shown to harm freshwater microbial assemblages, but there is little understanding of whether similar consequences occur in coastal environments.

This project determined the ecological effect of coastal WWTP outfalls in two different coastal settings. The names and exact locations of the WWTPs have been anonymised and are hereafter referred to as WWTP A and WWTP B for confidentiality reasons. Treated effluent, seawater, and marine sediments were collected from the WWTP A and WWTP B outfalls, located within a temperate coastal embayment in southern Australia. This is a shallow and retentive receiving environment and may accumulate effluent contaminants. Additionally, sediments were collected from the WWTP C outfall in New South Wales. This outfall discharges into a highly dispersive environment and offers a point of comparison for contaminant retention relative to the WWTP A and WWTP B outfalls.

Work focused on five contaminants that water quality managers had identified in the NESP 1.16 project as being highly important: nutrients and metals as traditional effluent pollutants, and antibiotics, per- and poly-fluoroalkyl substances (PFAS) and microplastics as contaminants of emerging concern. Ecological effects of effluent were assessed by measuring changes to the diversity and composition of microbial assemblages in the water and sediment.

This work has generated a substantial dataset for baseline environmental contaminant concentrations. In total, the project quantified four nutrients, 39 metals, 15 antibiotics,

microplastics (<5 mm), and 26 species of PFAS. Contaminant and biological data produced by this project will be made publicly available according to the NESP Data Management Strategy. Additionally, genetic data from this project has been made available on the Australian Microbiome Initiative database.

The results of this study showed:

i. WWTPs are a source of emerging contaminants to marine ecosystems.

Effluent from WWTP A and a third WWTP located near WWTP B is characterised by low salinities and elevated concentrations of dissolved nutrients. These results align with the information recorded in the National Outfalls Database. In addition to these expected contaminants, several metals were detected. Some, like copper, were present in effluent at concentrations that exceeded the Commonwealth Default Guideline Values (see paragraph ii, below) for environmental protection. Trace concentrations of antibiotics, PFAS, and microplastics, in the form of fibres, were also detected in the effluent.

ii. Effluent contaminants are rapidly diluted by seawater. Despite this, some contaminants in the environment exceed Commonwealth thresholds for environmental protection.

Effluent discharged into the coastal outfalls is rapidly diluted in the water column. The concentrations of nutrients, metals, antibiotics and PFAS were substantially lower in seawater at the outfall compared to the effluent prior to discharge. All the contaminants were present in seawater at highly variable concentrations, indicating that the dispersion by the water column prevents the detection of a distinct plume.

The Commonwealth's Default Guideline Values (DGVs) are contaminant thresholds recommended for the protection of biodiversity. Currently, Commonwealth DGVs exist for several metals. This project found that some seawater samples collected from the WWTP A outfall contained chromium, copper and zinc at concentrations that exceeded the DGVs for marine waters. Chromium, nickel, selenium and zinc DGVs were exceeded in some seawater samples from the WWTP B outfall.

iii. WWTP outfalls are a source of total mercury pollution, and concentrations may exceed Commonwealth thresholds for environmental protection.

Australia ratified the Minamata Convention on Mercury on 7 December 2021. The Minamata Convention on Mercury seeks to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds (DCCEEW, 2023b). Among other obligations, Australia must contribute to international reporting on the effectiveness of measures taken to control the disposal, emissions and releases of mercury and mercury compounds.

WWTP outfalls were a considerable source of mercury pollution to coastal environments. Mercury was detected in seawater at and around the WWTP A outfall, with concentrations ranging from 0.026 to 0.440 µg/L, and in sediment from 0.079 to 0.992 mg/kg. Mercury levels

in sediments at the WWTP B outfall ranged from 0.051 to 0.928 mg/kg, and at the WWTP C outfall from 0.097 to 2.346 mg/kg. These represent total mercury concentrations.

Methylmercury concentrations are assumed to be approximately 1% of inorganic mercury levels, as indicated by Australian and international research. In several instances, the estimated methylmercury concentrations exceed the adjusted DGVs for methylmercury in both water (0.001 µg/L) and sediment (0.0015 mg/kg). This suggests potential environmental concerns. However, these are inferred values, and direct measurement of methylmercury is necessary for a more accurate assessment of environmental risks.

iv. Water quality guidelines for PFAS may already be exceeded at WTTP outfalls.

The PFAS discharged in effluent accumulates around coastal outfalls. In the freshwater channel at the WWTP B outfall, the concentration of perfluorooctane sulfonic acid (PFOS) was approximately five times higher than the guidelines. For marine waters, the PFOS threshold suggested by the Heads of EPAs of Australia and New Zealand was exceeded in the seawater collected adjacent to the WWTP A outfall; seawater collected over 1000 m away from the WWTP B outfall also contained more PFOS than the suggested guideline.

When proposed DGVs for PFAS species come into effect, it is likely that coastal environments around outfalls will already contain higher concentrations of PFAS than recommended.

v. **The concentration of contaminants showed different patterns of attenuation with distance from the outfall.**

At the WWTP A outfall, contaminants in seawater showed several patterns of dispersion:

a) Attenuation with distance from the outfall. This pattern was clear in the concentrations of total nitrogen, phosphorus, and PFAS, the concentrations of which were elevated at the outfall and declined with distance from the source.

b) Accumulation at a specific distance from the outfall. This was observed for microplastics, which were more abundant in seawater at 20 m from the outfall.

c) Similar concentrations at all sites, with no evident spatial pattern. This was observed for several metals that are associated with DGVs.

vi. Marine sediments are a repository for effluent contaminants in both retentive and dispersive receiving environments.

All the contaminants investigated in this study were detected in marine sediments in all three locations but not in seawater (e.g. antibiotics were in concentrations below detection). Commonwealth sediment DGVs exist for some metals, but not for the other contaminants quantified. No metal, at any site, was present in concentrations that exceeded its sediment DGV. However, total mercury was detected at all three outfalls.

In retentive receiving environments, antibiotics and microplastics were found at large distances from outfalls. At the WWTP A outfall, these contaminants were detected in sediments up to 1000 m away from the outfall. At the WWTP B outfall, antibiotics and microplastics were present in sediment more than 1600 m away from the outfall.

The WWTP C outfall, despite discharging into a highly dispersive environment, contributes detectable quantities of contaminants to marine sediment. This study detected several metals – including mercury – at this site, as well as trace concentrations of antibiotics and PFAS.

vii. There were ecological effects on the microbial assemblage at WWTP outfalls.

Our spatially-structured sampling enabled us to determine the effect of WWTP discharges at WWTP A and B outfalls included in this study.

Measurable changes in the marine microbial community could be directly attributed to impacts from the WWTP A outfall. While the abundance of microbial populations revealed only weak effects of WWTP discharge, DNA sequencing approaches revealed significant spatial changes in the microbial community that, in seawater samples, could be linked to the input of high phosphorus and PFAS concentrations within WWTP effluent. There was clear partitioning of the sediment microbial assemblage with distance from the outfall, but no clear association with any of the contaminants or environmental parameters measured.

Uncertainty in the exact discharge location of the WWTP B outfall reduced our ability to attribute changes in microbial assemblages to the third WWTP located near WWTP B. Despite this, our analyses revealed there was a distinct planktonic microbial community in the freshwater channel (likely site of effluent discharge) compared to coastal sites, with microbes sampled in seawater along the southeasterly transect being most dissimilar to communities at the other sampling sites. Sediment microbes at WWTP B were also spatially partitioned, with communities in the freshwater channel being most distinct from other sampling sites. Dissimilarity in sediment microbial communities mapped onto sediment metal content.

These findings indicate there is a significant impact of WWTP effluent on the structure of the base of the marine foodweb, and highlight the potential utility of marine microbial communities as sentinels of impact from contaminants present within sewage outfalls.

Conclusions and recommendations

This project provided a single snapshot study in three locations that had differing receiving water contexts. A greater understanding of temporal and spatial variability at WWTPs as well as untreated stormwater is still needed to understand the distribution of emerging contaminants in Australian coastal environments.

This project assessed the ecological responses of organisms at lower trophic levels. These organisms have short generation times and thus a high capacity for adaptation. Whilst

ecological effects were detected at these trophic levels, higher trophic level organisms are exposed to contaminants, and the consequences of this remain unknown.

The recommendations from this project are to:

- Leverage the results of this study by implementing an investigation of stormwater to assess the concentration of contaminants in untreated urban runoff.

- Monitor WWTPs as a source of mercury pollution to the environment. Investment is needed to ensure that Australia has the capability to measure organic mercury in future research projects.

- Enhance policy on the presence of environmental antibiotics pollution, and how it contributes to [Onehealth].

1. The importance of water quality to Australia's marine environments

Australia is an urban coastal nation. The most recent statistics revealed that in 2019, 22 million Australians – 87% of the country's population – lived within 50 km of the coast (Clark et al., 2021). Traditionally, coastal populations were concentrated in urban capital cities. However, populations in regional coastal towns are also increasing, due partly to the migration driven by the COVID-19 pandemic. Notably, healthy marine and estuarine environments with clean water are highly valued by the community (NSW Marine Estate Management Strategy 2018-2028).

Coastal populations generate pollution that enters coastal areas and degrades water quality. This has been identified as a key threat to the survival and health of marine and estuarine ecosystems, like the World Heritage listed Great Barrier Reef (Great Barrier Reef Marine Park Authority, 2020) and the Derwent River estuary (Coughanowr 1997). Poor water quality also jeopardises the provision of ecosystem services, such as providing habitat for key species, cycling nutrients, and supporting recreational activities. These services are expected to contribute $100 billion per annum to the Australian economy by 2025 (National Marine Science Committee, 2015), but these expectations can only be met when there are healthy ecosystems to deliver such services.

Improved water quality ranks as one of the highest priorities for restoration stakeholders, especially for Aboriginal and Torres Strait Islander organisations (Saunders et al., 2022) and the Commonwealth government (DCCEEW, 2023a). Yet, the existing poor water quality at a site can undermine the efficacy of restoration efforts (Brettschneider et al., 2023; Friberg et al., 2016). Managing land-based pollution has been identified as an ongoing challenge for Australian marine restoration activities (Saunders et al., 2022); quantifying pollution and its effects on marine ecosystems is urgently needed to support the increasing number of coastal restoration efforts in Australia (for example, see DCCEEW, 2022; Sydney Institute of Marine Sciences, 2018; The Nature Conservancy, 2023).

1.1 Historical contributions and diffuse sources of coastal pollution

Coastal environments are exposed to a wide variety of pollution types that can detrimentally impact water quality through the introduction of contaminants from both point source and diffuse source inputs. Point source pollution can arise from localised inputs of contaminants from wastewater pipes and infrastructure, stormwater and industrial discharge, while diffuse source pollution can include urban and agricultural runoff, contaminated groundwater seepage and non-localised industrial leaching (Beiras 2018). Types of contamination can differ or sometimes overlap according to input sources, and include a wide variety of chemical contaminants that can ultimately result in a range of environmental persistence and biomagnification effects (NSW Marine Estate Management Authority, 2017).

Many traditionally studied causes of coastal pollution have well-defined, albeit often diverse, sources of input. For instance, coastal eutrophication results from the input of inorganic nutrients that can be introduced to the environment from both point (e.g. wastewater pipes) and diffuse (e.g. agricultural runoff containing fertilizers and manure) sources (de Jonge et al.

2022), while heavy metal contamination of coastal ecosystems typically arises from smelter discharges, chemical industry releases and mining activities (Ansari et al. 2004). In contrast, the sources and/or points of input of more novel “emerging contaminants” including PFAS, microplastics and pharmaceuticals are often not as clearly resolved (Sultan et al. 2024). This creates challenges when attempting to isolate causes of contamination, which is critical for the development of any remediation strategy.

Within Australian coastal ecosystems, the major forms of chemical contamination have historically included: (i) nutrients, including phosphate, nitrate, nitrite, ammonia, that can arise from localised inputs from wastewater infrastructure and diffuse agricultural runoff; and (ii) a range of toxic contaminants, including metals and metalloids, inorganic contaminants (e.g. inorganic acids, chlorine based disinfectants and ammonia) and organic contaminants (e.g. pesticides, surfactants, and chemicals used in the manufacture of plastics) (NSW Marine Estate Management Authority, 2017). These contaminants can have a wide range of detrimental impacts on coastal ecosystems, spanning the stimulation of harmful algal blooms, toxic effects on marine flora and fauna and impacts on human health, as well as food safety and security. However, neither the sources nor the environmental impacts of more novel chemical contaminants are well resolved in Australian marine ecosystems.

1.2 Wastewater Treatment Plant contributions to coastal pollution

A key point source of coastal pollution is wastewater treatment plants (WWTPs). Influent entering WWTPs contains a diversity of contaminants which are not completely removed by water treatment processes; and discharged effluent contains residual micro-contaminants that are delivered directly to marine ecosystems. In Australia, there are 192 coastal WWTP outfalls around the country, with 71 being located in rivers or estuaries and the remainder discharging into the ocean (Rohmana et al., 2020). The wastewater is primary, secondary or tertiary treated, with outfalls such as WWTP C discharging relatively high volumes of water (>30,000 ML day^{-1}) and others such as WWTP A discharging 3 orders of magnitude less (60 ML day^{-1}).

WWTP effluent is a complex mixture of residual contaminants. Some of its constituents have long been recognised as harmful – for example, nutrients and metals can lead to blooms of harmful algae (Beman et al. 2005; Davis and Koop 2006). Other contaminants in effluent are synthetic chemicals found in pharmaceuticals and household products. In contrast to nutrients and metals, little is known about the biological effects of novel chemicals. However, emerging research suggests that several novel chemicals may harm the environment, leading to their categorisation as a contaminant of emerging concern (CEC).

Being new and relatively unstudied, CECs are unregulated. Hence, there is little incentive or funding available for environmental monitoring efforts. This has created a causal loop, where the limited distribution and concentration data for CECs in marine environments precludes an understanding of exposure levels, risk assessments, and eventual government regulation. Australia’s Waste Policy Action Plan, Threat Abatement Plan for the impacts of marine debris, and Australia’s One Health Master Action Plan all refer to the need for emerging pollutants to be incorporated into contaminant guidelines. To build an evidence-based understanding of the environmental concentrations of these contaminants and their ecological significance in Australian coastal waters, this project was co-designed with end-

users to determine environmental concentrations and their potential ecological effects at selected WWTP outfalls.

1.3 Ecological effects of WWTP effluent

WWTP effluent has the potential to significantly alter the ecology of the receiving ecosystem because the chemicals present in effluent harm bacteria and other microorganisms (herein referred to collectively as 'microbes'). This is particularly true in retentive receiving environments. For instance, effluent discharged into a retentive stream in South Australia altered the structure and nutrient cycling capacities of microbial assemblages (Wakelin et al., 2008).

Similar effects of WWTP effluent have been recorded in freshwater receiving environments around the world (Drury et al., 2013). In some ecosystems, effluent accounting for as little as 3% of the receiving waters is sufficient to trigger ecological changes (Pereda et al., 2020). Whilst WWTP effluent effects on freshwater ecosystems is receiving increased scientific attention, few studies have considered the ecological effects of coastal effluent discharges (Tuholske et al., 2021). This stands out as a significant knowledge gap for Australia, where approximately 60% of the number of WWTPs discharge into coastal areas (Rohmana et al., 2020).

1.4 Stakeholder-identified priorities for contamination research

The growing number of new chemicals manufactured each year (Binetti et al., 2008; Wang et al. 2020; Naidu et al. 2021) means that there is an ever-expanding list of CECs entering marine ecosystems. Whilst environmental monitoring cannot feasibly target all CECs, prioritising CECs for investigation is challenging. Researchers struggle to prioritise CECs based on environmental exposure or persistence because there is limited documentation of discharge concentrations and CEC behaviour in the environment. Similarly, selecting CECs based on potential harm is difficult because our understanding of toxicity is still developing for many CECs.

To select contaminants for investigation in this project, the National Environmental Science Project commissioned Project 1.16 to understand water management stakeholders' research priorities. Stakeholders identified several contaminants that they felt required monitoring in order to facilitate regulation: antimicrobials, per- and poly-fluoroalkyl substances (PFAS), and microplastics. Additionally, the study determined that there is a clear and consistent need for monitoring data on these concentrations, and a greater understanding of their impact on exposed marine ecosystems (Trestrail et al., 2022).

1.4.1 Nutrients

Australia's estuaries and sheltered coastal waters are typically low in nutrients, such as phosphorus and nitrogen (Clark G. et al., 2021). In high concentrations, these nutrients support the development of harmful algal blooms. The subsequent bacterial decomposition of the organic matter generated by algal blooms can deplete concentrations of dissolved oxygen and cause fish kills. Further, WWTP effluent also contains organic carbon, which can directly cause oxygen depletion, or exacerbate bloom-related dissolved oxygen dynamics.

Nutrients have long been an acknowledged contaminant of WWTP effluent, and in the recent State of the Environment report, all Australian states acknowledged the need to manage nutrient pollution from WWTP discharges (Clark G. et al., 2021).

WWTP discharges of nutrients

The National Outfalls Database (NOD) publishes the average monthly nutrient concentrations of WWTP effluent discharged into coastal and oceanic waters. However, this data is missing for some WWTPs as monitoring requirements vary among treatment facilities (see below). During the 2019-2020 financial year, the average combined nitrogen and phosphorus load of Australian WWTPs was 164,551 kg (Rohmana et al., 2021). Outfalls with the highest nutrient loads were typically associated with large urban populations. Nitrogen contributed to the overall nutrient load to a greater extent than phosphorus.

Regulatory frameworks for environmental nutrient contamination

The nutrient loads discharged in WWTP effluent is regulated by each jurisdiction's Environmental Protection Authority (EPA). The permissible nutrient concentrations vary between EPAs, WWTP operators, and in some cases individual outfalls (Gemmill et al., 2020). Individual monitoring arrangements are made in each case between EPAs and Water Treatment Authorities (WTAs). Monitoring requirements ultimately depend on EPA requirements, WWTP treatment level, and the condition of the marine environment (Gemmill et al., 2020).

1.4.2 Metals

A variety of metals are used in household products (Tjandraatmadja & Diaper, 2006). One common source is domestic cleaning products, which often contain metal ions as active ingredients. Disposal of electronic waste, batteries, and metal-containing products down the drain or toilet can also contribute to the metal load entering WWTPs.

Metals do not degrade, and thus accumulate in the receiving environment (Smith et al., 1996). They exhibit several toxic mechanisms, including their ability to disrupt the normal functioning of proteins and enzymes. This interference can lead to impaired enzymatic activity, cellular dysfunction, and ultimately, cellular death. Additionally, metals can induce oxidative stress by generating reactive oxygen species, which damages DNA, proteins, and lipids. In coastal areas, the toxicity of metals to marine life is expected to increase, as ocean acidification alters the speciation and bioavailability of metals (Zeng et al., 2015). Some metal species bioaccumulate in tissues and biomagnify along the food chain, with the potential for long-term exposure and chronic toxicity.

WWTP discharges of metals

Although some metals are removed from the water through partitioning (i.e. adsorption of dissolved metals to biosolids) during water treatment, other metal species remain predominantly waterborne and are discharged into the environment in effluent (Cantinho et al., 2016). For highly toxic metals such as cadmium, chromium, nickel and zinc, approximately 50 % of the influent concentration is discharged in the treated effluent (Karvelas et al., 2003).

Data on the metal concentrations in Australian WWTP effluents are scarce. The decadal average concentration of several metals in Malabar effluent provided by Besley & Birch (2019) were in the order of µg/L. The concentrations of copper, lead and zinc in the discharged effluent exceeded the environmentally safe concentrations recommended for biodiversity protection (see below), emphasising that outfalls can be a substantial source of these contaminants in marine ecosystems.

Regulatory frameworks for environmental metal contamination

The Australian and New Zealand guidelines for fresh and marine water quality list acceptable thresholds, known as Default Guideline Values (DGVs) for several metals for the protection of environmental biodiversity. These metals include cadmium, mercury, and zinc.

In accordance with the Minamata Convention, Australia has responsibility to identify significant sources of releases of mercury and mercury compounds to water. Since mercury can be present in a range of household items, including cosmetics, pesticides, pharmaceuticals, and dental amalgam, WWTPs may act as a source of mercury emissions to coastal ecosystems. According to the Conference of the Parties to the Minamata Convention on Mercury (2023), WWTPs that handle mercury or use mercury-containing raw materials may generate mercury-containing wastewater and be additional sources of mercury releases to coastal ecosystems.

1.4.3 Antibiotics

Antibiotics are natural or synthetic compounds that kill, or prevent the growth of, bacteria. Since antibiotics are poorly metabolised by the human body, 30-90 % of the antibiotics a person ingests is excreted, unaltered, in faeces and urine (Zhou et al., 2021).

Antibiotics pollution affects all levels of biological organisation. At the individual level, antibiotics in the environment kill, or slow the growth of, marine microbes (Välitalo et al., 2017). This cascades into population-level changes and modified microbial assemblage diversity, which can subsequently alter the provision of ecosystem services, such as nutrient cycling and pollution degradation (Näslund et al., 2008; Pinckney et al., 2013).

In addition to these ecological consequences, antibiotics pollution leads to the evolution of antibiotic resistant bacteria in the environment. Infections by these microbes are a significant threat to human health because they cannot be cured with current medications. Such infections are expected to be the leading cause of human deaths by 2050, and the United Nations Environment Program has identified antimicrobial resistance (AMR) as the most critical emerging environmental pollution issue (Gaze & Depledge, 2017).

WWTP discharges of antibiotics

Water treatment processes incompletely remove antibiotics from wastewater (Watkinson et al., 2009). This results in residual concentrations of antibiotics being discharged in effluent; studies from around the globe have detected them in concentrations ranging from ng/L to µg/L (Zhang et al., 2014). Only a few studies have quantified antibiotics in Australian WWTP effluents. Effluent discharged into Darwin Harbour contained cephalexin, erythromycin, lincomysin, roxithromycin, sulfamethoxozole and trimethoprim (French et al., 2015).

Concentrations of these antibiotics in the effluent ranged from 0.02 – 1.2 µg/L before it was diluted by the receiving seawater. In south-east Queensland, several antibiotics were present in effluent collected from five WWTPs, although the concentrations varied widely (Watkinson et al., 2009).

Regulatory frameworks for environmental antibiotics contamination

Notably, there are currently no Australian or international regulatory frameworks for antibiotics contamination in the environment.

1.4.4 PFAS

PFAS are a diverse group of synthetic chemicals that possess a chain of bonded carbon and fluorine atoms. The strength and stability of these carbon-fluorine bonds make PFAS extremely resistant to physical or chemical degradation; as a result, these chemicals are referred to as the 'forever chemicals'. There are over 4700 different species of PFAS in existence (Organisation for Economic Co-operation and Development, 2018). These can be divided into different classes based on the composition of their carbon chains and side chains.

PFAS have been widely used in industrial applications and consumer products since around the 1950s. They are routinely used to create grease-resistant food packaging, non-stick cookware, and textiles that are waterproof and stain-resistant. Initially, long-chain PFAS were the predominant PFAS compounds in use. However, regulatory efforts have largely phased out these PFAS in developed countries (Brase et al., 2021), although they are still detected in the environment as legacy contaminants. During the second phase of PFAS manufacturing, long-chain PFAS were replaced with short-chain PFAS and polyfluorinated compounds. These newer PFAS are equally persistent in the environment, and are considered emerging contaminants (Brase et al., 2021).

PFAS bioaccumulate in marine biota and biomagnify, increasing in concentration in organisms at higher trophic levels (Khan et al., 2023). PFAS can cause direct toxicity to marine microbes, invertebrates and fish (Mhadhbi et al., 2012; Simpson et al., 2021). A range of ecologically relevant sub-lethal effects have also been identified including delayed somatic growth, reduced reproductive output, endocrine disruption, and oxidative stress (Miranda et al., 2020; Simpson et al., 2021). In higher trophic-level marine organisms, PFAS exposure may cause intergenerational effects as maternal transfer of PFAS has been demonstrated in Australian marine mammals (Taylor et al., 2021) and several species of seabirds (Miller et al., 2015).

WWTP discharges of PFAS

Australian WWTPs release an estimated 399 kg of PFAS each year into receiving environments (Coggan et al., 2019). Analyses of effluent from Australian WWTPs have detected total PFAS concentrations of 21 – 250 ng/L before this water is discharged to the environment (Coggan et al., 2019; Gallen et al., 2018). These discharges can be a substantial source of PFAS pollution in shallow receiving waters: in the enclosed Port Phillip

Bay, located in Victoria, elevated PFAS levels were detected in the seawater and sediments surrounding the specific WWTP outfall (Coggan, 2020).

Regulatory frameworks for environmental PFAS contamination

The Commonwealth and jurisdictional governments are currently assessing the draft freshwater DGV of 0.0091 µg/L for perfluorooctane sulfonic acid (PFOS) anion (Water Quality Australia, 2023). This threshold has been recommended for bioaccumulating contaminants to protect 99 % of species in slightly to moderately disturbed ecosystems. No Commonwealth draft DGVs have been proposed for marine waters.

The Heads of EPAs of Australia and New Zealand have created PFAS guidelines in the PFAS National Environmental Management Plan Version 2.0 (Heads of EPAs Australia and New Zealand, 2020). This plan lists freshwater and interim marine water quality guideline values for two species of PFAS: thresholds of 0.13 µg/L for PFOS and 220 µg/L for perfluorooctanoic acid (PFOA) to protect slightly to moderately disturbed ecosystems. The plan also specifies that ecological assessments of PFAS should consider treated effluent from WWTP as a PFAS source. There are currently no guideline values for any species of PFAS in sediments.

Internationally, PFAS are managed under the Stockholm Convention on Persistent Organic Pollutants, an international treaty designed to protect human health and the environment. Australia is yet to ratify the addition of PFAS to the Convention (Australian Government PFAS Taskforce, 2019).

Note: The authors acknowledge that the regulatory limits applied in this document were based on the guideline values available at the time the analyses and data evaluation were performed. However, during the review period prior to publication, updated regulatory limits for PFOS and PFOA were released in 2025 under the *Heads of EPA Australia and New Zealand, PFAS National Environmental Management Plan (PFAS NEMP) Version 3.0*.

The revised guideline values are more stringent than the previous criteria. For example, the updated 99% species protection guideline value for PFOS in freshwater and interim marine waters is 0.00023 µg/L, compared with the previous freshwater guideline value of 0.0091 µg/L, representing an approximately 40-fold reduction. Similarly, when comparing the updated PFOS and PFOA guideline values from PFAS NEMP 3.0 (2025) with those from PFAS NEMP 2.0 (2020), the revised values are approximately 565-fold and 11-fold lower, respectively.

Importantly, the updated guideline values do not alter the interpretation of the results presented in this study.

1.4.5 Microplastics

Microplastics are synthetic solid particles of polymeric matrix, with regular or irregular shape and sizes ranging from 1 µm to 5 mm (Frias and Nash, 2019). These small plastic particles can be characterised as primary microplastics when they are intentionally manufactured to

these small sizes (e.g., nurdles, beads or others with specific functional, aesthetic, or industrial specifications), and secondary microplastics when they result from the degradation or breakup of larger pieces of plastic. Many sources and pathways drive the occurrence of microplastics in coastal and marine environments, including from wastewater treatment effluent, particularly for synthetic fibres from clothing and particles used in personal care products (Browne et al 2011, Ziajahromi et al 2021).

Due to their small size, microplastics are readily ingested by diverse marine species and can bioaccumulate (Carbery et al., 2018). This raises concerns for both biota and crucial ecosystem services they provide. Moreover, because of the widespread presence of microplastics in the environment, they are often found in a variety of seafood items (Wootton et al. 2021). Furthermore, microplastics act as vectors for chemical contamination, potentially amplifying any direct physical impacts (e.g., Rochman et al 2015, Cousin et al., 2020). Whilst our understanding of the full spectrum of microplastic impacts and risk of harm to biota remains incomplete, reported adverse effects include reduced growth and feeding rates, oxidative stress, or altered behavioural responses (e.g., Rochman et al 2015, Foley et al 2018).

WWTP discharges of microplastics

Several studies have shown variation in the removal efficiency of microplastics across WWTP and treatment levels. Whilst WWTP can be efficient at removing microplastics, WWTP effluent is still an important pathway to environmental contamination considering the large volumes of discharge, and with microplastics in effluent directly released into coastal and marine environments (Browne et al 2011, Raju et al 2020, Ziajahromi et al 2021). Without accounting for any potential re-entry of microplastics from land sources linked to the re-use of treated sludge and biosolids, estimates from three WWTP in Australia, indicated that between 22.1 million and 133 million microplastics (>25 µm) were released per WWTP from effluent per day (Ziajahromi et al. 2021).

Regulatory frameworks for environmental microplastics contamination

The regulatory framework for plastics and microplastics in Australia is evolving. The National Plastic Plan was launched in 2021. Whilst it does not address or regulate microplastic contamination in the environment it aims to address key root causes, including goals to phase out single use plastic, together with Australia's National Packaging Targets. There are also several state-based commitments to ban a variety of different single use plastics until 2025. Microplastics in wastewater effluent are not currently monitored or regulated. Yet, WWTP is recognised as a pathway for plastics to enter the environment, and the Federal Government has supported industry to voluntarily phase out microbeads from personal care and cleaning products sold in Australia. Support for an industry-led phase-in of microfibre filters in washing machines sold in Australia by 2030 is also part of the National Plastic Plan.

1.5 Project scope

This project aimed to determine the concentrations of contaminants in different coastal environments with WWTP outfalls and understand their ecological impacts. Focusing on traditional contaminants and stakeholder-identified CECs, the study's objectives were to:

i. Quantify the concentrations of contaminants in WWTP effluent and the different coastal receiving environments surrounding WWTP outfalls.
ii. Determine the ecological effects of WWTP coastal outfalls by assessing changes in the size and composition of marine microbial assemblages in the context of their receiving environment.

2. Selection of WWTP outfalls for investigation

Data published in the National Outfalls Database was used to assess the suitability of coastal WWTP outfalls as sampling locations for this study. Several environmental and social selection criteria (Table 1) were considered; the variability of outfall characteristics meant that the selection criteria could not be weighted. Rather, all selection criteria were considered together in an iterative process.

The initial assessment using NOD data identified several outfalls in South Australia, New South Wales, and Queensland as possible sampling sites. Hydrodynamic modelling was then undertaken (Appendix A) to assess the receiving environments at these locations. The final sampling sites selected were two WWTP outfalls in South Australia (hereafter referred to as Site/WWTP A and Site/WWTP B), and one outfall on the exposed coast of NSW (Site/WWTP C).

Table 1. Criteria used in the selection of sampling sites for this study.

Outfall selection criteria	Justification
Coastal location	Only outfalls listed as 'coastal' in the NOD were considered. This ensured outfalls were located in areas where data existed to support hydrodynamic modelling of the receiving environment.
Accessibility	The outfall coordinates listed in the NOD were used to assess which outfalls could be safely sampled in a research vessel.
Receiving environment	Outfalls in contrasting receiving environments were selected to answer project aim ii.
Population size	Preference was given to the outfalls of WWTPs that service large urban populations, as these have higher contaminant loads (see *1.4.1* Nutrients section) – and hence pose a greater environmental hazard – compared to WWTPs that service small populations.
Representativeness	The level of treatment and effluent characteristics were considered to select outfalls that were broadly representative of other WWTPs in Australia.
Research partnerships	Preference was given to outfalls in locations where water management authorities and EPAs were interested in collaborating on the project.
Cultural relevance	Preference was given to outfalls in locations where Aboriginal community groups expressed interest in understanding effluent effects on local water quality.

2.1 Outfalls in a Temperate Coastal Region, Southern Australia

Two outfalls within a coastal embayment were selected for sampling: one outfall in the southern metropolitan region (WWTP A) and a second outfall located in the northern metropolitan region (WWTP B), which receives combined effluent from a wastewater treatment plant and an associated high-salinity treatment facility. The WWTP A services approximately 250,000 people and discharges approximately 60 ML d^{-1} of tertiary-treated effluent through two adjacent outfall pipes located approximately 350 m from the shore. The northern WWTP discharges secondary-treated effluent, while the adjacent high-salinity facility discharges tertiary-treated effluent. These facilities share a combined offshore outfall (WWTP B). Together, they serve a combined population of approximately 493,250 and discharge approximately 197 ML effluent d^{-1}.

The hydrodynamic modelling determined that the coastal embayment is a shallow (< 6 m) and retentive receiving environment (Appendix A). It experiences weak bottom flows and has limited exchange with water outside the embayment. Stratification is minimal, and the well-mixed surface waters meant that it was feasible to sample one depth that was considered relatively representative.

The effluent discharged by the WWPT A is characterised by low concentrations of total nitrogen and phosphorus, and is representative of effluent produced by 96 other WWTPs around the country (Rohmana, pers. comm). The nature of the effluent discharged from the northern combined outfall is more complex, as it is combined from two WWTP. One produces effluent broadly similar to that of the southern metropolitan plant (Rohmana, pers. comm),, while the other typically exhibits higher electrical conductivity, total phosphorus, and turbidity, and is comparable to effluent from other treatment systems in other Australian jurisdictions (Rohmana et al., 2020).

Staff at the EPA and Water Authority expressed strong interest in understanding the ecological effects of outfalls, and sampling was undertaken with the help of both organisations. Both the WWTP A and WWPT B outfalls are located on the Sea Country of the Kaurna people. This community was contacted through the NESP Indigenous facilitator, and they expressed interest in learning about the results of the project.

2.2 Outfall in New South Wales

In New South Wales, the WWTP C outfall was selected for sampling. This WWTP services approximately 1,700,000 people, and discharges over 30,000 ML d^{-1} of primary-treatment effluent. The outfall is located approximately 82 m deep and 3.6 km offshore, and has been in operation since 1990 (Besley & Birch, 2019).

The WWTP C outfall is in the vicinity of the Ocean Reference Station, which has provided near-continuous measurements since the 1940s. Consequently, the oceanographic setting of this location is well understood, and facilitated robust hydrodynamic modelling at this site. The modelling showed that the WWTP C outfall exists in an open ocean-influenced environment that would facilitate effluent dilution (Appendix A, NSW: Site 1). Most of the particulate matter in the effluent settles within 5 km of the outfall (Tate et al., 2019), and a recent study did not attribute any CEC enrichments of the sediment to the outfall (Besley & Birch, 2019).

Effluent from the WWTP C outfall is characterised by high concentrations of oil and grease, total nitrogen, and total suspended solids (Rohmana et al., 2020). This outfall is representative of several other marine outfalls located in different Australian jurisdictions, including sites in New South Wales, Tasmania, and Western Australia (Rohmana et al., 2020).

As the operator of the WWTP C, Sydney Water conducts the Ocean Sediment Program to identify the spatial extent of any impacts caused by the discharged effluent (Sydney Water, 2022). Sediment is sampled around the outfall each year. Physical parameters, organic compounds and metals are quantified in the sediment every second year; in alternate years, only particle size and total organic carbon are assessed. Sydney Water expressed interest in the project and provided sediment samples collected in 2023 through their routine sampling operations.

Table 2. Characteristics of the outfalls sampled in this study. Data is taken from the National Outfalls Database for the year 2021, which at the time of writing was the most recent yearly dataset available. ML d-1 = Megalitre per day.

Characteristic	'A' outfall	'B' outfall		'C' outfall
WWTP serviced by outfall	WWTP A	WWTP B	High Salinity WWTP B	WWTP C
Population served	~ 250 000	~ 434 000	~ 59 250	~ 1 700 000
Level of WWTP treatment	Tertiary	Secondary	Tertiary	Primary
Effluent volume (ML d^{-1})	60	165	32	> 30 000
Range of monthly *E. coli* content of effluent in 2020	52 – 351 cells/L	114 – 1850 cells/L	50 – 368 cells/L	No data available
Range of monthly total nitrogen (mg/L)	9.40 – 14.30	4.07 – 12.08	5.01 – 8.13	46.55 – 61.00
Range of monthly total phosphorus (mg/L)	3.10 – 7.20	1.37 – 2.85	1.55 – 2.71	5.30 – 7.90
Outfall characteristics	Effluent is discharged from two outfall pipes located next to each other.	Effluent is discharged into a shared channel leading to coastal waters		Effluent is discharged through a diffuser, located 82 km below the surface.

2.3 Spatial design of sampling

2.3.1 The WWTP A outfall

At WWTP A, sampling transects were established along two perpendicular orientations to capture spatial gradients in effluent dispersion. One transect was aligned approximately parallel to the coastline to match the predominant current direction, while a second transect was oriented perpendicular to it. Along the transects, seawater and sediment samples were taken at the outfall (0 m), and at 20 m, 100 m, and 1000 m distant from it. The furthest sample that could be taken along the east transect was at 100 m, due to the proximity of the shoreline. At the intersect of these transects was the outfall, the 'origin' of pollution, the coordinates of which were taken from the National Outfalls Database. In this report, we refer to the outfall as being nominally '0 m' from the pollution source. However, the force of water discharged from the outfall was so great that the sampling vessel could not be maneuvered directly above the outfall pipe. We estimate the actual sampling location was approximately 4 m from the outfall.

2.3.2 The WWTP B outfall

At WWTP B, the outfall coordinates listed in the National Outfalls Database initially indicated that the outfall discharged directly into the ocean. However, at the time of sampling, local knowledge from EPA collaborators advised that the outfall was actually located further north of the NOD coordinates, and upstream in a freshwater channel (FWC). This critical knowledge was used to alter the sampling design.

The sampling vessel was taken as far upstream into the FWC as physically possible; samples at this site are as close to the 'origin' as the tides would allow. The transect design was adapted from that used at WWTP A, with transects oriented approximately parallel to the coastline to align with prevailing current direction, and a second set oriented perpendicular to this axis. Seawater and sediment samples were collected at distances of 20 m, 100 m, and 1000 m from the discharge origin. The shallow and rocky features of the location prevented a transect from being run in an easterly direction. Given the sampling design modifications, this meant that water and sediments were collected at various distances away from the outfall 'origin' along each transect.

2.3.3 The WWTP C outfall

Sediment samples from the WWTP C were collected by Sydney Water as part of its biennial sampling program (Besley & Birch, 2019). The sediment contributed to this project was sampled from two sites at the outfall that comprise part of their long-term monitoring program (0 km).

3. Material and methods

3.1 Sampling methodology

3.1.1 Collection of effluent samples

The Water Authority collected 24-hour composite effluent samples from the WWTP A and the WWTP B. To minimize contamination, the effluent collected for PFAS analysis was stored in polypropylene bottles that had been cleaned with methanol. Effluent was stored at -20 °C and thawed immediately prior to contaminant analysis.

At the time of sample collection, one of the four basins at the WWTP was offline for capital works. This means that the contaminants present in this effluent does not represent the typically operation at this WWTP.

3.1.2 Collection of seawater samples

Seawater samples were collected from around the 'A' and 'B' outfalls. This sampling was made possible with the assistance of the EPA, who provided a research vessel, sampling equipment and technical staff. Sampling was based along transects running in four directions from the outfall (the 'origin'), which was identified using the coordinates listed in the National Outfalls Database. The distance for each sampling location are provided in Table 3.

Seawater samples were collected using a 5 L Niskin bottle deployed to 1 m from the sea floor. Three Niskin bottles were taken at each site (n = 3), and water was immediately transferred into 5 L polyethylene bottles and stored on ice for transport to the lab. Additional Niskin bottles (n = 3) were collected for PFAS analysis; these samples were transferred from the Niskin bottle into polypropylene storage bottles, and stored on ice for transport to the lab.

3.1.3 Collection of sediment samples

Sediment was sampled at the 'A' and 'B' outfalls by EPA divers using polypropylene corers (n = 3). The average depth of sediment cores was similar at each site, and ranged between 66.9 – 75.9 mm at the 'A' outfall, and 56.5 – 64.8 mm at the 'B' outfall. Sediment cores were stored intact and on ice, and on arrival at the laboratory were frozen at -20 °C until genomic and chemical analyses. Note that core sampling does not allow for field blanks to be taken. Divers also collected sediment samples in polypropylene tubs to be used for microplastics analyses.

At the 'C' outfall, sediment was collected from two sites around the 'C' outfall (0 m). Five sediment grabs were taken at each site (n = 5), collecting material from the top 10 cm of the seafloor. Sediment was stored in glass containers at -20 °C. At both sites, two additional sediment samples were collected (n = 2) and stored in polypropylene containers for PFAS analysis. Microplastics were not analysed in 'C' sediment samples.

Table 3. Coordinates for seawater and sediment transect sampling locations around the 'A' and 'B' coastal outfalls in South Australia, and the sediment sampling sites 'C' outfall in NSW. Distance for the 'A' and 'C' outfalls refer to the distance from the outfall, whilst distance for the 'B' outfall represents the distance from the 'Centre' of the transects intersection. FWC = Freshwater Channel.

Site	Direction of transect from outfall	Distance (m)
'A' outfall	Origin	0
	E	20
		100
	SSE	20
		100
		1000
	W	20
		100
		1000
	NNW	20
		100
		1000
'B' outfall	FWC	NA
	Centre	0
	SE	20
		100
		1000
	W	20
		100
		1000
	NW	20
		100
		1000
'C' outfall	Origin	0 (Site 1)
		0 (Site 2)

3.2 Characterising ecological effects on microbial assemblages

3.2.1 Abundance of waterborne microbial assemblages

Flow cytometry was used to assess the abundance of the microbial populations in seawater. Seawater subsamples were preserved with paraformaldehyde added to a final concentration of 1% v/v. Samples were snap frozen in liquid nitrogen, stored at -80 °C and thawed immediately prior to analysis. Cell abundance was quantified using a flow cytometer (CytoFLEX LX, Beckman Coulter) and populations were gated on 2-parameter dot-plots using the CytExpert v2.4 software.

Rainbow fluorescent beads (Cytoflex Daily QC Fluorospheres, BD Sciences) were used to ensure the accuracy of the settings and gating strategy. Eukaryotic phytoplankton were

identified using chlorophyll fluorescence at 488 nm excitation and 690/50 nm bandpass filter, and side scatter signal. The cyanobacterium *Synechococcus* was identified using chlorophyll fluorescence at 488 nm excitation and 690/50 nm bandpass filter plotted against orange fluorescence at 561 nm excitation and 585/42 nm bandpass filter. Heterotrophic bacteria and Virus Like Particles (VLPs) were identified by fluorescently staining nucleic acid with SYBR Green I (BioRad). Samples were incubated in the dark for 10 min with stain before being introduced into the flow cytometer and enumerated using blue light (488 nm) excitation, SYBR 525/40 nm, Violet SSC detection and CytExpert v2.4 software.

3.2.2 Chlorophyll a concentration of microbial primary producers

As soon as possible after seawater collection, phytoplankton were collected by filtering 1 L seawater under low vacuum through a 25 mm 0.7 µm GF/F Whatman™ filter. Filters were stored in darkness at -80 °C until extraction. Chlorophyll was extracted and analysed following EPA Method 445 (Arar & Collins, 1997); these steps were conducted in darkness to avoid light-induced chlorophyll degradation. Extraction was achieved by immersing filters in 6 mL of cold (4 °C) 90% acetone, and steeping them for 24 h at 4 °C. Samples were centrifuged at 1000 x *g* for 5 minutes to remove glass fibres from the solution, and the chlorophyll a content of the supernatant was quantified with fluorometry using narrow bandpass filters (Trilogy Fluorometer, Turner Designs). Chlorophyll *a* from spinach (Merck) was used as a calibration standard.

3.2.3 Genomic analysis of bacteria

DNA extraction

As soon as possible after seawater collection, 2 L of seawater was filtered through 47 mm 0.22 µm Durapore® PVDF filters (Merck). Filter papers were frozen in liquid nitrogen and stored at -80 °C until extraction, which was conducted using a DNeasy PowerWater Kit (Qiagen). To ensure efficient extraction, samples were incubated at 50 °C for 10 min in the PW1 lysing reagent supplied with the kit. Then, the extraction proceeded as per the manufacturer's instructions. This process yielded high concentrations of extracted DNA (between 33 – 109 ng μL^{-1}) which was determined using the absorbance of samples at 260/280 nm. Extracted DNA was stored at -20 °C until sequencing.

For sediment collected from the WWTP A and WWTP B outfalls, a sterile spatula was used to shave approximately 500 mg from the top layer of the intact, frozen sediment cores. After thawing, DNA was extracted from this sample using a DNeasy PowerSoil Kit (Qiagen) according to the manufacturer's instructions. The concentrations of extracted DNA were calculated by measuring the absorbance of samples at 260/280 nm, and ranged between 0.75 – 200 ng μL^{-1}. The sampling method used to collect sediment from the WWTP C outfall did not preserve the sediment stratification. Therefore, it was not possible to identify which part of the samples contained the topmost sediment layer, and so we did not extract or analyse DNA from these sediments.

DNA Sequencing and Bioinformatic analysis

To characterise the composition and diversity of bacterial communities in sediment and water samples the bacterial 16S gene (V1-V3 variable region) was amplified using the 27F-519R primer (Lane, 1991; Lane et al., 1985) with the following PCR cycling conditions: 95°C for 10 min followed by 35 cycles of: 94°C for 30 s, 55°C for 10 s, 72°C for 45 s, and then

72°C for 10 min (Brown et al., 2018). Amplicon sequencing of amplified DNA was then performed using the Illumina Miseq platform (2x300bp) following the manufacturer's guidelines (Ramaciotti Centre for Genomics, University of New South Wales, Sydney, NSW, Australia).

Raw demultiplexed 16S rRNA data was processed using the Quantitative Insights into Microbial Ecology (QIIME 2 version 2019.1.0) pipeline. Briefly, paired-end sequences were imported, trimmed and denoised using DADA2 version 2020.6.0, which also removes chimeras (Callahan et al., 2016). Sequences were identified at the single nucleotide level (Amplicon Sequence Variants; ASV) and taxonomy was assigned using the classify-sklearn qiime feature classifier against the Silva v138 database (Quast et al., 2012). The 16S rRNA dataset was further cleaned by removing ASVs with less than 40 reads reads (0.001 % of the total reads) and those identified as chloroplasts, mitochondria or as unassigned sequences. Rarefaction plots were used to check sequencing depth, and data were rarefied to 5,200 (Nov 2023) and 21,000 (Jun 2023) sequences per sample.

3.3 Quantification of contaminants

3.3.1 Characterisation of physico-chemical parameters

Physico-chemical conditions of effluent & seawater

For thawed effluent samples, probes were used to measure the conductivity, oxygen saturation and temperature (Multi 3630 multiparameter meter, WTW) and turbidity (NEP 160 meter, Analite). Salinity was measured using a refractometer (H196822, Hanna Instruments). The abiotic conditions at each seawater and sediment sampling site were measured using a multiparameter sonde (EXO3, YSI).

Physico-chemical conditions of sediment

Since the surface area of sediment grains influences the capacity of sediment to adsorb contaminants, we measured the size distribution and specific surface area of collected sediments using laser diffraction. Firstly, freeze-dried sediments were sieved to < 1 mm to remove organisms and coarse organic debris. Particles below this size fraction were retained for analysis.

Sediment was then deflocculated by soaking in dispersant solution (33 g L^{-1} Calgon® and 7 g L^{-1} $NaCO_3$) to create a slurry that could be subsampled with a wide-bore pipette. This has been shown to be the most effective dispersant for sediments (Abdulkarim et al., 2021). Particle size was then measured using a Mastersizer MU2000 (Malvern Instruments) equipped with a wet dispersion unit. Instrument settings were those used by Abdulkarim et al. (2021), outlined in Section 3.3.1. Sample was added to 900 mL of reverse osmosis water until an obscuration of ~15% was achieved. The average of 10 measurement runs were taken per sample.

Mastersizer 2000 software v5.60 was used to calculate the D10, D50 and D90 - the sizes (µm) that encompasses 10%, 50% and 90% of sediment particles, respectively. Specific surface area was also calculated using this software.

Table 4. Malvern Mastersizer 2000 instrument settings used for sediment grain size analysis.

Parameter	Specification
Particle refractive index	1.55
Dispersant refractive index	1.33
Absorption index	0.1
Obscuration	15 %
Measurement duration	10 s
Measurement cycle	5
Stirrer speed	1500 rpm
Ultrasonication	30 s before measurement
Size fraction bins	101 bins (0.01 – 1000 µm)

3.3.2 Nutrient quantification

Frozen effluent was thawed and total carbon, non-purgeable organic carbon (NPOC), and total nitrogen were measured using a Total Carbon Analyser (TOC-$L_{CSH/CPH}$, Shimadzu). One procedural control, consisting of ultrapure reagent water, was analysed every 14 samples to determine the quantity of carbon introduced during sample preparation. Results were presented as parts per million (ppm).

Upon reaching the lab, seawater samples were decanted from the 5 L field storage containers into sterile polypropylene falcon tubes. Samples were stored at -20 °C and thawed immediately prior to nutrient analyses. After thawing, samples were diluted 1:3 with ultrapure reagent water to reduce the salt content prior to injection into the Total Carbon Analyser. Total carbon, non-purgeable organic carbon (NPOC), and total nitrogen were measured as per the effluent samples described above.

For sediments, the organic matter in the < 1 mm fraction was analysed using the loss on ignition method. Samples were combusted in a muffle furnace at 500 °C for 12 hours. Organic matter was determined as the gravimetric weight change of samples before and after combustion, and results were presented as g/g dry sediment weight. The total phosphorus content of effluent, seawater, and freeze-dried sediments (< 1 mm fraction) were measured using ICP-MS (see section 3.3.3 for details).

3.3.3 Metal quantification

Chemicals and standards

All sample preparation for metal quantification used ultrapure H_2O produced by a Sartorius system (0.22 µm filter, 18.2 MΩ cm^{-1}), and ultrapure nitric acid (HNO_3) and hydrochloric acid (HCl; Baseline®, Seastar Chemicals).

Three calibration standard solutions from High-Purity Standards (North Charleston, South Carolina, USA) were used: ICP-MS Multi Element Solution Standards ICP-MS-68A-A and ICP-MS-68A-B, and the mercury standard ICP-MS-KIT-A-Hg. These standards are traceable to the NIST SRM 3100 series, are ISO 9001:2015 certified, and ISO/IEC 17025:2017 and ISO 17034:2016 accredited.

Sample storage preparation

Effluent and seawater sample preparation
Effluent was thawed immediately prior to sample preparation. Upon reaching the lab, seawater samples were decanted from the 5 L field storage containers into polypropylene falcon tubes that had been pre-rinsed with HNO_3 and stored in darkness at 4 °C.

Effluent and seawater samples were centrifuged at 600 x *g* for 10 min to sediment any suspended particulates. We chose centrifugation instead of the more common technique of syringe filtering, which is a major source of metal contamination (Shiller, 2003). After centrifugation, supernatants were transferred to new falcon tubes in a laminar flow cupboard to avoid air-borne contamination. Samples were acidified to a final concentration of 1% v/v HNO_3 and 1% v/v HCl. Seawater samples were diluted 1:10 before introduction to the ICPMS to reduce the matrix effects caused by high salt content.

Sediment sample preparation
The total recoverable metals of freeze-dried sediments were analysed using a modified protocol of US EPA 3051A method. Briefly, 500 mg of sediment was mixed with 9 mL HNO_3 and 3 mL HCl, and digested in a microwave digestor. Using 800 psi and 900 W, the temperature of the samples was ramped to 180 °C over the course of 15 minutes, and held constant for a further 45 minutes. Preliminary tests determined that this protocol was sufficient to digest all particles, with only white particulates impervious to further digestion remaining after the procedure. Extracts were allowed to completely cool before opening sample tubes in order to retrieve volatised mercury. The digestates were centrifuged at 600 x *g* to deposit the undigested particles, and aliquots of the supernatant were diluted with ultrapure reagent H_2O to achieve a final concentration of 1% v/v HNO_3.

Quantification of metals & comparison against DGVs

Metals were quantified using an Agilent 7900 (Agilent Technologies, Tokyo, Japan) ICP-MS coupled with an autosampler (SPS 4, Agilent Technologies). Calibration was conducted using multi-elemental standards (High-Purity Standards, SC, USA). A total of 39 metals were quantified in the samples. Rhodium was used as an internal standard to prevent calibration drift, and a mixture of 1% HNO_3 and 1% HCl was used as a matrix blank. Results were presented as blank-corrected µg/L for effluent and seawater samples, and mg/kg dry weight for sediment samples.

QA/QC

Samples were prepared in batches of 20 samples with procedural blanks (ultrapure H_2O) to monitor contamination. Percentage recovery was assessed using seawater certified reference material (QC3163, Sigma-Aldrich) and marine sediment certified reference material (PACS-3, National Research Council Canada).

3.3.4 Antibiotics quantification

Samples were prepared and concentrated using solid phase extraction (SPE) following the protocol of Gros et al. (2013). Slight modifications were made to the retention times to accommodate a different HPLC column. The antibiotics quantified in this study are listed in Table 5.

Chemicals and standards

All sample preparation for antibiotics used ultrapure H_2O produced by a Sartorius system (0.22 µm filter, 18.2 MΩ cm^{-1}). Sigma-Aldrich (Australia) supplied reagent grade Na_2EDTA, oxalic acid, formic acid, premium HCl (EMSURE™), and hypergrade methanol (LiChrosolv™).

Effluent, seawater, and sediments were analysed for the antibiotics listed in Section 3.3.4. These compounds were selected because they are the most prescribed antibiotics by doctors in the Australian community (Australian Commission on Safety and Quality in Health Care & in Health Care, 2021), and hence are expected to enter WWTPs in higher concentrations than less commonly used antibiotics. Antibiotics standards were of high purity grade (≥ 94.5%; Table 5). Isotopically labelled representatives of each antibiotic class were used as per Gros et al. (2013) to account for analyte loss during sample processing. The isotopic purity of the mass labelled standards was ≥ 99%.

Sample storage and preparation

Effluent samples (700 mL) were thawed at 4 °C immediately prior to sample preparation. Samples were spiked with 1 µg L^{-1} deuterated internal standards to determine analyte loss during processing. Seawater samples were filtered through 0.7 µm GF/F Whatman™ filters to remove suspended particles. The samples were adjusted with HCl to pH 2.0 ± 0.5 to enhance retention on SPE cartridges. Special care was taken to ensure the pH did not drop below 1.95, as this affects the deuterated standards. To prevent antibiotics from chelating to any metals present in solution, 500 mg Na_2EDTA was added to each sample; samples were allowed to equilibrate for one hour before proceeding to solid phase extraction.

For seawater samples, 1 L was decanted from the 5 L field storage containers and immediately filtered through 25 mm 0.7 µm GF/F Whatman™ filters. Filtrates were stored overnight at 4 °C in amber glass bottles that had been washed in detergent and sequentially rinsed in ultrapure water and methanol to remove impurities. Samples were kept in darkness to minimise the deterioration of photosensitive antibiotics. Samples were processed as per the effluent samples, before proceeding with SPE extraction.

Freeze-dried sediments (< 1 mm fraction) were homogenized and three grams was added to a 50 mL falcon tube. Samples were spiked with 200 ng mL^{-1} of internal standards. Next, 12 mg Na_2EDTA was added, followed by 30 mL 0.01 M oxalic acid in methanol and 30 µl 0.1% formic acid. Samples were vortexed for 30 seconds and sonicated at 40 kHz for 30 minutes. Supernatant was obtained by centrifuging samples for 4000 x *g* for 15 minutes. These were evaporated to dryness under a gentle N_2 stream at 25 °C. The samples were reconstituted in 10 mL H_2O and filtered through 0.45 um PVDF syringe filter before proceeding to SPE extraction.

Solid Phase Extraction of antibiotics

Samples were extracted using Oasis® HLB SPE cartridges (60 mg, 3mL). These cartridges have been shown to deliver good retention for several antibiotic families compared to other SPE cartridge types (Gros et al., 2013). Cartridges were conditioned with 5 mL methanol, followed by 5 mL Milli-Q water acidified to pH 2.5 with HCl. Both of these conditioning solutions had a flow rate of 2 mL min^{-1}. Samples were then extracted at a flow rate of 5 mL min^{-1}. Then, SPE cartridges were rinsed with 5 mL ultrapure water (2 mL min^{-1}) and air dried

for 5 min. Analytes were eluted with 6 ml methanol (1 mL min^{-1}) and evaporated to 1 mL under a gentle nitrogen stream at 25 °C. Extracts were transferred to amber LC autovials and stored at 4 °C until analysis.

Quantification of antibiotics

Chromatographic separations were carried out with an Ascentis® Express 5 cm × 2.1 mm, 2 µm C18 UHPLC Column using an Agilent 1290 UHPLC. Gradient elution was performed with the solvent (A) acetonitrile and (B) 0.1% formic acid in water at a flow rate of 0.5 mL/min (initial condition 5% A; 0–3.0 min, 5–70% A; 3.0–3.5 min, 100% A; 3.5-5.0 min, 100% A; 5.0-5.1, return to initial conditions; 5.1–6.0, equilibration of the column). The sample volume injected was 5 µL.

Detection was performed using an Agilent 6490 triple quadrupole mass spectrometer operated in positive ESI mode using multiple reaction monitoring. The MS parameters used were: 200 °C source temperature; 14 L/min drying gas; 20 psi nebuliser flow; 3 kV capillary voltage; and the sheath gas flow of 11 L/min at a temperature of 250 °C. MassHunter QQQ analysis software (version 08.00, Agilent Technologies, USA) was used for quantitation.

The perform QA/QC, samples were extracted in batches with ultrapure H_2O as a method blank for effluent and seawater samples, and reagent-grade sand as a blank for sediment samples. Linear calibration curves were prepared in methanol. Limit of quantification was set as the lowest calibration point multiplied by four and ranged from 0.1 to 0.6 ng L^{-1} depending on the analyte. Limit of detection was set as the instrument detection limit, which varied by compound from 0.01 to 0.1 ng L^{-1}.

Table 5. The antibiotics analysed in this study. Antibiotics are categorised by their chemical family and class, CAS number, and chemical formula. The isotopically labelled internal standard used for the quantification of each antibiotic (as per Gros et al., 2013) is also listed.

Family (class)[a]	Antibiotic	CAS number	Chemical formula	Internal standard
β-lactams (penicillins)	Flucloxacillin sodium	1847-24-1	$C_{19}H_{16}ClFN_3NaO_5S$	Ampicillin-d5
	Penicillin V (Potassium salt)	132-98-9	$C_{16}H_{17}N_2O_5S{\cdot}K$	Ampicillin-d5
β-lactams (cephalosporins)	Cefalexin	15686-71-2	$C_{16}H_{17}N_3O_4S$	Ampicillin-d5
Dihydrofolate reductase inhibitors	Trimethoprim	738-70-5	$C_{14}H_{18}N_4O_3$	Ampicillin-d5
Fluoroquinolones	Enrofloxacin	93106-60-6	$C_{19}H_{22}FN_3O_3$	Ciprofloxacin-d8
	Ciprofloxacin	85721-33-1	$C_{17}H_{18}FN_3O_3$	Ciprofloxacin-d8
	Norfloxacin	70458-96-7	$C_{16}H_{18}FN_3O_3$	Ciprofloxacin-d8
	Ofloxacin	82419-36-1	$C_{18}H_{20}FN_3O_4$	Ciprofloxacin-d8
Macrolides	Clarithromycin	81103-11-9	$C_{38}H_{69}NO_{13}$	Azithromycin-d3
	Erythromycin	114-07-8	$C_{37}H_{67}NO_{13}$	Azithromycin-d3
	Roxithromycin	80214-83-1	$C_{41}H_{76}N_2O_{15}$	Azithromycin-d3
Sulfonamides	Sulfamethoxazole	723-46-6	$C_{10}H_{11}N_3O_3S$	Sulfamethoxazole-d4
Tetracyclines	Tetracycline hydrochloride	64-75-5	$C_{22}H_{24}N_2O_8{\cdot}HCl$	Sulfamethoxazole-d4
	Doxycycline hyclate	24390-14-5	$C_{24}H_{33}ClN_2O_{10}$	Sulfamethoxazole-d4
	Oxytetracycline hydrochloride	2058-46-0	$C_{22}H_{24}N_2O_9{\cdot}HCl$	Sulfamethoxazole-d4

[a] Only the family of β-lactam antibiotics are subdivided into classes.

Table 6.The purity and manufacturer of analytical and internal antibiotics standards used in this study. Purity information was obtained from manufacturers' chemical specification sheets.

Family (class)[a]	Antibiotic	Purity	Manufacturer
β-lactam (penicillins)	Ampicillin-d5	≥95% ampicillin; ≥99% deuterated forms	Cayman Chemical Company
	Flucloxacillin sodium	≥95%	Biosynth
	Penicillin V (Potassium salt)	≥98%	Cayman Chemical Company
β-lactam (cephalosporins)	Cefalexin	≥95%	Cayman Chemical Company
Dihydrofolate reductase inhibitors	Trimethoprim	≥98.5	Biosynth
Fluoroquinolones	Azithromycin-d3	≥98% azithromycin; ≥99% deuterated forms	Cayman Chemical Company
	Ciprofloxacin-d8 hydrochloride	≥95% ciprofloxacin; ≥99% deuterated forms	Cayman Chemical Company
	Ciprofloxacin	≥98%	Sigma-Aldrich
	Enrofloxacin	≥98%	Cayman Chemical Company
	Norfloxacin	≥98%	Cayman Chemical Company
	Ofloxacin	≥95%	Cayman Chemical Company
Macrolides	Clarithromycin	≥98%	Cayman Chemical Company
	Erythromycin	≥98%	Cayman Chemical Company
	Roxithromycin	≥95%	Cayman Chemical Company
Sulfonamides	Sulfamethoxazole	≥98%	Cayman Chemical Company
	Sulfamethoxazole-d4	≥98% sulfamethoxazole; ≥99% deuterated forms	Cayman Chemical Company
Tetracyclines	Tetracycline hydrochloride	≥95%	Sigma-Aldrich
	Doxycycline hyclate	≥95%	Biosynth
	Oxytetracycline hydrochloride	≥94.5%	Sigma-Aldrich

[a] Only the family of β-lactam antibiotics are subdivided into classes.

3.3.5 PFAS quantification

Samples were prepared and concentrated using SPE using the standard protocol of the US EPA Method 1633 (U.S. Environmental Protection Agency, 2023) with slight modifications. The 26 PFASs quantified in this study are listed in Table 7.

Chemicals and standards

LC-MS grade reagents were used to minimise sample contamination. Ultrapure H_2O was produced by a Sartorius system (0.22 µm filter, 18.2 MΩ cm^{-1}), methanol (LiChrosolv™ hypergrade) was purchased from Merck Millipore (Australia), whilst LiChropur™ HPLC-grade ammonium hydroxide (≥ 99.99%), ammonium acetate (≥ 99.99%), formic acid (≥ 98.0%), and acetonitrile (≥99.9%) were purchased from Sigma-Aldrich (Australia).

Analytical standards (PFAC30PAR) and isotopically labelled analogues of PFASs (MPFAC-24ES) were purchased from Wellington Laboratories (Ontario, Canada) as solutions of 1000

ng mL^{-1} in methanol. Stock solutions of PFASs were prepared in methanol and stored in darkness at 4 °C.

Sample preparation

Contamination is a common issue that arises during the analysis of PFASs as they are used as polymerisation aids in the manufacture of fluoropolymers for common laboratory equipment. For this study, PFAS-free polypropylene containers, tubing and vials were used for all reagents, standards and samples.

Effluent, seawater samples and seawater field blanks (1 L) were stored in polypropylene bottles in darkness until extraction. Immediately prior to SPE extraction, 5 ng of mass-labelled PFASs were added to each sample.

PFASs in sediments were extracted in polypropylene 50 mL falcon tubes that had been cleaned with methanol. Five grams of freeze-dried sediment (< 1000 µm fraction) was mixed with 10 mL of 0.3% methanolic ammonium hydroxide, and 5 ng of mass-labelled PFASs were added. Samples were vortexed to disperse, then shaken on a mixing table for 30 min. Following centrifugation at 3000 x *g* for 10 minutes, the supernatant transferred to a clean 50 mL falcon tube. Then extraction process was repeated a second time with an additional 10 mL of 0.3% methanolic ammonium hydroxide. The combined supernatants were condensed to 5 mL under a nitrogen stream at 55 °C, and 45 mL of reagent water was added to bring the final methanol concentration to approximately 10%. The extracts then underwent Solid Phase Extraction (SPE).

Solid Phase Extraction of PFAS

SPE was conducted under vacuum. All components of the SPE manifold were washed with methanol prior to use. Oasis® WAX solid phase extraction cartridges (6 mL, 200 mg WAX) were conditioned at a rate of 2 drops/sec, first with 15 mL of 1% methanolic ammonium hydroxide, followed by 5 mL of 0.3 M formic acid. Seawater samples were passed through the cartridge at 10 mL/min and were delivered to the SPE cartridges via methanol-rinsed polypropylene tubing. Sediment extracts were passed through the cartridge at 5 mL/min and were poured directly into the SPE cartridges to avoid introducing contamination through the use of pipettes. Sample containers were rinsed twice with 5 mL of reagent water, and these were sequentially passed through the SPE cartridges at 5 mL/min to act as a wash. The cartridges were dried with air under a vacuum for 15 sec. Sample containers were rinsed a final time using 5 mL of 1.0% methanolic ammonium hydroxide, and this was used to elute the samples from the SPE cartridges at 5 mL/min. Extracts were stored in certified PFC-free polypropylene HPLC vials with certified PFC-free polypropylene caps with silicone septa (Agilent).

Quantification of PFAS

PFASs were separated with a Phenomonex Luna Omega 2.1 × 50 mm, 1.6 µm C18 column using a Shimadzu Nexera MP UHPLC (Rydalmere, Australia). For each analyte, a mass-labelled compound from a similar class and/or close elution time was used. Sample injection volume was 5 µL. An ACQUITY® PFC isolator column (Waters; Rydalmere, Australia) was installed between the solvent mixer and autosampler to mitigate PFAS contamination from the fluoropolymer HPLC solvent lines (Lockwood et al., 2019). Gradient elution with the solvents acetonitrile (A) and 2 mM ammonium acetate in 95:5 water/acetonitrile (B) at 0.4

mL/min was performed, and the first 1.5 min was diverted to waste (0-0.2 min 98% B, 0.2-4 min 70% B, 4-7 min 45% B, 7-9 min 25% B, 9-10 min 5% B, 10-10.4 min 98% B, 10.4-12 min 98% B).

Detection was performed using a Shimadzu LCMS-8060 triple quadrupole mass spectrometer operated in negative ESI mode using multiple reaction monitoring. The MS parameters used were: 140 C source temperature; 500 C desolvation temperature; 0.70 kV capillary voltage; 70 L/h cone gas and 800 L/h desolvation gas. LabSolution analysis software (version 5.86, Shimadzu, Japan) was used for quantitation.

QA/QC

Effluent and seawater samples were extracted in batches containing the respective field blank, two method blanks (ultrapure H_2O), and a laboratory control sample. Laboratory control samples consisted of ultrapure H_2O spiked with a native PFAS mixture containing all measured compounds at a mass of 2 ng. Sediment samples were also extracted in batches, but no field blanks were possible; reagent-grade sand spiked with native PFAS mixture acted as a laboratory control sample.

Linear calibration curves with $r^2 > 0.99$ were prepared using the PFAS standard solution in methanol. Sulfonates were quantified as the acid form, and analytes that were present in the calibration standard as both branched and linear forms are presented as a total concentration for that analyte.

Table 7. Names, abbreviations, and CAS registry numbers for target PFASs analysed in this study. α denotes short chain PFCAs (≤ 7 carbons) or short chain PFSAs (≤ 5 carbons), β denotes long-chain PFCAs (≥ 8 carbons) or long chain PFSAs (≥ 6 carbons). Groupings and chain lengths are those used by US EPA (2021).

Group	Subgroup	Analyte	Abbreviation	CAS registry number
Perfluoroalkyl acids	Perfluoroalkyl carboxylic acids (PFCAs)	Perfluoroheptanoic acid[α]	PFHpA	375-85-9
		Perfluorooctanoic acid[β]	PFOA	335-67-1
		Perfluorononanoic acid[β]	PFNA	375-95-1
		Perfluorodecanoic acid[β]	PFDA	335-76-2
		Perfluoroundecanoic acid[β]	PFUnA	2058-94-8
		Perfluorododecanoic acid[β]	PFDoA	307-55-1
		Perfluorotridecanoic acid[β]	PFTrDA	72629-94-8
		Perfluorotetradecanoic acid[β]	PFTeDA	376-06-7
	Perfluoroalkane sulfonic acids (PFSAs)	Perfluorobutane sulfonic acid[α]	L-PFBS	29420-49-3
		Perfluoropentane sulfonic acid[α]	L-PFPeS	630402-22-1
		Perfluorohexane sulfonic acid[β] (linear and branched isomers)	PFHxS	3871-99-6
		Perfluoroheptane sulfonic acid[β]	L-PFHpS	21934-50-9
		Perfluorooctane sulfonic acid[β]	PFOS	1763-23-1
		Perfluorononane sulfonic acid[β]	L-PFNS	98789-57-2
		Perfluorodecane sulfonic acid[β]	L-PFDS	2806-15-7
Perfluoroalkane sulfonamido substances	N-Alkyl perfluoroalkane Sulfonamide acetic acids (N-Alkyl FASAAs)	N-methyl perfluorooctane sulfonamide acetic acid (linear and branched isomers)	NMeFOSAA	2355-31-9
		N-ethyl perfluorooctane sulfonamido acetic acid (linear and branched isomers)	NEtFOSAA	2991-50-6
Perfluoroalkane sulfonamides (FASAs)	Not applicable	Perfluorobutane sulfonamide	FBSA	30334-69-1
		Perfluorohexane sulfonamide	FHxSA	41997-13-1

Group	Subgroup	Analyte	Abbreviation	CAS registry number
Fluorotelomer-based substances	Fluorotelomer sulfonic acids (FTSAs)	4:2 fluorotelomer sulfonic acid	4:2FTS	757124-72-4
		6:2 fluorotelomer sulfonic acid	6:2FTS	27619-97-2
		8:2 fluorotelomer sulfonic acid	8:2FTS	39108-34-4
Per- and polyfluoroalkyl ether acids (PFEAs)	Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	Sodium dodecafluoro-3H-4, 8-dioxanonanoate	NaDONA	2250081-67-3
		Hexafluoropropylene oxide dimer acid	HFPO-DA	13252-13-6
	Per- and polyfluoroalkyl ether sulfonic acids (PFESAs)	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid	9Cl-PF3ONS	73606-19-6
		11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	83329-89-9

3.3.6 Microplastics quantification

Chemicals and standards

All sample preparation for microplastic quantification used ultrapure water produced by a MilliQ system (0.22 µm filter, 18.1 MΩ cm−1), and P.A. reagents, including Dichloromethane (CH_2Cl_2), Ferrous Sulfate (aka. iron (II) sulfate heptahydrate) ($FeSO_4$), Hydrogen peroxide (H_2O_2), Hydrochloric acid (HCl), Methanol (CH_3OH), and Zinc chloride ($ZnCL_2$). All chemicals were filtered through 25 µm Hollander weave mesh filters before use.

Sample preparation, microplastic quantification and validation

Microplastic quantification in water and sediment, follow Williams et al., (2021), Ogunola et al 2023, and general best practices and guidelines in GESAMP (2015). Briefly, water samples were first filtered onto 25 µm stainless steel Hollander weave mesh filters cut to fit a 47 mm vacuum filtration unit. For sediments, a subsample of 2 g was first freeze dried in glass centrifuge tubes, then a digestion step was performed using Fenton's reagent to remove organic matter, and finally a density separation step using a saturated zinc chloride solution to remove inorganic particles. Following this, residual solutions containing microplastics were filtered through 25 µm Hollander weave mesh filters (Sefar Pty Ltd; Sydney, Australia). All sample preparation took part in a laminar flow cabinet.

All filters were examined under a dissecting stereo-microscope (Leica M80 with integrated IC90E camera, magnification 7.5× to 60×) to identify and quantify microplastics, recording information on shape (fibre, film or fragment) and colour. Microplastics were collected and stored in aluminium foil. Plastic load was calculated as number of microplastics per Litre (microplastics/L) and microplastics per Kg (microplastics/kg). Subsequently, validation of microplastic identification was performed for a random subset of 20% of collected samples, using attenuated total reflectance Fourier transform infrared spectroscopy (µ-FTIR; Bruker Hyperion). For each sample, 64 scans were run with the spectrum range set to 3900-650 cm^{-1}, excluding the 2500 and 1900 cm^{-1} CO_2/water region. Spectral outputs were compared to Bruker ATR Library for Chemicals, Pharma, Polymers and Forensics.

QA/QC

Quality assurance and control procedures were taken to minimise the risk of external contamination during sample collection and preparation. All equipment, materials and glassware were pre-cleaned with ultrapure water and dried in a laminar flow. Field and laboratory procedural blanks and airborne contamination controls were used to monitor for environmental airborne contamination. In the laboratory, operators wore bright pink cotton-polyester lab coats and underclothing only of natural fibres. Any bright pink polyester fibres identified during microplastic analysis were deemed cross-contamination caused by the lab coats; though no microplastics of this description were found.

3.4 Statistical analyses

For statistical analyses, the total concentrations of contaminants were used. For metals, analytes associated with GDVs were summed to generate a metric of total metals. For water samples at the WWTP A outfall, metals with marine DGVs were summed; at the WWTP B outfall, metals associated with either a marine or freshwater DGV were combined, as a more

accurate reflection of the variable salinity expected in the FWC. For sediments, metals associated with sediment DGVs were combined to form a total for analysis. Total concentrations of antibiotics and PFAS were generated by adding the concentration of all detected analytes in each sample. Concentrations below detection limits were treated as zero.

3.4.1 Determining the ecological effects of WWTP coastal outfalls

At the WWTP A outfall, PERMANOVA was used to analyse the data using PRIMER 6 statistical software (Plymouth Marine Laboratory, UK). Transect direction (E, SSE, W, NNW) was treated as a random factor and distance from outfall (0 m, 20 m, 100 m, 1 000 m) as a fixed nested factor. Multivariate datasets were initially explored with pairwise correlations between variables (Draftsman Plot). Where variables were strongly correlated ($r > 0.9$), a single variable was selected as representative for further analyses. This only occurred in the case of salinity and conductivity. Data were normalised using a square root transformation and two principle component ordination analyses (PCA) performed on the resemblance matrix of the chemical and environmental datasets: in the first PCA, only physico-chemical data were used; in the second PCA, only data relating to the contaminants were used. In this way, we were able to compare the effects of physico-chemistry with contaminants.

At WWTP B, the sampling transects were located far from the outfall (see section 2.3.2 for explanation), and so did not facilitate a meaningful analysis. Instead, we conducted a PCA using data from only three sites: the FWC, 1000 m on the NW transect, and 1000 m on the W transect. These three sites represent increasing distances from the outfall in a relatively linear direction.

Data from the WWTP C outfall consisted only of chemical data, because the sampling methodology precluded biological analyses. Therefore, no statistical analyses for ecological effects could be conducted at this outfall.

3.4.2 Quantifying the concentration of contaminants in effluent and coastal environments

Twelve of the metals quantified in this study are associated with DGVs. For these metals, we compared the detected metal concentrations with the seawater or sediment DGVs recommended for slightly to moderately disturbed ecosystems. Metals detected at the FWC at the WWTP B outfall were compared against freshwater metal DGVs.

The concentrations of PFOA and PFOS in effluent and seawater were visually compared against the draft guideline value under consideration by the Commonwealth, and against the thresholds proposed by the Heads of EPAs (see section 0).

3.4.3 Determining accumulation of effluent contaminants in retentive and dispersive receiving environments

The mean concentrations of nutrients, total metals, total antibiotics, and total PFAS in sediments were compared between the WWTP A outfall (0 m), the WWTP B outfall (FWC), and the WWTP C outfall (0 m). This comparison used the average concentration of contaminants at WWTP C Site 1 and Site 2 ($n = 4$ for PFAS, and $n = 10$ for all other analytes). Homogeneity of variance was assessed using Levene's statistic, and significant differences between means were detected using a one-way ANOVA. Post-hoc comparisons were

conducted with Tukey's HSD for data with homogenous variances, and with Games-Howell statistic when data had unequal variances. A Pearson product-moment correlation was used to determine if the concentrations of these contaminants were related to the organic content of the sediment.

4. Results

The full chemistry and environmental datasets are provided in Appendices B – D.

4.1 Contaminant concentrations in effluent and coastal receiving environment

4.1.1 The WWTP A outfall

Physico-chemical parameters

The physico-chemical conditions of the seawater from the WWTP A outfall are presented in Table B1. The salinity at the outfall and at all sampling locations was relatively uniform, ranging between 37.5 – 38.1 PSU. This suggests that the freshwater effluent (2.3 PSU) is quickly dispersed and homogenized in the coastal seawater receiving environment. Oxygen saturation was also consistent across all sampling sites. Seawater acidity at the outfall (pH 7.7) and at 20 m east of the outfall pipe (pH 7.9) were slightly lower than that of the effluent and other sampling sites (pH 8.0 – 8.1). Turbidity decreased along the E, SSE and W transects with distance from the outfall. Whilst the effluent had elevated turbidity compared to these environmental sites, the turbidity at the outfall was most likely attributed to sediment suspension from the force of the effluent discharge.

The sediment at the outfall was predominately composed of fine sand, and particle size tended to increase with distance along all transects (Table B2). The specific surface area of the sediment was strongly negatively correlated with both D10 ($r = -0.769$, $n = 36$, $p < 0.01$) and moderately negatively correlated with D50 ($r = -0.456$, $n = 36$, $p < 0.01$), which are the sizes below which 10 % and 50 % of sediments fall below. This result indicates that samples with smaller particles have an increased capacity to absorb contaminants.

Nutrients

The concentration of total nitrogen and total phosphorus in the effluent (Table B3) were aligned with the ranges reported on the NOD (Table 2). Compared to seawater concentrations at the outfall (0 m), the effluent contained approximately 25 times more total phosphorus, and 40 times more nitrogen. Total organic carbon was approximately seven times higher in the effluent compared to seawater at the outfall, but total carbon was higher in the environment (Table).

In seawater, the highest concentrations of nutrients were found at the outfall; this location also showed the highest variability in nutrient concentration. The concentration and variability in nitrogen and phosphorus seawater concentrations decreased along all transects, with clear distance patterns observed for both nutrients along the NNW transect (Figure B1). This was potentially caused by the prevailing current at the time of sampling. The concentrations of total carbon and total organic carbon were uniform across all seawater sampling sites (Figure B1). In sediments, the organic content declined with distance from

the outfall but showed no clear patterns of distribution (Figure B2). Phosphorous content also did not show any clear patterns, although concentrations spiked at 100 m from the outfall along the east and NNW transects (Figure B2).

Metals

The concentrations of total recoverable metals are presented in Table B4 for effluent and seawater, and in Table B5 for sediments. Concentrations are plotted with their respective DGVs in Figure B3 and Figure B4.

Metals in effluent

WWTP A effluent was enriched with a variety of metals (Table B4). Of the metals associated with marine DGVs, chromium, copper, manganese, and nickel were present in higher concentrations in the effluent compared to the environmental sample taken at the outfall (0 m). Notably, copper in the effluent prior to discharge (23.36 ± 3.53 µg/L) far exceeded the marine DGV of 1.3 µg/L, and this was reflected in seawater concentrations at the outfall.

Metals in seawater

In the seawater, copper concentrations exceeded the marine DGV in some replicates sampled at 0 m and at 20 m along the eastern transect (Figure B3). Total metal concentrations did not show a clear pattern of attenuation with distance from the outfall.

Several replicates along all transects contained more zinc than that recommended by the marine DGV (Figure B3). The total chromium concentrations detected at 20 m along the SSE transect indicates that further investigation is warranted to determine speciation and enable comparison against the Cr (VI) DGV (Figure B3). The seawater concentration of total mercury was high at the outfall (Figure B3). Total mercury was also detected in seawater at 20 m along the eastern transect, and at 20 m and 100 m along the NNW transect.

The seawater concentration of some metals declined with distance from the outfall, however the high variability in the data obscured any clear patterns of attenuation. The concentration of total metals – generated by combining the concentrations of all metals associated with marine DGVs – also showed no clear pattern of attenuation (Figure B3).

The toxicant DGV for inorganic mercury in water is 0.1 µg/L, providing 99% protection for slightly to moderately disturbed marine systems. This indicates that the mercury concentration in seawater exceeded the DGV on several occasions, particularly at 0 and 20 meters from the outfall. Assuming methylmercury concentrations are approximately 1% of inorganic mercury levels, as indicated by Australian and international research, the corresponding DGV for methylmercury can be estimated at 0.001 µg/L in water. Using this assumption, the estimated methylmercury concentrations in water at WWTP A range from 0.00026 to 0.0044 µg/L. In several instances, these estimated methylmercury concentrations in water exceed the adjusted DGVs for methylmercury. This suggests potential environmental concerns in these areas. However, these are inferred values, and direct measurement of methylmercury is necessary for a more accurate assessment of environmental risks.

Metals in sediments

In sediments, metals were present in concentrations an order of magnitude (ppm) higher compared to seawater (ppb). A Pearson product-moment correlation was run to determine the relationship between organic content and the concentration of total metals, which was

generated by combining the concentrations of all metals associated with DGVs. The relationship between organic content and the concentration of total metals associated with sediment DGVs was a moderate, positive correlation, which was statistically significant ($r = 0.448$, $n = 36$, $p < 0.01$). The concentration of total metals tended to decline with distance from the outfall, although peaks in some replicates were observed at 100 m E and 100 m NNW (Figure B4); these samples also showed peaks in total phosphorus concentration (Figure B2).

The concentration of copper and total mercury in the sediments were highest at the outfall, and decreased with distance along the transects (Figure B4). The concentrations of other metals associated with DGVs, and the total concentration of these metals did not show clear patterns of attenuation (Figure B4; Table B5). No metals exceeded their respective sediment DGVs at any location (Figure B4). Notably, total mercury, which was detected in seawater at the outfall, was also present in sediment at the outfall (Figure B4).

Mercury was detected in sediment at concentrations ranging from 0.079 to 0.992 mg/kg, exceeding the DGV for 99% protection (0.15 mg/kg) on several occasions at 0 meters from the outfall. The estimated methylmercury concentrations in sediment, based on the 1% assumption, range from 0.00079 to 0.00992 mg/kg. The toxicant DGV for inorganic mercury in sediment is 0.0015 mg/kg. The estimated methylmercury levels exceed the adjusted DGVs in several instances. This suggests that methylmercury levels may pose potential risks at this site.

Relationship between metals in seawater and sediments

A Pearson product-moment correlation was used to determine if there was a relationship between the concentration of metals in the seawater and sediments. This test was conducted on the total concentration of metals in associated with marine DGVs in both partitions. There was no significant correlation present ($r = -0.032$, $n = 36$, $p = 0.852$). This result is expected, as metals in sediments accumulate over time, and are unlikely to reflect the seawater concentrations which can be expected to fluctuate with effluent input and dilution with currents.

Antibiotics

Four antibiotics were detected in the WWTP A effluent: trimethoprim and sulfamethoxazole, which are regularly prescribed together, as well as clarithromycin and roxithromycin from the macrolide family (Table B6). The total concentration of antibiotics in the effluent was 0.950 ± 0.096 µg/L.

No antibiotics were detected in the seawater around the outlet (0 m) at 20 m, 100 m or 1000 m distant from the outfall.

Antibiotics were detected in the sediments. The antibiotics present in the sediment were different to those detected in the WWTP A effluent: sediment contained, trimethoprim, and the three fluoroquinolone antibiotics enrofloxacin, ofloxacin and norfloxacin (Table B7). Although highly variable between replicates, the total concentration of antibiotics increased with distance from the outfall (Figure B5). The highest concentrations were observed at 20 m NNW of the transect, followed by 100 m along the three transects. This pattern was unrelated to the organic content of the sediment ($r = 0.117$, $n = 36$, $p = 0.497$) or particle size as measured by D10 ($r = -0.137$, $n = 36$, $p = 0.426$) or D50 ($r = -0.161$, $n = 36$, $p = 0.349$).

At the outfall (0 m), only trimethoprim was detected, with an average concentration of 0.017 ± 0.004 ng/g dry weight. This antibiotic appears to travel long distances, as it was also detected at 1000 m distant from the outfall along the SSE, W and NNW transects. Notably, trimethoprim was present at 20 m along the eastern transect, indicating that effluent contaminants travel towards the shore. Norfloxacin was present along all transects, including at 1000 m from the outfall in the SSE direction. Enrofloxacin and ofloxacin were present at 1000 m from the outfall in variable concentrations.

PFAS

PFAS were quantified in the effluent from the WWTP A, and in the seawater at 0 m and 1000 m west of the outfall. Samples were collected at 20 m and 100 m but were not extracted due to the length of the sample preparation process and project time constraints. The number of PFAS species, and their concentrations, were highest in the effluent, and substantially declined with distance from the outfall (Figure B6, Table B8). Fourteen different PFAS were detected in the effluent, ten different PFAS at 0 m, and three species of PFAS at 1000 m west of the outfall.

All seawater samples at 0 m and 1000 m west of the outfall exceeded the Commonwealth draft PFOS DGV of 0.0091 µg/L (Figure B6). Additionally, some samples at 0 m also exceeded the threshold of 0.13 µg/L proposed by the Heads of EPAs (Figure B6).

PFAS were quantified in the sediment for all locations along the four transects. The total concentration of PFAS was not related to the organic content of the sediment ($r = -0.203$, $n = 36$, $p = 0.235$). Total PFAS concentrations were moderately positively correlated with sediment grain size and had statistically significant relationship with D10 ($r = 0.467$, $n = 36$, $p = 0.004$) and D50 ($r = 0.354$, $n = 36$, $p = 0.034$). Concentrations of PFAS were higher in sediment at the outfall (0 m) and generally declined with distance along the four transects (Figure B6). Samples taken at 1000 m west of the outfall were an exception, with some replicates containing higher concentrations of PFAS than sediment at the outfall. There is no clear explanation for this anomalous result. Whilst it could potentially be the result of contamination during core sampling by the divers, the probability of this is unlikely given the same divers, equipment and protocols were used at each sampling site.

Across all sampling locations, the average total PFAS concentrations detected in sediment ranged between 0.007 – 0.3 ng/g dry weight (Table B8). These concentrations are lower than those reported in sediment around the Westernport WWTP in Victoria, which ranged between 0.78 – 4.8 ng/g (Coggan, 2020). This difference could be due to different absorption capacities of the sediments, or the different characteristics of the effluent being discharged.

Microplastics

The concentrations of microplastics in the WWTP A effluent ranged between 0 and 4 microplastics/L, with an average concentration of 2 microplastics/L (Table). In seawater, the concentration of microplastics ranged from 0 to 5 microplastics/L, with a total average concentration of 1.2 microplastics/L across the entire collection gradient (Table). Concentrations were generally more elevated 20 m from the outfall along the E, W, and NNW transects (Figure B8). This contrasts with the concentrations of microplastics in sediment, which tended to be greater 1000 m from the outfall (Figure B8).

Overall, sediment concentrations ranged from 166.7 to 667.6 microplastics/Kg, with an average of 305.6 microplastics/Kg across the entire collection gradient. All microplastics found in effluent, seawater and sediment were fibres, except for one fragment found at the site nearest the outfall. All tested fibres were plastic, confirming the accuracy of microplastics identification, and included polymers associated with fabrics such as rayon but also others such as polyaniline. Clear fibres dominated in water and sediment (n=21 and 11, respectively), followed by black (n=17 and 8, respectively). There were also five blue fibres in water and three others of assorted colours in the sediment. However, there was no clear trend regarding distance from the outfall.

4.1.2 The WWTP B outfall

As section 2.3 explains, the transect sampling design at WWTP B was modified in the field which meant that water and sediments were collected at different distances from the outfall origin. Given this, some biological and chemical endpoints were measured only in selected samples from this location as it was deemed that the full complement of samples would not enhance the interpretation of the data.

Physico-chemical parameters

The physico-chemical data for seawater samples from the WWTP B outfall are provided in Table C1. The physico-chemical parameters at the freshwater channel (FWC) were distinctly different from the conditions at the other sampling sites. Water collected at the FWC showed slightly lower salinity, and higher pH and temperature compared to sites along the sampling transects. The oxygen saturation at the FWC (211.9 %) was double that of other sites (100.9 – 135.9 %). As expected (see section 2.1), the effluent had high turbidity (26.7 ± 6.1 NTU). Turbidity decreased to 2.6 NTU at the FWC and fell to 0.23 – 1.63 NTU at the seaward transect sites.

The physico-chemical parameters of sediment were analysed for samples taken at the FWC, the transect intersection ('Centre'), and at 1000 m along the transects (Table C2). Sediment at the FWC showed a wide distribution of particle sizes (Figure C1). It was predominantly composed of fine sand and contained equal proportions of coarse sand and silt. Notably, FWC sediment contained double the proportion of silt compared to the other sites, resulting in higher specific surface area of FWC sediment (0.24 ± 0.04 $m^2\ g^{-1}$) compared to that of other sites (0.03 – 0.06 $m^2\ g^{-1}$; Table C2). For all samples, higher specific surface area was strongly linked to smaller particle size as shown by the correlations with D10 ($r = -0.637$, $n = 15$, $p = 0.011$), D50 ($r = -0.670$, $n = 15$, $p < 0.01$) and D90 ($r = -0.613$, $n = 15$, $p = 0.015$).

Nutrients

The concentrations of total nitrogen and total phosphorus in the effluent were within the lower ranges reported on the NOD (Table 2).

In the seawater, the highest concentrations of nutrients were found at the FWC (Figure C2). Generally, nitrogen and phosphorus concentrations showed no pattern with distance along the transects, although there appeared to be a decline in nitrogen along the SE and W transects. The cause of this is unclear given the Centre was not the outfall. Phosphorus content of the sediments was consistent across all the sites tested.

The concentrations of total carbon and total organic carbon in seawater showed no pattern with transect or distance. The organic content of sediments at the FWC was higher than that of other locations (Figure C2).

Metals

The concentrations of total recoverable metals are presented in Table C4 for effluent and seawater, and in Table C5 for selected sediments. Concentrations are plotted with their respective DGVs in Figures 5 and C6.

Metals in effluent

The third WWTP located near WWTP B effluent contained several metals (Table C4). The concentrations of cadmium and nickel in the effluent prior to discharge were slightly higher than the DGVs recommended for environmental protection. Additionally, the effluent concentration of copper was approximately seventeen times the environmental DGV (mean 25.9 ± 12.57 µg/L versus the DGV of 1.4 µg/L), and the concentration of zinc was approximately six times the DGV (50.13 ± 16.14 µg/L versus the DGV 8.0 µg/L).

Metals in seawater

In some replicates, the seawater concentration of zinc at the Centre and nickel at 1000 m along the NW transect exceeded the marine DGVs (Figure C4). The 1000 m NW site also showed high seawater concentrations of total chromium; depending on the species of chromium present, the marine DGVs for chromium (III) and chromium (VI) may have been surpassed (Figure C4); further work to quantify the different species of chromium in the samples is needed to confirm this. Some replicates at the FWC contained selenium at concentrations approaching to the freshwater DGV (Figure C4). The seawater concentrations of metals did not show a clear pattern of attenuation with distance from the FWC (Figure C4) although selenium showed a slight decreasing trend. The concentration of total metals also showed no clear pattern.

Metals in sediments

Metals were quantified in the sediment at the FWC, Centre, and at 1000 m on the SE, W and NW transects. Samples were collected at 20 m, 100 m, and 1000 m along all transects, but they were not analysed due to the length of the sample preparation process and project time constraints.

In sediments, metals were present in concentrations an order of magnitude (ppm) higher compared to seawater (ppb). A measure of total metal concentration was generated by combining the concentrations of all metals associated with freshwater or marine DGVs; total metal concentration was strongly and positively correlated with organic content, and this relationship was statistically significant ($r = 0.786$, $n = 36$, $p < 0.001$).

The concentration of most individual metals, and total metal concentration, were highest at the FWC (Figure C5), and remained constant across the other sites. Mercury concentrations in sediments at the WWTP B outfall ranged from 0.051 to 0.928 mg/kg, exceeding the DGV for 99% protection levels in sediment (0.15 mg/kg) on several occasions. Using the 1% assumption for methylmercury, the estimated concentrations in sediment range from 0.00051 to 0.00928 mg/kg. The DGV for methylmercury in sediment is 0.0015 mg/kg, and the estimated methylmercury concentrations at WWTP B exceed this threshold in some instances. This suggests a potential risk from methylmercury at this location.

Relationship between metals in seawater and sediments

There was no relationship between the concentration of metals in the seawater and sediments. This test was conducted on the total concentration of metals in associated with marine DGVs in both partitions. There was no significant correlation present ($r = -0.032$, $n = 36$, $p = 0.852$). This result is expected, as metals in sediments accumulate over time, and are unlikely to reflect the seawater concentrations which can be expected to fluctuate with effluent input and dilution with currents.

Antibiotics

Similar to WWTP A effluent, the antibiotics roxithromycin, and sulfamethoxazole were detected in the third effluent located near to WWTP B, but trimethoprim and clarithromycin were absent (Table C6). The total concentration of antibiotics in this effluent was 1.313 ± 1.008 µg/L.

No antibiotics were detected in any samples taken at the FWC or in seawater along the transects.

In sediments, samples were analysed at the FWC, the Centre of the transects, and at 1000 m along the SE, W and NW transects. Samples were collected at other distances, but they were not extracted due to the length of the sample preparation process and project time constraints.

Antibiotics were not detected in the FWC sediments, nor at the Centre of the transect or at sites 1000 m along the SE, W and NW transects (Table C7).

PFAS

PFAS were quantified in the effluent from the third WWTP located near WWTP B, and in the seawater at the FWC and at 1000 m on the west transect. In sediment, PFAS were quantified only at the FWC. Seawater and sediment samples were collected at 20 m, 100 m, and 1000 m along all transects, but they were not extracted due to the length of the sample preparation process and project time constraints.

The number of PFAS species, and their concentrations, were highest in the effluent (Table C8). PFAS in seawater at the FWC was less than that of the effluent, and PFAS at 1000 m west declined further (Table C8, Figure C7). Seventeen different PFAS were detected in the effluent, 13 different PFAS at the FWC, and five species of PFAS at 1000 m on the west transect.

All seawater samples at the FWC and 1000 m west of the outfall exceeded both the Commonwealth PFOS draft DGV of 0.0091 µg/L, and the threshold of 0.13 µg/L proposed by the Heads of EPAs (Figure C7). A small amount of PFOA was detected at the FWC; this was well below the threshold guideline proposed by the Heads of EPAs and the concentration had dropped to below detection limits at 1000 m west (Figure C7).

Sediment concentration of PFAS were quantified only at the FWC. Twelve species of PFAS were detected, and the mean total PFAS concentration was 0.34 ng/g (Table C8). At the FWC, the concentrations of total PFAS, PFOA and PFOS were all greater than that found at the WWTP A outfall. The concentrations of PFASs in sediment cannot be compared against guideline values and there are currently none proposed for sediments.

Since PFAS are associated with organic matter, the sediment in the FWC likely acts as a sink – absorbing some of the PFAS discharged with the effluent before it enters the coastal environment at the mouth of the freshwater channel. This would facilitate the significant decline in total PFAS concentrations between the third WWTP effluent located near WWTP B and the seawater at the FWC. Conversely, periods of high rainfall that flush out large volumes of water and sediment out of the FWC may translocate PFAS-containing sediment particles into the coastal system.

Microplastics

The concentrations of microplastics in the WWTP B effluent ranged between 0 and 2 microplastics/L, with an average concentration of 1.3 microplastics/L (Table C10). In seawater, the concentration of microplastics ranged from 0 to 2 microplastics/L, with a total average concentration of 0.6 microplastics/L across the entire collection gradient (Table C10). No clear trend in concentration of microplastics in seawater was found with distance or direction from outfall (Figure C8). This was similar for microplastic concentrations in sediments collected around the WWTP B outfall (Figure C8).

Overall, sediment concentrations ranged from 0 to 212.1 microplastics/Kg across the entire collection gradient. All microplastics found in effluent, seawater and sediment were fibres. All tested fibres were plastic, confirming the accuracy of microplastic identification, and included polymers such as rayon but also others such as polyaniline. There were no clear trends in colour of microplastics with distance or direction from the outfall. Overall, clear fibres dominated in the water (n=15), followed by black (n=10). In the sediment, black fibres were the most abundant (n=14), with low numbers of microplastics of clear, blue or other colours (all n=<2).

4.1.3 The WWTP C outfall

This section presents the quantification of contaminants in sediment sampled at 0 m at the WWTP C outfall (see section 2.3.3).

Physical parameters

The particle size distribution varied slightly between the two collection sites at the WWTP C outfall (Table D1). At both sites, we detected a higher proportion of fines (< 63 µm) than previously reported (Besley & Birch, 2019). This was driven by a high proportion of silt at both sites. The sediment had similar specific surface area (Table D2), suggesting that the sediments at both sites had equal capacity to absorb contaminants.

Nutrients

The concentrations of total phosphorus and organic matter was higher at Site 2 (Table D3 , Figure D2).

Metals

At Site 1 and Site 2, the concentrations of all metals were well below sediment DGVs (Figure D3). Total mercury concentrations detected ranged from 0.097 to 2.346 mg/kg dry weight across the two sites, exceeding the DGV for 99% protection on several occasions at both sites. These concentrations are consistent with those reported by Besley & Birch (2019). The

estimated methylmercury concentrations in sediment, based on the 1% assumption, range from 0.00097 to 0.02346 mg/kg. The inferred DGV for methylmercury in sediment is 0.0015 mg/kg, and the estimated methylmercury concentrations at WWTP C significantly exceed this threshold in multiple instances. The elevated concentrations, particularly in sediment, indicate a potential environmental risk from methylmercury at this site. Direct measurement of methylmercury is essential for a more accurate risk assessment.

Antibiotics

Antibiotics were detected at both sites, but their presence and concentrations were highly variable. At Site 1, trimethoprim and ofloxacin were present. These were also present at Site 2, in addition to clarithromycin and roxithromycin (Figure D4, Table D5). Trimethoprim was the only antibiotic consistently present, and was detected in all five replicates at both sites. The concentration of total antibiotics at the sites ranged between 0.037 – 1.109 ng/g dry weight.

PFAS

Five species of PFAS were detected in sediment at Site 1, and four species were detected at Site 2 (Table D6). The average concentration of total PFAS at Site 2 was approximately double that of Site 1 (Figure D6). This was driven by higher concentrations of long-chain PFDoA, N-Me-FOSAA, and the polyfluoroalkyl ether sulfonic acids 9Cl-PF3ONS and 11Cl-PF3OUdS. The long-chain legacy PFOA was detected only at Site 1, and PFOS was not detected at either site. The concentrations of PFASs cannot be compared against guideline values and there are currently none proposed for sediments.

4.2 Comparing contaminant accumulation in retentive and dispersive environments

The concentration of nutrients, total metals, total antibiotics, and total PFAS in sediments were compared between the WWTP A outfall (at 0 m), the WWTP B outfall (at FWC), and the WWTP C outfall (at 0 m). The methodology of computing contaminant totals and conducting the statistical analyses are described in the *Material and methods* section 3.4.3.

Sediment at the WWTP A outfall contained significantly less organic matter (ANOVA, $p < 0.05$) than sediments at the WWTP B and C outfalls (Figure 1). The total phosphorus content of sediments was also significantly different between the three sites, as was the concentration of total metals.

The organic content of the sediment from all outfalls was strongly positively correlated with total concentrations of phosphorus ($r = 0.821$, $n = 16$, $p < 0.001$) and metals ($r = 0.739$, $n = 16$, $p = 0.001$). A moderate positive correlation existed between organic content and the total concentration of antibiotics ($r = 0.594$, $n = 16$, $p = 0.015$). The relationships between these variables are depicted in Figure 3.

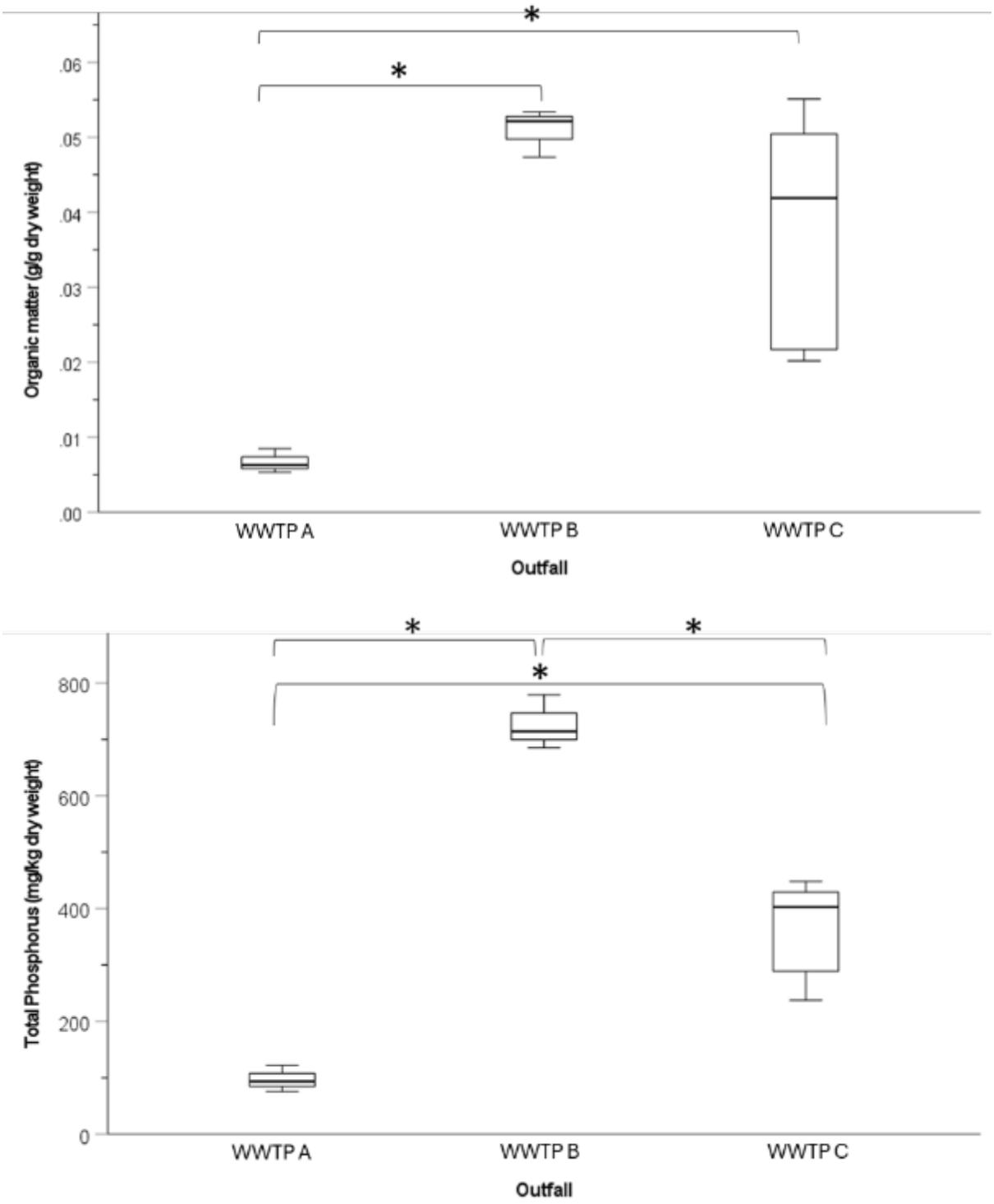

Figure 1. Comparison of (top) organic matter and (bottom) total phosphorus in sediments from 0 m at the WWTP A outfall (n =3), the freshwater channel (FWC) at the WWTP B outfall (n = 3) and the WWTP C outfall (n = 10). * indicates means are significantly different ($p < 0.05$) between sites.

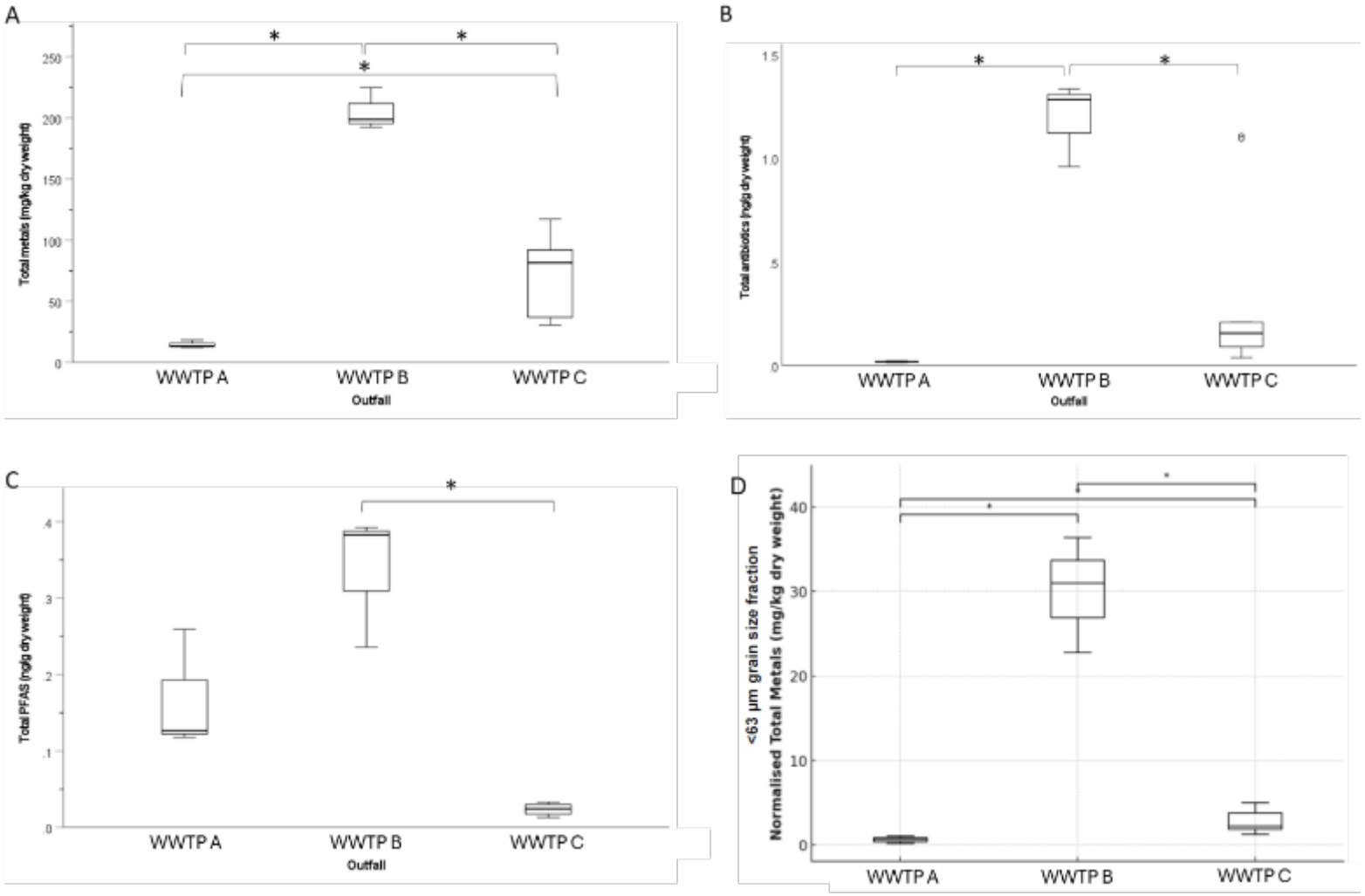

Figure 2. Comparison of total (A) metals (clay and silt), (B) antibiotics, and (C) PFAS in sediments from 0 m at the WWTP A outfall (n =3), the freshwater channel (FWC) at the WWTP B outfall (n = 3) and 0 m at the WWTP C outfall (n = 10). Total metals are the sum of metals associated with sediment (≤2 mm) Default Guideline Values. Total metal concentrations, normalized to the sediment <63 µm grain size fraction, are presented in panel D. The <63 µm sediment particle size fraction (clay and silt) is considered a suitable representation of the sediment materials that are mostly readily resuspended or potentially ingested by organisms. Open circles represent extreme outliers, defined as values that are more than 3.0 times the interquartile range below quartile 1 or above quartile 3. * indicates means are significantly different ($p < 0.05$) between outfalls.

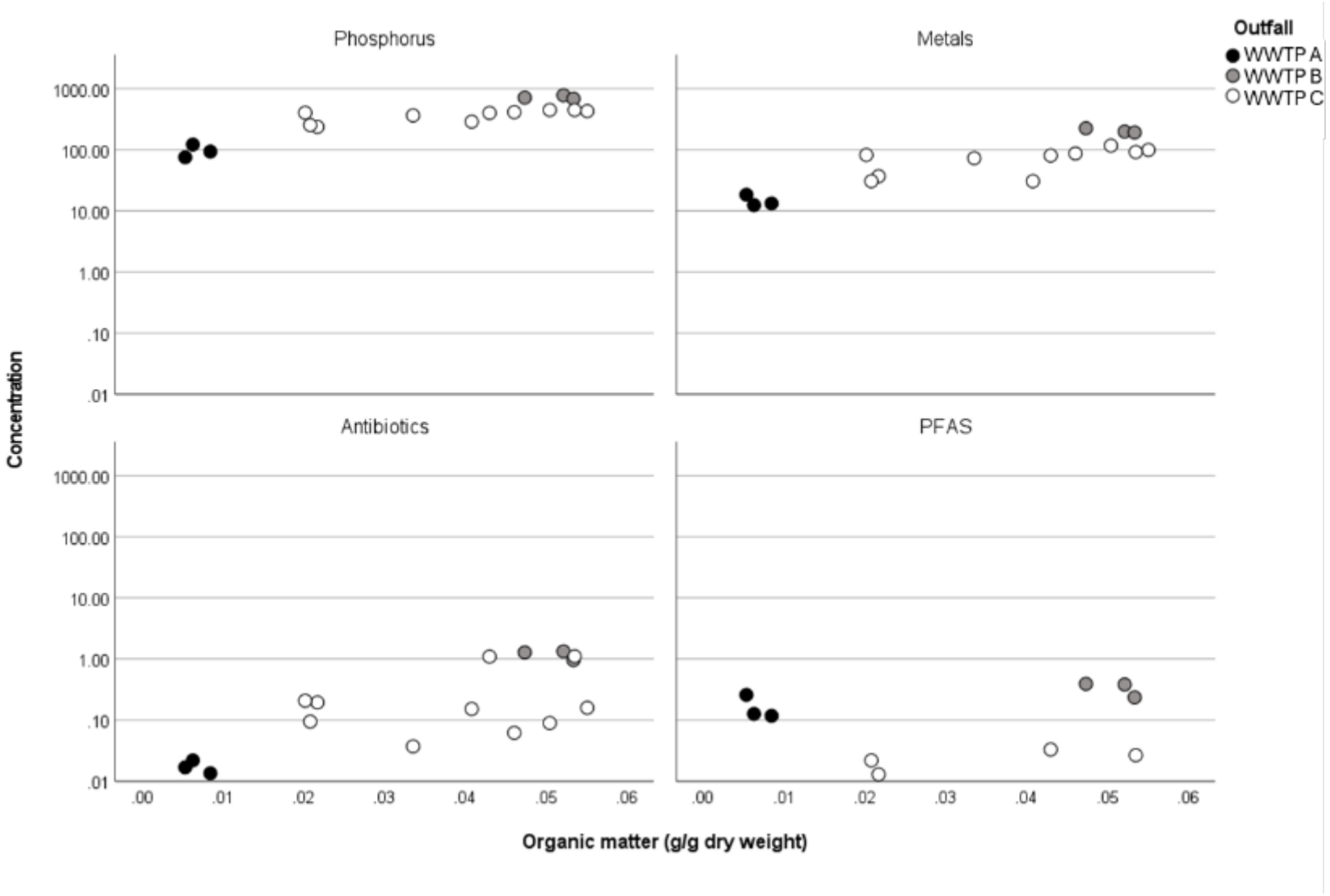

Figure 3. Variability in the concentrations of total phosphorus (mg/kg dry weight; ppm), metals (mg/kg dry weight; ppm), antibiotics (ng/g dry weight; ppb), and PFAS (ng/g dry weight; ppb) with organic content of sediment at the three outfalls.

4.3 The ecological effects of WWTP coastal outfalls

We examined the ecological impacts of contamination on marine microbial assemblages through two lenses: (i) changes in the absolute abundance of different groups of microorganisms in water samples at the WWTP A site, and (ii) shifts in the diversity and composition of microbial communities in seawater and sediment samples as measured using DNA sequencing approaches.

4.3.1 Microbial Abundance

Changes in the biomass of phytoplankton communities were assessed in water samples by quantifying chlorophyll *a* levels. At the WWTP A site, chlorophyll *a* levels remained within the range typical of relatively oligotrophic, coastal temperate environments (2-4 ug/L) and generally did not differ significantly according to proximity to the WWTP outfall point. The one exception was the 1000m W sampling point, where chlorophyll *a* levels were significantly ($p < 0.05$) lower than the origin (outfall discharge pipe). We, however, believe this is likely to simply be an indication of the generally more oligotrophic conditions in offshore waters of the coastal embayment, rather than any impact from the WWTP outfall.

We applied flow cytometry to enumerate the numbers of cells within four broad microbial groups: eukaryotic phytoplankton, *Synechococcus* (a common and abundant cyanobacteria within coastal waters), bacteria and virus-like particles.

The abundance of eukaryotic phytoplankton was relatively homogenous across the sampling area, but was significantly ($p< 0.05$) lower at the origin compared to the 20 m and 100 m samples in the W and WNW transects and in the 1000 m transect in the NNW transect.

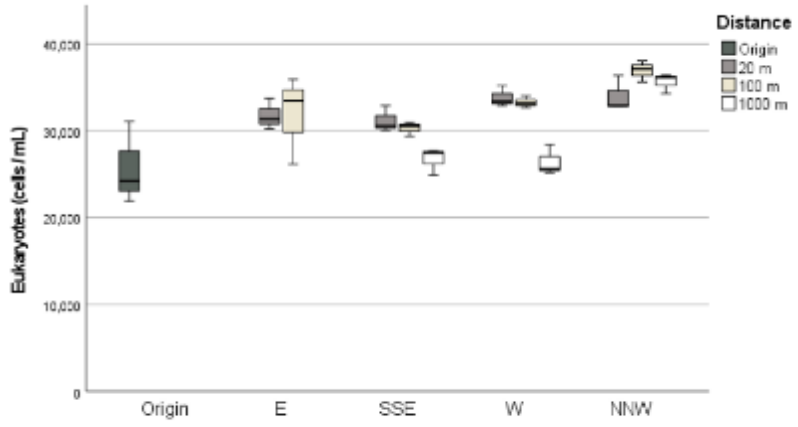

Figure 4. Concentrations of eukaryotic phytoplankton (as determined using flow cytometry) near the WWTP A outfall point.

Across the sampling region, mean abundances of heterotrophic bacteria (9×10^5 ml^{-1}) and the common and ecologically important marine cyanobacterium *Synechococcus* (9×10^3 ml^{-1}) were within the ranges expected for temperate coastal environments in southern Australia. Abundances of both groups were homogenous across the sampling region, with no significant differences ($p > 0.05$) to the origin observed in any samples.

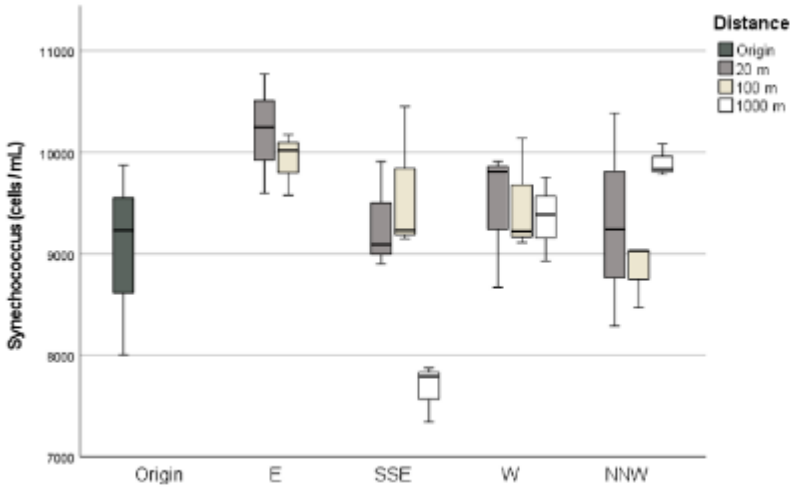

Figure 5. Concentrations of *Synechococcus* (as determined using flow cytometry) near the WWTP A outfall point.

Virus like particles (VLPs) were identified using flow cytometry according to size and DNA content. Abundances of VLPs were significantly ($p < 0.05$) lower at the origin and 20 m samples than in the 100m and 1000m samples in the E, SSE and NNW transects.

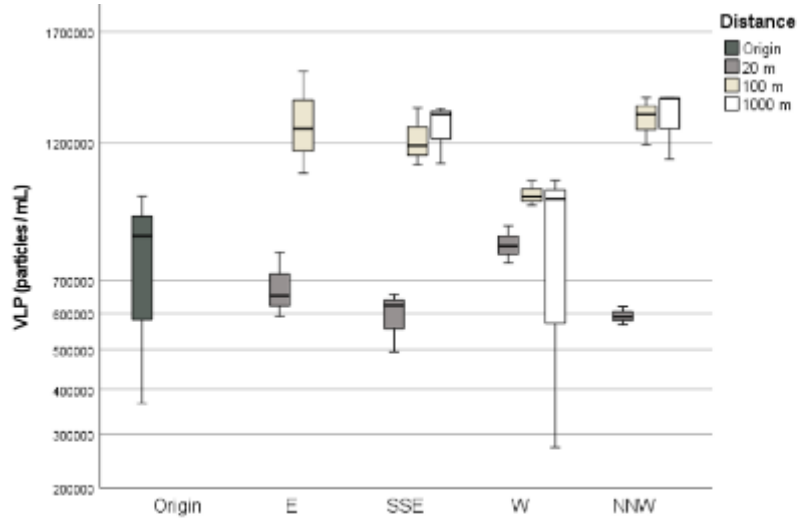

Figure 6. Concentrations of Virus-like Particles (as determined using flow cytometry) near the WWTP A outfall point.

4.3.2 Microbial composition

The seawater and sediment microbial community composition was spatially partitioned according to distance from the WWTP A outfall. The community at the outfall (0 m) was significantly different to the community as close as 20 m away (Figures 7 and 8).

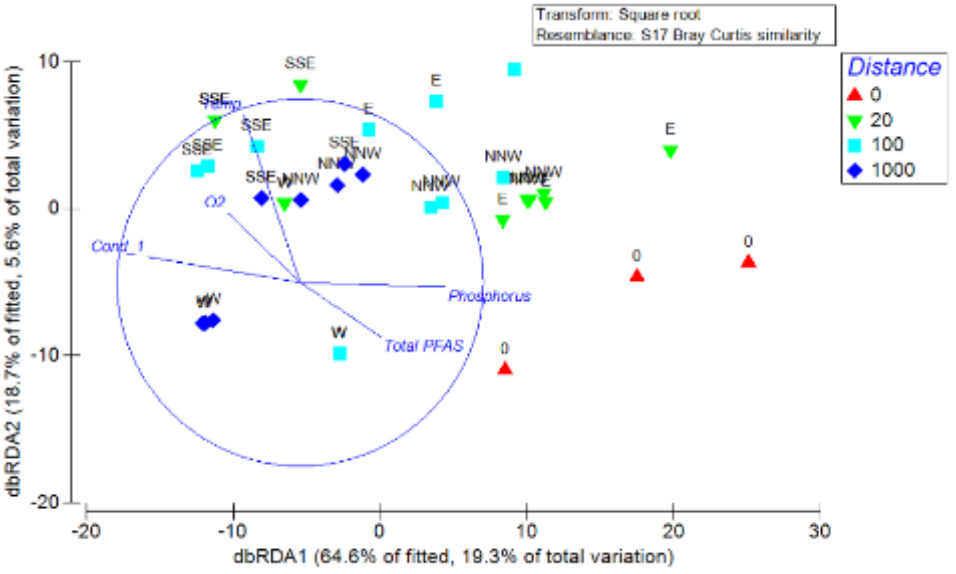

Figure 7. Similarity of seawater bacteria community composition according to distance from the WWTP A outfall overlaid with the distribution of seawater environmental parameters and contaminants.

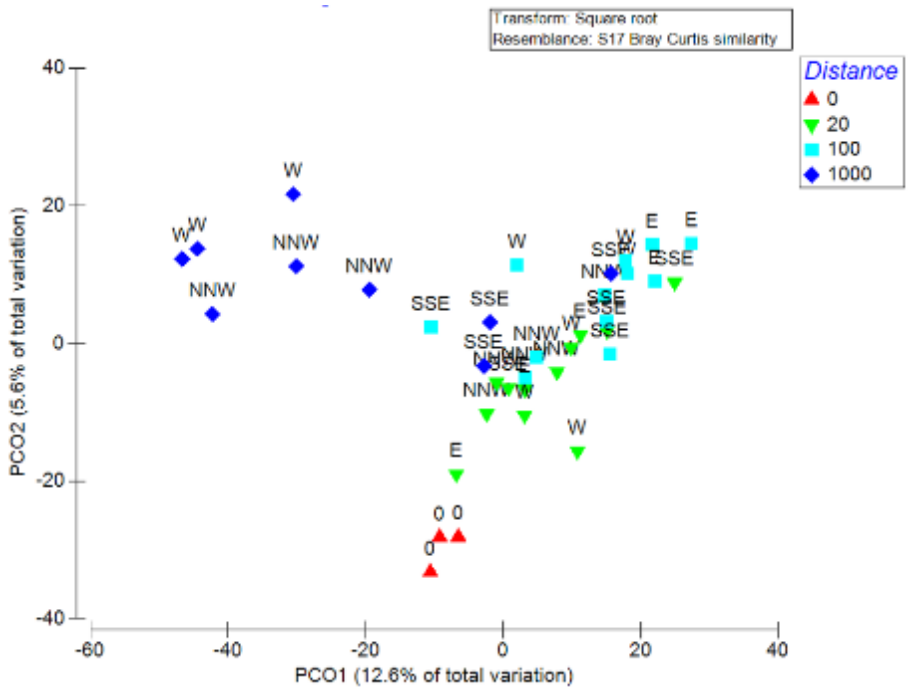

Figure 8. Similarity of sediment bacteria community composition according to distance from the WWTP A outfall.

At the WWTP B outfall there was also strong spatial structuring in the microbial community composition in both water and sediments. The FWC seawater had a distinct community that was most dissimilar to the communities located along the southeasterly transect at 100 and 1000 m, with those along the northwesterly transect at 20 and 100 m being most similar (Figure 9).

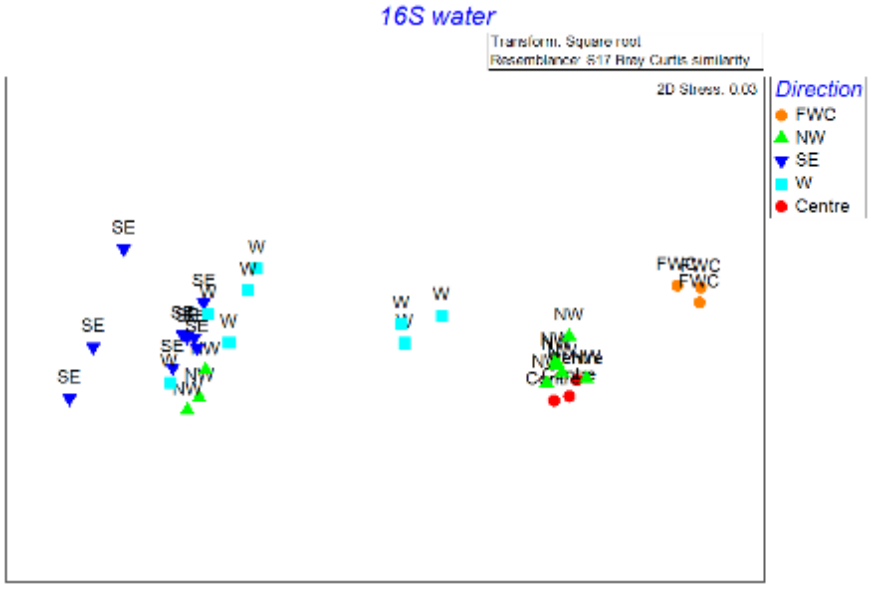

Figure 9. Similarity of seawater bacteria community composition according to direction from the WWTP B outfall (freshwater channel; FWC). Centre is the centre of the transects.

The same pattern was evident in the sediment microbial communities with the FWC showing more similarity with sediments from the northwestern transect compared to the western and southeastern transect (Figure 10).

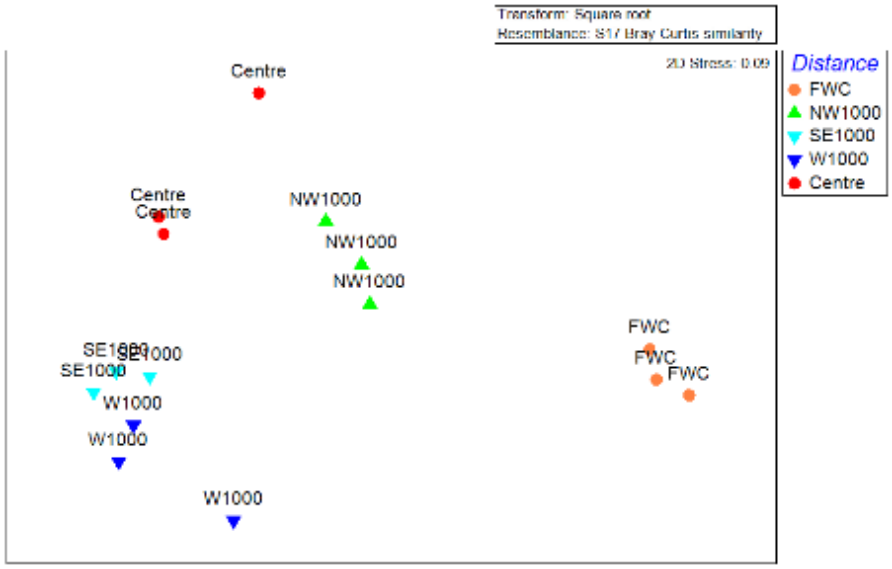

Figure 10. Similarity of sediment bacteria community composition according to direction from the WWTP B outfall (freshwater channel; FWC). Centre is the centre of the transects.

4.3.3 Association of environmental variables with microbial community composition

Water column

There were significant changes in physicochemical properties of seawater at different distances (PERMANOVA p = 0.001) away from the WWTP A outfall, but this varied depending on direction (NNW, SSE, E, W) (evidenced by the significant interaction between transect direction and distance p = 0.001).

Notably, seawater directly at the WWTP A outfall was highly variable in its properties (distance between the replicate samples was relatively large compared to that between samples collected 20 or 1000 m away; Figure 11), suggesting the mixing of discharged water into the receiving waters was not instantaneous. Seawater collected at sites 100 m away from the outfall appeared to be the most heterogeneous compared to samples collected at 20 or 1000 m away from the outfall.

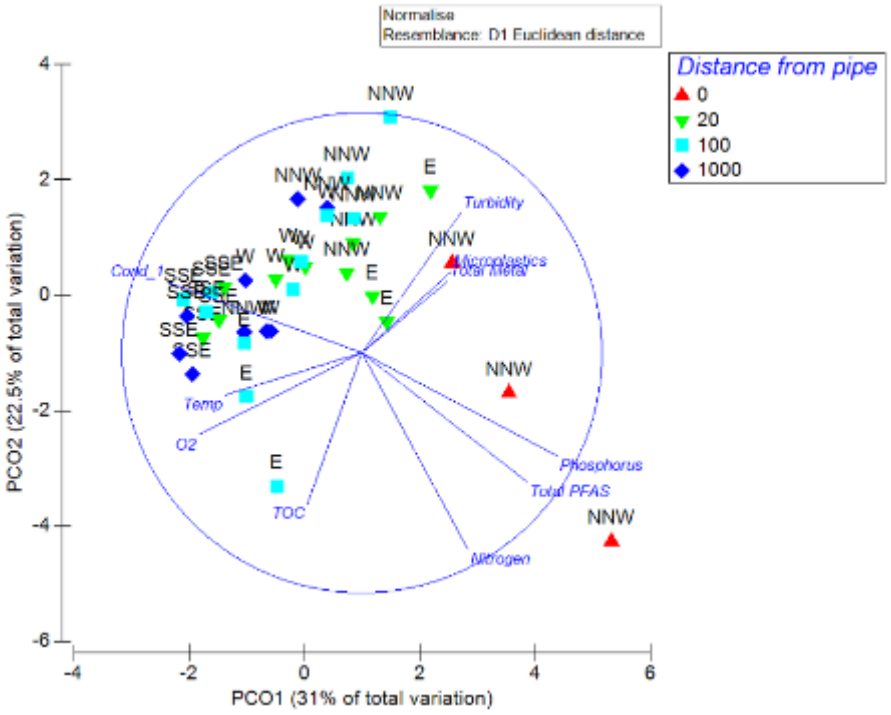

Figure 11. Distribution of environmental parameters as well as contaminants in seawater around the WWTP A outfall, South Australia. Note that antibiotics were not detected in water samples and are therefore not present on the plot.

Distance-based redundancy analysis, a method for analysing and modelling the relationship between a multivariate data cloud and one or more predictor variables, determined that approximately 25% of variation in seawater bacteria 16S community composition at WWTP A was associated with the distribution of conductivity, total phosphorus, total PFAS and temperature (Figure Y). For environmental datasets, this proportion of ecological variance associated with environmental parameters is not unusual, and suggests the contaminants of

phosphorus and PFAS are influencing bacteria community composition in the water column to an equal degree as the physico-chemical parameters of conductivity and temperature (non-contaminants). Thus, there is evidence that contaminants impact the lower foodweb which could have implications for water column productivity, transformations of elements such as mercury, or foodweb interactions.

Sediments

There were also significant changes in physicochemical and contaminant sediment properties with distance (PERMANOVA p = 0.001) from the WWTP A outfall. In contrast to seawater however, sediment properties were consistent across transects (i.e. there was no significant difference between different compass directions; PERMANOVA p = 0.127; Figure 12).

Furthermore, there appeared to be greater homogeneity of sediment properties collected at the outfall and sites 20 and 100 m distant compared to samples collected from the water column where seawater collected at the outfall was distinct from seawater collected only 20 m away.

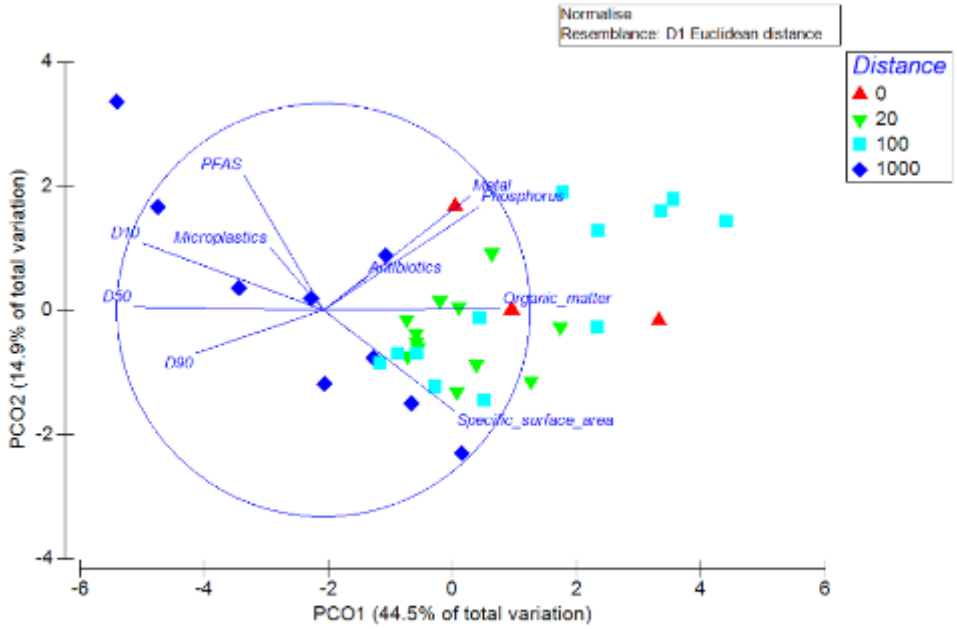

Figure 12. Distribution of sediment environmental parameters as well as contaminants around the WWTP A outfall, South Australia. Note that antibiotics were not detected in water samples and are therefore not present on the plot.

While sediment bacteria community composition was also spatially structured according to distance from the WWTP A outfall (PERMANOVA p = 0.001; Figure 8), only approximately 9% of variation in composition was associated with physicochemical variables, namely the proportion of sediment particles < 10 µm. This suggests that there are additional contaminants or other environmental variables not measured during this study that are linked to changes in bacteria community composition.

At the WWTP B outfall, we were able to compare sediment microbial communities with the physicochemical properties of sediments (including nutrients and metal concentration but none of the CECs). We determined that approximately 25% of the variation in sediment microbial community composition was associated with the distribution of some metals, alongside sediment surface area (Figure 13). With the FWC relatively high metal concentrations (Table C5) we therefore have some evidence that the discharge of effluent at WWTP B is also impacting microbial communities.

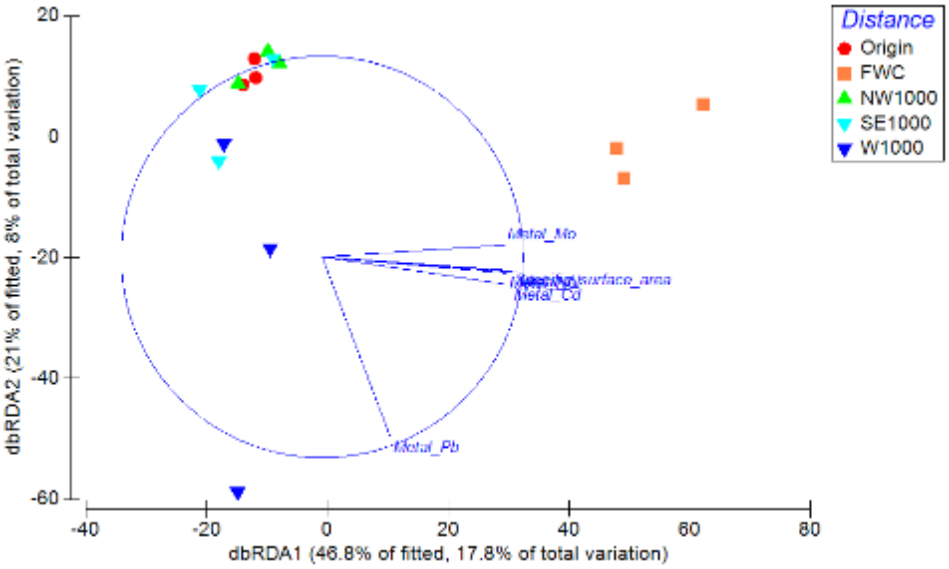

Figure 13. Similarity of sediment bacteria community composition according to distance from the WWTP B outfall overlaid with the distribution of sediment physico-chemical parameters and nutrients and metal contaminants.

5. DISCUSSION

5.1 Contaminants

This study determined the concentrations of 85 contaminants in seawater and sediments adjacent to WWTP outfalls in coastal waters. A total of four nutrients, 39 metals, 15 antibiotics, microplastics (<5 mm), and 26 species of PFAS were analysed. At WWTP A, where we implemented a balanced spatial sampling design, we were able to specifically test the distribution of contaminants in the environment in relation to the origin of discharge.

We determined that there were three spatial patterns of contaminants in coastal waters and sediments. Some contaminants had highest concentrations in the vicinity of the outfall and then attenuated with distance (total nitrogen, phosphorus, and PFAS). Others accumulated close to the outfall (microplastics that accumulated at 20 m), and some had similar concentrations at all sites, with no evident spatial pattern. This indicates that in a retentive receiving environment with weak bottom flows, residual contaminants in WWTP effluent are not evenly dispersed in the environment. Analysis of water and sediment properties (physicochemical and contaminant concentrations) collectively revealed there was clear partitioning of the water and sediment quality in relation to the outfall. This underlines that ecological effects are likely to be linked to these combined properties.

Importantly, all contaminants were detected in sediments but not in seawater, suggesting sediments accumulate historical WWTP discharges and form more of a repository. That total metal concentrations were in the same order of magnitude within sediments at all three locations, spanning WWTP C, an outfall that discharges primary treated sewage at 30,000 ML/day, WWTP B, an outfall that discharges secondary treated sewage from the third WWTP located near WWTP B at 197 ML/day and WWTP A that discharges tertiary treated sewage at 60 ML/day, suggests that metals have a relatively long retention time in receiving environments and that total loads to coastal waters are potentially being managed by adjusting effluent discharge volume with treatment level.

5.2 Ecological impacts determined through microbial analysis

Here, we tested the utility of marine microbial communities as sensitive indicators of impact from chemical contaminants within WWTP effluent. Our rationale for focussing on marine microbes was that these communities are fast growing, diverse and known to be highly sensitive to environmental perturbations, suggesting that they have the potential to function as excellent sentinels of environmental impact.

We used two approaches to characterise marine microbial communities, which we hypothesised would have different levels of utility as environmental indicators. These included (i) enumeration of total abundance of broad taxonomic groups of microorganisms using flow cytometry and chlorophyll analysis and (ii) characterisation of microbial community composition and diversity using DNA sequencing. Due to unforeseen issues with sampling site selection relative to the outfall discharge location at WWTP B in SA, we focused our analysis on the WWTP A located in a temperate coastal embayment, near to the major metropolitan area in southern Australia.

The coarser population-level analysis was used to assess changes in total phytoplankton biomass and the abundance of populations of eukaryotic phytoplankton, *Synechococcus* (a common and abundant cyanobacteria within coastal waters), bacteria and virus-like particles (VLP) in seawater samples at different distances from the WWTP A outfall. This analysis revealed generally low levels of impact on microbial community abundance, when comparing samples from the outfall (origin) to more distant samples, situated 20 m, 100 m and 1,000 m from the origin. The only notable changes included slightly lower abundances of eukaryotic phytoplankton near to the WWTP outfall than more distant samples in some transects and decreased VLP abundances in the origin and 20 m samples than more distant samples.

At first glance, the lower concentrations of eukaryotic phytoplankton near to the WWTP outfall is the antithesis of the hypothesis that elevated nutrient levels in WWTP effluent have the potential to support elevated phytoplankton growth. However, it is likely that dispersal of nutrients from the origin and a temporal lag in phytoplankton growth will mean that “blooms” of phytoplankton stimulated by WWTP nutrient inputs would likely occur spatially removed from the point of nutrient input. Nevertheless, the change in eukaryotic phytoplankton abundance observed here was very small – much less than 2-fold across the entire sampling area – meaning that any impact on phytoplankton growth was minor. In-line with this relative homogeneity in eukaryotic phytoplankton abundance, it does not appear that any chemical contaminants released from the WWTP outfall had a measurable toxic effect on eukaryotic phytoplankton at a broad community level.

The decreased levels of VLPs in the origin and 20 m samples is somewhat surprising given that most planktonic VLPs are expected to be bacteriophage, and we did not see any corresponding pattern in bacterial abundance. However, a potential mechanism for the decreased levels of VLP close to the WWTP outfall is adsorption of VLPs to particulate material emanating from the WWTP outfall plume. Indeed, the lower levels of VLPs in the origin and 20 m samples correspond to higher levels of turbidity within these samples. While further examination of this potential mechanism is required, a shift in the abundance of marine viruses could have significant impacts on the function of the base of the microbial foodweb and marine carbon cycling (Suttle 2007).

While the enumeration of broad microbial populations did not reveal any strong patterns of impact from the WWTP A outfall, DNA sequencing approaches using the bacterial 16S rRNA gene as a taxonomic marker revealed marked changes in the microbiology of the environment surrounding WWTP outfalls. In seawater samples surrounding the WWTP A and B, clear partitioning of the microbial community occurred with distance from the outfall, indicating a significant impact of WWTP effluent on the structure of the base of the marine foodweb.

Distance based redundancy analysis revealed that phosphorus and PFAS, both of which were significantly elevated in the WWTP A effluent and samples close to the outfall, were the major drivers of the significant shifts in bacterial community composition. These patterns are consistent with observations in other regions that phosphorus and PFAS can have significant effects on aquatic microbial assemblage structure, and are indicative of a measurable environmental impact of these contaminants at this location.

Microbial communities within sediments surrounding the WWTP A outfall were also highly spatially structured and indicative of an ecological influence of the input of contaminants from the outfall. However, in contrast to the seawater samples, statistical analyses did not reveal any discrete “explainer variables” for the changes in bacterial community composition, meaning it is not possible to isolate the impact of a single contaminant. The reason for this difference between the seawater and sediment samples is currently unclear, but the lack of identification of variables (i.e. contaminants) responsible for shifts in the sediment microbial community could potentially be explained by (i) the strong impact of a contaminant that was not included within our chemical analyses, or (ii) a highly complex response of the different compartments of the sediment microbial assemblage to the cocktail of contaminants present within WWTP effluent, precluding the identification of a single, or set of, contaminants responsible for impact.

In summary, measurable changes in the marine microbial community could be attributed to contaminant impacts from the WWTP A outfall. While measurement of the abundance of coarse microbial populations revealed only weak, and largely unexplainable effects, DNA sequencing approaches revealed significant spatial changes in the microbial community that, in seawater samples, could be linked to the input of high phosphorus and PFAS concentrations within WWTP effluent. These findings highlight the potential utility of marine microbial communities as sentinels of impact from contaminants present within sewage outfalls.

6. References

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7. Appendix A: Modelling to support sampling site selection

NESP Water Quality Project – oceanographic perspectives on site selection
Version 4.0 – 09 December 2022

This document provides oceanographic context for site selection for outfall sampling based on oceanographic conditions. As there is no preference list, we do not attempt to make recommendations on the priority order of these sites. However, the information presented here should help to inform prioritisation of sites at a later time.

Site overview

Site	General environment	Mixing environment	Tidal regime	Velocity regime	Dispersiveness
Qld 1	Small estuarine creek	Very shallow, surface driven mixing	Strong tidal pumping	Typical estuarine flow varying with upstream inputs	Moderate to high dispersiveness in this esturaine environment with moderate-high tidal influence
Qld 2	Open, very shallow bay	Very shallow, well mixed	Moderate tidal flows	Weak flow	Weaker dispersiveness in this shallow environment
Qld 3	Shallow coastal environment (bay w/ rocky headland)	Shallow, surface driven mixing	Moderate-high tidal flows *Will depend on exact outfall location.	Moderate flow from ocean currents	Moderate-high dispersiveness through tides and ocean influences
Qld 4	Large estuarine creek	Shallow, surface driven mixing	Strong tidal pumping in a region of high tides	Typical estuarine flow varying with upstream inputs	Moderate to high dispersiveness in this estuarine environment combined with tides
NSW 1	Offshore and open to ocean	Periods of weak stratification	Relatively weak	Periods of high open ocean currents	Low-moderate dispersiveness due to deeper location and relatively weaker tides
NSW 2, 3, 4	Shallow coastal environment (bay; beach; and rocky headland)	Shallow, surface driven mixing	Moderate tidal flows	Weak to moderate coastal flow	Low-moderate dispersiveness due to surface mixing and low-moderate tides
SA 1 *Other SA sites are similar	Shallow, open location in large gulf	Very shallow, surface driven mixing	High tides but with periods of quiescence	Weak non-tidal flow	Shallow well-mixed environment with strong tides. *n.b. periods of quiescent tides
	Legend:	**Low**	**Moderate**	**High**	

7.1 A1. Queensland

Site 1:

- Small estuarine creek, 1 km SE of Site 1 township.
- Depth: Uncertain of depth, but probably reasonably shallow (5-10 m).
- Stratification: We have no modelling of creek flow or conditions. We could infer that a reasonably shallow (<10m deep) creek would be well mixed with low stratification. This is because it is probably tidally flushed (downstream proximity to the ocean) and the shallow depth means that surface-driven mixing can easily occur to full depth. Further enquiries could be made with outflow operators if this was deemed necessary
- Tidal regime: The creek is likely subject to tidal flows. Offshore (ie. Outside of the creek) the bay adjacent to Site 1 experiences moderate tidal flows (e.g. 0.5m/s), and these likely inundate the creek semidiurnally (2 highs and 2 lows per day). This would probably lead to regular (6hrly?) flooding and draining of the creek system. Flushing/mean velocities: Site is downstream in a small creek, close to ocean. As a result, it is subject to both ocean influence (tides) and creek flow. It probably flushes at typical estuarine rates dependent on local rainfall.
- A snapshot of 2 m depth currents (31 August 2022, 16:00) from the eReefs 1 km GBR hydrodynamic model indicates notable tidal influence in the region. Strong tidal currents are observed around the coastal point located to the east of Site 1, and the adjacent creek is likely to respond dynamically to these changes in flow. It should be noted that the creek is not resolved or explicitly simulated in this model, despite its relatively high spatial resolution; therefore, tidal currents within the creek cannot be directly assessed. Additional tidal current data from IMOS OceanCurrent for the same date (31 August 2022) indicate current velocities ranging from approximately 0.1 to 0.2 m/s in the broader region at high tide.

Site 2:

- Large bay, 10 km SE of Site 2.
- Depth: Situated in a wide bay, open to offshore influence and along shore currents with depths probably of around 1-2 m or less. Bathymetry charts place this outfall on or very near to mudflats at minimal depth.
- Stratification: If the bay is relatively quiescent, it has the potential to develop more stratification through surface heating and evaporation. However, wind-driven mixing will relatively quickly erode stratification in such shallow water.
- Tidal regime: Site 2 bay seems to experience slightly weaker tides, compared to for example, the Site 1 region. As the site is in a bay, as opposed to a creek, there is probably no strong flooding/draining cycle.
- Flushing/mean velocities: This site is potentially less flushed than the estuarine environments; coastal oceanographic influences will be more present (such as for example, wind-driven coastal currents) but weaker tidal flows are still present.

- A snapshot of 2m depth currents (31 August 22) from the eReefs 1 km GBR hydrodynamic model indicates relatively weak currents flowing through bay at this time, especially compared to the other sites.

Site 3:

- Offshore of headland, 3 km SE of Site 3
- Depth: Site 3 is located offshore of a coastal headland, within a channel connecting a semi-enclosed bay to the open ocean. The site is estimated to be in waters ranging from approximately 1 to 10 m in depth. If positioned within the channel, dredging activities have likely created a deeper passage that connects to deeper offshore waters located approximately 1–2 km to the northeast. If the site is situated to the west of the channel, water depth is likely to be around 2 m.
- Stratification: This location is in relatively shallow water and in a higher flow environment, meaning that stratification is likely not strong at this location.
- Flushing/mean velocities: The location of the outfall site, in the 1-2km wide gap between point and island, means that this location will probably have constant flow passing by it. This is because as the coastal current or tides flow past, they will be forced to accelerate as they pass through this narrower gap into the wider bay beyond. Velocities are probably on the order of 0.1 to 0.5 m/s. Note that the following analysis is based on an outflow site closer to the channel, however if outflow is closer to shore, flow will be slower leading to less flushing.
- Tidal regime: This location is probably subject to a constant but moderate tidal regime. The narrower constriction between point and island would produce faster tidal velocities through this area. While overall tides in this region don’t seem to be as strong as other locations, the outfall site is probably in a higher tidal environment.
- A snapshot of 2 m depth currents (31 August 2022) from the eReefs 1 km GBR hydrodynamic model indicates that flow accelerates through the narrow between the coastal headland and the adjacent island at Site 3, as tidal outflow drains the semi-enclosed bay.

Site 4:

- Large river feeding into bay/harbour, 3 km W of Site 4
- Depth: Site 4 is located near the mouth of a river system, depths are probably 5~10 m. The river discharges into a coastal harbour, where there is dredging for ship access which would probably provide deeper channels (~20m). Bathymetry charts suggest a deep channel of 7 m within the river, with shallower banks of 1 m.
- Stratification: The higher tidal range resulting from the confined harbour, combined with the strong tides in this region, likely results in a strongly estuarine, tidally-influenced environment at the outflow site. Stratification is likely weak, except in deeper, quiescent parts of the river.
- Tidal regime: The coastal harbour associated with Site 4 is subject to a relatively wide tidal range, and it's therefore likely that the adjacent river system is also strongly tidally flushed by flow from the harbour. Furthermore, this section of coastline is known to experience relatively strong tidal conditions, which are expected to influence hydrodynamic processes at Site 4.
- Flushing/mean velocities: Flow in this environment is likely strongly tidally influenced. Example snapshot image: A snapshot of 2 m depth currents (31 August 2022) from the eReefs 1 km GBR hydrodynamic model indicates strong, tidally driven flow (up to ~0.5 m/s) within the coastal harbour near Site 4. The proximity of the site to this outflow suggests that the adjacent river system is also likely to be strongly influenced by tidal processes.

  Flow length-scale:
  We estimate a length scale that represents the average, rectified currents over a 24-hour period as $d = v \times t$. Here d is our flow-length scale, v is a representative velocity, and t is a representative time scale. We choose v as the velocity magnitude, calculated from the u- and v-components, where the magnitude will capture forwards and backwards tidal flow. We average this velocity over a 2-week period to capture a full tidal cycle including spring and neap tides. The time scale (t) is chosen as 24 hours. This should be considered as a proxy for mean flow – but not as the straight-line distance a particle will travel in that time (for which full particle tracking simulations would be required).

Site	Flow length-scale
2	3.7 km
3	4.0 km – 14.2 km

* Note that we do not consider the Site 1 or 4 in this analysis as they are situated within estuarine creeks, for which we do not have velocity data. Data for Site 2 Bay and Site 3 is bottom velocities from eReefs 1.0km model for January 2018.
** The range stated for the Site 3 is based on velocity magnitudes at two locations: shoreward of the headland (where velocities are much weaker) and closer to the headland and Stone Is. (where velocities are very strong).

7.2 A2. New South Wales

Due to the close proximity of many of the identified potential locations in relation to the resolution of the model, we have first performed separate analyses for the whole model domain. We then provide a closer interpretation of a single site (Site 1), which has been previously identified as a priority choice for the sampling location. Analysis of Site 4 is presented, and we group this analysis as being broadly representative of the other central NSW sites (Site 2, and 3) which are in similar coastal environments. We do not present analysis of Site 5, as it is on the edge of our model domain, and hence results may not be as accurate.

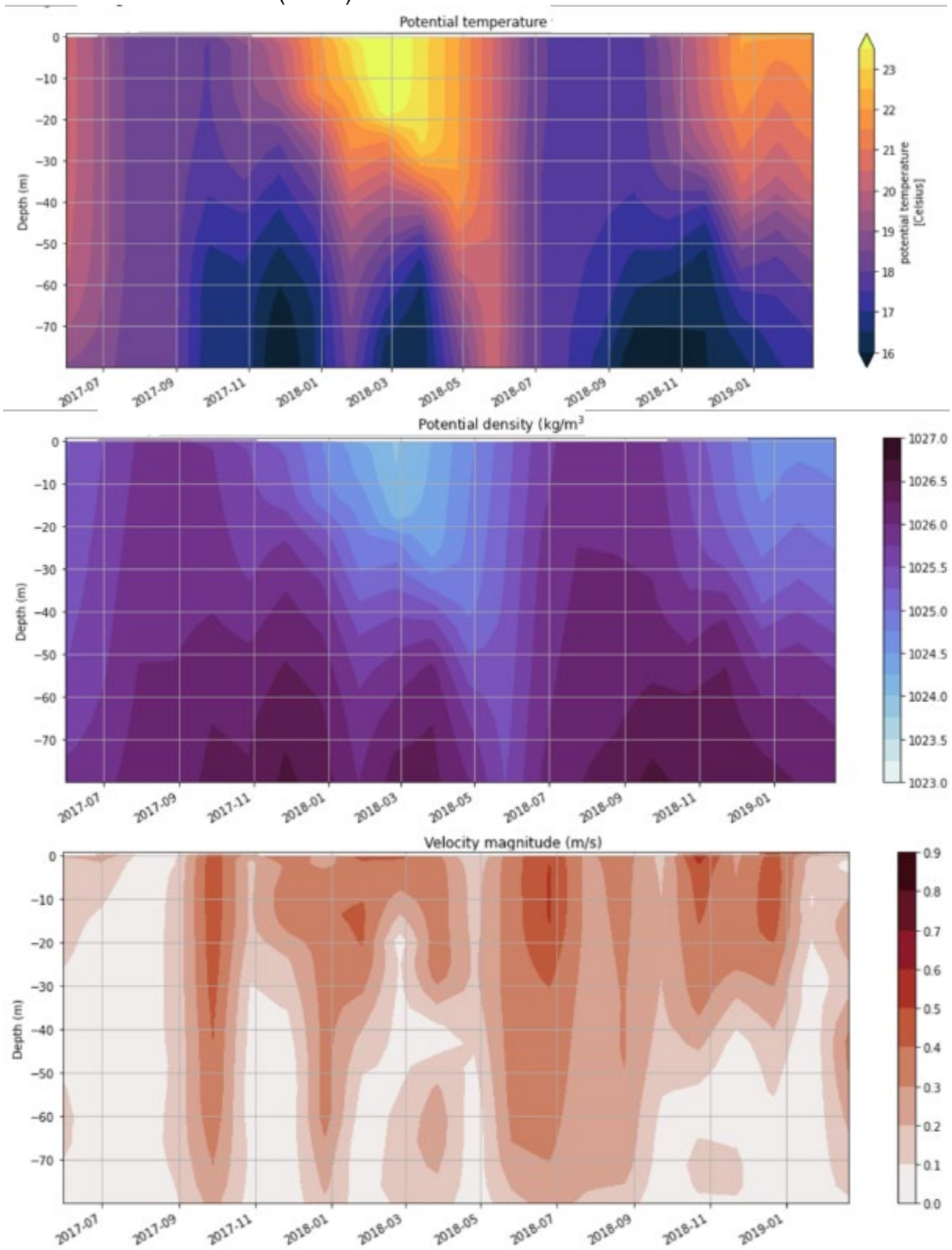
• Map: All sites are located close to the shoreline and in less than 100m of water.

• Location and general environment:
Site 1 outflow is the deepest outfall site. It is coincident with the Ocean Reference Station, which has provided near-continuous measurements since the 1940s; consequently, the oceanographic setting of this location is better measured (and understood) than the other sites. Its outfall site, being both deep and approximately 4 km offshore, means that it is exists in a more open ocean-influenced environment.

Site 2, 3, and 4 are located in shallow coastal environments, namely a bay, beach, and rocky headland, respectively. The shallow depths at these locations will limit oceanographic influences and tidal flows, but will open the potential for more surface-driven mixing. Site 4 is off a submarine rock shelf, and hence slightly deeper (15-20 m) than the other sites. Neverthless, the proximity to the shore will limit open ocean influences. Note that these three sites, being coastal locations, will be responding to fine-scale coastal processes, which our model will not resolve.

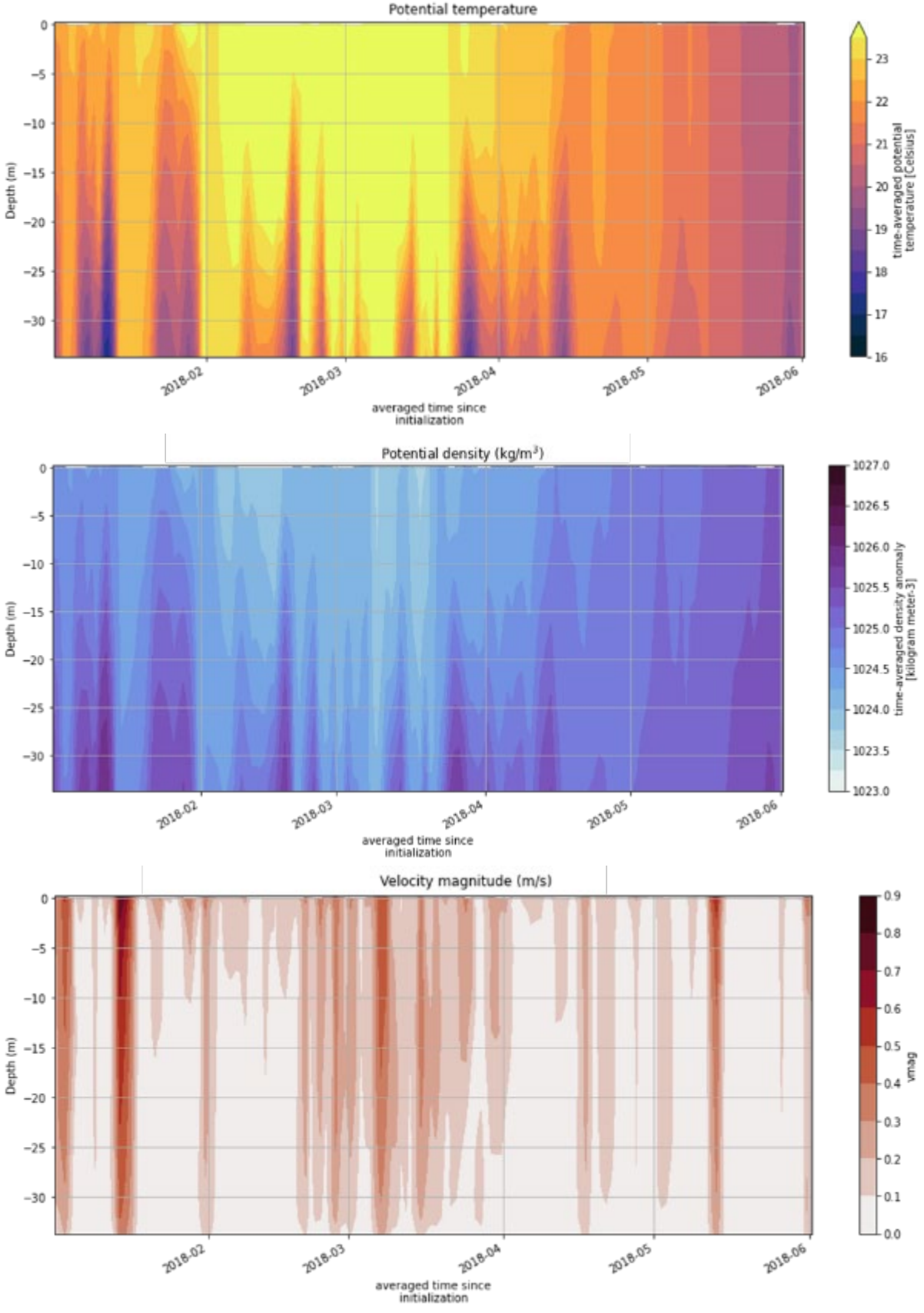
• Mean bottom velocity: The time-mean velocity magnitude at the ocean floor reflects the combined influence of tidal motion and broader circulation patterns. Velocities through most of the sites are difficult to assess given their locations at the coastline, but velocities are likely relatively weak (<5cm/s). Site 1 is further offshore, where mean velocities are 5-10 cm/s.

• Profiles at select location (Site 1):



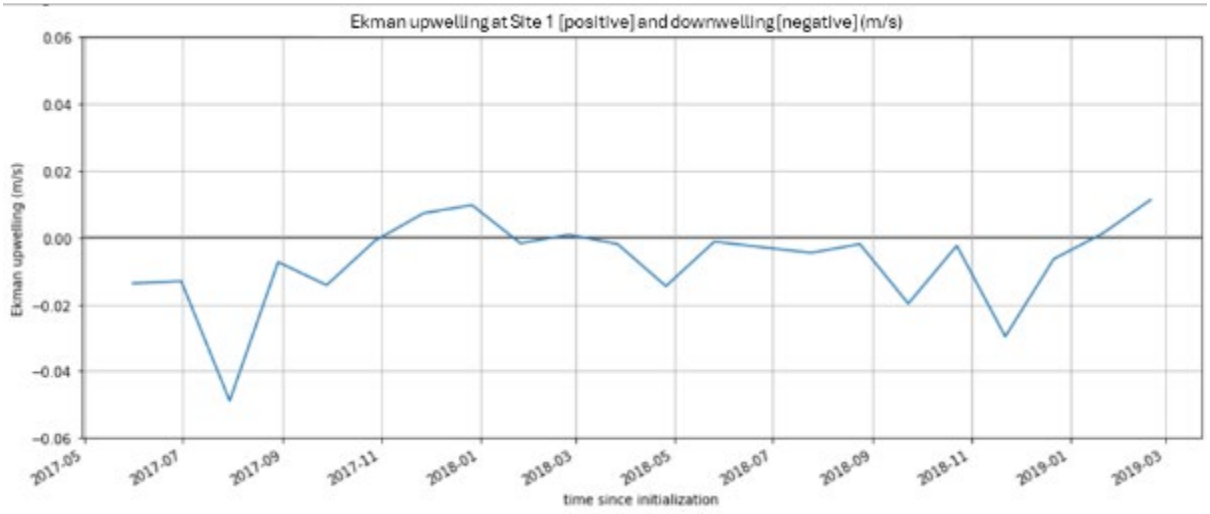
The time-depth profiles of key variables temperature, potential density and velocity magnitude are shown for the Site 1. This site exhibits periods of high stratification (e.g. 2018-03) and low stratification (2018-09), and likewise for velocities at the sea floor.

Profiles at select location (Site 4):



The time-depth profile of conditions at Site 4 is similar in some ways to Site 1 – it experiences periods of low and high stratification, though this site responds more strongly to surface mixing, as it is more shallow. It also has weaker velocity magnitude at the seafloor. Note that as the actual outfall location is clipped from the model domain, an adjacent point within the model domain is chosen. Consequently, the model site is deeper than the actual outfall site – and should be considered as the upper-end of estimated conditions at this location.

• Ekman upwelling:



As the Site 1 is potentially more influenced by coastal and ocean processes, we also consider the impact of Ekman upwelling/downwelling. Ekman upwelling and downwelling is the vertical transport of water that results from the divergence and convergence of water. In this coastal context, an example would be northerly winds causing offshore surface flow and resultant divergent upwelling below the surface. Conversely, southerly winds would cause onshore surface flows, and convergent downwelling. The analysis above shows time-mean Ekman upwelling as weakly negative near the coast, but positive further offshore. For Site 1, Ekman pumping in general is relatively weak, though possibly slightly negative (i.e. downwelling).

• Flow length-scale:
We estimate a length scale that represents the average, rectified currents over a 24-hour period as $d = v \times t$ (see above for details).

Site	Flow length-scale
1	7.8 km
2	3.0 km
3	3.7 km
4	4.8 km

• Interpretation for WWTP C:
The potential investigation Site 1 can be summarised as a location in relatively deep coastal environment (80m), that is more subject to the offshore oceanographic environment and less subject to estuarine conditions. As a result, bottom velocities and stratification can change through a range of conditions, from relatively strong to weak flow and high to low stratification. Dispersal at the seafloor will vary with time and will be dependent on current

conditions. Flows are generally moderate and influenced predominantly by ocean currents. As a result, there is the potential to aim for sampling when stratification is stronger and flow weaker. Likewise, as this region is subject to Ekman downwelling, sampling could be undertaken when wind conditions are more favourable to weaker upwelling and dispersal.

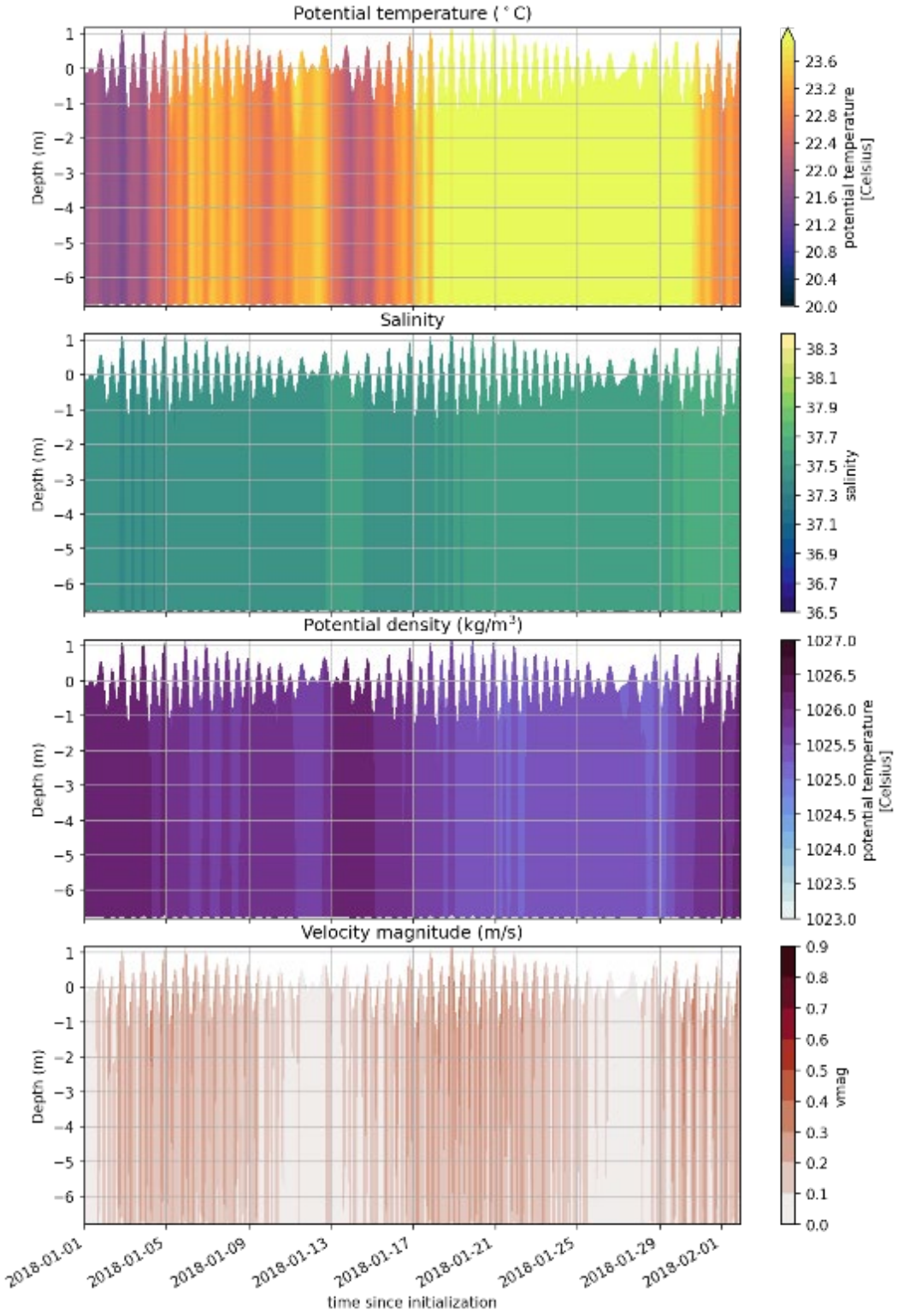
• Interpretation for Sites 2, 3, and 4:
The coastal locations for these three sites are generally relatively shallow, and more subject to fine-scale coastal processes, rather than the open-ocean environment. As a result, they will be more subject to surface-driven mixing and stratification can build and be degraded rapidly though influences such as winds and air temperatures. These shallower locations will also have tides – though this broader region is not a location of particularly strong tides, which will limit that impact. Flows are generally low to moderate.

7.3 A3. South Australia

Given the proximity of Sites 1a and 1b, as well as Sites 3a and 3b, the analysis focuses on representative location (Sites 1b, 2, and 3a, and 3b). In the broader context, the study region is a shallow (20-40m deep) and relatively wide embayment, and consequently all sites are likely subject to both tidal and surface mixing processes. We consider 4 weeks of high resolution model output, as it contains 1 full several spring-neap cycle. As this location is less influenced by slower oceanographic processes, excluding longer term variability is acceptable.
Site 1b is analysed in greater detail, and refer to that for the conditions at Sites 2, 3a, and 3b. This is justified by the close proximity and generally similar shallow, coastal environment for each site. A flow length-scale is presented for each of the three sites to further justify this.

• Mean bottom velocity:
The monthly-mean bottom velocity magnitude at the three potential sites show moderate flow of approximately 20cm/s. This bottom velocity magnitude rectifies tidal flow and this moderate current speed represents the strong tidal regime present at these sites (see velocity profile below)

• Profile at select location (Site 1b):



Temperature, density and velocity magnitude profiles at Site 1b show that this site can be characterised as a shallow, coastal site subject to strong tides and surface-driven mixing. There is little to no stratification detected, and apart from tidal flow, velocities are relatively weak. The (tidally-dominated) flow is general barotropic, however there are periods of weaker flow that coincide with weak tides (e.g. 27 January 2018).

• Flow length-scale:

We estimate a length scale that represents distance travelled if moving at the average, rectified current over a 24-hour period at each site (see above for details). This should be considered as a proxy for mean flow – but not as the straight-line distance a particle will travel in that time (for which full particle tracking simulations would be required).

Site	Flow length-scale
1b	9.6 km
2	9.4 km
3a, and 3b	9.8 km

• Interpretation:
The potential investigation sites in this coastal embayment are very similar in character. We focus on Site 1b here. This location can be characterised as a shallow (~5m), coastal environment with tides and surface-driven mixing. As this location is so shallow, the oceanographic conditions will be highly sensitive to atmospheric conditions and tides. Dispersal will be weaker than an open-ocean location, but will be relatively moderate based on the current tidal conditions.
The region is also subject to a so-called ‘dodge tide’ with almost constant water level for several days. This occurs when both the semidiurnal and diurnal constituents are out of phase and cancel. A weak dodge tide event is demonstrated by the period of weaker velocity magnitude and smaller changes in surface elevation at around 27 January 2018. Consequently, it is likely the period of greatest stratification and weakest flow would be during a ‘dodge tide’ when there has been a period of warm air temperatures and low wind.

Appendix B: Data from the WWTP A outfall

7.4 B1. Physico-chemical parameters

Table B1. Physico-chemical conditions of composite effluent from the WWTP A and seawater sampled around the WWTP A outfall. Thawed effluent was measured in the laboratory, and values presented are the mean ± SD of three composite replicates (n = 3). Seawater parameters were measured at the time of sampling, and values represent single measures taken at each site. Total suspended solids were not detected at any seawater sampling location. NA = not applicable; NTU = nephelometric turbidity units; PSU = practical salinity units.

Direction of transect from outfall	Distance from outfall (m)	Depth of sonde (m)	Temperature (°C)	O_2 (% saturation)	Temperature compensated conductivity (mS cm^{-1})	Salinity (PSU)	pH	Turbidity (NTU)
Effluent	NA	NA	13.7 ± 0.6	102.6 ± 1.5	1.7 ± 0.0	2.3 ± 0.6	8.0 ± 0.0	2.3 ± 0.4
Origin	0	1.89	18.1	94.7	56.4	37.5	7.7	2.1
E	20	2.16	18.2	95.1	56.8	37.8	7.9	1.6
	100	1.67	18.3	97.1	56.8	37.8	8.0	1.1
SSE	20	3.12	18.3	96.0	57.1	38.0	8.1	1.4
	100	3.92	18.2	97.1	57.1	38.1	8.2	1.6
	1000	2.83	18.2	99.0	57.0	38.0	8.1	1.2
W	20	3.92	18.2	95.1	57.0	38.0	8.1	2.1
	100	3.97	18.1	95.5	57.0	38.0	8.1	2.0
	1000	4.93	18.1	95.5	57.2	38.1	8.1	1.0
NNW	20	2.56	18.1	95.2	56.9	37.9	8.0	2.3
	100	3.35	18.2	95.2	56.9	37.9	8.0	4.2
	1000	3.08	18.2	95.0	56.9	37.9	8.0	2.4

Table B2. Depth of sediment cores and particle size distribution metrics of the sediments collected from the WWTP A outfall. D10, D50 and D90 represent the size which encompasses 10%, 50% and 90% of sediment particles, respectively. Data are mean ± SD, n = 3.

Direction of transect from outfall	Distance from outfall (m)	Depth of sediment core (mm)	D10 (µm)	D50 (µm)	D90 (µm)	Specific surface area ($m^2 g^{-1}$)
Origin	0	74.1 ± 4.8	93.9 ± 20.6	196.6 ± 23.6	490.3 ± 211.1	0.05 ± 0.01
E	20	66.9 ± 13.6	96.4 ± 1.9	180.7 ± 2.1	326.4 ± 5.5	0.05 ± 0.01
	100	69.5 ± 7.8	82.5 ± 1.5	138.3 ± 2.8	235.3 ± 6.9	0.05 ± 0.00
SSE	20	75.5 ± 0.9	108.1 ± 11.0	211.0 ± 18.1	395.4 ± 26.1	0.04 ± 0.01
	100	74.9 ± 5.6	106.5 ± 1.6	195.6 ± 3.5	343.1 ± 13.2	0.04 ± 0.00
	1000	72.7 ± 4.4	105.5 ± 24.5	293.5 ± 38.8	671.5 ± 83.3	0.06 ± 0.01
W	20	70.4 ± 6.9	124.7 ± 5.6	223.5 ± 5.5	384.4 ± 7.9	0.03 ± 0.00
	100	75.9 ± 0.9	137.6 ± 2.3	241.4 ± 5.5	399.7 ± 11.8	0.04 ± 0.00
	1000	68.9 ± 7.3	228.8 ± 6.8	354.8 ± 10.8	553.5 ± 17.8	0.02 ± 0.00
NNW	20	67.2 ± 3.7	113.5 ± 1.6	210.0 ± 6.8	373.0 ± 23.7	0.04 ± 0.00
	100	75.4 ± 4.8	96.1 ± 6.9	176.1 ± 11.9	309.0 ± 19.8	0.05 ± 0.01
	1000	72.2 ± 2.1	151.9 ± 21.4	260.1 ± 18.3	437.7 ± 14.7	0.03 ± 0.00

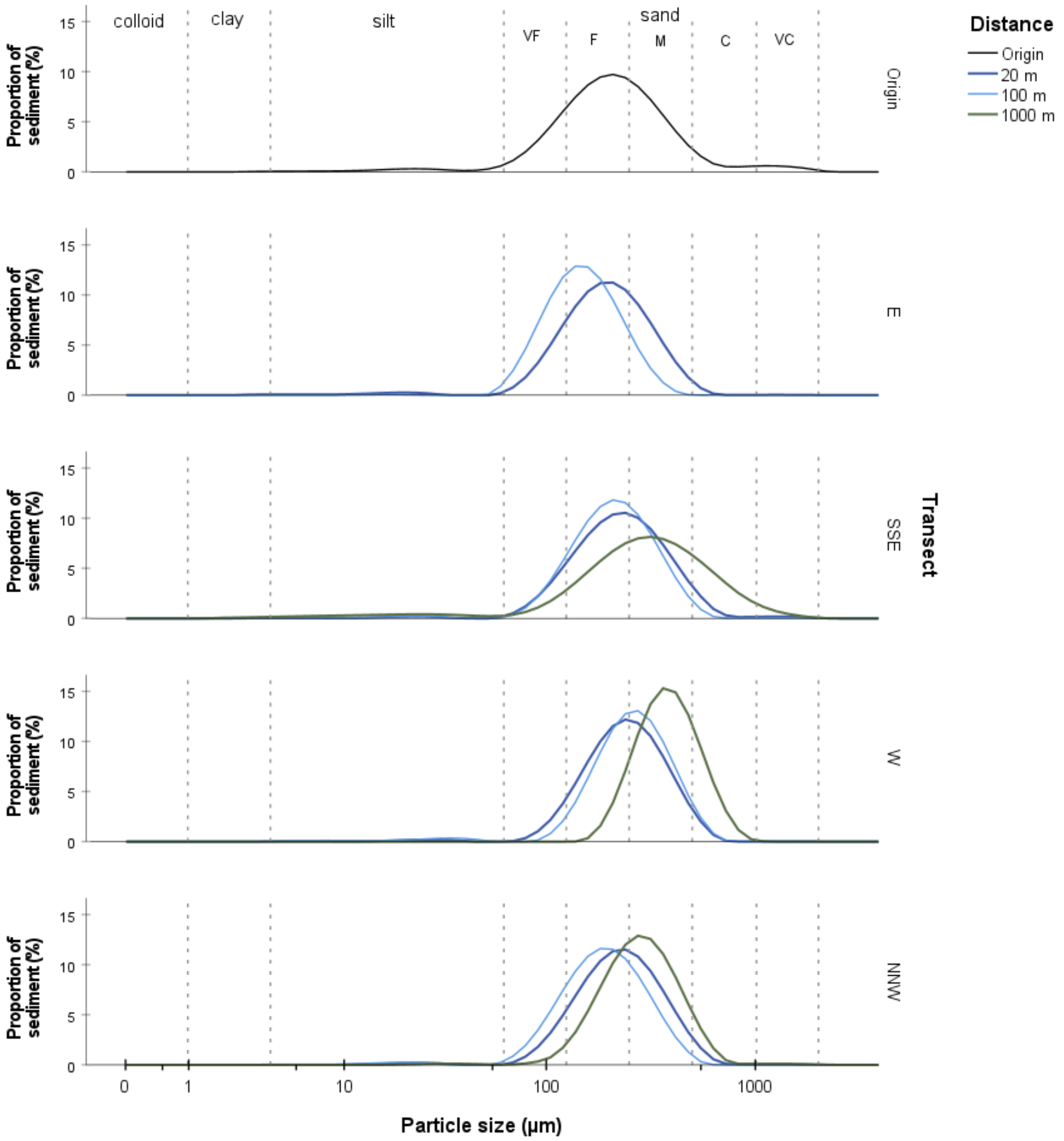
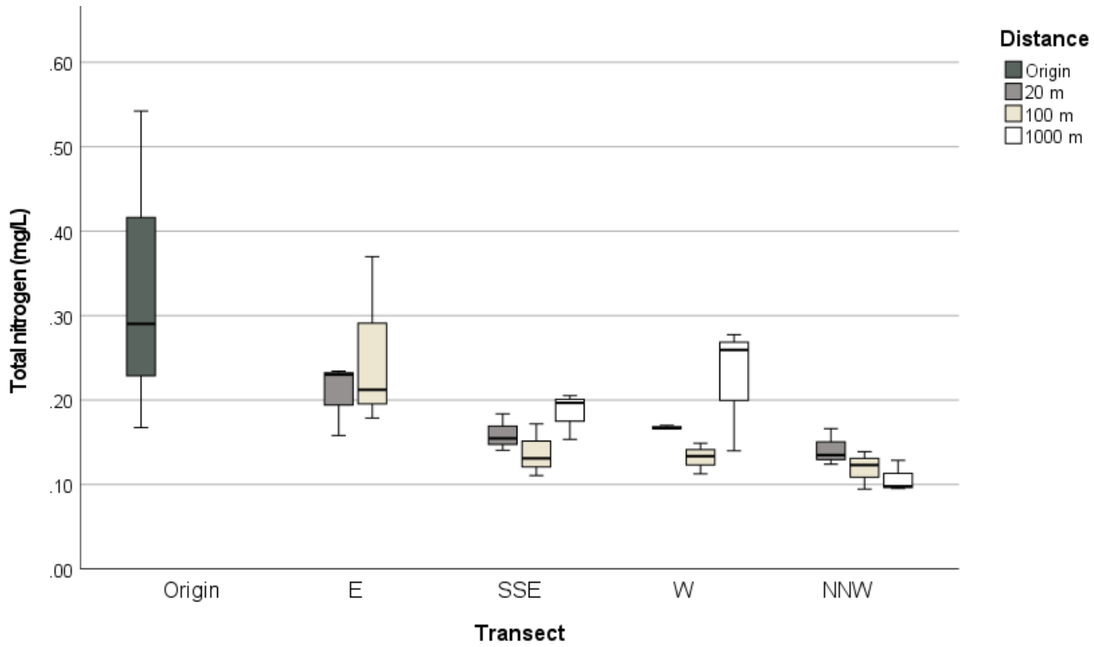
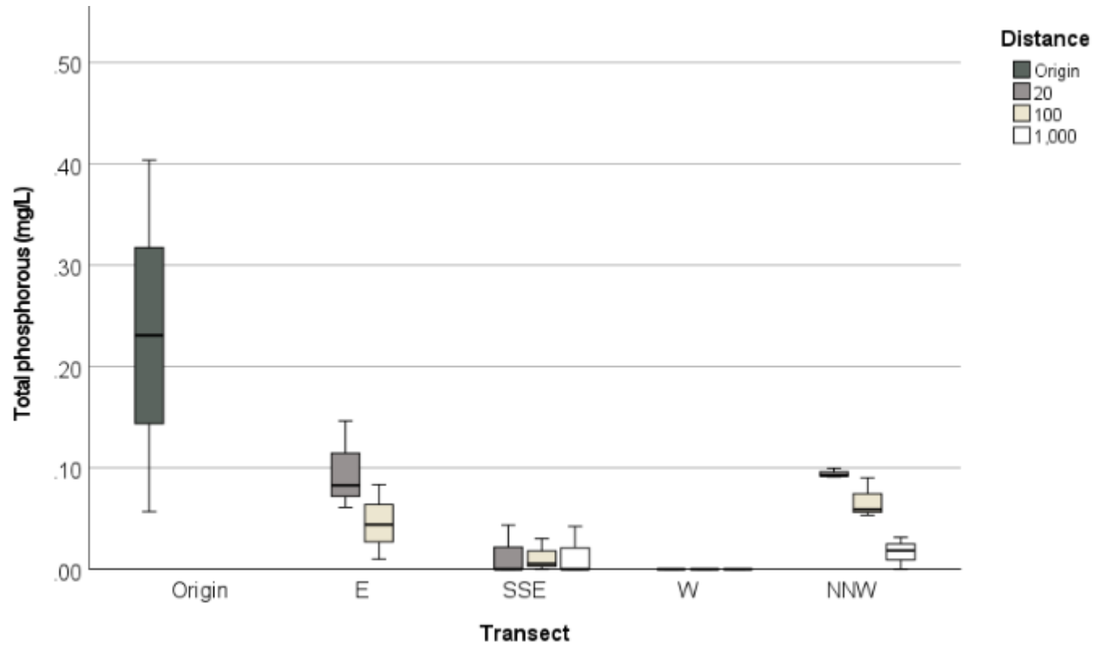
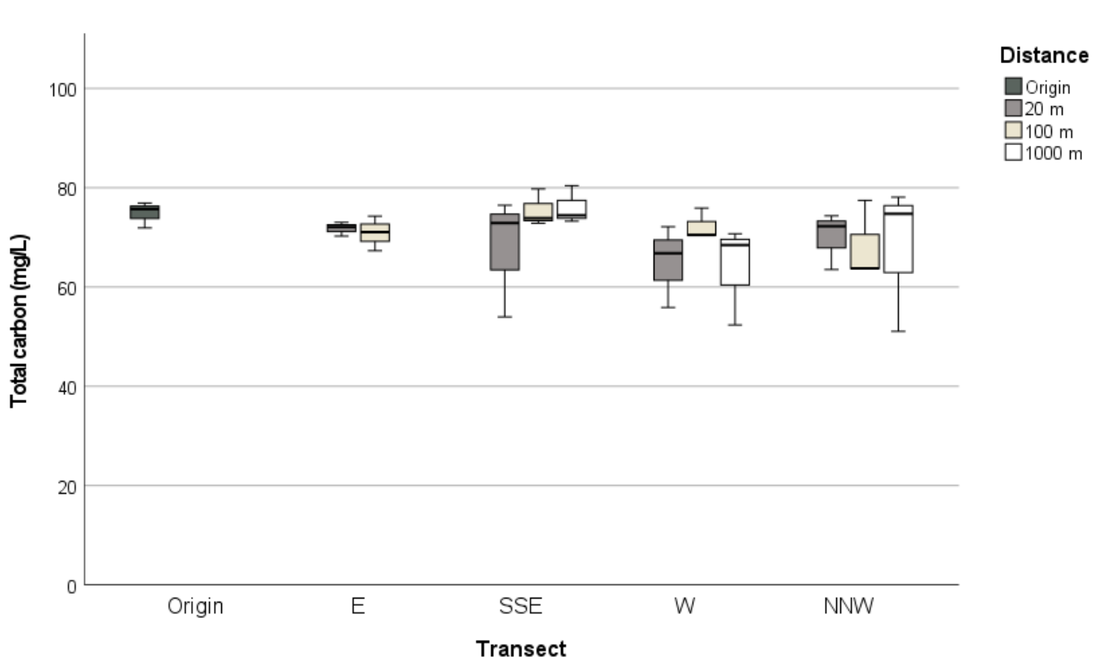


Figure B2. Particle size distribution of sediments collected from the WWTP A outfall. Results are the average of three replicates at each site (n = 3). Aggregate names listed at the top of the chart are taken from the Wentworth scale. C = coarse; F = fine; M = medium; VC = very coarse; VF = very fine.

7.5 B2. Nutrient quantification







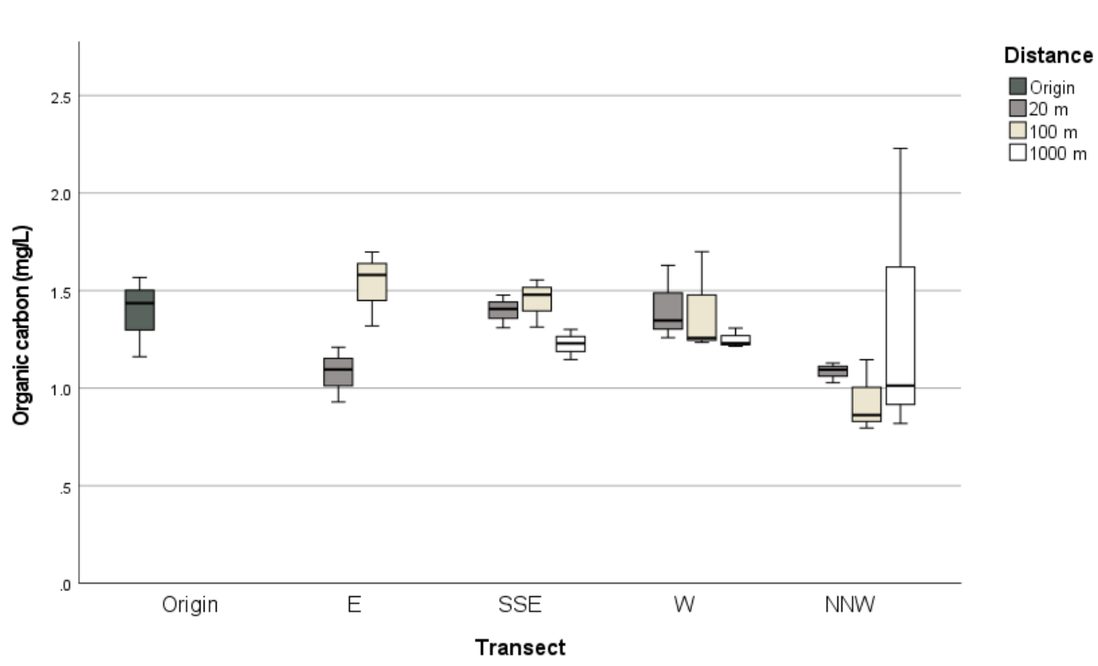


Figure B1. Concentrations of dissolved nutrients (mg/L) in seawater collected from the WWTP A outfall. (A) total nitrogen, (B) total phosphorus in seawater, (C) total carbon, and (D) organic carbon. At each sampling location, n = 3.

Table B3. Concentrations of dissolved nutrients in composite effluent from the WWTP A, and in seawater and sediments collected from transects around the WWTP A outfall. Data are mean ± SD, n = 3. NA = not applicable.

Partition	Nutrient	Conc.	Effluent	Origin	E		SSE			W			NNW		
				0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Water	Total carbon (mg/L)	Mean	39.699	74.841	71.787	70.895	67.790	75.497	76.058	64.946	72.273	63.867	70.041	68.313	67.983
		SD	0.970	2.611	1.407	3.491	12.074	3.735	3.852	8.290	3.144	10.015	5.737	7.914	14.725
	Organic carbon (mg/L)	Mean	10.805	1.388	1.079	1.533	1.398	1.449	1.226	1.412	1.397	1.251	1.084	0.935	1.354
		SD	0.188	0.207	0.141	0.194	0.084	0.123	0.077	0.194	0.262	0.050	0.051	0.186	0.764
	Total nitrogen (mg/L)	Mean	13.277	0.333	0.208	0.254	0.160	0.138	0.185	0.168	0.132	0.226	0.142	0.119	0.107
		SD	0.353	0.191	0.043	0.102	0.022	0.031	0.028	0.002	0.018	0.075	0.022	0.022	0.019
	Total phosphorus (mg/L)	Mean	5.570	0.230	0.097	0.046	0.015	0.012	0.014	0.000	0.000	0.000	0.094	0.067	0.017
		SD	0.823	0.173	0.044	0.037	0.025	0.016	0.024	0.000	0.000	0.000	0.005	0.020	0.016
Sediment	Organic matter (g/g)	Mean	NA	0.007	0.005	0.007	0.005	0.005	0.005	0.005	0.004	0.003	0.005	0.006	0.004
		SD	NA	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.001
	Total phosphorus (mg/kg)	Mean	NA	94.443	50.584	170.771	14.282	18.778	5.187	5.259	2.049	11.554	0.000	109.040	0.000
		SD	NA	19.825	37.430	23.506	12.391	32.525	8.984	8.360	3.550	7.405	0.000	48.906	0.000

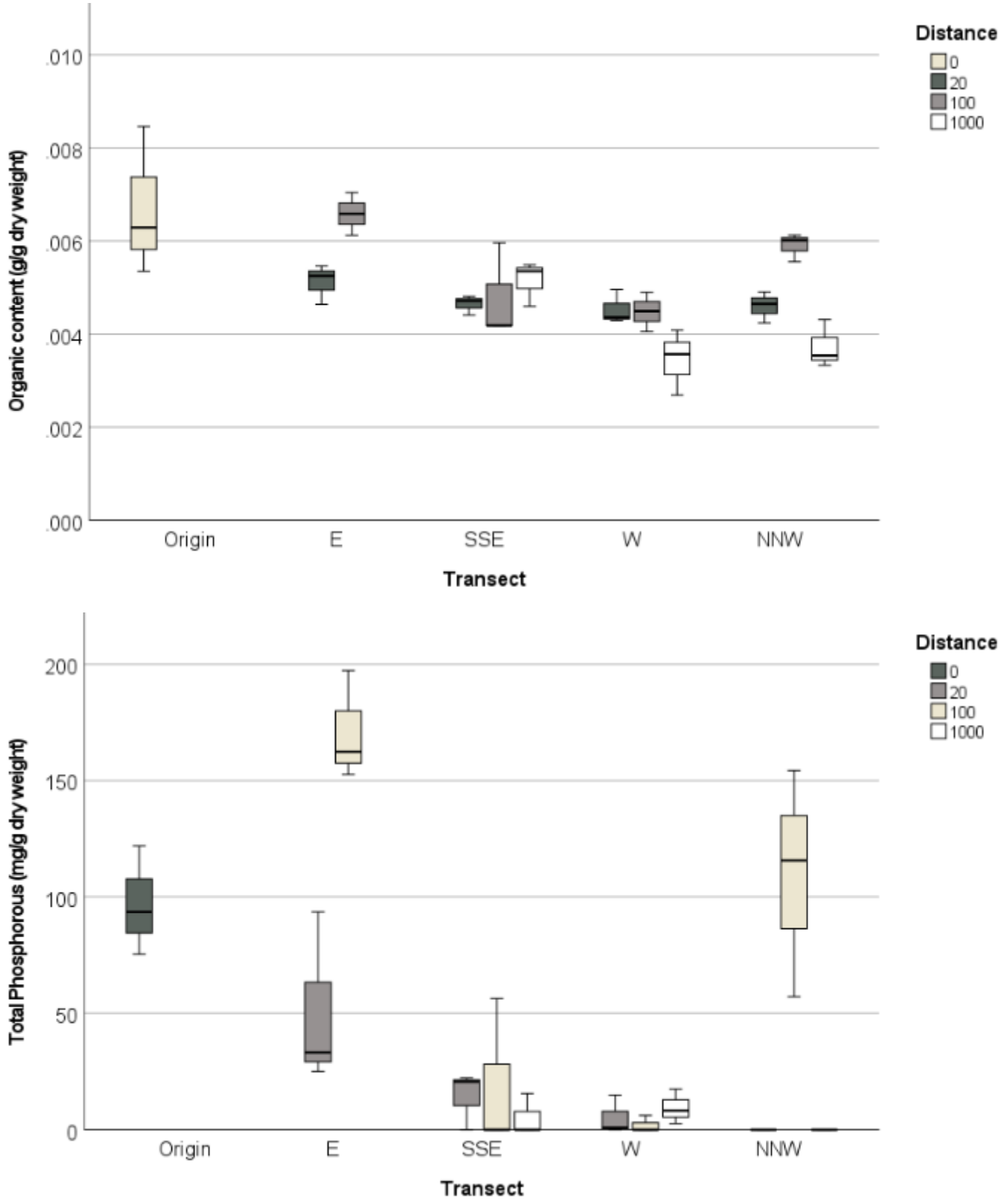
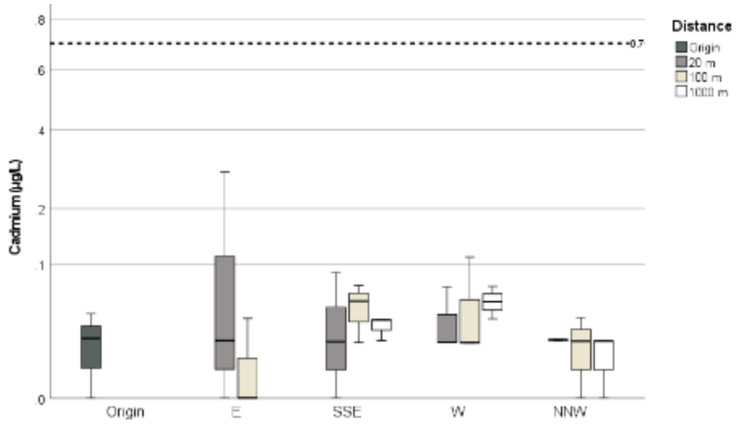
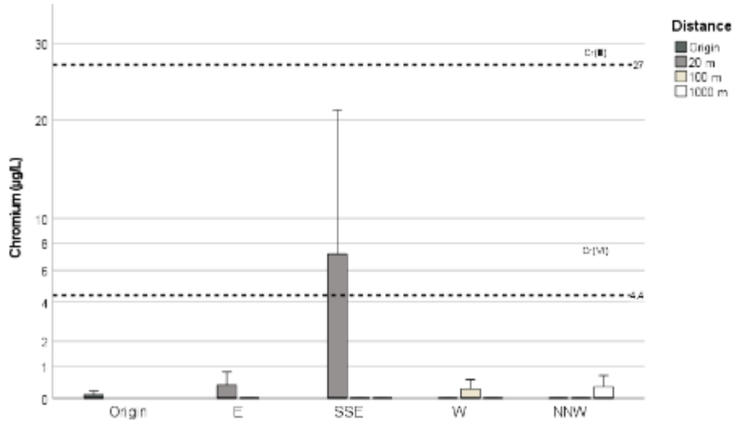
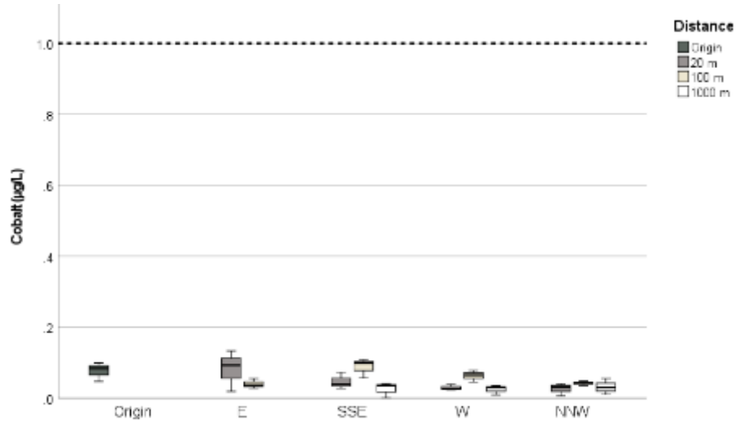


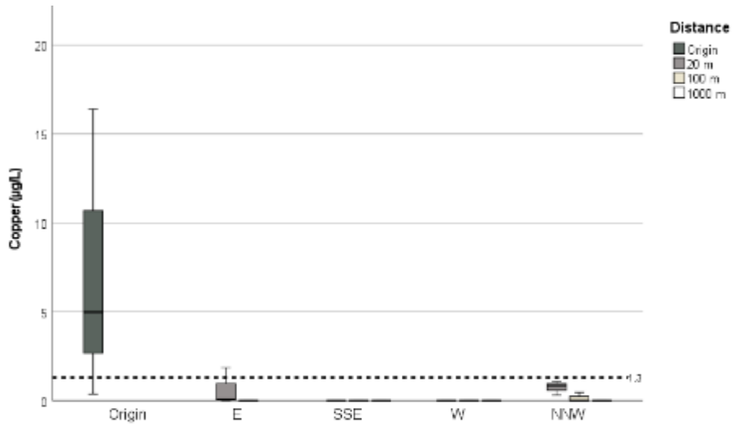
Figure B2. Concentrations of (top) total organic matter and (bottom) total phosphorus in sediments collected from the WWTP A outfall. At each sampling location, n = 3.

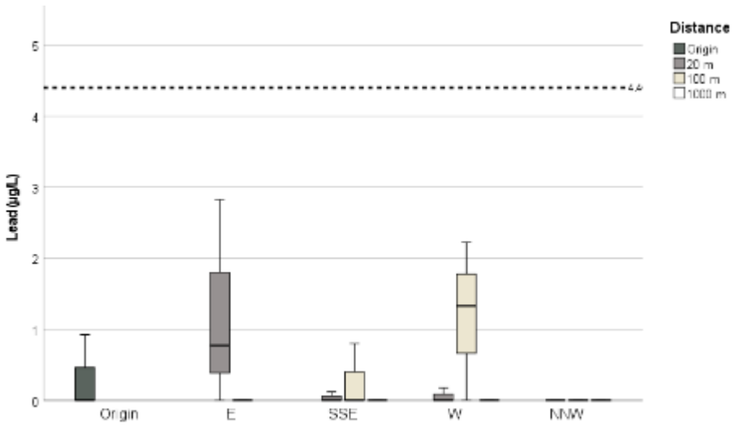
7.6 B3. Metal quantification

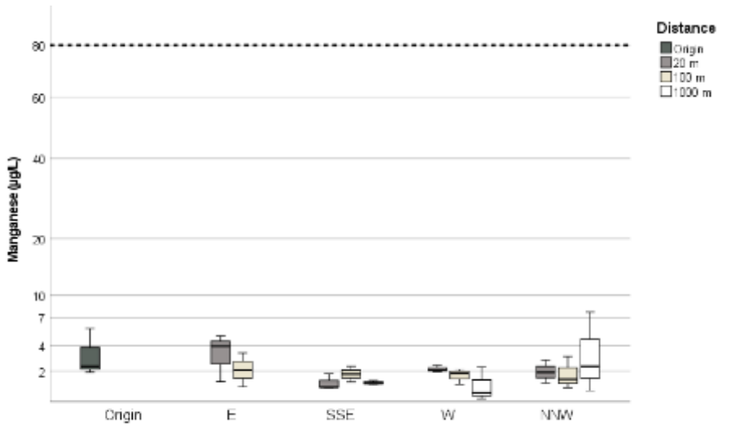


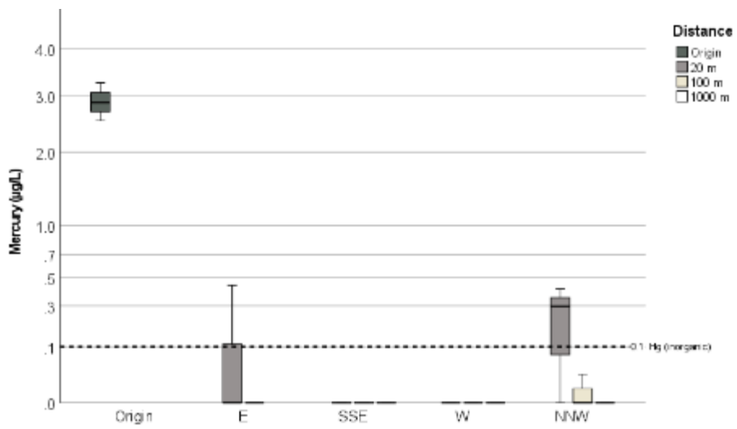


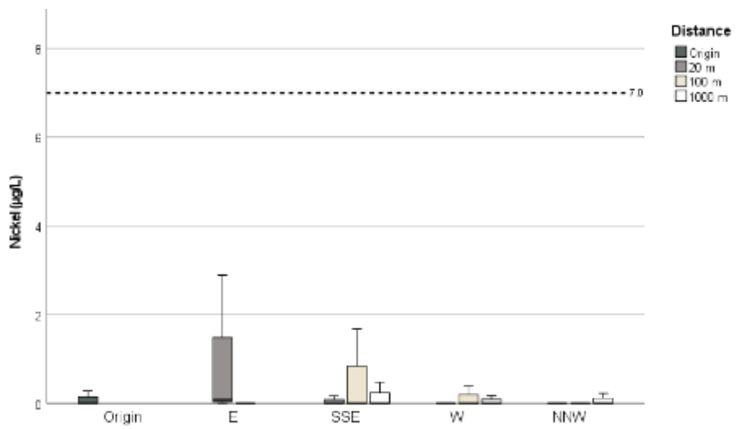


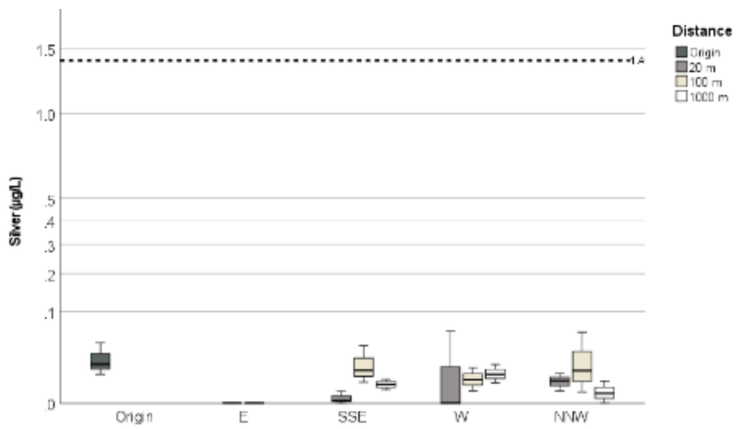


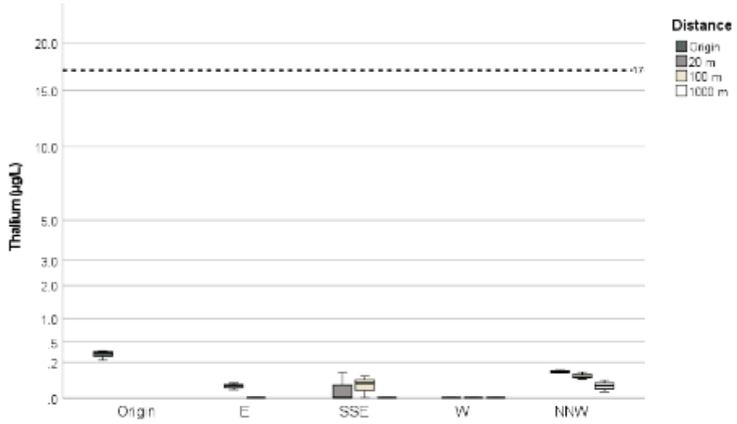


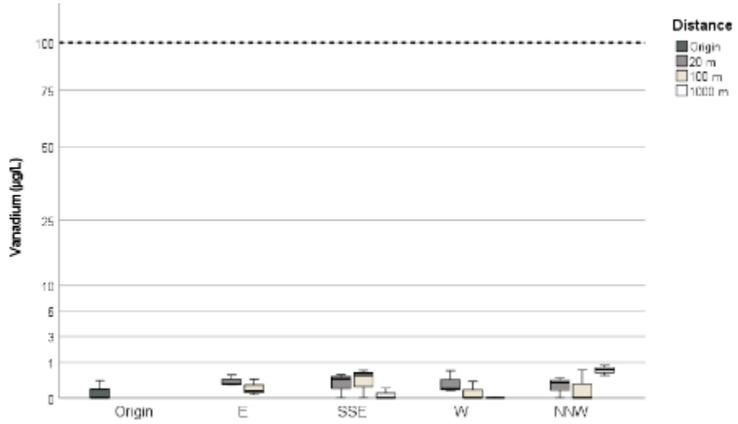


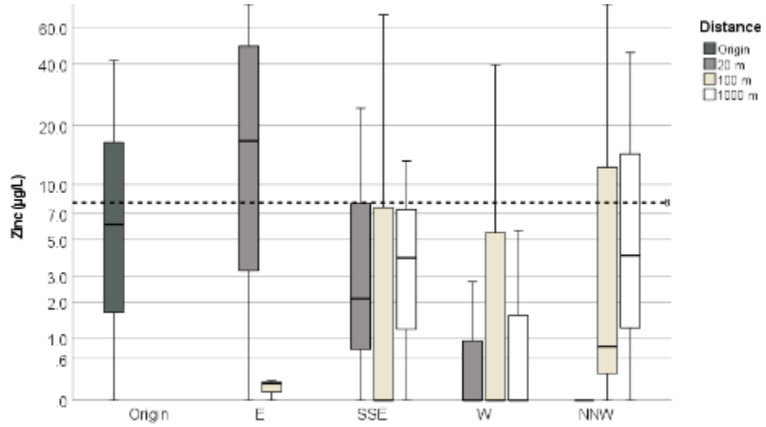












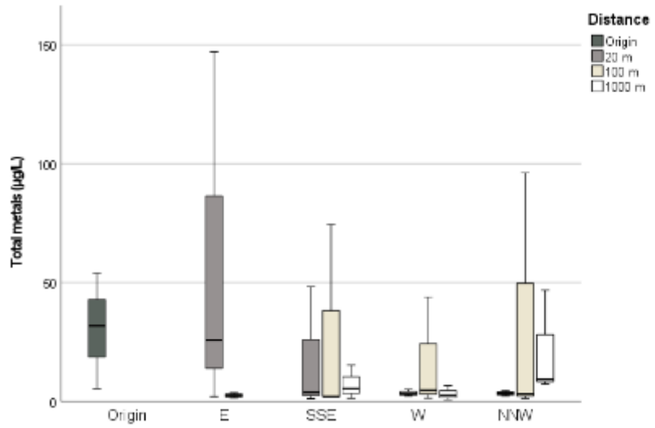


Figure B3. Concentration of dissolved total recoverable metals (µg/L; ppb) associated with a marine Default Guideline Value in the seawater surrounding the WWTP A outfall (n = 3). Dotted lined represent the marine Default Guideline Values recommended for slightly to moderately disturbed ecosystems. For all metals, these Default Guideline Values protect 95% of species except for manganese and thallium (unknown % species protection), and cadmium, nickel and mercury (99% species protected). Total metals represent the sum of all metals associated with a marine Default Guideline Value. A full list of total recoverable metals is provided in Table C4.

Table B4.Concentrations of dissolved total recoverable dissolved metals (µg/L; ppb) in composite effluent from the WWTP A, and in seawater collected from transects around the WWTP A outfall. At each location, n = 3. α indicates metals associated with marine Default Guideline Values that were combined to form a metric of 'total metal' for statistical analyses.

Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Aluminium	Median	49.412	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	83.918	0.000
	Mean	45.777	0.060	0.000	0.000	3.457	0.000	0.000	0.000	0.000	0.000	0.263	818.722	0.000
	SD	10.535	0.103	0.000	0.000	5.988	0.000	0.000	0.000	0.000	0.000	0.456	1346.048	0.000
	Minimum	33.906	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	54.014	0.179	0.000	0.000	10.372	0.000	0.000	0.000	0.000	0.000	0.789	2372.249	0.000
Antimony	Median	0.000	0.083	0.000	0.000	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.073	0.007	0.012	0.044	0.000	0.000	0.000	0.008	0.000	0.000	0.050	0.019
	SD	0.000	0.068	0.012	0.021	0.048	0.000	0.000	0.000	0.014	0.000	0.000	0.087	0.033
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.136	0.021	0.036	0.095	0.000	0.000	0.000	0.024	0.000	0.000	0.150	0.058
Arsenic	Median	0.000	2.443	2.672	2.879	3.175	2.666	2.405	3.719	2.684	2.642	2.655	2.447	3.130
	Mean	0.000	2.432	2.796	2.853	3.251	2.664	2.521	3.237	2.850	2.750	2.632	2.598	2.927
	SD	0.000	0.107	0.437	0.654	0.278	0.144	0.584	0.945	0.438	0.195	0.304	0.548	0.470
	Minimum	0.000	2.319	2.434	2.186	3.018	2.518	2.004	2.147	2.519	2.633	2.317	2.142	2.389
	Maximum	0.000	2.532	3.281	3.493	3.559	2.806	3.153	3.843	3.347	2.975	2.923	3.206	3.260
Barium	Median	28.566	4.691	1.478	1.490	0.800	2.009	1.016	1.237	0.669	1.441	3.278	1.256	1.517
	Mean	28.521	4.567	1.602	1.242	0.728	2.012	0.866	1.231	0.839	1.241	3.171	1.974	1.319
	SD	0.219	1.607	1.161	0.696	0.314	0.358	0.801	0.321	0.378	0.633	0.786	1.447	0.611
	Minimum	28.284	2.901	0.508	0.456	0.385	1.655	0.000	0.906	0.576	0.532	2.338	1.027	0.634
	Maximum	28.714	6.108	2.820	1.781	1.000	2.371	1.581	1.548	1.272	1.749	3.899	3.641	1.807
Bismuth	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	3.158	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	5.469	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	9.473	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Cadmium[α]	Median	0.000	0.020	0.018	0.000	0.018	0.052	0.034	0.017	0.017	0.052	0.019	0.018	0.018
	Mean	0.000	0.020	0.101	0.012	0.035	0.047	0.029	0.035	0.048	0.052	0.019	0.018	0.012
	SD	0.000	0.020	0.159	0.020	0.046	0.027	0.009	0.030	0.054	0.017	0.000	0.018	0.010
	Minimum	0.000	0.000	0.000	0.000	0.000	0.017	0.018	0.017	0.017	0.035	0.018	0.000	0.000
	Maximum	0.000	0.040	0.284	0.035	0.087	0.070	0.034	0.069	0.111	0.070	0.019	0.036	0.018
Cerium	Median	0.000	0.006	0.003	0.000	0.003	0.000	0.000	0.001	0.001	0.000	0.007	0.012	0.003
	Mean	0.099	0.025	0.005	0.000	0.003	0.001	0.002	0.002	0.001	0.001	0.005	0.034	0.003
	SD	0.171	0.038	0.005	0.000	0.001	0.002	0.003	0.002	0.001	0.002	0.002	0.049	0.003
	Minimum	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000
	Maximum	0.297	0.069	0.011	0.000	0.004	0.003	0.005	0.004	0.002	0.003	0.007	0.090	0.006
Cesium	Median	0.000	0.362	0.376	0.349	0.356	0.366	0.362	0.401	0.376	0.352	0.333	0.340	0.377
	Mean	0.000	0.341	0.407	0.350	0.374	0.369	0.365	0.367	0.365	0.333	0.344	0.352	0.366
	SD	0.000	0.046	0.070	0.032	0.036	0.007	0.021	0.065	0.029	0.039	0.046	0.035	0.020
	Minimum	0.000	0.288	0.357	0.319	0.351	0.364	0.346	0.292	0.332	0.288	0.305	0.325	0.342
	Maximum	0.000	0.372	0.487	0.382	0.415	0.377	0.387	0.407	0.388	0.358	0.395	0.392	0.377
Chromium[α]	Median	8.583	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	8.805	0.064	0.265	0.000	7.063	0.000	0.000	0.000	0.179	0.000	0.000	0.000	0.223
	SD	0.387	0.110	0.458	0.000	12.234	0.000	0.000	0.000	0.309	0.000	0.000	0.000	0.387
	Minimum	8.580	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	9.251	0.191	0.794	0.000	21.190	0.000	0.000	0.000	0.536	0.000	0.000	0.000	0.670
Cobalt[α]	Median	0.000	0.084	0.092	0.036	0.039	0.098	0.034	0.027	0.064	0.029	0.031	0.043	0.029
	Mean	0.075	0.076	0.081	0.039	0.046	0.087	0.025	0.029	0.062	0.024	0.026	0.042	0.031
	SD	0.130	0.027	0.058	0.014	0.024	0.027	0.022	0.008	0.016	0.014	0.018	0.006	0.023
	Minimum	0.000	0.047	0.019	0.027	0.027	0.056	0.000	0.023	0.045	0.009	0.006	0.035	0.009
	Maximum	0.225	0.099	0.133	0.055	0.073	0.108	0.040	0.039	0.078	0.035	0.040	0.048	0.055
Copper[α]	Median	22.968	4.980	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.843	0.000	0.000
	Mean	23.364	7.250	0.642	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.743	0.154	0.000
	SD	3.528	8.255	1.051	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.391	0.266	0.000

Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Minimum	20.051	0.367	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.312	0.000	0.000
	Maximum	27.073	16.402	1.854	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.073	0.461	0.000
Dysprosium	Median	0.000	0.004	0.000	0.000	0.004	0.000	0.003	0.004	0.003	0.000	0.004	0.000	0.000
	Mean	0.000	0.004	0.004	0.001	0.005	0.000	0.004	0.005	0.003	0.001	0.008	0.001	0.004
	SD	0.000	0.005	0.007	0.002	0.002	0.000	0.000	0.006	0.002	0.002	0.011	0.002	0.007
	Minimum	0.000	0.000	0.000	0.000	0.004	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.009	0.012	0.004	0.008	0.000	0.004	0.011	0.004	0.004	0.020	0.004	0.012
Gadolinium	Median	0.049	0.027	0.018	0.012	0.006	0.012	0.000	0.006	0.000	0.000	0.006	0.012	0.000
	Mean	0.038	0.033	0.014	0.010	0.008	0.010	0.002	0.006	0.002	0.004	0.008	0.012	0.006
	SD	0.034	0.023	0.012	0.009	0.003	0.009	0.003	0.006	0.004	0.007	0.004	0.006	0.011
	Minimum	0.000	0.014	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.006	0.006	0.000
	Maximum	0.064	0.059	0.024	0.018	0.012	0.018	0.006	0.012	0.007	0.012	0.012	0.018	0.018
Gallium	Median	0.000	0.000	0.025	0.000	0.011	0.000	0.000	0.000	0.011	0.000	0.016	0.026	0.001
	Mean	0.000	0.013	0.029	0.005	0.012	0.012	0.003	0.000	0.010	0.000	0.027	0.081	0.018
	SD	0.000	0.022	0.031	0.008	0.012	0.021	0.006	0.000	0.010	0.000	0.035	0.118	0.030
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.039	0.062	0.014	0.024	0.036	0.010	0.000	0.020	0.000	0.067	0.216	0.053
Germanium	Median	0.000	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.046	0.000
	Mean	0.000	0.152	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.038	0.000
	SD	0.000	0.187	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
	Maximum	0.000	0.360	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.065	0.000
Hafnium	Median	0.000	0.191	0.067	0.010	0.000	0.098	0.033	0.000	0.000	0.000	0.047	0.000	0.066
	Mean	0.011	0.183	0.115	0.009	0.093	0.156	0.043	0.006	0.000	0.000	0.041	0.010	0.090
	SD	0.019	0.090	0.088	0.009	0.162	0.115	0.025	0.011	0.000	0.000	0.014	0.017	0.071
	Minimum	0.000	0.089	0.062	0.000	0.000	0.082	0.024	0.000	0.000	0.000	0.025	0.000	0.034
	Maximum	0.033	0.268	0.217	0.017	0.280	0.288	0.072	0.018	0.000	0.000	0.051	0.029	0.170
Indium	Median	0.000	0.044	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.008

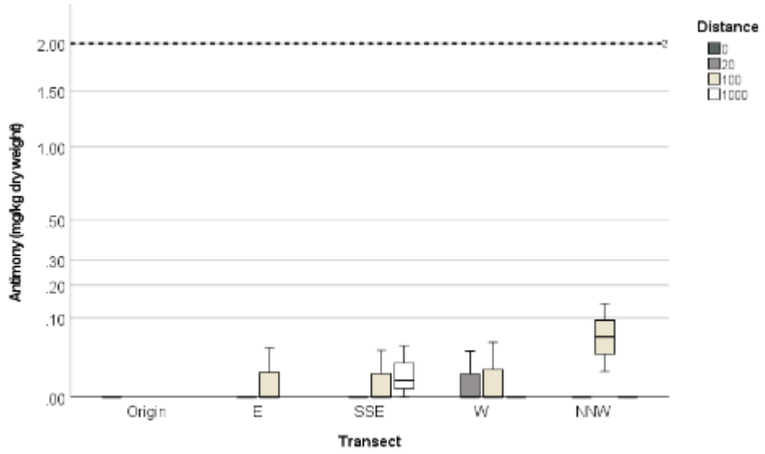
Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Mean	0.000	0.044	0.000	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.007	0.007
	SD	0.000	0.033	0.000	0.003	0.000	0.001	0.000	0.000	0.000	0.000	0.004	0.003	0.006
	Minimum	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000
	Maximum	0.000	0.076	0.000	0.006	0.000	0.002	0.000	0.000	0.000	0.000	0.008	0.009	0.012
Lead[α]	Median	0.754	0.000	0.772	0.000	0.000	0.000	0.000	0.000	1.329	0.000	0.000	0.000	0.000
	Mean	0.689	0.308	1.199	0.000	0.040	0.267	0.000	0.059	1.185	0.000	0.000	0.000	0.000
	SD	0.327	0.534	1.461	0.000	0.069	0.462	0.000	0.102	1.120	0.000	0.000	0.000	0.000
	Minimum	0.334	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.979	0.925	2.826	0.000	0.120	0.800	0.000	0.176	2.225	0.000	0.000	0.000	0.000
Manganese[α]	Median	9.471	2.317	3.946	2.073	1.089	1.812	1.281	2.059	1.846	0.836	1.907	1.504	2.329
	Mean	11.378	3.331	3.420	2.178	1.327	1.828	1.311	2.136	1.728	1.232	1.989	1.877	3.653
	SD	4.199	2.106	1.848	1.130	0.436	0.483	0.109	0.231	0.455	0.901	0.745	1.052	3.581
	Minimum	8.470	1.924	1.366	1.104	1.061	1.353	1.221	1.954	1.226	0.597	1.288	1.062	0.923
	Maximum	16.192	5.752	4.948	3.357	1.829	2.319	1.432	2.396	2.112	2.263	2.772	3.064	7.707
Mercury[α]	Median	0.000	2.872	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.297	0.000	0.000
	Mean	0.000	2.889	0.147	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.236	0.009	0.000
	SD	0.000	0.365	0.254	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.213	0.015	0.000
	Minimum	0.000	2.533	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	3.263	0.440	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.412	0.026	0.000
Molybdenum	Median	0.697	13.725	13.092	13.947	13.726	13.727	13.357	13.437	13.400	13.435	13.317	13.761	13.456
	Mean	1.175	13.433	13.346	13.923	13.650	13.703	13.888	13.416	13.441	13.582	13.387	13.352	13.474
	SD	0.873	0.912	0.459	0.393	0.135	0.044	0.975	0.241	0.259	0.316	0.235	0.751	0.058
	Minimum	0.646	12.410	13.070	13.519	13.494	13.653	13.294	13.165	13.206	13.366	13.195	12.486	13.427
	Maximum	2.183	14.163	13.875	14.303	13.730	13.731	15.013	13.646	13.718	13.945	13.649	13.810	13.538
Nickel[α]	Median	4.894	0.002	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	4.735	0.093	0.989	0.000	0.056	0.558	0.158	0.000	0.130	0.058	0.000	0.000	0.075
	SD	0.565	0.160	1.646	0.000	0.097	0.967	0.274	0.000	0.225	0.100	0.000	0.000	0.130
	Minimum	4.107	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Maximum	5.203	0.278	2.889	0.000	0.168	1.675	0.474	0.000	0.390	0.174	0.000	0.000	0.225
Niobium	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005
	Mean	0.000	0.002	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.004
	SD	0.000	0.003	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.006	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.006
Rubidium	Median	18.587	151.689	162.341	167.537	163.707	165.240	163.746	165.510	162.322	166.298	157.494	155.065	161.989
	Mean	18.438	149.699	163.907	165.860	164.691	165.227	166.713	165.022	161.902	166.130	157.213	156.675	161.138
	SD	0.397	3.664	2.798	3.613	2.066	1.519	5.990	1.030	0.960	0.939	0.610	5.102	2.059
	Minimum	17.988	145.471	162.243	161.714	163.301	163.702	162.785	163.838	160.804	165.118	156.514	152.572	158.789
	Maximum	18.738	151.937	167.138	168.330	167.065	166.740	173.607	165.717	162.580	166.975	157.632	162.388	162.634
Scandium	Median	0.000	0.116	0.183	0.080	0.060	0.154	0.102	0.069	0.015	0.116	0.137	0.076	0.052
	Mean	0.000	0.109	0.151	0.096	0.042	0.134	0.102	0.070	0.069	0.077	0.108	0.080	0.068
	SD	0.000	0.023	0.087	0.044	0.036	0.035	0.038	0.071	0.098	0.067	0.057	0.022	0.027
	Minimum	0.000	0.082	0.053	0.063	0.001	0.094	0.064	0.000	0.009	0.000	0.042	0.061	0.052
	Maximum	0.000	0.128	0.219	0.146	0.066	0.154	0.140	0.142	0.182	0.116	0.144	0.103	0.099
Selenium	Median	0.000	2.124	2.768	2.158	1.915	1.983	3.538	2.575	3.025	2.351	1.789	2.112	2.385
	Mean	0.000	1.605	2.764	2.404	2.270	1.896	3.173	2.354	3.137	2.735	1.755	1.484	1.974
	SD	0.000	1.001	0.177	0.678	1.106	1.536	0.796	0.537	0.924	0.870	0.062	1.231	1.242
	Minimum	0.000	0.451	2.586	1.885	1.385	0.318	2.261	1.742	2.274	2.124	1.683	0.066	0.579
	Maximum	0.000	2.241	2.939	3.171	3.510	3.387	3.721	2.745	4.112	3.731	1.791	2.276	2.959
Silver[α]	Median	0.000	0.018	0.000	0.000	0.000	0.013	0.004	0.000	0.007	0.010	0.006	0.013	0.001
	Mean	0.000	0.024	0.000	0.000	0.001	0.019	0.004	0.021	0.008	0.011	0.006	0.025	0.002
	SD	0.000	0.017	0.000	0.000	0.001	0.018	0.002	0.036	0.007	0.007	0.004	0.031	0.003
	Minimum	0.000	0.010	0.000	0.000	0.000	0.005	0.002	0.000	0.002	0.005	0.002	0.001	0.000
	Maximum	0.000	0.043	0.000	0.000	0.002	0.039	0.007	0.062	0.015	0.018	0.011	0.060	0.006
Tantalum	Median	0.000	0.006	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.004	0.000	0.000
	Mean	0.000	0.006	0.001	0.000	0.002	0.005	0.000	0.000	0.000	0.000	0.003	0.000	0.000

Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	SD	0.000	0.004	0.002	0.000	0.003	0.006	0.001	0.000	0.000	0.000	0.003	0.000	0.000
	Minimum	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.009	0.004	0.000	0.006	0.012	0.001	0.000	0.000	0.000	0.005	0.000	0.000
Tellurium	Median	0.000	0.000	0.000	0.000	0.000	0.166	0.329	0.165	0.000	0.000	0.000	0.167	0.000
	Mean	0.000	0.063	0.111	0.111	0.000	0.166	0.336	0.219	0.241	0.055	0.000	0.114	0.057
	SD	0.000	0.109	0.192	0.193	0.000	0.166	0.017	0.095	0.418	0.096	0.000	0.099	0.099
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.324	0.163	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.188	0.333	0.333	0.000	0.332	0.355	0.329	0.724	0.166	0.000	0.175	0.171
Thallium[α]	Median	0.000	0.328	0.022	0.000	0.000	0.034	0.000	0.000	0.000	0.000	0.105	0.069	0.022
	Mean	0.000	0.302	0.023	0.000	0.035	0.036	0.000	0.000	0.000	0.000	0.109	0.077	0.026
	SD	0.000	0.067	0.012	0.000	0.060	0.037	0.000	0.000	0.000	0.000	0.012	0.025	0.022
	Minimum	0.000	0.226	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.100	0.057	0.006
	Maximum	0.000	0.350	0.035	0.000	0.104	0.074	0.000	0.000	0.000	0.000	0.123	0.106	0.050
Thorium	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tin	Median	0.199	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.282	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Titanium	Median	0.000	0.495	0.004	0.000	0.136	0.428	0.135	0.000	0.133	0.421	0.000	0.299	0.462
	Mean	0.000	0.572	0.098	0.002	0.454	0.332	0.191	0.188	0.208	0.281	0.104	0.352	0.349
	SD	0.000	0.438	0.166	0.003	0.672	0.168	0.098	0.326	0.254	0.243	0.181	0.381	0.308
	Minimum	0.000	0.178	0.000	0.000	0.000	0.138	0.134	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	1.043	0.289	0.005	1.226	0.429	0.304	0.565	0.491	0.422	0.313	0.756	0.583

Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Tungsten	Median	0.000	0.162	0.052	0.014	0.012	0.015	0.000	0.000	0.002	0.005	0.056	0.040	0.039
	Mean	0.000	0.145	0.043	0.021	0.018	0.025	0.004	0.004	0.004	0.013	0.051	0.043	0.037
	SD	0.000	0.085	0.021	0.014	0.021	0.023	0.007	0.007	0.006	0.013	0.011	0.013	0.015
	Minimum	0.000	0.053	0.019	0.013	0.000	0.009	0.000	0.000	0.000	0.005	0.039	0.031	0.021
	Maximum	0.000	0.221	0.057	0.038	0.041	0.051	0.011	0.012	0.011	0.028	0.058	0.057	0.050
Uranium	Median	0.000	2.996	2.870	2.974	2.933	2.942	2.856	2.826	2.719	2.917	2.951	2.919	2.896
	Mean	0.000	3.057	2.886	2.935	2.931	2.934	2.920	2.829	2.737	2.875	2.978	2.901	2.902
	SD	0.000	0.151	0.081	0.129	0.084	0.024	0.189	0.059	0.038	0.117	0.085	0.099	0.055
	Minimum	0.000	2.947	2.813	2.791	2.847	2.908	2.770	2.771	2.711	2.742	2.911	2.794	2.851
	Maximum	0.000	3.230	2.974	3.039	3.014	2.953	3.133	2.889	2.780	2.965	3.074	2.990	2.960
Vanadium[α]	Median	0.000	0.000	0.154	0.042	0.288	0.406	0.000	0.069	0.000	0.000	0.192	0.000	0.633
	Mean	0.000	0.080	0.237	0.111	0.240	0.336	0.025	0.235	0.073	0.000	0.168	0.205	0.627
	SD	0.000	0.138	0.157	0.148	0.220	0.307	0.044	0.309	0.126	0.000	0.157	0.356	0.219
	Minimum	0.000	0.000	0.138	0.010	0.000	0.000	0.000	0.044	0.000	0.000	0.000	0.000	0.405
	Maximum	0.000	0.239	0.419	0.280	0.433	0.603	0.076	0.591	0.218	0.000	0.311	0.616	0.844
Yttrium	Median	0.000	0.063	0.071	0.055	0.057	0.058	0.053	0.051	0.068	0.042	0.060	0.071	0.052
	Mean	0.000	0.064	0.063	0.050	0.053	0.056	0.050	0.052	0.058	0.045	0.061	0.075	0.050
	SD	0.000	0.010	0.015	0.010	0.028	0.015	0.008	0.007	0.029	0.010	0.007	0.010	0.008
	Minimum	0.000	0.055	0.046	0.039	0.024	0.040	0.042	0.045	0.026	0.037	0.055	0.067	0.042
	Maximum	0.000	0.075	0.073	0.057	0.079	0.070	0.056	0.059	0.081	0.056	0.068	0.087	0.057
Zinc[α]	Median	84.865	6.096	16.755	0.210	2.120	0.000	3.901	0.000	0.000	0.000	0.000	0.824	4.034
	Mean	86.664	15.923	51.166	0.152	8.838	22.906	5.723	0.922	13.210	1.875	0.000	31.084	16.482
	SD	12.481	22.508	74.584	0.133	13.513	39.675	6.819	1.596	22.881	3.248	0.000	53.128	25.135
	Minimum	75.181	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	99.947	41.674	136.743	0.246	24.393	68.719	13.269	2.765	39.631	5.626	0.000	92.429	45.412
Zirconium	Median	0.780	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.991	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.494	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Metal	Concentration (µg/L)	Effluent	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Minimum	0.637	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	1.556	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total metals	Median	132.512	31.793	25.752	2.433	3.740	1.989	5.321	3.106	4.671	2.553	3.189	3.157	9.317
	Mean	135.709	30.360	58.269	2.492	17.680	26.085	7.276	3.436	16.623	3.252	3.296	33.490	21.132
	SD	20.768	24.290	77.827	1.111	26.450	41.814	7.198	1.458	23.661	3.018	1.153	54.233	22.247
	Minimum	116.725	5.386	1.973	1.412	1.116	1.898	1.258	2.172	1.323	.646	2.200	1.210	7.286
	Maximum	157.891	53.902	147.081	3.632	48.185	74.367	15.249	5.032	43.877	6.559	4.499	96.103	46.794


Antimony (mg/kg dry weight)
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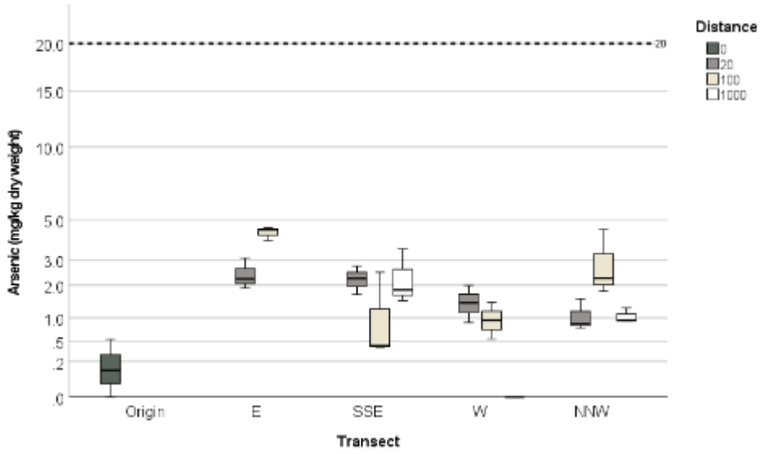
1.50
1.00
.50
.30
.20
.10
.00
Origin
E
SSE
W
NNW
Transect
Distance
0
20
100
1000


Arsenic (mg/kg dry weight)
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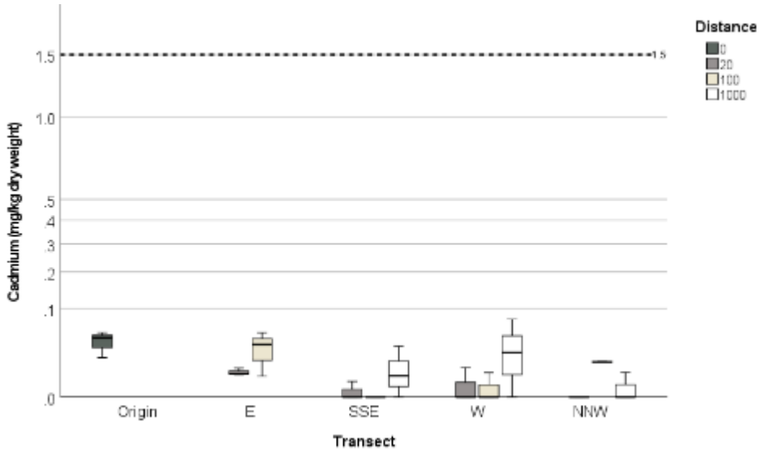
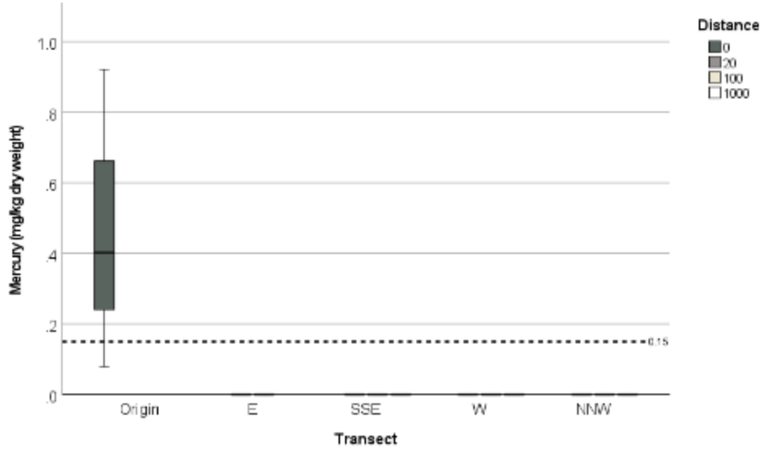
15.0
10.0
5.0
3.0
2.0
1.0
.5
.2
.0
Origin
E
SSE
W
NNW
Transect
Distance
0
20
100
1000


Cadmium (mg/kg dry weight)
1.5
1.0
.5
.4
.3
.2
.1
.0
Origin
E
SSE
W
NNW
Transect
Distance
0
20
100
1000


Mercury (mg/kg dry weight)
1.0
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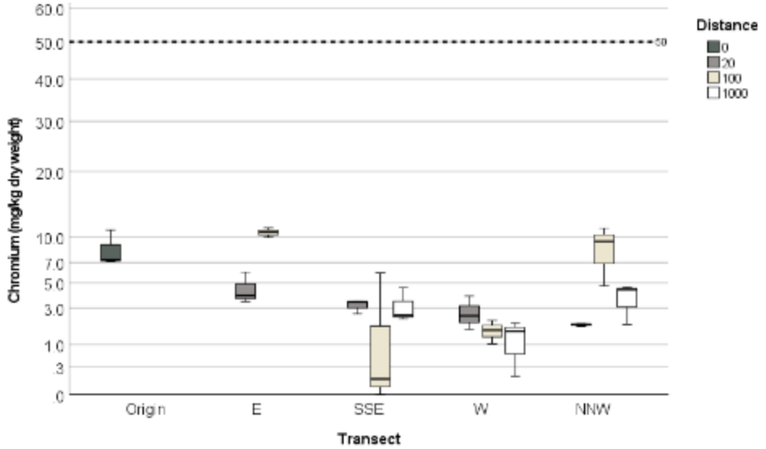
.4
.2
.0
Origin
E
SSE
W
NNW
Transect
Distance
0
20
100
1000


Chromium (mg/kg dry weight)
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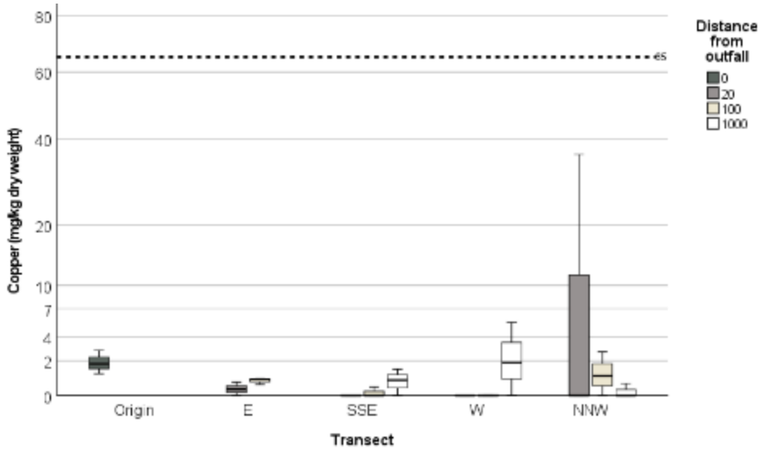
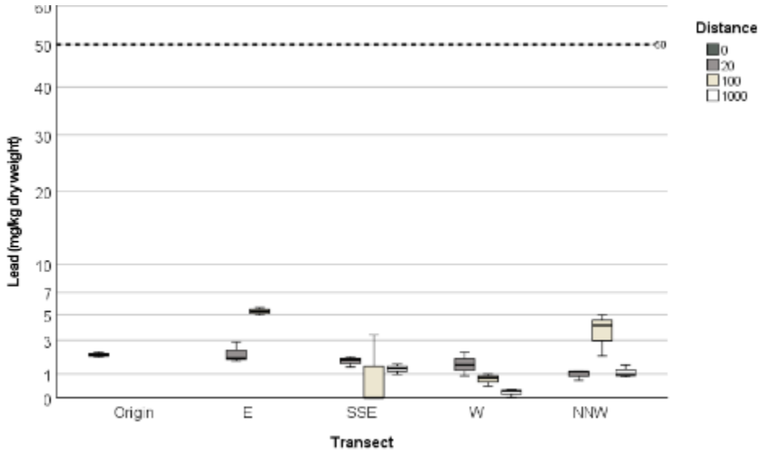
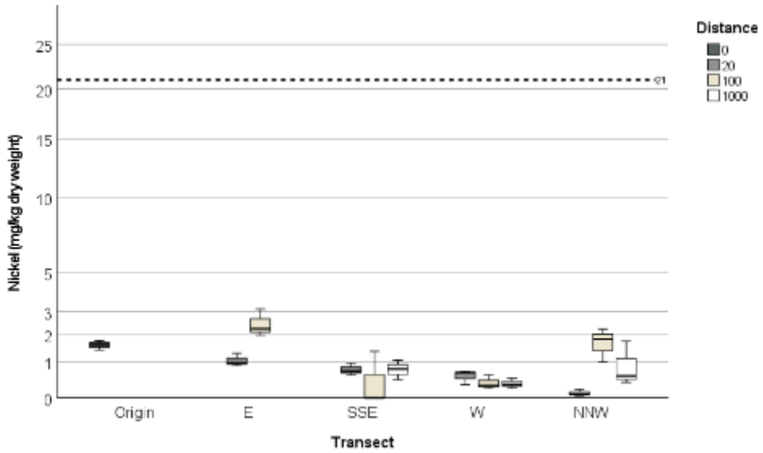
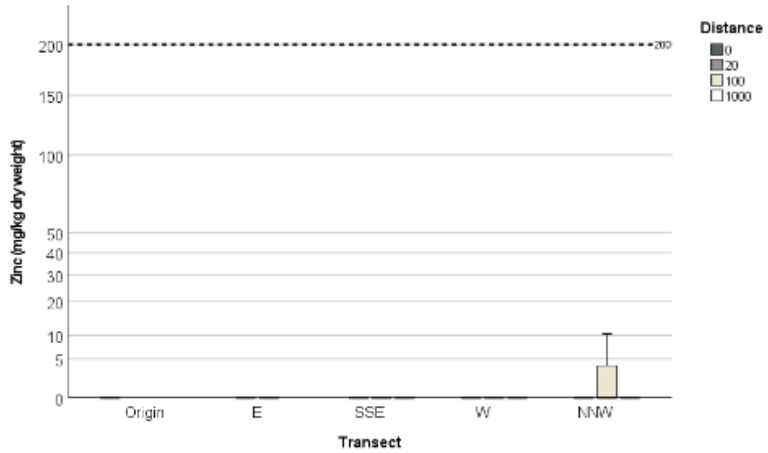
50.0
40.0
30.0
20.0
10.0
7.0
5.0
3.0
1.0
3
0
Origin
E
SSE
W
NNW
Transect
Distance
0
20
100
1000


Copper (mg/kg dry weight)
80
60
40
20
10
7
4
2
0
Origin
E
SSE
W
NNW
Transect
Distance from outfall
0
20
100
1000







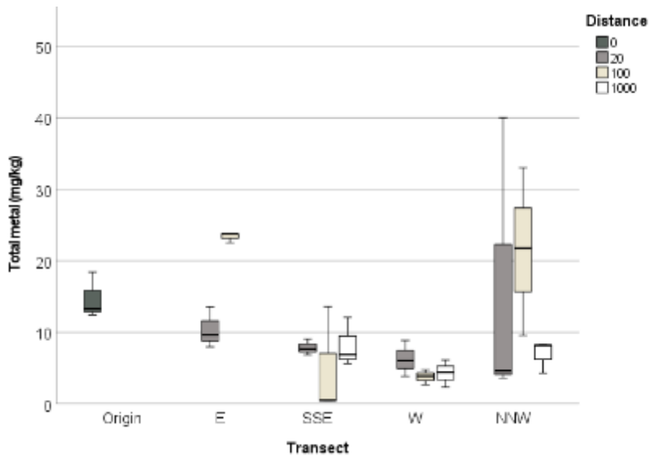


Figure B4. Concentrations of total recoverable metals (mg/kg dry weight; ppm) in the sediment at the WWTP A outfall. Data are from three replicates at each site (n = 3). Metals presented are those associated with sediment Default Guideline Values, which are represented by the dashed reference lines. Total metals represent the sum of all metals associated with a sediment Default Guideline Value. A full list of total recoverable metals is provided in Table C5.

Table B5. Concentrations of total recoverable metals (mg/kg dry weight; ppm) from sediment around the WWTP A outfall. At each location, n = 3. α indicates metals associated with sediment Default Guideline Values that were combined to form a metric of 'total metal' for statistical analyses.

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Aluminium	Median	1520.241	1181.420	2180.118	763.024	84.575	658.139	829.993	395.252	307.427	622.805	1559.309	815.818
	Mean	1645.955	1153.104	2250.907	789.037	500.808	726.028	717.460	390.938	279.217	606.307	1725.590	963.279
	SD	452.037	362.404	229.571	73.666	752.207	280.755	248.498	39.065	96.971	205.303	342.777	557.714
	Minimum	1270.082	777.373	2065.068	731.907	48.715	485.443	432.604	349.895	171.269	393.252	1497.670	494.114
	Maximum	2147.542	1500.521	2507.536	872.180	1369.135	1034.502	889.784	427.667	358.955	802.863	2119.792	1579.907
Antimony[α]	Median	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.058	0.000
	Mean	0.000	0.000	0.013	0.000	0.012	0.015	0.011	0.016	0.000	0.000	0.069	0.000
	SD	0.000	0.000	0.022	0.000	0.020	0.023	0.019	0.028	0.000	0.000	0.065	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000
	Maximum	0.000	0.000	0.038	0.000	0.035	0.042	0.034	0.048	0.000	0.000	0.139	0.000
Arsenic[α]	Median	0.115	2.231	4.478	2.247	0.423	1.830	1.416	0.943	0.000	0.857	2.261	0.943
	Mean	0.216	2.408	4.325	2.226	1.102	2.275	1.432	0.970	0.000	1.055	2.848	1.046
	SD	0.281	0.617	0.360	0.530	1.203	1.087	0.553	0.448	0.000	0.426	1.446	0.198
	Minimum	0.000	1.899	3.914	1.686	0.393	1.482	0.887	0.537	0.000	0.763	1.787	0.922
	Maximum	0.534	3.094	4.582	2.746	2.491	3.514	1.992	1.431	0.000	1.544	4.496	1.274
Barium	Median	6.345	3.704	14.950	2.037	0.000	6.116	2.222	0.835	0.854	1.209	6.418	3.131
	Mean	6.810	5.647	16.988	2.308	1.396	20.443	2.038	0.829	1.018	1.704	8.154	3.315
	SD	2.966	3.757	5.078	0.590	2.418	25.704	0.768	0.225	0.535	1.040	3.202	2.134
	Minimum	4.104	3.259	13.245	1.903	0.000	5.096	1.195	0.602	0.585	1.005	6.194	1.280
	Maximum	9.981	9.978	22.768	2.985	4.188	50.118	2.698	1.051	1.616	2.899	11.849	5.535
Bismuth	Median	0.000	0.020	0.013	0.096	0.000	0.000	0.064	0.032	0.000	0.115	0.035	0.011
	Mean	0.000	0.021	0.097	0.134	0.128	0.004	0.118	0.099	0.000	0.112	0.025	0.012
	SD	0.000	0.020	0.150	0.092	0.222	0.007	0.129	0.145	0.000	0.024	0.018	0.003
	Minimum	0.000	0.002	0.007	0.067	0.000	0.000	0.025	0.000	0.000	0.087	0.004	0.010

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Maximum	0.000	0.042	0.270	0.239	0.385	0.012	0.266	0.265	0.000	0.133	0.036	0.016
Cadmium[α]	Median	0.045	0.007	0.035	0.000	0.000	0.006	0.000	0.000	0.025	0.000	0.016	0.000
	Mean	0.039	0.008	0.031	0.001	0.000	0.013	0.004	0.003	0.034	0.000	0.016	0.003
	SD	0.017	0.002	0.024	0.002	0.000	0.018	0.006	0.004	0.039	0.000	0.001	0.004
	Minimum	0.020	0.006	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.000
	Maximum	0.053	0.011	0.053	0.003	0.000	0.033	0.011	0.008	0.077	0.000	0.016	0.008
Cerium	Median	24.863	13.561	60.936	13.055	1.248	5.560	13.616	7.588	3.087	15.434	49.306	16.190
	Mean	26.114	15.715	57.363	13.340	7.920	6.309	12.909	7.370	4.892	14.659	43.109	16.280
	SD	2.463	6.770	9.426	2.979	11.639	4.245	3.603	3.218	3.200	5.193	17.739	2.518
	Minimum	24.527	10.285	46.672	10.513	1.152	2.488	9.005	4.049	3.002	9.122	23.103	13.808
	Maximum	28.951	23.300	64.480	16.451	21.359	10.879	16.106	10.474	8.587	19.421	56.918	18.841
Cesium	Median	0.502	0.195	0.397	0.154	0.007	0.099	0.131	0.067	0.036	0.079	0.300	0.077
	Mean	3.103	0.174	0.382	0.151	0.075	0.098	0.127	0.064	0.038	0.081	0.274	0.089
	SD	4.738	0.043	0.044	0.016	0.124	0.023	0.018	0.015	0.004	0.007	0.077	0.034
	Minimum	0.234	0.125	0.333	0.134	0.000	0.075	0.107	0.047	0.035	0.075	0.187	0.062
	Maximum	8.572	0.203	0.417	0.165	0.218	0.121	0.142	0.077	0.042	0.089	0.334	0.127
Chromium[α]	Median	7.322	3.926	10.560	3.445	0.098	2.537	2.492	1.669	1.597	1.964	9.432	4.419
	Mean	8.430	4.473	10.550	3.187	2.012	3.144	2.703	1.635	1.258	1.953	8.437	3.675
	SD	2.132	1.362	0.634	0.489	3.401	1.260	1.113	0.589	0.999	0.074	3.301	1.470
	Minimum	7.081	3.470	9.910	2.623	0.000	2.302	1.711	1.030	0.133	1.875	4.752	1.982
	Maximum	10.888	6.024	11.178	3.493	5.939	4.593	3.907	2.206	2.043	2.021	11.125	4.625
Cobalt	Median	0.329	0.094	0.575	0.089	0.000	0.000	0.068	0.000	0.045	0.000	0.181	0.018
	Mean	0.337	0.122	0.576	0.089	0.111	0.068	0.047	0.000	0.073	0.001	0.239	0.061
	SD	0.022	0.059	0.043	0.001	0.193	0.118	0.041	0.000	0.055	0.002	0.273	0.091
	Minimum	0.321	0.081	0.534	0.088	0.000	0.000	0.000	0.000	0.038	0.000	0.000	0.000
	Maximum	0.362	0.189	0.620	0.089	0.334	0.205	0.074	0.000	0.136	0.004	0.537	0.166
Copper[α]	Median	1.785	0.276	0.815	0.000	0.000	0.751	0.000	0.000	1.879	0.000	0.998	0.000
	Mean	1.906	0.308	0.727	0.000	0.133	0.723	0.001	0.005	2.446	11.971	1.231	0.191

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	SD	0.845	0.325	0.181	0.000	0.231	0.710	0.003	0.009	2.768	20.734	1.362	0.330
	Minimum	1.128	0.000	0.520	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000
	Maximum	2.805	0.648	0.847	0.000	0.400	1.418	0.004	0.015	5.454	35.913	2.694	0.572
Dysprosium	Median	0.703	0.479	2.053	0.459	0.041	0.369	0.431	0.196	0.128	0.510	1.224	0.631
	Mean	0.754	0.586	1.968	0.494	0.319	0.297	0.472	0.204	0.160	0.470	1.269	0.574
	SD	0.130	0.225	0.229	0.086	0.484	0.166	0.157	0.032	0.058	0.150	0.540	0.165
	Minimum	0.657	0.435	1.708	0.430	0.038	0.107	0.339	0.176	0.125	0.304	0.753	0.388
	Maximum	0.902	0.844	2.142	0.591	0.877	0.415	0.645	0.239	0.227	0.596	1.831	0.702
Gadolinium	Median	1.422	1.019	4.226	0.862	0.080	0.632	0.893	0.412	0.238	0.970	2.298	1.276
	Mean	1.371	1.133	3.968	0.958	0.567	0.476	0.854	0.415	0.290	0.919	2.518	1.188
	SD	0.095	0.361	0.706	0.213	0.847	0.280	0.221	0.181	0.126	0.231	1.011	0.243
	Minimum	1.261	0.842	3.170	0.809	0.074	0.153	0.617	0.234	0.198	0.668	1.636	0.913
	Maximum	1.430	1.537	4.509	1.202	1.545	0.643	1.053	0.597	0.434	1.120	3.621	1.374
Gallium	Median	2.697	1.919	7.401	1.685	0.151	0.870	1.704	0.664	0.331	1.623	3.326	2.085
	Mean	2.649	2.087	6.921	1.744	1.018	0.667	1.608	0.709	0.491	1.523	4.302	2.056
	SD	0.181	0.744	1.117	0.325	1.521	0.391	0.521	0.109	0.363	0.603	1.888	0.293
	Minimum	2.448	1.442	5.644	1.451	0.129	0.217	1.046	0.630	0.234	0.876	3.101	1.749
	Maximum	2.801	2.901	7.718	2.094	2.774	0.916	2.076	0.833	0.906	2.069	6.478	2.333
Germanium	Median	1.585	0.639	3.181	0.827	0.060	0.316	0.864	0.246	0.494	0.507	1.206	0.776
	Mean	1.689	0.786	2.965	0.883	0.377	0.272	0.777	0.242	0.467	0.618	1.764	0.810
	SD	0.343	0.461	0.655	0.313	0.576	0.119	0.356	0.120	0.098	0.196	1.088	0.177
	Minimum	1.411	0.416	2.230	0.602	0.029	0.137	0.385	0.120	0.358	0.504	1.068	0.652
	Maximum	2.073	1.302	3.485	1.220	1.043	0.364	1.081	0.360	0.549	0.844	3.018	1.001
Hafnium	Median	0.000	0.020	0.051	0.030	0.000	0.000	0.007	0.000	0.000	0.000	0.028	0.017
	Mean	0.000	0.017	0.047	0.027	0.007	0.003	0.005	0.000	0.000	0.000	0.025	0.012
	SD	0.000	0.006	0.024	0.008	0.011	0.005	0.004	0.000	0.000	0.000	0.024	0.011
	Minimum	0.000	0.009	0.020	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.021	0.068	0.033	0.020	0.009	0.008	0.000	0.000	0.000	0.047	0.020

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Indium	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.003	0.001
	SD	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.005	0.001
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.008	0.002
Iron	Median	2953.801	2008.875	5229.104	1768.143	270.076	1266.120	1613.725	697.647	390.541	1411.309	4137.437	1400.910
	Mean	2993.394	2194.276	5269.575	1790.990	1171.866	1650.608	1499.170	651.831	455.537	1411.408	4280.552	1912.218
	SD	389.979	680.308	141.894	298.520	1655.930	854.674	672.803	105.572	235.750	142.733	1485.458	1134.377
	Minimum	2624.722	1625.888	5152.314	1504.551	162.561	1055.708	776.444	531.091	259.103	1268.725	2871.831	1123.490
	Maximum	3401.659	2948.066	5427.308	2100.277	3082.961	2629.994	2107.340	726.755	716.967	1554.190	5832.388	3212.254
Lead[α]	Median	2.041	1.845	5.277	1.763	0.000	1.292	1.466	0.822	0.266	1.115	4.101	0.981
	Mean	2.058	2.140	5.267	1.681	1.126	1.261	1.532	0.756	0.195	0.980	3.684	1.101
	SD	0.154	0.648	0.342	0.296	1.950	0.268	0.654	0.284	0.160	0.246	1.532	0.329
	Minimum	1.913	1.693	4.919	1.353	0.000	0.979	0.913	0.444	0.013	0.696	1.987	0.849
	Maximum	2.219	2.883	5.604	1.928	3.378	1.513	2.216	1.002	0.307	1.128	4.964	1.474
Manganese	Median	45.948	23.467	93.718	19.967	2.377	14.524	19.980	7.884	4.617	37.034	58.752	23.754
	Mean	47.293	28.749	91.583	19.992	12.875	13.697	18.186	7.482	7.175	30.789	64.490	46.615
	SD	5.884	9.723	3.709	3.931	19.281	6.195	6.319	1.114	6.374	15.479	12.386	45.454
	Minimum	42.197	22.810	87.300	16.074	1.121	7.130	11.164	6.222	2.478	13.163	56.013	17.130
	Maximum	53.733	39.970	93.732	23.935	35.127	19.436	23.414	8.339	14.430	42.169	78.704	98.961
Mercury[α]	Median	0.402	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.468	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.425	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.922	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Median	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.000	0.000	0.000

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Molybdenum	Mean	0.135	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.039	0.000	0.000	0.000
	SD	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000
	Minimum	0.103	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000
	Maximum	0.185	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.055	0.000	0.000	0.000
Nickel[α]	Median	1.612	0.972	2.253	0.719	0.000	0.781	0.672	0.305	0.340	0.082	1.822	0.573
	Mean	1.599	1.054	2.450	0.762	0.457	0.772	0.567	0.383	0.361	0.114	1.686	0.904
	SD	0.176	0.218	0.596	0.185	0.791	0.298	0.207	0.190	0.134	0.082	0.627	0.739
	Minimum	1.417	0.888	1.978	0.602	0.000	0.469	0.328	0.244	0.239	0.053	1.002	0.389
	Maximum	1.768	1.301	3.120	0.965	1.370	1.064	0.701	0.600	0.505	0.207	2.234	
Niobium	Median	0.427	0.043	0.178	0.029	0.003	0.017	0.021	0.002	0.128	0.046	0.188	0.125
	Mean	0.450	0.051	0.173	0.033	0.029	0.022	0.021	0.013	0.125	0.060	0.192	0.117
	SD	0.133	0.048	0.015	0.011	0.047	0.022	0.010	0.020	0.017	0.025	0.023	0.089
	Minimum	0.330	0.007	0.156	0.024	0.000	0.002	0.011	0.000	0.107	0.045	0.172	0.024
	Maximum	0.594	0.102	0.185	0.045	0.083	0.046	0.030	0.035	0.140	0.089	0.217	0.202
Rubidium	Median	2.606	1.989	4.403	1.588	0.173	1.587	1.809	0.893	0.574	1.105	3.554	1.462
	Mean	2.754	2.162	4.629	1.678	1.044	1.537	1.584	0.937	0.576	1.190	3.607	1.598
	SD	0.760	0.514	0.666	0.186	1.511	0.345	0.432	0.082	0.166	0.201	0.698	0.677
	Minimum	2.078	1.757	4.107	1.554	0.170	1.170	1.086	0.886	0.412	1.046	2.937	0.999
	Maximum	3.577	2.740	5.379	1.892	2.789	1.854	1.856	1.032	0.743	1.419	4.330	2.333
Scandium	Median	0.000	0.328	1.201	0.274	0.059	0.230	0.276	0.022	0.000	0.293	0.599	0.204
	Mean	0.000	0.407	1.115	0.279	0.280	0.223	0.232	0.071	0.000	0.276	0.581	0.346
	SD	0.000	0.171	0.198	0.084	0.436	0.220	0.127	0.105	0.000	0.042	0.295	0.262
	Minimum	0.000	0.289	0.889	0.197	0.000	0.000	0.089	0.000	0.000	0.229	0.278	0.185
	Maximum	0.000	0.603	1.257	0.365	0.782	0.440	0.332	0.192	0.000	0.307	0.867	0.648
Selenium	Median	0.000	0.739	1.210	0.243	0.000	0.000	0.438	0.000	0.000	0.288	0.631	0.127
	Mean	0.000	0.878	1.242	0.717	0.208	0.400	0.866	0.722	0.000	0.424	0.613	0.489
	SD	0.000	0.837	0.360	0.955	0.360	0.692	1.141	1.251	0.000	0.270	0.605	0.739
	Minimum	0.000	0.119	0.900	0.092	0.000	0.000	0.000	0.000	0.000	0.249	0.000	0.000

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Maximum	0.000	1.776	1.617	1.816	0.624	1.199	2.159	2.167	0.000	0.735	1.209	1.339
Silver	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000
	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.000
Tantalum	Median	0.082	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.039	0.000	0.000	0.000
	Mean	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.013	0.000
	SD	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.022	0.000
	Minimum	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.000
	Maximum	0.122	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.038	0.000
Tellurium	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.002	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.004	0.000	0.000	0.000	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.007	0.000	0.000	0.000	0.078	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Thallium	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.188	0.000
	SD	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.325	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.563	0.000
Thorium	Median	3.591	1.975	10.816	2.037	0.162	0.436	2.112	0.392	0.077	1.507	2.980	2.298
	Mean	3.746	2.337	10.482	2.189	1.309	0.383	1.895	0.518	0.118	1.538	5.517	2.185
	SD	0.398	0.957	2.238	0.588	2.010	0.275	0.786	0.240	0.086	0.511	4.905	0.567
	Minimum	3.449	1.615	8.095	1.692	0.135	0.086	1.023	0.368	0.060	1.044	2.399	1.570
	Maximum	4.198	3.422	12.534	2.838	3.630	0.628	2.550	0.794	0.217	2.064	11.171	2.687
Tin	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	SD	0.000	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.191	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Titanium	Median	167.860	90.344	300.157	69.213	12.760	52.588	77.567	41.308	33.658	119.300	245.116	129.619
	Mean	168.152	106.080	294.594	73.045	49.326	48.152	67.215	41.007	32.347	114.362	281.053	183.165
	SD	8.183	58.026	16.662	13.062	66.898	24.324	17.993	14.065	14.483	37.157	90.930	119.553
	Minimum	160.119	57.545	275.862	62.328	8.681	21.915	46.439	26.795	17.254	74.983	213.584	99.745
	Maximum	176.477	170.352	307.763	87.595	126.537	69.953	77.639	54.919	46.131	148.804	384.460	320.131
Tungsten	Median	0.019	0.000	0.028	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.026	0.018
	Mean	0.026	0.003	0.026	0.002	0.007	0.023	0.000	0.002	0.001	0.000	0.028	0.022
	SD	0.013	0.005	0.006	0.004	0.011	0.012	0.000	0.003	0.001	0.000	0.029	0.008
	Minimum	0.018	0.000	0.020	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.017
	Maximum	0.042	0.009	0.031	0.007	0.020	0.037	0.000	0.006	0.002	0.000	0.057	0.031
Uranium	Median	0.448	0.356	1.372	0.320	0.020	0.170	0.395	0.161	0.069	0.315	0.957	0.335
	Mean	0.453	0.430	1.419	0.344	0.217	0.175	0.335	0.162	0.070	0.311	0.898	0.331
	SD	0.017	0.137	0.270	0.059	0.343	0.076	0.118	0.041	0.013	0.064	0.387	0.050
	Minimum	0.439	0.345	1.177	0.301	0.018	0.101	0.199	0.122	0.058	0.245	0.485	0.279
	Maximum	0.472	0.588	1.710	0.411	0.613	0.253	0.412	0.205	0.083	0.373	1.252	0.378
Vanadium	Median	5.476	5.262	12.126	4.462	0.731	3.679	4.595	2.185	0.072	3.171	8.928	3.345
	Mean	5.893	5.453	12.237	4.722	3.004	4.660	4.388	2.353	0.194	3.224	9.657	4.342
	SD	0.752	1.462	0.517	0.922	4.247	1.855	1.507	0.308	0.276	0.270	3.370	1.885
	Minimum	5.442	4.096	11.784	3.959	0.378	3.502	2.788	2.165	0.000	2.985	6.711	3.165
	Maximum	6.762	7.001	12.801	5.746	7.904	6.800	5.782	2.708	0.510	3.517	13.332	6.516
Yttrium	Median	2.767	2.417	9.121	2.050	0.216	1.406	2.154	0.958	0.511	2.031	5.147	2.840
	Mean	2.918	2.643	8.905	2.156	1.442	1.459	2.087	0.894	0.588	1.976	5.354	2.746
	SD	0.447	0.991	0.631	0.345	2.151	0.859	0.595	0.186	0.203	0.583	2.017	0.994
	Minimum	2.567	1.784	8.195	1.877	0.184	0.628	1.462	0.685	0.434	1.367	3.449	1.709
	Maximum	3.421	3.727	9.399	2.542	3.926	2.344	2.646	1.039	0.819	2.529	7.467	3.690

Metal	Concentration (mg/kg dry weight)	Origin	E		SSE			W			NNW		
		0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Zinc[α]	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.486	0.000
	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.037	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	10.457	0.000
Zirconium	Median	1.479	0.843	1.755	1.065	0.043	0.329	0.337	0.352	0.110	0.248	1.261	0.346
	Mean	1.788	0.688	2.073	0.895	0.384	0.372	0.468	0.304	0.187	0.284	1.049	0.447
	SD	0.673	0.291	0.590	0.337	0.628	0.090	0.389	0.174	0.236	0.213	0.481	0.181
	Minimum	1.326	0.352	1.710	0.507	0.000	0.312	0.162	0.111	0.000	0.092	0.499	0.339
	Maximum	2.560	0.869	2.755	1.112	1.109	0.476	0.906	0.448	0.452	0.513	1.388	0.656
Total metals	Median	13.270	9.629	23.755	7.661	.491	6.881	6.046	3.877	4.427	4.599	21.786	8.154
	Mean	14.716	10.391	23.363	7.858	4.842	8.204	6.250	3.767	4.295	16.072	21.456	6.920
	SD	3.243	2.888	.720	1.140	7.595	3.434	2.519	1.055	1.905	20.745	11.739	2.275
	Minimum	12.448	7.961	22.531	6.829	.423	5.627	3.839	2.661	2.327	3.598	9.556	4.294
	Maximum	18.430	13.584	23.801	9.084	13.612	12.102	8.865	4.763	6.130	40.019	33.027	8.311

7.7 B4. Antibiotics quantification

Table B6. Concentrations of antibiotics in composite effluent (µg/L; ppb) from the WWTP A (n = 3). Antibiotics were not detected in seawater samples around the WWTP A outfall. Note that only the family of β-lactam antibiotics are subdivided into classes. ND = not detected; SD = standard deviation.

		Concentration (µg/L)				
Family (class)	**Antibiotic**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**
β-lactams (penicillins)	Flucloxacillin sodium	-	-	-	ND	ND
	Penicillin V	-	-	-	ND	ND
β-lactams (cephalosporins)	Cefalexin	-	-	-	ND	ND
Dihydrofolate reductase inhibitors	Trimethoprim	0.121	0.199	0.166	0.087	0.390
Fluoroquinolones	Enrofloxacin	-	-	-	ND	ND
	Ciprofloxacin	-	-	-	ND	ND
	Norfloxacin	-	-	-	ND	ND
	Ofloxacin	-	-	-	ND	ND
Macrolides	Clarithromycin	0.401	0.432	0.151	0.298	0.595
	Erythromycin	-	-	-	ND	ND
	Roxithromycin	0.228	0.222	0.017	0.204	0.236
Sulfonamides	Sulfamethoxazole	0.145	0.145	0.023	0.129	0.161
Tetracyclines	Tetracycline hydrochloride	-	-	-	ND	ND
	Doxycycline hyclate	-	-	-	ND	ND
	Oxytetracycline hydrochloride	-	-	-	ND	ND
	Total antibiotics	0.952	0.950	0.096	0.853	1.045

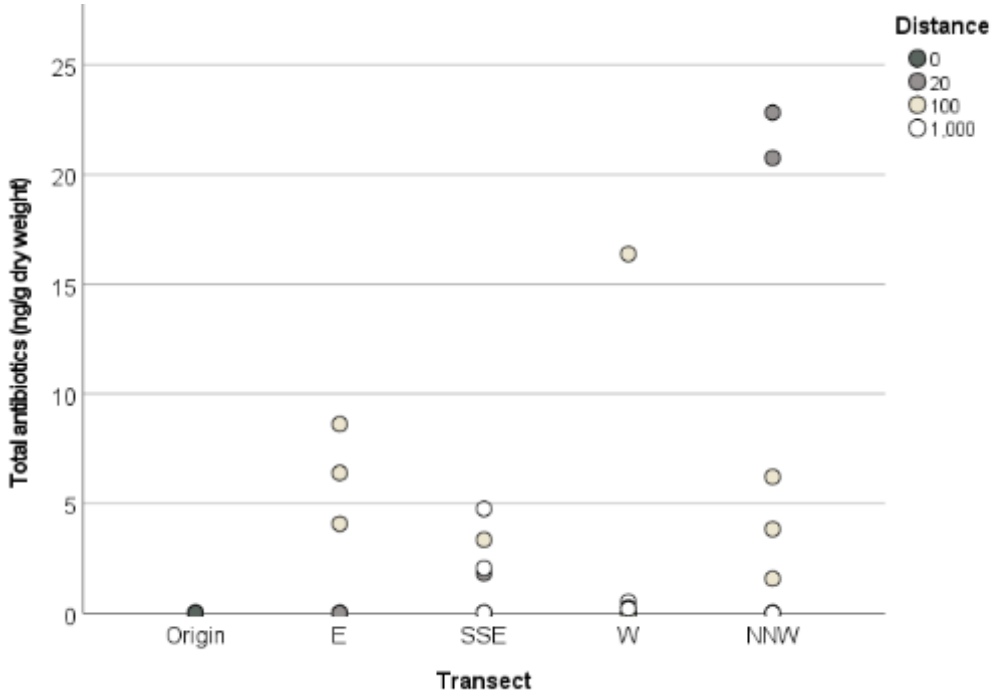


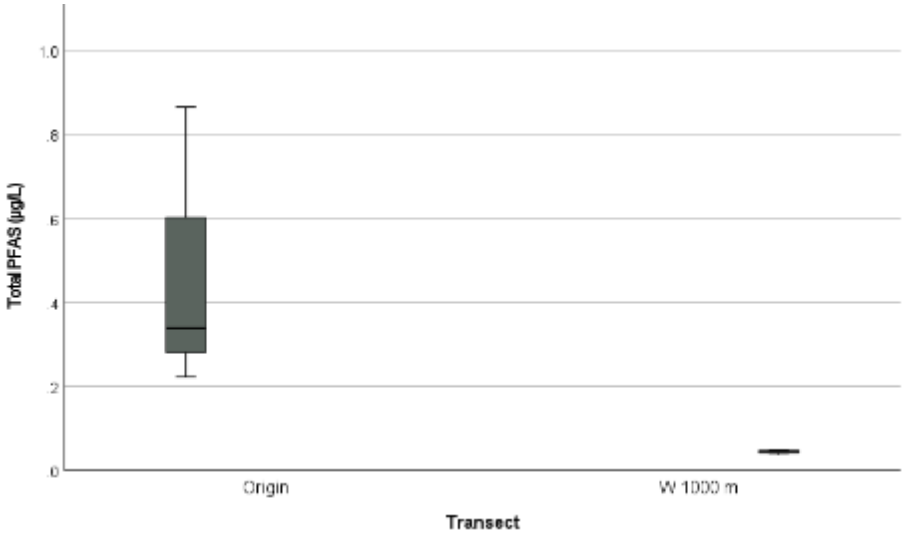
Figure B5. The total concentration of antibiotics (ng/g dry weight; ppm) detected in sediment around the WWTP A outfall. Dots represent replicates. At each site, n = 3.

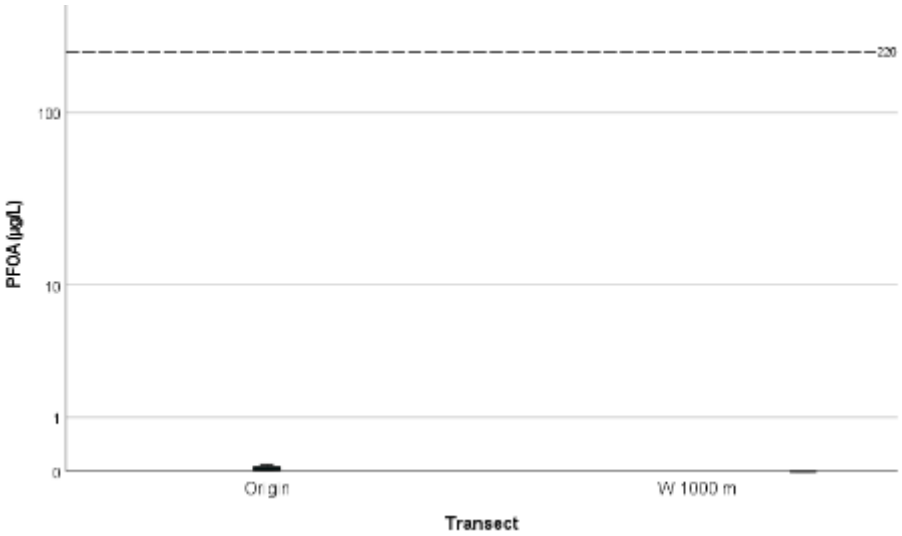
Table B7. Concentrations of antibiotics in sediments (ng/g dry weight; ppb) from around the WWTP A outfall. For each sample, n = 3. Note that only the family of β-lactam antibiotics are subdivided into classes. ND = not detected; SD = standard deviation.

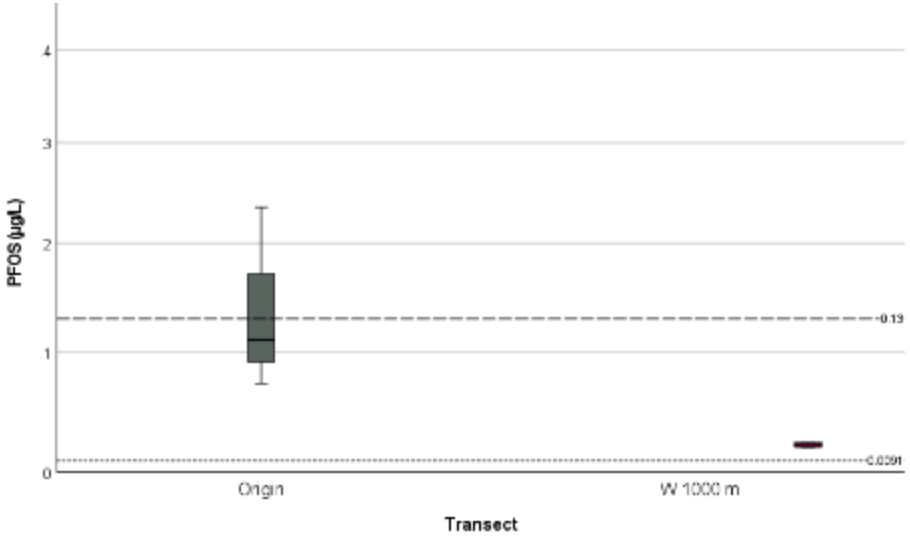
Family (class)	Antibiotic	Concentration (ng/g dry weight)	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
β-lactams (penicillins)	Penicillin V	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
		Maximum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
β-lactams (cephalosporins)	Cefalexin	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	ND	<LOD	ND	<LOD	ND	ND	ND	<LOD	ND	ND	ND
		Maximum	<LOD	ND	ND	ND	ND	ND	ND	ND	<LOD	ND	ND	ND
Dihydrofolate reductase inhibitors	Trimethoprim	Median	0.017	0.01	-	-	0.002	0.047	-	-	0.191	0.054	-	-
		Mean	0.017	0.01	-	-	0.002	0.047	-	-	0.206	0.054	-	0.001
		SD	0.004	-	-	-	0.003	0.034	-	-	0.063	0.049	-	-
		Minimum	0.014	ND	<LOD	ND	ND	ND	ND	ND	0.152	ND	ND	ND
		Maximum	0.022	0.01	ND	ND	0.004	0.071	ND	ND	0.275	0.088	ND	0.001
Fluoroquinolones	Enrofloxacin	Median	-	-	-	-	-	-	-	-	0.085	-	-	-
		Mean	-	-	-	-	-	-	-	-	0.085	-	-	-
		SD	-	-	-	-	-	-	-	-	0.056	-	-	-
		Minimum	<LOD	ND	ND	ND	ND	ND	ND	ND	<LOD	ND	ND	ND
		Maximum	<LOD	ND	ND	ND	ND	ND	ND	ND	0.125	ND	ND	ND
	Ciprofloxacin	Median	-	-	-	-	-	-	-	0.374	-	1.622	-	-
		Mean	-	-	-	-	-	-	-	0.374	-	1.622	-	-
		SD	-	-	-	-	-	-	-	.	-	0.062	-	-
		Minimum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
		Maximum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.374	<LOD	1.666	<LOD	<LOD
	Norfloxacin	Median	-	-	6.39	1.814	3.345	3.371	-	16.007	-	20.127	3.831	-
		Mean	-	-	6.361	1.814	3.345	3.371	-	16.007	-	20.127	3.871	-
		SD	-	-	2.272	-	-	1.96	-	-	-	1.464	2.323	-
		Minimum	<LOD	<LOD	4.076	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1.569	<LOD
		Maximum	<LOD	<LOD	8.619	1.814	3.345	4.757	<LOD	16.007	<LOD	21.163	6.214	<LOD
	Ofloxacin	Median	-	-	-	-	-	-	-	-	0.062	-	-	-
		Mean	-	-	-	-	-	-	-	-	0.061	-	-	-
		SD	-	-	-	-	-	-	-	-	0.053	-	-	-
		Minimum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.008	<LOD	<LOD	<LOD
		Maximum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	ND	<LOD	0.114	<LOD	<LOD	ND
Macrolides	Clarithromycin	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	ND	ND	ND	ND	ND	ND	ND	<LOD	ND	ND	ND
		Maximum	<LOD	ND	ND	ND	ND	ND	ND	ND	<LOD	ND	ND	ND

Family (class)	Antibiotic	Concentration (ng/g dry weight)	Origin	E		SSE			W			NNW		
			0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Roxithromycin	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
		Maximum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Sulfonamides	Sulfamethoxazole	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<LOD
		Maximum	<LOD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<LOD
Tetracyclines	Tetracycline hydrochloride	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
		Maximum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
	Doxycycline hyclate	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
		Maximum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
	Oxytetracycline hydrochloride	Median	-	-	-	-	-	-	-	-	-	-	-	-
		Mean	-	-	-	-	-	-	-	-	-	-	-	-
		SD	-	-	-	-	-	-	-	-	-	-	-	-
		Minimum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
		Maximum	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
	Total antibiotics	Median	0.017	-	6.39	-	0.004	2.056	-	-	0.259	20.758	3.831	-
		Mean	0.017	0.003	6.361	0.605	1.116	2.278	-	5.46	0.324	14.535	3.871	-
		SD	0.004	0.006	2.272	1.047	1.93	2.375	-	9.458	0.168	12.614	2.323	0.001
		Minimum	0.014	< LOD	4.076	< LOD	< LOD	0.023	< LOD	< LOD	0.198	0.019	1.569	< LOD
		Maximum	0.022	0.01	8.619	1.814	3.345	4.757	0	16.381	0.514	22.828	6.214	0.001

7.8 B5. PFAS quantification







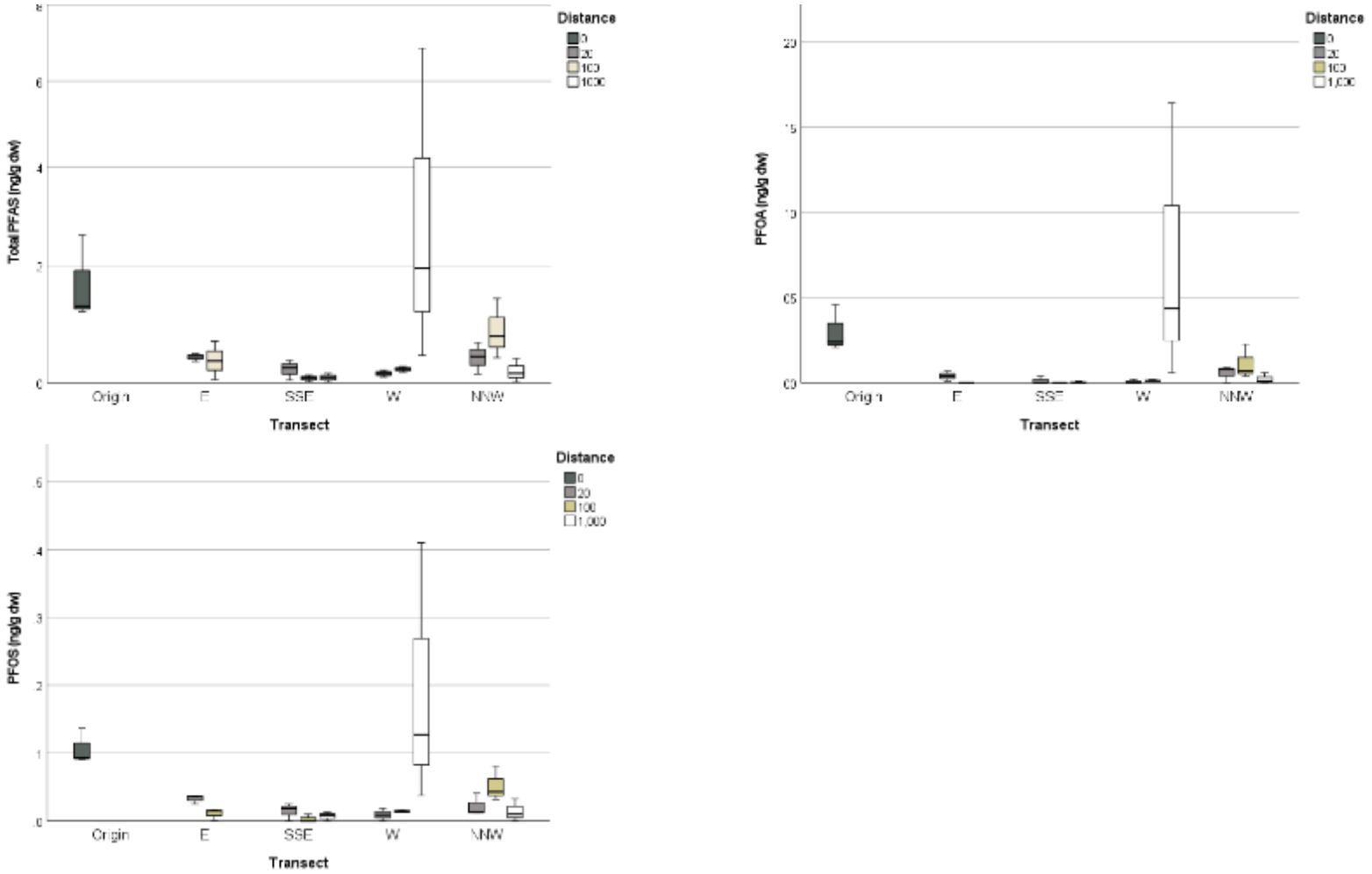


Figure B6. Concentrations of total PFAS, PFOA and PFOS in (A-C) seawater (µg/L; ppb) and (D-E) sediment (ng/g dry weight; ppm) collected from around the WWTP A outfall. At each location, n = 3. The reference line with short dashes represents the draft freshwater Default Guideline Values for PFOS for 99 % species protection in slightly to moderately disturbed ecosystems, which is currently being considered by the Commonwealth government. Reference lines with long dashes represent marine guideline values proposed by the Heads of EPAs. There are no guidelines for PFAS concentrations in sediment. A full list of detected PFAS is provided in Table B9.

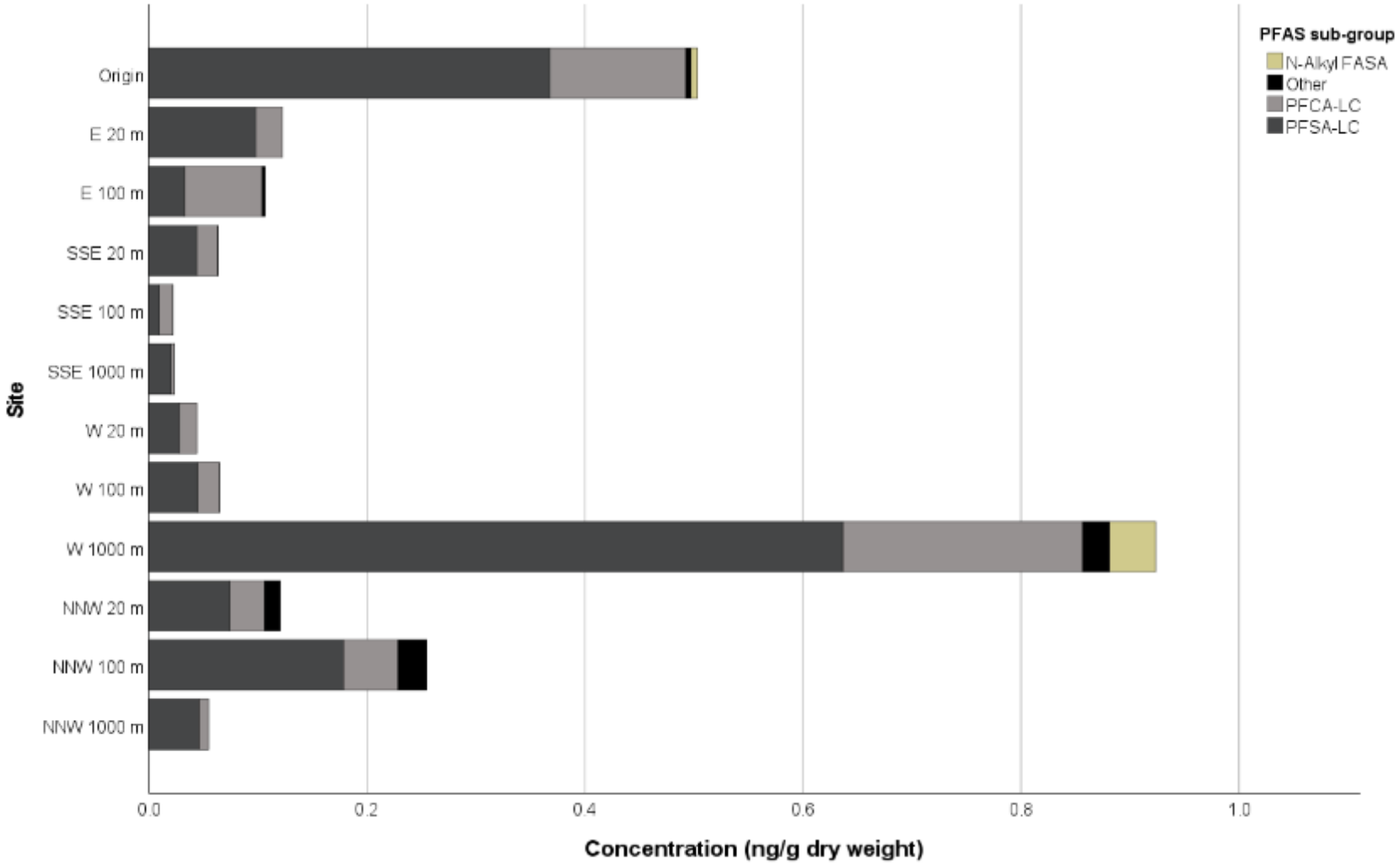


Figure B7. The concentration of PFAS sub-groups (ng/g dry weight) in sediment at each sampling site. Sub-groups that represent < 2% of PFAS in a sample have been amalgamated into the category 'Other'. 'LC' refers to 'long chain'. At each site, n = 3.

Table B8. Concentrations of PFAS (µg/L; ppb) in composite effluent from the WWTP A (n = 2), and in seawater collected from the origin (0 m) and 1000 m along the west (W) transect at the WWTP A outfall (n = 3). LOD = limit of detection; ND = not detected; SD = standard deviation.

				Concentration (ng/mL)				
Group	**Sub-group**	**Analyte**	**Sample**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**
Perfluoroalkyl acids	Perfluoroalkyl carboxylic acids (PFCAs)	PFHpA	Effluent	0.210	0.210	0.006	0.206	0.214
			Origin	0.006	0.013	0.018	0.000	0.034
			W 1000 m	-	-	-	< LOD	< LOD
		PFOA	Effluent	0.738	0.738	0.042	0.708	0.768
			Origin	0.026	0.044	0.040	0.017	0.090
			W 1000 m	-	-	-	< LOD	< LOD
		PFNA	Effluent	0.060	0.060	0.008	0.054	0.065
			Origin	0.004	0.004		0.004	0.004
			W 1000 m	-	-	-	< LOD	ND
		PFDA	Effluent	0.085	0.085	0.027	0.066	0.104
			Origin	0.007	0.007		0.007	0.007
			W 1000 m	-	-	-	< LOD	< LOD
		PFUna	Effluent	-	-	-	< LOD	< LOD
			Origin	-	-	-	< LOD	< LOD
			W 1000 m	-	-	-	ND	ND
		PFDoA	Effluent	0.005	0.005	-	< LOD	0.005
			Origin	-	-	-	< LOD	< LOD
			W 1000 m	-	-	-	ND	ND
		PFTrDa	Effluent	-	-	-	< LOD	ND
			Origin	-	-	-	< LOD	ND
			W 1000 m	-	-	-	< LOD	< LOD
		PFTeDa	Effluent	-	-	-	< LOD	< LOD
			Origin	-	-	-	< LOD	< LOD
			W 1000 m	-	-	-	< LOD	< LOD
	Perfluoroalkane sulfonic acids (PFSAs)	PFBS	Effluent	0.462	0.462	0.074	0.410	0.514
			Origin	0.009	0.018	0.016	0.008	0.037
			W 1000 m	-	-	-	< LOD	< LOD
		PFPeS	Effluent	0.207	0.207	0.004	0.204	0.209
			Origin	0.007	0.007	0.008	0.001	0.012
			W 1000 m	-	-	-	< LOD	< LOD
		PFHxS	Effluent	2.256	2.256	0.203	2.112	2.399
			Origin	0.086	0.114	0.072	0.061	0.196
			W 1000 m	0.017	0.017	0.002	0.020	0.020
		PFHpS	Effluent	0.041	0.041	0.008	0.035	0.046
			Origin	-	-	-	< LOD	ND
			W 1000 m	-	-	-	ND	ND
		PFOS	Effluent	2.987	2.987		2.987	2.987
			Origin	0.111	0.140	0.085	0.073	0.235
			W 1000 m	0.022	0.022	0.003	0.020	0.020
		PFNS	Effluent	-	-	-	ND	ND
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	< LOD	ND
		PFDS	Effluent	-	-	-	ND	ND
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
Perfluoroalkane sulfonamido substances	N-Alkyl perfluoroalkane sulfonamide acetic acids (N-Alkyl FASAAs)	N-MeFOSAA	Effluent	-	-	-	ND	ND
			Origin	-	-	-	< LOD	ND
			W 1000 m	-	-	-	ND	ND
		N-EtFOSSA	Effluent	-	-	-	ND	ND
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
Perfluoroalkane sulfonamides (FASAs)	Not applicable	FBSA	Effluent	0.267	0.267	0.011	0.259	0.275
			Origin	0.011	0.017	0.012	0.009	0.030
			W 1000 m	-	-	-	< LOD	ND

Group	Sub-group	Analyte	Sample	Concentration (ng/mL)				
				Median	Mean	SD	Minimum	Maximum
		PFHxA	Effluent	1.711	1.711	0.025	1.693	1.729
			Origin	0.091	0.122	0.088	0.053	0.221
			W 1000 m	0.005	0.012	0.016	0.001	0.030
Per- and polyfluoroalkyl ether acids (PFEAs)	Fluorotelomer-based substances	4:2 FTS	Effluent	-	-	-	ND	ND
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
		6:2 FTS	Effluent	0.010	0.010	0.013	0.000	0.019
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
		8:2 FTS	Effluent	0.021	0.021		0.021	0.021
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
	Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	NaDONA	Effluent	-	-	-	ND	ND
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	< LOD	<ND
		HFPO-DA	Effluent	-	-	-	ND	ND
			Origin	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
	Per- and polyfluoroalkyl ether sulfonic acids (PFESAs)	9Cl-PF3ONS	Effluent	-	-	-	< LOD	< LOD
			Origin	-	-	-	< LOD	< LOD
			W 1000 m	-	-	-	< LOD	< LOD
		11Cl-PF3OUdS	Effluent	-	-	-	< LOD	< LOD
			Origin	-	-	-	< LOD	< LOD
			W 1000 m	-	-	-	< LOD	< LOD
		Total PFAS	Effluent	7.551	7.551	2.432	5.831	9.271
			Origin	0.339	0.476	0.343	0.223	0.866
			W 1000 m	0.046	0.044	0.006	0.040	0.050

Table B9. Concentrations of PFAS (ng/g dry weight; ppm) from sediment around the WWTP A outfall. At each location, n = 3. LOD = limit of detection; ND = not detected; SD = standard deviation.

Group	Sub-group	Analyte	Concentration (ng/g dry weight)	Origin	E		SSE			W			NNW		
				0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Perfluoroalkyl acids	Perfluoroalkyl carboxylic acids (PFCAs)	PFHpA	Median	-	-	-	-	-	-	-	-	0.000	0.000	-	-
			Mean	-	-	-	-	-	-	-	-	0.003	0.001	-	-
			SD	-	-	-	-	-	-	-	-	0.005	0.001	-	-
			Minimum	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	< LOD	< LOD	< LOD	< LOD	ND	< LOD	< LOD	< LOD	0.008	0.002	< LOD	< LOD
		PFOA	Median	0.024	0.004	-	0.000	-	0.000	0.000	0.001	0.044	0.008	0.007	0.001
			Mean	0.030	0.004	-	0.001	-	0.000	0.001	0.001	0.071	0.006	0.011	0.002
			SD	0.014	0.003	-	0.002	-	0.001	0.001	0.001	0.083	0.005	0.010	0.003
			Minimum	0.021	0.001	< LOD	< LOD	< LOD	< LOD	< LOD	0.001	0.006	< LOD	0.004	< LOD
			Maximum	0.046	0.007	< LOD	0.004	< LOD	0.001	0.002	0.002	0.164	0.009	0.023	0.006
		PFNA	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	< LOD	< LOD	ND	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	ND	ND	ND	< LOD	< LOD	ND	ND	< LOD	ND	ND	ND	ND
		PFDA	Median	-	-	0.000	-	-	0.000	0.000	-	-	0.000	0.000	-
			Mean	-	-	0.000	-	-	0.000	0.000	-	-	0.000	0.001	-
			SD	-	-	0.001	-	-	0.001	0.001	-	-	0.001	0.002	-
			Minimum	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	ND	< LOD	0.001	ND	< LOD	0.001	0.001	< LOD	< LOD	0.001	0.003	ND
		PFUnA	Median	-	-	-	0.000	-	-	-	-	-	-	-	-
			Mean	-	-	-	0.001	-	-	-	-	-	-	-	-
			SD	-	-	-	0.001	-	-	-	-	-	-	-	-
			Minimum	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	< LOD	< LOD	< LOD	0.002	ND	< LOD	< LOD	ND	ND	< LOD	< LOD	< LOD
		PFDoA	Median	0.006	0.001	0.004	0.001	0.002	0.000	0.006	0.004	0.000	0.003	0.004	-
			Mean	0.005	0.002	0.003	0.002	0.003	0.000	0.004	0.005	0.002	0.003	0.004	-
			SD	0.002	0.002	0.002	0.001	0.001	0.001	0.003	0.005	0.003	0.004	0.001	-
			Minimum	0.003	0.001	0.001	0.001	0.002	ND	0.001	< LOD	< LOD	ND	0.003	< LOD
			Maximum	0.007	0.004	0.004	0.003	0.004	0.001	0.006	0.010	0.006	0.007	0.004	< LOD
		PFTrDA	Median	0.002	0.002	0.008	0.003	0.000	-	-	0.000	-	0.001	0.001	0.001
			Mean	0.003	0.002	0.010	0.003	0.001	-	-	0.001	-	0.001	0.001	0.001
			SD	0.003	0.002	0.009	0.002	0.002	-	-	0.001	-	0.000	0.001	0.001
			Minimum	< LOD	0.001	0.003	0.001	ND	< LOD	ND	ND	< LOD	0.001	ND	ND
			Maximum	0.007	0.004	0.020	0.004	0.004	ND	ND	0.002	ND	0.001	0.001	0.001
		PFTeDA	Median	0.002	-	0.008	-	-	-	-	-	-	-	-	-
			Mean	0.003	-	0.010	-	-	-	-	-	-	-	-	-
			SD	0.003	-	0.011	-	-	-	-	-	-	-	-	-

Group	Sub-group	Analyte	Concentration (ng/g dry weight)	Origin	E		SSE			W			NNW		
				0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
			Minimum	0.000	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	0.007	< LOD	0.023	ND	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	Perfluoroalkane sulfonic acids (PFSAs)	PFBS	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	< LOD	< LOD	< LOD	ND	< LOD	< LOD	< LOD	ND	< LOD	< LOD	< LOD	< LOD
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PFPeS	Median	-	-	-	-	-	-	-	-	0.000	-	-	-
			Mean	-	-	-	-	-	-	-	-	0.003	-	-	-
			SD	-	-	-	-	-	-	-	-	0.005	-	-	-
			Minimum	< LOD	ND	ND	ND	< LOD	ND	ND	ND	< LOD	ND	ND	ND
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	0.009	ND	ND	ND
		PFHxS	Median	0.000	-	-	-	-	-	-	0.000	0.019	0.002	0.010	0.000
			Mean	0.016	-	-	-	-	-	-	0.000	0.020	0.003	0.008	0.001
			SD	0.028	-	-	-	-	-	-	0.001	0.021	0.004	0.007	0.002
			Minimum	< LOD	< LOD	ND	ND	ND	< LOD	< LOD	ND	ND	ND	ND	ND
			Maximum	0.048	ND	ND	ND	ND	ND	ND	0.001	0.043	0.007	0.013	0.003
		PFHpS	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PFOS	Median	0.093	0.036	0.015	0.019	0.000	0.008	0.009	0.014	0.127	0.013	0.043	0.010
			Mean	0.107	0.033	0.011	0.015	0.003	0.007	0.009	0.015	0.192	0.022	0.052	0.014
			SD	0.026	0.007	0.009	0.013	0.006	0.006	0.009	0.002	0.194	0.016	0.026	0.017
			Minimum	0.090	0.025	0.001	ND	ND	ND	ND	0.013	0.038	0.012	0.032	ND
			Maximum	0.137	0.037	0.017	0.025	0.010	0.013	0.019	0.017	0.410	0.041	0.081	0.033
		PFNS	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	ND	ND	ND	ND	ND	ND	< LOD	ND	ND	ND	ND
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		PFDS	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	ND	< LOD	ND	< LOD	ND	< LOD	ND	< LOD	ND	ND	< LOD
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	N-Alkyl perfluoroalkane	MeFOSAA	Median	0.000	-	-	-	-	-	-	-	0.000	-	-	-
			Mean	0.002	-	-	-	-	-	-	-	0.014	-	-	-

Group	Sub-group	Analyte	Concentration (ng/g dry weight)	Origin	E		SSE			W			NNW		
				0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Perfluoroalkane sulfonamido substances	sulfonamide acetic acids (N-Alkyl FASAAs)		SD	0.003	-	-	-	-	-	-	-	0.025	-	-	-
			Minimum	ND	< LOD	ND	ND	ND	ND	ND	ND	ND	< LOD	< LOD	< LOD
			Maximum	0.006	ND	ND	ND	ND	ND	ND	ND	0.043	ND	ND	ND
		EtFOSAA	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Perfluoroalkane sulfonamides (FASAs)	Not applicable	FBSA	Median	-	-	-	-	-	-	-	-	-	-	0.011	-
			Mean	-	-	-	-	-	-	-	-	-	-	0.009	-
			SD	-	-	-	-	-	-	-	-	-	-	0.008	-
			Minimum	ND	< LOD	ND	< LOD	ND	ND	ND	ND	< LOD	< LOD	< LOD	< LOD
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.016	ND
		PFHxA	Mean	-	-	-	0.000	-	-	-	-	0.003	0.004	-	-
			SD	-	-	-	0.001	-	-	-	-	0.005	0.007	-	-
			Minimum	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	< LOD	< LOD	< LOD	0.001	< LOD	< LOD	< LOD	< LOD	0.008	0.013	< LOD	< LOD
Per- and polyfluoroalkyl ether acids (PFEAs)	Fluorotelomer-based substances	4:2 FTS	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND	< LOD	ND	< LOD
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		6:2 FTS	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	< LOD	ND	ND	ND	< LOD	ND	< LOD	ND	ND	< LOD	ND	< LOD
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		8:2 FTS	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	< LOD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	NaDONA	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	ND	< LOD	ND	< LOD	< LOD	ND	< LOD	ND	< LOD	< LOD	ND
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		HFPO-DA	Median	-	-	-	-	-	-	-	-	-	-	-	-
			Mean	-	-	-	-	-	-	-	-	-	-	-	-

Group	Sub-group	Analyte	Concentration (ng/g dry weight)	Origin	E		SSE			W			NNW		
				0 m	20 m	100 m	20 m	100 m	1000 m	20 m	100 m	1000 m	20 m	100 m	1000 m
			SD	-	-	-	-	-	-	-	-	-	-	-	-
			Minimum	ND	< LOD	ND	ND	ND	ND	ND	< LOD	ND	ND	< LOD	ND
			Maximum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Per- and polyfluoroalkyl ether sulfonic acids (PFESAs)	9Cl-PF3ONS	Median	0.000	-	-	-	-	-	-	-	-	-	-	-
			Mean	0.001	-	-	-	-	-	-	-	-	-	-	-
			SD	0.002	-	-	-	-	-	-	-	-	-	-	-
			Minimum	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	0.003	ND	< LOD	< LOD	ND	< LOD	< LOD	ND	< LOD	< LOD	< LOD	< LOD
		11Cl-PF3OUdS	Median	0.000	-	0.000	-	-	-	-	-	-	-	-	-
			Mean	0.001	-	0.001	-	-	-	-	-	-	-	-	-
			SD	0.001	-	0.002	-	-	-	-	-	-	-	-	-
			Minimum	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
			Maximum	0.002	< LOD	0.003	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		Total PFAS	Median	0.127	0.043	0.035	0.024	0.008	0.008	0.015	0.022	0.196	0.042	0.075	0.015
			Mean	0.168	0.041	0.036	0.021	0.007	0.008	0.015	0.021	0.308	0.040	0.085	0.018
			SD	0.079	0.006	0.031	0.016	0.005	0.007	0.005	0.004	0.335	0.026	0.051	0.019
			Minimum	0.118	0.034	0.005	0.004	0.002	0.001	0.009	0.017	0.044	0.014	0.040	0.001
			Maximum	0.259	0.046	0.067	0.036	0.012	0.015	0.020	0.026	0.684	0.065	0.141	0.039

7.9 B6. Microplastics quantification

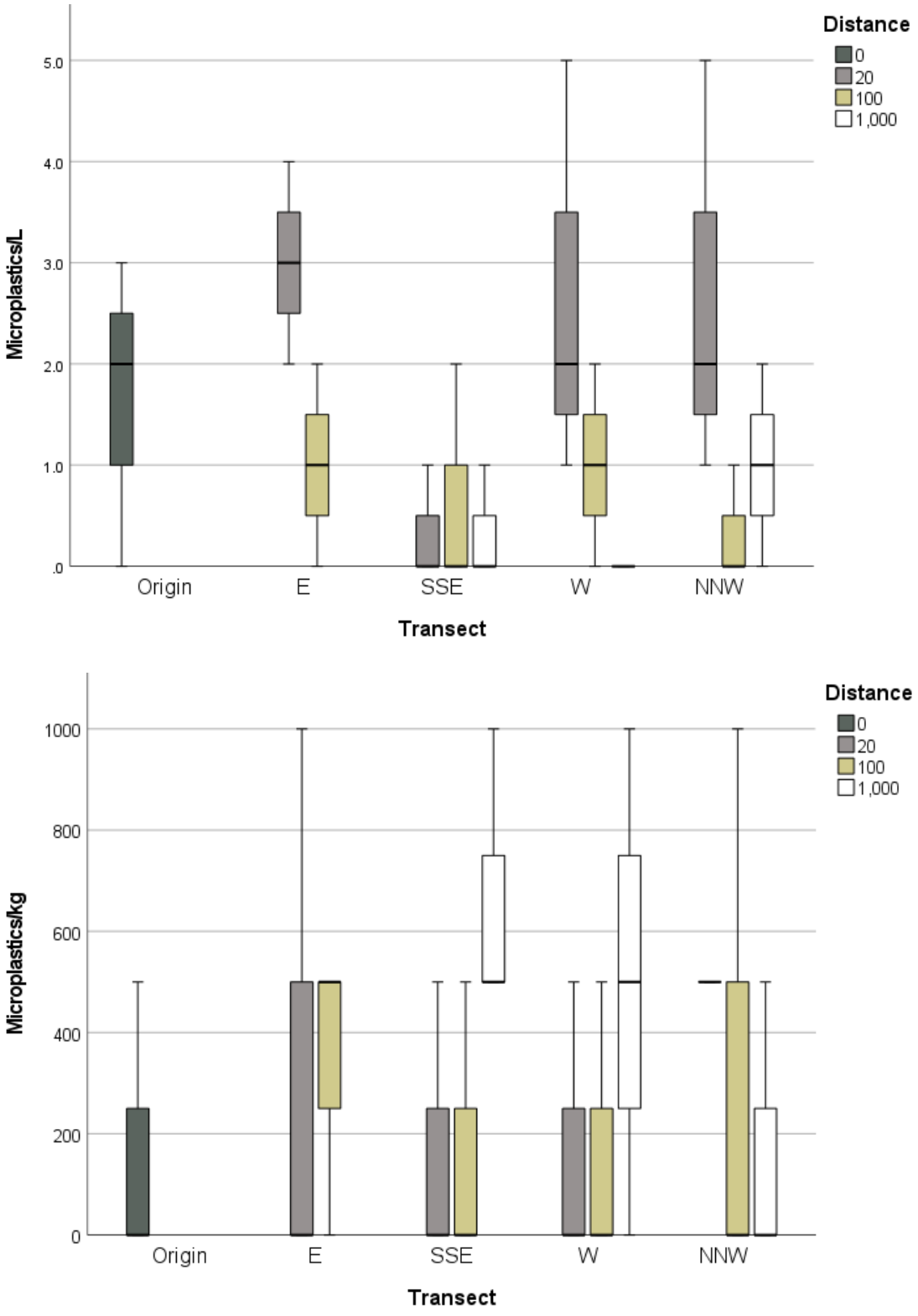


Figure B7. Concentration of microplastic particles in (top) seawater (microplastics/L) and (bottom) sediment (microplastics/kg) surrounding the WWTP A outfall. At each location, n = 3.

Table B10. Concentrations of microplastics in composite effluent from the WWTP A (microplastics/L), and in seawater (microplastics/L) and sediment (microplastics/kg) collected from the WWTP A outfall. For all samples, n = 3. SD = standard deviation.

Partition	Transect	Distance from outfall (m)	Median	Mean	SD	Minimum	Maximum
Effluent	NA	NA	2	2.0	2.0	0	4
Seawater	Origin	0	2	1.7	1.5	0	3
	E	20	3	3.0	1.0	2	4
		100	1	1.0	1.0	0	2
	SSE	20	0	0.3	0.6	0	1
		100	0	0.7	1.2	0	2
		1000	0	0.3	0.6	0	1
	W	20	2	2.7	2.1	1	5
		100	1	1.0	1.0	0	2
		1000	0	0.0	0.0	0	0
	NNW	20	2	2.7	2.1	1	5
		100	0	0.3	0.6	0	1
		1000	1	1.0	1.0	0	2
Sediment	Origin	0	0	166.7	288.7	0	500
	E	20	0	333.3	577.4	0	1000
		100	500	333.3	288.7	0	500
	SSE	20	0	166.7	288.7	0	500
		100	0	166.7	288.7	0	500
		1000	500	666.7	288.7	500	1000
	W	20	0	166.7	288.7	0	500
		100	0	166.7	288.7	0	500
		1000	500	500.0	500.0	0	1000
	NNW	20	500	500.0	0.0	500	500
		100	0	333.3	577.4	0	1000
		1000	0	166.7	288.7	0	500

Appendix C: Data from the WWTP B outfall

7.10 C1. Physico-chemical parameters

Table C1. Physico-chemical conditions of composite effluent from the third WWTP located near WWTP B and seawater sampled around the WWTP B outfall. Thawed effluent was measured in the laboratory, and values presented are the mean ± SD of three composite replicates (n = 3). Seawater parameters were measured at the time of sampling, and values represent single measures taken at each site. Total suspended solids were not detected at any seawater sampling location. FWC = freshwater channel.

Direction of transect from outfall	Distance from transect centre (m)	Depth of sonde (m)	Temperature (°C)	O_2 (% saturation)	Temperature compensated conductivity (mS cm^{-1})	Salinity (PSU)	pH	Turbidity (NTU)
Effluent	NA	NA	15.3 ± 0.6	101.9 ± 0.8	1.9 ± 0.0	2.0 ± 0.0	8.2 ± 0.1	26.7 ± 6.1
FWC	NA	0.46	20.25	211.9	54.99	36.50	8.75	2.60
Centre	0	0.19	18.00	135.9	57.06	38.04	8.50	0.37
SE	20	0.37	17.95	100.9	58.09	38.81	8.29	0.23
	100	0.36	17.93	101.5	58.06	38.80	8.30	0.23
	1000	0.37	17.93	101.6	58.10	38.67	8.29	0.31
W	20	0.34	17.97	101.4	58.10	38.82	8.29	0.25
	100	0.34	17.95	102.4	58.15	38.86	8.28	0.23
	1000	0.44	17.75	112.2	57.81	38.61	8.36	0.39
NW	20	0.20	17.85	129.4	57.12	38.09	8.49	0.43
	100	0.50	17.80	125.3	57.20	38.15	8.47	0.44
	1000	0.49	17.64	100.7	57.90	38.67	8.24	1.63

Table C2. Depth of sediment cores and particle size distribution metrics of the sediments collected from the WWTP B outfall. D10, D50 and D90 represent the size which encompasses 10%, 50% and 90% of sediment particles, respectively. Data are mean ± SD, n = 3. FWC = freshwater channel.

Direction of transect from outfall	Distance from transect centre (m)	Depth of sediment core (mm)	D10 (µm)	D50 (µm)	D90 (µm)	Specific surface area (m^2 g^{-1})
FWC	NA	58.7 ± 4.8	10.5 ± 2.2	122.1 ± 27.9	577.4 ± 138.1	0.24 ± 0.04
SE	1000	58.0 ± 5.9	173.6 ± 100.2	684.7 ± 99.4	1324.7 ± 83.7	0.03 ± 0.02
Centre	0	62.0 ± 3.2	128.1 ± 24.2	538.8 ± 38.5	1149.9 ± 73.6	0.04 ± 0.01
W	1000	64.6 ± 3.4	70.6 ± 9.4	308.6 ± 80.9	928.8 ± 170.1	0.05 ± 0.01
NW	1000	62.2 ± 5.1	47.9 ± 41.4	202.9 ± 88.8	539.8 ± 138.2	0.06 ± 0.00

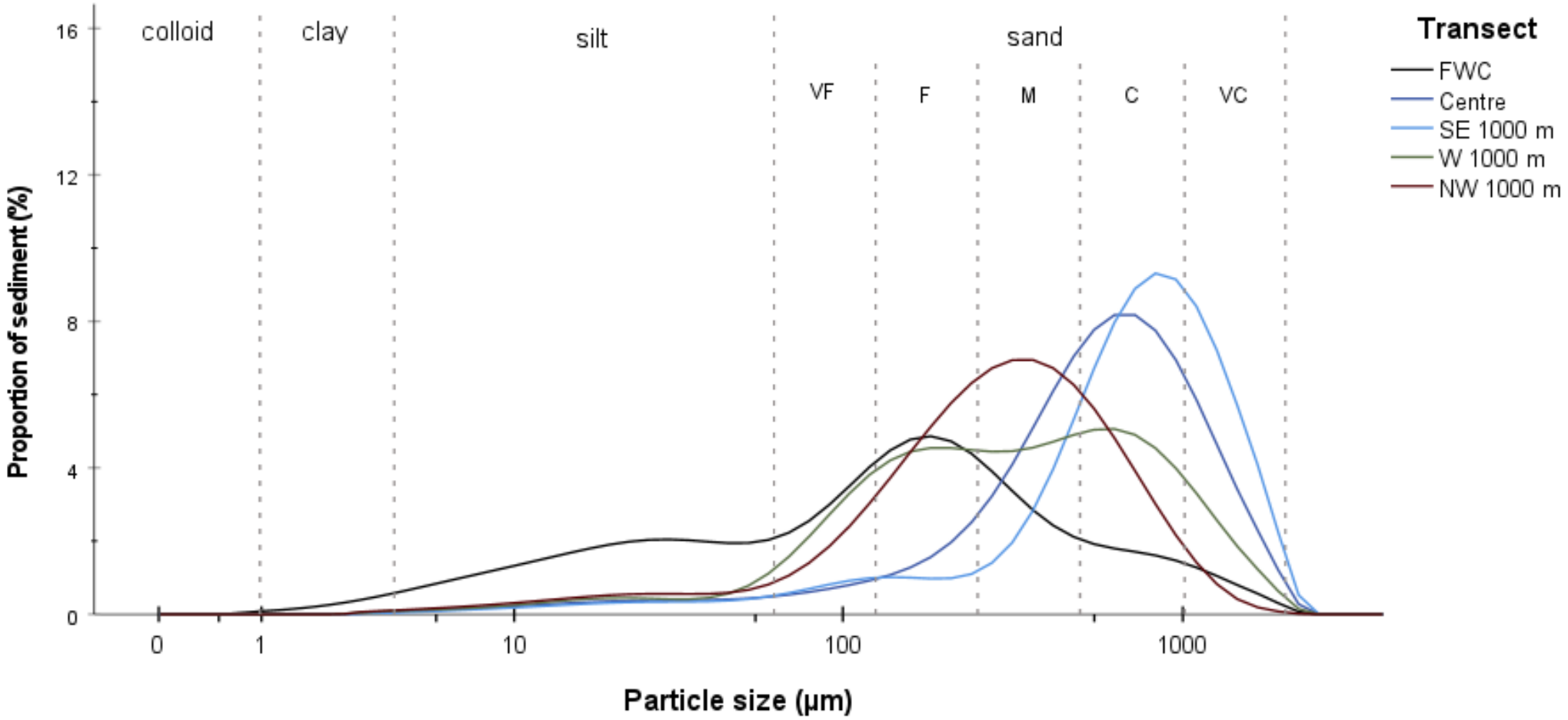
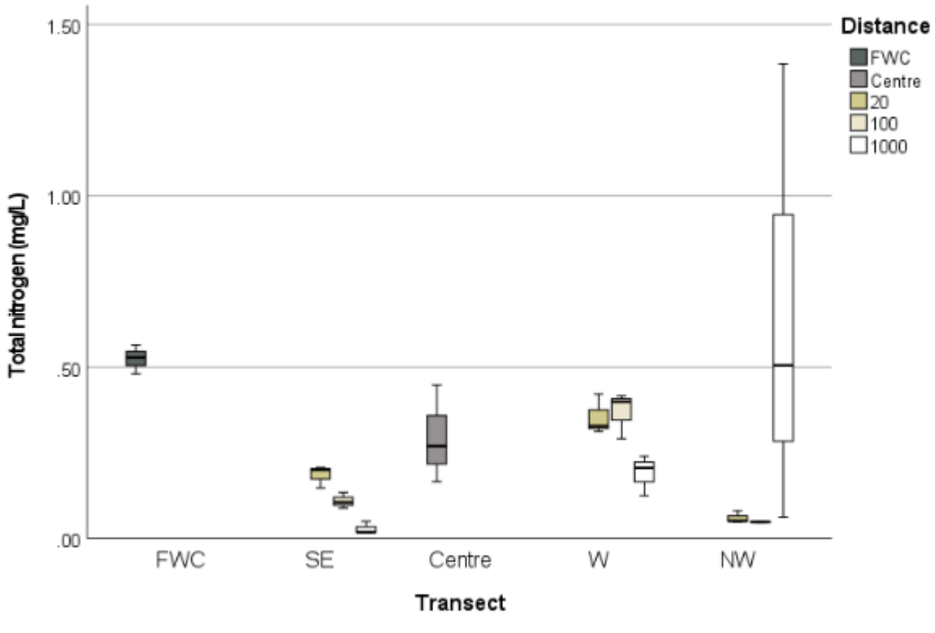
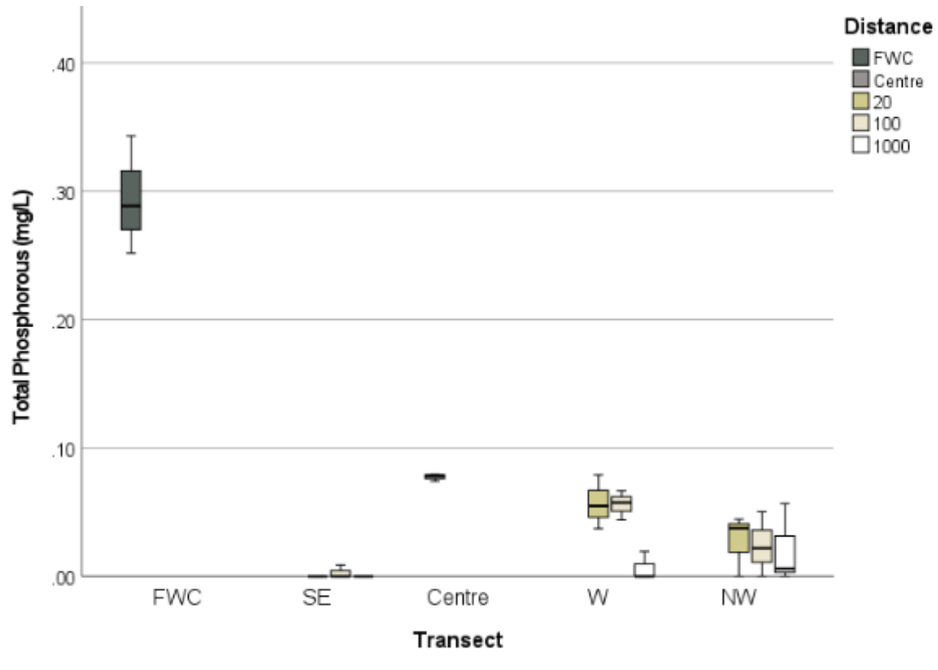
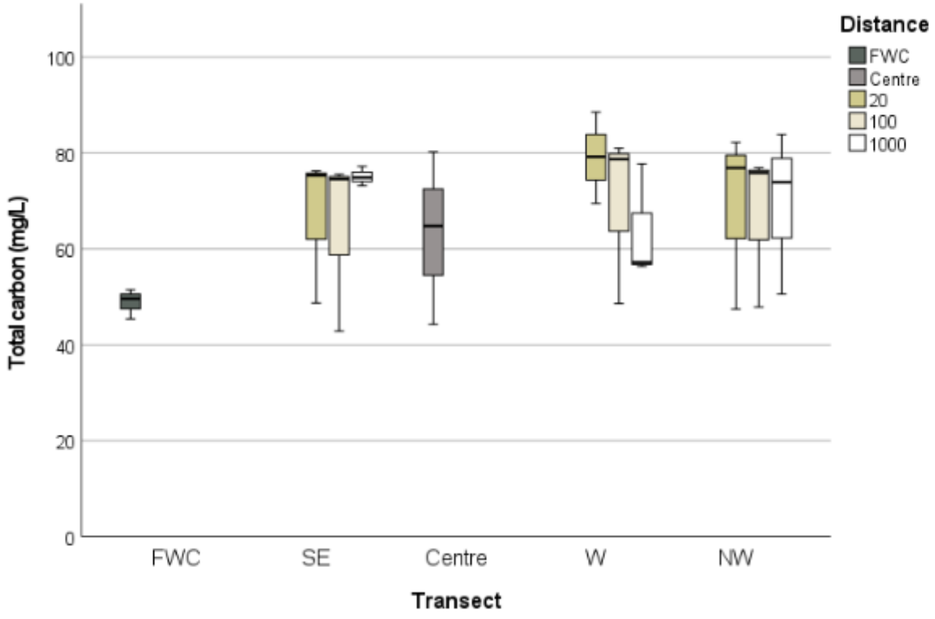


Figure C1. Particle size distribution of sediments collected from the WWTP B outfall. Results are the average of three replicates at each site (n = 3). Aggregate names listed at the top of the chart are taken from the Wentworth scale. C = coarse; F = fine; FWC = freshwater channel; M = medium; VC = very coarse; VF = very fine.

7.11 C2. Nutrient quantification







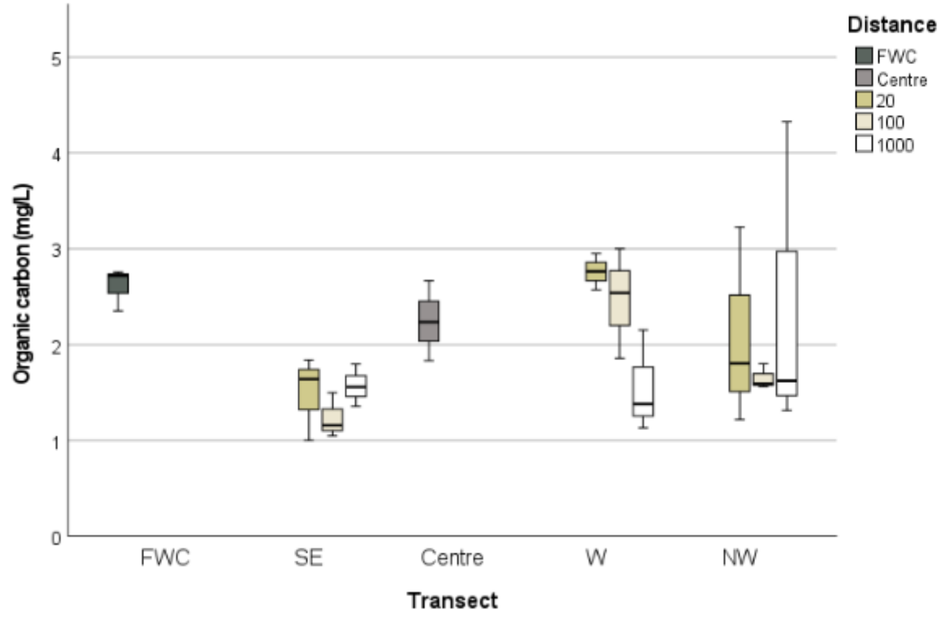


Figure C2. Concentrations of nutrients in seawater collected from the WWTP B outfall. (A) total nitrogen, (B) total phosphorus in seawater, (C) total carbon, and (D) total purgeable carbon. At each sampling location, n = 3. FWC = freshwater channel.

Table C2. Concentrations of nutrients in composite effluent from the third WWTP located near WWTP B, and in seawater and sediments collected from transects around the WWTP B outfall. Data are mean ± SD from three replicates (n = 3). FWC = freshwater channel, NA = not applicable. Dashes indicate samples that were not analysed.

					SE				W			NW		
Partition	**Nutrient**	**Concentration**	**Effluent**	**FWC**	**20 m**	**100 m**	**1000 m**	**Centre**	**20 m**	**100 m**	**1000 m**	**20 m**	**100 m**	**1000 m**
Water	Total carbon (mg/L)	Mean	52.795	48.859	66.772	64.339	75.109	63.105	79.086	69.465	63.793	68.848	66.901	69.466
		SD	1.733	3.131	15.632	18.614	2.025	18.060	9.518	18.068	12.107	18.744	16.477	17.102
	Organic carbon (mg/L)	Mean	14.035	2.610	1.496	1.236	1.572	2.247	2.763	2.467	1.556	2.084	1.653	2.421
		SD	0.164	0.224	0.438	0.234	0.220	0.417	0.189	0.575	0.533	1.033	.130	1.657
	Total nitrogen (mg/L)	Mean	6.031	0.525	0.186	0.110	0.029	0.295	0.355	0.369	0.191	0.061	0.049	0.651
		SD	0.167	0.042	0.032	0.023	0.018	0.143	0.059	0.068	0.059	0.018	0.002	0.673
	Total phosphorus (mg/L)	Mean	1.234	0.295	0.000	0.003	0.000	0.077	0.057	0.056	0.006	0.027	0.024	0.021
		SD	0.346	0.046	0.000	0.005	0.000	0.003	0.021	0.011	0.011	0.024	0.025	0.031
Sediment	Organic matter (g/g dry weight)	Mean	NA	0.051	-	-	0.041	0.041	-	-	0.039	-	-	0.040
		SD	NA	0.003	-	-	0.001	0.001	-	-	0.006	-	-	0.001
	Total phosphorus (mg/kg dry weight)	Mean	NA	726.235	-	-	865.953	664.558	-	-	769.501	-	-	1031.227
		SD	NA	48.263	-	-	374.672	136.063	-	-	300.960	-	-	327.166

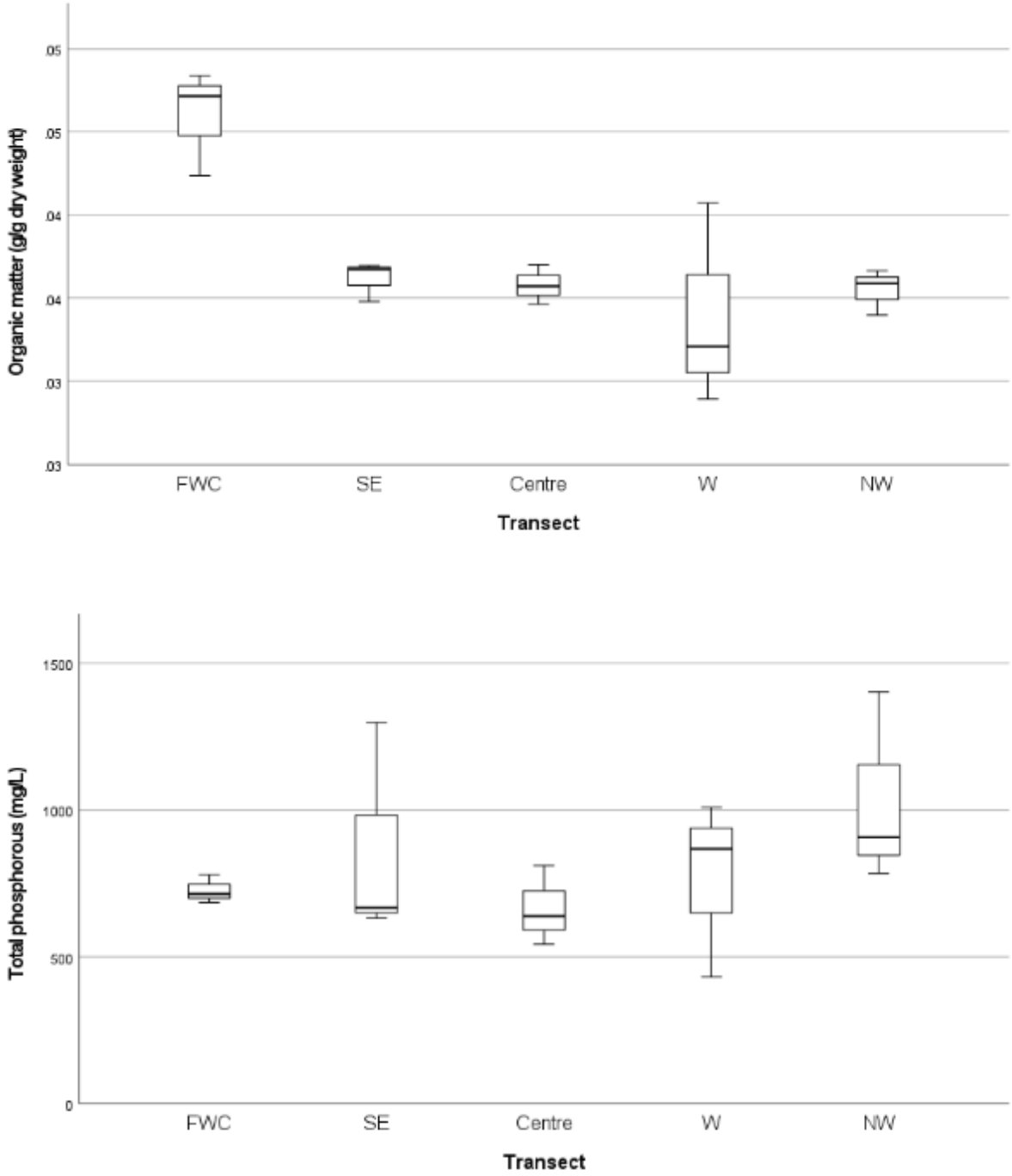
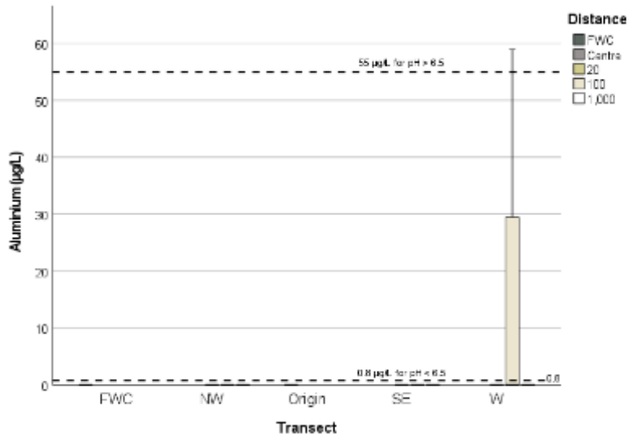
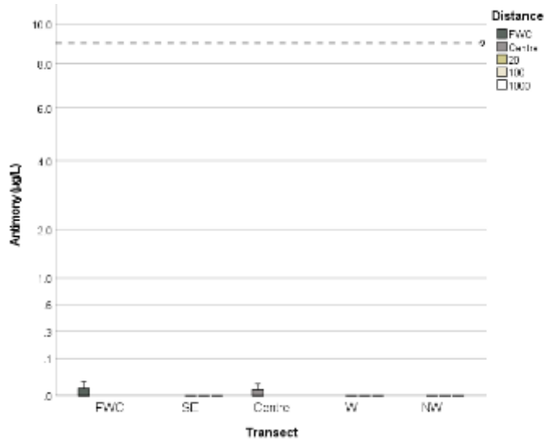
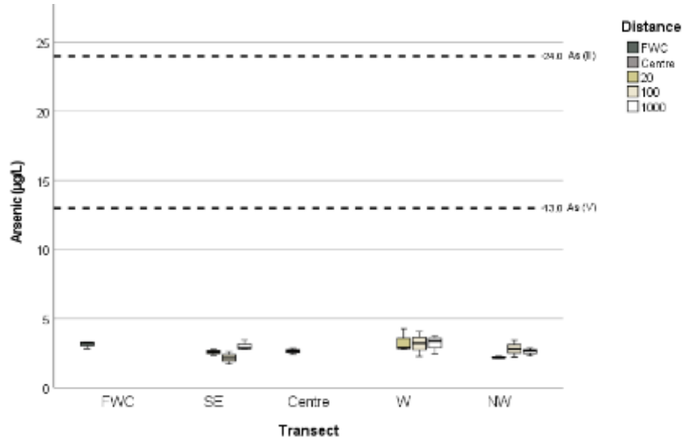


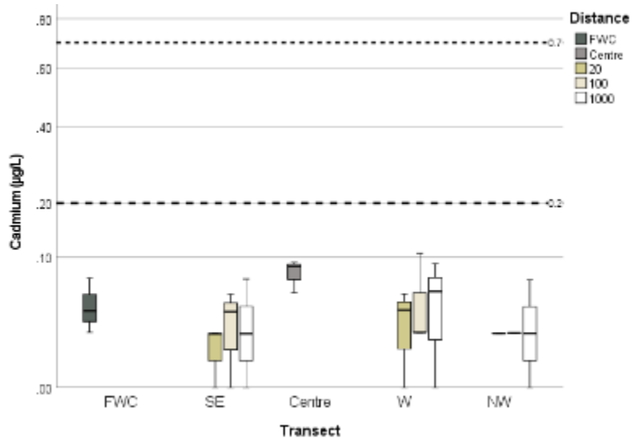
Figure C3. Concentrations of (top) total organic matter and (bottom) total phosphorus in sediments collected from the WWTP B outfall. Samples sites were the freshwater channel (FWC), the transect intersection (Centre), and 1000 m along the SE, W and NW transects. At each sampling location, n = 3.

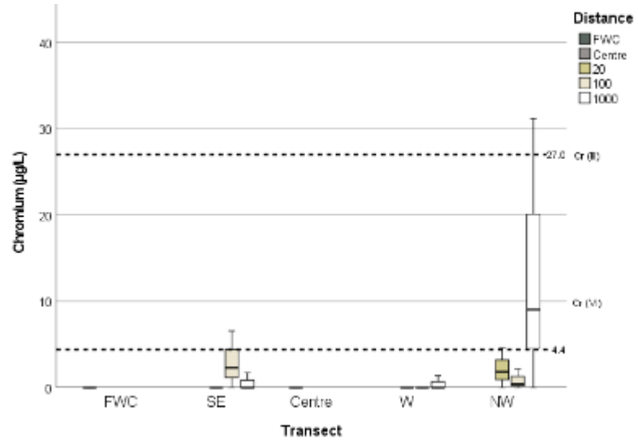
7.12 C3. Metal quantification

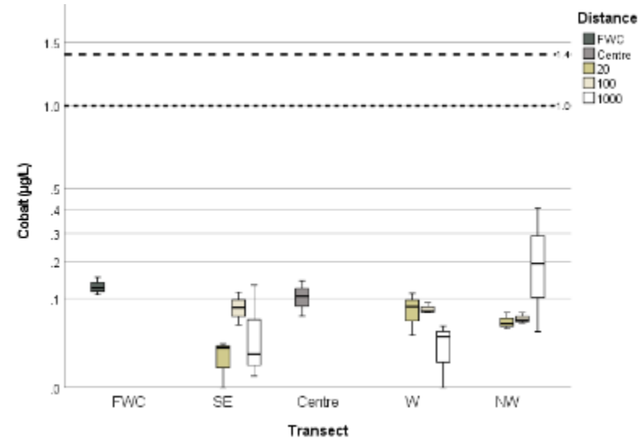


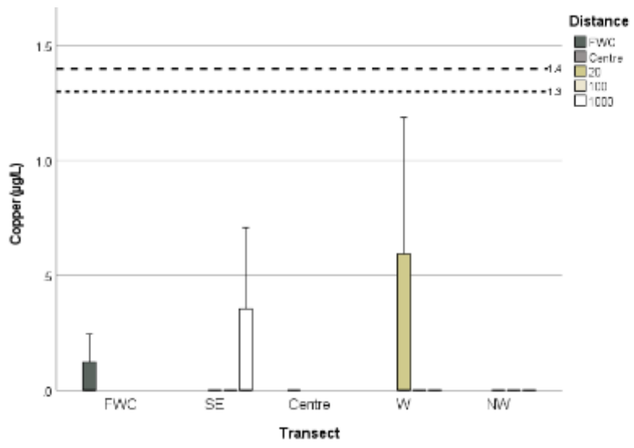


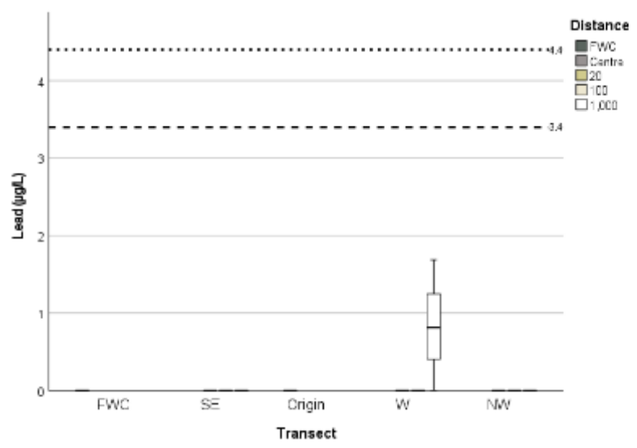


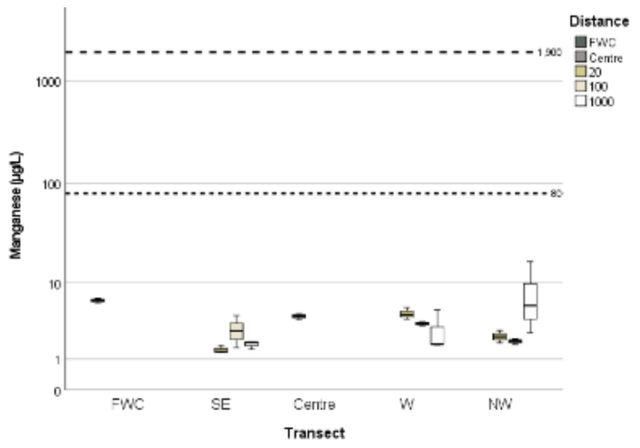


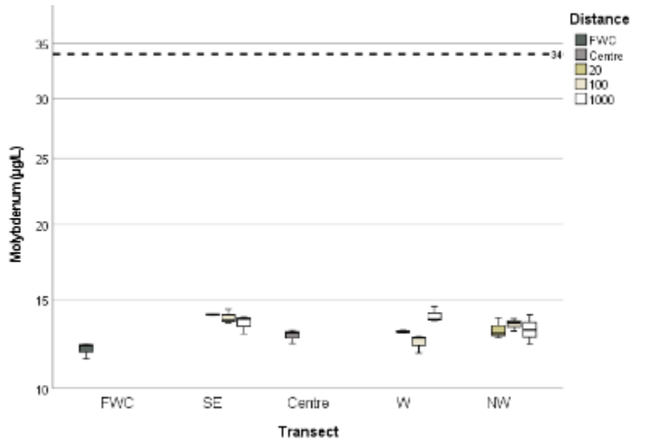


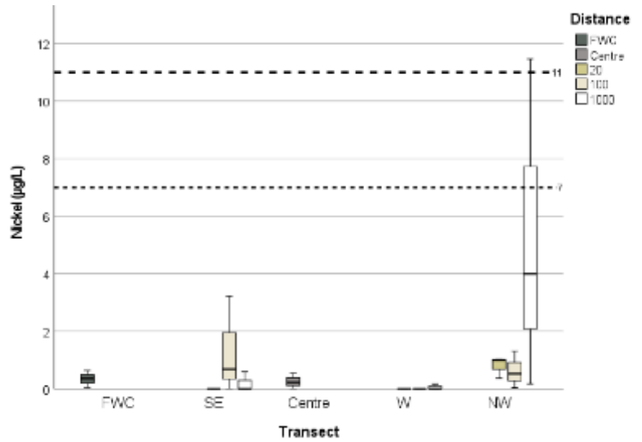


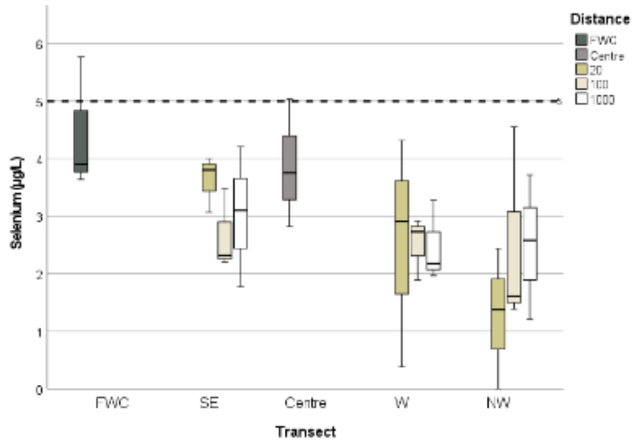


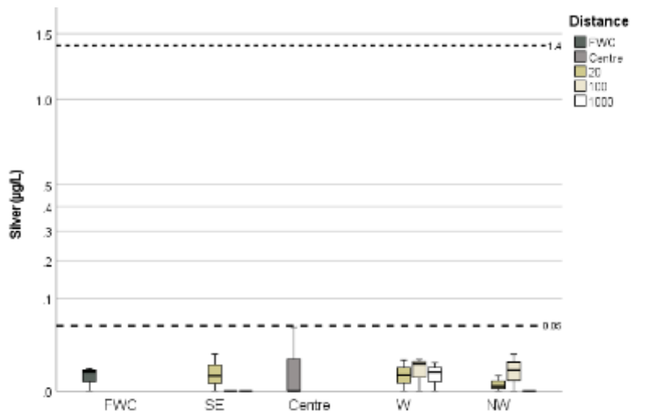


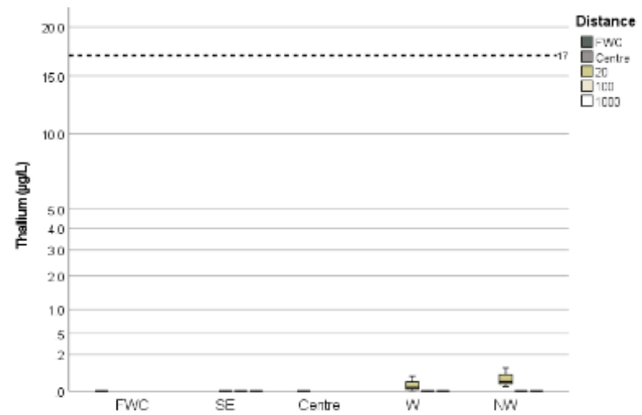


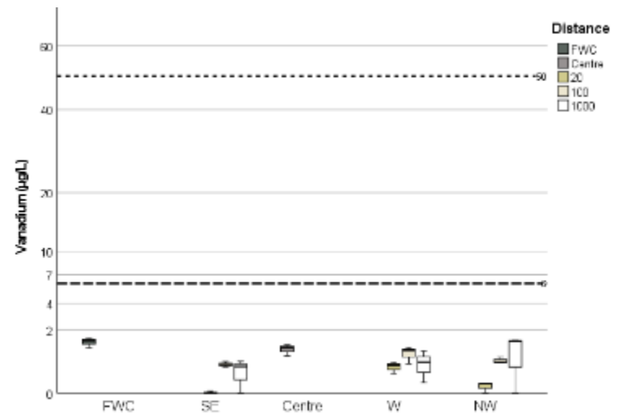


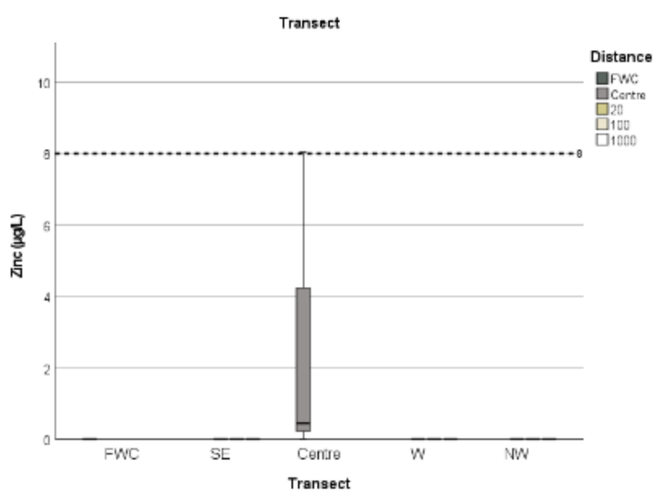












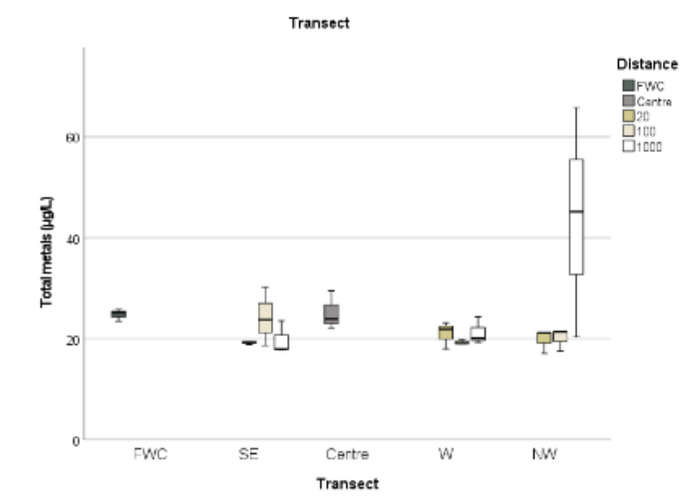


Figure C4. Concentration of dissolved total recoverable metals (µg/L; ppb) in seawater surrounding the WWTP B outfall (n = 3). Metals presented are those associated with a freshwater or marine Default Guideline Value. Reference lines with short dashes represent marine Default Guideline Values; reference lines with long dashes represent freshwater Default Guideline Values. For all metals, Default Guideline Values protect 95% of species except for: freshwater vanadium, freshwater cobalt, marine manganese, marine thallium (unknown % species); and marine nickel (99% species). Total metals represent the sum of all metals associated with a freshwater or marine Default Guideline Value.

Table C3. Concentrations of dissolved total dissolved recoverable metals (µg/L; ppb) in composite effluent collected from the third WWTP located near WWTP B, and in seawater collected from the freshwater channel, and transects around the WWTP B outfall. At each location, n = 3. α indicates metals associated with marine or freshwater Default Guideline Values that were combined to form a metric of 'total metal' for statistical analyses.

		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Aluminium	Median	234.595	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	271.185	0.000	0.000	0.000	0.000	0.000	0.000	19.644	0.000	0.000	0.000	0.000
	SD	94.330	0.000	0.000	0.000	0.000	0.000	0.000	34.025	0.000	0.000	0.000	0.000
	Minimum	200.631	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	378.329	0.000	0.000	0.000	0.000	0.000	0.000	58.933	0.000	0.000	0.000	0.000
Antimony	Median	0.210	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.343	0.005	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.426	0.008	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.820	0.014	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Arsenic$^{\alpha}$	Median	0.000	3.253	2.569	2.153	2.870	2.666	2.886	3.213	3.352	2.156	2.788	2.662
	Mean	0.000	3.129	2.568	2.156	3.040	2.641	3.313	3.177	3.185	2.195	2.818	2.610
	SD	0.000	0.266	0.208	0.460	0.358	0.223	0.827	0.900	0.686	0.077	0.613	0.280
	Minimum	0.000	2.824	2.360	1.698	2.799	2.407	2.788	2.259	2.432	2.145	2.220	2.308
	Maximum	0.000	3.310	2.776	2.618	3.451	2.851	4.266	4.058	3.772	2.284	3.445	2.861
Barium	Median	14.692	5.138	1.310	1.835	1.216	3.169	2.659	3.647	1.659	0.938	1.851	2.414
	Mean	15.195	5.467	1.227	1.805	1.021	3.221	2.814	5.843	2.069	1.262	1.974	2.621
	SD	1.430	0.684	0.293	0.423	0.443	0.591	0.347	5.165	0.719	0.613	0.267	0.882
	Minimum	14.085	5.009	0.902	1.368	0.514	2.658	2.571	2.139	1.647	0.879	1.791	1.860
	Maximum	16.808	6.254	1.470	2.212	1.334	3.837	3.211	11.744	2.899	1.969	2.280	3.588
Bismuth	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	1.407	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	2.438	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	4.222	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Cadmium[α]	Median	0.261	0.035	0.017	0.034	0.017	0.087	0.035	0.018	0.054	0.017	0.018	0.017
	Mean	0.243	0.041	0.012	0.028	0.029	0.077	0.029	0.047	0.048	0.017	0.018	0.029
	SD	0.234	0.027	0.010	0.026	0.036	0.021	0.026	0.051	0.046	0.000	0.000	0.035
	Minimum	0.000	0.018	0.000	0.000	0.000	0.053	0.000	0.018	0.000	0.017	0.017	0.000
	Maximum	0.466	0.071	0.018	0.051	0.069	0.092	0.052	0.106	0.090	0.018	0.018	0.068
Cerium	Median	0.124	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000
	Mean	0.156	0.003	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.002
	SD	0.175	0.006	0.002	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.001	0.004
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.345	0.010	0.003	0.001	0.000	0.000	0.002	0.000	0.000	0.001	0.003	0.007
Cesium	Median	0.066	0.339	0.366	0.358	0.370	0.368	0.371	0.418	0.375	0.338	0.382	0.374
	Mean	0.087	0.358	0.366	0.337	0.363	0.358	0.339	0.362	0.364	0.342	0.382	0.375
	SD	0.100	0.039	0.024	0.040	0.043	0.027	0.067	0.099	0.035	0.048	0.059	0.007
	Minimum	0.000	0.333	0.342	0.291	0.316	0.327	0.262	0.247	0.325	0.295	0.323	0.368
	Maximum	0.196	0.403	0.391	0.363	0.402	0.378	0.384	0.419	0.392	0.392	0.440	0.383
Chromium[α]	Median	1.848	0.000	0.000	2.293	0.000	0.000	0.000	0.000	0.000	1.843	0.423	9.029
	Mean	2.186	0.000	0.000	2.953	0.571	0.000	0.000	0.000	0.454	2.136	0.861	13.407
	SD	0.733	0.000	0.000	3.333	0.990	0.000	0.000	0.000	0.787	2.297	1.144	16.051
	Minimum	1.683	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	3.028	0.000	0.000	6.567	1.714	0.000	0.000	0.000	1.363	4.565	2.159	31.193
Cobalt[α]	Median	0.500	0.125	0.020	0.081	0.014	0.105	0.083	0.074	0.033	0.051	0.058	0.193
	Mean	0.409	0.129	0.015	0.082	0.049	0.105	0.077	0.078	0.027	0.055	0.060	0.213
	SD	0.315	0.023	0.013	0.033	0.072	0.040	0.039	0.011	0.024	0.014	0.009	0.185
	Minimum	0.059	0.109	0.000	0.050	0.002	0.065	0.035	0.071	0.000	0.044	0.053	0.039
	Maximum	0.669	0.154	0.024	0.115	0.133	0.144	0.112	0.091	0.048	0.071	0.071	0.407
Copper[α]	Median	26.861	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	25.894	0.082	0.000	0.000	0.236	0.000	0.396	0.000	0.000	0.000	0.000	0.000
	SD	12.569	0.141	0.000	0.000	0.409	0.000	0.685	0.000	0.000	0.000	0.000	0.000

		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Minimum	12.870	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	37.952	0.245	0.000	0.000	0.708	0.000	1.187	0.000	0.000	0.000	0.000	0.000
	Median	0.104	0.008	0.000	0.000	0.004	0.000	0.000	0.004	0.004	0.000	0.000	0.004
	Mean	0.081	0.007	0.000	0.003	0.003	0.001	0.001	0.003	0.003	0.001	0.000	0.003
Dysprosium	SD	0.073	0.006	0.000	0.004	0.002	0.002	0.002	0.002	0.002	0.002	0.000	0.002
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.140	0.012	0.000	0.008	0.004	0.004	0.004	0.004	0.004	0.004	0.000	0.004
	Median	0.306	0.035	0.006	0.006	0.000	0.031	0.017	0.024	0.000	0.006	0.006	0.023
	Mean	0.214	0.034	0.008	0.008	0.000	0.030	0.025	0.022	0.000	0.004	0.006	0.019
Gadolinium	SD	0.186	0.003	0.003	0.009	0.000	0.024	0.019	0.009	0.000	0.003	0.006	0.012
	Minimum	0.000	0.030	0.006	0.000	0.000	0.006	0.012	0.012	0.000	0.000	0.000	0.006
	Maximum	0.336	0.036	0.012	0.018	0.000	0.053	0.047	0.030	0.000	0.006	0.012	0.029
	Median	0.427	0.000	0.000	0.000	0.000	0.014	0.013	0.001	0.001	0.000	0.000	0.035
	Mean	0.286	0.009	0.012	0.000	0.012	0.013	0.016	0.004	0.018	0.020	0.023	0.043
Gallium	SD	0.247	0.015	0.020	0.000	0.020	0.012	0.018	0.007	0.029	0.035	0.041	0.024
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024
	Maximum	0.429	0.027	0.035	0.000	0.035	0.025	0.035	0.013	0.052	0.060	0.070	0.070
	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Germanium	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.158	0.025	0.000	0.154	0.076	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.138	0.024	0.000	0.156	0.109	0.007
Hafnium	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.129	0.012	0.000	0.108	0.099	0.012
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.049	0.031	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.256	0.035	0.000	0.264	0.220	0.022
Indium	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

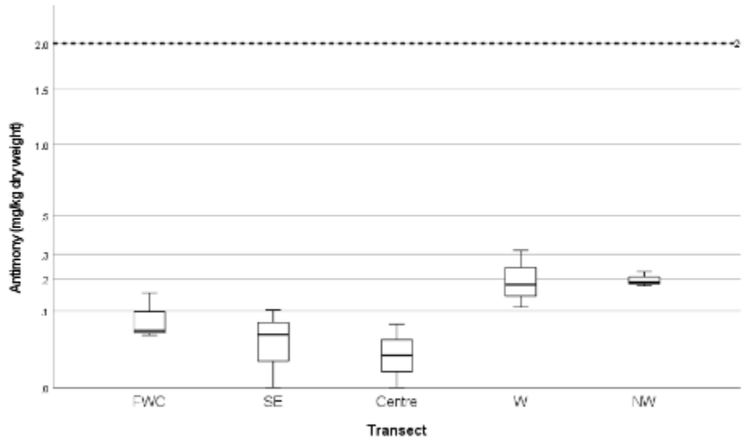
		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Mean	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.000	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.002	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Lead[α]	Median	1.561	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.811	0.000	0.000	0.000
	Mean	1.847	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.833	0.000	0.000	0.000
	SD	0.523	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.844	0.000	0.000	0.000
	Minimum	1.528	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	2.451	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.688	0.000	0.000	0.000
Manganese[α]	Median	8.383	6.466	1.367	2.751	1.907	4.260	4.387	3.461	1.805	2.286	2.012	5.635
	Mean	8.516	6.420	1.480	2.871	1.785	4.204	4.531	3.425	2.860	2.319	1.982	8.299
	SD	0.929	0.384	0.215	1.360	0.244	0.320	0.732	0.193	1.878	0.455	0.189	7.396
	Minimum	7.660	6.014	1.344	1.574	1.504	3.859	3.882	3.216	1.747	1.882	1.779	2.604
	Maximum	9.503	6.779	1.728	4.287	1.944	4.492	5.325	3.597	5.028	2.791	2.154	16.657
Mercury[α]	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Molybdenum[α]	Median	3.802	12.303	14.096	13.746	13.840	13.020	13.066	12.732	13.806	12.977	13.590	13.187
	Mean	3.971	12.083	14.090	13.918	13.583	12.864	13.098	12.472	14.041	13.205	13.519	13.214
	SD	0.444	0.441	0.047	0.442	0.537	0.395	0.071	0.509	0.472	0.607	0.360	0.849
	Minimum	3.636	11.575	14.040	13.589	12.966	12.415	13.048	11.885	13.733	12.745	13.129	12.378
	Maximum	4.474	12.370	14.134	14.420	13.943	13.157	13.178	12.798	14.584	13.892	13.839	14.077
Nickel[α]	Median	7.511	0.353	0.000	0.685	0.000	0.225	0.000	0.000	0.000	0.991	0.528	3.993
	Mean	7.533	0.345	0.000	1.301	0.197	0.257	0.000	0.000	0.056	0.795	0.624	5.209
	SD	1.579	0.299	0.000	1.696	0.342	0.274	0.000	0.000	0.097	0.373	0.643	5.743
	Minimum	5.965	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.365	0.035	0.171

		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Maximum	9.123	0.639	0.000	3.219	0.592	0.545	0.000	0.000	0.169	1.029	1.310	11.463
Niobium	Median	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.031	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
	SD	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.068	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000
Rubidium	Median	27.879	162.798	169.047	170.690	172.001	169.107	166.765	161.279	170.012	167.104	173.401	172.967
	Mean	27.754	164.210	169.054	170.195	170.328	171.498	166.052	160.816	170.535	166.686	173.778	172.491
	SD	1.740	3.748	0.173	2.602	2.943	6.063	1.598	1.771	3.506	5.511	2.682	1.445
	Minimum	25.955	161.372	168.885	167.382	166.930	166.996	164.222	158.860	167.320	160.978	171.305	170.868
	Maximum	29.428	168.459	169.230	172.515	172.053	178.392	167.171	162.310	174.273	171.975	176.629	173.638
Scandium	Median	0.000	0.060	0.043	0.091	0.066	0.092	0.115	0.107	0.060	0.083	0.068	0.055
	Mean	0.000	0.074	0.059	0.070	0.053	0.068	0.132	0.086	0.060	0.088	0.095	0.047
	SD	0.000	0.038	0.038	0.056	0.047	0.060	0.050	0.057	0.050	0.024	0.068	0.014
	Minimum	0.000	0.045	0.033	0.006	0.000	0.000	0.094	0.021	0.010	0.067	0.044	0.030
	Maximum	0.000	0.117	0.103	0.112	0.092	0.112	0.188	0.130	0.109	0.115	0.172	0.056
Selenium[α]	Median	0.000	3.901	3.804	2.320	3.099	3.754	2.912	2.728	2.176	1.381	1.605	2.580
	Mean	0.000	4.436	3.625	2.668	3.029	3.871	2.537	2.513	2.474	1.274	2.514	2.501
	SD	0.000	1.161	0.492	0.707	1.216	1.113	1.993	0.544	0.705	1.223	1.767	1.257
	Minimum	0.000	3.639	3.069	2.202	1.779	2.822	0.383	1.894	1.967	0.000	1.387	1.207
	Maximum	0.000	5.768	4.002	3.481	4.208	5.038	4.316	2.917	3.279	2.440	4.550	3.717
Silver[α]	Median	0.028	0.004	0.003	0.000	0.000	0.000	0.003	0.009	0.004	0.000	0.005	0.000
	Mean	0.063	0.003	0.006	0.000	0.000	0.016	0.005	0.007	0.005	0.001	0.007	0.000
	SD	0.086	0.003	0.009	0.000	0.000	0.028	0.006	0.006	0.005	0.001	0.008	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.161	0.006	0.016	0.000	0.000	0.048	0.011	0.012	0.009	0.003	0.016	0.000
Tantalum[α]	Median	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	SD	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
	Median	0.000	0.165	0.163	0.000	0.160	0.163	0.164	0.170	0.000	0.325	0.332	0.000
	Mean	0.076	0.111	0.164	0.054	0.109	0.164	0.218	0.167	0.057	0.375	0.332	0.164
Tellurium	SD	0.132	0.096	0.002	0.093	0.094	0.165	0.249	0.165	0.098	0.402	0.004	0.285
	Minimum	0.000	0.000	0.163	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.327	0.000
	Maximum	0.228	0.167	0.166	0.161	0.167	0.329	0.490	0.331	0.170	0.799	0.336	0.493
	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.014	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.033	0.000	0.000
Thallium[α]	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.042	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.000	0.000	0.081	0.000	0.000
	Median	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Thorium	SD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Median	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.405	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tin	SD	0.684	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	1.194	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Median	0.000	0.571	0.133	0.000	0.000	0.563	0.722	0.140	0.445	0.143	0.284	0.287
	Mean	0.000	0.634	0.137	0.093	0.046	0.433	0.482	0.143	0.298	0.429	0.282	0.465
Titanium	SD	0.000	0.240	0.140	0.160	0.080	0.385	0.417	0.145	0.257	0.624	0.281	0.449
	Minimum	0.000	0.433	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.133
	Maximum	0.000	0.899	0.280	0.278	0.138	0.736	0.723	0.290	0.447	1.145	0.561	0.977

		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
Tungsten	Median	0.000	0.012	0.000	0.000	0.002	0.017	0.018	0.028	0.006	0.015	0.015	0.021
	Mean	0.000	0.013	0.003	0.003	0.003	0.020	0.034	0.024	0.009	0.020	0.017	0.020
	SD	0.000	0.006	0.005	0.005	0.004	0.007	0.042	0.014	0.006	0.012	0.010	0.008
	Minimum	0.000	0.009	0.000	0.000	0.000	0.016	0.002	0.009	0.006	0.011	0.008	0.011
	Maximum	0.000	0.019	0.009	0.008	0.008	0.028	0.081	0.035	0.016	0.034	0.028	0.027
Uranium	Median	0.222	2.771	2.883	2.832	2.880	2.892	2.871	2.746	3.017	2.803	2.898	2.895
	Mean	0.173	2.705	2.870	2.905	2.859	2.886	2.829	2.739	3.033	2.871	2.892	2.862
	SD	0.155	0.170	0.084	0.128	0.072	0.045	0.074	0.015	0.092	0.174	0.138	0.110
	Minimum	0.000	2.511	2.780	2.830	2.778	2.838	2.744	2.722	2.951	2.741	2.751	2.740
	Maximum	0.298	2.832	2.947	3.052	2.919	2.928	2.872	2.750	3.132	3.069	3.026	2.952
Vanadium[α]	Median	2.088	1.381	0.000	0.399	0.353	1.036	0.387	0.917	0.479	0.048	0.475	1.354
	Mean	2.230	1.297	0.001	0.413	0.285	0.963	0.349	0.788	0.473	0.033	0.535	0.917
	SD	0.651	0.250	0.001	0.078	0.258	0.240	0.146	0.315	0.413	0.029	0.108	0.794
	Minimum	1.662	1.016	0.000	0.343	0.000	0.695	0.188	0.430	0.056	0.000	0.470	0.000
	Maximum	2.940	1.495	0.002	0.497	0.502	1.157	0.472	1.018	0.883	0.052	0.659	1.396
Yttrium	Median	0.089	0.043	0.069	0.063	0.045	0.056	0.057	0.035	0.041	0.043	0.042	0.058
	Mean	0.067	0.043	0.060	0.054	0.046	0.051	0.053	0.044	0.043	0.047	0.041	0.057
	SD	0.059	0.006	0.022	0.018	0.010	0.011	0.008	0.018	0.014	0.010	0.004	0.001
	Minimum	0.000	0.038	0.035	0.034	0.036	0.038	0.045	0.033	0.030	0.040	0.037	0.056
	Maximum	0.112	0.050	0.077	0.066	0.056	0.058	0.059	0.065	0.058	0.059	0.044	0.058
Zinc[α]	Median	46.135	0.000	0.000	0.000	0.000	0.444	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	50.127	0.000	0.000	0.000	0.000	2.827	0.000	0.000	0.000	0.000	0.000	0.000
	SD	16.139	0.000	0.000	0.000	0.000	4.517	0.000	0.000	0.000	0.000	0.000	0.000
	Minimum	36.359	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	67.887	0.000	0.000	0.000	0.000	8.037	0.000	0.000	0.000	0.000	0.000	0.000
Zirconium	Median	0.272	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Mean	0.461	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SD	0.419	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

		Effluent	FWC	SE			Centre	W			NW		
				20 m	100 m	1000 m	0 m	20 m	100 m	1000 m	20 m	100 m	1000 m
	Minimum	0.171	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Maximum	0.942	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total metal	Median	115.558	25.180	19.339	23.802	17.973	23.903	21.932	19.091	20.125	21.212	21.376	45.174
	Mean	103.019	24.836	19.228	24.234	19.764	25.183	21.033	19.330	21.270	19.868	20.119	43.789
	SD	25.540	1.220	.309	5.817	3.290	3.883	2.695	0.459	2.718	2.378	2.190	22.754
	Minimum	73.633	23.480	18.879	18.645	17.759	22.102	18.003	19.040	19.312	17.123	17.590	20.374
	Maximum	119.865	25.847	19.467	30.255	23.561	29.545	23.163	19.860	24.374	21.270	21.392	65.818


Antimony (mg/kg dry weight)
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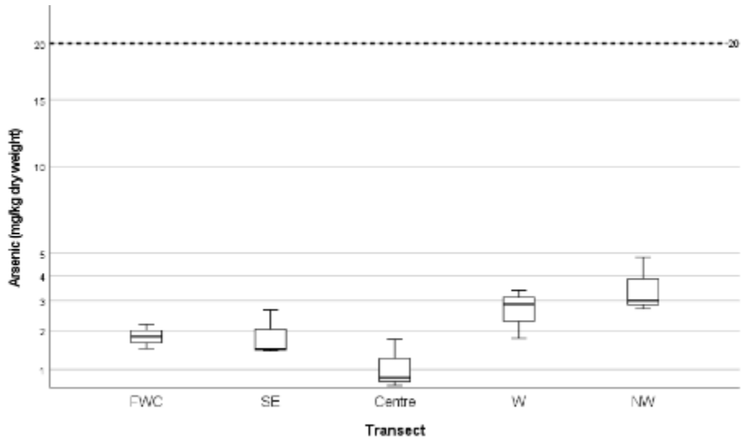
1.5
1.0
.5
.3
.2
.1
0
PWC
SE
Centre
W
NW
Transect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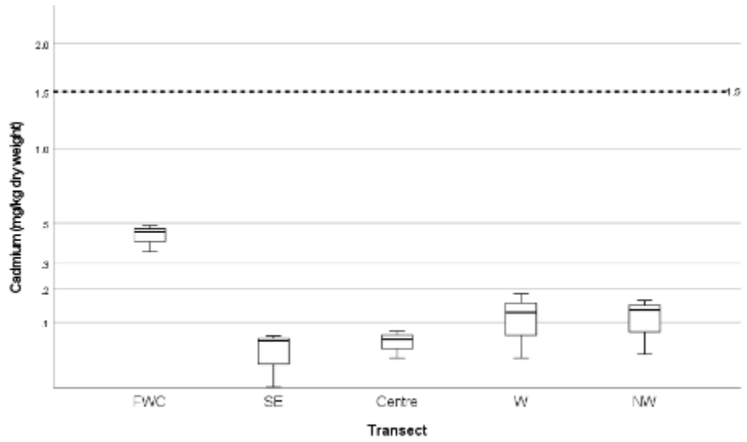
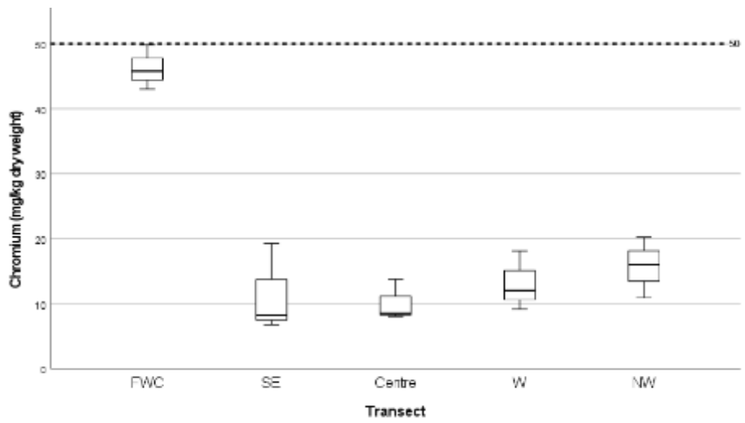
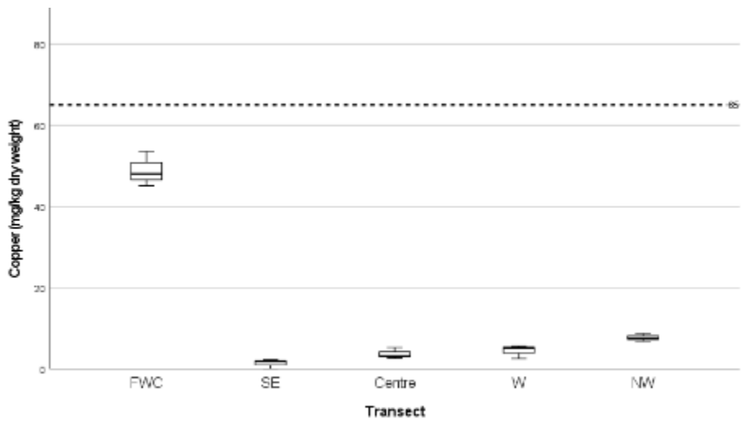
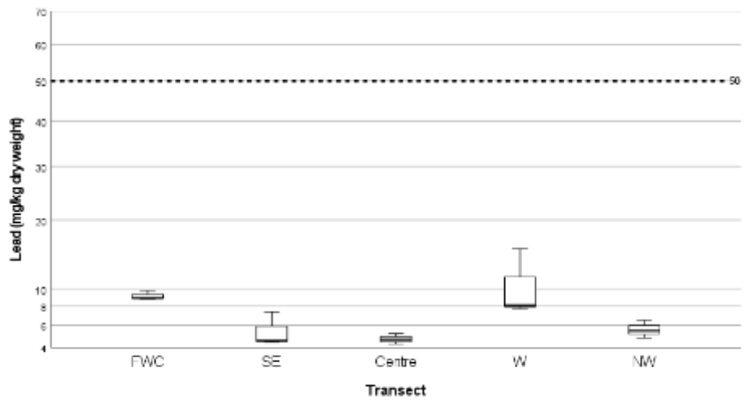
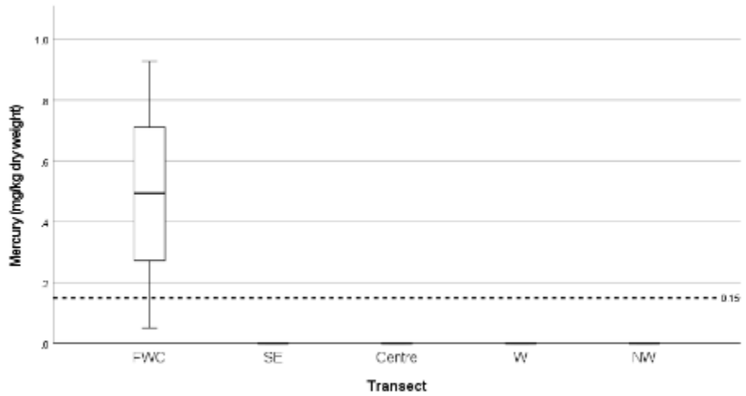
20
15
10
5
4
3
2
1
PWC
SE
Centre
W
NW
Transect

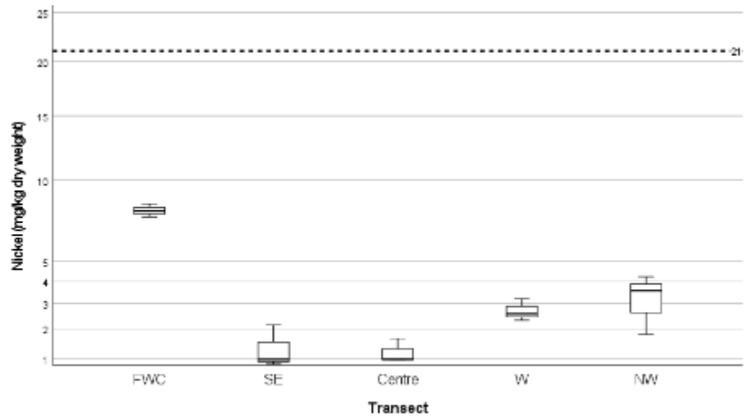

Cadmium (mg/kg dry weight)
2.0
1.5
1.0
.5
.3
.2
.1
PWC
SE
Centre
W
NW
Transect

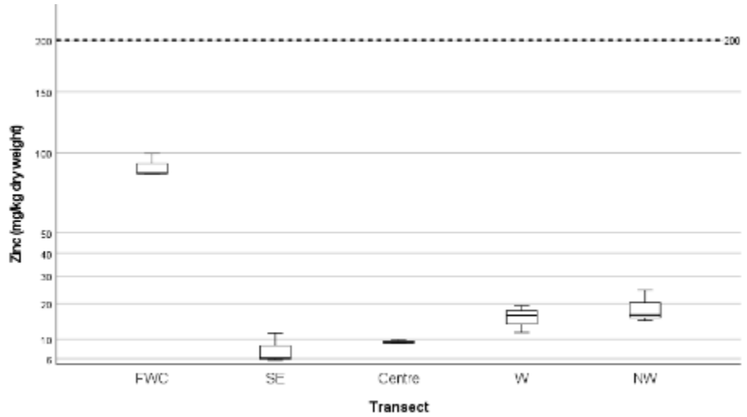

Chromium (mg/kg dry weight)
50
40
30
20
10
0
PWC
SE
Centre
W
NW
Transect


Copper (mg/kg dry weight)
80
60
40
20
0
PWC
SE
Centre
W
NW
Transect


Lead (mg/kg dry weight)
70
60
50
40
30
20
10
8
6
4
PWC
SE
Centre
W
NW
Transect







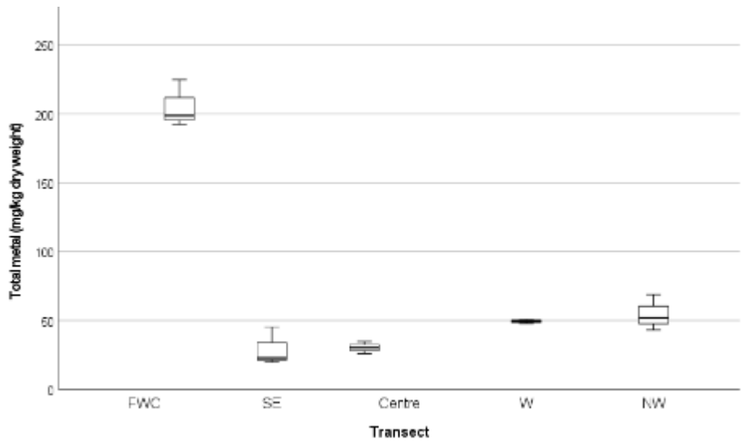


Figure C5. Concentration of selected total recoverable metals (mg/kg dry weight; ppm) in sediments surrounding the WWTP B outfall (n = 3). Samples sites were the freshwater channel (FWC), the transect intersection (Centre), and 1000 m along the SE, W and NW transects. Metals presented are those associated with sediment Default Guideline Values, which are represented by the dashed reference lines. Total metals represent the sum of all metals associated with a sediment Default Guideline Value. A full list of total recoverable metals is provided in Table D5.

Table C4. Concentrations of total recoverable metals (mg/kg dry weight; ppm) from sediments surrounding the WWTP B outfall. Sampling locations were the freshwater channel (FWC), the transect intersection (Centre), and at 1000 m along the SE, W, and NW transects. At each location, n = 3. α indicates metals associated with sediment Default Guideline Values that were combined to form a metric of 'total metal' for statistical analyses.

		Transect				
			SE		W	NW
Metal	Concentration (mg/kg dry weight)	FWC	1000 m	Centre	1000 m	1000 m
Aluminium	Median	11080.452	773.929	652.129	2266.221	1599.336
	Mean	11275.675	1036.085	689.272	2192.514	1587.327
	SD	1005.716	461.488	177.638	712.380	348.347
	Minimum	10381.883	765.384	533.142	1446.146	1233.131
	Maximum	12364.689	1568.943	882.545	2865.175	1929.515
Antimony$^{\alpha}$	Median	0.055	0.047	0.018	0.179	0.189
	Mean	0.084	0.050	0.029	0.202	0.197
	SD	0.059	0.051	0.035	0.106	0.027
	Minimum	0.046	0.000	0.000	0.109	0.175
	Maximum	0.152	0.102	0.068	0.318	0.227
Arsenic$^{\alpha}$	Median	1.824	1.491	0.833	2.872	2.998
	Mean	1.836	1.866	1.089	2.683	3.512
	SD	0.349	0.700	0.573	0.828	1.146
	Minimum	1.493	1.432	0.687	1.776	2.712
	Maximum	2.191	2.673	1.745	3.399	4.824
Barium	Median	33.400	8.066	8.105	13.340	11.994
	Mean	31.592	9.846	8.243	11.904	13.002
	SD	3.687	3.909	1.587	2.956	3.407
	Minimum	27.350	7.144	6.730	8.505	10.213
	Maximum	34.027	14.328	9.895	13.868	16.799
Bismuth	Median	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000
	SD	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000
Cadmium$^{\alpha}$	Median	0.453	0.059	0.063	0.126	0.134
	Mean	0.431	0.044	0.058	0.114	0.111
	SD	0.069	0.035	0.025	0.077	0.066
	Minimum	0.354	0.004	0.031	0.031	0.037
	Maximum	0.486	0.069	0.079	0.184	0.162
Cerium	Median	26.610	11.428	12.877	17.592	16.774
	Mean	25.814	12.781	13.490	17.355	17.148
	SD	3.706	2.609	1.574	1.909	1.576
	Minimum	21.775	11.126	12.316	15.338	15.792
	Maximum	29.058	15.788	15.278	19.134	18.877
Cesium	Median	0.924	0.064	0.055	0.187	0.113
	Mean	0.999	0.081	0.064	0.180	0.118

Metal	Concentration (mg/kg dry weight)	Transect				
			SE		W	NW
		FWC	1000 m	Centre	1000 m	1000 m
	SD	0.172	0.036	0.018	0.035	0.021
	Minimum	0.877	0.058	0.051	0.141	0.100
	Maximum	1.197	0.122	0.085	0.211	0.140
Chromium[α]	Median	45.795	8.199	8.519	12.062	16.050
	Mean	46.219	11.414	10.106	13.120	15.730
	SD	3.415	6.847	3.177	4.566	4.673
	Minimum	43.035	6.765	8.035	9.176	10.905
	Maximum	49.826	19.277	13.764	18.122	20.234
Cobalt	Median	1.714	0.000	0.000	0.000	0.000
	Mean	1.713	0.088	0.016	0.166	0.140
	SD	0.075	0.152	0.027	0.288	0.242
	Minimum	1.637	0.000	0.000	0.000	0.000
	Maximum	1.787	0.263	0.047	0.499	0.419
Copper[α]	Median	48.043	1.840	3.156	5.191	7.573
	Mean	48.878	1.362	3.670	4.430	7.674
	SD	4.288	1.167	1.371	1.662	0.944
	Minimum	45.070	0.032	2.631	2.524	6.784
	Maximum	53.523	2.215	5.224	5.575	8.664
Dysprosium	Median	1.408	1.000	1.145	1.490	1.270
	Mean	1.361	1.271	1.233	1.393	1.496
	SD	0.115	0.506	0.272	0.379	0.428
	Minimum	1.230	0.958	1.016	0.975	1.228
	Maximum	1.444	1.855	1.539	1.715	1.990
Gadolinium	Median	2.043	1.080	1.466	1.709	1.818
	Mean	2.013	1.498	1.470	1.646	1.838
	SD	0.121	0.731	0.286	0.404	0.415
	Minimum	1.881	1.072	1.185	1.214	1.433
	Maximum	2.117	2.343	1.757	2.016	2.263
Gallium	Median	4.599	0.708	1.057	1.486	1.339
	Mean	4.614	1.198	1.061	1.757	1.552
	SD	0.396	0.915	0.233	0.650	0.511
	Minimum	4.226	0.632	0.830	1.286	1.183
	Maximum	5.017	2.254	1.296	2.499	2.135
Germanium	Median	1.203	0.350	0.345	0.496	0.606
	Mean	1.146	0.517	0.501	0.618	0.544
	SD	0.221	0.338	0.310	0.226	0.357
	Minimum	0.902	0.295	0.301	0.478	0.160
	Maximum	1.333	0.906	0.858	0.879	0.865
Hafnium	Median	0.009	0.004	0.010	0.006	0.011
	Mean	0.039	0.068	0.138	0.061	0.114
	SD	0.060	0.115	0.231	0.101	0.182

Metal	Concentration (mg/kg dry weight)	Transect				
			SE		W	NW
		FWC	1000 m	Centre	1000 m	1000 m
	Minimum	0.000	0.000	0.000	0.000	0.007
	Maximum	0.108	0.201	0.405	0.178	0.325
Indium	Median	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000
	SD	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000
Iron	Median	6969.652	963.636	708.000	2171.774	1587.830
	Mean	7056.771	1411.774	836.023	2216.262	1687.007
	SD	325.716	786.232	329.246	850.727	501.761
	Minimum	6783.474	952.075	590.018	1388.652	1242.241
	Maximum	7417.188	2319.613	1210.052	3088.361	2230.951
Lead[α]	Median	8.894	4.601	4.698	8.114	5.495
	Mean	9.170	5.477	4.743	10.426	5.610
	SD	0.542	1.655	0.467	4.344	0.843
	Minimum	8.821	4.444	4.300	7.728	4.831
	Maximum	9.794	7.386	5.232	15.437	6.505
Manganese	Median	87.311	113.893	150.476	169.220	145.952
	Mean	88.014	160.888	170.381	170.465	174.166
	SD	4.552	89.031	55.455	57.607	61.825
	Minimum	83.855	105.201	127.626	113.490	131.481
	Maximum	92.877	263.569	233.042	228.685	245.065
Mercury[α]	Median	0.494	0.000	0.000	0.000	0.000
	Mean	0.491	0.000	0.000	0.000	0.000
	SD	0.439	0.000	0.000	0.000	0.000
	Minimum	0.051	0.000	0.000	0.000	0.000
	Maximum	0.928	0.000	0.000	0.000	0.000
Molybdenum	Median	1.232	0.000	0.000	0.164	0.462
	Mean	1.205	0.000	0.000	0.231	0.395
	SD	0.076	0.000	0.000	0.271	0.251
	Minimum	1.119	0.000	0.000	0.000	0.118
	Maximum	1.265	0.000	0.000	0.530	0.606
Nickel[α]	Median	7.922	0.982	0.985	2.579	3.564
	Mean	7.955	1.323	1.199	2.706	3.197
	SD	0.419	0.714	0.393	0.457	1.256
	Minimum	7.553	0.844	0.960	2.326	1.799
	Maximum	8.390	2.143	1.653	3.212	4.230
Niobium	Median	0.166	0.025	0.015	0.035	0.035
	Mean	0.149	0.026	0.018	0.042	0.031
	SD	0.042	0.002	0.011	0.017	0.019
	Minimum	0.101	0.024	0.008	0.029	0.010

Metal	Concentration (mg/kg dry weight)	Transect				
			SE		W	NW
		FWC	1000 m	Centre	1000 m	1000 m
	Maximum	0.179	0.028	0.029	0.062	0.047
Rubidium	Median	15.055	1.632	1.522	3.852	2.712
	Mean	15.668	1.982	1.376	3.645	2.715
	SD	1.214	0.771	0.307	0.944	0.583
	Minimum	14.882	1.449	1.022	2.614	2.133
	Maximum	17.066	2.865	1.583	4.468	3.299
Scandium	Median	0.529	0.530	0.530	0.670	0.844
	Mean	0.627	0.957	0.792	0.900	1.048
	SD	0.319	0.840	0.496	0.625	0.737
	Minimum	0.369	0.416	0.481	0.424	0.435
	Maximum	0.984	1.924	1.363	1.608	1.865
Selenium	Median	0.000	0.000	0.269	0.753	0.799
	Mean	0.000	0.710	0.678	1.266	0.638
	SD	0.000	1.230	0.950	1.094	0.322
	Minimum	0.000	0.000	0.000	0.523	0.268
	Maximum	0.000	2.130	1.764	2.521	0.848
Silver	Median	0.942	0.000	0.000	0.000	0.029
	Mean	0.942	0.000	0.000	0.000	0.035
	SD	0.073	0.000	0.000	0.000	0.018
	Minimum	0.869	0.000	0.000	0.000	0.021
	Maximum	1.015	0.000	0.000	0.000	0.056
Tantalum	Median	0.025	0.000	0.000	0.000	0.000
	Mean	0.020	0.000	0.000	0.000	0.000
	SD	0.011	0.000	0.000	0.000	0.000
	Minimum	0.007	0.000	0.000	0.000	0.000
	Maximum	0.027	0.000	0.000	0.000	0.000
Tellurium	Median	0.000	0.000	0.000	0.000	0.000
	Mean	0.000	0.000	0.000	0.000	0.000
	SD	0.000	0.000	0.000	0.000	0.000
	Minimum	0.000	0.000	0.000	0.000	0.000
	Maximum	0.000	0.000	0.000	0.000	0.000
Thallium	Median	0.087	0.000	0.000	0.000	0.000
	Mean	0.089	0.000	0.000	0.000	0.000
	SD	0.020	0.000	0.000	0.000	0.000
	Minimum	0.069	0.000	0.000	0.000	0.000
	Maximum	0.110	0.000	0.000	0.000	0.000
Thorium	Median	3.422	0.397	0.622	0.849	1.004
	Mean	3.391	0.706	0.716	1.074	0.909
	SD	0.747	0.569	0.371	0.474	0.193
	Minimum	2.629	0.359	0.402	0.755	0.688
	Maximum	4.121	1.363	1.125	1.619	1.035

Metal	Concentration (mg/kg dry weight)	Transect				
			SE		W	NW
		FWC	1000 m	Centre	1000 m	1000 m
Tin	Median	2.380	0.000	0.000	0.000	0.000
	Mean	2.535	0.000	0.000	0.000	0.000
	SD	0.275	0.000	0.000	0.000	0.000
	Minimum	2.373	0.000	0.000	0.000	0.000
	Maximum	2.853	0.000	0.000	0.000	0.000
Titanium	Median	226.625	23.638	18.700	53.482	41.083
	Mean	229.103	27.486	18.830	61.537	41.009
	SD	26.404	10.858	4.266	22.238	4.815
	Minimum	204.025	19.077	14.630	44.450	36.159
	Maximum	256.659	39.744	23.159	86.680	45.787
Tungsten	Median	0.023	0.004	0.012	0.015	0.018
	Mean	0.025	0.009	0.009	0.021	0.018
	SD	0.003	0.010	0.008	0.025	0.017
	Minimum	0.023	0.003	0.000	0.000	0.000
	Maximum	0.028	0.021	0.016	0.048	0.035
Uranium	Median	1.305	1.925	2.419	3.676	4.588
	Mean	1.300	2.336	2.406	3.641	4.503
	SD	0.092	0.734	0.323	0.703	0.479
	Minimum	1.206	1.899	2.076	2.921	3.988
	Maximum	1.390	3.183	2.723	4.325	4.935
Vanadium	Median	11.354	3.384	3.483	10.368	7.505
	Mean	11.406	4.654	3.597	9.072	7.310
	SD	0.943	2.461	0.977	3.510	1.847
	Minimum	10.490	3.088	2.681	5.098	5.374
	Maximum	12.373	7.491	4.626	11.749	9.052
Yttrium	Median	6.107	5.742	7.205	8.273	8.081
	Mean	5.922	7.820	7.861	8.498	9.185
	SD	0.351	3.860	2.120	2.701	2.586
	Minimum	5.516	5.445	6.147	5.917	7.334
	Maximum	6.141	12.273	10.231	11.304	12.139
Zinc[α]	Median	85.670	6.080	9.231	16.215	16.348
	Mean	90.260	7.762	9.393	15.727	18.607
	SD	8.113	3.227	0.413	3.873	5.293
	Minimum	85.482	5.724	9.086	11.633	14.818
	Maximum	99.628	11.483	9.862	19.333	24.654
Zirconium	Median	5.428	0.532	0.571	1.243	1.044
	Mean	5.532	0.832	0.873	1.123	1.062
	SD	0.556	0.596	0.600	0.370	0.239
	Minimum	5.035	0.447	0.483	0.708	0.833
	Maximum	6.132	1.518	1.565	1.418	1.309
Total metal	Median	198.741	22.792	30.218	49.520	51.980

Metal	Concentration (mg/kg dry weight)	Transect				
			SE		W	NW
		FWC	1000 m	Centre	1000 m	1000 m
	Mean	205.324	29.298	30.287	49.407	54.637
	SD	17.239	13.881	4.378	1.587	13.035
	Minimum	192.347	19.864	25.944	47.766	43.136
	Maximum	224.885	45.237	34.699	50.935	68.797

7.13 C4. Antibiotics quantification

Table C5. Concentrations of antibiotics in composite effluent (µg/L; ppb) from the third WWTP located near WWTP B (n = 3). Antibiotics were not detected in seawater samples around the WWTP B outfall. Note that only the family of β-lactam antibiotics are subdivided into classes. ND = not detected; SD = standard deviation.

		Concentration (µg/L)				
Family (class)	**Antibiotic**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**
β-lactams (penicillins)	Flucloxacillin sodium	-	-	-	ND	ND
	Penicillin V	-	-	-	ND	ND
β-lactams (cephalosporins)	Cefalexin	-	-	-	ND	ND
Dihydrofolate reductase inhibitors	Trimethoprim	-	-	-	ND	ND
Fluoroquinolones	Enrofloxacin	-	-	-	ND	ND
	Ciprofloxacin	-	-	-	ND	ND
	Norfloxacin	-	-	-	ND	ND
	Ofloxacin	-	-	-	ND	ND
Macrolides	Clarithromycin	-	-	-	ND	ND
	Erythromycin	-	-	-	ND	ND
	Roxithromycin	0.083	0.081	0.004	0.077	0.084
Sulfonamides	Sulfamethoxazole	0.907	1.231	1.006	0.428	2.360
Tetracyclines	Tetracycline hydrochloride	-	-	-	ND	ND
	Doxycycline hyclate	-	-	-	ND	ND
	Oxytetracycline hydrochloride	-	-	-	ND	ND
	Total antibiotics	0.991	1.313	1.008	0.505	2.442

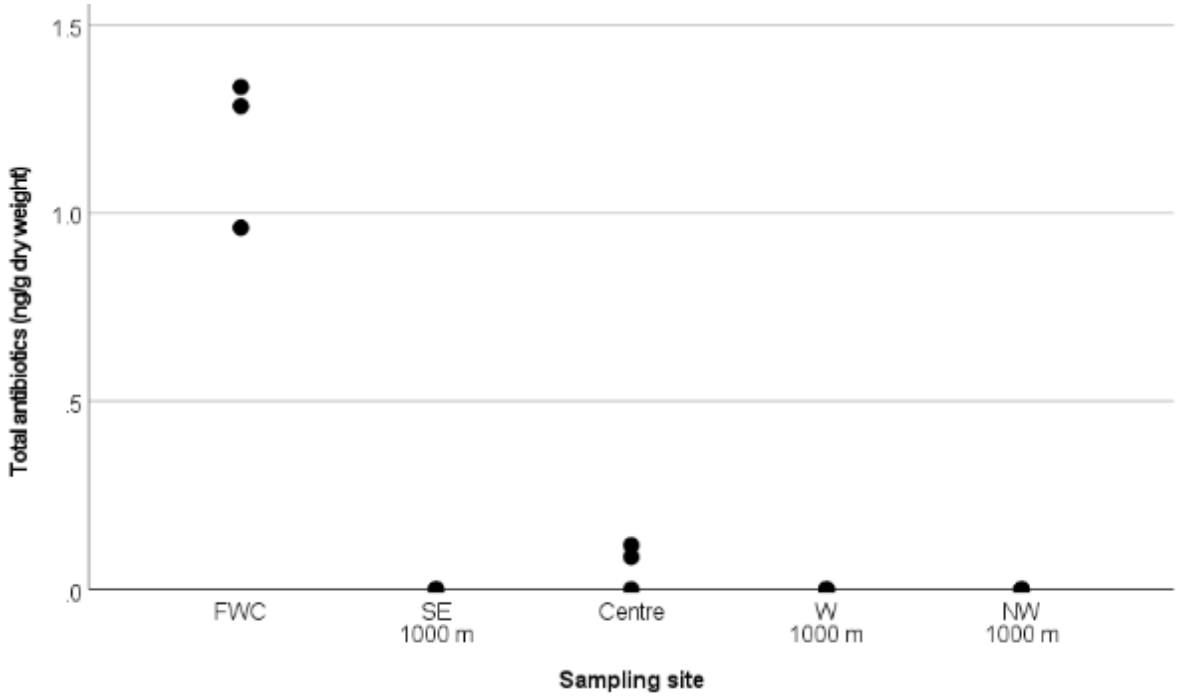


Figure C6. The total concentration of antibiotics (ng/g dry weight; ppm) detected in sediment around the WWTP B outfall. Dots represent replicates. Samples were analysed at the Freshwater Channel (FWC), at the Centre of the transect intersection, and at 1000 m along the SE, W and NW transects. At each site, n = 3.

Table C6. Concentrations of antibiotics in sediments (ng/g dry weight; ppb) from around the WWTP B outfall. For each sample, n = 3. Note that only the family of β-lactam antibiotics are subdivided into classes. ND = not detected; SD = standard deviation.

Family (class)	Antibiotic	Concentration (ng/g dry weight)	FWC	SE 1000 m	Centre	W 1000 m	NW 1000 m
β-lactams (penicillins)	Penicillin V	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	< LOD	< LOD	< LOD	< LOD
		Maximum	< LOD	< LOD	< LOD	< LOD	< LOD
β-lactams (cephalosporins)	Cefalexin	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	ND	< LOD	< LOD	< LOD
		Maximum	< LOD	ND	< LOD	ND	ND
Dihydrofolate reductase inhibitors	Trimethoprim	Median		-		-	-
		Mean		-		-	-
		SD		-		-	-
		Minimum		ND		ND	ND
		Maximum		ND		ND	ND
Fluoroquinolones	Enrofloxacin	Median		-	-	-	-
		Mean		-	-	-	-
		SD		-	-	-	-
		Minimum		ND	< LOD	ND	ND
		Maximum		ND	< LOD	ND	ND
	Ciprofloxacin	Median		-	-	-	-
		Mean		-	-	-	-
		SD		-	-	-	-
		Minimum	< LOD	< LOD	< LOD	< LOD	< LOD
		Maximum		< LOD	< LOD	< LOD	< LOD
	Norfloxacin	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	< LOD	< LOD	< LOD	< LOD
		Maximum	< LOD	< LOD	< LOD	< LOD	< LOD
	Ofloxacin	Median		-	-	-	-
		Mean		-	-	-	-
		SD		-	-	-	-
		Minimum	< LOD	ND	< LOD	ND	< LOD
		Maximum		ND	< LOD	ND	ND
Macrolides	Clarithromycin	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	ND	< LOD	ND	ND

Family (class)	Antibiotic	Concentration (ng/g dry weight)	FWC	SE 1000 m	Centre	W 1000 m	NW 1000 m
		Maximum	< LOD	ND	< LOD	ND	ND
	Erythromycin	Median					
		Mean					
		SD					
		Minimum					
		Maximum					
	Roxithromycin	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	< LOD	< LOD	< LOD	< LOD
		Maximum	< LOD	< LOD	< LOD	< LOD	< LOD
Sulfonamides	Sulfamethoxazole	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	ND	< LOD	ND	ND
		Maximum	< LOD	ND	< LOD	ND	ND
Tetracyclines	Tetracycline hydrochloride	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	< LOD	< LOD	< LOD	< LOD
		Maximum	< LOD	< LOD	< LOD	< LOD	< LOD
	Doxycycline hyclate	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	< LOD	< LOD	< LOD	< LOD
		Maximum	< LOD	< LOD	< LOD	< LOD	< LOD
	Oxytetracycline hydrochloride	Median	-	-	-	-	-
		Mean	-	-	-	-	-
		SD	-	-	-	-	-
		Minimum	< LOD	< LOD	< LOD	< LOD	< LOD
		Maximum	< LOD	ND	< LOD	ND	< LOD
	Total antibiotics	Median					
		Mean					
		SD					
		Minimum					
		Maximum					

7.14 C5. PFAS quantification

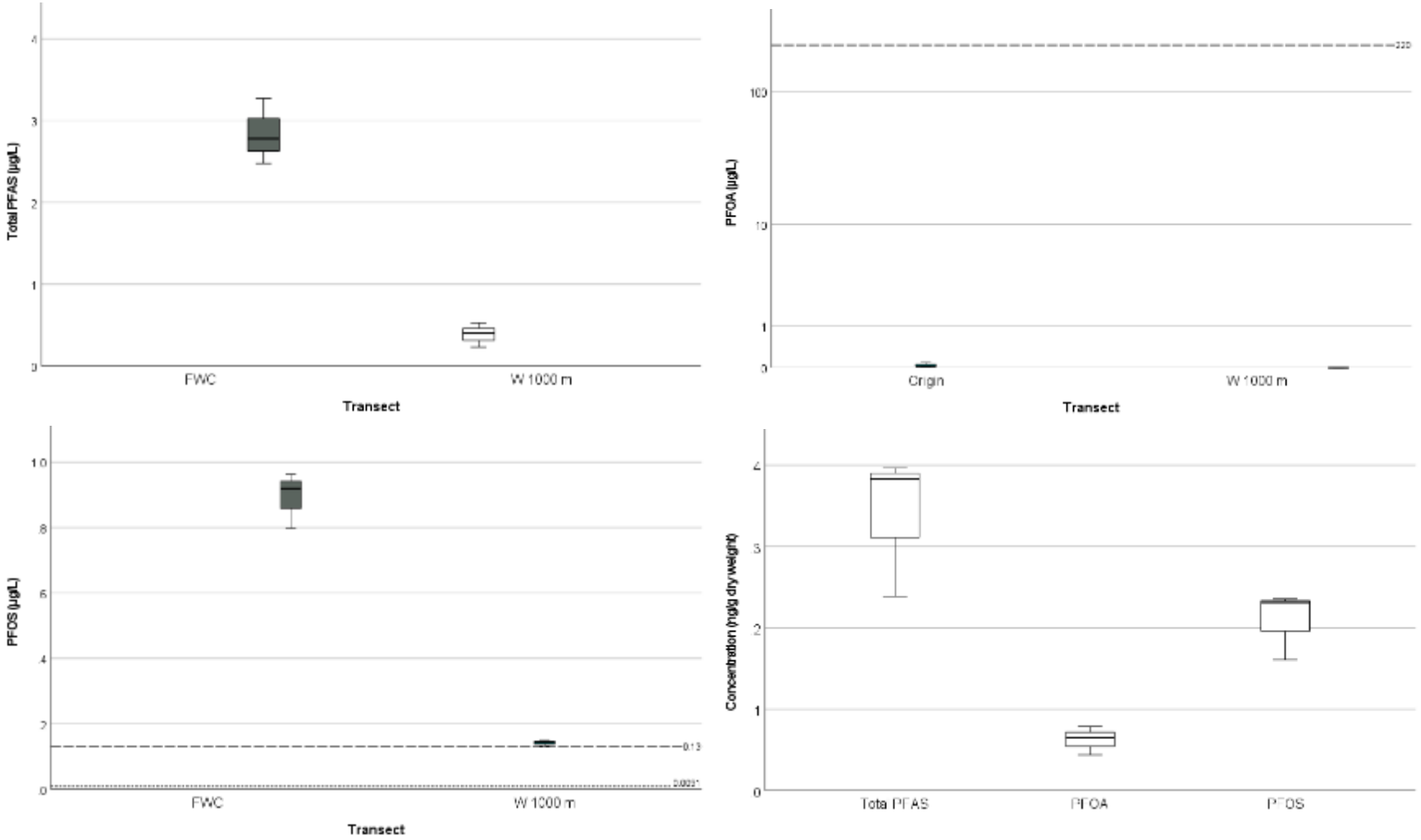


Figure C7. Concentrations of total PFAS, PFOA and PFOS in (A-C) seawater (µg/L; ppb) collected from around the WWTP B outfall, and (D) concentrations of PFAS in sediment (ng/g dry weight; ppm) from the FWC. At each location, n = 3. The reference line with short dashes represents the draft freshwater Default Guideline Values for PFOS for 99 % species protection in slightly to moderately disturbed ecosystems, which is currently being considered by the Commonwealth government. Reference lines with long dashes represent interim freshwater and marine guideline values proposed by the Heads of EPAs. There are no guidelines for PFAS concentrations in sediment.

Table C7. Concentrations of PFAS (µg/L; ppb) in composite effluent from the third WWTP located near WWTP B, and in water collected from FWC and 1000 m along the west (W) transect at the WWTP B outfall. For each location, n = 3. LOD = limit of detection; ND = not detected; SD = standard deviation.

				Concentration (ng/mL)				
Group	**Sub-group**	**Analyte**	**Sample**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**
Perfluoroalkyl acids	Perfluoroalkyl carboxylic acids (PFCAs)	PFHpA	Effluent	0.331	0.317	0.037	0.275	0.346
			FWC	0.101	0.106	0.013	0.096	0.121
			W 1000 m	0.015	0.015	0.004	0.012	0.017
		PFOA	Effluent	1.133	1.085	0.119	0.950	1.173
			FWC	0.269	0.274	0.044	0.233	0.320
			W 1000 m	0.043	0.041	0.009	0.031	0.049
		PFNA	Effluent	0.090	0.085	0.016	0.067	0.097
			FWC	0.014	0.014	0.002	0.013	0.016
			W 1000 m	-	-	-	<LOD	<LOD
		PFDA	Effluent	0.118	0.120	0.018	0.103	0.138
			FWC	0.007	0.007	0.004	0.003	0.011
			W 1000 m	-	-	-	<LOD	ND
		PFUna	Effluent	-	-	-	ND	ND
			FWC	-	-	-	<LOD	ND
			W 1000 m	-	-	-	<LOD	ND
		PFDoA	Effluent	0.005	0.015	0.021	0.001	0.039
			FWC	0.012	0.009	0.007	0.001	0.013
			W 1000 m	-	-	-	<LOD	<LOD
		PFTrDa	Effluent	-	-	-	ND	ND
			FWC	-	-	-	<LOD	ND
			W 1000 m	-	-	-	ND	ND
		PFTeDa	Effluent	0.016	0.016	-	<LOD	0.016
			FWC	-	-	-	<LOD	<LOD
			W 1000 m	-	-	-	<LOD	<LOD
	Perfluoroalkane sulfonic acids (PFSAs)	PFBS	Effluent	0.644	0.649	0.017	0.634	0.668
			FWC	0.136	0.142	0.013	0.134	0.157
			W 1000 m	-	-	-	<LOD	<LOD
		PFPeS	Effluent	0.314	0.303	0.045	0.254	0.342
			FWC	0.060	0.065	0.010	0.058	0.077
			W 1000 m	-	-	-	<LOD	<LOD
		PFHxS	Effluent	3.143	3.236	0.212	3.086	3.479
			FWC	0.704	0.746	0.149	0.622	0.912
			W 1000 m	0.090	0.066	0.058	<LOD	0.109
		PFHpS	Effluent	0.091	0.089	0.010	0.079	0.098
			FWC	0.017	0.017	-	ND	0.017
			W 1000 m	-	-	-	ND	ND
		PFOS	Effluent	4.564	4.356	0.700	3.576	4.928
			FWC	0.920	0.894	0.086	0.798	0.963
			W 1000 m	0.145	0.142	0.009	0.132	0.149
		PFNS	Effluent	-	-	-	ND	ND
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
		PFDS	Effluent	-	-	-	ND	ND
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
Perfluoroalkane sulfonamido substances	N-Alkyl perfluoroalkane sulfonamide acetic acids (N-Alkyl FASAAs)	N-MeFOSAA	Effluent	0.197	0.197	-	ND	0.197
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
		N-EtFOSSA	Effluent	-	-	-	ND	ND
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
	Not applicable	FBSA	Effluent	0.341	0.344	0.055	0.291	0.401
			FWC	0.082	0.086	0.015	0.073	0.103

Group	Sub-group	Analyte	Sample	Concentration (ng/mL)				
				Median	Mean	SD	Minimum	Maximum
Perfluoroalkane sulfonamides (FASAs)			W 1000 m	-	-	-	<LOD	<LOD
		PFHxA	Effluent	2.162	2.080	0.177	1.877	2.200
			FWC	0.48	0.495	0.082	0.421	0.583
			W 1000 m	0.098	0.127	0.093	0.052	0.231
Per- and polyfluoroalkyl ether acids (PFEAs)	Fluorotelomer-based substances	4:2 FTS	Effluent	0.001	0.001	-	ND	0.001
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
		6:2 FTS	Effluent	0.048	0.075	0.091	0.000	0.176
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
		8:2 FTS	Effluent	-	-	-	ND	ND
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
	Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	NaDONA	Effluent	-	-	-	<LOD	ND
			FWC	-	-	-	<LOD	ND
			W 1000 m	-	-	-	ND	ND
		HFPO-DA	Effluent	-	-	-	ND	ND
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	ND	ND
	Per- and polyfluoroalkyl ether sulfonic acids (PFESAs)	9Cl-PF3ONS	Effluent	-	-	-	ND	ND
			FWC	-	-	-	ND	ND
			W 1000 m	-	-	-	<LOD	<LOD
		11Cl-PF3OUdS	Effluent	0.004	0.004	-	<LOD	0.004
			FWC	-	-	-	<LOD	<LOD
			W 1000 m	-	-	-	<LOD	<LOD
		Total PFAS	Effluent	13.020	12.827	1.084	11.659	13.801
			FWC	2.782	2.843	0.402	2.476	3.272
			W 1000 m	0.399	0.386	0.148	0.232	0.527

Table C8. Concentrations of PFAS (ng/g dry weight; ppm) from sediment around the freshwater channel (FWC) at the WWTP B outfall (n = 3). SD = standard deviation.

			FWC				
Group	**Sub-group**	**Analyte**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**
Perfluoroalkyl acids	Perfluoroalkyl carboxylic acids (PFCAs)	PFHpA	-	-	0.001	<LOD	0.001
		PFOA	0.065	0.063	0.017	0.044	0.079
		PFNA	-	-	0.001	<LOD	0.001
		PFDA	0.012	0.011	0.003	0.008	0.013
		PFUnA	0.006	0.006	0.001	0.006	0.007
		PFDoA	0.015	0.015	0.002	0.013	0.018
		PFTrDA	-	-	-	<LOD	ND
		PFTeDA	-	-	-	<LOD	ND
	Perfluoroalkane sulfonic acids (PFSAs)	PFBS	-	-	-	<LOD	ND
		PFPeS	-	-	-	ND	ND
		PFHxS	0.024	0.018	0.016	ND	0.030
		PFHpS	-	-	-	ND	ND
		PFOS	0.231	0.209	0.042	0.161	0.236
		PFNS	-	-	-	ND	ND
		PFDS	-	-	-	<LOD	ND
Perfluoroalkane sulfonamido substances	N-Alkyl perfluoroalkane sulfonamide acetic acids (N-Alkyl FASAAs)	N_MeFOSAA	0.010	0.008	0.007	<LOD	0.013
		N_EtFOSSA	-	0.003	0.006	ND	0.010
Perfluoroalkane sulfonamides (FASAs)	Not applicable	FBSA	-	-	-	<LOD	ND
		PFHxA	0.001	0.002	0.003	<LOD	0.005
Per- and polyfluoroalkyl ether acids (PFEAs)	Fluorotelomer-based substances	4:2 FTS	-	-	-	ND	ND
		6:2 FTS	-	-	-	ND	ND
		8:2 FTS	-	-	-	ND	ND
	Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	NaDONA	-	-	-	ND	ND
		HFPO-DA	-	-	-	<LOD	ND
	Per- and polyfluoroalkyl	9Cl-PF3ONS	0.003	0.004	0.003	0.002	0.007

			FWC				
Group	**Sub-group**	**Analyte**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**
	ether sulfonic acids (PFESAs)	11Cl-PF3OUdS	-	-	-	<LOD	<LOD
		Total PFAS	0.383	0.340	0.088	0.239	0.397

7.15 C6. Microplastics quantification

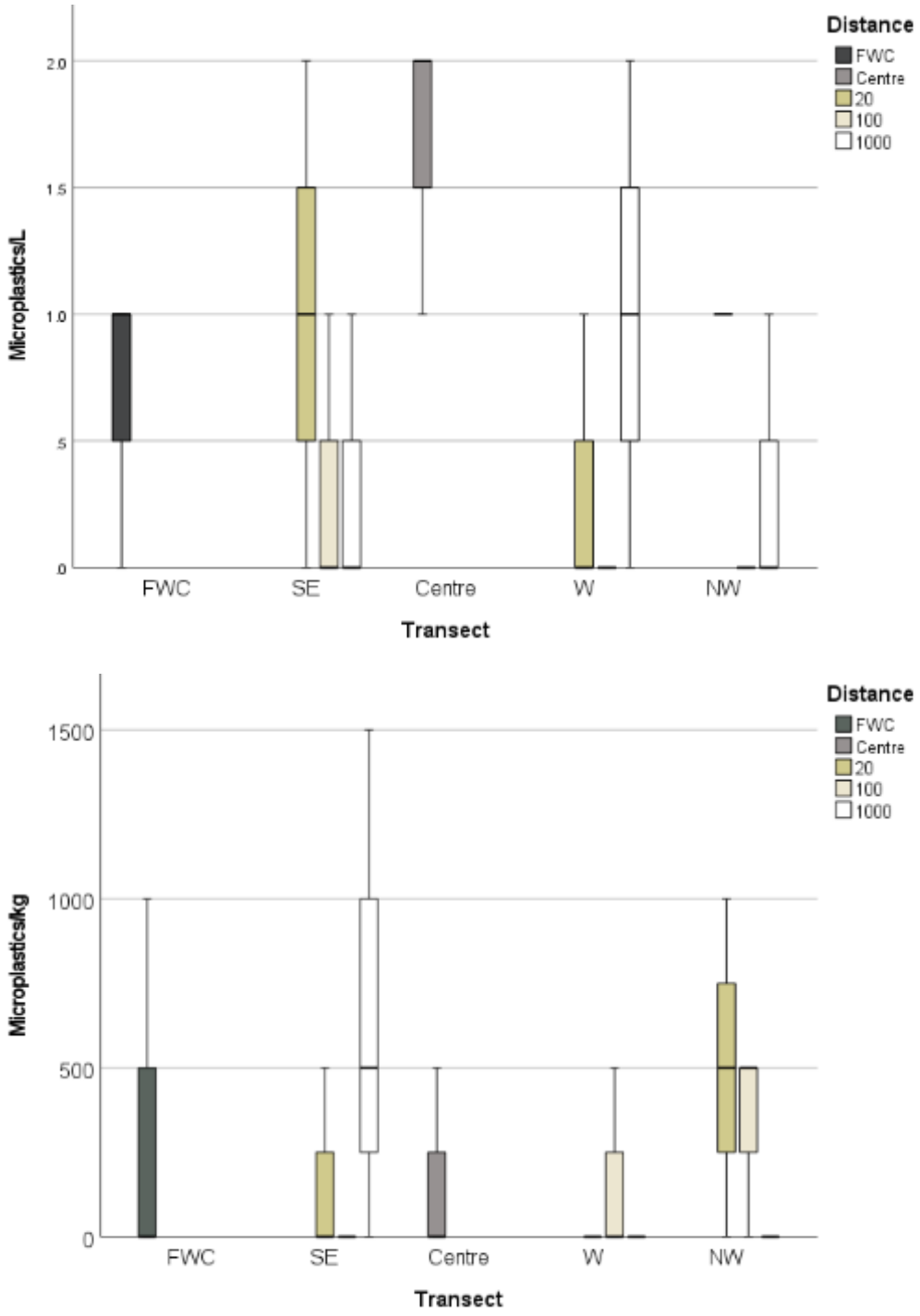


Figure C8. Concentration of microplastics surrounding the WWTP B outfall in (top) seawater (microplastics/L) and (bottom) sediment (microplastics/kg). At each sampling location, n = 3. Distances are taken from the Centre of the transects. FWC = freshwater channel.

Table C9. Concentrations of microplastics in composite effluent from the third WWTP located near WWTP B (microplastics/L), and in seawater (microplastics/L) and sediment (microplastics/kg) collected from the WWTP B outfall. For all samples, n = 3. FWC = freshwater channel; SD = standard deviation.

Partition	Transect	Distance from Centre (m)	Median	Mean	SD	Minimum	Maximum
Effluent	NA	NA	2	1.3	1.1	0	2
Seawater	FWC	NA	1	0.7	0.6	0	1
	SE	20	1	1.0	1.0	0	2
		100	0	0.3	0.6	0	1
		1000	0	0.3	0.6	0	1
	Centre	0	2	1.7	0.6	1	2
	W	20	0	0.3	0.6	0	1
		100	0	0.0	0.0	0	0
		1000	1	1.0	1.0	0	2
	NW	20	1	1.0	0.0	1	1
		100	0	0.0	0.0	0	0
		1000	0	0.3	0.6	0	1
Sediment	FWC	NA	0	333.3	577.6	0	1000
	SE	20	0	166.7	288.7	0	500
		100	0	0	0	0	0
		1000	500	666.7	763.8	0	1500
	Centre	0	0	166.7	288.7	0	500
	W	20	0	0	0	0	0
		100	0	166.7	288.7	0	500
		1000	0	0	0	0	0
	NW	20	500	500.0	500.0	0	1000
		100	500	333.3	288.7	0	500
		1000	0	0	0	0	0

Appendix D: Data from the WWTP C outfall (NSW)

7.16 D1. Physical parameters

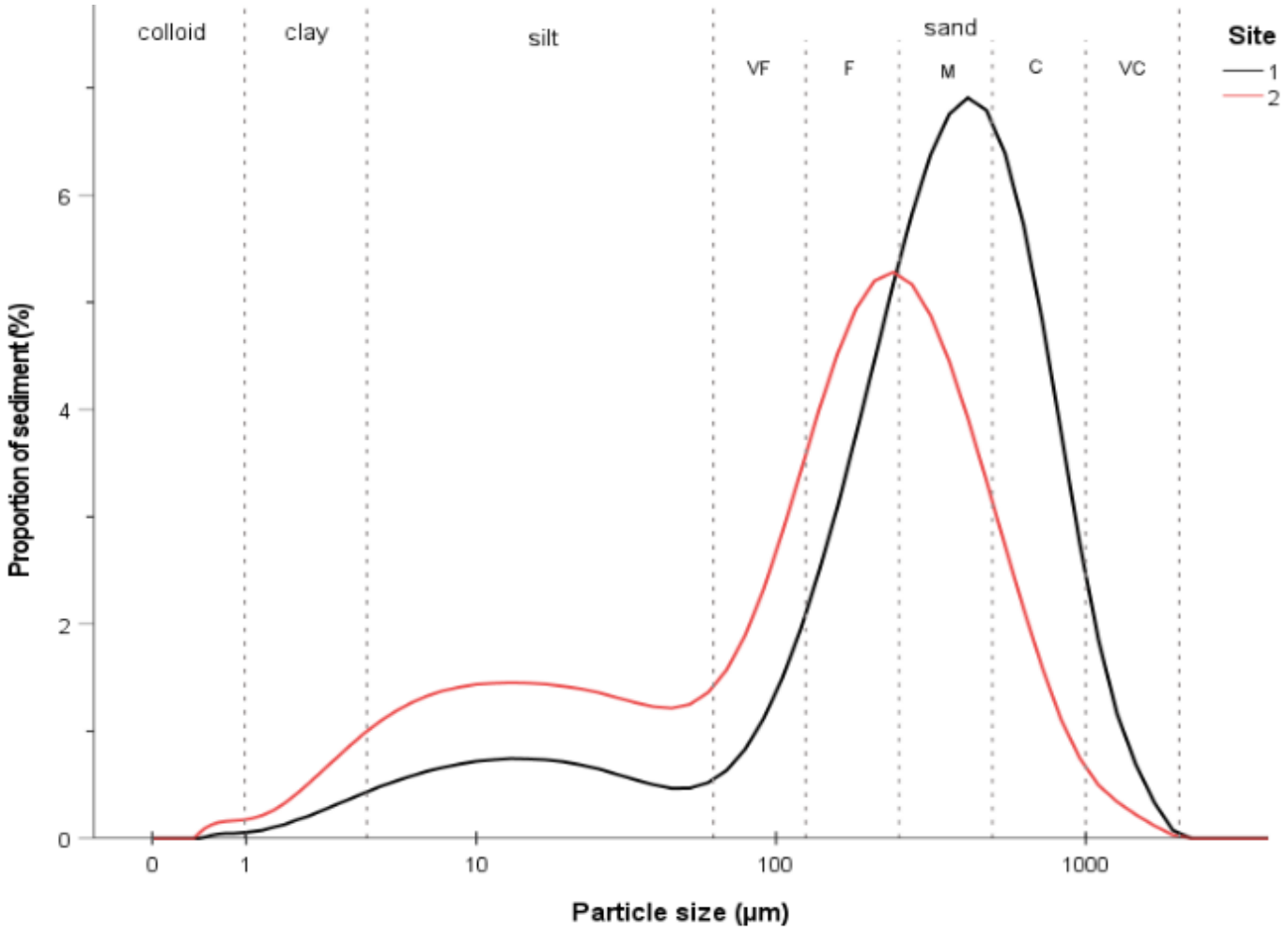


Figure D1. Particle size distribution of sediments collected from two sites adjacent to the WWTP C outfall (NSW). Results are the average of five replicates at each site (n = 5). Aggregate names listed at the top of the chart are taken from the Wentworth scale. VF = very fine; F = fine; M = medium; C = coarse; VC = very coarse.

Table D1. Particle size percentage composition for sediment collected at two sites at 0 m at the WWTP C (NSW) outfall. For both sites, n = 5. Data from this study (2023) are compared to Besley & Birch (2019), who measured proportions of broader aggregates called 'fines' and 'sand' for samples collected between 2000 – 2017. Dashes indicate unavailable data. VF = very fine; F = fine; M = medium; C = coarse; VC = very coarse.

		Besley & Birch (2019) aggregates		Wentworth scale aggregates							
Sampling year	**Proportion (%)**	**Fines (< 63 µm)**	**Sand (63 – 2000 µm)**	**Colloid (< 0.97 µm)**	**Clay (0.98 – 3.9 µm)**	**Silt (3.9 – 63 µm)**	**Sand – VF (63 – 125 µm)**	**Sand – F (125 – 250 µm)**	**Sand – M (250 – 500 µm)**	**Sand – C (500 – 1000 µm)**	**Sand – VC (1000 – 2000 µm)**
2000-2017, Besley & Birch (2019)	Minimum	0.4	84.8	-	-	-	-	-	-	-	-
	Median	6.8	92.4	-	-	-	-	-	-	-	-
	Maximum	14.4	98.8	-	-	-	-	-	-	-	-
2023, Site 1	Minimum	7.9	78.6	0.0	1.1	6.7	2.2	9.7	27.1	6.8	0.2
	Median	15.8	84.2	0.3	2.3	13.2	4.5	16.2	30.8	21.6	3.0
	Maximum	21.4	92.1	0.5	3.2	17.8	12.5	32.1	38.7	37.9	11.1
2023, Site 2	Minimum	27.4	63.9	0.6	3.5	23.3	10.3	19.0	19.9	3.4	0.5
	Median	32.3	67.7	1.0	5.4	26.5	12.2	24.8	21.0	7.8	1.3
	Maximum	36.1	72.6	1.1	6.0	29.1	13.6	26.7	24.5	14.0	2.0
2023, Site 1 & 2 combined	Minimum	7.9	63.9	0.0	1.1	6.7	2.2	9.7	19.9	3.4	0.2
	Median	24.4	75.6	0.5	3.4	20.5	11.1	22.6	25.8	12.0	1.3
	Maximum	36.1	92.1	1.1	6.0	29.1	13.6	32.1	38.7	37.9	11.1

Table D2. Particle size distribution metrics for the two sampling sites at the WWTP C outfall (NSW). Data are mean ± SD from five replicates at each site (n = 5).

Metric	Site 1	Site 2
D10 (µm)	58.9 ± 61.2	7.3 ± 2.0
D50 (µm)	364.2 ± 130.4	166.3 ± 22.2
D90 (µm)	812.8 ± 238.3	535.9 ± 99.2
Specific surface area ($m^2 g^{-1}$)	0.20 ± 0.1	0.28 ± 0.1

7.17 D2. Nutrient quantification

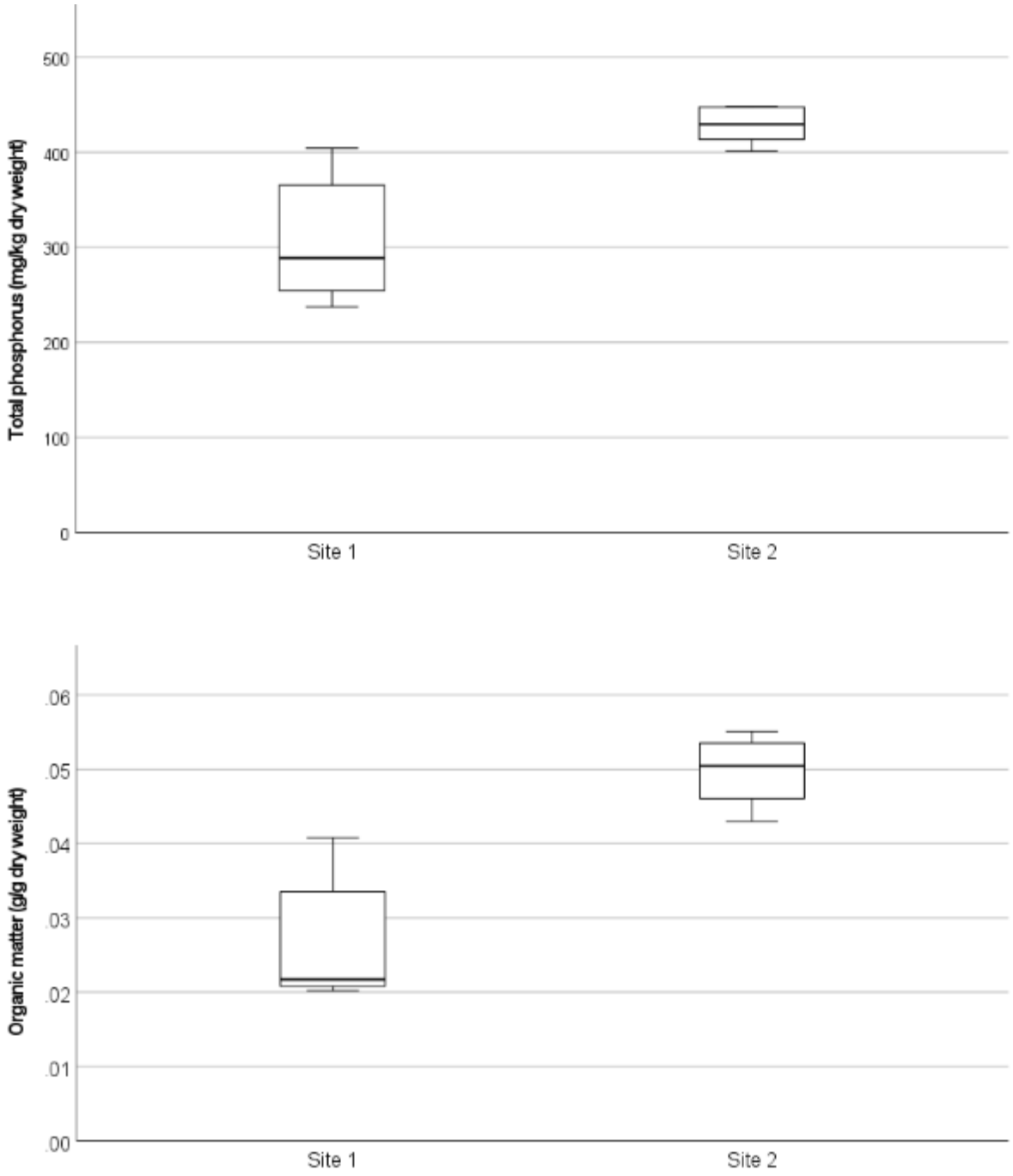
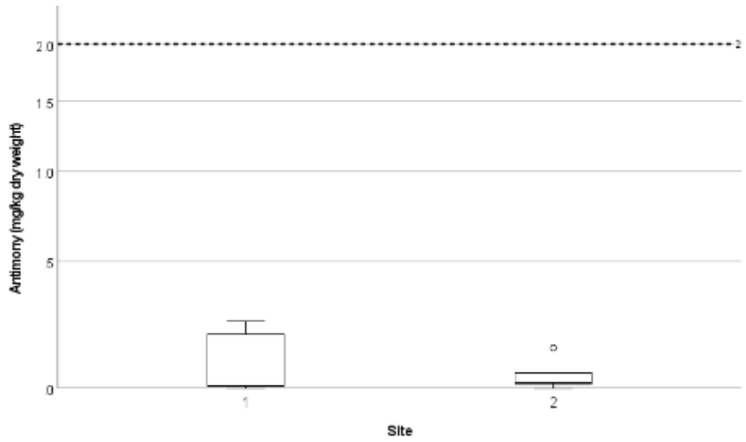


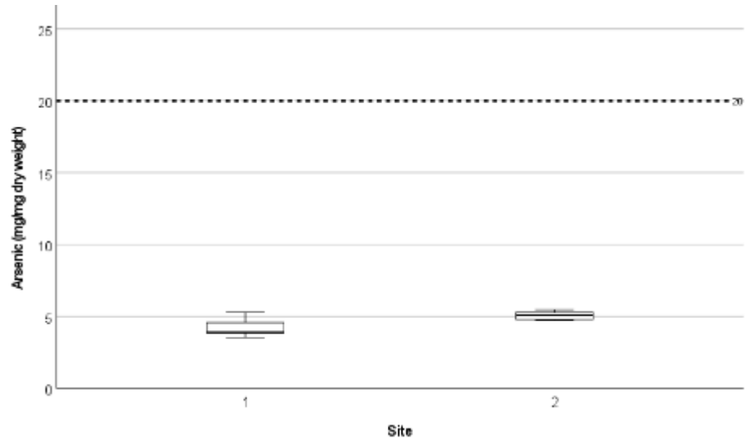
Figure D2. Concentrations of (top) total phosphorus and (bottom) organic matter in sediments collected from two locations at the WWTP C outfall (0 m from point source). At both sites, five sample grabs were obtained (n = 5).

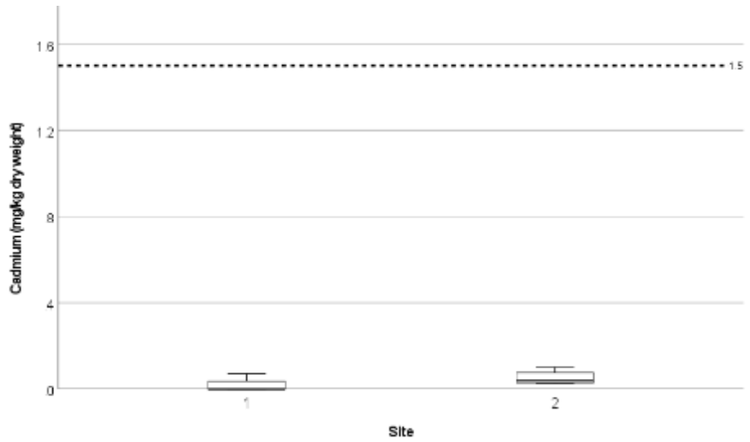
Table D3. Concentration of nutrients in sediments collected from two locations at the WWTP C outfall (0 m from point source). At both sites, five sample grabs were obtained (n = 5). SD = standard deviation.

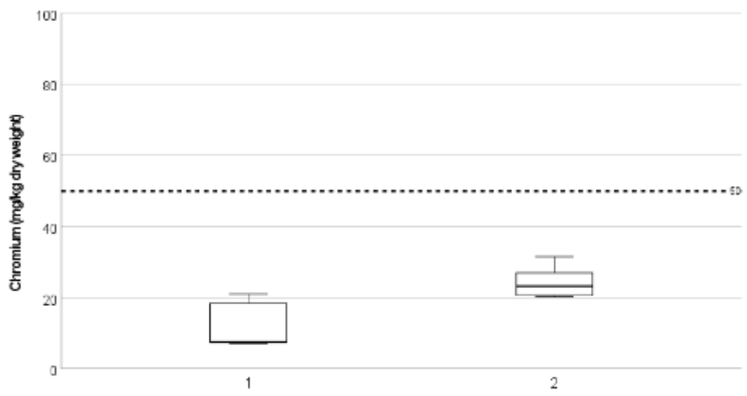
Nutrient	Concentration	Site 1 (*n* = 5)	Site 2 (*n* = 5)
Organic matter (g/g dry weight)	Median	0.022	0.050
	Mean	0.027	0.050
	SD	0.009	0.005
	Minimum	0.020	0.043
	Maximum	0.041	0.055
Total phosphorus (mg/kg dry weight)	Median	288.878	429.439
	Mean	310.019	427.987
	SD	72.114	20.813
	Minimum	237.245	401.049
	Maximum	404.346	448.237

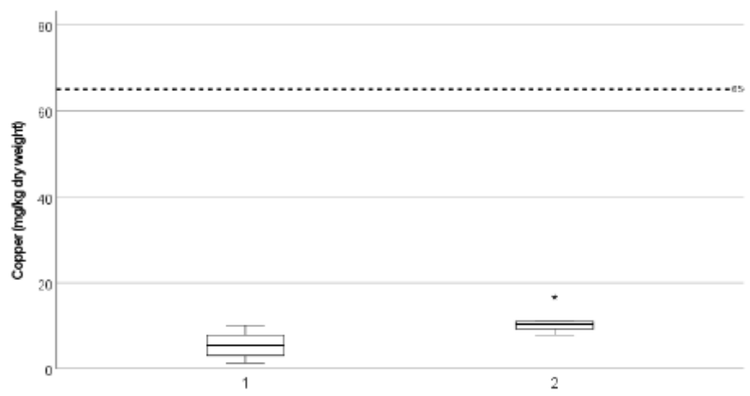
7.18 D3. Metal quantification

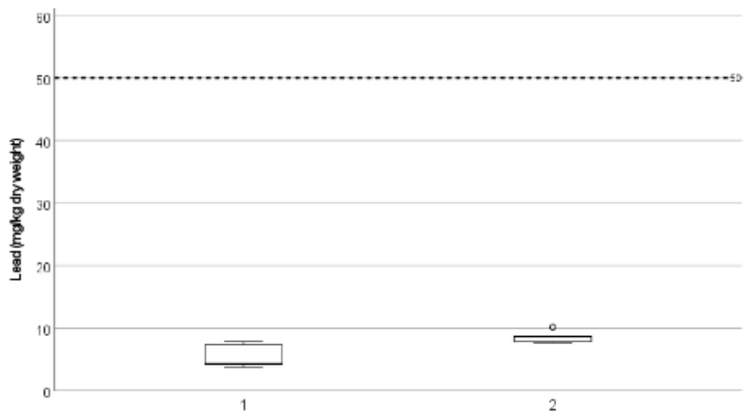


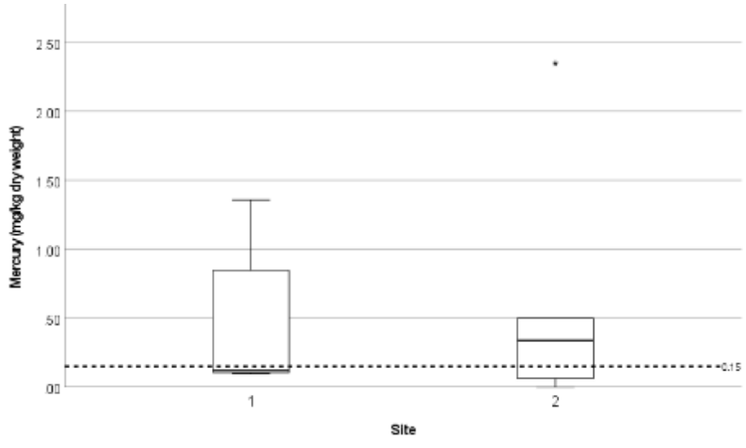


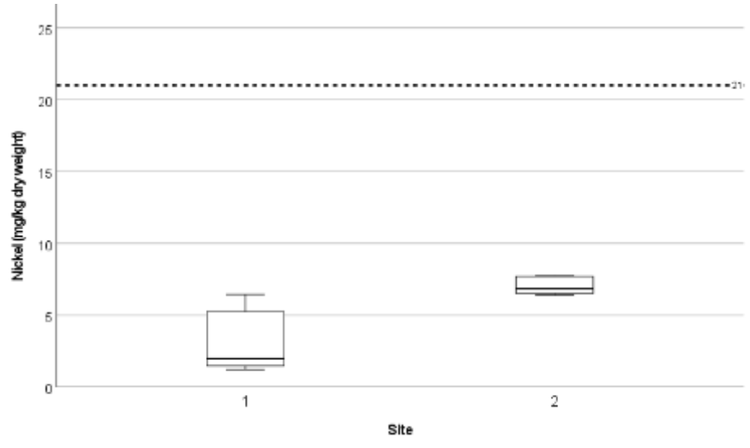


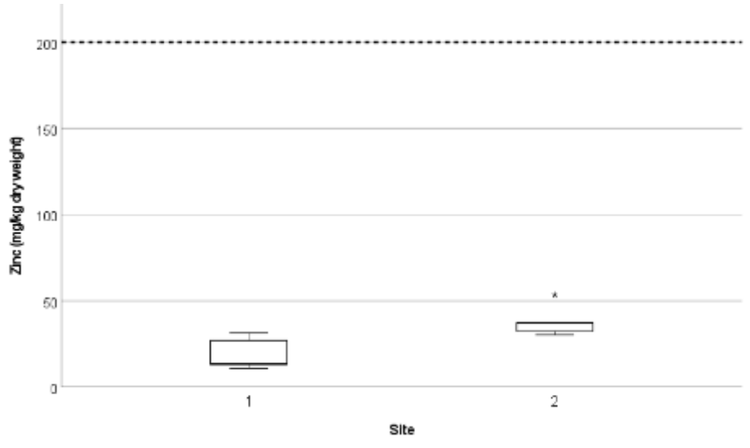












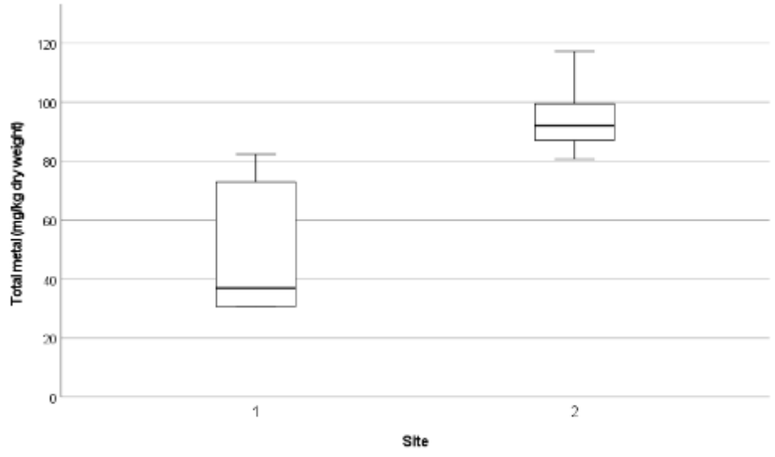


Figure D3. Concentrations of total recoverable metals (mg/kg dry weight; ppm) from sediment at the WWTP C outfall (0 m). Data are from five replicates at each site (n = 5). Open circles represent mild outliers, defined as values 1.5 times the interquartile range below quartile 1 or above quartile 3. Stars represent extreme outliers, defined as values that are more than 3.0 times the interquartile range below quartile 1 or above quartile 3. Metals presented are those associated with sediment Default Guideline Values, which are represented by the dashed reference lines. Total metals represent the sum of all metals associated with a sediment Default Guideline Value. A full list of total recoverable metals is provided in Table E4.

Table D4. Concentrations of total recoverable metals (mg/kg dry weight; ppm) from the two sites at the WWTP C outfall (0 m). Data are from five replicates (n = 5) at each site. SD = standard deviation. α indicates metals associated with sediment Default Guideline Values that were combined to form a metric of 'total metal' for statistical analyses.

Metal	Concentration (mg/kg dry weight)	Site 1 (*n* = 5)	Site 2 (*n* = 5)
Aluminium	Median	4664.164	12278.386
	Mean	5958.149	11906.300
	SD	3449.442	1815.574
	Minimum	3194.489	9988.204
	Maximum	11653.962	14485.542
Antimony$^{\alpha}$	Median	0.008	0.018
	Mean	0.089	0.044
	SD	0.116	0.055
	Minimum	0.000	0.000
	Maximum	0.239	0.137
Arsenic$^{\alpha}$	Median	3.898	5.083
	Mean	4.228	5.072
	SD	0.704	0.319
	Minimum	3.531	4.723
	Maximum	5.292	5.473
Barium	Median	15.316	34.108
	Mean	18.285	34.551
	SD	8.825	4.138
	Minimum	11.373	28.584
	Maximum	32.467	39.728
Bismuth	Median	0.000	0.000
	Mean	0.000	0.000
	SD	0.000	0.000
	Minimum	0.000	0.000
	Maximum	0.000	0.000
Cadmium$^{\alpha}$	Median	0.000	0.038
	Mean	0.021	0.054
	SD	0.032	0.033
	Minimum	0.000	0.027
	Maximum	0.071	0.101
Cerium	Median	7.122	14.021
	Mean	8.874	14.575
	SD	3.830	2.698
	Minimum	5.592	11.742
	Maximum	15.116	17.630
Caesium	Median	0.331	0.816
	Mean	0.429	0.809
	SD	0.225	0.094

Metal	Concentration (mg/kg dry weight)	Site 1 (*n* = 5)	Site 2 (*n* = 5)
	Minimum	0.225	0.719
	Maximum	0.787	0.953
Chromium[α]	Median	7.538	23.285
	Mean	12.320	24.551
	SD	6.849	4.740
	Minimum	7.151	20.264
	Maximum	21.036	31.538
Cobalt	Median	0.821	1.888
	Mean	1.158	1.835
	SD	0.525	0.262
	Minimum	0.716	1.523
	Maximum	1.817	2.167
Copper[α]	Median	5.524	10.430
	Mean	5.597	11.074
	SD	3.528	3.374
	Minimum	1.370	7.908
	Maximum	10.137	16.715
Dysprosium	Median	0.391	0.835
	Mean	0.493	0.832
	SD	0.171	0.152
	Minimum	0.342	0.659
	Maximum	0.731	1.007
Gadolinium	Median	0.564	1.081
	Mean	0.670	1.096
	SD	0.249	0.190
	Minimum	0.434	0.908
	Maximum	1.029	1.295
Gallium	Median	1.771	4.230
	Mean	2.248	4.001
	SD	0.945	0.540
	Minimum	1.400	3.411
	Maximum	3.698	4.487
Germanium	Median	0.000	0.000
	Mean	0.013	0.035
	SD	0.028	0.058
	Minimum	0.000	0.000
	Maximum	0.063	0.133
Hafnium	Median	0.000	0.000
	Mean	0.000	0.000
	SD	0.000	0.000
	Minimum	0.000	0.000
	Maximum	0.000	0.000

Metal	Concentration (mg/kg dry weight)	Site 1 (*n* = 5)	Site 2 (*n* = 5)
Indium	Median	0.000	0.000
	Mean	0.000	0.000
	SD	0.000	0.000
	Minimum	0.000	0.000
	Maximum	0.000	0.000
Iron	Median	5916.167	10994.404
	Mean	7449.478	11412.579
	SD	2290.762	1281.638
	Minimum	5793.184	9962.597
	Maximum	10890.621	13141.584
Lead[α]	Median	4.319	8.635
	Mean	5.513	8.618
	SD	1.941	0.979
	Minimum	3.799	7.684
	Maximum	7.870	10.175
Manganese	Median	30.536	75.020
	Mean	40.841	66.696
	SD	17.801	13.754
	Minimum	27.059	47.992
	Maximum	65.542	78.666
Mercury[α]	Median	0.119	0.339
	Mean	0.505	0.650
	SD	0.574	0.970
	Minimum	0.097	0.000
	Maximum	1.357	2.346
Molybdenum	Median	0.205	0.220
	Mean	0.243	0.338
	SD	0.144	0.226
	Minimum	0.080	0.154
	Maximum	0.424	0.711
Nickel[α]	Median	1.971	6.868
	Mean	3.275	7.048
	SD	2.405	0.642
	Minimum	1.218	6.397
	Maximum	6.446	7.756
Niobium	Median	0.091	0.006
	Mean	0.099	0.037
	SD	0.046	0.051
	Minimum	0.048	0.000
	Maximum	0.173	0.113
Rubidium	Median	5.488	13.964
	Mean	6.818	13.176
	SD	3.524	2.191

Metal	Concentration (mg/kg dry weight)	Site 1 (*n* = 5)	Site 2 (*n* = 5)
	Minimum	3.862	10.700
	Maximum	12.582	15.352
Scandium	Median	0.000	0.579
	Mean	0.063	0.515
	SD	0.141	0.350
	Minimum	0.000	0.000
	Maximum	0.314	0.928
Selenium	Median	0.000	0.000
	Mean	0.000	0.000
	SD	0.000	0.000
	Minimum	0.000	0.000
	Maximum	0.000	0.000
Silver	Median	0.000	0.000
	Mean	0.000	0.000
	SD	0.000	0.000
	Minimum	0.000	0.000
	Maximum	0.000	0.000
Tantalum	Median	0.000	0.000
	Mean	0.000	0.000
	SD	0.000	0.000
	Minimum	0.000	0.000
	Maximum	0.000	0.000
Tellurium	Median	0.000	0.000
	Mean	0.001	0.001
	SD	0.002	0.002
	Minimum	0.000	0.000
	Maximum	0.005	0.005
Thallium	Median	0.000	0.044
	Mean	0.022	0.057
	SD	0.030	0.040
	Minimum	0.000	0.028
	Maximum	0.055	0.126
Thorium	Median	0.481	1.345
	Mean	0.637	1.476
	SD	0.417	0.514
	Minimum	0.251	0.885
	Maximum	1.296	2.094
Tin	Median	0.000	0.000
	Mean	0.140	0.094
	SD	0.313	0.211
	Minimum	0.000	0.000
	Maximum	0.699	0.471

Metal	Concentration (mg/kg dry weight)	Site 1 (*n* = 5)	Site 2 (*n* = 5)
Titanium	Median	109.244	220.733
	Mean	133.743	220.246
	SD	66.346	25.333
	Minimum	80.158	185.583
	Maximum	243.677	246.357
Tungsten	Median	0.006	0.000
	Mean	0.009	0.001
	SD	0.010	0.002
	Minimum	0.000	0.000
	Maximum	0.020	0.005
Uranium	Median	0.325	0.719
	Mean	0.438	0.778
	SD	0.188	0.130
	Minimum	0.286	0.670
	Maximum	0.710	0.996
Vanadium	Median	10.583	23.193
	Mean	13.279	22.256
	SD	5.305	2.921
	Minimum	8.567	18.905
	Maximum	21.255	25.435
Yttrium	Median	1.846	4.096
	Mean	2.363	4.042
	SD	0.933	0.656
	Minimum	1.489	3.317
	Maximum	3.738	4.877
Zinc[α]	Median	13.581	37.194
	Mean	19.200	38.188
	SD	9.366	9.098
	Minimum	10.906	30.392
	Maximum	31.450	53.546
Zirconium	Median	1.919	4.729
	Mean	2.273	4.637
	SD	1.302	0.490
	Minimum	1.141	3.994
	Maximum	4.323	5.292
Total metal	Median	37.002	92.042
	Mean	50.747	95.298
	SD	24.949	14.061
	Minimum	30.679	80.704
	Maximum	82.389	117.253

7.19 D4. Antibiotics quantification

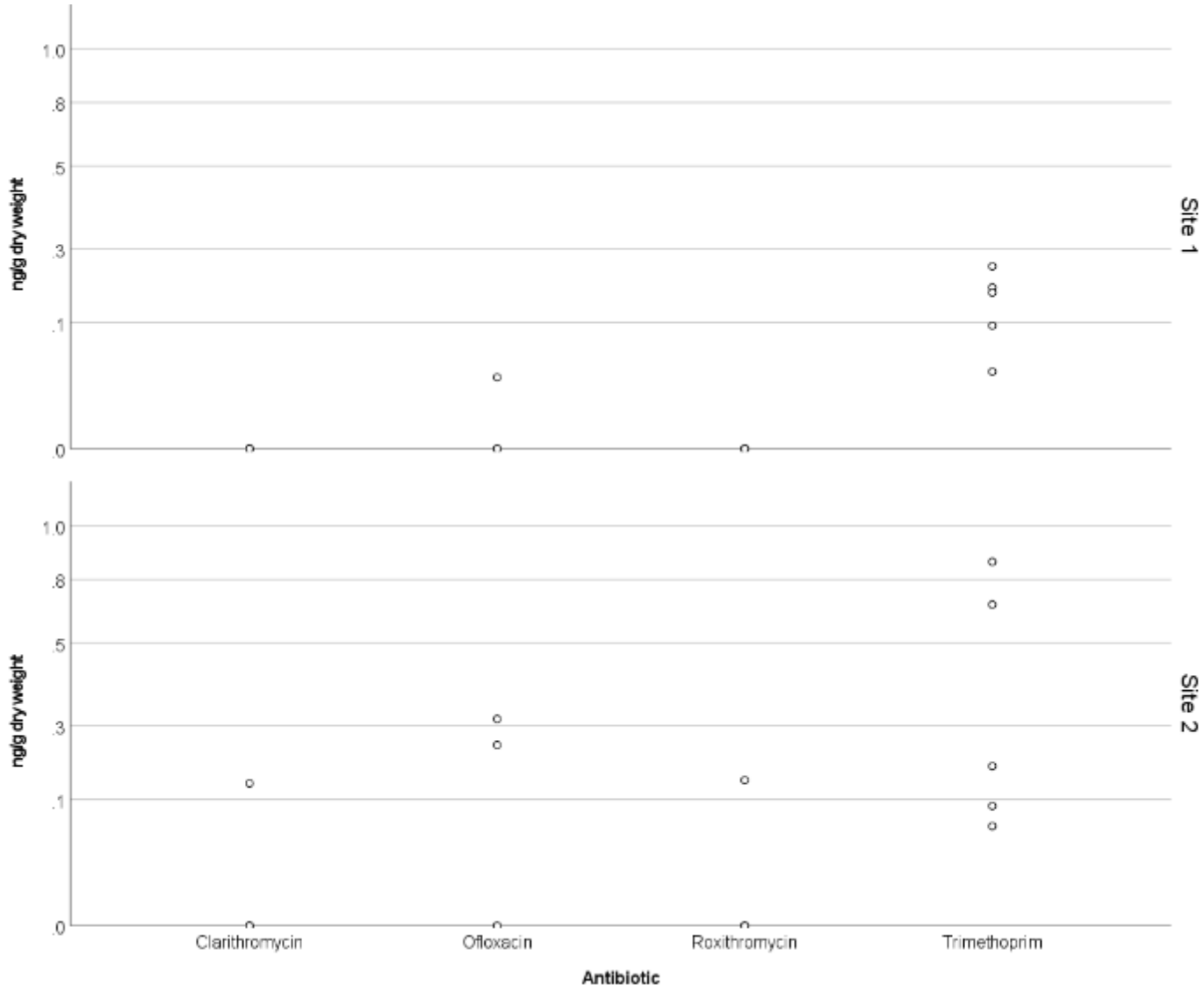


Figure D4. The concentration (ng/g dry weight) of individual antibiotics detected in sediment at Site 1 (top) and Site 2 (bottom) at the WWTP C outfall (0 m). At each site, n = 5. Dots represent replicates.

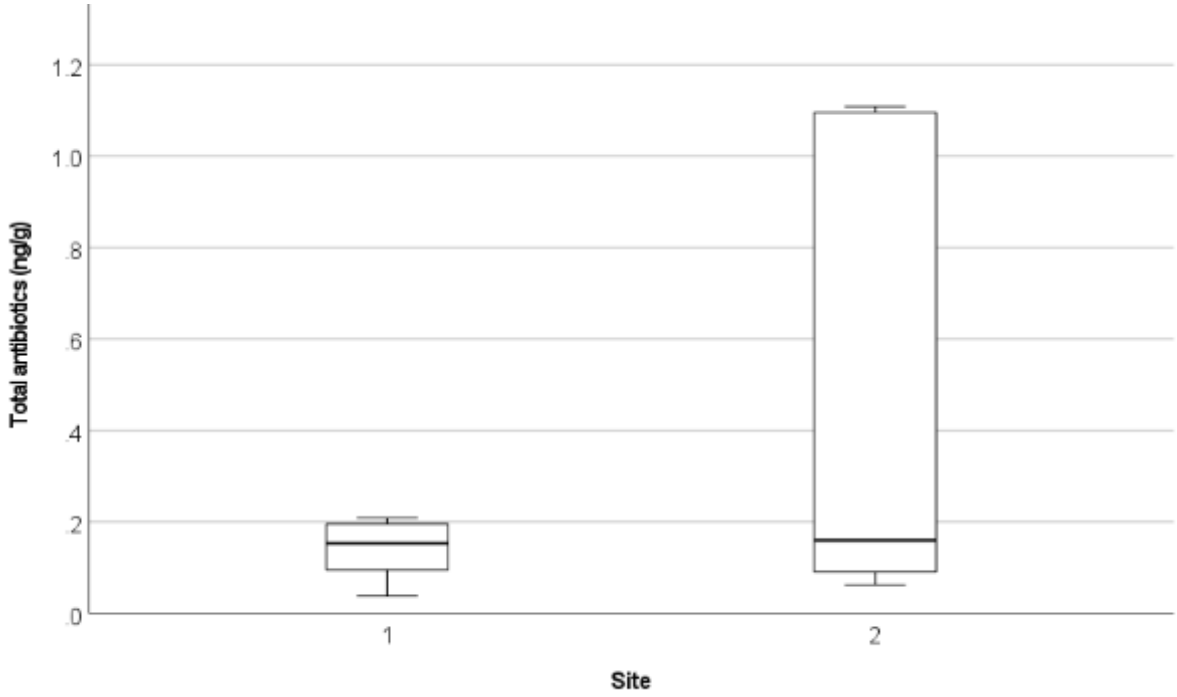


Figure D5. The total concentration of antibiotics (ng/g dry weight) detected in sediment at the WWTP C outfall (0 m). Data are from five replicates at each site (n = 5).

Table D5. Concentrations of antibiotics (ng/g dry weight; ppb) from the two sites at the WWTP C outfall (0 m). Data are from five replicates (n = 5) at each site. LOD = limit of detection; ND = not detected.

		Site 1 (*n* = 5)					Site 2 (*n* = 5)				
Family (class)	**Antibiotic**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**	**Median**	**Mean**	**SD**	**Minimum**	**Maximum**
β-lactams (penicillins)	Flucloxacillin sodium	-	-	-	ND	ND	-	-	-	ND	ND
	Penicillin V	-	-	-	ND	ND	-	-	-	ND	ND
β-lactams (cephalosporins)	Cefalexin	-	-	-	ND	ND	-	-	-	ND	ND
Dihydrofolate reductase inhibitors	Trimethoprim	0.153	0.131	0.066	0.037	0.208	0.159	0.357	0.355	0.062	0.829
Fluoroquinolones	Enrofloxacin	-	-	-	ND	ND	-	-	-	ND	ND
	Ciprofloxacin	-	-	-	ND	ND	-	-	-	ND	ND
	Norfloxacin	-	-	-	ND	ND	-	-	-	ND	ND
	Ofloxacin	0.000	0.008	0.016	< LOD	0.032	0.102	0.118	0.139	ND	0.267
Macrolides	Clarithromycin	-	-	-	ND	ND	-	0.025	0.057	ND	0.127
	Erythromycin	-	-	-	ND	ND	-	-	-	ND	ND
	Roxithromycin	-	-	-	ND	ND	0.000	0.025	0.057	ND	0.127
Sulfonamides	Sulfamethoxazole	-	-	-	ND	ND	-	-	-	ND	ND
Tetracyclines	Tetracycline hydrochloride	-	-	-	ND	ND	-	-	-	ND	ND
	Doxycycline hyclate	-	-	-	ND	ND	-	-	-	ND	ND
	Oxytetracycline hydrochloride	-	-	-	ND	ND	-	-	-	ND	ND
	Total antibiotics	0.153	0.138	0.071	0.037	0.208	0.159	0.503	0.548	0.062	1.109

7.20 D5. PFAS quantification

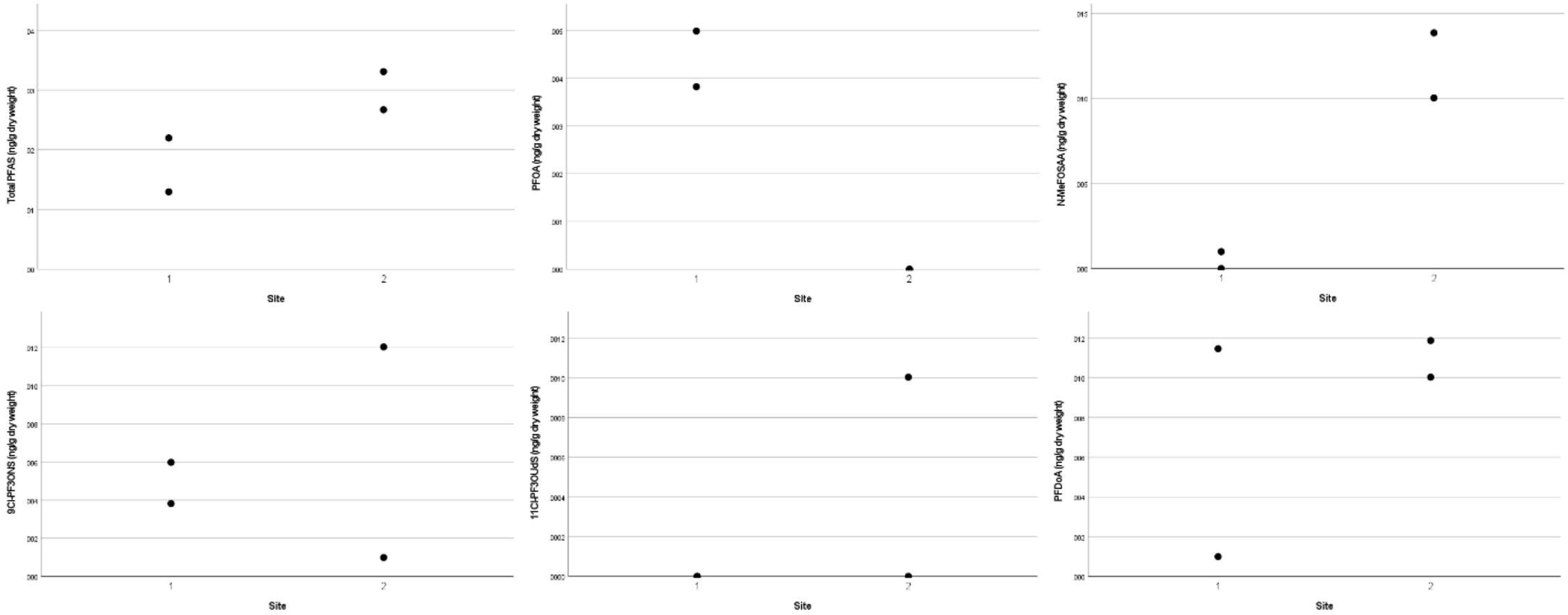


Figure D6. Concentration of total PFAS and individual PFAS species in sediments (ng/g dry weight; ppm) collected from two sites at the WWTP C outfall (0 m). There are no guidelines for PFAS concentrations for sediments. Dots represent two replicates (n = 2) taken at each site.

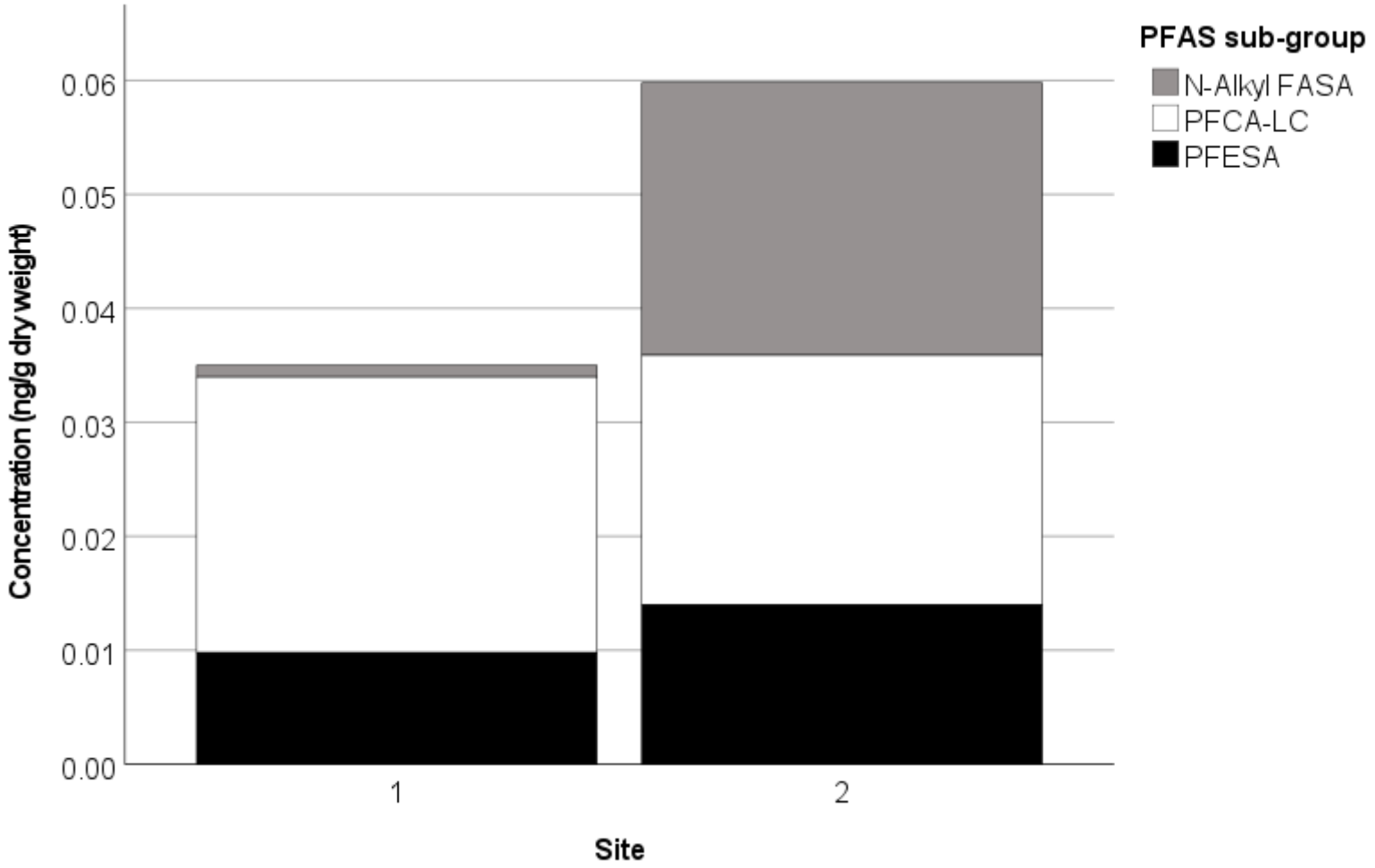


Figure D7. The concentration of PFAS sub-groups in sediments (ng/g dry weight; ppm) collected from two sites at the WWTP C outfall (0 m). At each Site, n = 2. ‘LC’ refers to ’long chain’.

Table D6. Concentrations of PFAS (ng/g dry weight; ppm) from the two sites at the WWTP C outfall (0 m). Data are from two replicates (n = 2) at each site. LOD = limit of detection; ND = not detected.

			Site 1 (*n* = 2)			Site 2 (*n* = 2)		
Group	**Sub-group**	**Analyte**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
Perfluoroalkyl acids	Perfluoroalkyl carboxylic acids (PFCAs)	PFHpA	-	< LOD	< LOD	-	< LOD	ND
		PFOA	0.004	0.004	0.005	-	< LOD	< LOD
		PFNA	-	< LOD	ND	-	< LOD	ND
		PFDA	-	< LOD	< LOD	-	< LOD	< LOD
		PFUnA	0.000	0.000	0.000	-	< LOD	< LOD
		PFDoA	0.006	0.001	0.011	0.011	0.010	0.012
		PFTrDA	-	ND	ND	-	ND	ND
		PFTeDA	0.001	< LOD	0.003	-	ND	ND
	Perfluoroalkane sulfonic acids (PFSAs)	PFBS	-	ND	ND	-	ND	ND
		PFPeS	-	ND	ND	-	ND	ND
		PFHxS	-	ND	ND	-	ND	ND
		PFHpS	-	ND	ND	-	ND	ND
		PFOS	-	ND	ND	-	ND	ND
		PFNS	-	ND	ND	-	ND	ND
		PFDS	-	ND	ND	-	ND	ND
Perfluoroalkane sulfonamido substances	N-Alkyl perfluoroalkane sulfonamide acetic acids (N-Alkyl FASAAs)	N_MeFOSAA	0.000	ND	0.001	0.012	0.010	0.014
		N_EtFOSSA	-	ND	ND	-	0.000	< LOD
Perfluoroalkane sulfonamides (FASAs)	Not applicable	FBSA	-	ND	ND	-	ND	ND
		PFHxA	-	< LOD	< LOD	-	< LOD	< LOD
Per- and polyfluoroalkyl ether acids (PFEAs)	Fluorotelomer-based substances	4:2 FTS	-	ND	ND	-	ND	ND
		6:2 FTS	-	ND	ND	-	ND	ND
		8:2 FTS	-	ND	ND	-	ND	ND
	Per- and polyfluoroalkyl ether carboxylic acids (PFECAs)	NaDONA	-	< LOD	ND	-	< LOD	ND
		HFPO-DA	-	ND	ND	ND	ND	ND
	Per- and polyfluoroalkyl ether sulfonic acids (PFESAs)	9Cl-PF3ONS	0.005	0.004	0.006	0.007	0.001	0.012
		11Cl-PF3OUdS	-	< LOD	< LOD	0.001	< LOD	0.001
		Total PFAS	0.017	0.013	0.022	0.030	0.027	0.033

7.21 D6. Microplastics quantification

Microplastics were not quantified in the WWTP C samples.

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