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Tyre wear and associated chemicals in water and sediment: Oxley Creek pilot study

Title

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Disclaimer

Project Team

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Executive Summary

Tyre wear particles (TWPs) are small pieces of tyre tread that are generated through the abrasion of tyres against road surfaces. They are gaining increasing attention by the scientific community, policy makers and the general community, related to increasing concerns over the potential risk they pose towards environmental and human health from both the TWPs themselves and the range of chemical additives that they contain. This pilot study, conducted in collaboration with the Queensland Alliance for Environmental Health Sciences (QAEHS), The University of Queensland, and the Queensland Government Department of the Environment, Tourism, Science and Innovation (DETSI), investigated the presence and distribution of tyre wear particles (TWPs), tyre additive chemicals (TACs), and high production microplastics (MPs) in water and sediment samples across 19 sites in the Oxley Creek catchment, Brisbane. The study builds on previous research in the Moreton Bay region and aims to identify sources of road-related pollution and understand the fate and transport of these contaminants.

Key Findings:

- **Widespread Occurrence**: Clear spatial trends were observed of the TACs with higher concentrations at the downstream (estuarine) sites closest to the Brisbane River intersection. Total TAC concentrations were 100 times higher at downstream sites than the background site. The TAC 6PPD-quinone was only detected at the downstream sites (0.9 – 8.7 ng/L) although concentrations were recorded lower than the US EPA surface water guideline values (11 ng/L).

- **Impact of severe weather events:** Mixed trends were observed in sediment at two sites that were sampled previously in 2023. TACs were higher at the river mouth but lower upstream, whereas MPs and TWPs were both lower. Ex-Tropical Cyclone Alfred impacted the study with increased sediment input from bank erosion as well as flushing and resuspension of older sediments. This impacted the ability to determine trends and is likely to have provided a new baseline for non-storm event concentrations in this catchment.

- **Source Attribution**: While many sites had identifiable potential sources (e.g., industrial areas, STP, airport, major highways), no single dominant source was confirmed. However, the elevated concentrations in Moolabin and Stable Swamp Creeks suggest significant sources that warrant further investigation.

Recommendations:

1. **Source identification**: Moolabin and Stable Swamp Creeks were clear sources of road-related pollutants to Oxley Creek. Both these creeks contain a number of automobile related activities upstream of the sampling sites and further monitoring is required to identify specific significant sources and to determine the impact of these sources during different conditions (storm events etc).

2. **Storm Event Monitoring**: Future studies should target estuarine sites (e.g. OC_12.0 to OC_0.0) during storm events and post-flood conditions to quantify contaminant levels, sediment resuspension, and fluxes into the Brisbane River and Moreton Bay.

3. **Ecotoxicological Assessment**: Laboratory and field-based testing is needed to determine whether observed levels of TWPs and TACs pose acute or chronic risks to native aquatic species, and whether they bioaccumulate through the food chain.

4. **Expanded Monitoring**: Seasonal and multi-year studies across Oxley Creek and other South-East Queensland catchments will provide a more complete picture of exposure pathways, temporal variability, and long-term trends providing data for risk assessment and management.

Introduction

Environmental contamination of microplastics (MPs; defined as synthetic polymer particles sized between 1 µm and 5 mm) is recognised as one of the biggest pollution challenges the globe is facing. MPs are routinely detected in all environmental compartments including water, air, soil, sediment and biota [1], from highly populated urban areas to remote regions including the Arctic [2]. Due to the wide environmental reach, and concerns over potential adverse health effects, there are now calls for regulatory action on plastics and microplastics pollution including ongoing efforts for formation of a Global Plastics Treaty [3].

MPs are a diverse category of contaminant and include polymers with wide ranging properties and characteristics. One of the more recently recognised sources of MPs are tyre wear particles (TWPs). TWPs are small pieces of tyre tread that form through the abrasion of tyres on road surfaces. They are transferred directly to road surfaces and can then be transported to different environmental compartments including the atmosphere, roadside soil and through stormwater runoff can enter local water systems. The occurrence of TWPs have been reported in surface water, stormwater, air, soil, sediment and biota [4].

Tyre tread contains a complex mixture of chemicals including synthetic and natural rubber, fillers such as carbon black, heavy metals, and a range of organic chemicals that are added as vulcanisation accelerators, antioxidants and antiozonants and transformation products within the final product [5]. Many of these tyre additive chemicals (TACs) are known to leach from TWPs into the surrounding environment, posing a risk to local species. One chemical that has raised global concern is the antioxidant/antiozonant N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD), which transforms into the chemical 6PPD-quinone during exposure to ozone. 6PPD-quinone has shown acute toxicity to certain salmonoid species with a reported LC_{50} of 95 ng/L for adult [6] and 41 ng/L for juvenile [7] coho salmon (*Oncorhynchus kisutch*). These LC_{50} values are lower than most organochlorine and organophosphate pesticides and there are calls to label it as “very highly toxic” to this particular species [6]. This has led to the US EPA recently publishing screening values for 6PPD-quinone in freshwater of 11 ng/L, to protect sensitive salmon species and other aquatic life [8]. Interestingly, aquatic toxicity to this chemical is highly species specific with no observed effects on many species such as *Daphnia magna* and *Hyalella azteca* [9]. However, TWPs contain a wide range of leachable chemicals and TWP leachate itself has now been investigated in an increasing number of studies have reported toxicity to many aquatic species at environmentally relevant concentrations [10]. TWPs have also shown a toxicity response following ingestion in model aquatic species such as *Daphnia magna* [11].

In Australia, it is estimated that up to 20,000 tonnes of TWPs are emitted to Australian roads every year, equating to 0.9 kg/capita [5], but there is still little understanding on the extent of environmental exposure and fate of tyre related contaminants within the Australian environment. There are few studies that have reported TWPs or TACs in the Australian environment, primarily from Queensland. TWPs have been previously identified in stormwater floating treatment wetlands [12] and road dust [13]. More recently, mass-based concentrations of TWPs and a range of TACs have been reported in urban water systems around Queensland. Severe storms result in significant loads to local tributaries with an estimated mass load of up to 730 kg of TWPs and 3 g of 6PPD-quinone per storm, with concerns for prolonged exposure to aquatic species [14]. Additionally, TWPs and a range of additives (including 6PPD-quinone) have been detected at 21 urban surface water sites monitored around Queensland [15], suggesting their ubiquity in the Australian environment.

To further understand environmental occurrence and fate in the Moreton Bay region, a scoping study was initiated in 2023 as a collaboration between the Queensland Alliance for Environmental Health Sciences (QAEHS), The University of Queensland, and the Queensland Government Department of the Environment, Tourism, Science and Innovation (DETSI) [16]. This study aimed to provide new monitoring data on tyre related pollutants and further understanding on the transport potential of TACs and the role that sediment plays as a sink for TWPs and conventional MPs in the Moreton Bay catchments. TACs were detected ubiquitously in water and sediment samples, although 6PPD-quinone water concentrations were low (<0.1 – 0.35 ng/L), as

compared to previous concentrations reported in the Australian environment (up to 88 ng/L [14]). The samples were collected during dry conditions with no recent inputs from stormwater so likely represented baseline concentrations. 6PPD-quinone was reported for the first time in sediment from Australia (<0.07 – 3.2 ng/g, dw (dry weight)), with concentrations comparable to those previously reported in China. TWPs were detected in sediment at 11 of the 29 sites (<2 – 91 µg/g dw) and MPs at 26 of the 29 sites (<MDL – 500 µg/g dw). Higher detection frequencies of both the additives and TWPs were reported in sites south of the Brisbane River, which may be related to higher population densities.

Key knowledge gaps identified from this pilot study included a need for i) improved understanding of sources and fate in Moreton Bay, including pinpointing key sources and mapping the transport dynamics from source entry points through to Moreton Bay itself ii) understanding the impact of extreme weather events, including heavy precipitation or floods, on elevated mass loads iii) monitoring data in different catchments to understand areas of concern and iv) provide monitoring data on exposure and uptake in local flora and fauna to support future risk assessment efforts.

To address the first knowledge gap, a follow up scoping study was initiated focussing on the Oxley Creek catchment. Two sites in Oxley Creek were investigated in the previous pilot study and identified to have elevated concentrations of both TWPs and TACs. Additionally, the Oxley Creek catchment has a diverse range of land uses and potential sources of these contaminants including, industrial activities such as used vehicle recycling, STP inputs, an airport, and high-density residential areas with several highways/motorways. The aim of the current study was to identify key sources or activities that contribute road and tyre related pollution into the Oxley Creek catchment and provide further understanding on fate and transport dynamics of TWPs, TACs and MPs.

Site Selection

Nineteen (19) sites were chosen for investigation based on sampling accessibility and their proximity to potential sources of TWPs and TACs. The site locations ranged from ~36 km upstream of the Brisbane River (assumed to be representative of a baseline site) to the mouth of Oxley Creek and its intersection with Brisbane River. The two Oxley Creek sites included in the previous Moreton Bay study [16] (Sites OC_6.0 and OC_0.0) were again sampled in the current campaign for comparison. Table 1 describes site specific details and Figures 1 and 2 depicts a map of sampling locations. Samples were collected during the week of 20th May 2025 with downstream samples collected on the first day during the outgoing tide in the estuarine section. Two months prior to sampling (March 2025) the catchment suffered heavy rainfall, creek flooding and bank erosion into the creek, due to ex-Tropical Cyclone Alfred (Figure 3).

Table 1: Site details, with numbers roughly corresponding with the order of sites from upstream to downstream.

Site Number	Site ID	Coordinates (lat, long)	Description
1	OC_35.7	152.9721305, -27.704964	Oxley Creek, upstream of Goodna Road
2	OC_26.5	153.0003802, -27.65439531	Oxley Creek, Nth of Johnson Road
3	OC_24.9	152.9979678, -27.63995124	Oxley Creek, Nth of Logan Motorway
4	BC_10.0	152.9695283, -27.63638344	Blunder Creek, downstream of Johnson Road
5	SSG_0.1	153.023885, -27.61333666	Sheep Station Gully, Paradise Road
6	OC_20.0	153.0233938, -27.61013976	Oxley Creek, Brookbent Road

7	OC_18.2	153.0157254, -27.59665481	Oxley Creek, Learoyd Road
8	BC_3.3	152.9970321, -27.5931815	Blunder Creek, King Avenue
9	OC_14.0	153.0105077, -27.58523705	Oxley Creek, Success Street, downstream Beatty Rd
10	OC_12.0	152.997133, -27.575565	Oxley Creek, Bowhill Road
11	BC_0.1	152.9886844, -27.57113805	Blunder Creek, Riviera Circuit
12	OC_11.2	152.9895818, -27.56382221	Oxley Creek, Ipswich Motorway
13	OC_9.4	152.9823487, -27.55830807	Oxley Creek, Kendall Street
14	OC_6.0	152.9918851, -27.55210286	Oxley Creek, Clivedenn Avenue, pontoon opposite STP
15	SSC_3.5	153.0162956, -27.55005258	Stable Swamp Creek, Tramore Street
16	SSC_2.0	153.005031, -27.54920973	Stable Swamp Creek, Dunn Road
17	OC_3.1	152.9919767, -27.53551651	Oxley Creek, Sherwood Road, pontoon @ Oxley common
18	MC_1.2	153.003362, -27.53118204	Moolabin Creek, Curzon Road, downstream of bridge
19	OC_0.0	152.994612, -27.52394242	Mouth of Oxley Creek, intersection with Brisbane River

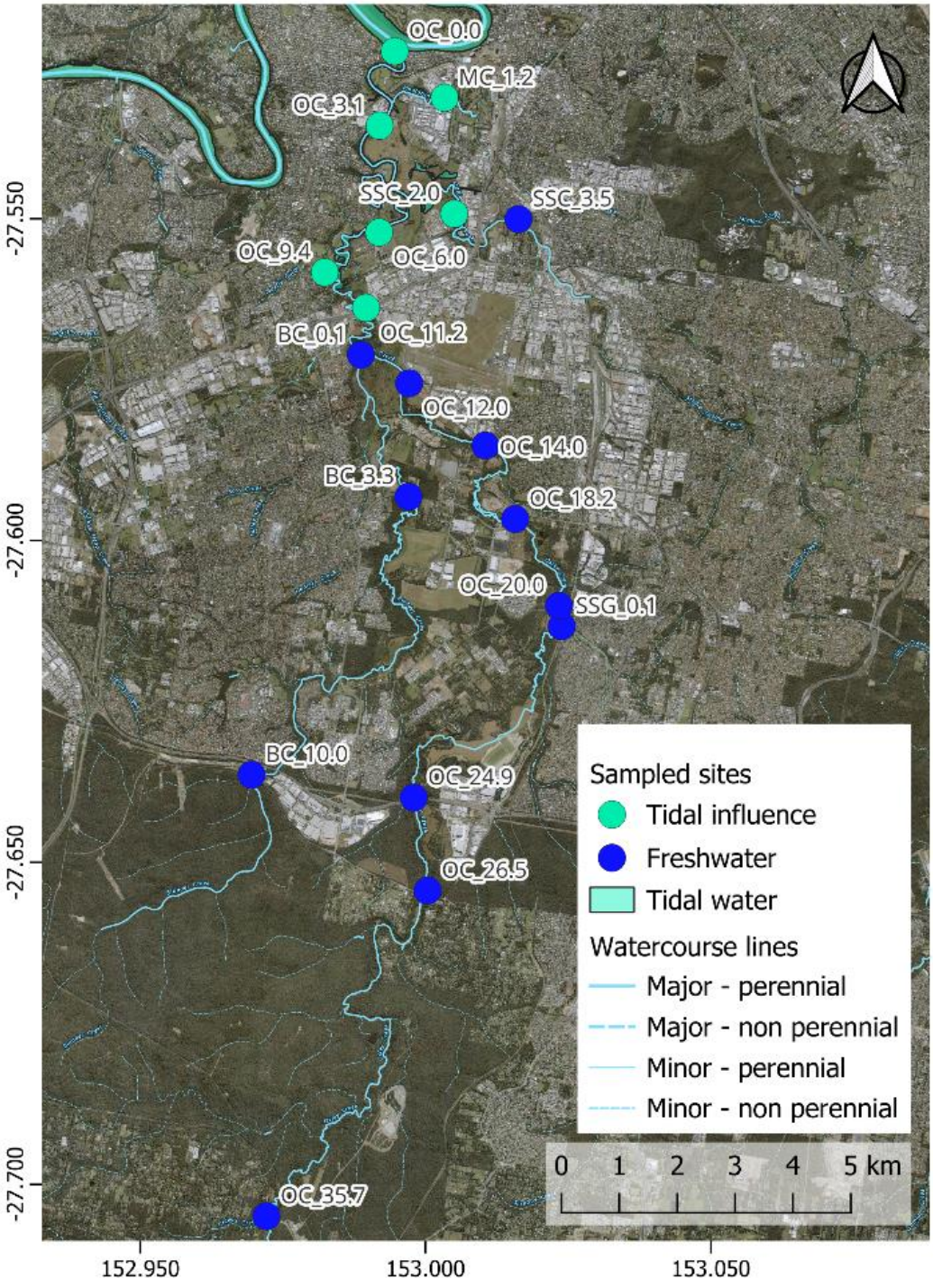

Figure 1: Sampling locations with site codes included in this study.

Note: Site codes correspond to the first letter in the name of the waterbody and the distance upstream from the nearest confluence (i.e. OC_3.1 is 3.1 km upstream from the Brisbane River in Oxley Creek

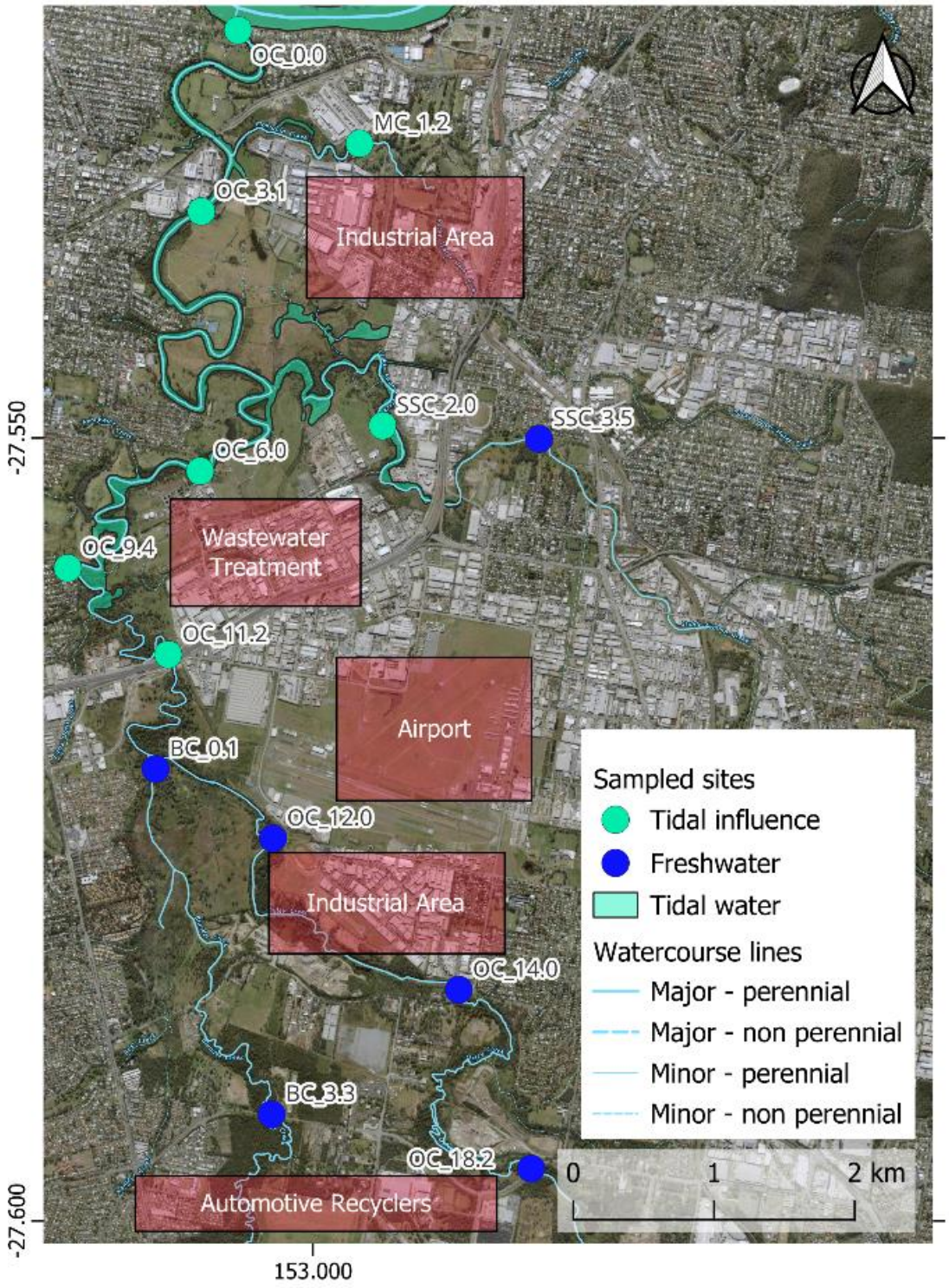

Figure 2:: Map of downstream sampling sites with major industries in the area.

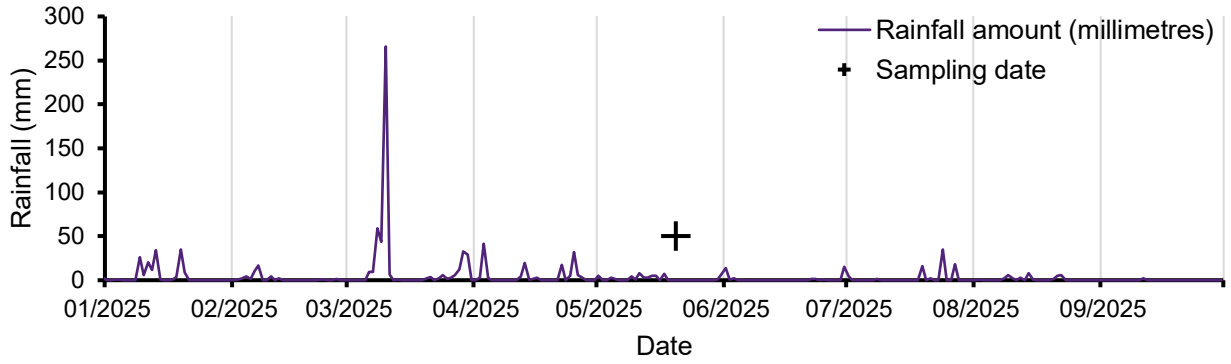

Figure 3: Rainfall record at Oxley weather station (040463) with the sampling date marked

Sampling Methodology

Water and sediment samples were collected at every site over the course of a 1-week sampling campaign. Water samples (500 mL) were collected at approximately 30cm below the surface in polypropylene collection jars. All collection jars were precleaned with methanol and acetone prior to the commencement of field sampling. Sediment samples were collected using a standardised Van Veen grab sampler. Collected sediments were emptied into a stainless-steel bowl (that had been pre-cleaned with ultrapure water between sites), homogenised and subsampled into a glass sampling jar (120 mL). The process was repeated 5 times at each site, sampling 5 spots that were at least 1 m apart and resulting in 5 subsamples for each site. All collection jars were pre-cleaned with dichloromethane and methanol prior to the commencement of field sampling. All sediment and water samples were transported back to the QAEHS laboratory on the day of sampling and immediately frozen until processing and analysis.

Sample Extraction and Analysis

Target analytes

The monitored analytes included fifteen common tyre additive chemicals (TACs), previously reported in the Australian environment (Table 2)[15, 16], tyre wear particles (TWPs) and 9 high production plastics (Table 3).

Table 2: Tyre additive chemicals monitored in the study

Name	Abbreviation
N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine quinone	6PPD-Quinone
2,4,6-Tris[bis(methoxymethyl)-amino]-1,3,5-triazine	HMMM
1,3-diphenylguanidine	DPG
2-hydroxybenzothiazole	2-OHBT
2-aminobenzothiazole	2-ABT

2-(methylthio)benzothiazole	2-MTBT
5-methyl-1H-Benzotriazole	5-MBTR
2-morpholin-4-yl-Benzothiazole	24MoBT
1H-Benzotriazole	BTR
Benzothiazole	BTH
1-cyclohexyl-3-phenylurea	CPU
1,3-dicyclohexylurea	DCU
3-cyclohexyl-1,1-dimethylurea	C-DMU
1,3-diethyl-1,3-diphenylurea	D-DPU
N,N-dicyclohexylmethylamine	M-DCA
N-cyclohexyl-1,3-benzothiazol-2-amine	NCBA

Table 3: Microplastics (including tyre wear particles) monitored in the study

Name	Abbreviation
Polyethylene	PE
Polypropylene	PP
Polyethylene terephthalate	PET
Polystyrene	PS
Polymethyl methacrylate	PMMA
Polycarbonate	PC
Polyvinylchloride	PVC
Tyre Wear Particles	TWP

Conductivity

Water conductivity was measured at the sites using a standard conductivity meter. Most sites had relatively low conductivity and would be considered freshwater, apart from site OC_0.0 with is at the intersection with the tidal Brisbane River (Figure 4). It is noted that as sampling was conducted either at the shore or in areas with wadable depth, it is possible that the water column in some parts formed a halocline, with denser, saltier water in deeper parts that were not attainable in the current study.

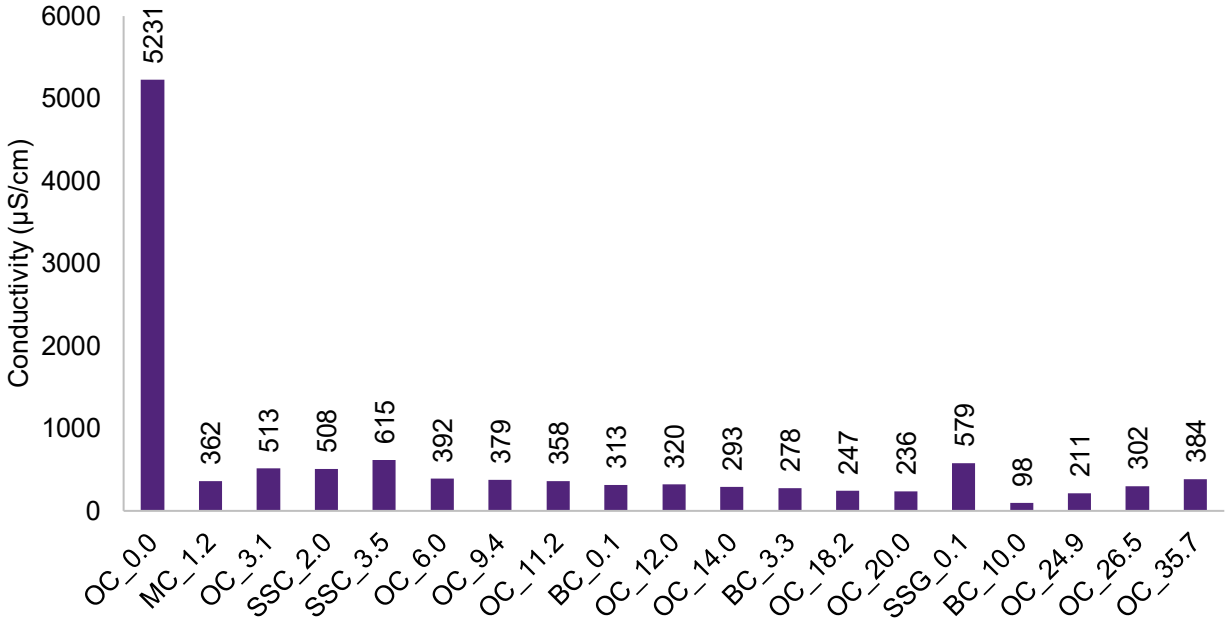

Figure 4: Conductivity from in situ measurements at each site at the time of sampling.

Water

Water samples were processed and analysed for TACs, TWPs and MPs following previously reported methodologies [15]. Briefly, water samples were filtered through a 1 µm glass fibre filter (GFF) to separate particulates (MPs and TWPs) and dissolved organic compounds (TACs). The GFFs were directly analysed for MPs and TWPs with pyrolysis gas chromatography mass spectrometry (Py-GC-MS). The filtrate was concentrated and purified using solid phase extraction (Oasis HLB, 6cc cartridges) before the samples were analysed for TACs with liquid chromatography tandem mass spectrometry (LC-MS/MS).

Sediment

The 5 jars of sediment collected at each site were combined to produce 1 composite sample for that site. An aliquot of the mixed sediment (~10 g) was analysed for particle size distribution (PSD) at the Chemistry Centre, DETSI. The remaining sediment was freeze dried to remove residual water and extracted following previously published methods [17]. One gram of each sediment composite sample was extracted for TACs with pressurised liquid extraction and analysed using LC-MS/MS. For the MPs analysis, an additional one-gram subsample was extracted with pressurised liquid extraction and analysed with Py-GC-MS. For TWPs, a one-gram subsample was digested with 10% potassium hydroxide for 1 week to remove organic matter. The residue was collected through filtration (1 µm GFF), and the collected particulates were directly analysed with Py-GC-MS.

Quality Assurance/Quality Control

All sample processing was conducted in a fume cupboard, cotton lab coats worn at all times and all glassware and metalware were prerinsed with solvent before use to minimise background contamination. For the water samples, replicate samples were collected at 9 of the 19 sites and field blanks were collected at 7 sites. Field blanks consisted of an additional sampling jar filled with MilliQ water, transported to the collection site, opened for approximately 10 seconds, closed and transported back to the laboratory with other samples. For the sediment samples, replicates were collected at two sites and field blanks at 7 sites. Field blanks consisted of an empty precleaned jar, opened for the duration of the sampling process, closed and transported back to the laboratory with the samples. Method detection limits (MDLs) were calculated as the mean concentration of an analyte in a blank added to three times the standard deviation of concentrations. All samples were blank corrected with the mean concentration detected in blanks.

The water replicate samples were shown to be consistent with a relative percent difference (RPD) ranging 0.4 – 11% for TACs, 1.2 – 18% for MPs and TWPs, although TACs at Site OC_12.0 had a larger % difference of 34%. The low RPD suggests the water concentrations were relatively uniform at these sites and samples collected were representative of the site.

For the sediment samples, however, the concentrations were highly variable between replicates, demonstrating the heterogeneity of the particles and particle bound contaminants in the sediment matrix. Only TWPs at OC_0.0 has acceptable RPD (9.7%), all other analytes at both sites showed >30% RPD. These results highlight the difficulty in obtaining a representative sample for MP analysis, a commonly recognised challenge with these environmental contaminants.

Results

Sediment particle size distribution (PSD)

Particle size was not uniform among sites, nor within the main drainage channel (Oxley Creek), Figure 5. The sediment sample from the most upstream site in Oxley Creek (OC_35.7) contained mostly sand and the contribution of sand declined downstream (except for OC_20.0 where the percentage of other particle was greater), with silt as the primary sediment type at the most downstream site (OC_0.0). Silt tended to dominate in the estuarine sites (OC_11.2 through to OC_0.0).

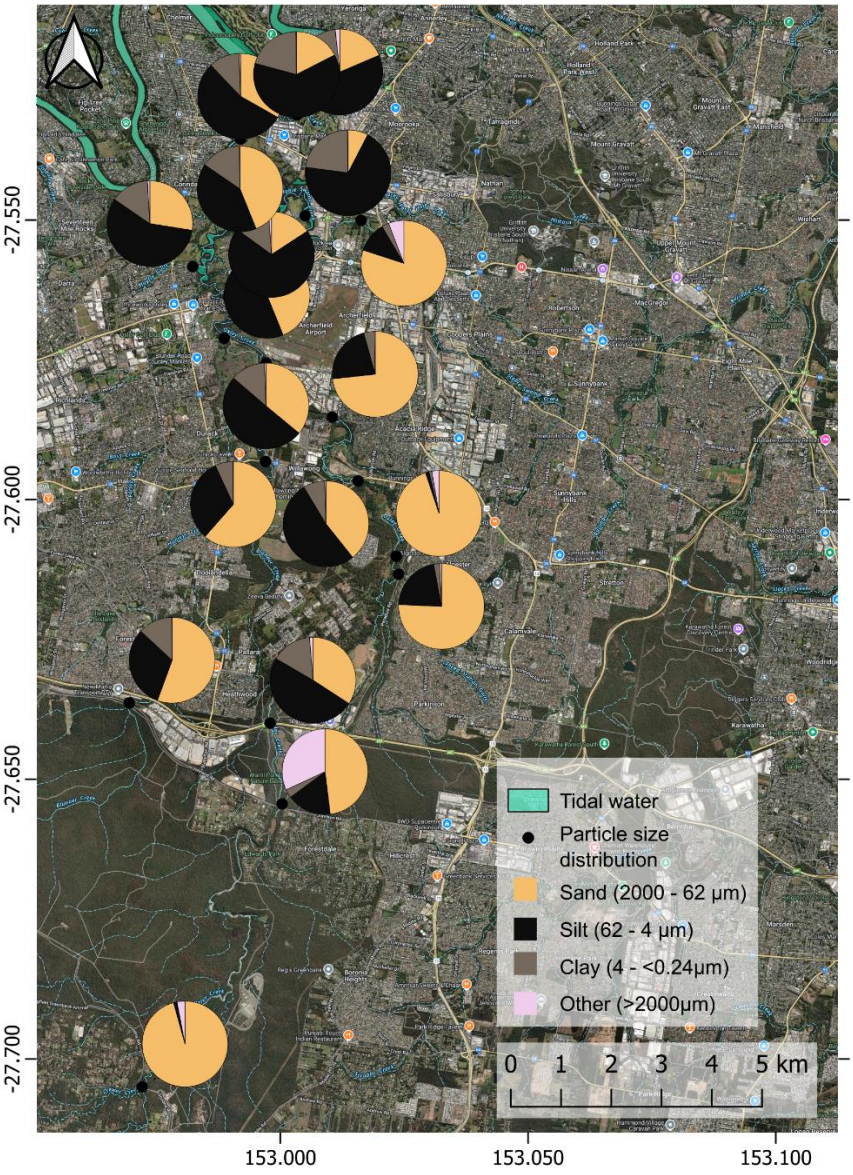

Figure 5: Particle size distribution in sediments of Oxley Creek and its tributaries.

Tyre additive chemicals (TACs)

Water (TACs)

TACs were detected at every site in Oxley Creek, with concentrations increasing from 9.3 ng/L total TACs at the most upstream site in Oxley Creek (OC_35.7) to 500 ng/L total TACs directly at the confluence with the Brisbane River (OC_0.0), Figures 6,10a. Concentrations at OC_0.0 were lower than the nearest sites upstream, suggesting that concentrations are diluted by the river water at this site. The highest concentrations of total TACs in Oxley Creek were 1032 ng/L at OC_3.1. This site is just upstream of the confluence of Moolabin Creek (with a concentration of total TACs of 1268 ng/L) and downstream of the confluence with Stable Swamp Creek which had total TAC concentrations in excess of 1100 ng/L at the two sites within this creek, Figure 7. Specific TACs with the highest concentrations were 2-MTBT (5.4 – 410 ng/L), 5-MBTR (2.9 – 445 ng/L), BTR (9.5 – 575 ng/L) and HMMM (8.0 – 230 ng/L). 6PPD-quinone was only detected at 6 sites with concentrations ranging 0.92 – 8.7 ng/L at these sites, approaching the US EPA surface water guideline value of 11 ng/L [8]. Furthermore, 6PPD-quinone was found at sites either in Stable Swamp Creek, Millipin Creek or the Oxley Creek estuary downstream of the confluences of these creeks, apart from OC_9.4, suggesting activities around Stable Swamp and Millipin creeks are primary sources of TACs to the catchment. Water samples were not collected at Oxley Creek in the previous Moreton Bay scoping study, however concentrations are higher than those previously detected at Caboolture, Brisbane and Nerang rivers (<0.1 – 0.35 ng/L) [16], and are in line with our previous study surveying 5 Queensland urban centres [15] (<0.05 – 24 ng/L). Concentrations were lower than maximum concentrations reported in a Brisbane River tributary during severe storm conditions (up to 88 ng/L) although these sites were sampled during dry conditions (no precipitation five days prior to sampling). Similarities in upstream TAC profiles are further discussed in Section 6.

Sediment (TACs)

In the sediment samples, TACs were detected at every site except OC_26.5, with highest concentrations and the more diverse profiles at sites MC_1.2 and OC_0.0 (52 and 93 ng/g dw total TACs respectively), with MC_1.2 being a stream that flows into Oxley Creek approximately 2km upstream of OC_0.0, Figures 8, 9, 10b. Lowest detected concentrations were at sites OC_6.0 and SSC_3.5 (1 – 1.3 ng/g dw). Interestingly site SSC_3.5 had the highest concentrations of total TACs in the water. C-DMU was detected in the highest frequency in sediments (15 out of 19 samples). At sites MC_1.2 and OC_0.0, 2-OHBT, DPG, BTR and DCU were present in the highest concentrations. Similarly, MC_1.2 had the highest water concentrations of 2-OHBT and DCU, with third highest concentrations of DPG, BTR. 6PPD-quinone was only detected at 5 of the estuarine sites with concentrations ranging 0.78 – 1.6 ng/g dw. Other than the highest concentrations of analytes being present at sites MC_1.2 and OC_0.0, there were no clear spatial trends and there was no correlation between total TAC concentrations in the water or sediment samples.

Total TAC concentrations in sediment in Oxley Creek were in line with the previous Moreton Bay pilot study (n=29 sites), (<MDL – 55 ng/g dw, excluding Bramble Bay at 311 ng/g). Two of the Oxley Creek sites were sampled in both studies, sites OC_6.0 and OC_0.0. Concentrations at OC_6.0 were higher in the previous study (11 vs 1.0 ng/g dw) whereas concentrations at OC_0.0 were lower in the previous study (1.4 vs 52 ng/g dw). A similar pattern was determined for 6PPD-quinone with higher concentrations at OC_6.0 in the prior study (3.2 vs <0.9 ng/g dw) but lower concentrations at OC_0.0 (0.24 vs 0.78 ng/g dw). This may be related to sediment movement associated with flooding events caused by ex-Tropical Cyclone Alfred.

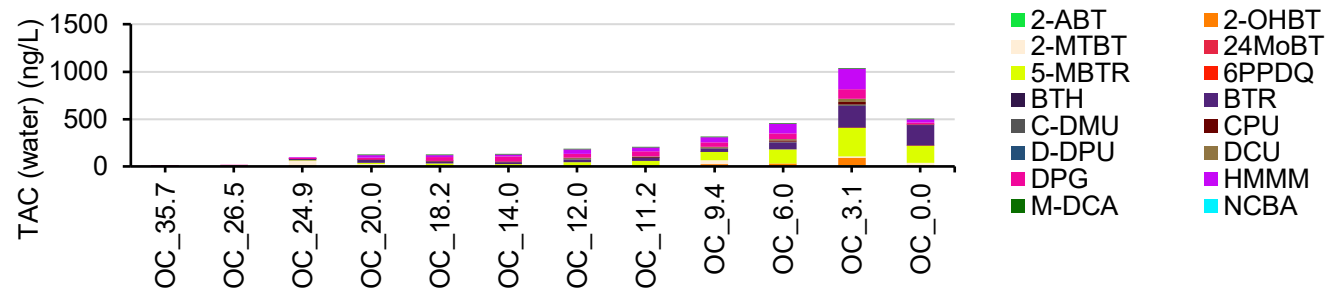

Figure 6: Tyre additive chemical concentrations in water at sites in Oxley Creek.

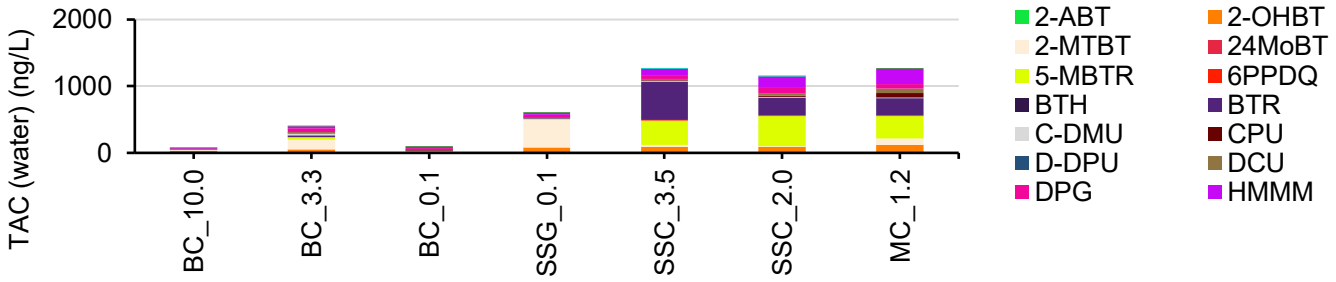

Figure 7: Tyre additive chemicals at sites in water in tributaries of Oxley Creek.

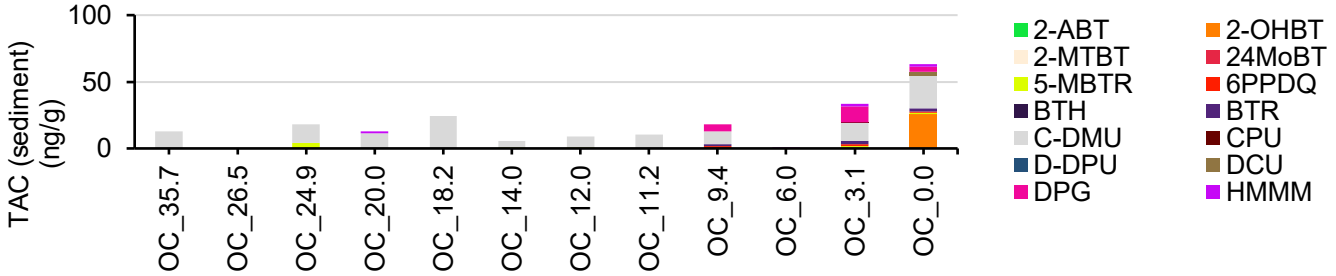

Figure 8: Tyre Additive Chemicals in sediments at sites in Oxley Creek.

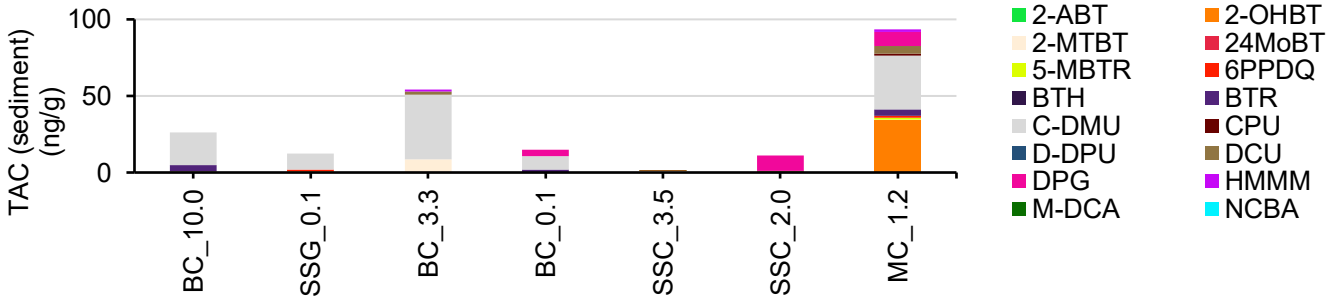

Figure 9: Tyre Additive Chemicals in sediments at sites in tributaries of Oxley creek.

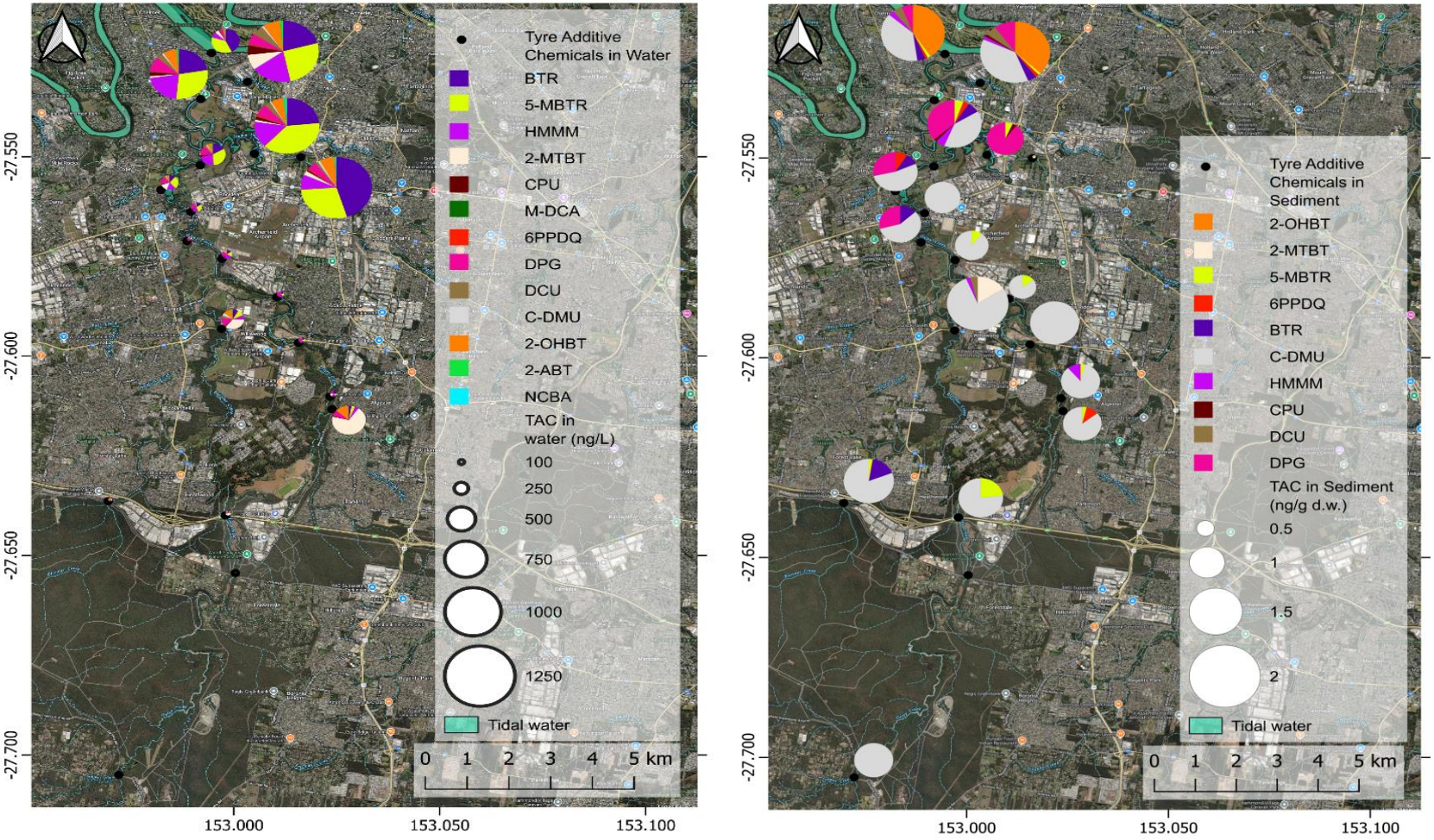

Figure 10: (a) TAC profiles in water samples across all sites and (b) TAC profiles in sediments across all sites.

Tyre Wear Particles (TWPs)

Water (TWPs)

TWPs were detected at every site, except SSG_0.1, with concentrations ranging 39 – 409 µg/L; MDL 10 µg/L. The highest concentration of TWP's were at site OC_14 (Figures 11, 13a). In the previous Moreton Bay pilot study, TWPs were not detected in water samples from Caboolture, Brisbane or Nerang Rivers however TWPs have been reported in surface water at five urban Queensland centres ranging from <MDL – 1,300 µg/L [15] and much higher concentrations were reported in a Brisbane River tributary during severe storm conditions with up to 12,430 µg/L [14].

Sediment (TWPs)

TWPs were detected at nine of the nineteen sites (11 – 166 µg/g dw; MDL <5) with six of these sites dominated by silt, indicating a depositional zone (Figures 12, 13b). However, higher concentrations were also detected at Sites SSG_0.1, OC_18.2 and OC_9.4 which may indicate point sources near these sites. It is noted that TWP were not detected in water at Site SSG_0.1. As Site SSG_0.1 was primarily surrounded by residential areas the sources of TWPs to the sediment at this site are not clear.

In the previous Moreton Bay study, TWPs were much higher at OC_0.0 and OC_0.6 than in the current study. Size fractionated concentrations at OC_0.0 ranged 94 to 262 µg/g dw (150 – 500 and 500 – 1000 µm particles respectively) and at OC_0.6 ranged 206 to 515 µg/g dw (<63 and 150 – 500 µm particles respectively). Again, this is likely related to sediment movement associated with flooding events caused by ex-Tropical Cyclone Alfred.

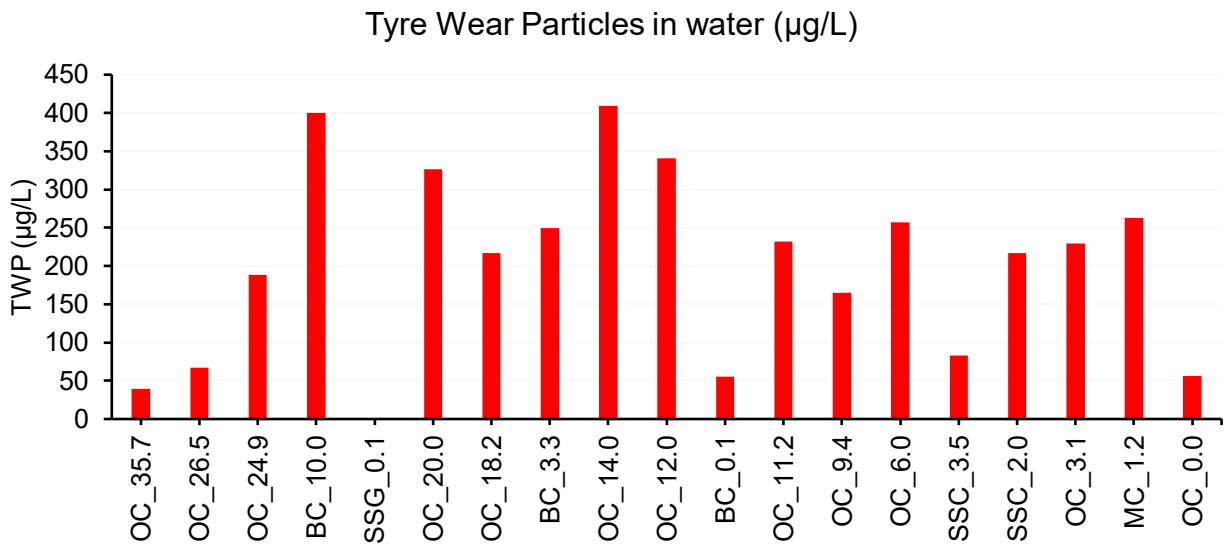

Figure 11: Tyre wear particle concentrations in water across all sites.

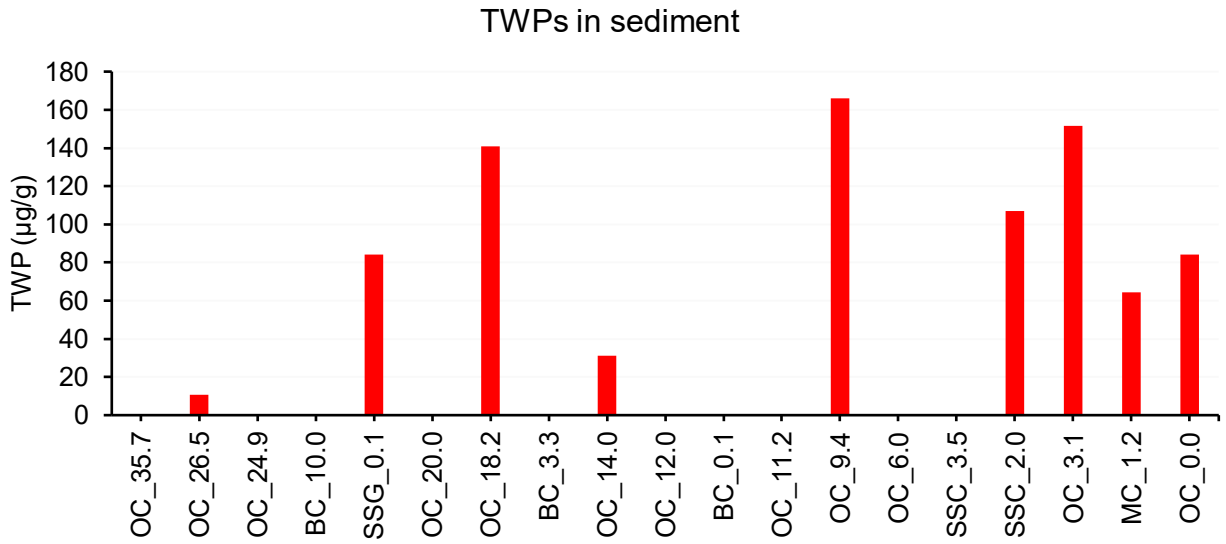

Figure 12: Tyre wear particle concentrations in sediments across all sites.

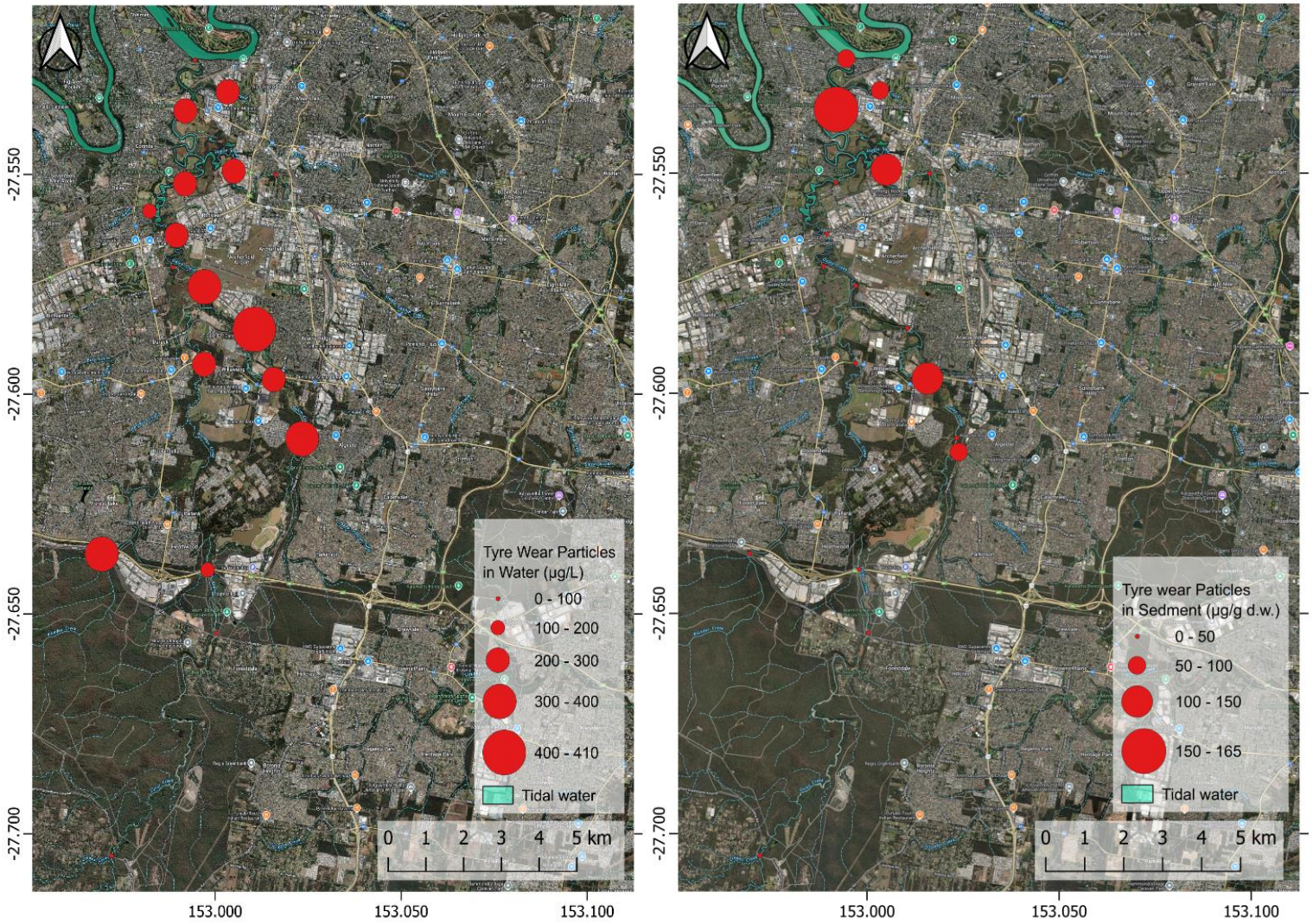

Figure 13: (a) TWP trends in water across all sites and (b) TWP trends in sediments across all sites.

Microplastics (MPs)

Water (MPs)

MPs were detected at every site, with PVC at the highest concentrations (15 – 592 µg/L). PE, PP, PET, PS and PC were also detected, with the most diverse MPs profile at the mouth of Oxley Creek (OC_0.0) (Figures 14, 15, 17a). The highest concentrations were detected at BC_10.0 with a total concentration of 619 µg/L and lowest concentrations in Sheep Station Gully (SSG_0.1) and Oxley Creek, just below the confluence with Sheep Station Gully (OC_20) (15 and 22 µg/L respectively).

Previously reported MP water concentrations in Caboolture, Brisbane and Nerang rivers were generally higher than the current study, ranging 339 – 1,160 µg/L [16]. Concentrations in this study were also comparatively lower than those previously reported from five Queensland urban locations (16 – 1,770 µg/L) [15].

Sediment (MPs)

MPs were detected at nine of the nineteen sites (0.06 – 0.20 µg/g dw) and showed a similar trend to the TWPs with higher detection frequencies and concentrations at estuarine sites (OC_9.4 to OC_0.0). PE was detected at all nine sites, while PS was detected at Site SSC_2.0 (0.05 µg/g dw) and PP at Site BC_0.1 (0.04 µg/g dw) (Figures 16, 17b).

Similarly to the TWPs, in the previous Moreton Bay study total MP concentrations were much higher. Size fractionated concentrations ranged 0.9 to 74 µg/g dw (<63 and 150 – 500 µm particles respectively) at OC_0.0 and 47 to 295 µg/g dw (<63 and 500 – 1000 µm particles respectively) at OC_6.0 and again PE was predominantly detected. Similar to the TACs and TWPs, this also suggests sediment movement associated with flooding events caused by ex-Tropical Cyclone Alfred.

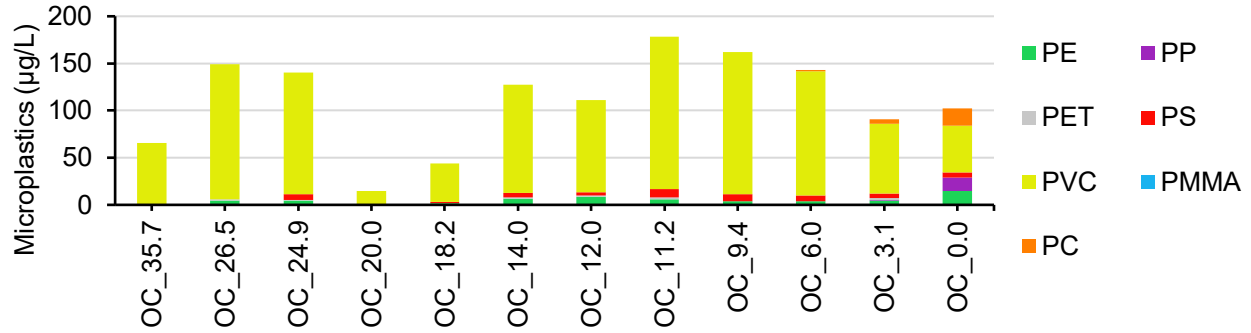

Figure 14: Microplastic concentrations in water samples across sites in Oxley Creek.

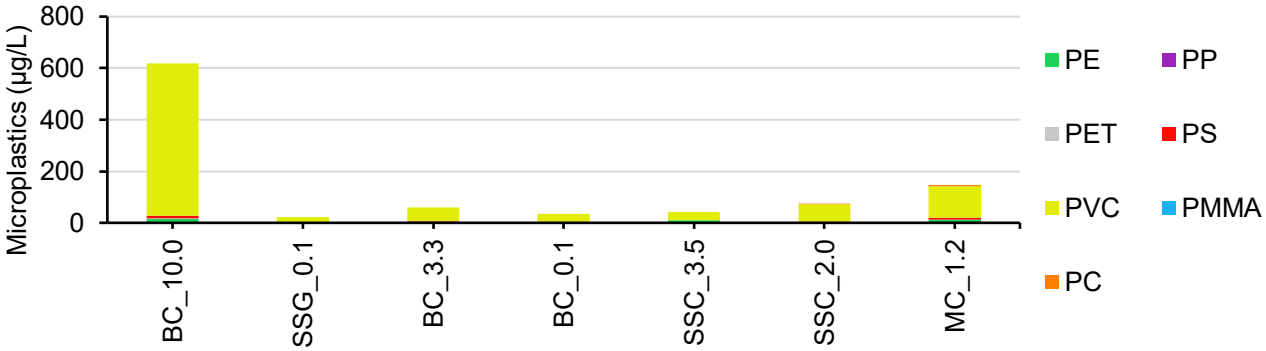

Figure 15: Microplastic concentrations in water samples from tributaries that flow into Oxley Creek.

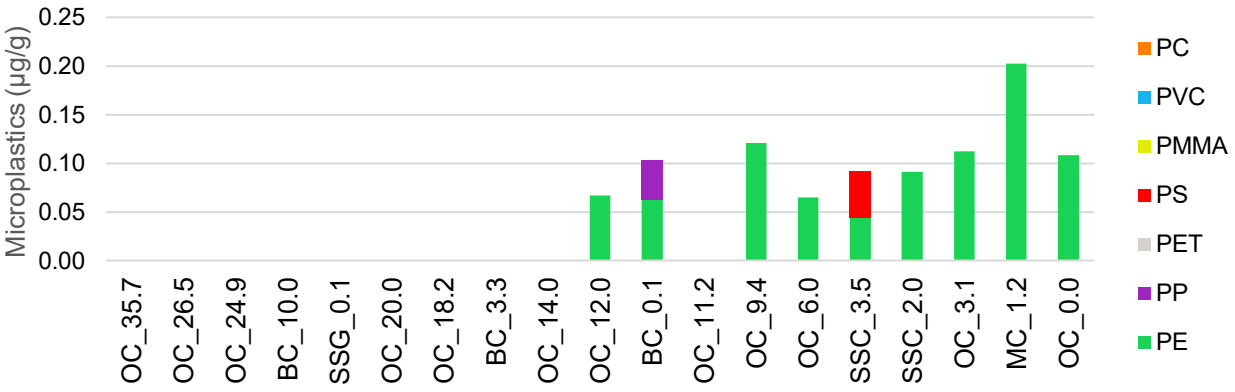

Figure 16: Sediment microplastic concentrations across all sites

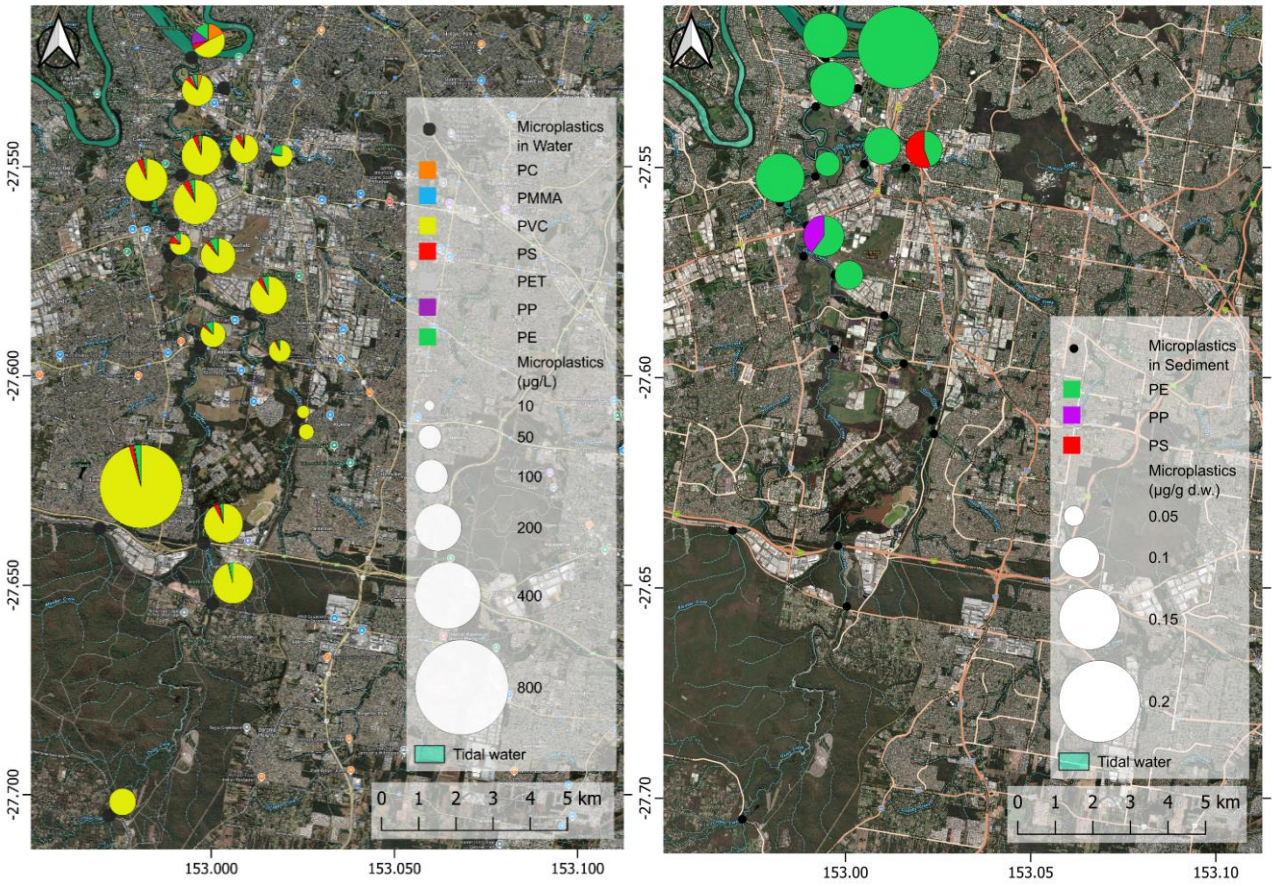

Figure 17: (a) Microplastic concentrations in water samples and (b) Microplastics in sediment samples across all sites.

Analysis of combined data.

Grouped data were used to construct a principal component analysis (PCA) biplot depicting the similarities between sites. The majority of upstream and non-tidal sites grouped together (Figure 18), whilst OC_0.0 and MC_1.2 were outliers with unique pollution profiles. OC_3.1 is notably distanced from other sites. This site is located between the confluence of Stable Swamp and Moolabin creeks and the profile is more representative of the sites sampled in Stable Swamp (SSC_2.0, SSC_3.5) and Moolabin creeks (MC_1.2), suggesting these creeks directly impact this area of Oxley Creek.

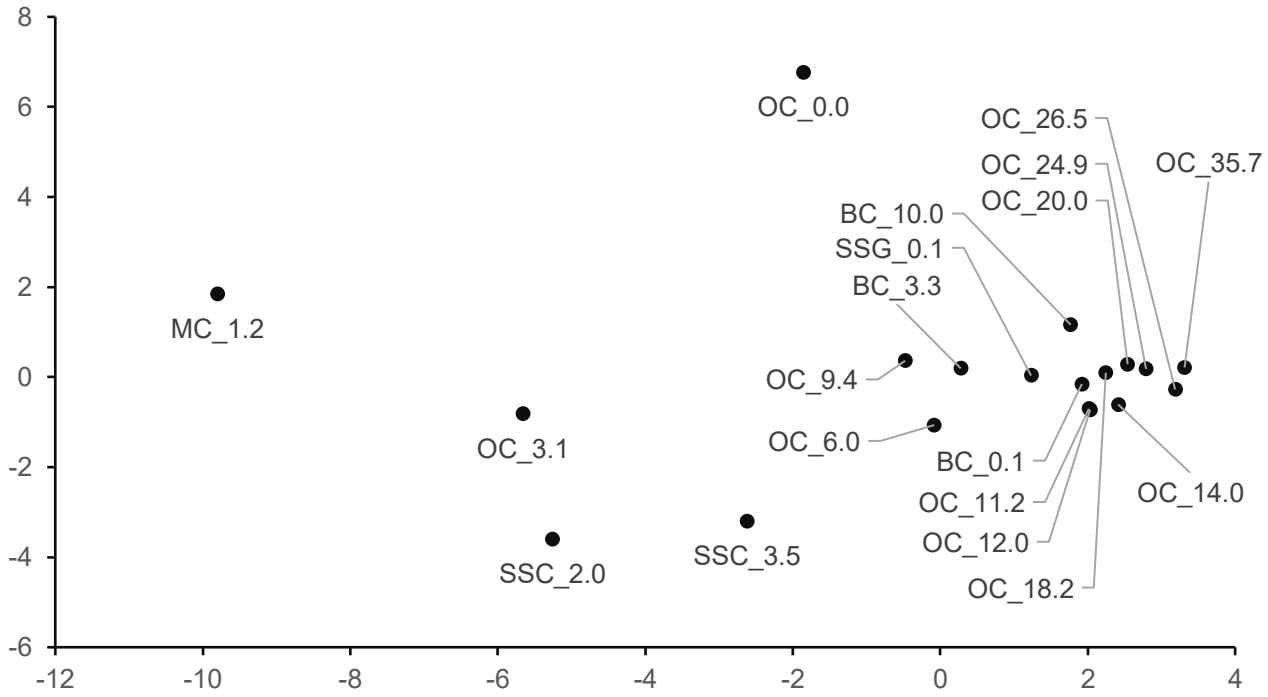

Figure 18: Site specific principal component analysis (PCA) of all variables excluding PSD.

Discussion

This pilot study provides critical insights into the occurrence, distribution, and behaviour of tyre-related pollutants, including TACs, TWPs, and MPs, within the Oxley Creek catchment. The most prominent trend was the increasing TAC concentrations in the estuarine section of Oxley Creek (Figure 10a and b). The elevated concentrations reported from sites in Stable Swamp Creek (SSC) and Moolabin Creek (MC) that flow into the estuarine reach suggest that these two tributaries constitute a major source of TAC pollution in the lower reaches of the Oxley Creek catchment. At site OC_3.1, the chemical profile closely resembled those of Stable Swamp Creek (SSC_2.0 and SSC_3.5) and Moolabin Creek (MC_1.2). Principal component analysis (PCA) plotted OC_3.1 as having a contaminant profile between those of SSC and MC, suggesting the blending of pollutants from these tributaries in the Oxley Creek. Tidal sites generally exhibited similar pollutant profiles.

TWPs and MPs were detected in both water and sediment samples with PVC dominating the water column and PE dominating the sediment. Both TWPs and MPs had higher sediment detection frequencies at estuarine sites and concentrations were much lower than in the previous Moreton Bay study, indicating the influence of bank erosion in diluting contaminant concentrations.

The detection of 6PPD-quinone in sediments, with concentrations ranging from below detection limits to 1.62 ng/g dw, represents a significant finding as it further shows the environmental distribution of this chemical, with the only other report of 6PPD-quinone in Australian sediments from the Moreton Bay pilot study. This compound was strongly correlated with higher TWP concentrations in sediment (Spearman correlation 0.68) and with CPU and DPG concentrations in sediment, indicating potential co-occurrence or shared transport pathways. Sediment composition played a key role in pollutant retention, with silts and clays positively correlated with most pollutants, except for 2-MTBT. Sandy sediments generally exhibited lower pollutant concentrations, likely due to their reduced adsorption capacity [5,14].

The TAC 2-MTBT was noteworthy, as it was more likely to occur at sites with higher sand content and did not follow the same occurrence pattern as other TAC compounds. These findings suggest that 2-MTBT may exhibit unique solubility or adsorption characteristics that warrant further investigation.

The study was conducted under relatively dry conditions, providing a baseline for pollutant concentrations in the absence of recent stormwater inputs. However, the data likely still reflects the effects of ex-Tropical Cyclone Alfred, which occurred two months prior to sampling. Cyclonic events are known to mobilise sediments and alter hydrological flows, potentially redistributing pollutants within the catchment.

Despite the valuable baseline data provided by this study, there is very little ecotoxicological information available on the concentrations of TACs and TWPs in water, and no data for sediment. The most widely studied TAC, 6PPD-quinone, has demonstrated highly species-specific toxicity, particularly to coho salmon [6, 7, 18]. However, there is currently no data available on its toxicity to Australian native aquatic species. The concentrations observed in this study (<0.2 – 8.7 ng/L) were lower than the US EPA surface water guideline value of 11 ng/L [8], suggesting limited acute toxicity. Toxicological data for other TACs are similarly limited, with predicted no-effect concentration (PNEC) values for HMMM, DPG, and BTR reported to be at least an order of magnitude higher than the surface water concentrations detected in this study [19, 20, 21].

Recommendations

1. Further assessment of Moolabin and Stable Swamp Creeks: These two creeks were identified as significant sources of road-related pollutants to the Oxley Creek catchment. Both these creeks contain a number of automobile related industries upstream of sampling sites and further monitoring is needed to assess which are the primary sources, the extent of their release and the ecotoxicological impact of these concentrations.

2. Assess concentrations during storm and flood events: The current study provides baseline concentrations in relative dry conditions, however it has been shown that during storm events surface water concentrations in Brisbane can increase at least 40 times. Future studies should target high-concentration sites (e.g., OC_12.0 to OC_0.0) during storm events and post-flood conditions. This will allow quantification of contaminant loads, sediment resuspension, and fluxes into the Brisbane River and Moreton Bay.

3. Investigate ecotoxicological impacts on local species: Laboratory and field-based testing are urgently needed to determine whether observed levels of TWPs and TACs pose acute or chronic risks to native aquatic species and whether they bioaccumulate through the food chain. Testing both baseline and urban flush (during storm events) concentrations is needed to understand the total impact.

4. Expand and extend environmental monitoring: Monitoring should move beyond water and sediments to include groundwater, wastewater, and local biota such as fish and invertebrates. Seasonal and multi-year studies across Oxley Creek and other South-East Queensland catchments will provide a more complete picture of exposure pathways, temporal variability, and long-term trends.

Conclusions

Tyre and road-related pollutants (TACs, TWPs, and MPs) were monitored in surface water and sediment at 19 sites across the Oxley Creek catchment. Sites were chosen to represent a range of conditions and inputs from diverse land uses in the area, and to understand potential significant sources of these pollutants to the catchment. Generally, target pollutants saw higher concentrations at the downstream (estuarine) sites, and these sites also had clear tyre-related sources (major highways, automobile industrial activities, airport, and industrial/logistics areas). Individual key sources were not able to be identified in the present study, highlighting the complexity of tyre related pollution including mixed sources of TWPs and TACs, non-tyre related sources of some TACs, differing site conditions (road surface, car vs truck, traffic density) and the lack of information on different formulations (e.g. TAC or synthetic rubber content) of tyres in use of Australian roads which limits the ability to deduce associations.

While a clear spatial trend was observed for surface water TACs, with the highest inputs coming from Milipin and Stable Swamp creeks, trends for TWPs and MPs were less clear, especially in sediments. The analysis of trends was further complicated by the impacts of ex-Tropical Cyclone Alfred, which occurred two months prior to sampling and included flooding and bank erosion that likely influenced sediment movement and contaminant distribution.

This study provides valuable baseline data on tyre-related pollutants in the Oxley Creek catchment, but further research is needed to address knowledge gaps regarding storm-related dynamics, ecological effects, and pollutant sources. By building on the insights gained from this pilot study, future research can contribute to the development of targeted strategies for mitigating the environmental impacts of tyre-related pollution in the region.

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