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# **The Plastic Problem: Stormwater's Role in Polluting Lake Rotorua**

A thesis  
submitted in partial fulfilment  
of the requirements for the degree  
of  
**Master of Science (Research)**  
in Ecology and Biodiversity  
at  
**The University of Waikato**  
by  
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THE UNIVERSITY OF  
**WAIKATO**  
*Te Whare Wānanga o Waikato*

2025

**“ONLY WE HUMANS MAKE WASTE THE EARTH CAN’T DIGEST.”**  
- Charles J. Moore, Oceanographer

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## ABSTRACT

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With the ever-increasing rate of plastic production, pollution of the aquatic environment is worsening. While microplastics (<5 mm), and marine plastic pollution are well studied, less is known about large plastic and its fate in freshwater systems. Large plastics include mesoplastics (5 mm – 2.5 cm) and macroplastics (>2.5 cm). This study aims to provide a baseline quantification of large plastics entering Lake Rotorua, focusing on the Rotorua city urban stormwater streams which are a known source of plastic entering the lake. A five-month sampling campaign collected large plastics from seven 50 m stream reaches across Rotorua city, including four sites along the longitudinal gradient of the Utuhina Stream (Headwater, Devon, Blomfield, and Depot Street sites) and three stream mouth sites (Waingaehe, Owkata Point, and Waiowhiro Stream). Sampled plastics were visually classified by polymer type to determine what plastics have been entering the lake, this was done using the New Zealand recycling and polymer guidelines. Results of the field campaign and plastic polymer classification were coupled with a systematic literature review of *in situ* plastic capturing devices and community initiatives to inform potential plastic reduction management options for Rotorua city. Devices were assessed against tailored suitability criteria (including Rotorua stormwater stream specific variables like channel depth and narrowness). The monthly sampling captured a total of nearly 6 kg of plastic, 30.2% (51 of 169 collected samples) of which was recyclable plastics (polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polypropylene (PP)). From the literature review, booms and boom-receptacles were the best suited devices for Rotorua streams; however, they are best paired with stormwater traps to increase effectiveness. Additionally, education on recycling procedures and the plastic lifecycle, increasing awareness, and implementation of community-led initiatives are management strategies that are best coupled with *in-situ* devices. The findings from this study provide a foundational understanding of large plastic in the Rotorua urban stormwater system.

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## ACKNOWLEDGEMENTS

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First and foremost, I would like to thank my supervisors Deniz Özkundakci and Maggie Armstrong. To have been able to work with such knowledgeable and kind individuals has been a privilege. I am beyond grateful for their support, guidance, and dedication to seeing me succeed.

I would also like to thank the Rotorua Lakes Council, namely Alison Lowe, Colin Bates, Craig Goodwin, Hallam Bailey, and Steve Harwood, for their continued involvement throughout my project. The resources they provided and stimulating discussion during meetings spurred me on and enabled me to create something of real value.

Credit must also be given to residents around our study sites for their clean-up effort of Lake Rotorua beaches and surrounding stream banks. Volunteers drive change and help highlight the extent of plastic pollution in their backyards; their ongoing cleanup effort is hugely beneficial.

To my partner Caleb, thank you for everything. Your support and unwavering faith in me are so deeply appreciated.

To my family and friends, special thanks must be given, each and every one of you have helped me through this process. Endless conversations with my parents, Bernard and Shaz Kerebs, have kept me grounded and helped me to see the light at the end of the tunnel. So, please relish in the completion of this masters, we have accomplished it together.

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# CHAPTER I

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## Thesis Introduction

## PLASTICS HISTORY

Humans crave convenience, and nothing has made life easier than plastic (Heidbreder et al., 2019). All manner of items, including food, drink, clothes, cosmetics, and household goods consist of plastic or are packaged in it for readily available consumption. At the surface level, the invention of plastic revolutionised daily life and made everything easier and more convenient (Heidbreder et al., 2019).

The term ‘plastic’ encompasses man-made synthetic polymers (Geyer, 2020). The first human-made polymer, Parkesine, was composed of cellulose treated with nitric acid creating thermoplastic nitrocellulose (Geyer, 2020). The first entirely synthetic polymer was created in 1907 when phenol and formaldehyde were combined and was patented under the name ‘Bakelite’ (Geyer, 2020). Early plastics included thermoplastics – those that melt when heated and harden when cooled (Geyer, 2020), and thermosets – those that undergo a chemical change forming an irreversible three-dimensional network and are unable to be melted and reformed (American Chemical Society, 1993; Freinkel, 2011; Geyer, 2020). The addition of chemical additives (plasticisers) like phthalates and phthalate esters alter plastic properties, enabling materials to be softer and more flexible than pure plastic polymers (Geyer, 2020). In modern times, the addition of plasticisers has increased the abundance of thermoplastic and thermoset derivatives as well as made the products more readily available to the commercial market. Popular thermoplastics include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene (PS), and polyamide (PA) (Geyer, 2020). Popular thermosets include polyurethane (PUR), unsaturated polyester, silicone, epoxy, melamine, and phenolic and acrylic resins (Geyer, 2020). Nowadays, plastic production and usage supersedes materials like metal and glass (Ilyas et al., 2018). In 2014, annual plastic production was in excess of 300 million metric tonnes globally (Ilyas et al., 2018). By 2019, this number had increased to 460 million metric tonnes per year (Vidal et al., 2024). Still, the rate of plastic production is expected to increase (Vidal et al., 2024).

Plastic has become so commonplace in society and daily routines that we often overlook the true extent of our plastic consumption (Soares et al., 2021). Whether it is a plastic

toothbrush, cling film, single use drink bottles, ball point pen casings, or food packaging – we use, consume, and dispose of plastic. But when this plastic is not disposed of correctly, when it is misplaced somewhere between our hands and the bin, it finds its way into the environment and causes harm (Mugobo et al., 2022; Soares et al., 2021).

## **PLASTICS IN THE ENVIRONMENT**

Plastic endures within the environment, so much so that plastics have been proposed as a geological indicator of the Anthropocene due to their absence in soils prior to 1950, and its sudden and increasing abundance thereafter (Zalasiewicz et al., 2016; Geyer, 2020). Long polymer chain plastics are designed to be durable (Freinkel, 2011), resulting in almost all plastic produced by humans still existing on the earth, whether that be on a store shelf, buried in a landfill, or littered throughout the environment (Freinkel, 2011). In humic lakes, PE microplastics may persist for 100-200 years before completely biodegrading, while in clear-lake waters, PE may persist for 300-4000 years (Taipale et al., 2023).

Plastics are an issue in aquatic ecosystems. Marine ecosystems are known to be heavily affected by plastic pollution due to e.g. commercial fishing waste, outflow from inland aquatic systems, and accumulation gyres like The Great Pacific Garbage Patch (Lebreton et al., 2018; The Ocean Cleanup, n.d.). Freshwater environments are also vulnerable to plastic pollution as they can be affected by the introduction, concentration, and degradation of plastic materials. These plastics often originate from land based activities, and improper waste management (Dalu et al., 2025). Plastic may travel through rivers and lakes to the marine environment, but rivers and lakes can also be sinks where they accumulate considerable plastic debris over time (Nava et al., 2023; Winton et al., 2020). With this, the geographical positioning of lakes (typically located in lower elevations) allows them to receive significant overland flow from their catchment (Azevedo-Santos et al., 2021). Inflow from catchments into lakes provides an indication of overall plastic pollution, i.e. lakes can act as ‘sentinels of plastic pollution’ (Nava et al., 2023).

Large plastics including meso (5 mm – 2.5 cm) and macro (>2.5 cm) size classes (Blettler et al., 2018) in freshwater aquatic systems cause a myriad of issues to the system inhabitants (fish, crustaceans, etc; Azevedo-Santos et al., 2021), including entanglement, adhesion to gills, and intestinal blockages (Blettler & Wantzen, 2019; Lechthaler et al., 2020; Azevedo-Santos et al., 2021). Plastic ingestion is more common and has higher mortality rates than entanglement (Zbyszewski et al., 2014). Environmental factors like temperature, biological activity, mechanical stress, and photodegradation increase plastic breakdown rate (Monira et al., 2021). Higher temperatures increase rate of change in plastic polymer properties (Zhang et al., 2024). Biological activity refers to plastic degrading microorganisms (like bacteria and fungi) that can colonise and enzymatically degrade plastic polymers (Zhang et al., 2024), as well as fish and aquatic omnivores which may chew on and degrade plastics (Zhang et al., 2024). Mechanical stress (of plastic) is the degradation caused by factors such as wind, water turbulence, and sand/sediment abrasion (Zhang et al., 2024). The shortwave UV radiation of sunlight increases aging rate in exposed plastics (Zhang et al., 2024). Breakdown from large plastics into microplastic produces other environmental issues, including microplastic (<5 mm; Blettler et al., 2018) infiltration of food webs (Blettler et al., 2017; Lechthaler et al., 2020), and fragments acting as vectors for microorganisms, heavy metals, and persistent organic materials (Lechthaler et al., 2020; Li et al., 2021). Large plastics cause harm in freshwater environments and degrade into smaller particles that are harder to capture and manage.

Failure to act upon the issue of plastic and its pollution of freshwater environments can reduce freshwater biodiversity, diminish the aesthetic value of rivers and lakes, and threaten human health (Blettler et al., 2018; Mugobo et al., 2022). While there have been examples of these negative outcomes in systems globally, the specific way that plastic interacts within the environment is not always predictable. Studies therefore need to be done for different systems to provide a more informed understanding of plastic in local settings and different scenarios. In this instance, the research aims to inform measures to prevent the ingress of plastic into Lake Rotorua.

## LAKE ROTORUA

Lake Rotorua is a large (~80 km<sup>2</sup>), relatively shallow lake (45 m max depth) located in the central North Island of New Zealand (Sigma Consultants Ltd, 2023; LAWA Land Air Water Aotearoa, n.d.). The lake resides in the Rotorua district of the Bay of Plenty region. Lake Rotorua is a volcanic caldera, formed after the large Mamaku Ignimbrite eruption ~140,000 years ago (Wood, 1992). The geothermal nature of the lake, and its subsequent high sulphur and volcanic mineral loading, produces a natural dark green-yellow colouration to the lake (Rotorua Te Arawa Lakes Programme, n.d.). The lake is eutrophic and polymictic, making it susceptible to adverse warming-related effects (algal blooms, reduced water quality, etc.; Spears et al., 2022). There are nine major stream inflows feeding into Lake Rotorua. The seven streams Waingaehe, Waitawa, Puarenga, Utuhina, Waiowhiro, Ngongotahā, and Waitetī are positioned within the ‘Rotorua Urban Area Catchment’ (Sigma Consultants Ltd., 2023). Water flows out from Lake Rotorua via the Ōhau Channel into Lake Rotoiti where it eventually travels down the Kaituna River and into the Bay of Plenty (Sigma Consultants Ltd., 2023).

The lake is a taonga (noun: “*treasure, anything prized*”; Te Aka Māori Dictionary, n.d.), to the people of the Te Arawa iwi, and it holds significant cultural and spiritual connection (Spears et al., 2022). Lake Rotorua is one of 12 Te Arawa lakes (Rotorua Te Arawa Lakes Programme, n.d.). Historically, Lake Rotorua was home to native mahinga kai (noun: “*cultivation, food-gathering place*”; Te Aka Māori Dictionary, n.d.), species Kōura (Freshwater Crayfish (*Paranephrops planifrons*)) and Kōaro (Whitebait (*Galaxias brevipinnis*); Spears et al., 2022). Nowadays, the lake is stocked with introduced predatory fish Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) facilitating a world class recreational sport fishery and significantly increasing the economic value of the lake's ecosystem services (Spears et al., 2022; Sigma Consultants Ltd., 2023) but reducing populations of mahinga kai species.

Lake Rotorua has a catchment area of 508 km<sup>2</sup>. Portions of Lake Rotorua are surrounded by native bush, farmland and pasture, and geothermal vents and springs (Rotorua Te Arawa Lakes Programme, n.d.). With this, Lake Rotorua has the greatest percentage of

urbanisation along its shoreline as compared to other Te Arawa lakes (Rotorua Te Arawa Lakes Programme, n.d.). Land use surrounding the lake includes residential (25.21 km<sup>2</sup>), city centre/commercial (4.59 km<sup>2</sup>), industrial (5.75 km<sup>2</sup>), reserves (28.39 km<sup>2</sup>), roads (8.12 km<sup>2</sup>), and rural areas (239.96 km<sup>2</sup>; Sigma Consultants Ltd., 2023). Rotorua city is the greatest urban centre around the lake, comprising ~3 km<sup>2</sup> of catchment land (Scholes & McIntosh, 2010; Sigma Consultants Ltd., 2023). As recorded in the 2023 annual census, the Rotorua district has a total population of 74,058 (Stats NZ, 2024).

Historically, degradation of Lake Rotorua has been attributed to nutrient enrichment and a change in land use, i.e. the change from forested to agricultural and urban land use around the lake (Sigma Consultants Ltd., 2023). While this contributes to decreasing water quality, other pollutants like plastic are often overlooked and not systematically quantified. A study published in 2023 compared plastic debris in lakes and reservoirs globally to collate a “standardised cross-national survey” assessing types of plastic and their abundance (Nava et al., 2023). This study was the first published measurement of plastic pollution in Lake Rotorua. From this study, Lake Rotorua was found to have plastic pollution levels comparable to that of much larger lakes with far denser urbanisation in their catchments (Nava et al., 2023).

## **OBJECTIVES AND SCOPE**

The overarching objective of this thesis is to investigate large plastics within the stormwater system of Lake Rotorua. The lack of existing estimates of meso- and macroplastics entering Lake Rotorua through stormwater systems provides an opportunity to establish this necessary baseline. With large plastics, early intervention in their life cycle is critical, i.e. capturing large plastics as they move through stormwater streams and drains before they begin to break down, and before they enter the lake.

There are three aims in this study. The first aim is to quantify the amount of meso- and macroplastic entering Lake Rotorua through the stormwater system. The second aim is to classify the types of plastic in the stormwater system. Rotorua city is the largest and

densest urban centre around Lake Rotorua, so obtaining data of in-stream plastic pollution during a set sampling period will provide a baseline to build upon. Other townships around Lake Rotorua are much smaller, including the second largest urban centre of Ngongotahā with a population of 1,692 (Stats NZ, 2023). Key study sites will be chosen to focus on plastic moving through Rotorua city, as this is an area where mitigation methods can be implemented and reductions in plastic pollution can be achieved. Therefore, all plastic pollution data included will be a subset of the greater Rotorua catchment. The third aim is to identify potential plastic reduction management options; this will involve a systematic literature review of various instream capturing devices. Primary data gathered during a five-month sampling campaign, coupled with a literature review of plastic capturing methodologies, will inform recommendations of how to capture plastic in the stormwater system.

The scope of this research is restricted to investigation of meso- and macroplastics. Compared to the comprehensive discussion of microplastic pollution in scientific literature, large plastic in freshwater is less frequently studied. This research intends to lessen that knowledge gap. While numerous other pollutants affect freshwater, this study focuses on plastic pollution in the Lake Rotorua catchment to better understand their source and fate in the systems. Other freshwater pollutants and any interaction they may have with large plastics is outside the scope of this study.

## **THESIS STRUCTURE**

This thesis consists of four chapters. This first chapter introduces background information on plastic pollution and provides context for the research conducted. The second chapter is on the field study. It details the methodologies used throughout the sampling campaign, analyses undertaken on data gathered, results found, and an interpretation of the results. The third chapter is a systematic literature review of plastic capturing devices and methodologies. Recommendations for interventions in the Rotorua stormwater system are outlined based on the capture devices and insights from community-led plastic-free and cleanup initiatives. The fourth chapter discusses

implications of this research, including learnings about plastics in Rotorua freshwater systems, and areas for future research.

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## **CHAPTER II**

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### **Tracking Meso- and Macroplastic Pollution in Lake Rotorua's Stormwater**

## **ABSTRACT**

Lake Rotorua is renowned throughout New Zealand for its cultural and ecological significance and provides value to Rotorua city, but the influx of plastic pollution is adversely affecting the lake and inflowing streams. Information on large (meso- (5 mm - 2.5 cm) and macroplastic (>2.5 cm)) pollution in freshwater is limited. This research focuses on stormwater streams (inflows to Lake Rotorua) by sampling seven 50 m stream sites - three stream mouth sites, and four longitudinal gradient sites. Sampling occurred over October 2024 - February 2025 and produced a total of 5,982 g of plastic. Sites were selected with different catchment land use composition; however, land use was found to have no strong relationship with plastic load. During stream sampling 169 plastic fragments were collected. Polymer identification revealed 30.2% of these fragments (51/169) to be recyclable plastics (polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polypropylene). Plastic loading was found to be consistently high across stream sites, and the data likely underestimates the true extent of plastic entering Lake Rotorua.

## INTRODUCTION

The invention of plastic in the early 1900s (Geyer, 2020) dawned a new era for humanity. While Aqua's song 'Barbie Girl' coined the phrase "Life in plastic, it's fantastic" (Aqua, 1997), the reality of the situation might not be so great. Plastic endures within the environment. As is it was designed to withstand water and heat, when exposed to the elements, rather than decomposing like organic materials would, plastic fragments into smaller versions of itself and can become embedded in the environment and the food chain (Lechthaler et al., 2020). Plastic accumulates within the freshwater environment (Lebreton et al., 2022). Freshwater bodies, like lakes and rivers, are unique in that they act as both sources and sinks for pollutants. To the marine environment, freshwater bodies deliver water and plastic and are thus considered a source. But in and of themselves, rivers, and especially lakes, can also be a sink for dense plastic materials. Consequently, as freshwater systems are both critical pathways and reservoirs for plastic the effects of plastic pollution are not limited to marine environments. Therefore, it is essential to understand plastic input into freshwater systems to assess ecological risks and develop mitigation strategies.

While plastic in freshwater environments can be found spanning various size classes (Lebreton et al., 2022), this study focuses on mesoplastics (5 mm – 2.5 cm) and macroplastics (>2.5 cm; Blettler et al., 2018). Plastic may also disperse to various compartments (sections in water bodies), i.e. water surface, littoral sediment, sublittoral sediment, water column, etc. (Lebreton et al., 2022). Sampling these different compartments provides insight into fluvial plastic transport and provides a more comprehensive overview of plastic in the entire system. For example, water surface sampling provides an understanding of plastics currently in transit, while stream bed sediments reflect sunken plastics and those with longer-term accumulation and retention rates. Bankside vegetation may also trap plastics and rerelease them during high flow events.

Lake Rotorua is located in the central-north North Island of New Zealand, and spans ~80 km<sup>2</sup>. The lake has a maximum depth of 45 m (Sigma Consultants Ltd, 2023; LAWA Land Air Water Aotearoa, n.d.). Over time, the lake has filled with sediment, leading to the relatively shallow depths and contributing to its eutrophic status (Burns et al., 2005). The catchment area of Lake Rotorua (508 km<sup>2</sup>) is comprised of numerous land uses, including the city of Rotorua, commercial, industrial, residential, reserves, roads, and rural (agricultural and urban; Sigma Consultants Ltd., 2023). Lake Rotorua receives inflow via various natural streams and stormwater flow channels, with many streams contributing to the valued trout (brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*)) fisheries within the lake (Scholes & McIntosh, 2010).

This research chapter investigates plastic pollution in the stormwater system and urban streams of Lake Rotorua. Rotorua Stream study sites were chosen to reflect various land uses and to display any differences in plastic loading within such. With this, Rotorua stormwater streams receive flow from nearby urban centres and therefore provide a good assessment of plastic loading within the catchment. This chapter aims to answer the following questions.

1. Does the catchment land use type surrounding the stream sections influence amount of plastic input into Lake Rotorua?

Answering this question should provide an understanding as to whether land use surrounding streams effects how much plastic pollution enters the water body. It is hypothesised that greater quantities of plastic pollution are entering the streams within the residential sector as opposed to farmland. Further, it is anticipated that larger abundances of in-stream plastic will be found in streams sites within the city centre as compared to stream mouths which are located further from the central city.

2. Is plastic being pushed ashore and buried by wave action near stream mouths after it has entered Lake Rotorua?

As plastic is flushed into the lake via streams, it is hypothesised that plastic is being pushed back onshore due to wave action and then buried in the sediment. Moreover, it is predicted that this occurring within proximity to the stream mouth (50 m either side).

3. What are the most common polymer types that are being transported through or accumulated in the stormwater stream system?

Identifying if there are specific plastic polymers that are more abundant within in-stream plastic pollution will enable more informed suggestions regarding plastic cleanup/capture devices. Specifically, if there are some polymers that are significantly more abundant across sample streams, then capture methodologies would need to accommodate for this, and for how these polymers are transported (e.g. readily float/sink and move with sediment disruption).

## **MATERIALS AND METHODS**

### **Site Description**

#### *Utuhina Stream*

The Utuhina stream is one of the major inflows into Lake Rotorua with a mean annual discharge of 1.7 m<sup>3</sup>/s (Bay of Plenty Regional Council, 2025). It drains a catchment of ~60 km<sup>2</sup> (Wallace, 2014), flowing from the Western boundary of Rotorua city's Tihiotonga suburb (Te Wai Māori, 2022), through residential and industrial areas within Rotorua city, and ultimately discharging into Lake Rotorua (Wallace, 2014). The main branch of the Utuhina is joined by several tributaries, including the Mangakākahi Stream, and the Otamatea Stream (Wallace, 2014), as well as various stormwater drains and inflows (Te Wai Māori, 2022). Nowadays the stream is considered highly polluted, and anecdotal evidence reports large masses of rubbish flowing downstream that ranges from food packaging, tyres, mattresses, and fridges. Various council efforts and community cleanup groups have endeavoured to clean the Utuhina Stream, with focus given to cleaning up the mouth of the stream where it enters the lake. However, due to the constant inflow of rubbish in the stream, and the highly mobile sediments which cover and expose

rubbish on bottom sediments, anecdotal evidence suggests rapid re-accumulation of plastic pollution at the stream mouth.

During the selection of study sites, particular emphasis was given to select regions of the stream within different land uses to assess what, if any, effect land use has on plastic pollution within a given stream reach. Stream mouth sites were spread along the southern shoreline of Lake Rotorua. These included the Waingaehe Stream mouth (located in Holden's Bay Reserve) (38°7'9.95"S, 176°17'49.92"E), Owhata Point stream/stormwater drain mouth (38°7'22.76"S, 176°17'21.29"E), and the Waiowhiro Stream mouth (38°6'12.34"S, 176°14'18.41"E). In being further from the central city, land use and surrounding vegetation at the stream mouth sites varied including a larger proportion of forested catchment land than other sites.

#### *Waingaehe Stream*

Waingaehe Stream outflow entered the lake at the Western edge of Holden's Bay Reserve. Bank vegetation of the 50 m sample reach was limited to mown grass, with virtually no riparian margin, and no shading (Figure 2.1g). During early sampling (October - December) the stream mouth flow was channelled parallel to the beach for ~10 m due to a small sand spit, however during January and February sampling this spit had disappeared suggesting high winds and/or strong flows had changed the outflow point.

#### *Owhata Point*

A notable feature of the Owhata Point site was the rock riprap hardening on the true right bank. The left bank was dominated by long grasses, Blackberry, and Gorse (*Ulex europaeus*). The 50 m reach featured steep banks, a narrow channel, anoxic sediments, and submerged and surface scum (Figure 2.1f). The sample reach ran parallel to Owhata road.

### *Waiowhiro Stream*

The Waiowhiro Stream mouth was situated amongst residential housing and pastoral land (Figure 2.1a). Both banks were vegetated with flax (Harakeke; *Phormium tenax*), long grasses, and non-native trees and shrubs. The upstream portion of stream included anoxic sediments; however, the downstream portion (beyond the excluded pool) included a mixture of boulders, gravel, and sand.

The Utohina stream was identified as a key stream contributing to plastic pollution inflow into Lake Rotorua due to its flow path through various land uses. Along the Utohina Stream, four sites were chosen for regular monthly sampling. These included a headwater site (38°9'39.94"S, 176°13'5.41"E), Devon Street site (38°9'9.13"S, 176°13'47.45"E), Blomfield Street site (located on the Mangakākahi Stream tributary of the Utohina Stream; 38°8'18.26"S, 176°12'14.70"E), and Depot Street site (38°08'03.3"S, 176°14'07.5"E; Figure 2.1). Along the longitudinal gradient site composition varied, a brief description of each site is given below to illustrate site characteristics.

### *Headwater Site*

At the headwater site, riparian planting was restricted to the true right bank of the stream, with a mixture of non-native shrubs/trees, ferns, and tree ferns. The left bank was dominated by long grasses (closest to the water's edge) and shorter mown grass starting ~3 metres from the bank (Figure 2.1e).

### *Devon Street*

The Devon Street site was located directly adjacent to the Ray Boord Park Reserve. Along the 50 m study section, riparian planting was very limited, and instead the bankside was dominated by long grasses, including various *Carex* sp. Several large Willow trees (*Salix fragilis*) were in the riparian margin. Figure 2.1d displays the grass dominated banks and presence of willows. The stream banks were eroded and very silt/clay dominated, with little stable structure.

### *Blomfield Street*

The Blomfield Street site was located in the Pukehangi suburb of Rotorua City. The study site was situated on the Mangakākahi Stream - a tributary of the Utuhina Stream. The site was surrounded by residential housing and had considerably less canopy cover and surrounding vegetation than previous sites. Within the 50 m sampled, there was no shading (as visible in Figure 2.1b) and bank vegetation was composed of unmown paddock grasses (~30 cm tall). Set slightly back from the true right bank was a public walking track that runs along a portion of the stream length.

### *Depot Street*

The Depot Street site was the most central city location. The site was surrounded by urban (commercial/industrial) land use and extensive roading. The 50 m sample reach began ~5 m downstream of the State Highway 5 Old Taupo Road bridge. The Depot Street site was situated along the Mangakākahi tributary, but shortly downstream the stream connected to the Utuhina (Figure 2.1c). The site featured steep banks covered in long grasses, including *Carex* sp., and Blackberry (*Rubus fruticosus*), as well as a mixture of non-native trees and shrubs.

## **Field Study**

### *Rapid Habitat Assessment*

On 23 January 2025, a river Rapid Habitat Assessment (RHA) was conducted at each site to provide a uniform estimate of environmental conditions and habitat state. Ten variables were assessed per site including e.g. deposited sediment, invertebrate habitat diversity, bank vegetation, riparian width, riparian shade, etc. (Clapcott, 2015) (Appendix 2.1). Each habitat parameter was scored 1-10, with a maximum total score of 100/100. Habitat conditions categories are 0-25 = Poor, 26-50 = Fair, 51-75 = Good, and 76-100 = Excellent (Clapcott et al., 2020). Results from the RHAs are displayed in Table 2.1.

Monthly stream mouth sampling occurred over the period October 2024 - February 2025. The five-month sampling period covered the summer months where it was anticipated that the increase in tourism and human activities would result in larger quantities of plastic than other times of the year.

Following a meeting with the Rotorua Lakes Council stormwater team on 19 August 2024, key sites for this study were suggested. Discussion within this meeting focused on experiences of council stormwater team members with areas of heavy plastic pollution. Specifically, information was discussed as to what areas were consistently found to have high levels of plastic pollution, what systems the council already had in place to prevent plastic pollution or capture it, and what were potential causes for higher rates of plastic pollution in some areas/streams.

The field study consisted of two parts: a beach survey, and stream surveys. Stream surveys were divided into secondary categories of stream mouth sampling, and longitudinal gradient sampling.

### *Beach Survey*

Three sites were selected as ‘beach’ sampling sites, i.e. sites of beach front along Lake Rotorua directly adjacent to a stream mouth. These sites included the Utuhina Stream beach, the Waingaehe Stream beach, and the Waiowhiro Stream beach.

Sites were selected based on multiple key criteria. It was required that all sites be a part of the Rotorua storm water system. Accessibility was critical to the design of the field campaign as all sites had to be publicly accessible and not within private property. Distance to the city of Rotorua was considered, and as a result all beach sample sites were located on the southern shoreline of the lake to best measure the impacts of human cityscapes/urban centres around the lake and streams. Beach sites of interest were initially identified by maps provided by the Rotorua Lakes Council stormwater team for

the Rotorua stream and stormwater monitoring programme. The maps highlighted priority stormwater sites and indicated both major and minor streams flowing through the catchment into the lake.

This study used a purposive sampling approach to ensure coverage of known problem areas within Rotorua city, and to maximise study relevance to local management authorities. More specifically, the aim of the beach survey was to establish a base point of accumulated plastics in the nearshore area. At each beach sample site, two sampling methods were undertaken. First, a 50 m transect was established on the beach on either side of the stream mouth. This 50 m stretch was slowly walked, and all visible large (meso- and macro-) plastic was collected (by hand picking). This sampling process acted as a site-clean for all following study. The true left bank of Waiowhiro Stream beach was only sampled within a 10 m transect. While there was a possibility that the beach continued beyond this 10 m mark, there was no obvious continuation of the beach, and land ownership was called into question. To avoid trespassing, only the readily accessible beach was sampled.

The second method of sampling undertaken was sand sieving. This sampling was conducted on 9 September 2024 to establish whether meso- and macroplastics were being pushed back onshore via wave action and deposited or buried in beach sediments. The sieve sampling was carried out along a 50 m transect parallel to the lake extending both sides of the stream mouth (total 100 m sampled per beach sample site). Samples were taken at 10 m intervals for a total five samples per 50 m (e.g. 10 m, 20 m, 30 m, 40 m, and 50 m). At each 10 m mark, a spade was used to dig out sand into a sieve. The spade blade measured ~300 x 180 mm. Sediment was collected from an area of 300 x 300 x 180 mm. The sieve used during sampling measured -2.0  $\phi$ , (4 mm mesh size). Sand was collected closest to the edge of the water and all samples along the transect were sieved individually. All plastic pollution collected during sieving was stored for analysis in the lab.

### *Stream Survey - Stream Mouth*

Stream mouth sampling occurred across three sites, the Waiowhiro Stream mouth, Waingaehe Stream mouth, and the Owkata Point Stream/stormwater mouth (see Figure 2.1 and Figure 2.2). Stream survey sites were informed by discussion with council as well as through investigations into the accessibility of sites. Potential sampling locations were scouted to ascertain if sampling activities would be feasible and repeatable without special access or permissions. During sampling of the Waiowhiro Stream mouth, it was discovered that the middle section of the 50 m reach included a deep pool that exceeded wader height. From locals swimming in the stream, it was concluded that this exceeded acceptable sampling conditions. To accommodate for this, ~10 m distance from shoreline to pool edge was sampled, and the opposite pool edge was sampled back upstream for a further ~15 m (further upstream sampling was limited due to increasing depths). Initial field plans also included the sampling of the Utuhina stream mouth (38°7'32.15"S, 176°14'47.61"E). However, the stream mouth site was considerably deeper than other sites during each sampling day and exceeded the acceptable maximum depth for sampling. The Utuhina stream mouth also had high levels of sedimentation, and at any given entry point those sampling would sink ~30 cm - 1 m deep, further increasing the water depth rendering the site unsafe for wading, and thus sampling was not undertaken at this site.

At each site, a 50 m transect line was run parallel to the stream body. Each transect extended the width of the stream and ~1 m of the surrounding bank vegetation to ensure collection of any plastics captured in immediate vegetation. The sampling process included systematically wading through the 50 m transect to collect all visible plastic pollution within, on, and surrounding the water. Wading began from the downstream point of the transect and worked upstream to avoid reducing water visibility due to disturbance of the stream sediment. Any areas too deep to wade through and areas of fast flowing water were avoided to ensure safety of sampling crew. Where possible, visual inspections of these inaccessible stream stretches were conducted, and visible plastic was noted. All plastics collected were stored for analysis in the lab.

### *Stream Survey - Longitudinal Gradient*

The second component of the stream survey process included sampling four sites, the Headwater site, Devon Street site, Blomfield Street site, and Depot Street site, forming a longitudinal gradient of the Utuhiina stream. To ensure sites were representative of stream diversity, various land uses and the inherent stream gradient were considered when selecting stream locations. These sites are shown in Figures 2.1 and 2.2. Methods used for the stream mouth sampling were repeated for longitudinal gradient sampling.

### **Laboratory Processing and Analysis**

Following the field sampling procedures, plastic samples were delivered back to the laboratory for processing. Each sample (per location, per monthly sample) was processed and stored individually. Processing included three stages. Firstly, each sample and plastic fragment was cleaned (primarily removing excess sediment/biofilm and drying with paper towels) then weighed in a balance scale (Denver Instrument SI-234). For larger items that exceeded the weight capacity of the SI-234 balance scale (230 g), the Denver XL-3100 was used. Each value was recorded to four decimal places. Plastic fragments were then measured (in mm). Where possible, values for length, height, and width were recorded. All plastic fragments were assigned an identification number (i.e. site name, date of sampling, and number tally) and photographed. Each fragment was either identified (e.g. polystyrene, pump water bottle, lollipop stick, etc.) or noted as unidentified. Within New Zealand, recyclable plastics are numbers 1 (PET - Polyethylene Terephthalate), 2 (HDPE - High Density Polyethylene), and 5 (PP - Polypropylene). Non-recyclable plastics include 3 (PVC - Plasticised/Unplasticised Polyvinyl Chloride), 4 (LDPE - Low density Polyethylene, LLDPE - Linear low-density Polyethylene), 6 (PS - Polystyrene, EPS - Expanded Polystyrene), and 7 (Other). Appendix 2.2 lists plastic identity, count, recyclability, and plastic type (polymer) by site. Plastic (polymer) type was informed by the Plastics New Zealand 'The Plastic Identification Code - Label your plastics' handout (n.d.).

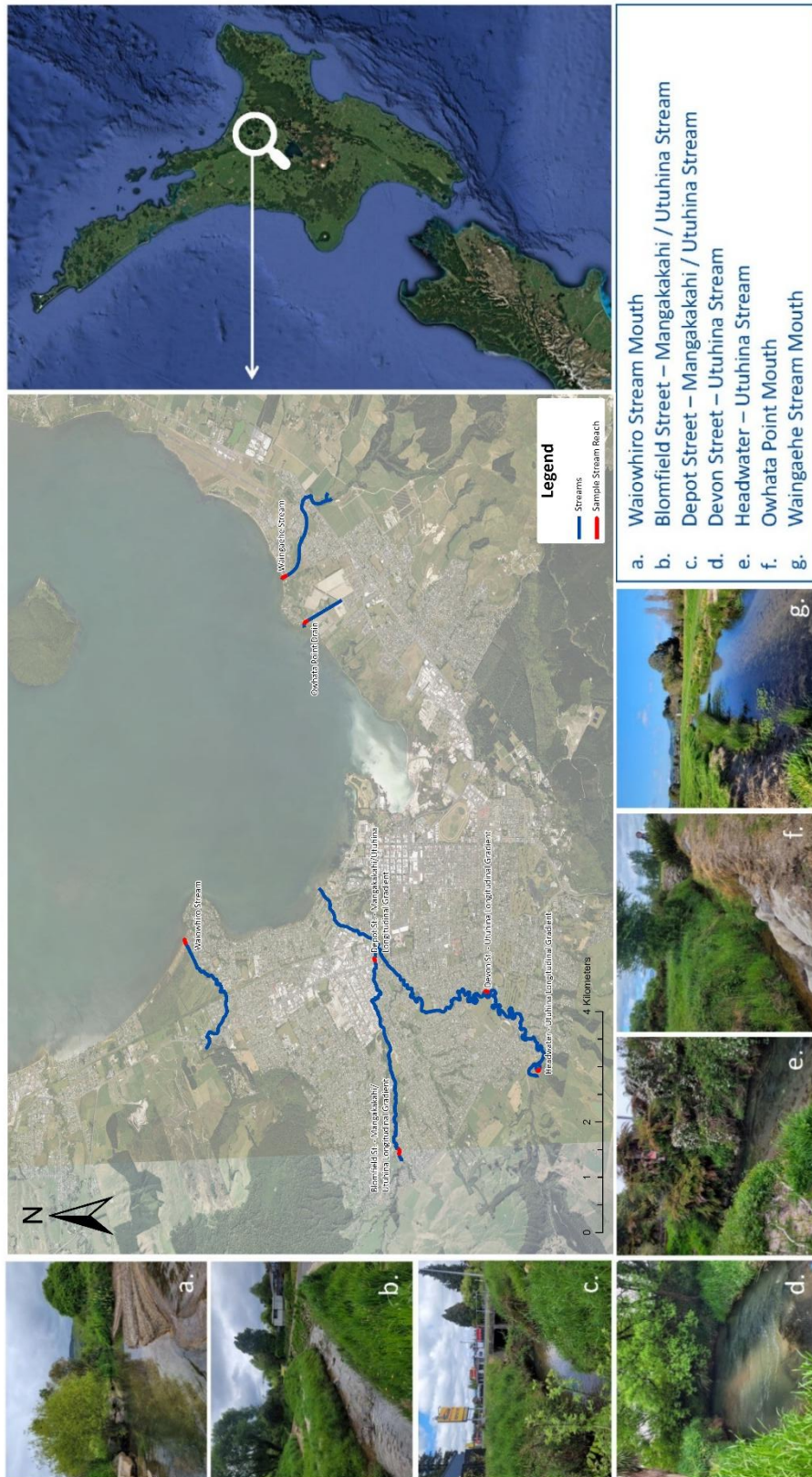


Figure 2.1. Map of Rotorua City showing study site locations (Waiowhiro Stream mouth, Blomfield Stream mouth, Devon Street, Headwater, Owkata Point mouth, and Waingaehe Stream reaches) and photos of study stream reaches.

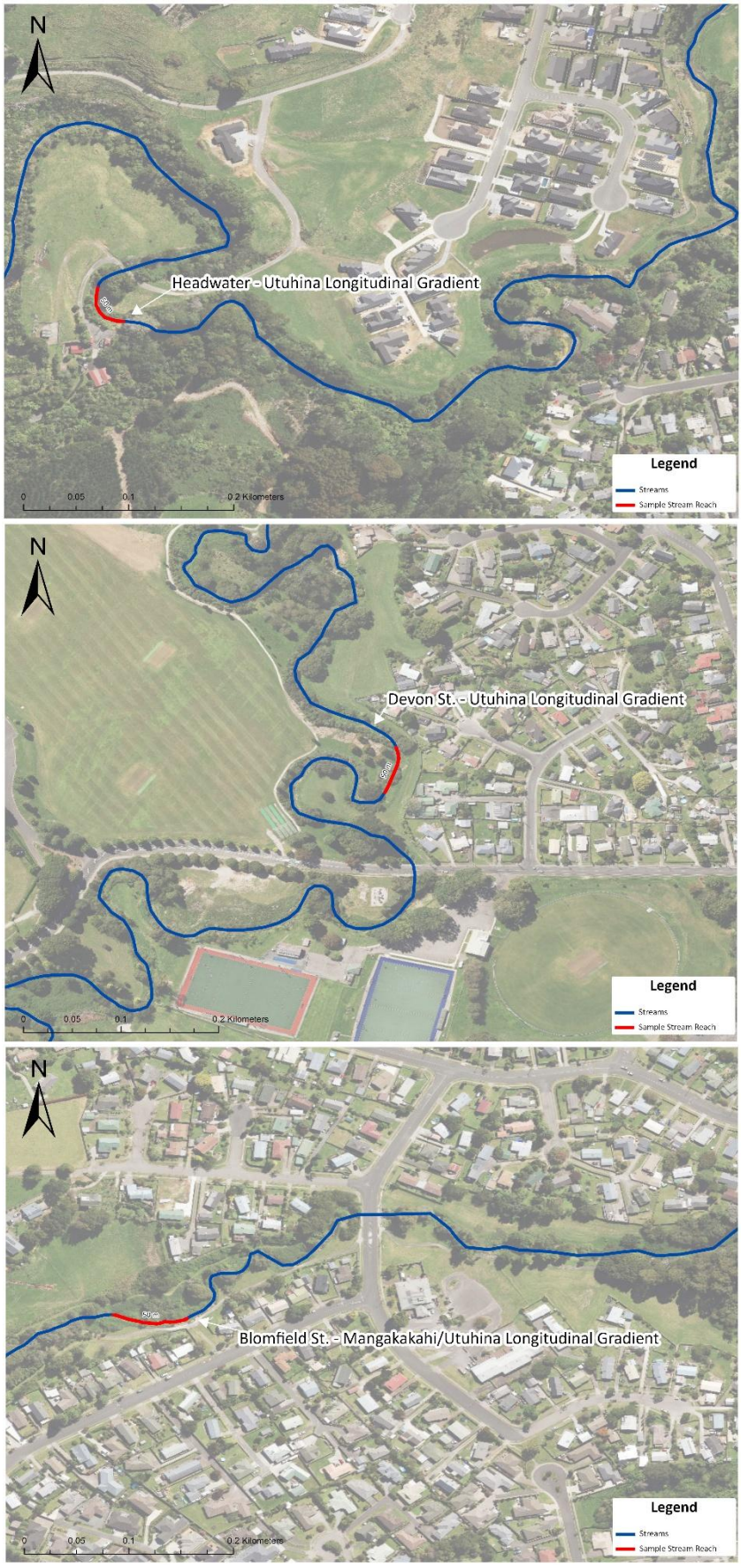


Figure 2.2. GIS maps of study site stream reaches. Stream channels are drawn in blue, and 50 m study reaches are indicated in red



Figure 2.2. GIS maps of study site stream reaches contd.

## **Land Use Analysis**

Land use across the seven sites was split into five categories: urban, forested, parks/reserves, arable, and lifestyle block/mixed land use. Land use data for the Rotorua region was sourced from the Bay of Plenty Land Use 2017 - Land Use 2017 ArcGIS layer (Bay of Plenty Regional Council, 2025). For each site, a 200,000 m<sup>2</sup> polygon was drawn encompassing the stream section and surrounding land. Where possible, land area on every 50 m reach edge was made to be equal, i.e. a square shape, however for stream mouth sites, water was excluded so the 200,000 m<sup>2</sup> extended further upstream than inland sites. Percentage of each land use was measured to the nearest ten percent. Initial land use results (from the ArcGIS Bay of Plenty Land Use 2017 layer) included the categories urban, lifestyle block/mixed land use, parks/reserves, sheep and beef, arable, and wetland. Land use categories sheep and beef and arable were combined, as well as exotic forest and wetland together as forested to streamline data.

## **Statistics**

An ANOVA test was conducted using R version 4.4.1 (R Core Team, 2024). Tests were conducted to compare total weight to site, total count to site, and weight to month. Further post hoc testing using Tukey's Honestly Significant Difference (HSD) test (Abdi & Williams, 2010) was undertaken to test pairwise comparisons for any significant results.

## **RESULTS**

### **Rapid Habitat Assessment**

The Rapid Habitat Assessment scores for the seven sites revealed one site was classified as 'good', five were 'fair', and one was 'poor' (Table 2.1). Numeric scores for each site are presented in Table 2.1. The low score for Waingaehe Stream and Owhata Point was influenced by low scores (1 or 0.5) for the habitat parameters riparian width, and riparian shade.

Table 2.1. Rapid Habitat Assessment scoring results and corresponding stream condition for sample sites.

Rapid Habitat Assessment		
	Score	Condition
Headwater Site	72	Good
Devon Street	46	Fair
Blomfield Street	41	Fair
Depot Street	45	Fair
Waingaehe Stream	29.5	Fair
Owhata Point	21	Poor
Waiowhiro Stream	44	Fair

## Monthly Sampling Results

Data from stream mouth and longitudinal gradient surveys were combined. Monthly sampling over the period October 2024 - February 2025 collected in total 5,982 g of meso- and macroplastic from the seven sites. Table 2.2 presented total weight (g), total count, average weight (g), and standard deviation of the seven sites.

Table 2.2. Total weight (g), total count, average weight (g), and standard deviation for seven study sites.

Total				
	Total weight (g)	Total Count	Average weight (g)	Standard Deviation
Headwater Site	34.6983	3	6.9397	14.6063
Devon Street	561.1398	24	112.228	140.7440
Blomfield Street	209.3892	13	41.8778	56.1536
Depot Street	2978.4793	111	595.6959	899.0030
Waingaehe Stream	487.9948	26	97.599	142.9833
Owhata Point	821.8933	70	164.379	123.5366
Waiowhiro Stream	888.2596	59	177.6519	205.7916

The weight and count data are presented per month at each site in Table 2.3. Monthly weight measurements fluctuated over the sampling period, with no month producing consistently less plastic across sites. In total, Depot Street had the largest total weight (2978 g) compared to other sites, as well as the largest total count of plastic fragments (111). The highest variability was recorded at Depot Street with a maximum total weight

of 2194 g in October and a minimum total weight of 49 g in February. Depot Street also had the highest plastic count (60 fragments in October). The lowest plastic weight and count (0) were found at the Headwater site in October, November, and January, and Blomfield Street in January. The Headwater site also had the lowest variability in recorded plastic weights (maximum of 33 g and minimum of 0 g). Across all sites, there was no apparent temporal pattern in plastic count over the sampling period.

Compiled plastic fragments were displayed per site, with each image separated by month and labelled accordingly (Figure 2.3-9). Due to the sheer mass of plastic at Depot Street and Owhata Point, two images were included for each site, with labels denoting which image corresponded to which month.

Table 2.3. Total weight (g) and count for study sites per month (October-February).

Site	Month																	
	October			November			December			January			February			Total		
	Total weight (g)	Count	Total weight (g)	Count	Total weight (g)	Count	Total weight (g)	Count	Total weight (g)	Count	Total weight (g)	Count	Total weight (g)	Count	Total weight (g)	Count		
<b>Headwater Site</b>	0	0	0	0	33.0365	2	0	0	1.6618	1	0	0	1.6618	1	34.6983	3		
<b>Devon Street</b>	77.705	13	25.9071	3	-	-	104.5946	6	352.9331	2	561.1398	24	352.9331	2	561.1398	24		
<b>Blomfield Street</b>	104.423	8	102.343	2	1.3102	2	0	0	1.313	1	209.3892	13	1.313	1	209.3892	13		
<b>Depot Street</b>	2194.0598	60	163.2863	20	299.8751	10	272.4369	7	48.8212	14	2978.4793	111	48.8212	14	2978.4793	111		
<b>Waingaehe Stream</b>	35.1212	3	0.222	1	34.3947	7	349.6965	6	68.5604	9	487.9948	26	68.5604	9	487.9948	26		
<b>Owhata Point</b>	190.3669	17	85.3732	10	355.3385	30	31.5786	5	159.2361	8	821.8933	70	159.2361	8	821.8933	70		
<b>Waiowhiro Stream</b>	45.9902	11	521.8838	11	3.3394	4	193.5495	22	123.4967	11	888.2596	59	123.4967	11	888.2596	59		

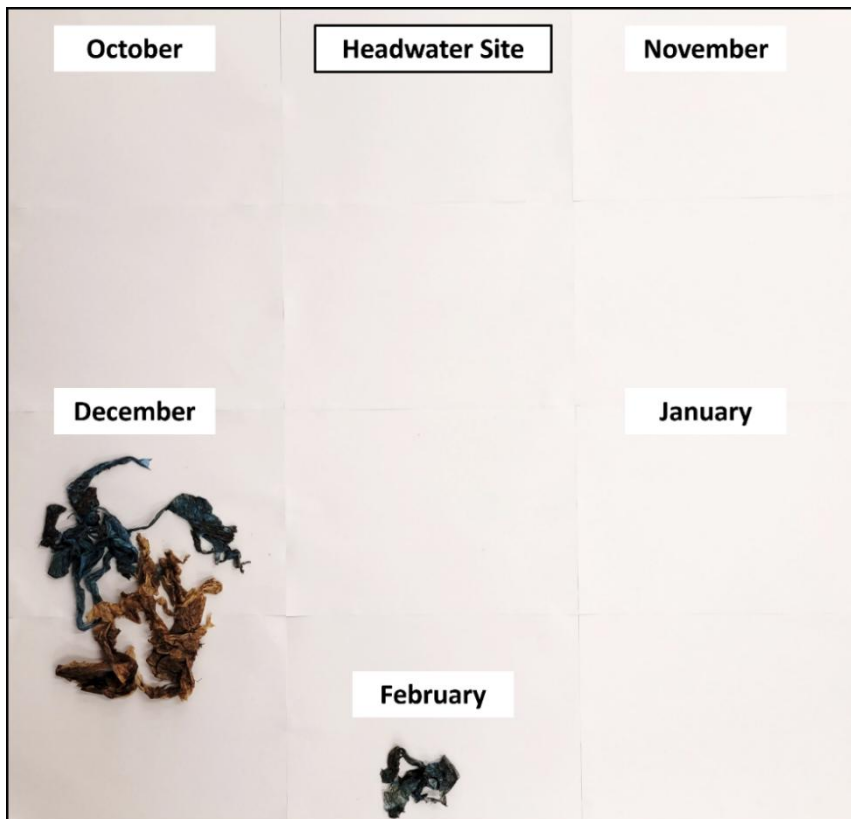


Figure 2.3. Image of collated plastic fragments collected at the Headwater site. Plastic within each photo (site) is separated by month and labelled accordingly.



Figure 2.4. Images of collated plastic fragments collected at the Devon Street site. Plastic within each photo (site) is separated by month and labelled accordingly.

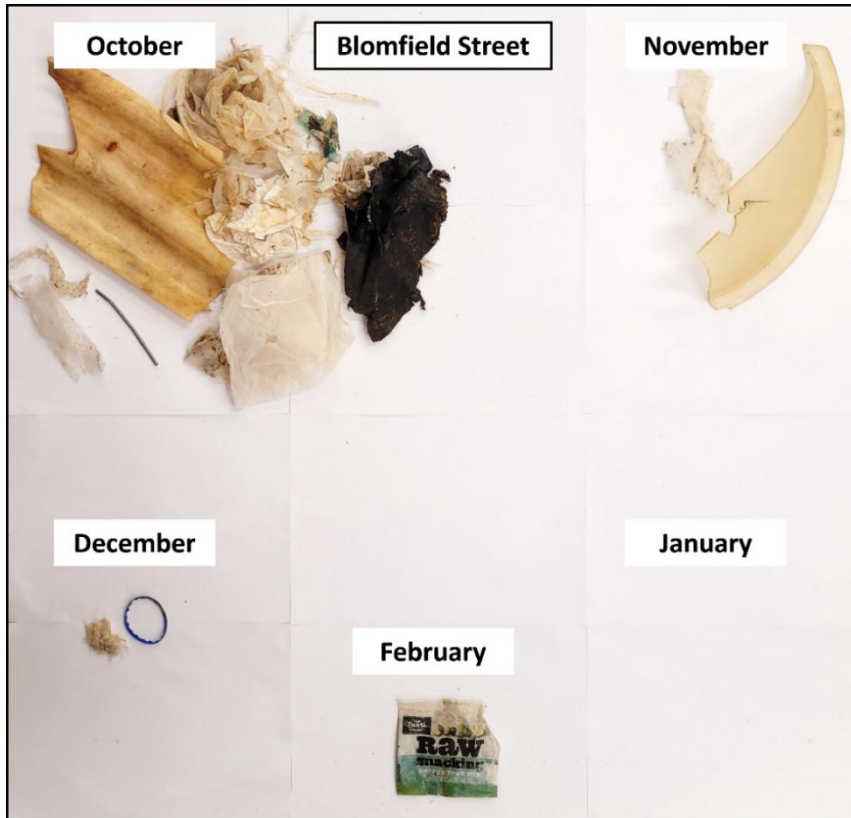


Figure 2.5. Images of collated plastic fragments collected at the Blomfield Street site. Plastic within each photo (site) is separated by month and labelled accordingly.



Figure 2.6. Images of collated plastic fragments collected at the Waingaehe Stream site. Plastic within each photo (site) is separated by month and labelled accordingly.



Figure 2.7. Images of collated plastic fragments collected at the Depot Street site. Plastic within each photo (site) is separated by month and labelled accordingly. Image a. = plastic from October sampling (site clear out). Image b. = plastic from monthly sampling.



Figure 2.8. Images of collated plastic fragments collected at the Owghata Point site. Plastic within each photo (site) is separated by month and labelled accordingly. Image a. = plastic from October, November, and December sampling. Image b. = plastic from January, and February sampling.



Figure 2.9. Images of collated plastic fragments collected at the Waiowhiro Stream site. Plastic within each photo (site) is separated by month and labelled accordingly.

A time series graph (Figure 2.10) plotted plastic fragment count over month (October - February). Count appeared relatively high across all sites, excluding the Headwater site where no plastic was found during three of the five sampling months. Across all other sites, 14 of the 30 data points recorded monthly count values between 5-20. November plastic count decreased for all sites except Waiowhiro Stream mouth which recorded the same plastic count as October (11). Across the December to February sampling period, there was no steady increase or decrease of plastic count, rather count per site varied every sampling period. Notable peaks occurred at Owkata Point mouth in December (30 plastic fragments), and Waiowhiro Stream mouth in January (22 plastic fragments).

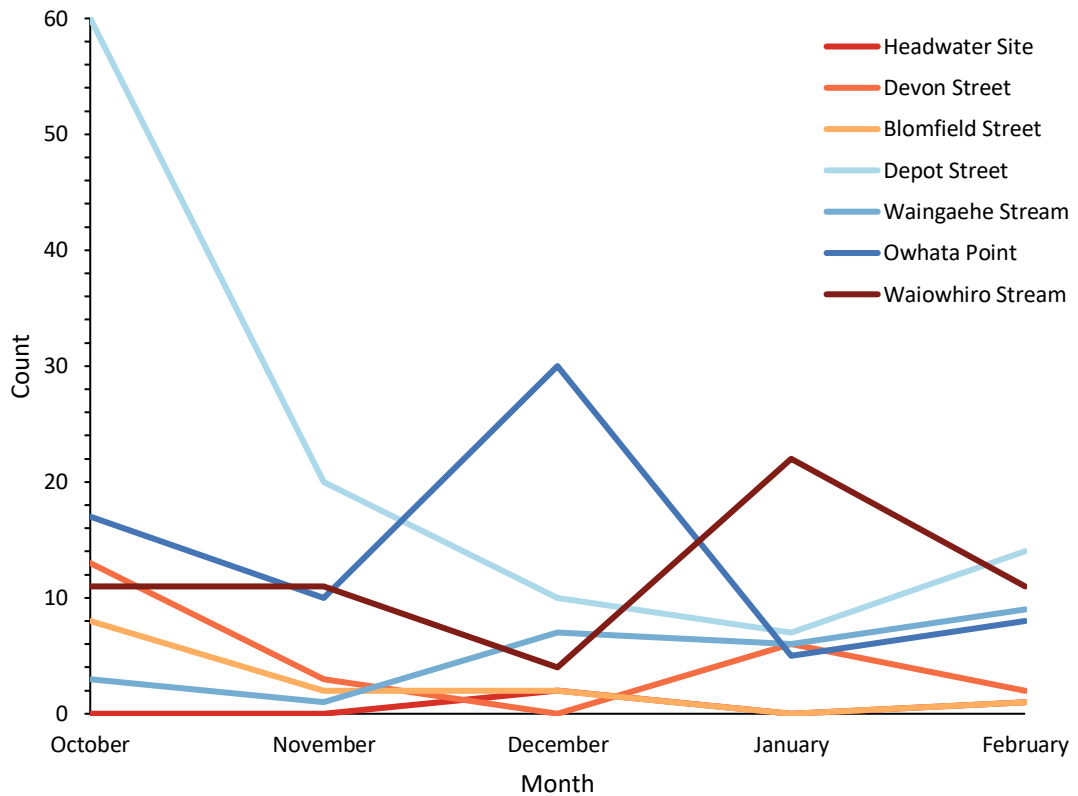


Figure 2.10. Time series graph plotting count (of plastic fragments) and month (October-February) for seven study sites (colour coded according to key).

A second time series graph plotted total plastic weight against month (October - February; Figure 2.11). Similar to Figure 2.10, October's Depot Street recorded a very high total weight of 2194 g. November showed a distinctive peak at Waiowhiro Stream mouth with the value of 522 g (Figure 2.11). December and January appeared to have peaks close in weight (Owhata Point (355 g) and Depot Street (300 g) in December, and Waingaehe Stream (350 g) and Depot Street (272 g) in January). The Headwater Site consistently recorded the lowest weight across months, with Blomfield Street following closely.

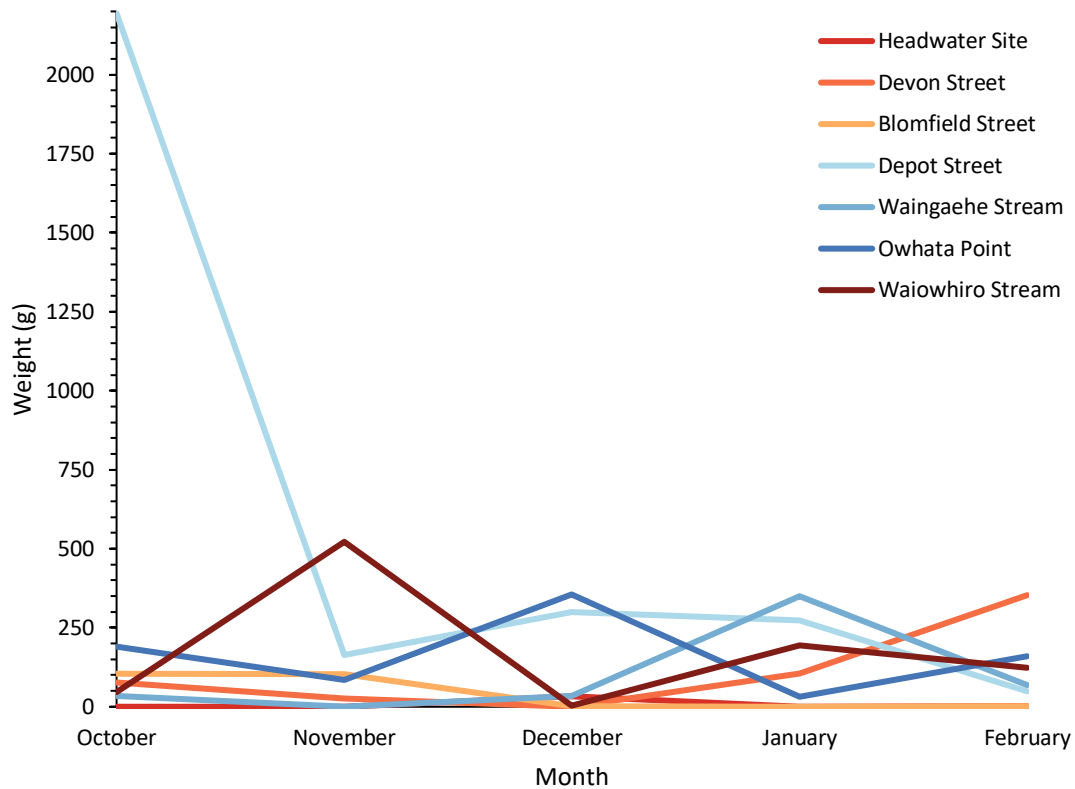


Figure 2.11. Time series graph plotting plastic weight (g) and month (October-February) for seven study sites (colour coded according to key).

The mean measurements for length (mm), height (mm), and width (mm) for the plastic collected at each site per month are displayed in Table 2.4. The mean values were paired with standard deviations. From length, height, and weight measurements, 100% of plastic fragments at the Headwater, Devon Street, Waingaehe Stream, Owhata Point, and Waiowhiro Stream mouth sites were within the macroplastic size range. Most plastic fragments at Depot and Blomfield Street sites fell within the macroplastic size class (110 of 111 fragments and 12 of 13 fragments respectively). The remaining fragments at both sites were within the mesoplastic size range. The greatest mean length occurred at Owhata Point during January sampling (721 mm), followed by Depot Street in February and Devon Street in November (291 mm). Over the sampling period, there was no trend in mean length, height, or width per site.

Table 2.4. Mean measurements of plastic fragments (length, height, width (mm)) and standard deviation for seven study sites per month.

Month		Site							Waiowhiro Stream
		Headwater Site	Devon Street	Blomfield Street	Depot Street	Waingaehe Stream	Owhata Point		
October	Mean length (mm)	0	167.9231	123.25	266.0333	31.3333	131.5882	86.3636	
	Standard deviation	0	144.12	148.6864	332.0872	27.1355	101.225	63.003	
	Mean height (mm)	0	108.6923	72.875	6.7	80.6667	24.7647	2.6363	
	Standard deviation	0	93.5301	92.1821	28.5219	121.8291	77.0807	6.0543	
	Mean width (mm)	0	0.7692	20.5	96.2833	46.6667	87.3529	73	
	Standard deviation	0	2.7735	56.7803	147.4604	14.1539	75.8287	50.4242	
	Mean length (mm)	0	290.6667	211	181.85	21	183.3	164	
November	Standard deviation	0	158.5696	90.5097	252.7857	-	125.6821	188.3194	
	Mean height (mm)	0	0	1.5	2.95	2	1	12.9091	
	Standard deviation	0	0	2.1213	4.7514	-	3.1623	18.5497	
	Mean width (mm)	0	158.3333	112.5	69.225	7	77.9	78.0909	
	Standard deviation	0	142.7772	17.6777	77.7652	-	78.0163	115.0534	
	Mean length (mm)	0	-	0	157.7	176.5714	112.7767	59	
	Standard deviation	0	-	0	106.021	90.7025	124.1511	59.7383	
December	Mean height (mm)	0	-	2	0.7	1.5714	29.4	0.5	
	Standard deviation	0	-	2.8284	1.4944	2.864	67.2297	0.5774	
	Mean width (mm)	45	-	35.25	96.8	62.8571	57.9367	338.5	
	Standard deviation	7.0711	-	47.7297	57.0045	47.8415	66.2579	28.712	
	Mean length (mm)	0	89.8334	0	126.6429	220.8333	721.2	71.0455	
	Standard deviation	0	94.364	0	68.1001	144.2878	1070.5677	82.2438	
	Mean height (mm)	0	30.4167	0	9.2857	4	0	17.4545	
January	Standard deviation	0	68.5466	0	16.4389	9.798	0	22.8749	
	Mean width (mm)	0	101	0	75.0729	107.8333	71.2	41.9545	
	Standard deviation	0	81.4371	0	48.8958	61.8301	69.3556	23.4388	
	Mean length (mm)	0	24.5	96	290.7143	109.909	121.125	148.8333	
	Standard deviation	0	34.6482	0	510.5931	85.4909	119.9219	81.628	
	Mean height (mm)	0	0	0	1.1786	46.1363	2.6875	20.3333	
	Standard deviation	0	0	0	2.3988	92.651	4.4154	57.6346	
February	Mean width (mm)	2	6	102	72.7143	66.5909	70.5625	54.6667	
	Standard deviation	0	8.4853	0	52.0197	42.7755	57.6984	37.021	

A bar chart was produced to plot plastic count against plastic type, specifically recyclable, non-recyclable/single use, and unknown (Figure 2.12). While ‘unknown’ had the highest count (130) across all sites and sampling occasions, ‘non-recyclable/single use’ plastic count (118) was 2.3x higher than recyclable plastics count (51). Majority of the seven study sites had a mixture of recyclable and non-recyclable polymers; however, the Headwater site was the only location to record only non-recyclable plastics (three LDPE fragments).

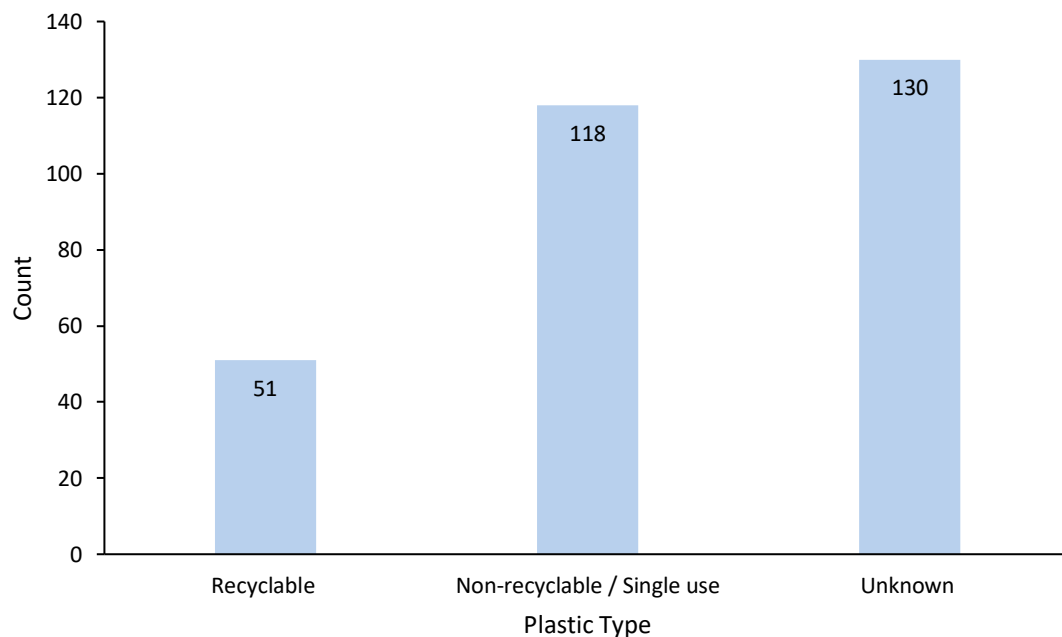


Figure 2.12. Bar graph plotting plastic fragment count (y-axis) against plastic type (x-axis), specifically recyclable, non-recyclable/single use, and unknown. Recyclable plastic count = 51, non-recyclable/single use plastic count = 118, unknown plastic count = 130.

Figure 2.13 plotted total count across all sites and sampling occasions against recycling/polymer code. Along the x-axis, the previously grouped recyclable and non-recyclable plastics (as seen in Figure 2.12) were split into the seven polymer recycling categories recognised in New Zealand. Of the 51 collected recyclable plastic pieces, 17 (33.33%) were PET (typically soft drink/water bottles), 5 (9.80%) were HDPE, and 29 (56.86%) were PP. Of the 118 non-recyclable plastics, 64 (54.24%) fell into the category of other (number 7 plastics).

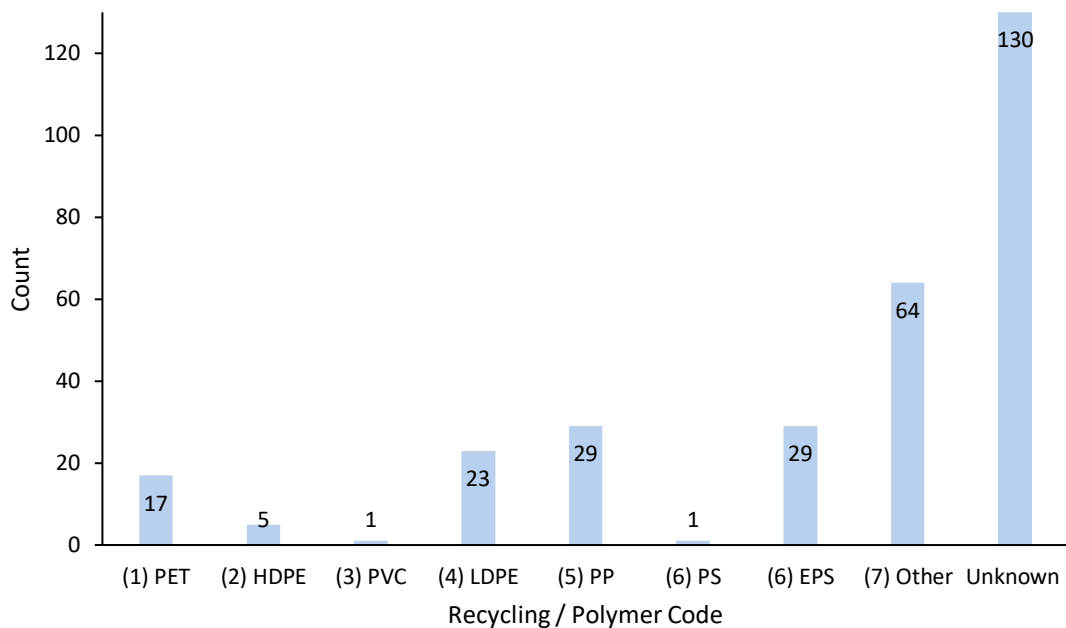


Figure 2.13. Bar graph plotting plastic fragment count against recycling/polymer code. Recycling codes are as listed in Plastics New Zealand Plastic Identification Code.

## Land Use

The composition of catchment land use type varied across the seven sample sites. From Figure 2.14, urban land use constituted a majority of the land use proportion for most study sites. Across the sites, urban land included residential, commercial, and industrial. Urban land at the Headwater, Devon Street, Blomfield Street, Waingaehe Stream, Owkata Point, and Waiowhiro Stream sites was residential land use, however, Depot Street urban land use was predominantly industrial land, with some sections of commercial intermixed. The Headwater and Owkata Point site both had 50% arable land within their catchment area, while the other five sites had 0% arable land. Devon Street however was dominated by parks/reserves land use (60%). The percentage of forested land use varied across catchments, with the Headwater and Owkata Point sites comprised of 20%, Waingaehe Stream with 25%, and the Waiowhiro Stream surrounding forested land encompassing 10%.

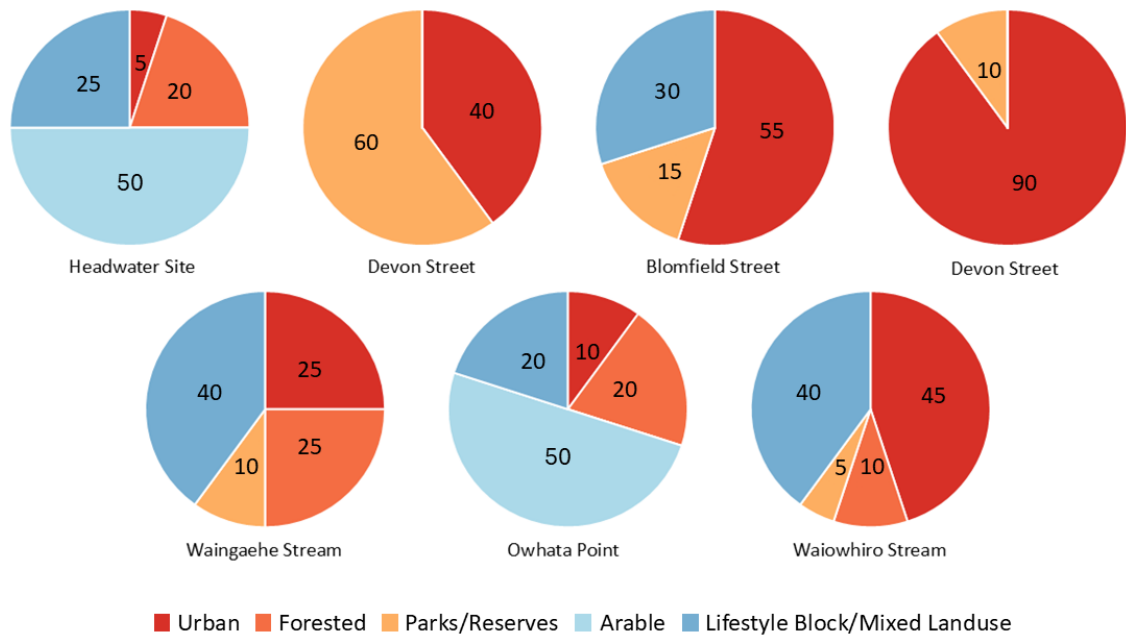


Figure 2.14. Pie graphs displaying land use percentage at seven study sites. Land use groupings include Urban = Red, Forested = Orange, Parks/Reserves = Yellow, Arable = Light blue, Lifestyle Block/Mixed Landuse = Blue.

### Land Use vs. Plastic Weight

The comparison between land use and plastic weight investigated the percentage of different land uses within sample sites (urban, parks and reserves, forested, arable, and lifestyle block/mixed land use) to determine if there was a relationship with plastic weight. The October Depot Street sampling event was removed from Figures 2.15-19 to reduce outlier effects and skews in data. Percent urban land use is displayed in Figure 2.15. All seven sites had a percentage of urban land use within their 200,000 m<sup>2</sup> catchment. The Headwater site and Owkata Point had  $\leq 10\%$  urban land use. Waingaehe Stream, Devon Street, Waiowhiro Stream, and Blomfield Street had between 20-60% urban land use in their immediate 200,000 m<sup>2</sup> catchment. Depot Street had the largest percentage at 90% urban land use. Once a catchment surpassed 10% urban land use, cumulative per site plastic weight dramatically increased (Figure 2.15). However, weight did not continue to increase with % urban land use, rather it remained consistently high wherever urban land was present.

Figure 2.16 presented the land use category parks and reserves. The Headwater, Blomfield Street, Depot Street, Waingaehe Stream, Owkata Point, and Waiowhiro

Stream sites all had < 20% parks and reserve land use within their 200,000 m<sup>2</sup> catchment. In Figure 2.17, the two land use categories of ‘exotic forest’, and ‘wetland’ were grouped together into the larger ‘forested’ category.

The findings of Figure 2.17 (% forested land use~plastic weight) was comparable to Figure 2.15 (% urban land use). Figure 2.18 (% arable land use) showed only two sites (Headwater Site and Owhata Point) as having arable land within their 200,000 m<sup>2</sup> catchment, both recording 50% arable land use. Figure 2.19 (% lifestyle block/mixed land use) showed a clear increase in plastic weight as % lifestyle block/mixed land use increased.

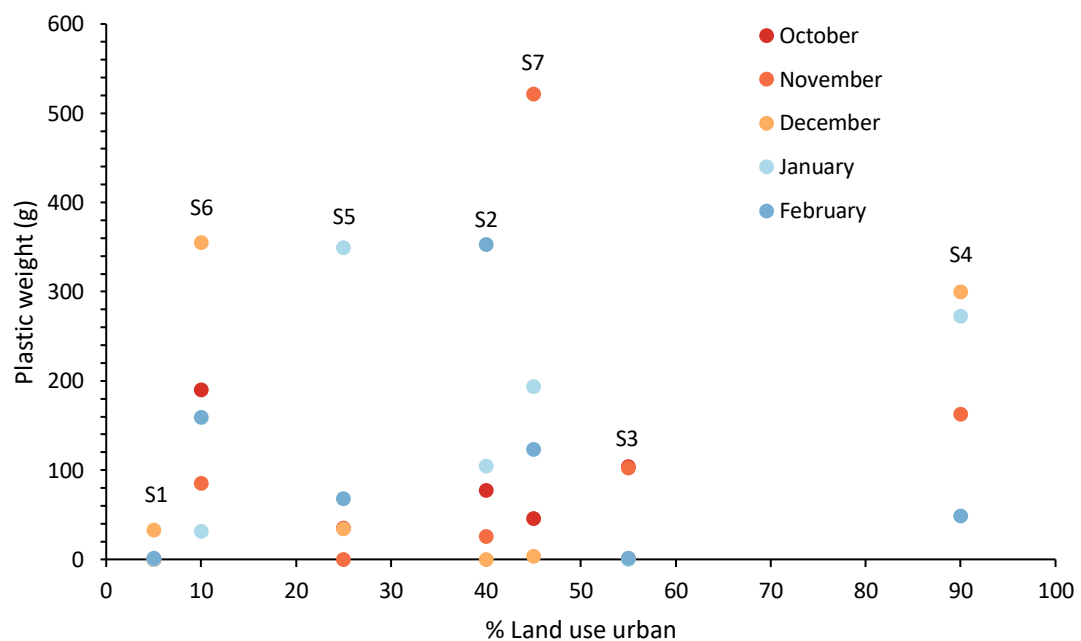


Figure 2.15. Scatter plot comparing plastic weight to % land use urban. S1 = Headwater Site, S2 = Devon Street, S3 = Blomfield Street, S4 = Depot Street, S5 = Waingaehe Stream, S6 = Owhata Point, S7 = Waiowhiro Stream. The five stacked dots per site indicate the five sampling events.

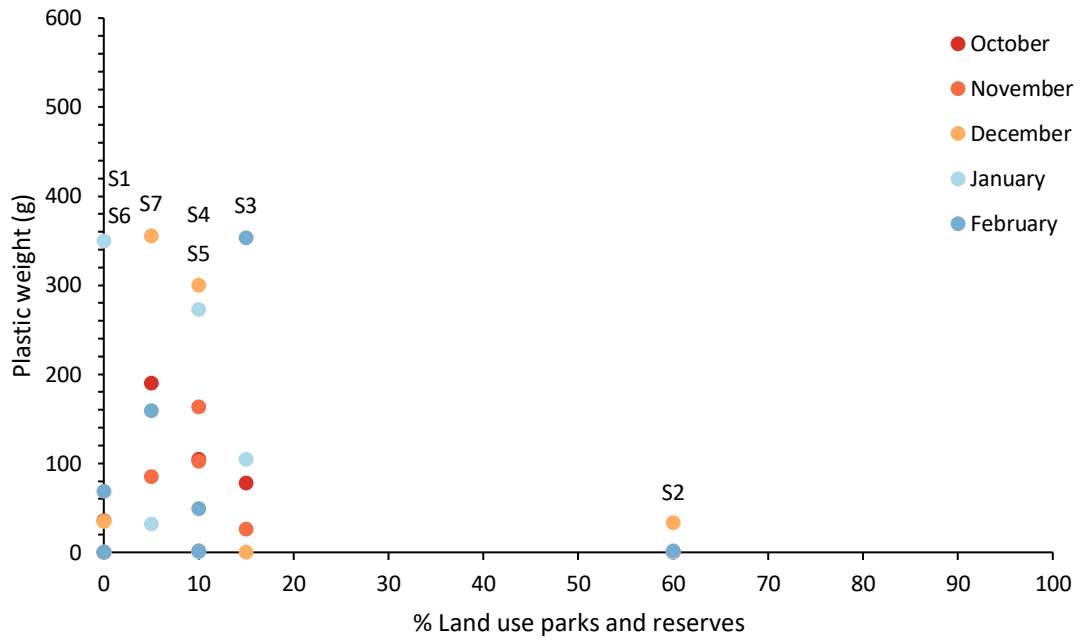


Figure 2.16. Scatter plot comparing plastic weight to % land use parks/reserves. S1 = Headwater Site, S2 = Devon Street, S3 = Blomfield Street, S4 = Depot Street, S5 = Waingaehe Stream, S6 = Owhata Point, S7 = Waiowhiro Stream. The five stacked dots per site indicate the five sampling events.

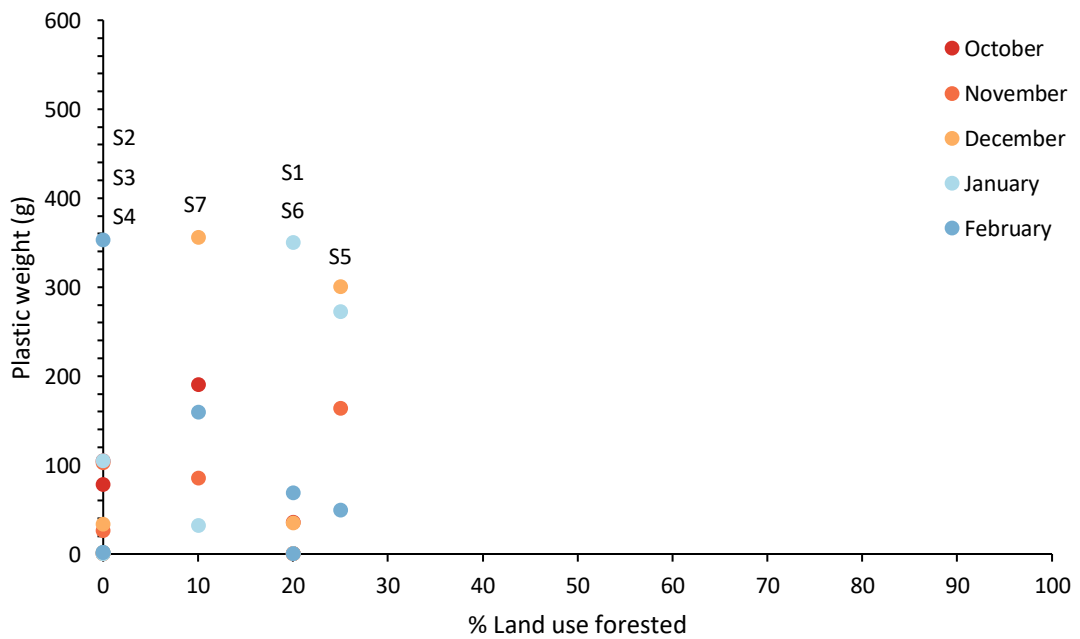


Figure 2.17. Scatter plot comparing plastic weight to % land use forested. S1 = Headwater Site, S2 = Devon Street, S3 = Blomfield Street, S4 = Depot Street, S5 = Waingaehe Stream, S6 = Owhata Point, S7 = Waiowhiro Stream. The five stacked dots per site indicate the five sampling events.

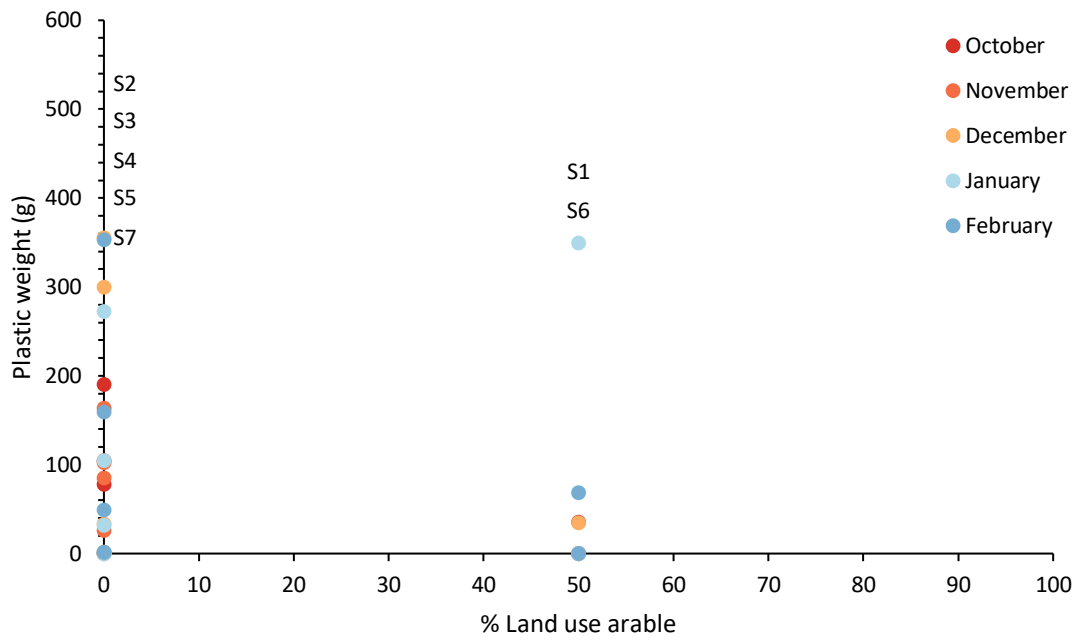


Figure 2.18. Scatter plot comparing plastic weight to % land use arable. S1 = Headwater Site, S2 = Devon Street, S3 = Blomfield Street, S4 = Depot Street, S5 = Waingaehe Stream, S6 = Owhata Point, S7 = Waiowhiro Stream. The five stacked dots per site indicate the five sampling events.

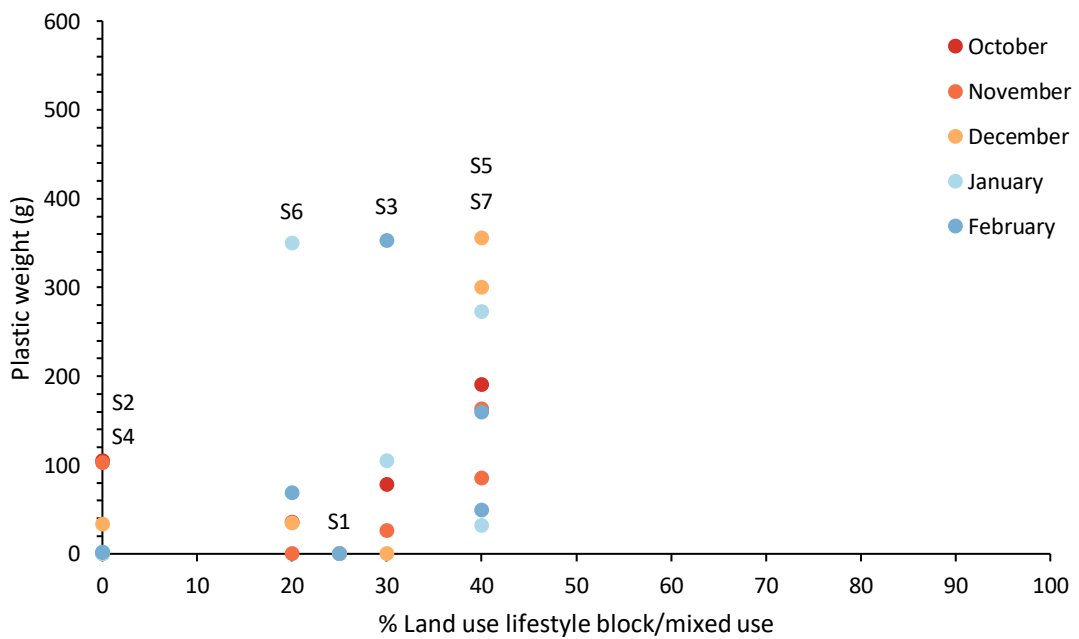


Figure 2.19. Scatter plot comparing plastic weight to % land use lifestyle block/mixed use. S1 = Headwater Site, S2 = Devon Street, S3 = Blomfield Street, S4 = Depot Street, S5 = Waingaehe Stream, S6 = Owhata Point, S7 = Waiowhiro Stream. The five stacked dots per site indicate the five sampling events.

## Statistics

ANOVA tests were conducted using R version 4.4.1 (R Core Team, 2024). The ANOVA comparing total (plastic) weight to site revealed no significant difference ( $p = 0.217$ ). An ANOVA comparing count (of plastic fragments) to site produced a statistically significant result ( $p = 0.0166$ ). A final ANOVA was used to test for temporal differences between (plastic) weight and month, results proved no statistical significance ( $p = 0.634$ ). A post hoc test using Tukey's HSD test (Abdi & Williams, 2010) was conducted to test pairwise comparisons for the significant results found with the ANOVA of plastic count and sites. From these results, there were statistically significant differences ( $p < 0.05$ ) between Depot Street and Blomfield Street ( $p = 0.0394$ ) and Headwater Site and Depot Street ( $p = 0.0179$ ). All other site comparisons were not statistically significant.

## DISCUSSION

Results drawn following the five-month sampling campaign answer the three research questions posed above.

### *Question 1. Is there a catchment influence of plastic input into Lake Rotorua?*

To determine if there was a catchment influence on plastic input, land use surrounding the seven study sites was investigated. From Figures 2.9-13, there is no consistent pattern, implying that overall, there is no strong relationship between land use and plastic. From observation during sampling, it appeared that plastic decreased further away from main city centres. However, the gathered data does not show a catchment influence on plastic input into Lake Rotorua, rather, plastic input is consistently high across all human involved land uses. As all sites studied were a combination of land uses, every site received some degree of human interaction. Contrary to the original hypothesis that land within the residential sector would contribute greater quantities of plastic pollution, the lack of statistical significance between (plastic) weight and site supports that varying catchment land use does not influence plastic input.

A study investigating microplastic pollution in Auckland (New Zealand) streams along an urbanisation gradient found similar results between human population densities and microplastic abundance (Dikareva & Simon, 2019). Although microplastics may behave differently in freshwater (such as how they disperse and their environmental interactions), studies on them can be used to infer information on the nature of general plastics, and subsequently may be relevant to meso- and macroplastics. As well as this, Dikareva & Simon (2019) found explanatory power between microplastic abundance and land use (residential land cover) to be low. Along the South African Crocodile system, Dalu et al. (2025) found no significant differences in macroplastic pollution across stream locations. These studies align with data from Rotorua stream studies, suggesting that the relationship between macroplastics and land use is often not significant (Dalu et al., 2025; Dikareva & Simon, 2019).

*Question 2. Is plastic being pushed ashore and buried by wave action near stream mouths after it has entered Lake Rotorua?*

With the common accumulation mechanisms of meso- and macroplastics, it was expected that these plastics would be detected in shoreline sediments. However, the sand sieving methodology yielded no plastic at any of the lake shore sites. This absence suggests that plastic is unlikely to be buried in sediments at these locations. Environmental factors like wave action, wind, and hydrodynamics can affect plastic movement within water bodies, ultimately affecting accumulation in sediments (Ghayebzadeh et al., 2023). Alongside this, the season (and corresponding weather conditions) during sampling affects abundance and distribution of mesoplastics in sediments (Ghayebzadeh et al., 2023). Mesoplastics are often buried in sand sediment on beaches (Jeyasanta et al., 2020), and their abundance may surpass macroplastics due to being missed during any cleanup activities (Jeyasanta et al., 2020). During sampling of the coastal estuarine system along the Atlantic coast of Ondo State, Nigeria, Olanipekun et al. (2024) saw greater total abundance of plastic particles in surface waters during wet seasons, likely due to increased stormwater and surface run-off. Conversely, mesoplastic abundance in sediments was greater in dry seasons as lower flow rates enabled plastics to settle (Olanipekun et al., 2024).

The absence of plastic in Rotorua shoreline sediment samples is likely a reflection of the limited spatial extent of sampling, rather than a true absence of shoreline deposition. As only the 50 m either side of the stream mouth was sampled, it is possible that burial onshore was happening further from the stream mouth. Conversation with residents of the Ohinemutu suburb of Rotorua city reported large masses of plastic washing ashore on the Eastern shoreline of Lake Rotorua. A more comprehensive study would be needed to investigate this, and to delve deeper into this research question, but within the scope of this study plastics were not observed re-entering the terrestrial environment via wave action and onshore burial.

*Question 3. What are the most common polymer types being captured/transported through the stormwater stream system?*

Analysis of data revealed 169 known plastic fragments from the monthly stream sampling over October 2024 - February 2025. Of the 169 known plastics, 51 were the recyclable types of 1, 2, or 5 (PET, HDPE, and PP, respectively). In comparison, 118 of the 169 known plastic fragments were non-recyclable or single use plastics (types 3 (PVC), 4 (LDPE), 6 (PS & EPS), or 7 (other)).

#### *Polymer Composition and Recycling Implications*

Within the plastic waste stream (the flow of end-of-life plastics) the most commonly found polymers are PP and PE (Lahtela et al., 2019). PP (type 5 plastic) is recyclable within New Zealand. From their global literature review, Cera et al. (2022) found PP to be among the most frequently found macroplastic polymer in lakes. Additionally, Andrade-Muñoz et al. (2025) found single-use plastics (PP, PET, HDPE, and LDPE) to be the most abundant plastics within Patagonia urban waterways. Of the recyclable plastics found within Rotorua stream sampling, PP was the most abundant. The presence of these plastic films within Rotorua streams, which commonly originate through commercial and domestic activities, reemphasise inadequate disposal practises (Andrade-Muñoz et al., 2025). These findings highlight the need for more effective plastic diversion systems, especially ones which target commonly used and recyclable polymers.

As of 1 July 2023, New Zealand banned or phased out various single use plastics, including produce bags, plates, bowls, cutlery, produce labels, and straws (Ministry for the Environment, 2023). Alongside this, 1 February 2024 marked the start of a nationwide shift to standardise recycling (Wise Move, 2024). Following recycling standardisation, only type 1, 2, and 5 plastics are viable for collection in kerbside recycling. Plastic bottles larger than four litres, small lids or bottle caps, bread tags (items under 50 g), and biodegradable or compostable plastics such as bottles are not kerbside recyclable as they are either too large or too small for sorting machines or not appropriate (RecyclingRules.nz, n.d.; Wise Move, 2024). Such nationwide regulatory changes are significant but also highlight the ongoing challenges of plastic waste stream management, such as how commonly found plastics in the Rotorua streams still appear to evade effective capture and disposal.

The plastic polymers considered recyclable in New Zealand degrade at different rates. Petroleum-based polymers degrade slower in marine environments than in landfills due to lower dissolved oxygen concentrations and ambient temperatures (Chamas et al., 2020). However, prolonged exposure to environmental conditions will weather plastics and cause fragmentation into smaller particles (Chamas et al., 2020). Degradation of PET in the environment is amplified by thermal-, and photooxidation, and hydrolytic cleavage (splitting of compounds by H<sub>2</sub>O addition) (Chamas et al., 2020). HDPE is a grade of polyethylene plastic that is denser and more rigid than PE (Brenner, 2022). Literature analysis by Chamas et al. (2020) found that average degradation rates of HDPE are higher in marine environments than on land. Lastly, as PP is a semi-crystalline polymer, the polymer degrades or fragments into microplastic at a faster rate (~3x higher) than other polymers such as PS (Nakatani et al., 2022). It is important to note that the studies referenced here refer to polymer degradation in marine environments and are included under the assumption that degradation rates would be similar in freshwater (as opposed to rates in landfills or other terrestrial environments). It is likely that polymer degradation rates influence the persistence and distribution of recyclable plastics within Rotorua streams and within Lake Rotorua. Therefore, it seems necessary to consider specific polymer environmental behaviours, like degradation rates, when designing plastic mitigation and management strategies.

Non-recyclable plastic bags, which are now banned throughout New Zealand, are commonly composed of PE. Interestingly, sampling at the Depot Street site recorded 10 plastic bags during sampling. It is important to note that, due to the degraded nature of the plastic bags (i.e. tearing apart during their extraction from streambank vegetation (e.g. blackberry)), it was hard to define the exact quantity of plastic bags. The bag fragments were therefore condensed into one mass and then weighed. Due to this, it is likely that the actual count of plastic bags at this site exceeded 10. Nonetheless, the presence of plastic bags within the stream environment, when they were banned and removed from circulation years prior, suggests that plastics must be accumulating within the stormwater system for some time, or are still being used from old stockpiles. These conventional petroleum-based polymers are resistant to biological degradation, meaning they will not be broken down by microorganisms and will remain in the environment as a pollutant (Teixeira et al., 2023). Additionally, the discovery of VHS tapes, also at Depot Street, confirm that plastics can persist in the stream environment for long periods. Unlike the plastic bags which deteriorated upon extraction, the VHS tapes were intact and not noticeably worn down but were lodged with sediment. VHS tapes are primarily made up of PP, so if correctly dismantled they can be recycled. The presence of recyclable plastics within the stream/stormwater system suggests there may be a gap in the recycling process. Whether this is due to improper disposal, and/or individuals not following correct recycling procedures is unknown, but nearly all plastics entering the stream are no longer recyclable due to contamination as plastics need to be clean and dry for processing at recycling centres.

#### *Plastic Transport and Accumulation in Rotorua Streams*

The combined total plastic weight collected over the five-month sampling period can be extrapolated to provide an estimate of how much plastic might be entering Lake Rotorua over 12 months (one full calendar year). The combined total five-month plastic weight equals 5,982 g (5.98 kg). When extrapolated out, this gives a theoretical value of 14,356 g per year (14.36 kg). This value is produced to estimate only the seven sample sites, and it is reasonable to assume that the total weight of plastic entering the lake from every inflow exceeds this value. Moreover, this value includes data from the October sampling period (which acted as a site cleanout) where all plastic that had accumulated was

captured. The period contributing to this initial accumulation is unknown. However, findings from this study and the discharge data (BOPRC, 2025) suggest floating plastics would have flushed through the system and this plastic accumulation consists almost entirely of trapped or submerged plastics. Lastly, as data was gathered over late Autumn through Summer, plastic flow may change over Winter and Spring. The quantity of plastics entering the lake via the stormwater system could be affected by less human traffic during the low tourist seasons or by increased precipitation during those months.

While monthly sampling did capture the plastic accumulating within the stormwater system, it is reasonable to assume that the data is an underrepresentation of total plastic within the system. As no nets or structures were put out and left *in situ* in between sampling periods, the methodology used likely missed highly mobile floating plastics that were flushed through streams in between sampling periods. As well as this, the study sites investigated in this research are only a subset of streams and inflows to Lake Rotorua, so overall plastic debris loading into the lake will be greater. Supporting this, river and stream discharge data was found through the Bay of Plenty Regional Council Environmental Data Portal for location EK378429 – Utuhina at Depot St. This data was used as a proxy for all the sample sites due to the close physical location of sites and assumption of shared weather conditions. From the stream discharge data, peaks were revealed where plastic flushing may have occurred. Monthly average stream discharge remained within the 1.3-2 m<sup>3</sup>/s range (October 2024 – February 2025) (Bay of Plenty Regional Council (BOPRC), 2025). Maximum discharge flows (m<sup>3</sup>/s) (peaks) occurred on October 3 (16.581 m<sup>3</sup>/s; 20 days before sampling), November 15 (9.700 m<sup>3</sup>/s; 2 days after sampling), December 26 (7.408 m<sup>3</sup>/s; 3 days after sampling), January 26 (7.710 m<sup>3</sup>/s; 3 days after sampling), and February 28 (2.747 m<sup>3</sup>/s; 4 days after sampling; BOPRC, 2025).

Understanding the sources and transport mechanisms of plastics in urban streams is critical to interpreting observed plastic distributions within the Rotorua stormwater system. However, it can be difficult to determine whether plastic in streams was directly deposited by humans, or if it was transported by wind or the downstream flow (Dalu et al., 2025). Distribution of plastic in streams may also differ with changing stream

composition and conditions (Gallitelli & Scalici, 2022). Pools may act as semi-permanent storage zones where plastics sink and accumulate, until flushed by a heavy flow event (Gallitelli & Scalici, 2022). Vegetation and organic material may block or influence the flow of macroplastics in streams (Gallitelli & Scalici, 2022). However, as all plastic originates from humans, population centres within urban areas are considered the key driver of plastic pollution within streams and waterways (Andrade-Muñoz et al., 2025). Although this study did not directly assess these drivers, the lack of any clear relationships with land use suggests that factors like stream hydrodynamics, rainfall induced flushing events, and local landscape composition may influence large plastic distribution within the Rotorua stormwater system.

### **Limitations**

A notable limitation of this study was the process of manual wading to collect the plastic debris. In accordance with health and safety, water was only waded in where it would not exceed wader height (chest height). Because of this precaution, plastics that may have been in these deep areas were not collected. Where this occurred, and where possible, visual inspection from the shoreline and streambeds were undertaken. In some instances, namely Waiowhoro Stream, large plastic objects (e.g. bottles, sports balls) were identified floating on the surface in heavily vegetated areas. These observations emphasise that the true extent of plastic pollution within the Rotorua stream system may be underestimated, especially in deep or heavily vegetated areas inaccessible for manual sampling.

As well as this, due to time restraints, polymer identification was restricted to visual identification. During data processing, unidentifiable plastic fragments tended to include things that were not discernible and ambiguous plastic films and objects. Future studies could employ methods such as Fourier-transform infrared spectroscopy (FTIR) to identify the polymers of unidentifiable plastic fragments (Villegas-Camacho et al., 2024). This method has been used previously and an existing open repository of PET, HDPE, PVC, LDPE, PP, and PS spectra are available for comparison (Villegas-Camacho et al., 2024). This would improve the accuracy of plastic polymer classification and enhance

understanding of their environmental fate and recyclability within Rotorua streams and within the lake itself.

A follow-up of this study could sample plastics over a greater seasonal variation to investigate what differences this may have on plastic flow through the stormwater system. It would also be recommended to modify the sampling methodology through implementation of a non-powered vessel (kayak, etc.) to sample reaches of stream too deep to wade. This would enable study sites to be diversified, and to include previously inaccessible sample sites (Utuhina Stream mouth).

## **Conclusion**

Overall, plastic debris was consistently found at a majority of the seven sample sites in the Rotorua stormwater streams across October 2024 - February 2025. Immediate catchment land use was found to not affect plastic input, and instead plastic loading was high across land uses. Polymer identification revealed a combination of recyclable (PET, HDPE, and PP), and non-recyclable/single-use plastics (PVC, LDPE, PS, EPS, and Other) in streams, with non-recyclable/single-use plastics more than doubling the quantity of recyclable plastics.

Ultimately, whether plastics are recyclable or not, or what land use they are occurring from is not the core issue. What matters is the pervasive abundance of plastics throughout Rotorua streams. The environment is not capable of enduring such plastic pollution and, without positive human change, the issue will only worsen.

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## **CHAPTER III**

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# **A Critical Review of Cleanup Methodologies in Urban Stormwater Management**

## ABSTRACT

While plastic is widespread throughout the environment, it is often overlooked as a contaminant in freshwater systems. Plastics in marine settings and microplastic (<5 mm) in general are well studied in comparison to the effects of freshwater meso- (5 mm – 2.5 cm) and macroplastic (> 5 mm) pollution, including its lifecycle, and what methods of removal are effective. This review examined plastic cleanup methodologies, with particular focus given to cleanup devices – booms, receptacles, and watercraft vehicles. Literature informed suggestions of device suitability to the Rotorua streams case study. Adaptation of capturing devices within existing literature to Rotorua-specific suitability criteria revealed booms and boom-receptacles to be suited to the stream study sites. Stormwater traps (a receptacle derivative) should be used in combination with *in situ* devices to effectively capture plastics both before and after entry into streams. Ultimately, a combination of methodologies is recommended to tackle plastic pollution in freshwater systems. Methods should include preventative action (education, increased awareness, and shifts away from single use plastics), minimisation (community initiatives, and upstream capture (stormwater traps)), and downstream capture (*in situ* devices).

## **INTRODUCTION**

Plastic pollution is ubiquitous within the environment and is often introduced into the environment through ineffective waste management strategies and human littering. Within riverine systems, macroplastics (>5 mm; Blettler et al., 2018) constitute the dominant proportion of plastics (Buschman et al., 2024). Historically, rivers and lakes have been considered only as channels for plastic to enter the marine environment, but now freshwater ecosystems are being acknowledged as sinks for plastic debris (Hoellein & Rochman, 2021).

### **Plastic in the Environment**

Plastic is remarkable in that it can be recycled and reconstituted into something new. However, not all plastic possesses this capability, and when it is discarded and improperly disposed, any recycling potential is lost (DeYoung et al., 2023). Improper disposal results in plastic in the environment. Approximately 80% of plastic in aquatic bodies (marine and freshwater) originates from land-based sources (Driedger et al., 2015; Kozikowski & Corcoran, 2024), including stormwater runoff within urban areas, anthropogenic litter, and ineffective waste management systems (Kozikowski & Corcoran, 2024). Within urban areas, the abundance of impervious surfaces allows plastic debris to be transported through stormwater where it ultimately enters catchment ponds, lakes, and/or rivers (Kozikowski & Corcoran, 2024).

The fate of plastics can vary once it enters the environment. Because freshwaters may act as both sources and sinks of plastic (Hoellein & Rochman, 2021; Bergmann et al., 2023), it is important to understand the plastic characteristics and mechanisms that influence where plastic accumulates and deposits, how it degrades, and how permanent it remains in freshwater systems. These plastic characteristics and mechanisms include polymer type, size, shape, density, as well as biofouling, and water hydrological characteristics of the receiving water body (Winton et al., 2020). With different origins, composition, and size, every plastic fragment entering freshwater interacts with the environment differently (Kozikowski & Corcoran, 2024). Over the period 1950-2015, an estimated

79% of plastics created were sent to landfill or discarded into the environment (Hoellein & Rochman, 2021). Of the plastic waste entering the environment, water bodies receive a significant proportion (~50%) (Fraga Filho, 2025). Plastic fragments and particles in water can be up taken by all organisms, thus polluting the food chain at every level, and harming freshwater ecosystems (Fuchs et al., 2024).

As plastics can be found throughout interconnected hydrological networks (Barnes et al., 2009), it is important to determine how they enter water systems and how to capture them before degradation occurs. Depending on the composition and presence of additives or plasticisers in plastics, rates of fragmentation and degradation in freshwater will vary (Hennebert, 2022; Hines et al., 2023; Nikiema & Asiedu, 2022). When plastic is captured early within the fluvial system, further downstream travel to other systems can be prevented or at the very least minimised. *In situ* capturing devices are one method of cleaning up waterways. This chapter presents a systematic literature review of current plastic cleanup methodologies, with particular focus given to *in situ* capture devices, and community-centred clean-up strategies. Across the review, emphasis is placed on suitability of existing plastic capture technologies in freshwater systems, specifically streams. Moreover, the primary objective is to assess which devices are the most suited to implementation in Rotorua urban streams considering hydrological, logistical, and environmental conditions. From this review, recommendations will be made for practical and context-appropriate solutions.

## **METHODS**

### **Literature Review**

Literature searches were conducted using a Boolean search string on the public access database Google Scholar, with a set date range of 2000-2025. Two searches were conducted to capture literature related to macroplastic in the environment, as well as capture devices for freshwater systems. The first search included the keyword string [macroplastic AND freshwater AND lakes or rivers AND capture or “capture devices”]. The second keyword string was [macroplastic AND water AND booms AND receptacles

AND “watercraft vehicles”]. Marine focused literature was included in this second search. While mesoplastic was not explicitly included as a keyword, literature identified from the two searches included discussion around mesoplastic. Literature commonly referenced throughout the publications (but were not identified through the keyword string searches) was included within the review to ensure a comprehensive overview of the topic. The resulting literature was also examined for information regarding plastic composition. Some literature within the ‘community based cleanup’ section was searched for independent of keyword searches to support the review. This expanded the search and included literature on areas such as citizen science, circular economies, and community initiatives. All literature reviewed was published or otherwise readily available and in English. Publication types include journal articles, books, websites, PhD theses, and conference papers. Exclusion criteria for the literature included publications that were focusing on microplastics, double up results, and literature in different languages.

### **Assessment of Rotorua Device Suitability**

Review of capturing device suitability was made within the context of the seven stream study sites that flow into Lake Rotorua. These included the Waingaehe Stream mouth, the Owkata Point Stream mouth, the Waiowhiro Stream mouth, and the Headwater, Devon Street, Blomfield Street, and Depot Street sites located along the longitudinal gradient of the Utuhina Stream/Mangakākahi Stream tributary. Detailed study site descriptions are available in the Materials and Methods section of Chapter II under subsection ‘Site Description’. The key site assessment criteria variables are provided in Table 3.1.

The plastic capturing devices were sourced from Helinski et al., (2021), who comprehensively reviewed plastic capturing devices across various aquatic systems and created a broadscale device suitability selection outline. However, existing information was adapted, and devices were tested against criteria specific to the Rotorua study sites.

All devices were assigned suitability scores against each criterion. Only devices listed as ‘in use’ (I) or in ‘pilot testing’ (P) in Helinski et al., (2021) were reviewed. Devices with insufficient data regarding Rotorua-specific criteria were omitted. Information on device cost can be found in Helinski et al. (2021).

*Assessment categories for each criterion*

1. Ability to capture meso- and macroplastics:

Devices must be able to capture plastics  $\geq 5$  mm. This information was either explicitly stated on device/organisation websites or was inferred through device design (e.g. solid floating bar with no visible holes or mesh). Devices scored 1-3, where 1 = low suitability, 2 = medium suitability, and 3 = high suitability.

2. Ability to capture surface plastics:

Devices should be designed to skim water or float at the surface, as opposed to devices being designed to target sunken plastics. Information found across devices websites (often videos showing device operation) informed effectiveness of devices at capturing surface plastics. Devices scored 1-3, where 1 = low suitability, 2 = medium suitability, and 3 = high suitability.

3. Suitability in turbulent conditions:

Devices should be suited to flowing water with variable flow, and not designed for use in “calm, consistent waters” (harbours, mariners, etc.). All Rotorua study sites experience variable flow (Table 3.1), with peak flow flushing events occurring regularly. Devices scored 1-3, where 1 = low suitability, 2 = medium suitability, and 3 = high suitability.

4. Suitability in shallow waters:

The seven Rotorua study sites were all described as shallow. As no section of stream overtopping water height ( $\sim 110$  cm) was sampled, the maximum depth regarding device

suitability to shallow waters was 110 cm (Table 3.1). Devices should be adjustable, customisable, or surface floating. Devices scored 1-3, where 1 = low suitability, 2 = medium suitability, and 3 = high suitability.

#### 5. Suitability in narrow channels:

Rotorua study streams were narrow (Table 3.1). Devices should be adjustable to site specifications (width). Devices should not be designed for expansive waters (mariners, ports, etc.). Devices scored 1-3, where 1 = low suitability, 2 = medium suitability, and 3 = high suitability.

#### 6. Ongoing maintenance requirements:

Maintenance requirements included operational needs, such as human operation, and disposal of accumulated waste. Energy and electricity requirements were also considered. Devices scored low (L), medium (M), or high (H).

*Table 3.1: Site descriptive variables used to inform assessment criteria. Depth scored 1-3. 1 = 0-40 cm, 2 = 41-70 cm, 3 = 71-110 cm. Width scored a-d. a = 1-2 m, b = 2-3 m, c = 3-4 m, d = >4 m.*

Site	Depth	Width
Headwater Site	2	c
Devon Street	3	b
Blomfield Street	1	a
Depot Street	2	c
Waingaehe Stream	2	c
Owhata Point	2	a
Waiowhiro Stream	3	d

## RESULTS AND DISCUSSION

The two keyword literature searches collectively produced 46 results (Appendix 3.1). The first search initially yielded 31 publications. After removing irrelevant results, only 10 were further reviewed. Notably, this first search excluded marine focused literature. The second search produced 15 results, of which 10 were new (not found from the prior

search) and two were deemed relevant. All literature reviewed from these searches were open access or available through institutional log-in. Literature produced across both searches (that was used within the review) included Helinski et al. (2021), Brouwer et al. (2023), Fraga Filho (2025), Keisling (2021), and Bergmann et al. (2023).

Literature findings were grouped into four sections as described below:

### **1. Plastic Composition**

Developing an understanding of plastic composition and degradation processes is essential to evaluating the challenges of *in situ* capture in urban streams. Plastic is durable and strong. It is light, easily manipulated, and has uses across all sectors (Nikiema & Asiedu, 2022). Plastics are divided into two groups – group I and group II (Pathak et al., 2023). Group I plastics have a polymer backbone of carbon-carbon bonds, whereas group II plastics contain non-carbon atoms (Pathak et al., 2023). Group II plastics contain chemical linkages similar to those found in nature, so enzymatic breakdown of plastics can occur, however, carbon-carbon bonds lack such linkages and points of ‘attack’, so fragments must first be oxidised before any breakdown can occur (Pathak et al., 2023). Many plastics contain additives or plasticisers that improve specific qualities, like thermal resistance/flame retardants, and flexibility (Hines et al., 2023). Composite materials such as inclusion of plasticisers complicates recycling processes (Hennebert, 2022). Some plastics, mainly PVC and PU, contain plasticisers used in hazardous concentrations (Hennebert, 2022). Addition of chemical additives makes plastics more resilient, in turn making them a marked environmental threat when improperly discarded (Hines et al., 2023). Inadequate waste management, including fragmentation, weathering, and landfilling, leach these hazardous substances into the environment (Hennebert, 2022).

Fragmentation occurs when plastic is exposed to environmental factors, mechanical degradation (wetting/drying, heating/cooling), atmospheric and instream pollutants, UV exposure (photodegradation), and thermo-oxidative degradation (Nikiema & Asiedu, 2022). Plastics fragment at different rates and into different shapes (Nikiema & Asiedu, 2022). Typically, plastics fragment at a rate of 1-3% weight per year in water, with photo- and mechanical degradation being the greatest drivers of this rate (Nikiema & Asiedu,

2022). These characteristics affect how plastics behave in freshwater systems and therefore affect the suitability and design requirements of *in situ* capture devices. The five-month sampling campaign revealed large, intact plastic items within Rotorua streams, particularly within vegetated and low flow zones. The slowing of plastic transport and potential slowing of fragmentation within these environments creates an opportunity for collection to occur before plastics degrade. Therefore, *in situ* capture strategies could be enhanced by targeting their implementation to these accumulation zones, where large plastics are often retained.

## **2. Plastic Capturing Devices**

To prevent further breakdown of plastics into microplastics, plastic should be removed from the system. Removing plastics while they are moving through stream tributaries is easier than after they have entered large, deep lakes. Plastic capturing devices are comparably well researched and implemented within the marine space. The vast openness and depths of marine environments facilitates the implementation of large capturing structures, vehicles, and devices. However, within freshwater, especially streams and rivers, depth, width, and natural flow regimes restrict device suitability. The fundamental design of plastic capturing devices aims to either collect existing plastic from waterways or prevent plastic from entering waterways entirely (Schmaltz et al., 2020). To assess what method may be best suited to Rotorua riverine locations, the following major types of plastic cleanup technologies will be reviewed below: booms, receptacles, and watercraft vehicles (Fraga Filho, 2025). Additionally, stormwater traps will be reviewed as a subset of the receptacle category.

### *Booms*

A boom is a barrier that prevents the downstream flow of debris (plastic) (Brouwer et al., 2023; Helinski et al., 2021). They constitute the largest category of independent devices, as stated in Helinski et al. (2021). Booms are often situated near river mouths to prevent plastic ingress into lakes or oceans (Brouwer et al., 2023), the adjustable design of booms allows them to withstand varying debris loads and be manipulated to function across different site and water conditions (Helinski et al., 2021; Nikiema & Asiedu, 2022).

Booms capture plastics travelling on the water surface, however they are an ineffective technology for sub-surface plastics (Nikiema & Asiedu, 2022). Regarding maintenance, booms require checking approximately fortnightly, however, unlike other devices, booms do not require energy for operation (Brouwer et al., 2023). In turbulent waters booms last 3-5 years, but in calmer water can last upwards of 10 years (Nikiema & Asiedu, 2022). River booms have been successfully implemented worldwide, including the ‘Clean River Project River Boom’ (Clean River Project, n.d.) in the United States of America, the ‘Bandalong Boom’ (Bangalong Boom Systems, n.d.) in Australia, The ‘Litterboom Project’ (The Litterboom Project, n.d.) in South Africa, and the ‘Plastic Fischer Trash Boom’ (Plastic Fischer, n.d.) in Germany (Schmaltz et al., 2020).

Booms are often designed with skirt attachments that suspend downwards into the water column to capture debris (Wenchao et al., 2023). Barriers are similar to booms, but they tend to be built of harder materials – chain-link fencing, metal bars, etc., and are semi-permanently anchored to the riverbed and shoreline (Wenchao et al., 2023). Debris captured within booms (and barriers) needs to be removed, either manually, or by other devices like skimmers or excavators (Wenchao et al., 2023). For many devices, availability of maintenance labour is the limiting factor to implementation (Helinski et al., 2021).

### *Receptacles*

A receptacle is a container that captures and retains debris (Helinski et al., 2021). They are stationary and typically anchored or mounted on a floating platform (Helinski et al., 2021). Receptacles use trapping mechanisms driven by suction pumps or natural water flow (Helinski et al., 2021). Passive receptacles do not require an energy input, but during period of low/slow water flow, debris collection rate may slow (Wenchao et al., 2023).

‘The Great Bubble Barrier’ uses air bubbles produced by pumping air through a perforated pipe situated on the bottom of stream, river or other type of waterway to create a curtain of bubbles that intercepts plastic debris and directs it towards a receptacle

(Wenchao et al., 2023). The bubble barrier works by creating an upward current which influences the flow of plastics in the water body (Wenchao et al., 2023).

Sea bins float within the water column – half submerged with an opening at the top to allow inflow of plastics (Nikiema & Asiedu, 2022). The bins trap plastic fragments 2 mm and greater via a filter bag inside which allows free flow of water (Nikiema & Asiedu, 2022). However, recommendations for sea bins state to situate them in calm waters near a power source (Nikiema & Asiedu, 2022), so they are likely ill-suited to placement in dynamic riverine systems.

### *Watercraft Vehicles*

A watercraft vehicle is a buoyant structure on or in water that collects debris (Helinski et al., 2021). Watercraft vehicles may include skimmers that collect (skim) plastic from the water surface, and dredgers that collect plastic from the bottom of a water body (Brouwer et al., 2023), as well as conveyor belts, nets, vessels, and robots (Wenchao et al., 2023). Conveyor belts and nets are like skimmers, in the sense that they collect floating plastic from the water surface (Wenchao et al., 2023). Vessels tend to be human operated, and are thus suited to larger water bodies, where navigation of vessels is possible (Wenchao et al., 2023).

The scale of cleanup initiatives influences device suitability. For stream or river cleanups, larger vessels (i.e. boats able to carry passengers) may be impractical. Small-scale watercrafts, like remote control vehicles, may be better suited in these situations due to their flexibility (Wenchao et al., 2023). Robots, and similar digital technologies, are generally thought to be within the top-ranking solutions for plastic management in the future (Wenchao et al., 2023).

### *Stormwater Traps*

Stormwater traps capture large plastic near their point of release, essentially capturing them before they enter larger water bodies (Bergmann et al., 2023). These technologies tend to be composed of metal traps and/or mesh nets (Wenchao et al., 2023). These traps are installed at stormwater/wastewater outflow points and trap macroplastics (Wenchao et al., 2023).

Trash racks are structures built of metal bars that capture plastic and prevent its outflow into receiving water bodies (Nikiema & Asiedu, 2022). The spacing of the bars can be adjusted during the design process to capture plastics of specific size classes (Nikiema & Asiedu, 2022). Plastic captured in trash racks needs to be removed manually or by mechanical raking (Nikiema & Asiedu, 2022).

Enviropod's LittaTrap™ is a patented receptacle (catch basin basket) that is fixed in place inside stormwater drains to capture plastic debris while allowing water to flow through (Kozikowski & Corcoran, 2024). The trap effectively captures 100% of plastics 5 mm and greater (Kozikowski & Corcoran, 2024). Devices like the LittaTrap™ can be retrofitted to existing stormwater outlets to capture debris (Humes, n.d.). The devices are easily maintained by hand lifting the trap, tipping out debris, and replacing. The standard size LittaTrap™ fits precast concrete catchpits, however, there appears to be scope for design customisation.

### *Combination Devices*

Helinski et al. (2021) categorise capturing devices into three categories. The categories include independent devices, (i) those that utilise only one component (e.g. a boom), synergistic devices, (ii) those that use two components (e.g. a boom-receptacle), and all-inclusive devices, and (iii) – those using all three components (e.g. boom-receptacle-watercraft vehicle; Helinski et al., 2021).

The syngenetic boom-receptacle is an example of a device that uses booms to capture and guide flowing plastic to a receptacle where they are captured and stored until removal (Helinski et al., 2021). Such devices used in conjunction with one another can facilitate greater plastic debris removal. Using multiple devices is often the most efficient method for plastic debris capture. Independent devices, such as booms, receptacles, and watercraft vehicles are outperformed by synergistic and all-inclusive devices that have greater capacities and overall performance (Helinski et al., 2021). Keisling (2021) stated that the ideal plastic debris trap would be reliable, cost effective, non-powered, requiring minimal water head, designed to reduce flood levels, and ultimately efficient in collecting and removing plastic debris from water systems.

### **3. Device Suitability to Rotorua**

Booms, receptacles, watercraft vehicles, and combination devices were reviewed against the six Rotorua stream criteria. Among these, suitability in shallow waters and in narrow channels received the highest weighting (Table 3.2) reflecting the key physical characteristics of the Rotorua sites (Table 3.1). Final recommendations were based on devices scoring a value of 3 (high suitability) for both of these variables in Table 3.2. Devices meeting this threshold were classified as 'suitable' in the Table 3.2. Where only one variable was 3, and the other was 1 (low suitability) or 2 (medium suitability), the device was not recommended. Two values below 3 were also not recommended. Due to this, large vessels (typically those within the watercraft vehicle category) and large structures were unsuitable. Smaller, flexible, sturdier devices were those best suited to the Rotorua riverine environment. From Table 3.2, all devices deemed suitable to recommend for immediate use are booms, or boom receptacles.

Table 3.2. Device suitability table for Rotorua-specific criteria.

Device Name	Device Type	Ability to capture plastics >5 mm	Ability to capture surface plastics	Suitability in turbulent conditions	Suitability in shallow waters	Suitability in narrow channels	Ongoing maintenance requirements	Total Score	Shallow Suitability	Narrow Suitability	Recommendation
Bubble barrier	Boom	3	3	2	2	3	M	13	Not Suitable	Suitable	
PermaFence	Boom	3	3	3	3	3	L	15	Suitable	Suitable	✓
Bandolng Boom Systems™	Boom	3	3	3	3	3	M	15	Suitable	Suitable	✓
Litterbooms	Boom	3	3	3	3	3	M	15	Suitable	Suitable	✓
Floating barrier	Boom	2	3	2	3	3	M	13	Suitable	Suitable	✓
TrashBooms	Boom	2	3	2	3	3	M	13	Suitable	Suitable	✓
Seabin V5	Receptacle	3	3	1	1	1	H	9	Not Suitable	Not Suitable	
Hector the Collector (VideoRay Pro 4 ROV)	Watercraft Vehicle	1	1	1	1	1	H	5	Not Suitable	Not Suitable	
Marina Cleaner/Trash Skimmer	Receptacle Watercraft Vehicle	3	3	1	1	1	H	9	Not Suitable	Not Suitable	
Trash Cat	Receptacle Watercraft Vehicle	2	3	1	1	1	H	8	Not Suitable	Not Suitable	
Omni Catamaran	Receptacle Watercraft Vehicle	2	3	2	1	1	H	9	Not Suitable	Not Suitable	
Veri-Cat Trash Skimmer Boat	Receptacle Watercraft Vehicle	2	3	2	1	1	M	9	Not Suitable	Not Suitable	
Water Witch Workboats Mk. 2/Mk. 3	Receptacle Watercraft Vehicle	2	3	2	1	1	H	9	Not Suitable	Not Suitable	
WasteShark™	Receptacle Watercraft Vehicle	2	3	1	2	2	M	10	Not Suitable	Not Suitable	
Brute Bin	Boom Receptacle	2	3	3	3	3	M	14	Suitable	Suitable	✓
Litter Trap	Boom Receptacle	2	3	2	1	1	L	9	Not Suitable	Not Suitable	

Table 3.2. Device suitability table for Rotorua-specific criteria contd.

Device Name	Device Type	Ability to capture plastics >5 mm	Ability to capture surface plastics	Suitability in turbulent conditions	Suitability in shallow waters	Suitability in narrow channels	Ongoing maintenance requirements	Total Score	Shallow Suitability	Narrow Suitability	Recommendation
Litter Gitters	Boom Receptacle	2	3	3	3	3	M	14	Suitable	Suitable	✓
Mr Trash Wheel™	Boom Receptacle	3	3	1	1	1	L	9	Not Suitable	Not Suitable	
Marina Trash Skimmers	Receptacle	2	3	3	1	1	M	10	Not Suitable	Not Suitable	
Clewat Cleansweep Vessel	Boom Receptacle Watercraft Vehicle	3	3	3	1	1	H	11	Not Suitable	Not Suitable	
CirCleaner	Boom Receptacle	3	3	2	2	2	H	12	Not Suitable	Not Suitable	
Shoreliner	Boom Receptacle	3	3	2	2	2	L	12	Not Suitable	Not Suitable	
The Interceptor™	Boom Receptacle	3	3	2	1	1	L	10	Not Suitable	Not Suitable	
Trashbot	Boom Watercraft Vehicle	3	3	2	2	2	M	12	Not Suitable	Not Suitable	
ORCA-SMURF Water Cleaning Robot	Boom Receptacle Watercraft Vehicle	3	3	2	1	2	H	11	Not Suitable	Not Suitable	
FRED (Floating Robot for Eliminating Debris)	Receptacle Watercraft Vehicle	1	3	3	1	1	L	9	Not Suitable	Not Suitable	
Jellyfishbot	Receptacle Watercraft Vehicle	3	3	2	2	2	H	12	Not Suitable	Not Suitable	
Seehamster	Receptacle Watercraft Vehicle	2	3	2	1	1	M	9	Not Suitable	Not Suitable	
Bandalong Litter Trap™	Boom Receptacle	3	3	3	2	1	M	12	Not Suitable	Not Suitable	
SCG Litter Trap	Receptacle	2	3	2	1	1	M	9	Not Suitable	Not Suitable	
OC - Tech Horizon	Receptacle Watercraft Vehicle	3	3	3	1	1	H	11	Not Suitable	Not Suitable	

#### 4. Community Based Measures

*In situ* devices are not the only solution to the plastic problem. Larger scale community driven cleanup and societal shifts away from plastic are methods to combat and reduce riverine plastic pollution in the long run. Community initiatives, like ‘Plastic Free Anstruther’ in the village of Anstruther, Scotland, foster behavioural changes and increase awareness about extent of plastic consumption, and subsequent repercussions of improper plastic disposal (MacDonald et al., 2021). Anstruther, with a population of ~3,900, were the first on mainland Scotland to successfully implement a community-wide plastic free initiative (MacDonald et al., 2021). As a fishing village, marine pollution, especially plastic pollution, raised concern amongst locals about a potential downfall in tourism (MacDonald et al., 2021). In response to this, awareness of plastic use amongst community members increased, and thus the ‘Plastic Free Community’ initiative was implemented to shift away from single use plastics (MacDonald et al., 2021). However, moving away from single use plastics does not guarantee complete disuse of plastics. In the case of ‘Plastic Free Anstruther’, alternatives like bioplastic, biodegradable plastics, and reusable plastics increased in popularity following single-use removal (Walker et al., 2023). These alternatives all have varying and complex waste management pathways. As well as this, the use of alternative single use products, such as those made of paper or cardboard, increased (Walker et al., 2023). Therefore, it appears ‘Plastic Free Anstruther’, while raising awareness on the extent of single-use plastic consumption, has yet to fully shift behaviours to a circular economy approach (Walker et al., 2023).

In contrast to Anstruther, Rotorua has a much larger population (~74,000) (Stats NZ, 2024) and has a wide spread of plastics throughout the stream network. Rotorua also receives high tourist traffic, so implementing a city wide plastic free initiative would require collective societal effort and rigorous implementation plans. Currently across New Zealand, biodegradable plastics and some plastic alternatives are not accepted in standard recycling, and are instead disposed of in general waste (landfilling) where they may produce methane under anoxic conditions (Song et al., 2009). A city-scale shift away from petroleum-based plastics and towards a circular economy approach is unrealistic without dedicated waste infrastructure to appropriately manage the disposal of plastic

alternatives. Such a shift would also require strong support of plastic free initiatives through legislative action like government policy or parliamentary acts. To work towards being plastic free, and to avoid replacing one single-use product with another, alternative products introduced into the market should be accompanied with the capacity to recycle and/or appropriately dispose the product domestically.

“Smarter consumer choices and industrial consciousness and responsibility” (Vince & Stoett, 2018) are the idealised solution to the plastic crisis. Recycling enables spent plastics to be reformed into something new. But, the rise of composite and multi-layer plastics limits recyclability, resulting in only ~9% of global plastic waste being recycled (MacDonald et al., 2021). However, when faced with such an issue, innovative solutions occur. Items like waterproof (plastic lined) paper coffee cups are not recyclable in kerbside collection (Simply Cups, n.d.). But an Australian-New Zealand initiative ‘Simply Cups’, operated by ‘Closed Loop’ have developed a solution. Simply Cups accepts all paper cups (including plastic lined) at designated recycling stations (Simply Cups, n.d.). Their recycling stations require cups and lids to be separated, following which they are collected and processed (washed, dried, shredded, compacted/blended) and reformed into new products (Closed Loop, n.d.; Simply Cups, n.d.). Recycled products currently include ‘saveBOARD’ (sustainable building materials), ‘EnviroLite Concrete’ (lightweight concrete) and ‘PAK-PAVE™’ Roads (Australian roads made with more than 50% recycled materials) (SimplyCups, n.d.). Previous products have ranged from reusable coffee cups, food trays, speed bumps, garden edges, and fence posts (Simply Cups, n.d.). These developments seem promising in reducing plastic waste, and increasing circularity, but the scalability of such initiatives, any environmental trade-offs remain unclear. The collection, transport, and repurposing of spent plastic products requires resource and energy consumption and should therefore be considered when weighing the net environmental benefits of these initiatives. Developments like ‘Simply Cups’ provide innovative solutions to recycling niche products, however without broader systematic change, these efforts to reduce total plastic waste are likely limited.

The concept of a circular economy where (plastic) waste could be entirely recycled, reused, repaired, and remanufactured has been considered the solution to our plastic

problem (MacDonald et al., 2021). The polymer composition of plastic items dictates how many times the material can be recycled (Teixeira et al., 2023). Typically, recyclable plastics are only recycled around three times, and virgin plastics are added to the recycled materials to maintain desired qualities (Teixeira et al., 2023). Alongside this, there are challenges associated with recycling. These include the complexity of plastic products (such as inclusion of plasticisers and chemical additives) reducing recyclability, ‘new’ plastics often being more cost-effective to manufacture, and inconsistencies among global plastic policies (Teixeira et al., 2023). Within New Zealand, 308 kT of plastic waste is sent to landfill annually, ~40% of which arises from the construction and demolition industry (Berry et al., 2022). Currently, sending plastic waste to landfill is easier and cheaper than recycling it (Thomson et al., 2025). Construction waste is typically co-mingled, meaning in order to be effectively recycled they must be sorted (Thomson et al., 2025). In 2022, New Zealand’s Ministry for the Environment funded (through the Plastic Innovation Fund) a project to recycle plastic pipe offcuts (Thomson et al., 2025). This project successfully displayed how investment in infrastructure to clean, sort, and remanufacture plastic (PVC) can prevent landfilling, and placed an emphasis on education and on-site waste management systems for construction sites (Thomson et al., 2025). Ultimately, education and practical onsite solutions (signage, and the opportunity to separate/sort plastics) prevented ~66% of plastic waste from an Auckland construction company from being sent to landfill, where instead it was recycled (Thomson et al., 2025). Plastic pipe offcuts are typically composed of PVC and HDPE (Thomson et al., 2025). These polymers were not well represented in Rotorua stream sites, but solutions offered by Thomson et al. (2025) remain relevant and beneficial to the reduction of plastic pollution on a broader scale.

To pursue a circular economy, products should be intentionally designed to have a longer lifecycle. This may be achieved by shifting away from single use plastics and instead producing plastics that are entirely recyclable (streamlining polymers per product to ease recycling effort) (MacDonald et al., 2021; Thomson et al., 2025). Conversely, more durable plastics with longer lifecycles can be achieved using composite materials. Composites use fibres and nanoparticles to reinforce plastics, making them stronger, more resilient, and able to withstand harsh environmental conditions (Nuruzzaman et al., 2025). Composite plastics are also common within the packaging industry, and they have

been estimated to make up approximately 26% of all flexible plastic packaging globally (Torkelis et al., 2024). Recyclability of composite plastics depends on the quality of the waste plastics, and the technologies and infrastructure in place to manage the more complex materials (Torkelis et al., 2024). So, while plastics can be designed to be more durable, their longer lifecycle may not correlate with a circular economy, especially if there is no technology in place to recycle them at the end of their life cycle.

Biodegradable plastics are one solution to shift away from petroleum-based single use plastics. These plastics are broken down by microorganisms in the disposal environment (Havstad, 2020). However, not all biodegradable plastics are the same, and the environment needed for its breakdown (location, temperature, soil conditions, etc.) is the most important factor in its success as a plastic alternative (Havstad, 2020). Biodegradable plastics will not degrade in the natural environment, and are instead primarily designed for industrial composting facilities (Havstad, 2020). Polylactic acid (PLA) plastic is an example of a biodegradable plastic marketed as an alternative to traditional plastics. However, standard disposal processes render this alternative futile as landfills have been found to not produce correct conditions for PLA breakdown, and so PLA may persist in the environment just as other plastics do (MacDonald et al., 2021). While none of the identified plastic fragments within Rotorua streams were biodegradable plastics, future research could investigate how biodegradable plastics, like PLA, behave under stream conditions, particularly whether they degrade, and if so, if the extent is similar to what is seen with petroleum-based plastics. This research would highlight the fate of any biodegradable plastics entering the Rotorua stream system, and reinforce the importance of accurate labelling, public education, and recycling and waste management guidance. If biodegradable plastics are not showing up in stream systems, it could be inferred they are instead being sent to landfill and thus are no better than their petroleum-based plastic predecessor. Alternatively, these plastics may be entering the stream body, but by chance did not occur during the sampling period. Moreover, further investigation to understand the ecological effects of biodegradable plastics in stream environments would be beneficial. While biodegradable plastics appear to be a method to stem the flow of single-use plastics, the potential confusion regarding product labelling and its recyclability, and the corresponding need for appropriate waste infrastructure reduces its merit (Farrelly & Green, 2020).

Reducing the quantity of plastic used should minimise waste, this is already occurring for items like straws, utensils, and food takeaway containers (banned plastic items) where there are now alternatives made from raw materials (Areca palm (*Areca catechu*), coconut husks (*Cocos nucifera*), and various leaves; Gautam & Caetano, 2017), moulded pulp (Semple et al., 2022), and paper or cardstock. Many items found within Rotorua stream sampling, like confectionary and food packing, do not have non-plastic alternatives. However, these soft plastics are now recyclable in New Zealand. Clean and dry soft plastics can be collected and dropped off at specific soft plastic recycling bins (often located in supermarkets) where they are processed and remanufactured (The Packing Forum, n.d.). To achieve a circular economy, landfills should be reserved as the least desirable end destination for plastics (MacDonald et al., 2021; Thomson et al., 2025).

Education around the plastic lifecycle is critical for public buy in. In order to incentivise the public to not litter, it is essential to raise awareness of what happens to litter. The ‘Be a Tidy Kiwi’ campaign in New Zealand is a charity that “supports communities to clean up and protect Aotearoa’s environment for future generations” (Be a Tidy Kiwi Trust (BATK), n.d.). The ‘Be a Tidy Kiwi’ brand has permeated across generations and rewards and reminds people to dispose of their rubbish properly, and to pick up litter when they see it (Beverland et al., 2021). The charity was established 58 years ago (1967), and since then has promoted anti-littering behaviour, educated New Zealanders on the importance of recycling correctly, led environmental projects, partnered with other organisations and the government to unify and strengthen their mission, and influenced a generation of kiwis towards anti-littering behaviour (BATK, n.d.). Ultimately, the concept of being a tidy kiwi has been embedded into the national identity (Beverland et al., 2021). Despite this legacy, New Zealand’s environment is still being polluted with plastic. Ongoing cleanup effort and awareness campaigns have run throughout Rotorua city for the past decade, including the work of ‘Be a Tidy Kiwi’ ambassador Kiri Danielle (Smith, 2024). However, the findings of this study demonstrate that even with programmes such as ‘Be a Tidy Kiwi’, the increase in environmental education and awareness is not necessarily followed by behavioural changes. Therefore, it is evident that additional measures are needed.

Citizen science is another avenue to increase public awareness around plastic. Often gaps exist between what people think is recyclable and what actually is, leading to many plastic items being rejected at recycling plants (Popa et al., 2022). So, regimes that correct public perception on recyclables are beneficial. Citizen science programmes, especially those that involve immersive hands-on experience with plastic pollution are valuable, however they may not directly lead to behavioural changes, but this does not undermine their value (Popa et al., 2022). Citizen science offers an alternative approach from traditional science that enables communities to engage in scientific research, thus expanding study coverage, incorporating inclusivity into data collection (citizen science data collection is often available to all age ranges), and increasing knowledge around key issues (Nelms et al., 2022; Sinha et al., 2024). Reportedly, the most common benefits of (plastic pollution) citizen science initiatives are increasing awareness and education, and the public being able to experience the extent of plastic in the environment (Nelms et al., 2022). Alongside this, citizen science may be more cost effective than traditional scientific research, especially as community involvement tends to occur on a voluntary basis (Sinha et al., 2024). Citizen science improves both the breadth of research and provides a more cost effective solution to ongoing data collection projects (Sinha et al., 2024).

There are established community cleanup groups in Rotorua, including ‘Clean up Rotorua – Whakarauri o Rotorua’ (a public Facebook group organising volunteer cleanup events around streams and the Lake Rotorua beachfront) that remove plastic pollution from the environment regularly. This community effort is an example where a citizen science project could be implemented alongside recurring cleanup to raise awareness of the plastic issue and share results of plastic pollution on a wider scale. Community-led cleanups provide information into hotspot areas of plastic pollution (Sinha et al., 2024). Results from citizen science should be communicated to governmental agencies as data (on plastic pollution) may help better inform management strategies and changes to legislation (Popa et al., 2022). Ultimately, citizen science creates avenues for the public be actively involved in finding long-term solutions to plastic pollution while cleaning up their backyards (Nelms et al., 2022).

## CONCLUSION

While there are various technologies and plastic cleanup methodologies on the market, the most important factor to consider for successful meso- and macroplastic clean-up and capture is the site biophysical characteristics (Nikiema & Asiedu, 2022). Waterway type, flow rate, water depth and width, vegetation, and waterbody use (e.g. recreation) greatly impact the suitability criteria of capturing devices (Helinski et al., 2021; Nikiema & Asiedu, 2022), and these will vary from site to site, so there is no one size fits all solution.

As there is no one perfect solution, a combination of management strategies for plastic clean-up should be employed (Falk-Andersson et al., 2023). For example, capture of instream plastics can be achieved through technologies like booms, receptacles, and watercraft vehicles, but it is critical to prevent plastic debris from entering waterways in the first place. Regarding Rotorua streams, it would be best to implement the use of a boom or boom receptacle device (Table 3.2) to remove plastics in the stream, coupled with a stormwater trap (like LittaTrap™) system to capture them before they enter the water body.

Ultimately however, production and consumption must be slowed to reduce pollution in the environment. Only when there is less potential for plastic to be introduced into the environment will the pollution stop. A three-pronged approach is required to tackle the plastic problem. First, effort should be given to reducing plastic, i.e. turning off the tap of plastic production, and shifting to fully recyclable plastics and plastic alternatives (glass, metal, etc.). Secondly, plastic should be prevented from entering water bodies. Ideally this would stem from public education and conscious anti-littering behaviour where individuals appropriately dispose of and recycle used plastics. Initiatives like the ‘Be a Tidy Kiwi’ campaign and ‘Plastic Free Anstruther’ are examples where this occurs and could continue to inspire others. As well as this, stormwater traps should be installed on catchpits and outflows to capture plastic early before it enters greater water bodies. The third prong in this approach is to capture plastic in the stream through *in situ* devices. However, when implementing in stream capture devices, they should be installed with the end goal of not being required. Upstream prevention should ideally render these

devices obsolete. But without multiple management strategies and preventative actions occurring simultaneously, the flow of plastic will not likely stop, and *in situ* devices will be needed indefinitely. Plastic pollution is currently ubiquitous in our environment, but with dedicated prolonged effort, we can work to reduce this.

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## CHAPTER IV

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### **Key Findings, Implications, and Future Research**

## OVERVIEW

In the short geological time that plastic has been in production, it has caused unprecedented environmental damage (Welden, 2020), and is considered the mark of the Anthropocene epoch (Zalasiewicz et al., 2016). Scientific literature highlights that plastic accumulates within the environment, and that the non-biodegradable nature of plastic causes it to persist within the environment (Barnes et al., 2009; Freinkel, 2011; Lechthaler et al., 2020). Similarly problematic is the fragmentation of plastics in ecosystems into microplastics, which are pervasive pollutants and cause numerous ecological and health impacts (Chamas et al., 2020; Hennebert, 2022; Hines et al., 2023; Lechthaler et al., 2020; Nakatani et al., 2022; Nikiema & Asiedu, 2022). Given that Lake Rotorua is large (~80 km<sup>2</sup>) and has some deep points (45 m max depth), the fate of plastics after entry into the lake is largely unknown. Findings from a volunteer cleanup identified plastic bottles at the Lake Rotorua outflow (Ōhau Channel) that were last produced in the 1980s (K. McGrouther, personal communication, June 4, 2025). These findings reaffirm support for the idea that there is considerable plastic pollution within the lake (Nava et al., 2023) and that plastics can remain in the system for extended periods of time (K. McGrouther, personal communication, June 4, 2025). The likelihood of a long residence time increases the potential for plastics to fragment, accumulate, and exert prolonged ecological impacts within the lake ecosystem.

The lack of understanding of plastic movement into Lake Rotorua makes removal expensive and more challenging, particularly considering the lake's large size and depth. Once plastics enter the lake, retrieval becomes logistically complex and resource intensive. Therefore, intervention should occur earlier in stream systems, which are more accessible and better suited for the implementation of cost-effective capture technologies.

This study aimed to explore the extent of plastic pollution within the Rotorua urban stormwater system and develop reasonable solutions. This was achieved by quantifying plastic pollution, identifying types of plastic in the system, and evaluating practical methods of plastic interception and capture.

## KEY FINDINGS

From the five-month sampling campaign across seven sites, all study sites were shown to accumulate plastic between sampling events, and visible aging on many fragments also suggested its presence within the water system for extended periods. Notably, many plastics captured within the seven study sites were visibly degraded and clearly fragmented (many pieces would break apart while being removed). This was most evident for plastic bags, films, and thin plastics that had become brittle. Of the plastics captured within the stream, 51 of the 169 identifiable plastic fragments (30.18%) were recyclable (types 1 (PET), 2 (HDPE), and 3 (PP)). The other 118 plastic fragments were non-recyclable or single use plastics.

Based on the site characteristics described in Chapter II - Materials and Methods (site composition), a series of suitability criteria was developed to evaluate *in situ* plastic capturing devices. Various plastic capturing devices (see Table 3.2) were tested against these criteria. Booms and boom-receptacles were found to be best suited to the shallow and narrow Rotorua streams. Regarding community involvement, streams and rivers flowing through urban centres provide opportunity for community-led groups to be immersed in cleanup and citizen science initiatives. Subsequently, communities are exposed to plastic pollution in the environment, learn how to prevent plastic pollution leakage, and can drive change from the ground up.

Sampling results showed that there was not a strong relationship between the immediate catchment land use and (in stream) plastic weight (g). Additionally, lake shoreline sand sieving did not find mesoplastics (or macroplastics) buried in sand sediments, suggesting plastics were not being washed onshore and buried in terrestrial sediments after entering the lake. There was however considerable meso- and macroplastic on the beach surface, but whether that had washed onshore from wave action or was directly deposited by beachgoers was unknown.

Meso- and macroplastics can be found in various parts of the stream ecosystem, including water column, streambed, and riparian zones, highlighting the complex and dispersed nature of large plastic pollution. Findings from this research indicate that there is no singular solution, but rather a combination of capture devices, mitigation technologies, and site-specific interventions is required to effectively prevent plastics from entering downstream aquatic ecosystems. The following sections detail key research implications regarding plastic pollution mitigation including education driven behavioural changes, regulatory changes, and community engagement opportunities.

## **REAL WORLD IMPLICATIONS**

Results from this research highlight that there is a need for coordinated change across individual, community, and regulatory levels for effective addressal of the plastic pollution problem. Firstly, change should occur at the individual level. More conscious consumer choices (Vince & Stoett, 2018), like choosing non-plastic products, should stir the market to shift from single use plastics (Soares et al., 2021). Education will encourage this public behaviour change. Exposure to community cleanup initiatives, and education on the plastic lifecycle and recycling procedures are methods that can be implemented nationwide to drive change amongst communities (Soares et al., 2021). School-based environmental education programmes for students during their formative years are effective in instilling environmentally responsible behaviours in youth (Soares et al., 2021). In addition, youth may share this information with friends and family members, further increasing the spread of environmental and plastic pollution education (Soares et al., 2021).

Secondly, regulatory changes are needed to address the plastic problem in New Zealand. Changes in legislation will drive individual change (Karasik et al., 2020). New Zealand has already begun the process of single-use plastic phase-outs. The central government are currently implementing a three-tranche process. Tranche one and two occurred from October 2022, and July 2023 (Ministry for the Environment (MFE), 2024). The third tranche of phasing out PVC and polystyrene packing not included in the previous phase outs was set for 2025. However, the current New Zealand government has removed this

deadline, and no new date has been set (MFE, 2024). The deferral of the final phase-out leaves the fate of plastic pollution reduction uncertain. This research re-emphasises how ubiquitous and persistent plastic is in the environment. So, with this knowledge, the government and local authorities should continue to reduce non-recyclable plastic production.

Many of the stream study sites were located within or alongside parks, reserves, and walkways. Waingaehe Stream was the only site that had a rubbish bin visible, located in the Holden's Bay Reserve carpark. While the presence of a bin would likely encourage anti-littering behaviour, the bin was for general waste and did not provide any opportunity to distinguish between waste and recyclables. Therefore, it would be advantageous to increase recycling opportunity around Rotorua city centre, and within parks and reserves (i.e. places where people congregate) by implementing separate recycling bins. The distance to a rubbish bin is an important variable affecting success of litter reduction (Van Doesum et al., 2021). Typically, the further away a bin is, the more littering occurs (Van Doesum et al., 2021). If the means are created for the public to correctly recycle and dispose of waste, it is more likely that it will occur. Interestingly, moving rubbish bins to be only situated at park entry/exit points leads to an increase in littering, and it is more effective to have bins throughout parks, so long as they are emptied appropriately and do not spill over (Van Doesum et al., 2021). While this may increase cost of upkeep and resources for waste collection, the positive effects far outweigh the negatives. This approach would be more cost effective in the long term. Establishing these preventative measures would avoid plastic entering freshwater systems and would increase the abundance of recyclable plastics being correctly disposed of – so long as appropriate signage is implemented. Lotti et al. (2023) found that visual waste sorting instructions paired with 'watching eyes' (an image of human eyes) led to significant decreases in non- and mixed recycling errors. 'Watching eyes' as a form of observation acts as a subtle cue reducing littering and increasing recycling success (Lotti et al., 2023; Van Doesum et al., 2021)

Finally, nationwide initiatives like container return schemes, where individuals are refunded money when they return empty plastic beverage containers to drop-off

recycling points (Ministry for the Environment (MFE), 2025), would potentially incentivise people to appropriately handle and dispose plastics. While a container return scheme was designed for implementation in New Zealand, the scheme was deferred in 2023 (MFE, 2025). Container return schemes have the potential to phase non-recyclable plastic containers out of circulation (Farrelly & Green, 2020). But, with container return schemes, it is critical that their function and associated activities (return/retrieval, cleaning/processing, remanufacturing, etc.) does not cause more harm to the environment than single use practises (Kroon & Vrijens, 1995). Following the implementation of a container return scheme in Queensland, Australia in 2018, the littering rates decreased and recycling rates increased (63.5% of eligible containers recycled; Phipps et al., 2024). Additionally, anti-littering behaviours and habits of the Queensland public positively increased (Phipps et al., 2024). Phipps et al. (2024) suggest that the perceived “ease of recycling” following the container return scheme establishment may be due to the increase of readily available recycling bins and centres. Ultimately, government schemes that promote and incentive making a plastic-free or sustainable choice (i.e. refusing, reducing, reusing, and recycling) should be followed through with (Farrelly & Green, 2020). Deferring positive change, such as the development of plastic container return schemes, in the face of the global plastic problem is not a step forward.

## **FUTURE RESEARCH IMPLICATIONS**

To build upon the foundations established within this study (foundational information regarding plastics in the Rotorua stormwater system), further research could be undertaken regarding polymer degradation in freshwater.

This research has provided an initial assessment of where plastic loading is occurring, how much plastic is travelling through the stormwater system, and what the most common polymers are. However, to gather a more comprehensive understanding of these plastics and their effects in freshwater, ongoing research is required. For example, much of the research on plastic polymer degradation compares landfill and marine environments (Chamas et al., 2020; Nakatani et al., 2022), and comparatively little information is available on polymer degradation in freshwater. Further research could be

conducted on plastic polymer degradation in freshwater (streams/lakes), including investigation of biodegradable plastic degradation, and how degradation processes vary across different ecosystems and biota. Meso- and macroplastics degrade into microplastics, which can act as vectors for toxic substances in aquatic environments (Li et al., 2021; Osabuohien, 2025). Given that the Rotorua Te Arawa lakes and streams host many culturally significant species and trout fisheries that provide great economic benefit to the city, understanding the effects of plastic degradation on these species is important. While some studies have explored these relationships (Jakubowska et al., 2020, 2022), further research would help solidify this knowledge base.

As trout are fished for food, any effects of plastic degradation (like ingestion toxicity and food chain contamination; Osabuohien, 2025) would likely bioaccumulate and biomagnify up the food chain to humans resulting in potential toxicity exposure, and endocrine disruption (Osabuohien, 2025). Moreover, effects of plastic degradation in freshwater on native fauna, like mahinga kai species Kōura and Kākahi, would be beneficial to ongoing conservation effort. Any evidence of plastic harming native fauna would strengthen the case for managing plastic pollution more effectively. Lastly, if certain polymers are found to have particularly harmful ecological effects, this knowledge could guide legislative shifts to restrict or phase out the use of those plastic polymers.

Ultimately, this study establishes a crucial baseline quantification of plastic pollution within the Rotorua urban stormwater system. While the presence of plastic in Rotorua streams was previously acknowledged, this research provides the first concrete data on the extent of pollution. This knowledge provides local authorities and governments with the evidence needed to implement informed and effective waterway management strategies going forward.

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## APPENDIX

Habitat parameter	Condition category										SCORE	
1. Deposited sediment	The percentage of the stream bed covered by fine sediment.											
	0	5	10	15	20	30	40	50	60	≥ 75		
SCORE	10	9	8	7	6	5	4	3	2	1		
2. Invertebrate habitat diversity	The number of different substrate types such as boulders, cobbles, gravel, sand, wood, leaves, root mats, macrophytes, periphyton. Presence of interstitial space score higher.											
	≥ 5	5	5	4	4	3	3	2	2	1		
SCORE	10	9	8	7	6	5	4	3	2	1		
3. Invertebrate habitat abundance	The percentage of substrate favourable for EPT colonisation, for example flowing water over gravel-cobbles clear of filamentous algae/macrophytes.											
	95	75	70	60	50	40	30	25	15	5		
SCORE	10	9	8	7	6	5	4	3	2	1		
4. Fish cover diversity	The number of different substrate types such as woody debris, root mats, undercut banks, overhanging/encroaching vegetation, macrophytes, boulders, cobbles. Presence of substrates providing spatial complexity score higher.											
	≥ 5	5	5	4	4	3	3	2	2	1		
SCORE	10	9	8	7	6	5	4	3	2	1		
5. Fish cover abundance	The percentage of fish cover available.											
	95	75	60	50	40	30	20	10	5	0		
SCORE	10	9	8	7	6	5	4	3	2	1		
6. Hydraulic heterogeneity	The number of hydraulic components such as pool, riffle, fast run, slow run, rapid, cascade/waterfall, turbulence, backwater. Presence of deep pools score higher.											
	≥ 5	5	4	4	3	3	2	2	2	1		
SCORE	10	9	8	7	6	5	4	3	2	1		
7. Bank erosion	The percentage of the stream bank recently/actively eroding due to scouring at the water line, slumping of the bank or stock pugging.											
	Left bank	0	≤ 5	5	15	25	35	50	65	75	> 75	
	Right bank	0	≤ 5	5	15	25	35	50	65	75	> 75	
SCORE	10	9	8	7	6	5	4	3	2	1		
8. Bank vegetation	The maturity, diversity and naturalness of bank vegetation.											
	Left bank AND Right bank	Mature native trees with diverse and intact understorey	Regenerating native or flexes/sedges/tussock > dense exotic	Mature shrubs, sparse tree cover > young exotic, long grass	Heavily grazed or mown grass > bare/impervious ground.							
SCORE	10	9	8	7	6	5	4	3	2	1		
9. Riparian width	The width (m) of the riparian buffer constrained by vegetation, fence or other structure(s).											
	Left bank	≥ 30	15	10	7	5	4	3	2	1	0	
	Right bank	≥ 30	15	10	7	5	4	3	2	1	0	
SCORE	10	9	8	7	6	5	4	3	2	1		
10. Riparian shade	The percentage of shading of the stream bed throughout the day due to vegetation, banks or other structure(s).											
	≥ 90	80	70	60	50	40	25	15	10	≤ 5		
SCORE	10	9	8	7	6	5	4	3	2	1		
TOTAL	(Sum of parameters 1-10)											

Appendix 2.1. River Rapid Habitat Assessment scoring sheet (Clapcott, 2015).

Appendix 2.2. Plastic identification table including site, plastic fragment 'identity' and corresponding count, recyclability status (recyclable, non-recyclable, unknown), and plastic (polymer) type (LDPE, PET, PS, etc.).

Site	Identity	Count	Recyclable	Non-recyclable	Unknown	Plastic type
<b>Headwater Site</b>	Blue plastic film	2		2		LDPE
	White plastic film	1		1		LDPE
<b>Devon Street</b>	Cadbury caramilk chocolate wrapper	1		1		LDPE
	Duct tape	1		1		PE
	Foam	1		1		EPS
	Griffins wheaten wrapper	1		1		OPP
	Harvest snaps snack bag	1		1		PE/PET
	Moon bouncy ball	1		1		PE
	Onion rings chip bag	1		1		Unknown
	Oreo snack bag	1		1		OPP
	Plastic bag	1		1		PE
	Sistema lunch cooler bag	1				Unknown
	Twisties chip bag	1		1		Unknown
	Unknown	9			9	Unknown
	Washing peg	1	2			PP
	Water bottle	2	2			PET
	Zip lock bag	1		1		LDPE
	<b>Blomfield Street</b>	Lollipop stick	1		1	
Milk bottle seal		1	1			HDPE
Plastic bag		2		2		PE
Plastic film		2		2		LDPE
Tasti raw snacking mix mini pack		1		1		LDPE/PP
Unknown		6			6	Unknown

Appendix 2.2. Plastic identification table contd.

Site	Identity	Count	Recyclable	Non-recyclable	Unknown	Plastic type
<b>Depot Street</b>	Bic lighter	1		1		POM
	Bubble wrap	1		1		LDPE
	Bubble-o-bill ice-cream wrapper	1		1		PE / PS
	Cadbury chocolate bar wrapper	2		2		LDPE
	Clear tape	2	2			PP
	Condom wrapper	1		1		LLDPE
	Duct tape	2		2		PE
	Electrode patch	1		1		PU
	Fantastic 2-minute noodles wrapper	2		2		BOPP / PET
	Foam	1		1		PU
	Foam earplug	1		1		PU
	Hose attachment	1		1		PVC
	Malteser packet	1				Unknown
	McDonalds sauce container	1		1		PE
	Mentos individual lolly wrapper	1		1		Unknown
	Milky bar chocolate wrapper	1		1		PP
	Pams rocky road wrapper	1		1		Other
	Peanut slab ice cream wrapper	1		1		LDPE
	Plastic bag	10		10		PE
	Plastic bottle	1	1			PET
Plastic bottle (green)	1	1			PET	
Plastic film	1		1		LDPE	
Plastic packing strap	2	2			PP	
Polystyrene	6		6		EPS	

Appendix 2.2. Plastic identification table contd.

Site	Identity	Count	Recyclable	Non-recyclable	Unknown	Plastic type
<b>Depot Street Contd.</b>	Printers mate tape packaging	1		1		LDPE
	Rolo packet	1		1		Other
	Saw handle	1	1			PP
	Straw	1	1			PP
	Sweet kettle corn popcorn packet	1		1		Other
	Takeaway cup lid	1	1			PP
	Takeaway sushi tray	1	1			PP
	Tiptop magnum wrapper	2		2		Other
	Tiptop Memphis meltdown ice-cream wrapper	1		1		Other
	Unknown	48			48	Unknown
	Vape lid	1		1		POM
	Vhs tape	6	6			PP
	Zip lock bag	1		1		LDPE
<b>Waingaehe Stream</b>	Baby food pouch	1		1		other
	Cadbury dairy milk ice-cream wrapper	1		1		Other
	Indomie noodle wrapper	1		1		Other
	Kinder chocolate wrapper	1		1		Other
	Kiwi blue water bottle wrapper	1		1		BOPP
	L&P bottle (750 ml)	1	1			PET
	Oaty slice bar wrapper	1		1		LDPE
	Plastic film	1		1		LDPE
	Polystyrene	3		3		EPS

Appendix 2.2. Plastic identification table contd.

Site	Identity	Count	Recyclable	Non-recyclable	Unknown	Plastic type
<b>Waingaehe Stream Contd.</b>	Pop'n'good mini popcorn bag	1		1		other
	Sprite bottle	1	1			PET
	Sunlight dishwashing liquid bottle	1	1			PCR
	Unknown	11			11	Unknown
	Water bottle	1	1			PET
	Water bottle (e2)	1	1			PET
	White sugar packet	1		1		LDPE
<b>Owhata Point</b>	Milk bottle	1	1			HDPE
	Countdown cola 1.5 L bottle	1	1			PET
	Keri juice bottle	1	1			PET
	Camel balls lolly wrapper	1			1	Metallised plastic
	Lighter	1		1		POM
	Grain waves packet	1		1		LDPE
	Mentos individual lolly wrapper	1		1		other
	Unknown	23			23	Unknown
	Bluebird chip wrapper	1	1	1		PP
	Indomie noodle wrapper	1		1		BOPP / PET
	Twisties chip bag	1	1	1		PP
	Plastic bag	5			5	PE
	Chocolate baby fish wrapper	1	1	1		PP
	Chupa chup lollipop wrapper	2			1	Unknown
	Nature valley bar wrapper	1		1		BOPE

Appendix 2.2. Plastic identification table contd.

Site	Identity	Count	Recyclable	Non-recyclable	Unknown	Plastic type
<b>Owhata Point Contd.</b>	Tasti protein fix muesli bar wrapper	1		1		PP
	Schweppes 1.5 L bottle	1	1			PET
	Polystyrene	8		8		EPS
	Foam	1		1		EPS
	Rashuns mini chip bag	1	1	1		PP
	Listerine bottle and cap	1	1			PET
	Pump mini bottle and cap	1	1			PET
	V bottle	1	1			PET
	Zip lock bag	2		2		LDPE
	Plastic tweezers	1	1			PP
	Jack links beef stick wrapper	1		1		PET / PE
	Big fish confectionary wrapper	1	1	1		PP
	Felt tip pen	1	1			PP
	Big ben pie wrapper	2		1		PP
	Plastic film	2		2		BOPP
	Nescafe single serve coffee sachet	1			1	Unknown
	Milky bar mini wrapper	1		1		PP
	Bubble wrap	1		1		LDPE
	Rubber fragment				1	Unknown
Libra pad wrapper	1			1	Soft plastic	
<b>Waiowhoro Stream</b>	Bic lighter	1		1		POM
	Bubble wrap	2		2		LDPE
	Coke bottle lid	1	1			HDPE
	Foam	1		1		EPS
	Foam earplug	1		1		PU

Appendix 2.2. Plastic identification table contd.

Site	Identity	Count	Recyclable	Non-recyclable	Unknown	Plastic type
<b>Waiowhiro Stream Contd.</b>	Goodness me bar wrapper	1			1	Unknown
	Green plastic lid container (large)	1	1			HDPE
	H2GO water bottle label	1		1		BOPP
	Keri juice bottle (3 L)	1	1			PET
	McDonalds mayonnaise sachet	2			1	Other
	Mi goreng flavour sachet	1			1	Metallised plastic
	Natural confectionary bag	1			1	Soft plastic
	Nerf bullet	2		1		EVA
	Pams mini rice cracker bag	1			1	Unknown
	Plastic bottle	1	1			PET
	Plastic lid	1	1			PP
	Polystyrene	9		9		EPS
	Powerade bottle lid	1	1			PP
	Tiny teddies single serve packet	1			1	soft plastic
	Tiptop ice cream container lid	1	1			HDPE
	Tnt individual lolly wrapper	1			1	Metallised plastic
	Unknown	22			22	Unknown
	Up and go container	1	1			PET
	Up and go film	1		1		BOPP
	Water balloon	1			1	Unknown

Appendix 3.1. Results of literature searches. Inclusion column refers to suitability to literature review topic. "Yes" (green) = included in review. "No" (red) = excluded from review. "Repeat" (yellow) = already found in previous search and included in review.

Keyword String	Search Date	Author	Name	Link Address	Inclusion
macroplastic AND water AND booms AND receptacles AND "watercraft vehicles"	19/03/2025	Helinski, O. K., Poor, C. J., & Wolfand, J. M.	Ridding our rivers of plastic: A Framework for plastic pollution capture device selection	<a href="https://www.sciencedirect.com/science/article/pii/S0055268821001296">https://www.sciencedirect.com/science/article/pii/S0055268821001296</a>	Yes
	19/03/2025	Kozikowski, N.	Controls on Plastic Debris Capture in Urban Stormwater Drains of London, Canada: A Study Within the Great Lakes Watershed	<a href="https://search.proquest.com/openview/5e2f08a21637fb4d997b6e8d3ff31d717?pq-origsite=scholar&amp;cbl=187508&amp;isx=1">https://search.proquest.com/openview/5e2f08a21637fb4d997b6e8d3ff31d717?pq-origsite=scholar&amp;cbl=187508&amp;isx=1</a>	No
	19/03/2025	Markley, Laura AT.	Multi-Disciplinary Approach to Plastic Pollution from Environmental Sampling to Surveying: Quality Assurance, Freshwater Contamination, and Popular Opinions	<a href="https://search.proquest.com/openview/7234c8a5e21b8c376d9ab3e49245e65f17?pq-origsite=scholar&amp;cbl=187508&amp;isx=1">https://search.proquest.com/openview/7234c8a5e21b8c376d9ab3e49245e65f17?pq-origsite=scholar&amp;cbl=187508&amp;isx=1</a>	No
	19/03/2025	Driedger, A. G. J., Dürr, H. H., Mitchell, K., & Van Cappellen, P.	Plastic debris in the Laurentian Great Lakes: a review	<a href="https://www.sciencedirect.com/science/article/pii/S0380133015000064">https://www.sciencedirect.com/science/article/pii/S0380133015000064</a>	Yes
	19/03/2025	Sherlock, C., Gutierrez, R. F., David, M., & Rochman, C. M.	A methodology for quantifying and characterizing litter from trash capture devices (TCDs) to measure impact and inform upstream solutions.	<a href="https://www.frontiersin.org/journals/environmental-science/articles/10.3389/fenv.2024.1459259/full">https://www.frontiersin.org/journals/environmental-science/articles/10.3389/fenv.2024.1459259/full</a>	No
	19/03/2025	DeYoung, M., Fisher, M., & Hilken, C.	The Great Lakes Plastic Cleanup: An Effective Approach to Addressing Plastic Pollution in the Great Lakes.	<a href="https://www.taylorfrancis.com/chapters/edit/10.1201/9781003137742/6/great-lakes-plastic-cleanup-malissa-deyoung-mark-fisher-christopher-hilken">https://www.taylorfrancis.com/chapters/edit/10.1201/9781003137742/6/great-lakes-plastic-cleanup-malissa-deyoung-mark-fisher-christopher-hilken</a>	Yes
	19/03/2025	Kozikowski, N., & Corcoran, P. L.	Pedestrian traffic is the main driver of macro-and large microplastic debris deposition in urban stormwater drains	<a href="https://www.frontiersin.org/journals/environmental-science/articles/10.3389/fenv.2024.1459259/full">https://www.frontiersin.org/journals/environmental-science/articles/10.3389/fenv.2024.1459259/full</a>	Yes
	19/03/2025	Buschman, F. A., Veiga, J. M., Sulu-Gambari, F., Buckman, L., Markus, A., Eleveid, M., Rodenas, A. M., Krystek, P., van Dijk, T., Wijdeveld, A., & Troost, T.	A source-to-sea approach to evaluate policy measures that aim to reduce macroplastic transport in Dutch rivers	<a href="https://ns.ukwente.nl/ws/portalfiles/portalf/364082563/Book_of_abstracts_nordavis_2024.pdf#page=42">https://ns.ukwente.nl/ws/portalfiles/portalf/364082563/Book_of_abstracts_nordavis_2024.pdf#page=42</a>	No
	19/03/2025	Brouwer, R., Huang, Y., Huizenga, T., Frantzi, S., Le, T., Sandler, J., Dijkstra, H., Van Beukering, P., Costa, E., Garaventa, F., & Piazza, V.	Assessing the performance of marine plastics cleanup technologies in Europe and North America	<a href="https://www.sciencedirect.com/science/article/pii/S0954569123000807">https://www.sciencedirect.com/science/article/pii/S0954569123000807</a>	Yes
	19/03/2025	Semcesen, P. O., Sherlock, C., Gutierrez, R. F., Rochman, C., & Wells, M. G.	Wind Driven Transport of Microplastic Debris in a Large Urban Harbour Measured by Gps-Tracked Drifters	<a href="https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5072575">https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5072575</a>	No

Appendix 3.1. Results of literature searches contd.

Keyword String	Search Date	Author	Name	Link Address	Inclusion
macroplastic AND water AND booms AND receptacles AND "watercraft vehicles"	19/03/2025	Gao, G. H., Helm, P., Baker, S., & Rochman, C. M.	Bromine content differentiates between construction and packaging foams as sources of plastic and microplastic pollution	<a href="https://pubs.acs.org/doi/abs/10.1021/acs.estwater.2c00628">https://pubs.acs.org/doi/abs/10.1021/acs.estwater.2c00628</a>	No
	19/03/2025	Cowger, W. C.	Watershed Transport Processes of Anthropogenic Litter	<a href="https://search.proquest.com/openview/0c717e792fa1934942e872e9e66dd57/1?pq-origsite=scholar&amp;cbl=18750&amp;dlss=y">https://search.proquest.com/openview/0c717e792fa1934942e872e9e66dd57/1?pq-origsite=scholar&amp;cbl=18750&amp;dlss=y</a>	No
	19/03/2025	Keisling, C.	The characterization of the abundance and movement of anthropogenic litter via stormwater runoff with proposed reduction options	<a href="https://search.proquest.com/openview/b6590a12a08f69c753266b38019441d658/1?pq-origsite=scholar&amp;cbl=18750&amp;dlss=y">https://search.proquest.com/openview/b6590a12a08f69c753266b38019441d658/1?pq-origsite=scholar&amp;cbl=18750&amp;dlss=y</a>	Yes
	19/03/2025	Driedger, A. G.	Plastic debris in the Laurentian Great Lakes: Classification, distribution and environmental drivers	<a href="https://ui.wspace.uwaterloo.ca/handle/10012/9456">https://ui.wspace.uwaterloo.ca/handle/10012/9456</a>	No
	19/03/2025	Knight, E. G. J.	Marine Debris From River Margins: Wet and Dry Weathering Effects on the Fragmentation and Degradation of Discarded Plastic	<a href="https://search.proquest.com/openview/f3c60c82702d214fa8a6a803783cc003/1?pq-origsite=scholar&amp;cbl=18750&amp;dlss=y">https://search.proquest.com/openview/f3c60c82702d214fa8a6a803783cc003/1?pq-origsite=scholar&amp;cbl=18750&amp;dlss=y</a>	No
	19/03/2025	Cupp, A.R., Brey, M.K., Calfee, R.D., Chapman, D.C., Erickson, R., Fischer, J., Fritts, A.K., George, A.E., Jackson, P.R., Knights, B.C., & Saari, G.N.	Emerging control strategies for integrated pest management of invasive carps	<a href="https://bioone.org/journal-of-vertebrate-biology/volume-70/issue-4/pub.21.057/Emerging-control-strategies-for-integrated-pest-management-of-invasive-carps/10.29225/bjv.21.057.about">https://bioone.org/journal-of-vertebrate-biology/volume-70/issue-4/pub.21.057/Emerging-control-strategies-for-integrated-pest-management-of-invasive-carps/10.29225/bjv.21.057.about</a>	No
	19/03/2025	Adeniran-Obey, S. O., & Enuneku, A. A.	Plastics and Derived Contaminants in the Arctic	<a href="https://link.springer.com/chapter/10.1007/978-3-031-73584-4_8">https://link.springer.com/chapter/10.1007/978-3-031-73584-4_8</a>	No
	19/03/2025	Nikiema, J., & Astiedu, Z.	A review of the cost and effectiveness of solutions to address plastic pollution	<a href="https://link.springer.com/article/10.1007/s11356-021-18038-5">https://link.springer.com/article/10.1007/s11356-021-18038-5</a>	Yes
	19/03/2025	Fraga Filho, C. A. D.	Analysis of Brazilian plastic waste management in the global context and case study of the City of Vitória, Espírito Santo	<a href="https://link.springer.com/article/10.1007/s11356-024-35865-4">https://link.springer.com/article/10.1007/s11356-024-35865-4</a>	Yes
	19/03/2025	Smail, E., Campbell, J., Takaki, D., Plag, H.P., Gareilo, R., Djavidnia, S., Moutinho, J., El Serafy, G., Gioretti, A., Vinci, M., & Jack, M.E.M.	A global platform for monitoring marine litter and informing action	<a href="https://geochemplanet.org/wp-content/uploads/2020/03/Marine-Litter-White-Paper-Draft_07Mar2020.pdf">https://geochemplanet.org/wp-content/uploads/2020/03/Marine-Litter-White-Paper-Draft_07Mar2020.pdf</a>	No



Appendix 3.1. Results of literature searches contd.

Keyword String	Search Date	Author	Name	Link Address	Inclusion
macroplastic AND water AND booms AND receptacles AND "watercraft vehicles"	8/04/2025	Helinski, O. K., Poor, C. J., & Wolfand, J. M.	Ridding our rivers of plastic: A framework for plastic pollution capture device selection	<a href="https://www.sciencedirect.com/science/article/pii/S0025326X21001296">https://www.sciencedirect.com/science/article/pii/S0025326X21001296</a>	Repeat
	8/04/2025	Przyborowski, Ł., Cuban, Z., Łoboda, A., Robakiewicz, M., Biegowski, S., & Kolarski, T.	Effect of Groynes and Aquatic Vegetation on Floating Macroplastic Transport in a River	<a href="https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4646323">https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4646323</a>	No
	8/04/2025	Przyborowski, Ł., Cuban, Z., Łoboda, A., Robakiewicz, M., Biegowski, S., & Kolarski, T.	The effect of groyne field on trapping macroplastic. Preliminary results from laboratory experiments	<a href="https://www.sciencedirect.com/science/article/pii/S0048867240132938">https://www.sciencedirect.com/science/article/pii/S0048867240132938</a>	No
	8/04/2025	Shivhare, S., & Sharma, A.	Plastic Pollution from River to Ocean: A Comprehensive Review in Indian Scenario	<a href="https://www.preprints.org/frontera/main/us.cfm?id=57418&amp;seq=419&amp;seq=2cd881De1e2download_nab">https://www.preprints.org/frontera/main/us.cfm?id=57418&amp;seq=419&amp;seq=2cd881De1e2download_nab</a>	No
	8/04/2025	Fuchs, Y., Scherbaum, S., Huber, R., Rütger, N., & Hartlieb, A.	Removing Plastic Waste from Rivers: A Prototype-Scale Experimental Study on a Novel River-Cleaning Concept	<a href="https://www.mdpi.com/2073-4447/16/2/2248">https://www.mdpi.com/2073-4447/16/2/2248</a>	Yes
	8/04/2025	Bergmann, M., Arp, H. P. H., Carney Almroth, B., Cowger, W., Eriksen, M., Dey, T., Gündoğdu, S., Helm, R. R., Krieger, A., Syberg, K., Tekman, M. B., Thompson, R. C., Villarrubia-Gómez, P., Warrier, A. K., & Farrelly, T.	Moving from symptom management to upstream plastics prevention: The fallacy of plastic cleanup technology	<a href="https://www.cell.com/one-earth/fulltext/S2590-3329(23)00457-9?">https://www.cell.com/one-earth/fulltext/S2590-3329(23)00457-9?</a>	Yes
	8/04/2025	Roy, D., Palermo, M., & Pagliara, S.	Control of surface plastic transport in natural streams	<a href="https://ascelibrary.org/doi/abs/10.1061/(JHEND8)HYENG-13832">https://ascelibrary.org/doi/abs/10.1061/(JHEND8)HYENG-13832</a>	No
	8/04/2025	Brouwer, R., Huang, Y., Huibenga, T., Frantzi, S., Le, T., Sandler, J., Dijkstra, H., Van Beukering, P., Costa, E., Garaventa, F., & Piazza, V.	Assessing the performance of marine plastics cleanup technologies in Europe and North America	<a href="https://www.sciencedirect.com/science/article/pii/S0964569123000807">https://www.sciencedirect.com/science/article/pii/S0964569123000807</a>	Repeat
	8/04/2025	Fraga Filho, C. A. D.	Analysis of Brazilian plastic waste management in the global context and case study of the City of Vitória, Espírito Santo	<a href="https://link.springer.com/article/10.1007/s11356-024-35865-4">https://link.springer.com/article/10.1007/s11356-024-35865-4</a>	Repeat
	8/04/2025	Keisling, C.	The characterization of the abundance and movement of anthropogenic litter via stormwater runoff with proposed reduction options	<a href="https://search.proquest.com/openview/b45f0412c09169c763056b3630344b058/1?pq-origsite=scholar&amp;cbl=16750&amp;disfr">https://search.proquest.com/openview/b45f0412c09169c763056b3630344b058/1?pq-origsite=scholar&amp;cbl=16750&amp;disfr</a>	Repeat

Appendix 3.1. Results of literature searches contd.

Keyword String	Search Date	Author	Name	Link Address	Inclusion
macroplastic AND water AND booms AND receptacles AND "watercraft vehicles"	8/04/2025	Silva, M. F., Ferreira, P., & Guedes, P.	Floating trash collector—an EPS@ ISEP 2020 Project	<a href="https://books.google.com/books?hl=en&amp;lr=&amp;id=E6hBEAAAQBAJ&amp;oi=fnd&amp;pg=FA165&amp;dq=macroplastic+AND+water+AND+booms+AND+receptacles+AND+%E2%80%9Cwatercraft+vehicles%E2%80%9D.&amp;ots=V0DgnDnXMM&amp;sig=EPB95VM0s_1L44LHv4v4NT5v4IE">https://books.google.com/books?hl=en&amp;lr=&amp;id=E6hBEAAAQBAJ&amp;oi=fnd&amp;pg=FA165&amp;dq=macroplastic+AND+water+AND+booms+AND+receptacles+AND+%E2%80%9Cwatercraft+vehicles%E2%80%9D.&amp;ots=V0DgnDnXMM&amp;sig=EPB95VM0s_1L44LHv4v4NT5v4IE</a>	No
	8/04/2025	Serafia, A.B., Santos, A., Caddia, D., Zeeman, E., Castaner, L., Malheiro, B., Ribeiro, C., Justo, J., Silva, M.F., Ferreira, P., & Guedes, P.	Floating Trash Collector-An EPS@ ISEP 2020 Project	<a href="https://link.springer.com/character/10.1007/978-3-030-99304-5_17">https://link.springer.com/character/10.1007/978-3-030-99304-5_17</a>	No
	8/04/2025	Xue, W.	Innovations and future trends in plastic waste management	<a href="https://brainyopen.org/bitstream/handle/20.500.12857/638281/external_content.pdf?force=225">https://brainyopen.org/bitstream/handle/20.500.12857/638281/external_content.pdf?force=225</a>	No
	8/04/2025	Bergmann, M., Arp, H. P. H., Carney Almoth, B., Cowger, W., Eriksen, M., Dey, T., Gündoğdu, S., Helm, R. R., Krieger, A., Syberg, K., Tekman, M. B., Thompson, R. C., Villarrubia-Gómez, P., Warrier, A. K., & Farrelly, T.	Moving from symptom management to upstream plastics prevention	<a href="https://pearl.lplymouth.ac.uk/oboms-research/1641/">https://pearl.lplymouth.ac.uk/oboms-research/1641/</a>	Repeat
	8/04/2025	Nzama, S.	The application of environmental management accounting practices on plastic pollution control in food and beverages manufacturing firms in Durban, South Africa.	<a href="https://www.academia.edu/download/89430488/NeamsS_Masters_2021.pdf">https://www.academia.edu/download/89430488/NeamsS_Masters_2021.pdf</a>	No