MACRO-PLASTICS TO MICROPLASTICS; FINE TUNING THE TREATMENT TRAIN APPROACH TO ADDRESS A CONTAMINANT OF EMERGING CONCERN

Linda Norman (ACH Consulting Ltd)

ABSTRACT

Urban stormwater runoff, since 1950, has contained steadily increasing volumes of plastic. 80% of plastics in the marine environment are derived from terrestrial sources. Stormwater runoff is the principal vector for plastics reaching the aquatic environment. During a rainfall event, plastics are washed into stormwater catchpits and urban streams. Many of the plastics are straws, drink bottles, cup lids etc. referred to as macro-plastics.

The longer a macro-plastic remains in the environment, the more it breaks down, becoming secondary microplastics (MP), defined as a particle with dimensions of <5 mm and > 1 µm. Secondary MP account for anywhere between 69% - 80% of MP in the ocean. Recently MP have been designated as a contaminant of emerging concern. MP are in most drinking water, present in 97% of all fish species in the South Pacific and are pervasive in our lakes and streams, impacting every part of the food chain from bacteria to mammals. MP cause reduced fecundity, lower immunity, reduced fitness, affecting blood chemistry, hormone levels and genetics. Human ingestion of shellfish in New Zealand includes ingesting between 920 – 4600 MP particles per annum.

Stormwater treatment of urban runoff targets metals and nutrients. Fine-tuning the treatment train of stormwater processes provides a feasible methodology for reducing the amount of plastic entering natural surface waters. Trapping macro-plastics prior to their entry into the stormwater system will reduce MP. Densely planted riparian margins, in-catchpit filters and vegetated swales all act as gross pollutant traps (GPT), trapping particles >5 mm. GPT are the front end of the treatment train, acting as a gate keeper for macro-plastics. With comprehensive maintenance programs GPT are highly effective at removal of macro-plastics prior to their becoming secondary MP.

Addressing MP in stormwater runoff prior to entry into natural waters requires a toolbox of methodologies, appropriate to the size and nature of the contributing catchment. Wetlands have historically provided a reliable part of the stormwater treatment train for larger catchments. However, constructed wetlands can contain anywhere between 85 - 1100 µg/m^3 of MP and sufficient wetlands residence times are required (up to 10 days), if the trapped MP are not going to be discharged into surface waters. Increasing residence time is the best option, as it can increase the efficiency of MP removal to nearly 100%, as well as reducing total nutrients. Limited land availability can be an obstacle to designing wetlands with sufficient residence time. Where ideal residence times cannot be achieved other options must be explored.

For large catchments, further filtration at the wetland outlet, or a series of smaller wetlands, can provide more efficient MP removal. Bioretention systems run in series have the potential to provide comprehensive MP removal for large catchments. Subdividing large catchments into small subcatchments allows for the use of proprietary treatment devices downstream of GPT, filtering out MP prior to discharge into a reticulated

stormwater network. This paper examines ways in which our current toolbox can be adjusted to address macro-plastics and MP for a variety of catchments.

KEYWORDS

Microplastics, Contaminant of Emerging Concern, Treatment Train

PRESENTER PROFILE

Linda joined ACH Consulting Ltd after immigrating to New Zealand in 2006. She trained in the US as an oceanographer and environmental engineer. Having achieved degrees in Chemistry and geology as well as an advanced degree in oceanography and marine geophysics, she has worked for NASA, Woods Hole Oceanographic Institution, US Geological Survey and others. A scientist and an engineer, she brings her multidisciplinary experience to engineering design.

1 INTRODUCTION

Plastic has, in the past, been classed as solid waste and not been considered as a toxic pollutant. Since the 1970s marine biologists working with mammals, birds and sea turtles have become increasingly aware of the deadly nature of macro plastic to wildlife populations. It is only recently that scientists have started looking at the potential long term impacts on human health. Plastic does not break down as much as it breaks up. Macro plastic becomes MP and nano-plastic, passing through cell walls into the tissues of plants, animals and humans. Plastic has the potential to bio-amplify and MP have become a persistent and ubiquitous problem across the three waters and the marine environment.

In 1950, the global plastic production was two million metric tons (MT). In 2015 380 million MT were produced. Two thirds of the plastic produced since 1950 remains in the environment in some form [1]. By 2050 it is estimated that plastics production will increase to 33 billion MT [2]. New Zealand generates 159 g/pp/day of plastic waste. In contrast Norway, which has a similar population generates 26 g/pp/day [3].

According to a study [4], approximately 16% of all New Zealanders litter, mostly between the ages of 18 -34, with those people under 18 and over 55 having the lowest rate of littering. Moreover, 53% of that littering occurs by people while driving. Plastic waste comprises about 8% of New Zealand's waste stream, which is higher than our neighbour Australia.

Stormwater runoff, particularly from the built environment creates a direct pathway for plastics entering the freshwater and subsequently the marine environment. Much of the litter in the built environment, finds its way into stormwater drains and catchpits. A fraction of New Zealand's 1,000,000 catchpits contain gross pollutant traps. Moreover, gross pollutant traps designed in the 1990s were not designed to address the level of plastics now entering the reticulated stormwater systems. A considerable volume of stormwater discharging into the freshwater or marine environment, does so untreated. According to a 2019 report from New Zealand's Office of the Prime Minister's Chief Science Advisor [5] there were 2,680 plastic litter items per 1,000 m^2 of surveyed waterways.

Photograph 1: Auckland stormwater inlet to a portion of a piped, unnamed stream.

Cigarette butts and vape waste products account for up to 75% of litter [4]. Food packaging was the second biggest source of litter in the environment. Cigarette butts and vape waste products can and do breakdown to MP. Auckland's waterways have between 17 and 303 particles of MP per cubic metre of water and between 9-90 items in each kilogram of sediment [5].

Proprietary treatment devices and raingardens, if properly constructed and maintained can reduce the volume of plastics entering stormwater system and the freshwater environment. Evidence from studies in Sweden demonstrates that not only is a treatment train approach necessary for effective removal of MP from stormwater runoff, but residence times can affect the efficiency.

For the past few decades Councils have put great emphasis on removal of metals and nutrients. Removal of heavy metals from stormwater has been largely successful, in part because the science is well understood. What is certain is that a new look at the treatment train is required if stormwater is not going to remain the prevalent vector of transport for plastics and MP entering the environment.

2 SOURCES OF PLASTICS

A study of plastic pollution entering the world's oceans indicates that the majority is in the form of plastic waste [6]. East Asia and Oceania release 1.3 million MT of plastic waste into the ocean as opposed to 0.23 million MT of MP. However, plastic waste becomes MP as it breaks down.

In general MP are defined as primary and secondary. Primary MP include resin pellets, glitter, and have been manufactured small. Secondary MP are formed from the breaking down, or rather breakup, of larger plastic debris by UV degradation, photo oxidation, bacterial degradation and physical abrasion.

Sources for secondary MP, particularly polypropylene (PP), polyvinylchloride (PVC), polyethylene (PE) polyethylene terephthalate (PET) and polystyrene(PS), are largely a result of terrestrial pollution or littering. A visual survey of 1 km of roads in various environments yielded the following numbers of macro plastic items in table drains, kerb and channel or along the kerb:

Table 1: Visual assessment of road side plastics in the Auckland region.

Environment	Plastic Count
Rural Village	20/km (AVG)
Rural Bush (Regional Park)	12/km (AVG)
Rural Agricultural Land	7/km (AVG)
Sub Urban Residential (single house sites)	16/km
Urban Commercial & Terraced Housing	18/km
4 lane Urban Motorway	34/km (AVG)
State Hwy (Just outside the RUB)	50/km (AVG)

During February and March 2021 over 200 stormwater catchpits were examined for evidence of plastic waste. Catchpits on or around school grounds proved to be the more likely to be devoid of plastic debris while the ones sited in outdoor shopping areas, with readily available rubbish bins always contained plastic waste. Of the stormwater catchpits examined, 91% of the catchpits contained plastic waste.

Photograph 2-4: Catchpits with macro plastic present.

Volume and types of plastics found in stormwater ponds and wetlands vary depending on the type of catchment which discharges into the stormwater ponds. A study assessed [7] MP in seven different ponds, treating different types of catchments, found that stormwater ponds serving highway and residential areas had the lowest MP concentration, while ponds whose catchments were comprised of commercial retail and industrial activities had the highest concentrations. The compositional makeup of plastics was dominated by PP, PVC, PET, PS, PE and polyester. All but polyester are primarily used for packaging and all but polyester have a specific gravity of less than 1. Where the specific gravity is greater than 1 the likelihood of a plastic sinking in the freshwater environment is greater. Polyester and other fibre based MP also are a component of wastewater due to laundry effluent. MP in wastewater streams are comprised principally of textile fibres and while textile fibres, pose a risk to the marine environment and the abundance can be directly attributed to discharges from large-scale wastewater treatment plants, they are beyond the scope of this paper.

New Zealand has many small urban streams. A study across 52 streams in 5 urban centres completed in 2019 showed that the small urban streams act as a major vehicle for transporting MP [3]. Concentrations of MP ranged from 1-44 items per m^3 of water.

3 THE STATE OF THE SCIENCE:

Most of what is understood about the behaviour and fate of MP in aquatic systems is known either from the marine environment or from wastewater treatment. What has been determined, is that different MP and plastics in general behave differently. Moreover, depending on catchment use, the type or population of plastic and MP can also vary considerably. The science is still relatively young and there are significant data gaps.

4 BIOLOGICAL IMPACT MP

MP have a large surface area to volume ratio, and chemical compositions that provide a vector for a variety of contaminates into the food web [8] including:

- Metals
- PCB
- DDT
- PAHs (polycyclic aromatic hydrocarbons)
- EDC (endocrine-disrupting compounds)

MP are a direct vector for toxic chemicals into the freshwater and marine ecosystems, as additives used to achieve desired properties including flame retardants, stabilizers and softeners, some of which are endocrine disruptors (chemicals with the ability to affect hormonal systems linked to cancer, birth defects and developmental disorders). The additives are weakly bound to the plastics and, as the plastic breakup, some of the chemicals are leached into the aquatic ecosystem [2].

In New Zealand, the ingestion of 440 g of mollusc species a year will also include the ingestion of between 924 - 4620 MP particles [6]. Biofilms that form on MP have been found to host Vibrio bacterium (a common bacteria associate with food borne illness).

There is no clear understanding whether MP can leach other contaminants like pharmaceuticals. In a study of six human placental tissues MP were found in four, three were identified as PP [9]. PP is primarily used for packaging. The vector for MP is believed to have been either airborne or ingestion. The study demonstrates the ubiquitous level the presence of MP have reached.

5 ASSESSMENT OF STORMWATER TREATMENT EFFICIENCIES

5.1 GROSS POLLUTANT TRAPS

Plastic litter is generated everywhere within the built environment, including roadways through rural areas. Gross pollutant traps (GPT) are the least expensive piece of hardware to include in a stormwater treatment train, and the first line of defence that can be employed by the stormwater professional. GPT are designed to remove litter and debris >5 mm. The effective placement and ongoing performance of GPT can lower the cost of maintenance further down the treatment train.

GPT include drainage screening or entrance devices, including in catchpit litter baskets, channel nets and trash racks installed across a stream or waterway. Recent developments include high strength mesh in catchpit installed traps, which are able to achieve the capture of finer materials. Entrance treatments if well maintained also help decrease the instances of pipe blockage.

In highly commercialised or industrial areas hydrodynamic separators are employed as part of the treatment train. The underground proprietary devices are efficient in treating stormwater, targeting hydrocarbons, sediments and large floatable items. The effectiveness for removal of plastics that are <5 mm has yet to be determined. As such, hydrodynamic separators will only act as a GPT in terms of plastic waste.

Planted vegetated swales, and rocky planted areas designed as flow through filters, are effective gross pollutant traps where a piped network is unavailable to trap gross pollutants. Planted roadside table drains in the rural environment can perform as gross pollutant traps. All GPT devices require an effective and achievable maintenance program to act as the gate keeper for macro-plastics entering fresh water systems. GPT situated along roads require an agreement between councils and the roading authorities for maintenance. In the past, both parties have been resistant to installing any kind of GPT, for fear of the maintenance costs. However the environmental and human health costs of plastic entering the freshwater environment are starting to outweigh the maintenance costs. The more macro-plastic that gets excluded from the stormwater stream the less MP will need to be addressed later.

5.2 BIORETENTION DEVICES

A two year study of a raingarden situated in the city of El Cerrito in the east San Francisco Bay area found that 90% of MP were removed [10]. The raingarden removed 100% of particles greater than 0.5 mm, 81% of those sized between 0.35-0.5 mm and 55% of those sized between 0.12 mm – 0.35 mm. The population of particles were made up of nearly 60% were fibres with the other 40% split between fragments and microbeads of which only 4% were rubber fragments from tire wear. Concentrations of MP in stormwater runoff were seasonal, due to the variation between wet and dry seasons experienced in the San Francisco Bay Area. Another study [11] centred on an urban bioretention device showed 84% removal of MP between 0.106 mm and 5 mm in size. Concentrations in the stormwater runoff ranged from none detected to over 700 particles/litre dependent on rainfall intensity and intervals between storms.

Sustaining the level of performance demonstrated in the above studies requires maintenance. An examination of core samples of the raingarden media showed the concentration of most contaminants to be located within the top 100 mm of soil [10]. The authors concluded that the surface media should be replaced annually and the remainder of the media be replaced every 8 years.

Photograph 5: El Cerrito street scape before and after.

Bioretention devices can also improve the street scape which can also contribute to reduction of general litter. Research indicates that littering as well as other nuisance behaviours can be attributed to low amenity value [12]. Moreover, where there is already litter there is a tendency for others to litter, as well.

5.3 PROPRIETARY TREATMENT DEVICES

Proprietary treatment devices by and large successfully remove macro plastics and have the potential to remove MP from stormwater runoff. Where a membrane filter is included in the device, there is a potential to remove particles down to 2 µm. Units without a membrane filter will generally remove particles down to 20 µm.

5.4 STORMWATER PONDS / WETLAND EFFICIENCY FOR MP REMOVAL

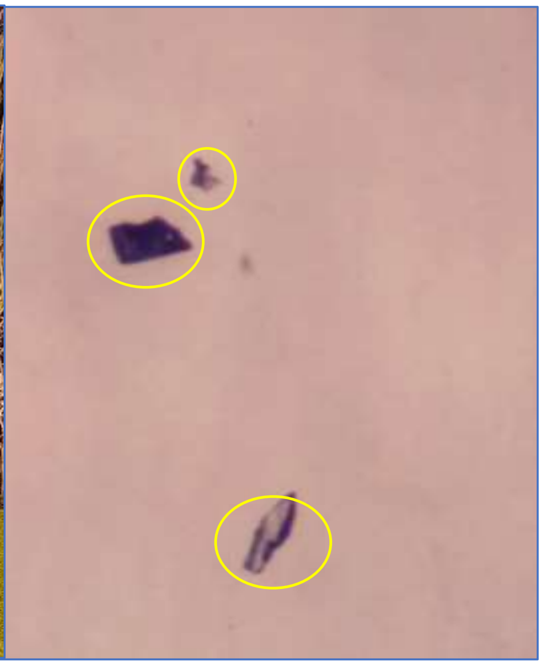
Constructed stormwater ponds and wetlands remove pollutants through a variety of mechanisms, and over time develop their own biological community of flora and fauna. It is the biota of the wetland community that allows the system to provide more than a settling process for TSS. As the system develops, and the biological diversity increases, nutrients, metals and carbon are retained. Recent studies have also demonstrated that the wetland and ponds can become a sink, or source for MP.

Samples were taken in the water column of two constructed wetlands 6 days after the last rainfall event, where it had rained just over 4 mm in a 24 hour period. One wetland was located in a commercial / light industrial subdivision where some construction is still occurring (Figure 4). The second sample was taken at a residential subdivision (Figure 5 & 6).

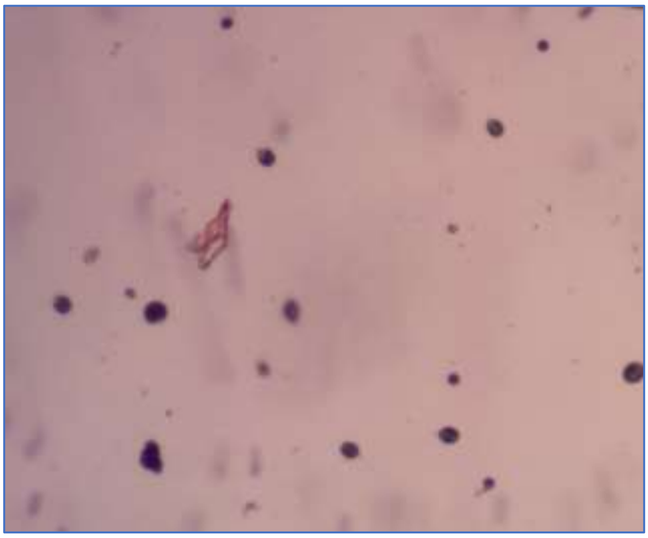
Fundamental analysis of the sample from the industrial subdivision yielded few MP particles. The only identifiable particles were two dark coloured fibres, which could have been part of degraded silt fencing from a nearby construction site.

Photograph 6 & 7: Fibre MP (inset) in a wetland within a commercial light industrial subdivision at the end of a treatment train.

The sample taken from the residential wetland held a greater number and variety of MP, including particles and fibres within the water column. Among the identifiable particles was a piece of a plastic bag shown in Figure 6. The wetland in the residential area showed evidence of an algal bloom on the day of sampling. Moreover, the upstream raingardens and vegetated swales appear to have not been maintained, in terms of plant density and mulch replacement.

Photograph 8 & 9: *MP (right) in a wetland (left)within a residential subdivision at the end of a degraded treatment train.*




Photograph 8 & 9: *MP in the residential subdivision showing a plastic bag fragment (right) and unidentified red fibres.*

The residential area wetland gets significantly more foot traffic than the one in the commercial subdivision, though the area of catchment and percentage of impermeable area is similar. Also previous studies [7] have demonstrated that land use plays a role in both the type and density of MP in stormwater ponds. Where there is less foot traffic in the contributing catchment there are less MP within the water column. Few studies have been completed looking at wetlands serving motorway catchments and the make-up of MP within the sediment. However, MP from tires have a specific gravity greater than 1, and, as such, will tend to sink more quickly than packaging and food wrappers, which tend to make up the larger portion of MP sourced from residential areas.

A detailed investigation of a stormwater detention and treatment pond found that the largest component of MP was stored in the sediment, with the second largest component being stored in the fauna [13]. The pond, that has a residence time of 10 days, had been operating for 30 years, and serves a 166 ha urban catchment. The average ratio of MP mass concentrations in the samples collected was 96,000(sediment): 3,100 (fauna): 1(water column). Curiously the study found the larger portion of MP found in the sediment were PP and PE, both with specific gravity of less than 1. Moreover, PP particles with length to width ratios of 5:1, which should have been buoyant, were found in the sediment. The study surmised that biofilms, likely ballasted materials and biological uptake by microorganisms, allowed the particles to sink to the bottom and become sequestered in the sediment.

A second study examined 2 stormwater ponds, including the one previously mentioned, and constructed wetlands used for tertiary wastewater polishing [14]. Residence times (the time water was meant to be detained prior to release) ranged from 2 days to 11.5 days. All four facilities showed a >90% reduction of MP in general. However, the wetland with the shortest residence time only demonstrated a 73% removal of MP >0.3 mm. The decreased efficiency of reduction of the larger sized MP, coupled with the short residence time, suggestions that larger particles will take longer to either have biofilms develop, or be ingested by fauna.

5.4.1 WASTEWATER TREATMENT PONDS AND MP REMOVAL

Wastewater is known to be a significant source of MP, particularly textile fibres from washing machines. A case study from NZ [3] found the greatest concentrations of fibre MP to be centred on the Manakau Harbour, and other areas which have discharges of treated wastewater. Wastewater treatment technology for settling MP out of the wastewater stream can play a part in promoting settling of MP in wetlands and stormwater ponds. Flocculation and coagulation have proved effective [15]. Laboratory testing flocculants on water samples with a pH of 7.5., showed a weathered MP settling of 97%, and pristine removal of 82%. As most of the MP entering stormwater ponds is secondary, flocculation may prove to be an effective tool. There is a suite of newer flocculants, which are produced from chiton, and are 100% biodegradable, which may prove useful in promoting settling of MP in wetlands and stormwater ponds. Further testing will need to occur.

6 THE TREATMENT TRAIN OVERHAUL:

The pathways of plastics and micro-plastics into the aquatic environment are complex, and the science is young. Preventing plastics from entering the aquatic environment will take a holistic multidisciplinary approach, involving engineers, scientists, educators, policy makers and landscape designers. The treatment train for reducing plastic entering the environment will require a few more tools.

6.1 POLICY & EDUCATION:

Policy and education are the more esoteric, yet unequivocally important, tools in the treatment train. New Zealand may be too small a country, and the omnipresence of plastic within the environment may be too large a problem, to allow for 78 separate pieces of legislation in 78 local, regional and unitary councils. A national target is likely needed as open waterways do not adhere to Council Boundaries. The EU has recently proposed a common plastics strategy for the EU, as part of the move towards a more circular economy.

The numbers showing how much plastic waste is generated by New Zealanders every day, compared to other countries of similar size, indicates that policy changes are needed. Plastic has always been considered to be solid waste; considering the health implications to humans and other species, it is time for a reclassification. Plastics must become reclassified as a constituent of concern.

Altering population behaviours takes education and the fates and dangers of plastic waste could be included as part of our New Zealand school curriculum. While schools proved to be amongst the cleanest catchpits assessed in the catchpit audit, the behaviour that young children learn to value at school will have a spill over effect into the wider community. Additionally, adopting more green infrastructure in community spaces, which adds amenity value and having some signage providing information about how the space helps the environment will contribute to educating the general population.

Research and sharing of knowledge across the three waters disciplines can also be part of education around MP, thus developing and honing both existing and new methodologies around MP removal from the three water streams.

6.2 GPTs

GPT situated along roads and transportation corridors will reduce the volume of macro plastics entering the stormwater system. Every catchpit should include a GPT, especially those in commercial centres. The success of GPT along roading and transport corridors will also require an agreement between councils and the roading authorities for maintenance. In the past, both parties have been resistant to installing any kind of GPT for fear of the maintenance costs. However the environmental and human health costs of plastic entering the freshwater environment are starting to outweigh the maintenance costs. The more macro-plastic that gets excluded from the stormwater stream the less MP will need to be addressed later.

6.3 BIORETENTION DEVICES

Bioretention devices are a powerful tool for both removal of macro plastics and MP. The problem is the bioretention devices are not a go to for many stormwater engineers. Moreover, developers still have an attitude of 'what is the least I can do to get this through the Council.' Where urban commercial centres and transport hubs are being either renewed or purpose built from scratch, bioretention devices need to be included as part of the design. Often landscape and green areas are required as part of the design. In such a situation it is vital to get the stormwater engineer and landscape designer working together before the drawings hit the page.

6.4 PROPRIETY TREATMENT DEVICES

There is no standardised national testing of proprietary devices in New Zealand. We know from on-site wastewater treatment, that standardized testing allows the designers to know efficiency, capabilities, maintenance requirements and OPEX costs with reasonable certainty. Such a system does not exist in the stormwater sector. Reliance on overseas assessments is useful, particularly if the assessment has come from the US, Canada or the EU. Where a device has no overseas assessment, it is difficult to determine what the actual field performance will be. Establishing a benchmark that can either depend on overseas independent testing, or NZ based testing, will ensure that the proprietary treatment device being installed will achieve the target removal of MP.

6.5 WETLANDS AND STORMWATER PONDS

For wetlands and stormwater ponds to be a sink rather than a source of MP entering natural freshwater systems, residence times need to be long enough to allow for biological settling of MP. The ultimate fate of sediments accumulating in constructed wetlands and ponds needs to be considered as part of the design life. Employing flocculation methodologies already employed in wastewater and sediment pond treatment may also provide a useful part of treatment. Where land area allows wetlands act as good polishing devices at the end of the treatment train.

7 CONCLUSIONS

Plastic and MP are ubiquitous throughout freshwater systems. Reducing macro plastics from entering the environment at all is the first step in MP reduction. Looking at the total plastic waste produced by each New Zealander on a daily basis, policy and legislation around plastic packaging must change. Moving towards a more circular economy, in terms of the waste streams, and returning to the concept of the importance of being a 'Tidy Kiwi' in our small island nation, will help reduce the volume of MP entering the aquatic environment.

In terms of stormwater treatment, the following can positively impact MP removal:

- Municipalities and road operating authorities installing and maintaining GPTs to treat road runoff.
- New development and redevelopment being fitted with either bioretention devices, or where space is limited, proprietary treatment devices.
- Setting up an independent body to assess the effectiveness of proprietary stormwater treatment devices available in NZ.
- Increasing wetland residence times to allow for MP settling.
- Collaborative research across disciplines with the goal of MP reduction.

While some will argue the expenditures involved, it must be weighed against the human health risks as well as the environmental costs.

ACKNOWLEDGEMENTS

The presenter would like to acknowledge, Peter Alderton, Debbie Keal, Brett Chick and Nick Holding at ACH Consulting Ltd for their support in completing this paper. Also thanks to Petra Saecker-Battley, Farzin Golzar, Clyde d'Souza, Lincoln Blair and Kimi Mikaere for helping with sampling, catchpit audits and road litter surveys. Special thanks to Darren Tiddy and Braden Van Leer, for use of the microscope and assistance in using the microscope.

REFERENCES

[1] Lisa Anne Hamilton and Steven Feit at CIEL; Carroll Muffett and Steven Feit. (2019) Plastic & Climate the hidden costs of A Plastic Planet: Center for International Environmental Law.

[2] Arianna Bellasi, Gilberto Binda, Andrea Pozzi, Silvia Galafassi, Pietro Volta and Roberta Bettinetti, Microplastic Contamination in Freshwater Environments: A Review, Focusing on Interactions with Sediments and Benthic Organisms: Environments 2020, 7, 30

[3] Goldy De Bhowmick, Ajit K. Sarmah, Brajesh Dubey Microplastics in the NZ environment: Current status and future directions, Case Studies in Chemical and Environmental Engineering Volume 3, June 2021, 100076

[4] Keep New Zealand Beautiful National Litter Behaviour Research 2018

[5] Office of the Prime Minister's Chief Science Advisor, Kaitohutohu Mātanga Pūtaiao Matua ki te Pirimia. (2019)Plastics and the environment.

[6] Yolanda Pico, and DamiàBarcelo, Analysis and Prevention of Microplastics Pollution in Water: Current Perspectives and Future Directions *ACS* Omega 2019 4 (4), 6709-6719

[7] Fan Liu, Kristina Borg Olesen, Amelia Reimer Borregaard, Jes Vollertsen (2019) Microplastics in urban and highway stormwater retention ponds, Science of The Total Environment, Volume 671, 25 June 2019, Pages 992-1000

[8] Martin Wagner, Christian Scherer, Diana Alvarez-Muñoz, Nicole Brennholt, Xavier Bourrain,Sebastian Buchinger, Elke Fries, Cécile Grosbois, Jörg Klasmeier, Teresa Marti, Sara Rodriguez-Mozaz, Ralph Urbatzka, A Dick Vethaak, Margrethe Winther-Nielsen & Georg Reifferscheid, Microplastics in freshwater ecosystems: what we know and what we need to know. Environmental Sciences Europe 2014, 26:12

[9] Antonio Ragusa, Valentina Notarstefano, Alessandro Svelato, Criselda Santacroce, Piera Catalano, Federico Baiocco, Oliana Carnevali, Fabrizio Papa, Mauro Ciro Antonio Rongioletti, Elisabetta Giorgini, Simonetta Draghi, Elisabetta D'Amore, Denise Rinaldo, Maria Matta & Elisabetta Giorgini, Plasticenta: First evidence of microplastics in human placenta. Environment International, Volume 146, January 2021, 106274

[10] Gilbreath A., L. McKee, I. Shimabuku, D. Lin, L. M. Werbowski, X. Zhu, J. Grbic, and C. Rochman. 2019. Multi-year water quality performance and mass accumulation of PCBs, mercury, methylmercury, copper and microplastics in a bioretention rain garden. SFEI Contribution #872. San Francisco Estuary Institute, Richmond, CA.

[11] Kelsey Smyth, Jennifer Drake, Yourong Li, Chelsea Rochman, Tim Van Seters, Elodie Passeport, Bioretention cells remove microplastics from urban stormwater, Water Research, Volume 191, 2021.

[12] Davoudi, Simin & Brooks, Elizabeth. (2013). Tackling Low Standards in Local Environmental Quality: GURU Electronic Working Paper 50.

[13] Kristina Borg Olesen*, Diana A. Stephansen, Nikki van Alst and Jes Vollertsen, Microplastics in a Stormwater Pond, Water 2019, 11, 1466

[14] Coalition Clean Baltic, 2017. Guidance on concrete ways to reduce microplastics inputs from municipal stormwater and waste water discharges. Uppsala, Sweden, 2017

[15] Mathieu Lapointe, Jeffrey M. Farner, Laura M. Hernandez, and Nathalie Tufenkji, Understanding and Improving Microplastics Removal during Water Treatment: Impact of Coagulation and Flocculation. Environ. Sci. Technol. 2020, 54, 14, 8719–8727