Generation and transport of plastic in an urban stormwater system

Production et transport de plastique dans un système d'eaux pluviales urbaines

Bradley Lamont*, Graham Jenkins*, Emad Kavehei*

* School of Engineering and Built Environment, Griffith University,Gold Coast Campus, 4222 Queensland Australia (graham.jenkins@griffith.edu.au)

RÉSUMÉ

Le plastique est un matériau polyvalent qui a été inventé pour la première fois en 1907. Depuis les années 50, le plastique a évolué et est devenu un matériau qui apparaît dans presque toutes les facettes de la communauté urbaine moderne. Malheureusement, cela signifie que de nombreuses matières plastiques pénètrent dans le système de drainage urbain et finissent par être des débris flottants dans nos océans. La décomposition de ce plastique en morceaux plus petits, éventuellement en micro-plastiques, signifie que ce matériau a commencé à apparaître dans de nombreuses chaînes alimentaires dans le monde. L'étude décrite dans cet article étudie la production et le transport de pollution plastique dans la région de la Gold Coast City Council, située dans le sud-est du Queensland, en Australie. Il a montré que les pièges à polluants bruts peuvent jouer un rôle important dans l'interception de cette pollution lorsqu'elle traverse le système de drainage urbain. La gestion du problème nécessitera un investissement important dans la conception urbaine sensible à l'eau dans l'ensemble du territoire du conseil municipal. Il est démontré que la maintenance joue un rôle important dans l'efficacité de ces systèmes dans la réduction de cette pollution plastique atteignant Broadwater et l'Océan Pacifique.

ABSTRACT

Plastic is a versatile material that was first invented in 1907. Since the 1950's plastic has evolved and grown into a material that appears in almost every facet of the modern urban community. Unfortunately, this means that many items of plastic make their way through the urban drainage system and end up as floating debris in our oceans. The break down of this plastic into smaller pieces, eventually into micro-plastics means that this material has now started to appear in many of the food chains in the world. The study described in this paper investigates the generation and transport of plastic pollution in the Gold Coast City Council area, located in South East Queensland, Australia. It has shown that gross pollutant traps can play a significant role in the interception of this pollution as it flows through the urban drainage system. Management of the problem will require a significant investment in Water Sensitive Urban Design throughout the city council area. Maintenance is shown to play a significant role in ensuring the efficiency of these systems in the reduction of this plastic pollution reaching the Broadwater and Pacific Ocean.

KEYWORDS

Environmental impacts, gross pollutants, water sensitive urban design, plastic, stormwater

1 INTRODUCTION

Leo Hendrik Baekeland created the synthetic polymer known as plastic in 1907. Due to its versatility and low cost, this product underwent a massive explosion in production rates, exponentially increasing since the 1950's. Plastic begins its life as raw materials including cellulose, coal, natural gas, salt, and crude oil. These materials are combined together in a factory and fabricated into an almost infinite number of shapes and sizes to accommodate the relative demand of the economy. They are then sold and transported to various industries like shipping, cosmetic, textile and clothing, food and drink, agriculture, wastewater, and construction (Simon & Schulte, 2017). The final stage of the plastic life cycle is where a large amount of variability and unaccountability occurs. Essentially, one or more of three different processes can describe the fate of plastic: recycling, incineration or discarded waste. Reisser et al., (2013) estimates that in 2013, out of 5700 tonnes; 9% is recycled and reused, 12% was incinerated and 79% was accumulated as waste. While much of this waste ends up in landfill, a large amount makes its way into the natural environment.

When the plastic reaches the environment it plastic begins to degrade due to different processes including photo oxidation, thermal, ozone-induced, mechanical, or chemical degradation. This leads to the fragmentation of whole size pieces into: meso, macro, micro and nano sized particles. After the plastic starts to break down it can follow one of many different paths. As the plastic is either less or more dense than seawater, it has two pathways. When the plastic is lighter than seawater, it will float through the ocean's surface collecting organisms from different ecosystems and depositing them into new environments (Seltenrich, 2015). The plastic can also sink, as becomes negatively buoyant due to fouling by organisms and adherence of particles (Woodall et al., 2014). As it sinks, the plastic is mistaken as food by very low, trophic level organisms such as zoo and phytoplankton Seltenrich, (2015). This entry point of the food chain leads to a bioaccumulation of the plastic's chemicals through the organism's gut (Moore, 2008, Koelmans, 2015, Seltenrich, 2015, Dawson et al., 2018). If the marine organisms do not consume them, they remain in the sediment where it takes an estimated hundreds to thousands of years to degrade (Van Cauwenberghe et al., 2013, Woodall et al., 2014).

One of the other pathways of plastic and micro plastic is the hydrologic cycle; the fibres are evaporated from the sea surface and released as atmospheric fallout (Dris et al., 2016). Prata, (2018) reports micro plastic being detected in airborne pollution. Rillig, (2017) has been a leading the research in micro plastic in the terrestrial ecosystem. The study follows the path of micro plastics in treated water as it is dispersed over agricultural land and the role in which earthworms transport micro plastic to deeper levels of the soil. Micro plastic in soil lead to contamination in ground water and to other soil biota (Rillig, 2017).

1.1 Plastic in the Environment

Many researchers have attempted to quantify the magnitude of plastic pollution, (Eriksen et al., 2014, NOAA, 2017, Reisser et al., 2013) just to name a few. Eriksen et al., (2014) has estimated that there are more than 5 trillion pieces of plastic weighing over 226,000 tonnes floating in the sea. Common methods used in these studies include sample collection and extrapolation, modelling the ocean currents and estimating yearly production and discard rates. It is from the quantification of this problem that scientists, engineers, and politicians will be able to work together to invoke change and implement management strategies to combat the problem.

To better manage plastic pollution, interception points have to be identified along the plastic's life cycle and combatted from various fronts such as government, industry, public, and structural controls. As plastic is so far embedded in the world's economy, eliminating the product from daily lives will cause negative impacts to the economies if it is not properly managed. For example, Kenya banned plastic bags in 2017, joining around 30 countries who have implemented restrictions on plastic bags. Kenya's government implemented fines of up to $40,000, and threatening up to four years imprisonment for anyone producing, carrying or selling plastic bags (The Guardian, 2018). The country has seen positive environmental effects but negative economic impacts with a multitude of businesses struggling to adapt.

Tackling this problem requires management over a multitude of approaches including policy and legislation, public awareness and perception, education, recycling, manufacturer responsibility, urban drainage, ocean and beach clean-ups, and a social change in single use plastics. The European Union has implemented a ban on single use plastics, with hopes of a complete ban by 2021. As of November this year, the Queensland Government in Australia will commence a take back scheme, rewarding the return of plastic containers with a 10 cents refund.

2 PLASTICS IN STORMWATER

Stormwater drainage systems are a key pathway of plastic pollution in the urban and natural enviornment. As plastic is largely discarded and associated with litter, when a large rain event occurs this litter is washed down the drains. These drains transport the litter through systems that eventually lead to rivers, waterways and the oceans.

Implementing systems that are able to trap the plastic will impede one of the major pathways for plastic into the ocean. Gross pollutant traps (GPT) can play a significant role in the trapping of litter and plastics as they flow through the urban drainage systems. Two main characteristics determine the long-term success of a GPT: efficiency, and maintenance. A low efficiency GPT means that a high number of pollutants bypass the trap and continue down water. The efficiency of the trap largely relies on the frequency of maintenance. Poor maintenance results in neglect of the GPT, leading to a build-up of pollutants that eventually breakdown, becoming a source for micro plastics (Allison et al., 1998).

The most common debris traps used in Australia are trash racks, floating booms, and gross pollutant traps (Allison et al., 1998). Whereas through the progression of water sensitive urban design and its relative implementation to local councils like the Gold Coast City Council, a number of urban drainage treatment systems are available. Systems like swales, bio retention swales, sediment basins, bio retention basins, constructed stormwater wetlands, infiltration measures, sand filters, aquifer storage, and filter plants all allow interception points for plastic.

This study investigates the generation of plastics in urban areas and its transport through the urban drainage system to the receiving waters. The study focusses on the pathways of plastic in the Gold Coast City Council area, located in South East Queensland, Australia. The study uses the MUSIC – Model for Urban Stormwater Conceptualisation to model the generation of plastic in the form or gross pollutants throughout the council area. The generated plastic is then geo-referenced through a GIS to identify the pathways of the plastic towards the Broadwater and Pacific Ocean.

3 METHODS

The Gold Coast City Council is located on the coast at the south eastern edge of Queensland, Australia. The city includes a range of different land uses from urban residential, light and heavy industry, farming and natural forests. The city faces onto the Pacific Ocean with many sand beaches which are popular with surfers and tourists. This means that although there is a large resident population, the city has a strong focus on tourism, especially within the coastal zone. The city also includes a number of rivers and waterways which also experience significant impacts from recreational boating and tourism.

The city has an area of 1,358 km^2 and has a population of approximately 556,000 people. The climate in the Gold Coast is defined as being sub-tropical with no dry season, using the Koppen classification. The annual average rainfall in the city is approximately 1500 mm per year. The subtropical nature of the climate means that although there is no dry season, the major rainfall events tend to happen as heavy storms which are more often occurring in the summer months.

The Gold Coast City Council area is comprised of 81 suburbs. The area is also made up of five (5) main rivers which mostly drain into the Broadwater, which is a coastal estuary, protected from the open ocean by the sand islands of North and South Stradbroke. Most of the urban creeks in the council area drain directly into one (1) of these river systems and deliver their runoff into the Broadwater. Eventually this stormwater will make its way top the open Pacific Ocean through the Gold Coast Seaway.

The study undertaken uses the urban stormwater modelling system MUSIC to model the generation and transport of stormwater and gross pollutants in each of the suburbs in the Gold Coast city Council area. The results of the model study have then been inputted into a GIS to identify the major locations of the plastic sources within the council area. This geo-referencing of the pollution generation is important due to the significant influence of the major river systems in the area as part of the overall drainage of stormwater and pollution into the Broadwater and the Pacific Ocean. This data has then been analysed to investigate management strategies to intercept and eliminate this plastic pollution before it reaches the ocean. An informal audit of a section of one of the rivers has also been undertaken to provide a validation of the data generated using the numerical model.

4 STUDY RESULTS

The model study has identified that more than 8,000 tonnes of plastic pollution is generated and transported through the Gold Coast City Council area each year, on average. The importance of this

number is that this is not a point source pollutant, but is distributed throughout the city council area. The nature of plastic as a pollutant is that it tends to take many decades or centuries to completely breakdown in the natural environment. Most importantly, the plastic will break down into smaller pieces and micro-plastics as part of this degradation process. This will have significant impacts on the natural environment if not managed efficiently. Possibly the most frightening part of this scenario is the impact this will and already is having on human health through the consumption of micro-plastics due to the consumption of sea food.

Management of the plastic pollution in the Gold Coast City Council area requires a coordinated approach using the principles of Water Sensitive Urban Design. The use of GPT's has been shown in this study to produce the best economic and environmental benefits in the reduction of plastic pollution in the city council area. However, other systems such as constructed wetlands, swales and bioretention systems are shown to play their part in the overall reduction of plastic as a pollutant. The study also indicates that appropriate maintenance plays a significant role in the management of this urban pollution problem.

5 CONCLUSION

Plastic is a versatile material that was first invented in 1907. Since the 1950's plastic has evolved and grown into a material that appears in almost every facet of the modern urban community. Unfortunately, this means that many items of plastic make their way through the urban drainage system and end up as floating debris in our oceans. The break down of this plastic into smaller pieces, eventually into micro-plastics means that this material has now started to appear in many of the food chains in the world.

The study described in this paper investigates the generation and transport of plastic pollution in the Gold Coast City Council area. It has shown that gross pollutant traps can play a significant role in the interception of this pollution as it flows through the urban drainage system. Management of the problem will require a significant investment in Water Sensitive Urban Design throughout the city council area. Maintenance is shown to play a significant role in ensuring the efficiency of these systems in the reduction of this plastic pollution reaching the Broadwater and Pacific Ocean.

LIST OF REFERENCES

Allison, R., Walker, T., Chiew, F., O'Neil, I., & McMahon, T. (1998). Gross Pollutant Removal From Urban Waterways. Cooperative Research Centre for Catchment Hydrology.

Dawson, A., Kawaguchi, S., King, C., Townsend, K., King, R., Huston, W., & Bengtson Nash, S. (2018). Turning microplastics into nanoplastics through digestive fragmentation by Antarctic krill. Nature Communications, 9(1).

Dris, R., Gasperi, J., Saad, M., Mirande, C., & Tassin, B. (2016). Synthetic fibers in atmospheric fallout: A source of microplastics in the environment?. Marine Pollution Bulletin, 104(1-2), 290-293.

Eriksen, M., Lebreton, L., Carson, H., Thiel, M., Moore, C., & Borerro, J. et al. (2014). Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. Plos ONE, 9(12),

Koelmans, A. (2015). Modeling the Role of Microplastics in Bioaccumulation of Organic Chemicals to Marine Aquatic Organisms. A Critical Review. Marine Anthropogenic Litter,

Moore, C. (2008). Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research, 108(2),

NOAA. (2017). Quantification of Microplastics on National Park Beaches. NOAA. Retrieved from https://marinedebris.noaa.gov/reports/quantification-microplastics-national-park-beaches

Prata, J. (2018). Airborne microplastics: Consequences to human health?. Environmental Pollution, 234, 115-126.

Reisser, J., Shaw, J., Wilcox, C., Hardesty, B., Proietti, M., Thums, M., & Pattiaratchi, C. (2013). Marine Plastic Pollution in Waters around Australia: Characteristics, Concentrations, and Pathways. Plos ONE, 8(11

Rillig, M., Ziersch, L., & Hempel, S. (2017). Microplastic transport in soil by earthworms. Scientific Reports, 7(1).

Seltenrich, N. (2015). New Link in the Food Chain? Marine Plastic Pollution and Seafood Safety. Environmental Health Perspectives, 123(2).

Simon, N., & Schulte, M. (2017). Stopping Global Plastic Pollution: The Case for an International Convention (43rd ed.). Creative common license.

The Guardian. (2018). Kenya brins in the worlds toughest plastic bag ban: four years jail of $40, 000 fine, pp. 1/2. Retrieved from https://www.theguardian.com/environment/2017/aug/28/kenya-brings-in-worlds-toughest-plastic-bag-ban-four-years-jail-or-40000-fine

Van Cauwenberghe, L., Vanreusel, A., Mees, J., & Janssen, C. (2013). Microplastic pollution in deep-sea sediments. Environmental Pollution, 182, 495-499.

Woodall, L., Sanchez-Vidal, A., Canals, M., Paterson, G., Coppock, R., & Sleight, V. et al. (2014). The deep sea is a major sink for microplastic debris. Royal Society Open Science, 1(4), 140317-140317.