Evaluating the effectiveness of stormsewer inlets to capture microplastics and tire wear particles of varying densities in roadway runoff

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Desired terms of assistantship: Spring 2021/Summer 2021

Abstract:
Microplastics are a pervasive pollutant in the environment. Microplastics are small polymer particles <5 mm in dimension and include diverse materials and sources. Tire wear particles (TWP) are an understudied class of microplastics that are small fragmentations of a vehicle’s tire produced by the friction interaction of tires on roadway surfaces. The composition of TWP makes them difficult to identify using spectrographic analysis or GC-MS analysis. Because of this, there is no standard SOP to identify concentrations of TWP in the environment. Microplastics found on roadways can end up in surrounding environments through stormwater runoff. Stormwater systems designed to mitigate sediment dispersal are available but have not been fully evaluated for the effectiveness in capturing lower-density sediments in runoff like microplastics and TWP. This study will evaluate the initial loadings of TWP on the roadways at selected sites and the effectiveness of different types of stormwater inlet particle capture devices to prevent the dispersal of microplastics and TWPs.
Statement of Interest

The journey I took to get into the environmental field was a bit convoluted. I had always wanted to be dedicated to a greater good in society. In high school and most of my undergraduate education, I focused on medicine and strived to become a physician. This background in medicine and a focus on studies in biology and chemistry helped to enhance my observational skills. I began asking questions like why there were higher rates of issues such as asthma in certain places, why were the years of drought on the west coast getting longer, where had all the bees gone? I ended up switching to Chemical Engineering with a focus on sustainable processes.

Growing up with constant drought in the high desert of Oregon I always understood how important and vital water was to a community and what happens where there is not enough of it. I believe that potable water is an absolute human right, and everyone should have access to it regardless of where they live or what their socioeconomic level is. As climate change progresses, access to potable water is going to become difficult. Ensuring that freshwater systems are not being exploited as well as improving the reuse and recycle process of wastewater systems can help to ensure there will be fresh water for future generations. There is a major lack of consistency amongst the standards for wastewater and stormwater treatment and discharge into the environment.

My proposed thesis project will investigate the transport and fate of microplastics, and chemicals associated with these pollutants as they move from roads, through stormwater systems, into the environment. The impact of stormwater is a growing issue especially in urban centers like Seattle, Washington, which has experienced fish die-offs and Orca whale infertility in Puget Sound and nearby rivers. These issues have been traced back to stormwater runoff from the city and nearby neighborhoods into its surrounding bodies of water.

This project will require a background of diversified skills in analytical chemistry, conservation biology, statistics, and ecology. Surveys of the Town of Mount Pleasant’s stormwater infrastructure will also need to be performed, as well as analysis of the town’s road and stormwater system cleaning cycles. This is a multidisciplinary approach to the problem and my classes such as Social Science Methods, Pollution in the Environment, and Public Policy have helped to expand my understanding of the techniques involved to execute the project properly.

In my post-College of Charleston career, I would like to go into the field of environmental consulting working with companies, government entities, or non-profit groups concerning wastewater and stormwater containment and pollutant removal. Preventing hazardous waste from entering bodies of water in the first place and helping to ease the burden of water pollution. My background in chemical engineering and my current studies in both environmental science and public administration would help to synthesize all these different aspects of my knowledge for the best use.
One of the more recently identified and ubiquitous pollutants throughout the world are microplastics. Microplastics are formed in several different ways, either being directly manufactured as microplastic or fragmented pieces of a larger plastic product. They are often defined to range in size from 1 µm to 5 mm (Coppock et al., 2017). Tire wear particles (TWP) are a type of microplastic generated by the friction interaction from tires on roadways during driving. TWP is estimated to contribute between 5-30% of all non-exhaust related emissions from vehicles (Wagner et al., 2018). Global estimations of the number of microplastics and TWP produced and entering nearby bodies of water are lacking. However, a study performed by Sutton et al., (2019) estimated the annual discharge of microplastics into the San Francisco Bay was around 7 trillion microplastic per year. The Sutton et al., (2019) study found that the majority of microplastics found in stormwater came in two varieties, fragments, and fibers, with nearly half of the fragment microplastics being TWP.

Tire composition varies depending on the type and performance of the vehicles which can affect TWP emission. Tires often come with a mixture of two very different types of rubber, natural rubber, and synthetic rubber. Airplanes, heavy trucks, and high-performance vehicles typically use tires that are composed of 80% natural rubber and 10% synthetic rubber, whereas lighter-weight vehicles such as commuter vehicles use tires composed of 75% synthetic rubber and 15% natural rubber (Camatini et al., 2001). There are also many chemical additives in tires, such as heavy metals, antioxidants, and plasticizers. TWP typically enter the environment either as small particles emitted into the air and are prone to dispersal via wind or as larger particles that collect on roadways and enter habitats via stormwater (Jan Kole et al., 2017). How a car is driven also has a significant factor in the size and amount of TWP being released into the environment. The style of driving between urban and highways has been shown to produce TWP at a significantly higher rate (Blok, 2005). Driving style and rubber type can also affect the density range of the TWP produced. TWP have been estimated to have a range of densities from 1.5 to 2.25 g/cm³ although lighter fractions have also been found (Leads and Weinstein, 2019) and the density of a TWP can vary depending on what is embedded or encrusted on it (Kayhanian et al., 2012). This range in densities and the encrustations on the particles can make it difficult to identify TWP in sediment.

Along with the components of rubber and heavy metals (such as Zn, Cu, Cr, Pb), TWP are also known to carry polycyclic aromatic hydrocarbons (PAHs) and benzothiazoles, which are hazardous compounds made from crude oil (Wagner et al., 2018). TWP are reported to range in size from 5.0 µm to 220 µm (Wagner et al., 2018). This drastic range in size affects how it will break down and leach chemicals in aquatic environments. A study conducted by Ellis and Mitchell (2006) found that runoff from highways contributed around 11% of heavy metal and hydrocarbon pollutants to receiving waters in the UK. Because of their size, composition, and density, exposure routes of TWP will be different depending on the food sources, size, and habitat of the lifeforms being affected (Wik & Dave, 2009). Tire composition can vary widely and will leach different kinds of toxic composition that will also vary in magnitude over time as the tire ages (Wik & Dave, 2005).

Due to their inconsistent morphology, TWP concentrations have been difficult to quantify in the environment. TWP contain a large amount of carbon black which makes it difficult to
identify by spectroscopic methods like Fourier Transform Infrared Spectroscopy (FT-IR) or Raman Spectroscopy (Wagner et al., 2018). There is also a lack of a certified analytical method for analyzing and quantifying TWP and microplastic concentrations (Klöckner et al., 2019; Sutton et al., 2019). For this reason, there are several different approaches to quantify TWP in environmental samples. There is a variety of protocols established for identifying microplastics that could be used to establish a routine protocol for identifying the concentration of TWP.

Microplastic and TWP have been linked to both lethal and sublethal toxicological effects on marine life in aquatic habitats, depending on material size, shape, and composition (Wik & Dave, 2009). Ingestion of microplastics can negatively affect food intake and reduce the amount of food available for growth and reproduction in an organism (Cole et al., 2015). Microplastics can contain harmful pollutants in concentrations up to one million times higher than surrounding seawater that may be detrimental to marine life through leaching or ingestion (Mato et al., 2001). Mutagenic, teratogenic, and estrogenic sublethal effects were observed in TWP leachate in a variety of aquatic organisms exposed to a concentration between 500 mg TWP/L and 500,000 mg TWP/L (Wik, 2008). Peter et al. (2018) linked cases of acute mortality episodes in Coho Salmon in the Seattle area to a chemical toxin found in TWP leachate. These incidents occurred after a flush runoff storm event which was hypothesized by Wik and Dave (2009) were the events that would cause the most risk to aquatic organisms.

**TWP in stormwater runoff and stormwater capture control systems and devices**

The fate and transport of TWP into water systems are still under investigation and the effectiveness of stormwater systems to remove TWP from outflows is unknown. Studies by Leads and Weinstein (2019) found that microplastics and TWP were widely distributed throughout the Charleston Harbor tributaries. They found that TWP were the second most abundant particle type in the tributaries of the Charleston Harbor, making up 17% of the total microplastics found (Leads & Weinstein, 2019). This shows a need to focus on microplastic and TWP retention by stormwater control systems. Charleston is home to many types of stormwater control systems that can be evaluated for their efficiency in capturing microplastics and TWP. There are different types of inlet particle capture devices installed in stormsewer drains. Figure 1 shows two different types of inlet capture devices. Photo A depicts a catch basin; a common type of sewer particle inlet capture device. Catch basins filter out particles by having them settle to the bottom of the basin through gravitation (Goodmanson Construction, 2020). Photo B is a 3D rendering of a CrystalClean Separator, a different type of inlet particle capture device that has been installed in parts of the Town of Mount Pleasant. CrystalSteam Technologies claims their devices can remove up to 89% of the debris that flows through them (CrystalSteam Technologies, 2020). However, neither of these types of inlet particle capture devices have been evaluated for their efficiency in capturing lower-density sediment materials such as microplastics and TWP.
Figure 1: Two different types of sewer particle capture devices. Photo (A) depicts a catch basin inlet capture device (source: Goodmanson Construction, 2020). Photo (B) shows a CrystalStream Technologies particle capture device (source: CrystalStream Technologies, 2020).

**Objectives**

   a. Additional method analysis is to evaluate if the H\textsubscript{2}O\textsubscript{2} digestion step in the 2-stage density separation method affects the structure of the TWP.
   b. If H\textsubscript{2}O\textsubscript{2} is found to be an issue, evaluate an alternative that could replace H\textsubscript{2}O\textsubscript{2} in the digestion step of the 2-stage density separation method.
2. Characterize types and concentration of TWP and microplastics in roadway dust both before and after a storm event.
   a. The accumulation and movement of different densities of TWP are unknown. We would expect to see a higher percentage of high-density particles on the roadways after a storm event.
3. Evaluate how effective stormwater sewer inlets are in capturing both high and low-density microplastics and TWP.
   a. A survey of different structure types will be conducted in the Town of Mount Pleasant and the industry literature.
   b. At least two different stormwater inlet types will be evaluated for effectiveness to capture particles by field sampling sediments.

**Methods**

*Location Selection [Objectives 2&3]*

One study site identified for the sample collections is a stormwater catchment near the Landings Run neighborhood off Whipple Road in Mount Pleasant, South Carolina (Figure 2). This site was chosen in collaboration with the Stormwater Manager of Mount Pleasant for the variety of stormwater mitigation measures it has in place such as a stormwater pond, and the advanced inlet...
particle capture device installed (produced by CrystalStream Technologies) shown in Figure 1. At least three other sites with catch basins and inlet particle capture devices will be identified and evaluated in this study as surveys of stormwater systems are completed.

**Site A.** Site A is marked in red in Figure 2 and is shown in an aerial view in Figure 3. This site contains the inlet structures for stormwater management that are being targeted to evaluate their effectiveness in preventing both high- and low-density TWP from entering surrounding bodies of water. The area highlighted in yellow is the street where samples will be collected at regular intervals both before and post a storm event. These will give a baseline comparison of the concentrations of TWP both before and after a storm. The red circle is the inlet capture device. To obtain samples and evaluate the concentration of TWP in the device we will be working with the town of Mount Pleasants public services department. Working with the Town of Mount Pleasant’s stormwater division will allow us to gain access and enter these inlet capture devices when they perform maintenance and obtain sediment samples from inside the device. Figure 4 shows a ground-level view of both the inlet capture device from the outside and the stream where the device empties.

Figure 2: Large scale map of the testing locations in Mount Pleasant, South Carolina. Site A marked in red is where the newer type of inlet capture device is located. Site B marked in blue is where a more traditional stormwater capture device and the stormwater pond is located (USGS, 2019).
Figure 3: Aerial view of Site A. The inlet capture device is outlined in a red circle. The blue box is the outlet from this capture device. The area highlighted in yellow is where roadside samples will be taken to evaluate what is entering the inlet capture device (Google.com, 2020).

Figure 4: Picture A is a backside view of the inlet capture device to where it drains. Two drains are exiting this area. Drain one (labeled in yellow) is an outlet from the opposite side of the street. Drain 2 is the outlet directly from the inlet capture device. Photo B is a topside view of the inlet capture device and the two access points into the device.

Site B. Site B is marked in blue in Figure 1. It is located about 500 ft away from Site A. There is no inlet particle capture device at this site but there is a more typical catch basin inlet (Figure 1A) before runoff enters the stormwater detention pond as shown in Figure 5. The outflow of the stormwater ponds is highlighted with the blue square. Roadside samples will be taken in random quadrants along Whipple Road highlighted in yellow and in the catch basins.
Sample Collection and Preparation [Objectives 2&3]

Samples will be chosen from randomized quadrants along the curbside of study site catchments, such as along Whipple Road in the example sites above. Samples will be collected using non-plastic materials such as metal dustpans, glass sample bottles, and metal scoops. Both wet and dry samples will be collected from the roadside, inside the inlet capture device, and the runoff streams from the inlet capture devices. Samples will be collected on a semi-regular basis both pre and post-storm events. All samples will be weighed before being dried. Samples will be dried in Petri dishes at a low temperature of 70°C for up to 12 hours to avoid damaging the TWP in the samples. Following methods laid out by Mohamed Nor and Obbard (2014) and Klöckner et al. (2019) samples will be sieved at 63 µm and 1 mm to remove both the finer particles and the larger particles to isolate the dominant TWP and MP size fraction and prevent clogging of the equipment in later processing steps.

2-Stage Density Separation Method [Objective 1]

Density separation analysis in concept is simple; a matrix is allowed to settle in a solution of specific density to separate a high- and low-density fraction. However, because TWP have such a broad range of densities, a separation method must be employed to isolate this range of TWPs from the matrix that can interfere with TWP detection (i.e. asphalt particles and sand). For this research, the plan is to use a hypersaline solution with a density of 1.12 g/mL to separate the low-density TWP from the sample. This has been used in previous studies (Leads & Weinstein, 2019). We will add a second step to the density separation and use a high-density solution of sodium polytungstate (density of 1.9 g/mL). This should float the heavier TWP to the top where they can be easily filtered off (Klöckner et al., 2019). This approach will enable reporting of both low density and high-density TWP fractions, a distinction which may have implications for environmental transport in stormwater runoff. An example of the set-up for these different stages can be seen in Figure 5.
Organic Matter Digestion [Objective 1]

The organic matter digestion step is to remove organic particulates that could interfere with the detection of TWPs by microscopy. This is done by soaking the sample in a 10% H\textsubscript{2}O\textsubscript{2} solution, which is used widely for microplastic analysis (Wagner et al., 2018). Redondo-Hasselerharm et al., (2018) have reported that hydrogen peroxide does not break-down tire material but used larger pieces (mm scale) for their study, and Leads and Weinstein (2019) have used more dilute 1-3% H\textsubscript{2}O\textsubscript{2} solutions for their work. Because a more concentrated hydrogen peroxide solution will aid the destruction of less-deteriorated organic matter that is found in roadway samples, this project will first confirm that this digestion step will not break down the structure of a TWP and cause them to lose form and thus be miscounted.

Identification and Analysis [Objectives 2&3]

Samples isolated from the two stages are washed onto a gridded filter and examined under a stereomicroscope equipped with 5x-110x magnification and a digital microscope with image analysis software. Microplastics and TWPs will be enumerated using visual and physical probing criteria as described in work by previous College of Charleston students (Leads and Weinstein, 2019, Parker et al. *In review*). If particles are too numerous to count, a random subsample of the filter will be enumerated and scaled by area to estimate the total count on the sample filter.

Microplastic particles identified will counted and characterized by their size, type (fragment, fiber, foam or TWP), color, and shape following guidelines laid out by Leads & Weinstein, (2019). A subset of identified microplastics will undergo confirmation of material performed by Raman or FT-IR spectroscopy at partnering laboratories to check if the material is composed of a plastic polymer (Sutton et al., 2019). Microplastic and TWP counts will be standardized to sample size (counts per dry weight) to allow comparison between sites.

Numerous samples will need to be collected both pre- and post-storm to understand variability of microplastics found on the roadides over time and to account for any effect of storm event size. The change in number and percentage of low and high density particles found on the roadides...
for the pre- and post-storm sampling time-points will be assessed to give a general idea of the number of low-density particles that will be mobilized. Because the inlet particle capture devices can only be sampled when the Town of Mount Pleasant does maintenance, about every 6 months, the comparison between what is on the road what is captured will be done using a composition similarity analysis (e.g. by size, type, density).

Other ways to evaluate the concentration of microplastic and TWP will be considered. Vinylcyclohexene is an organic compound found in high concentrations in tire tread polymer and has been considered as a maker to find TWP concentrations in a sediment sample (Unice et al., 2012). Unice et al., (2013) used pyrolysis GC-MS analysis on sediment samples to find the concentration of TWP in sediment samples using vinylcyclohexene as a marker. The study of marker analysis in tires to find the concentration of TWP in a sediment sample is ongoing and will require further investigation. Analysis using pyrolysis GC-MS, or other such analyses will need to be conducted outside of the College of Charleston possibly through a partnered university.

**Initial Results**

In the fall of 2019, an analysis of the roadside concentration of TWP was conducted. This involved collecting samples from three roadway types with different traffic patterns. The three roadway types were: highway, low-speed urban, and suburban. Studies by Blok (2005) have shown that highways and urban streets produce TWP at a higher rate than other roadway types, although analysis of the densities of TWP produced on these roadways had yet to be conducted. Preliminary analysis using the 2-stage density separation method showed there is a significant amount of TWP on different types of roadsides. Figure 6 shows the amount of TWP counted after density separation for three sites tested. Glenn McConnell Highway and Bee Street in Charleston, SC had estimated concentrations exceeding one million TWP/kg of sample. Heavy metal analysis of the street dust by inductively coupled plasma-mass spectrometry (ICP-MS) was also performed, showing that the concentration of heavy metal pollutants scaled with the level of TWP contamination on the roadside.
Figure 6: Total number of TWP per kg of sample were compared to the concentration of trace metals in mg of metal per kg of sample.

Figure 7 shows the percentage of high-density vs. low-density particles that were found at the three sites. This kind of street-side analysis shows there is a significant amount of high-density TWP being generated that would have been missed if a 2-stage density separation were not used. But there was also between 5-32% of TWPs in the low-density fraction that may be more susceptible to be mobilized in stormwater runoff and less able to be captured in stormwater inlets relying on settling and sedimentation.

Figure 7: Pie charts of the three sites and their relative percentage of TWP at each site using the different separation methods.
Expected Results

This study will profile the type and concentration of microplastics and TWP on roadsides and through stormwater sewer catch basin technology. These profiles will help us to understand the movement of microplastics and TWP in the urban environment. We expect to see a large amount of mobilization of lower-density microplastic and TWP during storm events. Characterization of the movement of these particles is a key part to understanding what precautions need to be taken in stormwater technology to prevent microplastics from entering nearby waterways. Evaluations of the different types of inlet particle capture devices will show if they have any significant effect on capturing low-density microplastics and TWP and possibly direct investment in stormwater infrastructure to prevent their dispersal. We expect to see the inlet particle capture devices with more advanced designs (e.g. screens or filter material) to have a higher rate of low-density particle capture than the catch basin inlet device type.

Work Cited


Google.com. (2020). *Google Maps: Landings Run Mount Pleasant, SC*. Google Maps. https://www.google.com/maps/place/Landings+Run,+Mt+Pleasant,+SC+29464/@32.8353105,-79.8473322,760m/data=!3m1!1e3!4m5!3m4!1s0x88fe71e65e9b9ee9:0x7e9e99fd8eb0d8b7!8m2!3d32.8369072!4d-79.8482308


5/15/2020

Re: MES RA Proposal Faculty Letter for Kayli Paterson

It is my pleasure to support Kayli Paterson in her MES project “Evaluating the effectiveness of stormsewer inlets to capture microplastics and tire wear particles of varying densities in roadway runoff to prevent dispersal in the environment”. Kayli Paterson has entered graduate school with an accomplished record in the private sector and armed forces and in her prior positions has demonstrated leadership and a diverse set of skills. She is proving already to be a motivated and thoughtful research student. During her first year as an MES student, she has reached out to other students who are a part of my collaborative research network to learn and trouble-shoot research methods together, and she has collected initial data.

In the U.S. alone, it is estimated that each year 100 tons of microplastics may enter the ocean and 500,000 tons of tire wear particles are released into the environment. These synthetic particles are able to be ingested by a variety of aquatic organisms and reported negative impacts of exposure range from weight loss and reduction of energy reserves, to decreased fitness, onset of oxidative stress, and even mortality from leachates or gut blockage. Studies have also identified urban areas as hotspots for contamination. Prior and ongoing research in my lab and collaborators’ has demonstrated high levels of microplastic and tire wear particles in Charleston Harbor waters, sediments, and biota such as commercially-important fish. We’ve shown capture of microplastics by local wastewater treatment plants, and accumulation in stormwater detention ponds. Yet, we estimate that the majority of microplastic and tire wear particles entering local waterways is via non-point sources in stormwater runoff. Therefore, there are specific needs for “up-watershed” identification of sources and mitigation strategies for microplastics and tire wear particles.

Kayli’s proposed research will fill important knowledge gaps using consistent methodologies to estimate the magnitude and source profile of microplastic and tire wear particles on roadways and in stormsewer infrastructure. Understanding their pathways into coastal waters is critical to informing policy and management decisions to minimize the environmental and economic impacts of this type of debris in the future. Kayli will be a member of a dynamic research team working to understand urban stormwater runoff as a source and toxicological risk to biota that was recently funded by SC Sea Grant Consortium. If Kayli were to receive this RA award (and budget, see Table below), we would be able to use this funding to further expand the research team and impact of our collaborative, interdisciplinary research.

Best regards,

Barbara Beckingham

Dr. Barbara Beckingham
Re: MES RA Proposal Faculty Letter for Kayli Paterson

The MES RA funding award will aid the purchase of consumables needed to process Kayli’s environmental samples, as described in her proposal and listed in the Table below.

Table of RA budget

<table>
<thead>
<tr>
<th>Product</th>
<th>Cost: Total = $600</th>
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<tbody>
<tr>
<td>Sodium polytungstate</td>
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<td>Sodium chloride (Granular)</td>
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<tr>
<td>Hydrogen peroxide (30%, ACS certified)</td>
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<td>Mixed cellulose ester gridded filters</td>
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