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# Lifecycle of a Wipe: Determining the Contamination, Fate, and Transformation of Wet Wipe Pollution in the Environment

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**ABSTRACT:** Globally, plastic wet wipes are common in urban rivers – likely due to unclear labeling about material composition, leading to improper disposal (i.e., flushed down the toilet). Once in the environment, wipes likely break down into microplastics (<5 mm). Here, we assessed the "lifecycle" of wet wipes to better understand their prevalence, transformation, and fate in aquatic ecosystems. In our study, we assess (1) the amount of wet wipe pollution in an urban river, (2) industry labeling practices related to material and disposal, and (3) wet wipe degradation under different environmental conditions. Wet wipes made up 25.7% of all macroplastics (>5 mm) collected in the urban river, located primarily downstream of combined sewer outflows. Of the collected wipes, 99% were plastic (predominantly polypropylene (PP) and polyester (PET)). Among the 72 wipe packages surveyed across six stores and 42 brands, 48 displayed disposal information and only 7 specified information on product material. Finally, our laboratory experiment showed that wipes shed microplastics, with PP shedding more than PET, and more were generated under wet conditions versus dry. This suggests that wipes that enter rivers as macroplastics can transform into microplastics. Our work highlights the need for better labeling and management practices to mitigate wet wipe pollution.


**KEYWORDS:** *plastic pollution, microplastic, wet wipes, sewage waste, freshwater*



## INTRODUCTION

Plastic pollution is a global issue understood to be intensified by rapid urbanization and industrialization.[1,2] There are many sources and pathways of plastic pollution including mismanaged waste and litter, which can reach aquatic ecosystems through wind and rain.[3,4] Other sources and pathways include agricultural practices,[5,6] plastic manufacturing,[7,8] and wastewater.[9] Plastics that enter sewage can be released into the environment either untreated (including when released via combined sewage overflows (CSOs)) or treated as wastewater effluent.

Wet wipes are a common type of macroplastic (pieces >5 mm in size) pollution, and sewage systems (including CSOs) are noted as their main pathway to enter aquatic environments.[10−12] A wet wipe is a small cloth treated by various chemical agents for a variety of cleaning purposes, including: sanitizing, facial cleansing, pet cleaning, and as an alternative to toilet paper. Wet wipes are predominantly made by weaving synthetic fibers into a sheet; in the case of plastic wipes these fibers are usually polypropylene or polyester.[11,12] Wipes advertised as biodegradable or flushable are likely made of organic materials like cellulose.[13]

While wet wipe pollution existed prior to the COVID-19 pandemic, the heightened public desire for better personal hygiene and sanitation exacerbated the issue.[12] Global plastic waste is predicted to increase over time[14] as is wet wipe production: for example, to meet COVID-19 pandemic demand, one wipe manufacturing company increased production by half a million packages of wipes.[15] An increase in general hygiene sensitivity has increased the proportion of litter made up of personal protective equipment (PPE) like facemasks and gloves and, in turn, wet wipes.[16] Across several countries, one study found wet wipes accounted for up to 0.6% of all litter during the pandemic, as compared to 0.2% prepandemic.[16] In Toronto, wet wipes made up 25% of all surveyed PPE litter.[17] While wet wipe litter has generally decreased following the pandemic, it is still at higher levels compared to before the pandemic;[16] more research is needed to inform wet wipe litter trends after the pandemic.

Flushing wet wipes is a well-known and costly concern among wastewater treatment professionals.[11,13,18] Wet wipes

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enter the environment after being flushed through the release of CSOs. Once in the environment, the transformation of wet wipes is not well understood.[14] Wet wipes likely break down into microfibers, a type of secondary microplastic (particles < 5 mm in size) that arise from the shedding of textiles. While microfibers are one of the most abundant microplastic shapes in the environment,[19] it is difficult to determine what products they are sourced from due to similarities across microfibers.[12] The degradation of wet wipes into microfibers may put organisms at risk of ingestion, as plastic pieces become smaller in size. Smaller microfibers may also be more likely to be transported than fragments due to their small size and weight,[20] potentially increasing their bioavailability. As such, we must understand the degradation of wet wipes in the environment. Previous wet wipe studies have looked at degradation, both mechanical and chemical, in short and long-term tests.[21,22] These studies do not account for the difference in wipe transformations across material types. Cellulose-based wipe studies have increased, likely due to the "flushability" of such products; yet plastic wet wipes are more frequently found in aquatic systems.[23]

Here, we assessed each stage of the wet wipe lifecycle, from supermarket shelves to their presence in the environment and transformation into microfibers. We had the following objectives: (1) to estimate wipe emissions to an urban river; (2) to understand how wipes are "marketed" and/or labeled and how that relates to wipe disposal practices and plastic pollution; and (3) to better understand wet wipe degradation into microplastics. To estimate wet wipe emissions, we used data from a local study on plastic pollution in the Don River in Toronto, Canada.[23] To better understand the "market" for wet wipes, we surveyed five major supermarket chains in Toronto and one major online retailer. We surveyed the types of wipes being sold, their applications, and information on wipe packages relevant to material type and disposal. To understand how wipes degrade, including into microfibers, three wipes of different materials were exposed to different abiotic environmental parameters over time to mimic environmental conditions. Our overarching objective was to gather data to increase our understanding of wet wipe pollution and to inform strategies for preventing plastic wet wipes from entering aquatic environments.

## ■ METHODS

### Quantifying and Characterizing Wet Wipe Pollution Locally

We quantified plastic pollution within four study sites along the Don River, in Toronto, Canada, during the summer and fall of 2022. The Don River watershed (358 km$^2$) is a highly urbanized catchment draining portions of the Greater Toronto Area, one of the largest metropolitan areas in Canada.[24,25] We established four sites along the river: two located in headwater streams (Taylor-Massey Creek, German Mills), one midstream site (York Mills), and one near the mouth of the river (Pottery Road) (Figure S1). We sampled these sites to capture a range of stream orders across the river network. More information about the sampling regime and watershed can be found in Haney et al. 2025.[23] In brief, we sampled each site three times during baseflow conditions: once to establish a baseline and then both before and after a storm event. Each site had three 60−80 m reaches, separated by 30−40 m buffer zones (depending on the stream morphology). Within each reach we sampled and surveyed all anthropogenic litter (AL; including plastics) stored within the following habitats: overhanging vegetation, riparian zones (extending 1 m from the water's edge), floating material, and the riverbed. Reaches were divided into two sections: the upstream half of the reach was designated as the "leave" section, where AL were counted but left untouched, while the downstream half was the "collect" section, where AL was picked up for further characterization in the laboratory.

In the lab, collected AL were washed and left to dry for several days. Once dry each item was measured, weighed, and categorized by product type (i.e., smoking, sanitary items, etc.).[22] The first five items of each category were further analyzed for polymer type using spectroscopy. For wet wipes, fibers were extracted from a clean portion of the wipe using forceps to perform infrared spectroscopy using an ATR-FTIR instrument (Alpha II ATR-FTIR with OPUS software; Bruker Corporation). Plastics were identified to polymer type, and any copolymers were classified as "copolymer". Organic materials like cotton and cellulose were recorded as such.

### Assessing the Wet Wipe Market

The wipe market was surveyed across five of the most popular stores in Toronto, Canada,[26] and a popular online retailer. We chose five different stores and an online retailer to get a broad selection. Store locations for each major chain were chosen by proximity to the University of Toronto's St. George campus. All available wipes in every in-person store were recorded. In person, packages were checked on all sides for information. Online, information was limited to the photos provided by merchants, as purchasing wipe packages would be an added expense. Online assessment still enabled a more general overview of the entire wipe market as it is available to consumers. Wipes available online were sorted by "Bestseller" and "Customer Review", and the top 20 results for both categories were recorded. We chose to shop at an online retailer to get a broader view. This was to ensure that products included in our review are representative of the products most purchased. We looked for the following information: brand, intended use, number of wipes, composition, disposal information, cost per wipe, and flushability status. Photos were taken of all products (screenshotted online). Disposal information included both the "Do Not Flush" written instructions and the do not flush logo; classified as either "clear" (high visibility, i.e., on front of package), "unclear" (low visibility, i.e., back of package, small, low-contrast colors), or unavailable. After data collection, duplicates were removed (i.e., packages of the same brand, number of wipes, composition, and disposal information across multiple stores). In the results section, rather than include brand names, wipes are given code names.

### Transformation into Microfibers

For our experiment, we aimed to measure the degradation of three material types − two plastic and one labeled "flushable". Eight wipes were chosen by popularity and intended use from the store surveys. They were then dried to determine polymer type through micro-Fourier transform infrared spectroscopy ($\mu$FTIR) analysis (Thermo Scientific Nicolet iN10; ThermoFisher Scientific). Of these, and because our work in the Don River confirmed that the most commonly polluted wipe polymer types were polypropylene (PP) and polyester (PET), we picked one type of each material. A popular flushable wipe made of regenerated cellulose (RC) was chosen to compare to the two plastic materials. Our experimental design included 18 treatments each with 3 replicates at each of the two sampling time points (n = 3). Factors that were fully factorial included material type (3 levels: PP, PET, cellulose), sun (2 levels: sun or no sun), water (2 levels: wet or dry), and time (2 levels: 2 and 6 weeks). In addition, the factor mixing was included only for wet treatments (2 levels: mixing and no mixing) to simulate turbulence in the water. To account for procedural contamination, 2 replicate blanks per treatment were prepared without wipes for a total of 120 samples. Microplastics quantified in the blanks were used to blank-correct the results.

All samples were prepared in precleaned glass jars, and wet treatments had 100 mL of RO water. Jars were cleaned with soap and triple rinsed with RO water. Wipes were cut into 4 cm x 4 cm squares and placed into the appropriate jar. The jars were covered with clear plastic wrap and sealed with an elastic band. The experiment was


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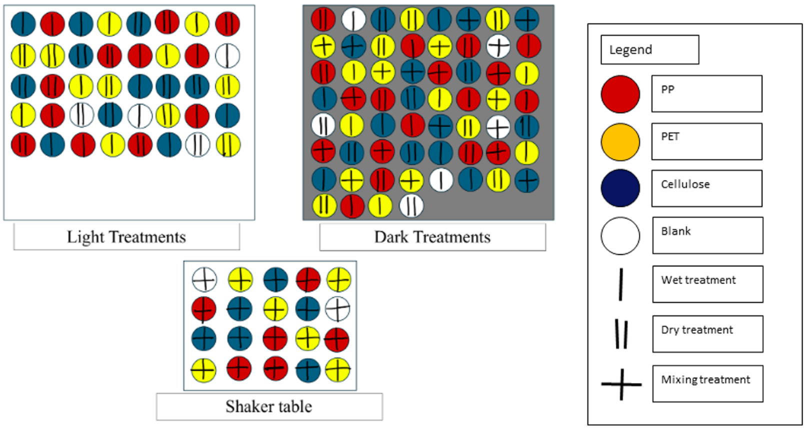


**Figure 1.** Model of experimental set up at the beginning of the experiment (note: there are six units per treatment due to sampling at 2 and 6 weeks). Experimental units are represented by circles: PP is shown in red, PET in yellow, cellulose (RC) in blue, and blanks in white. Light and dark treatments were separated by clear and opaque plastic containers, respectively. Experimental units are labeled by treatment: (I) wet treatments without mixing, (II) dry treatments, and (+) wet treatments with mixing. Here, light mixing treatments are on the shaker table under a second clear plastic container, to be replaced by the dark mixing treatments next with a second opaque plastic container. All of the jars were placed haphazardly across the palate.

done on a rooftop for full sun exposure. The jars were randomly organized on a board on top of a wooden palette (Figure 1). All sun-treated jars were on one side and covered by a large clear container, and the nonsun-treated jars were on the other side covered by a large opaque container. Both containers were not flush with the board to allow airflow. A shaker table connected by an extension cord was used for mixing. Because we only had one shaker table and did not have the resources to buy a second one, every 2 days the shaker table would switch between light and dark treatments. This means that jars in the mixing treatment were not mixed every day but all were mixed for equal periods of time. Both containers were secured by a bungee cord due to wind. At 2 weeks, half of the treated jars were removed to be processed. At 6 weeks, all remaining jars were collected.

The wipes were always handled with forceps. To assess the change in mass of the wipes, they were extracted from jars and, if wet, shaken three times to remove excess moisture. The plastic wrap and elastic band were left intact and reapplied once the wipe was removed. The wipes were placed flat in individual 65 mL weigh boats and covered with aluminum foil. Forceps were used to poke 5 holes in the foil to allow for drying. The boats were placed in the oven for 24 h at 55 °C. After drying, the wipes were stored in the laboratory at room temperature before the experiment, and all procedures to quantify and characterize materials were also at room temperature in the laboratory. After drying, wipes were placed onto a clean sheet of aluminum foil on a microbalance (Sartorius Entris 64i-1S Analytical Balance; Sartorius) and weighed three times. Four new 4 cm x 4 cm wipes of each polymer type were weighed following the same procedure and the weights were averaged to act as time 0 (Table S1). To assess microfiber creation, the remainder of the contents in the jars were rinsed into a glass filtering apparatus using RO water and onto 47 mm in diameter 10 $\mu$m polycarbonate filter paper. Filters were placed in small round Petri dishes and stored for microfiber counting. Filters with fewer microfibers were viewed entirely through a dissecting microscope at a magnification of 10−80x (Leica S8 APO Stereozoom; Leica Microsystems, Canada). Using grid paper, microplastics were characterized by color and morphology (fragment, fiber, film, foam, sphere, and pellet)[27] against both dark and light backgrounds. To aid quantification for samples with greater amounts of microfiber shedding, microfiber clumps were removed from the filter paper using forceps, placed on a clean sheet of aluminum foil, and weighed on a microbalance. Remaining microplastics on the filter paper were counted under the microscope as the "periphery" count (or the extra amount that we could not remove). A subsample of the microfiber clump was weighed and then placed in a new Petri dish to be counted under a microscope at a magnification of 10−80x (Leica S8 APO Stereozoom; Leica Microsystems, Canada). To aid in microfiber counting, one drop of 70% ethanol was added to each sample to reduce fiber static and enable the manual separation of fibers. The subsample was then counted under the microscope as were other samples. After counting, the subsample was extrapolated to the total amount in the weighed sample and added to the periphery count to render a total microfiber count.

## QA/QC

Quality assurance and control measures were followed during laboratory procedures to limit contamination among the samples. The laboratory was equipped with a HEPA filter, cotton laboratory coats were worn at all times, and all samples were covered when not in use. To account for procedural contamination, blank samples were scanned for each treatment. Blank correction of our samples was performed by subtracting the average microplastics counted by morphology and color in the blanks from each treatment to each sample.[28,29] Blank counts, in addition to blank corrected totals, are reported in Supporting Information. The average number of clear fibers in the blanks was 13. Samples with fewer particles than reported in the blanks had blank-corrected totals of 0. The representativeness of the subsampling method was measured, and the coefficient of variability of three replicated subsamples was no larger than 20% (Table S2).

## Statistical Analysis

We used ANOVAs to assess the changes in the mass and microplastic counts among treatments. Because we had an uneven sample design (i.e., it was not fully factorial due to mixing only included in wet treatments), we used two separate ANOVAs for each end point (mass and count). For each endpoint, we ran one four-factor ANOVA with factors material type, sun, wet, and time without the mixing treatment and another four-factor ANOVA with factors material type, sun, mixing, and time for the wet treatments only. Before running each ANOVA, we plotted histograms to assess the shape of the distribution and did a Bartlett's tests to assess homogeneity of variance. A Bartlett's test with $p > 0.05$ failed to reject the null hypothesis and suggested homogeneity of variance. Total microfibers produced a skewed histogram, so we log transformed the total microfiber count. Bartlett's tests for both the log of the microfiber count and wet wipe mass both produced $p > 0.05$. We used Tukey posthoc tests to analyze significant differences within treatments when factors were significant within ANOVAs. All analyses were run in R using RStudio (RStudio version 2021.9.0.351). Data visualizations were made using ggplot2.[30]


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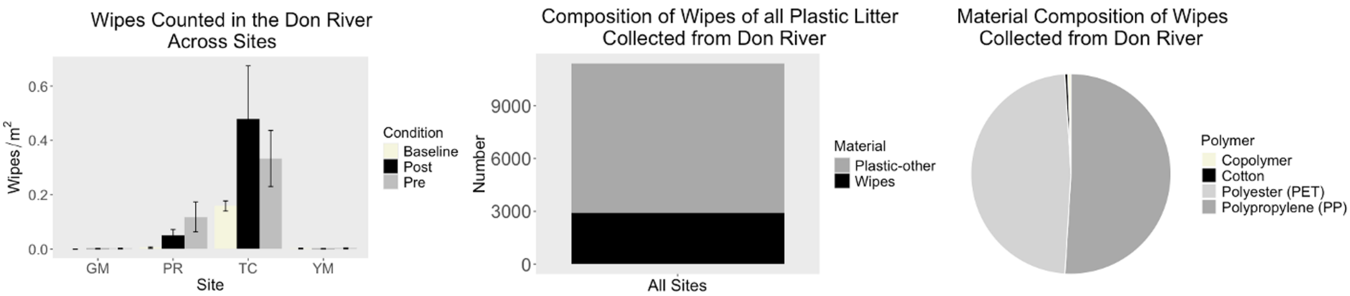


**Figure 2.** Observations of wet wipes collected from Toronto's Don River. Left: The mean number of wipes collected at each site over time (Baseline (white)), Prestorm (gray) and Poststorm (black). Error bars show the standard deviation. Middle: The proportion of wipes of all the total litter collected across all sites. Wipes are shown in black, and all other litter are shown in gray. Right: The material composition of wipes from the Don River (PET (light gray), PP (dark gray), cotton (black), copolymer (beige)).

**Table 1. Information Available on Wipe Packaging**

| Labeled Flushable? | Intended Use | Number of Packages | Composition Information Available | Disposal Information Available | Disposal Information Clear |
|---|---|---|---|---|---|
| No | Baby | 22 | 2 | 14 | 10 |
| No | Cleaning | 17 | 1 | 8 | 1 |
| No | Cleansing | 19 | 3 | 15 | 7 |
| No | Pet | 2 | 0 | 0 | 0 |
| No | Wiping | 1 | 0 | 0 | 0 |
| Yes | Baby | 2 | 0 | 2 | 1 |
| Yes | Cleaning | 0 | n/a | n/a | n/a |
| Yes | Cleansing | 0 | n/a | n/a | n/a |
| Yes | Pet | 0 | n/a | n/a | n/a |
| Yes | Wiping | 9 | 1 | 9 | 4 |

# RESULTS AND DISCUSSION

## Wet Wipes in the Don River Watershed

Overall, across all sites in the "leave" reaches, we found an average of 0.5 pieces of AL/m$^2$ (ranging from 0.1−1.3 pieces/m$^2$). Taylor-Massey Creek had the most AL, ranging from 0.4−1.3 pieces/m$^2$. The second greatest amount was at German Mills, ranging from 0.1−1.1 pieces/m$^2$. The litter categories included plastic bags, plastic water bottles, plastic fragments, food packaging, and clothing. See Haney et al. 2025 for more details.[22] Specific to this project, wet wipes were very abundant at some sites (Figure 2). Of all the AL quantified and characterized across all reaches, wet wipes were the second most represented category (second to plastic bags), making up 25.7% of all AL in the Don River. Apart from Taylor-Massey Creek, we found very few wet wipes, with amounts ranging from 0−1 wipes per transect at German Mills and 0−12 wipes per transect at York Mills. At Taylor-Massey Creek, we observed the most wipes, with 48−327 wipes per transect. Downstream of Taylor-Massey Creek, at Pottery Road, amounts ranged from 0−217 wipes per transect. Taylor-Massey Creek is a site of a CSO. Thus, flushed materials likely enter the Don River near Taylor-Massey Creek, resulting in this site having the highest number of wet wipes. Flushed litter is most likely to travel from Taylor-Massey Creek to its downstream site, Pottery Road, and this is reflected in the wet wipe count at Pottery Road. Wet wipe pollution adjacent to wastewater treatment facilities has been documented,[12] and the findings here support these observations.

The composition of wet wipes is consistent with reports that plastic wet wipes clog pipes[31] and are released in the environment with sewage overflow.[32] In total, 206 out of 734 collected wet wipes were analyzed using ATR-FTIR. Overall, 99% of wipes measured via FTIR were plastic (Figure 2). The compositions of wipes characterized were 51% polypropylene, 48% polyester, 0.005% a copolymer of plastic, and the remaining 0.005% cotton. The lack of cellulosic-derived wipes in our findings supports the flushability (or degradation) of some wipes on the market.

Based on our field observations in 2022, and the size of the river, we estimate that between 97,800−101,800 or 276 kg − 287 kg of plastic wet wipes could be found downstream of our Taylor-Massey Creek site toward the mouth of the Don River. To estimate the amount of wipes in this section of the river, we determined the cumulative length of this river section, which is approximately 9.7 km. We then estimated benthic area, using the cumulative length and bankfull width, derived from two estimation methods based on the relationship between the upstream drainage area and channel width[33,34] resulting in an area of 0.18 km$^2$ and 0.26 km$^2$. To estimate the total mass of these wipes, we used a representative average dry mass of 2.82 g per wipe from our collected samples and multiplied it by the estimated number of wipes. These findings indicate how prevalent wet wipes are in our study system and identify them as a significant source of macroplastic pollution, including likely to Lake Ontario downstream. These estimates are conservative, as they do not account for wet wipes buried within benthic sediments or along the riverbank. This highlights the need for policies to prevent plastic wet wipes from being flushed by consumers, entering sewer systems, and reaching aquatic ecosystems through pathways, such as CSOs.

## The Wet Wipe Market

We assessed the market for wipes to understand how it may explain our observations in the Don River. Specifically, we assessed what the intended uses of wipes are, how many are made out of plastic, and how that compares to what information is available regarding their proper disposal (see


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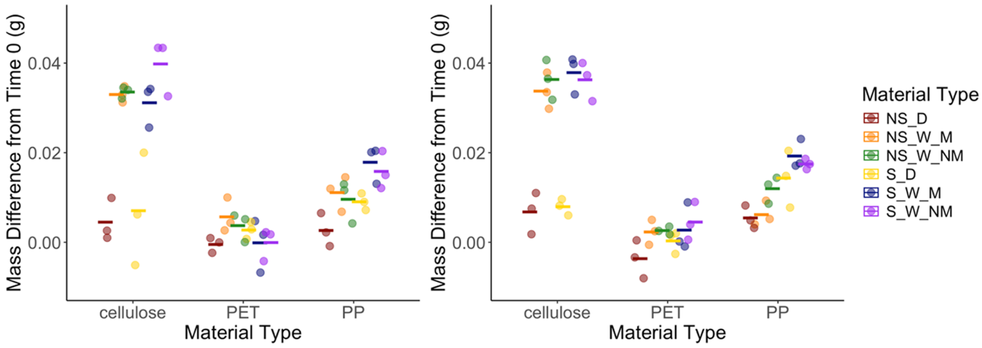


**Figure 3.** Change in mass from time 0 of different wipe materials across treatments ($n$ = 3). Circles represent each individual replicate within a treatment (denoted by different colors). Left: Change in wipe mass between time 0 and 2 weeks. Right: Change in wipe mass between time 0 and 6 weeks. The $y$-axis is the difference in mass of wipes in the jars from weighed wipes at time 0. The $x$-axis is material type (cellulose, PET = polyester, and PP = polypropylene). Horizontal bars represent the mean per treatment. Colors of the circles and horizontal bars represent treatment (D = dry, W = wet, M = mixing, NM = no mixing, S = sun, NS = no sun). Negative values (increases in wipe mass) are likely because wipes weighed at time 0 were separate from the wipes tested.

Supplementary Data). We found five general intended uses: baby wipes, cleaning/sanitizing wipes, cleansing/facial wipes, pet wipes, and wipes as alternatives to toilet paper. Across all wipes, the most common wipes for sale on shelves were baby wipes and cleansing/facial wipes. After filtering out duplicates, we collected information about 72 different products across 42 brands (Table 1). Overall, it was not easy to get information about material types as only seven out of 72 products contained this information. When they did, only one product identified as plastic. Six of the seven products that presented their compositions were organic, with cotton the most commonly reported.

For disposal, 48 of all 72 products had information available. Information for nonflushable wipes was always in the form of either a "Do not Flush" logo and/or written text. Disposal information was also provided when packages contained the term "flushable". Of the 61 nonflushable wipes, 37 packages presented disposal information. Of those 37, 18 products made the information clear, meaning the disposal information was on the front of the package, in large font, and in a contrasting color to the background. The only wipes to advertise themselves as "flushable" were toilet paper alternative wipes and some baby wipes. Despite the fact that no definition of "flushable" exists in Canada, the "flushable" label creates an association with being "eco-friendly" and safe for the environment. This trend likely reflects consumers' growing concerns around personal health and the environment.[35] Every flushable product provided disposal information by identifying as flushable. Five of the 11 flushable wipes provided additional disposal information such as "Flush one at a time". There was only one product in our survey that was sold as a substitute for toilet paper and was not labeled as flushable. However, this was sold online where packaging was difficult to assess since we could only see an image.

These findings are consistent with previous studies recording inconsistencies in labeling on wipe packages.[12,13] If it were difficult to intentionally find disposal information on all packages, it is likely even less visible to consumers who may not be actively seeking out this information. Considering wipes collected from the Don River were plastic, it indicates nonflushable wipes are also being treated as flushable. This suggests, as labeling practices in the wipe market stand, people are not following the disposal information.

## Degradation of Wet Wipes in the Environment

We assessed the degradation of wipes under simulated environmental conditions by measuring the change in mass over time and the total amount of microfibers shed. To quantify wipe mass loss, we assessed the change in the mass across treatments over time. As such, the values that follow are the differences in mass from time 0 for each material type. Overall, for mass loss across all treatments and replicates, we observed a total loss of 0−0.04 g within both 2 and 6 weeks (Figure 3). We did not see a significant difference with time ($p > 0.05$). We did see a significant difference among polymers, and cellulose wipes lost the most mass compared to both types of plastic wipes ($p < 0.05$). See ANOVA tables in the Supporting Information for more information (Tables S5 and S6). Cellulose wipe mass loss ranged from −0.005 - 0.4 g over time. Mean cellulose mass loss at 2 weeks was 0.025 g (SD = 0.015) and at 6 weeks was 0.025 ± 0.014 g. PET mass loss ranged from 0.008 - 0.01 g. Mean PET mass loss at 2 weeks was 0.002 ± 0.004 g and at 6 weeks was 0.001 ± 0.004 g. PP mass loss was between −0.0008 - 0.02 g. Mean PP mass loss at 2 weeks was 0.011 ± 0.006 g and at 6 weeks was 0.012 ± 0.006 g. Aside from material type, sun was a significant factor for PP only and the presence of water was a significant factor for cellulose and PP. Both sun and water increased mass loss. The difference in mass loss during mixing was greatest for cellulose.

We did not see a clear pattern across the mass loss. We expected sunlight to be a significant predictor of degradation because UV and visible light radiation is understood to degrade and fragment plastics.[36,37] While sunlight was important to the loss of wipe mass, it was not the most significant condition. Instead, in our study, degradation and fragmentation were generally most affected by polymer type and/or the presence of water and turbulence (or mixing). This conflicts with studies suggesting that moisture and mechanical mixing are weak stressors.[37] However, it may be possible that a longer exposure period (i.e., > 6 weeks) would affect wipe degradation and influence the effect of time on mass loss. Hoseini et al. (2023)[38] demonstrated that under accelerated weathering conditions, PP mass loss of film was several orders of magnitude higher than that of PET film. Our results support this pattern.

Below, we share patterns for the number of microfibers shed. The patterns were not identical with the mass loss. Still, in general, for PP and RC, there appears to be a positive

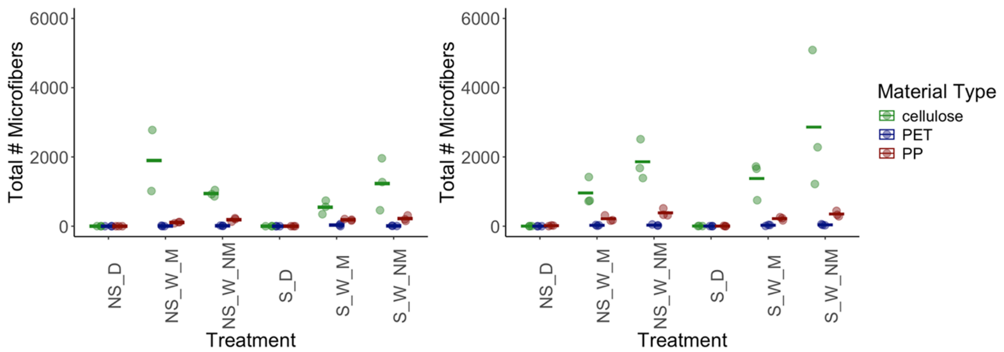


**Figure 4.** Degradation of different wipe materials into microfibers across treatments ($n$ = 3). Circles represent each individual replicate within a treatment (denoted by different colors). Left: Microfiber production at 2 weeks. Right: Microfiber production at 6 weeks. The $y$-axis is the total amount of microfibers in each jar. The $x$-axis is Treatment (D = dry, W = wet, M = mixing, NM = no mixing, S = sun, NS = no sun). Horizontal bars represent the mean per treatment. The colors of the circles and horizontal bars represent material type (cellulose, PET = polyester, PP = polypropylene).

relationship between wipe mass loss and number of microfibers shed (Figures S2 and S3). For PET, there does not appear to be a pattern between mass loss and microfibers shed (Figure S4). The lack of a pattern may be due to the light weight of the few PET fibers that were shed or because of the wipe weighing design. Across all treatments and replicates, microfiber shedding ranged from 0−7386 microfibers per jar at 2 weeks and 0−5088 at 6 weeks (Figure 4). Across both models for microfiber shedding, polymer type and time were significant factors ($p < 0.05$). There was also a significant effect of wet versus dry ($p < 0.05$). As expected, cellulose shed more microfibers than both types of plastic ($p < 0.05$). Mean cellulose fiber shed at 2 weeks was 1075.4 (SD = 1746.9) and at 6 weeks was 1177.7 ± 1284.1. The effective degradation of cellulose is well documented.[39−41] Moreover, PET shed significantly fewer microfibers than PP ($p < 0.05$). The amount of PET microfibers across treatments and replicates ranged from 0−67 (mean = 10.1, SD = 16.7) at 2 weeks and 0−59 (20.7 ± 19.0) at 6 weeks, whereas PP shed between from 0−231 (116.9 ± 98.3) microfibers at 2 weeks and 0−515 (198.5 ± 163) at 6 weeks. Generally, the amount of microfibers shed increased with time and when wet. We did not observe significant differences based on whether the wet wipes were exposed to sun ($p > 0.05$). For mixing, there was a significant difference (p = 0.02), where microfiber shedding increased slightly with mixing. We did observe some significant interactions, but with no clear pattern. See the ANOVA tables in the Supporting Information for more information (Tables S3 and S4).

Our experiment suggests that wet wipes degrade into microfibers in the environment. This can happen in aquatic ecosystems or even at the wastewater treatment plant. Wipes are likely screened out at treatment plants, but smaller fragments of the wipes and shed microfibers likely pass through. While modern wastewater treatment plants are able to capture up to 99% of microplastic particles in the biosolids,[12] the global average of microplastics released into the marine environment through effluent is still 19.2 microplastic particles per liter.[34] As such, microfibers from wipes may enter the environment via both treated and untreated wastewater. We observed greater fiber shedding from PP than PET, which is consistent with previous studies showing that PP sheds readily[42] compared to PET which demonstrates a slower degradation rate.[43] In our study, this is likely due to a combination of polymer-specific degradation, and differences in fiber weaving techniques between wipes;[44] our PP was sourced from baby wipes which may not need the same durability as the PET wipes created for cleaning and sterilization. Our findings cannot assess degradation patterns across intended wipe use (i.e., baby, cleaning) because information about wipe packaging regarding material type is very limited. But, it is likely many wet wipes are made from some form of synthetic or semisynthetic plastic material, and given the prevalence of PP and PET wipes in the Don River our findings are directly relevant to addressing wipe pollution in aquatic systems. Wipe degradation into microfibers poses an environmental threat as it increases the likelihood of aquatic organisms ingesting plastic material. Additionally, microfibers may act as toxicological vectors carrying other contaminants.[12]

## ■ CONCLUSIONS

Wet wipes are a significant source of both macroplastic and likely microplastic pollution (through transformation) in urban rivers. A common pathway for their release into the environment is sewage, including untreated sewage released from CSOs. During storm events, these CSOs prevent wastewater treatment plants from being overwhelmed by diverting flushed materials − including plastic wet wipes − to local rivers. Here, we focused on local emissions of wet wipes into a river in Toronto, Canada. Based on our empirical data, we estimate that ∼ 100,000 wet wipes are present in the Don River, concentrated at sites downstream of CSOs. Most of these wipes are plastic made of either PET or PP. Our findings suggest that a nonclarity of disposal information on wipe packaging exacerbates this issue. We found 37 of 61 surveyed nonflushable wipes presented disposal information, but only 18 made the information highly visible. Without clear disposal information, the flushing of wipes is likely more frequent. Once in the environment or even in water at the wastewater treatment plant, plastic wet wipes can shed microfibers. We found that on average, PP sheds more microfibers than PET. We also found that wet wipes shed more microfibers under turbulent conditions, which is common in aquatic ecosystems and water treatment facilities. The fate and transformation of wet wipes in the environment are important, given their potential interactions with organisms. We hope that our study informs mitigation strategies and policies to reduce the flushing of plastic wet wipes and prevent plastic wet wipe pollution in aquatic ecosystems.

## ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsestwater.5c00838.

Additional experimental details, including map of sampling sites, and statistical analyses (PDF)
Spreadsheet of store survey data (XLSX)
Spreadsheet of wipe degradation data (XLSX)

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### Notes

The authors declare no competing financial interest.

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