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# **Title:** Sewage transport volumes and physical degradation rates of personal care wipes

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## Research Impact Statement

Personal care wipes, despite being labeled as "flushable", show little degradation over time; these wipes pose a hazard to plumbing and thus should not be flushed or otherwise discharged to the sewer system.

## Abstract

As personal care wipes become increasingly popular, inappropriate disposal to the sewage system is raising significant environmental and economic concerns. Many commons brands, while marketed as "flushable", do not degrade appreciably in the plumbing and piping fixtures that the sewage transits. As such, these wipes can cause a myriad of problems including sewer blockage and destruction of pumps and grinders. This work sought to better understand key factors influencing the onset of such problems, including the volume of wipes present in the sewer and the degradation rates associated with a variety of personal wipe products, both "flushable" and non-flushable. The results suggest no correlation between the quantity of wipes in sewage and either the preceding precipitation or the sewage flow rate. To examine their degradability within a sewer system, we evaluated the degradation over time for six commercially available wipes under four conditions: static, kinetic, tap water, and sewage water. Five out of the six wipe types were greater than 93% intact after 48 hours of exposure to sewer-like conditions and only one wipe type degraded to less than 14% of its initial volume after 48 hours, which is similar to the degradation performance of tested toilet paper. Degradation rates were highest in tap water under kinetic conditions and lowest in raw sewage water under static conditions.

**Keywords**

Wipes, sewage, fatberg, degradation, wastewater

## Introduction

Increasing popularity of personal care wipes and their inappropriate disposal to sewage systems is raising significant environmental and economic concerns. The wipes arrive in the sewage system by a variety of pathways, including toilets and kitchen sinks. Moreover, in systems that have combined sanitary and storm piping (a common feature of many older urban communities), the wipes may also enter (as litter) through catch basins that deliver overland flows to the subsurface sewer.

While many household brands of personal care wipes are marketed as “flushable”, their lack of degradation in sewer systems has played a large role in many major sewer infrastructure failures. Wipes are composed of both natural and synthetic polymers and fibers including wood pulp, viscose, lyocell, polyester, high-density polyethylene (HDPE), polyethylene, polystyrene, and polyurethane (Munoz et al. 2018; Atasagun and Bhat 2020). Such polymers can degrade under certain environmental conditions, from photochemical degradation, thermal degradation, chemical attack, and mechanical stress (Bresee 1986). However, numerous reports have emerged that describe the insufficient degradation of such wipes under sewage conditions; (Mattsson et al., 2014; Ramirez 2018; Molina 2019; Schaverien 2019) in fact, disposed wipes do not properly degrade and make up large portion of solids found in sewage (Spence, Digman et al. 2016; Mitchell, Thamsen et al. 2017). Although many are marketed as “flushable” in the United States and Canada, there is no standard definition of what is flushable and no standard method to assess if a substance is flushable, neither by the Environmental Protection Agency (EPA) or Environment Canada (Mayberry 2016) is available. Thus, personal care wipes, increasing in demand by 1-2% on a yearly basis (Atasagun and Bhat 2020), largely enter the environment and sewer systems unregulated. Although they can pass through the toilet pipes and sewer lines, studies highly recommended wipes to be produced from materials that will properly degrade to prevent sewer blockages (Mango 2004; Smithers 2014; McIntyre 2014; Atasag˘un and Bhat 2020).

To further complicate this issue, when in the presence of fats, oils, and greases (FOGs) – a common component of residential sewage – wipes that have not been degraded can bind together and form increasingly massive accumulations. These wipes then combine with fats, oils, and greases (FOGs) to form a heterogeneous conglomeration, known as a “fatberg”(Alda-Vidal, Browne et al. 2020). Fatbergs can grow into a significant blockage in the sewer, causing backups and sewer overflows, exposing humans and the environment to raw sewage (Husain, Alkhatib et al. 2014). The Environmental Protection Agency (EPA) has noted that approximately 47% of sanitary sewer overflows in the U.S are due to these formations (Environmental Protection Agency 2004). However, wipe-induced fatbergs have also been found since 2018 worldwide, detailing this issue as globally-relevant especially for westernized nation where consumer wipe consumption has doubled since 2011 (Atasag˘un and Bhat 2020). The flushability of wet wipes is under question and the guidelines provided by INDA in the US, EDANA in Europe (60% dispersibility) and the International Water Services Flushability Group (30 minutes for dispersion) did not sufficiently result in wet wipes degradation and new ways of manufacturing wet wipes are suggested (Harter, Bernt et al. 2021). In addition to sewer blockages, it is also possible that smaller fatbergs will move with the sewage flow and reach an intermediate pumping station or the final point of treatment at the wastewater treatment plant. Pumps are a critical element at both, and even small fatbergs can cause complete failure of such pumps and associated motors.

Previous research has been completed to better understand the composition of solids and clogging mechanisms within sewage systems with the ultimate goal of preventing damage to wastewater infrastructure and sewer overflows into the environment (Mitchell et al. 2017; Jensen et al. 2018). However, no peer-reviewed studies, to date, have investigated the real-time degradation of “flushable” wipes under sewage system-like conditions (Engelhaupt 2017), despite increases in the global prevalence of fatbergs. Thus, this paper presents the results of a research investigation designed to better understand the sewage transport volumes and degradation rates of personal care wipes, using guidelines outlined by the Water Research Foundation (WRF) of the United States. The research makes use of hydrologic, sewage, and wipes data collected in response to a sewer blockage incident caused by a massive fatberg that developed within a sewer interceptor pipe just upstream of a major pumping station (Clintondale Pumping Station) in Macomb County, MI (Ramirez 2018). The research is unique in several aspects: (1) the research team was able to respond to this failure in "real time" and recover pieces of the fatberg during the extensive removal process, (2) the team was able to monitor wipe volumes at this location subsequent to the failure, (3) the team was able to assess the "per capita" wipe loading arriving at the pumping station. The results of these investigations have led to the installation of a museum exhibit in Detroit, creation of an educational video game, and fostering of unique academic/municipal collaborations.

## Methods

### *Study Location*

This research relies on data and observations gathered in the vicinity of the Clintondale Pumping Station (CPS) in Macomb County, MI during the period September 2018 to February 2020. The CPS receives sanitary sewer water from a tributary area that covers most of eastern Macomb County, Michigan, USA (**Figure 1**). The drain system for this region uses separated sewers, so the majority of the flow is presumed to be sanitary sewerage. However, the occurrence of cross-connections is well known. Sewage flows that arrive at the CPS are detained in a wet well as mechanical scrapers on a vertical conveyor system remove solids prior to the flow advancing to the pumping system. The pumps add energy to the sewage, enabling its subsequent transport through the sewer lines that deliver the flow for treatment at the Water Resource Recovery Facility (WRRF) of the Great Lakes Water Authority in Detroit, MI. Treated effluent is then delivered to the Detroit River.

The tributary area to the CPS (**Figure 1**) covers approximately 225 square kilometers and has a population of approximately 100,000 people. The area lies on the western shore of Lake St. Clair and includes the Selfridge Air National Guard Base. The land uses in the northern portion of the area are primarily rural and residential while the land uses in the southern portion are primarily commercial manufacturing and residential. Overall, the demographics vary widely throughout the county. Population parameters of interest include populations under 5 and those over 64. These groups tend to use “flushable” wipes the most, especially ageing populations (Spence et al, 2016). In addition, population density is also an important factor and varies from the dense southern portion of the sewershed relative to the rural northern portion.

### *Clintondale Pumping Station Bin Data*

Clintondale Pumping Station (CPS) in Clinton Township, Michigan, USA connects two major interceptors in the Macomb County drain system. In 2018, a fatberg located just upstream of the CPS, as shown on **Figure 1**, was removed. This fatberg was approximately 100 feet long, 10 feet wide, and 6 feet tall and weighed approximately 19 tons when it was removed.

At CPS, two Duperon Flexrake screens (bar spacing of 3 inches) remove large solid materials prior to sewer water entering pumps in order to prevent damage to the pumps and empty these solids into two bins. A large portion of the solids removed during screening are wipes (**Figure 2**). From April 2019 until February 2020, data was gathered on a weekly basis to quantify the solids removed during screening.

The volume of the solids was estimated in the bins by first spreading the solids surface evenly and then measuring the average depth of the collected solids in the bin of known cross-sectional area. A 5-gallon bucket was filled with a sample of the solids from each bin and was weighed. This weight was then extrapolated to estimate the weight of the solids in each of the bins. The weight of wipes per collected debris volume was estimated using manual sorting of the dried components of two samples of 5-gallon buckets of the collected solids (**Figure 3**).

Results of the analysis suggest that, on average, 9,200 wipes are removed weekly from the captured solids at the Clintondale Pumping Station with a maximum of 13,000 per week during the period of this study. The weekly bin data was analyzed by the project team to gain insights into variability of collected solid volumes/weight and to consider causal effects of such variation, including rainfall data for the region and flow data for the pumping station to determine if there was a correlation between collected solids and either of these variables.

### *Water Collection*

Drinking water or "tap water" was collected at Wayne State University, Detroit, Michigan, USA at temperatures ranging from 22.5 to 23.2°C and a pH of 7.25 to 7.42. Unfiltered sewage water or "raw water" was collected from the Clintondale Pumping station in Clinton Township, Michigan, USA. Raw water was transported back to the laboratory in 2L glass containers and then filtered through an 8 mm sieve to remove excessively large particles. Raw water was used in the experiments to assess for the potential for degradation from microbes present in sewage water. Tap water was also used as a comparative medium to test wipe degradation since wipes are flushed down the toilet using tap water. Sieves used for degradation experiments were 8 inch diameter, brass frame stainless mesh sieves of 2 inch height (Humboldt Manufacturing Company, Elgin, IL). All comply with ASTM E11, Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves, and AASHTO M92, Standard Specification for Wire-Cloth Sieves for Testing Purposes.

### *Commercial Wipes*

Six different commercially available wipes were utilized in these experiments: three marketed as flushable in sewer systems and three labelled non-flushable. Tests on flushable and non-flushable wipes were conducted since they were both collected from the pumping station and it has been reported in previous studies that both types of wipes are making their way into wastewater treatment plants (Briain et al. 2020). Wipe selection was then based on intended commercial use, which can likely alter its size, strength, plastic polymer composition, and, therefore, its potential degradability. Our selection includes some of the largest brands and most commonly used types of wipe products in the United States. Flushable wipes included a baby wipe (made with biodegradable materials and alcohol-free, parabens and sulfates-free and with added lotion), hand wipe (ingredients being 100% plant -based viscose, and plastic-free, alcohol-free, no polyoxymethylene or methenamine with aloe vera and vitamin E), and an adult wipe (ingredients being plant-based fibers and plastic-free, alcohol-free, paraben-free, free of harsh chemicals and dye-free) while non-flushable wipes included a baby wipe (made with viscose plant based natural fibers, alcohol and parabens free and containing aloe vera extract but indicated to not be flushable), makeup-remover wipe (contains plant extracts as lotion and is oil free but indicated as not biodegradeable), and a commonly used disinfecting wipe (does not contain bleach but is labelled as not for use as a diaper wipe or for personal cleaning which may indicate non degradable components). Nonflushable wipes were included to serve as a direct comparison to flushable wipes and due to the prevalence at the Clintondale pumping station, despite their advertisement as “nonflushable”. The wipes chosen did not have any detailed information on their constituents and the Materials Safety Data Sheet (MSDS) only listed ethanol as part of the solution they are stored in pre-use. Wipe degradation was assessed under static and kinetic conditions with five replicate wipes of each commercial brand used per condition (n=5). To draw comparisons, a commercial brand of 2-ply cotton toilet paper was placed under the same conditions per each replicate.

### *Experimental Conditions and Endpoint Determination*

The degradation of wipes was examined using both tap water and raw water and degradation was determined as wipe particles that could sufficiently pass through the sieve stacks. In each case, 500 mL of each liquid was placed in 2L flasks, followed by the addition of one pre-weighed wipe. For the evaluation of conventional toilet paper, two pieces (intact sections separated at point of serration) were tested in the same manner as wipes in a separate flask. Two sections were used to approximately equal the weight of a single wipe. Pilot studies of toilet paper experiments indicated that nearly 100% of toilet paper degraded over 2-hour time intervals, passing entirely through the sieve stack, making it a useful control substance. Each flask containing a wipe or toilet paper, done in 5 replicates (n=5), was placed on an orbital shaker at 150 rotations per minute (rpm), a comparative speed to what was found in Macomb County sewer systems, for up to 48 hours. To assess the variability in wipe degradation over time, flasks were removed from the orbital shakers at 2, 4, 8, 24, and 48 hours of shaking. 48 hours reflects an approximate time intervals for wipes to reach sewage treatment facilities after being flushed down a toilet. To determine if static verses kinetic conditions significantly impacted wipe degradation, for each group of experimental flasks, five replicate flasks (containing one of each wipe) were kept static for the duration of the experiment (n=5). This procedure is identical for raw water and tap water.

### *Measuring Wipe Degradation*

Methods adapted from (Karadagli et al. 2009) were used to assess wipe degradation, using definitions from the Water Research Foundation (WRF) of the United States (Water Research Foundation, 2003). We describe degradation of the wipes' physical structure between different polymer threads using the WRF's definition, as "the process by which [the consumer product] breaks up into smaller pieces by physical, chemical, or biological means. Degradation is assessed by the weight loss of a product under specific environmental conditions (Water Research Foundation, 2003).” In the literature other definitions are given of plastic degradation however overall mass loss is the most straightforward (and used in this study) to assess degradation but does not take into account complete degradation (Chamas, Moon et al. 2020). As such, after removing the flasks that were subjected to either static or kinetic conditions, the wipe was then passed through sieves containing 8, 4, 2, and 1 mm sized mesh. The top sieve was gently rinsed using a showerhead nozzle for 2 minutes. The top sieve was then removed, and the next sieve was rinsed. This sequence continued until all sieves in the structure were sufficiently rinsed. A simplified diagram of this process is illustrated in **Figure 4**. The proportion of wipe on each sieve was transferred to a pre-weighed aluminum drying pan and then placed in a drying oven overnight at 40°C. Wipe degradation per sieve was determined by the percent of wipe maintained of each size fraction using the following equation:

$$\frac{\text{Dried weight of retained fraction on sieve (gm)}}{\text{Initial weight of sample (gm)}} \times 100 = \%\text{ of initial added mass}$$

The initial weight of each wipe was used to determine the relative proportion in each sieve, with weight unaccounted for assumed to belong to degraded wipe passing through the smallest sieve (<1mm). Particles <1mm in size are classified as microfibers in the present study.

*Statistical Analysis and Replicability*

All data was analyzed using an ANOVA with a Tukey Test for post-hoc analysis to compare differences among treatment groups of the same size. Prior to running an ANOVA, these data sets were tested for normality using a Shapiro-Wilk test. All statistical analyses were performed in R

(2013) (version 3.3.1; R Project for Statistical Computing, Vienna, Austria) using α = 0.05 to determine statistical significance. Each experiment contained one of each respective wipe and was repeated a total of 5 times (n=5).

## Results

### *Clintondale Pumping Station Bin Data*

The weight of solids removed by screens at the Clintondale Pumping Station varied throughout the year with no significant pattern (**Figures 5 and 7**). The highest rates of weekly solid removal (by weight) occurred during the summer, fall, and early winter and lowest rates (by weight) were seen during spring, early summer, and fall. In addition, weekly solid removal (by weight) rates did not correlate with weekly rainfall rates or average flow rates at CPS for any given week. Therefore, suggesting that precipitation alone cannot account for increasing wipes in the sewer.

In addition to weight, volume of solids removed was also analyzed and showed no significant pattern throughout the year (**Figures 6 and 8**). Highest rates of weekly solid removal (by volume) occurred during late summer, fall, and early winter, while lowest rates of solid removal (by volume) were seen at points during nearly every season. Wipes were seen in all collections and averaged 9,200 wipes per week at the CPS, with a maximum of approximately 13,000 wipes per week. There are several ways to interpret this rate. If we assume that all wipes flushed into the network are collected at CPS, this rate corresponds to approximately 0.1 wipe per resident per week in the tributary region. However, the potential for fatberg formation has already been proven in this interceptor, and a portion of the wipes will be attached to the fatberg, reducing the numbers seen at CPS. Moreover, not all residences improperly dispose of wipes. Assuming that 5% of residential units improperly dispose of wipes, it can be estimated that residents that improperly dispose of wipes add 10 or more into the sewer system per week (depending on the number intercepted by fatberg formation prior to arrival at CPS). The rates did not correlate with weekly rainfall rates or average flow rates at CPS for any given week. This suggests that the presence of wipes in the sewer system could not only be a result of increased precipitation.

### *Wipe Degradation Study*

Five of the six wipes investigated in a tap water environment showed little evidence of degradation. For these samples there were no significant differences present in the percent retained in each respective sieve at each time interval (2, 4, 8, 24, and 48). These five wipes were greater than 93% intact after 48 hours and less than 3% of broken down into microfibers (**Figure 9**). Less than 1% was retained in the 1, 2, or 4 mm size fraction. However, one brand of adult wipes marketed as flushable (FW1) degraded significantly over time, with only 53% intact after 2 hours and 14% after 48 hours. Over 30% of this wipe was broken down into microfibers at each time interval. In comparison, only 4 to 5% of toilet paper was intact after 48 hours, with no significant differences among each time interval sampled. The majority (~45%) of the toilet paper sample passed through the entire sieve structure. **Figure 9** details the percentage of each wipe entirely intact after 2 and 48 hours of shaking in tap water.

### *Degradation under Static verses Kinetic Conditions*

After 48 hours in tap water, no significant differences were present in size differentiation among the same aforementioned wipes (three non-flushable and two flushable) between static and kinetic conditions. Similar to the result from the orbital shaker, wipes under static conditions remained approximately 95% intact. However, one brand of adult flushable wipes (FW3) had significantly increased degradation when placed in kinetic conditions for 48 hours (14% intact) relative to static conditions (53% intact). Toilet paper experienced a similar trend, with degradation significantly higher when shaken (5%) compared to when not shaken (71%).

Similar to tap water (**Figure 10**), for five of the six wipes investigated in raw sewage, each showed little evidence of degradation, with greater than 92% intact after 48 hours with less than 3% of wipes degraded to particles smaller than 1mm (labelled as Fibers) (**Figure 11**). Less than 1% was retained in the 1, 2, or 4 mm size fraction. However, the adult wipe brand (FW1) marketed as flushable degraded significantly after 48 hours, with 55% intact after 48 hours. Over 28% of this wipe was degraded into fibers at each time interval. In comparison, 25% of toilet paper was intact after 48 hours. The majority (about 55%) passed through the entire sieve structure and had degraded into fibers. **Figure 11** details the percentage of each wipe entirely intact after 48 hours of shaking in raw sewage water.

### *Comparison of Degradation Rates*

Over the 48-hour time period, wipe degradation rates reflect similar findings to previous results (**Figure 12**). The toilet paper and FW3, an advertised “flushable adult wipe”, experienced the highest rate of degradation over 48 hours at about 1.8-2% per hour during kinetic conditions in tap water. For kinetic conditions in raw water, the toilet paper experienced a slightly lower degradation rate of 1.8% per hour, but FW1 experienced a much lower degradation rate of 1% per hour. For static conditions in tap water, toilet paper and FW1 experienced lower degradation rates of 0.6% per hour and 0.9% per hour, respectively. The remaining wipes experienced less than 0.2% degradation rate per hour. However, there was no consistent pattern for significant difference between these different conditions.

## Discussion

Results indicate that for most wipes selected in our experiments, whether marketed as "flushable", or "non-flushable", do not degrade substantially over time. Five out of six wipes tested during this study showed little degradation of any kind regardless of the conditions that they were tested. One wipe did degrade over time; however, it still took nearly 48 hours of kinetic conditions to degrade. In addition, the degradation rate decreased in raw water conditions. Even though this wipe did degrade more than the other wipes, the 48-hour duration is problematic since it would likely arrive at the pumping station more rapidly than this duration allows and could potentially cause problems such as clogging.

The concern over wipes in the sewer system has caused increased alarm during the recent coronavirus pandemic. Due to the increased reliance on such wipes as a disinfecting agent, the number of wipes that have ended up in the sewer system has increased dramatically (Levenson 2020). Reports from the site of this investigation, Macomb County, MI, indicate an increase as great as threefold during the height of the pandemic (WWJ News 2020). Of course, this increases the risk of sewer blockage and pump damage, but it also increases concerns over the potential transport of the virus by way of contaminated wipes in wastewater.

While wipes are an important part of the fatberg equation, they are only one portion of the issue. Fatbergs are caused by a combination of solids and fats. Once fats enter the sewer, they saponify when coming in contact with calcium (He et al. 2011). The calcium is often released from concrete surfaces under low pH conditions and contribute to the formation of fatbergs (He et al. 2013). Flushing fats is still a consistent issue, particularly for restaurants but also residents (Schaverien 2019). Deposits often contain palmitic acid and oleic acid and often have a high oleic to palmitic acid ratio (Williams al. 2012). Palmitic acid is naturally occurring in lower levels in butter, cheese, milk, and meat as well as plant-based oils and oleic acid is common in higher levels in oils such as olive oil, pecan oil, and peanut oil among others. Flushing fats have been addressed through public campaigns (Wallace et al. 2017) and grease interceptors (Mattsson et al. 2014). Enzyme pretreatment has also shown promise in disrupting fat accumulation (Dong et al. 2017). Future studies need to be done to understand the other types of solids found in fatbergs and removed from screening. While wipes are clearly a cause of many fatberg related issues, other solids that are commonly flushed can cause similar issues for sewer systems.

Prevention is a tactic many municipalities have started taking to reduce flushing solids down the drain. Municipalities have begun campaigns to educate their residents on this issue when affected. Pumping station and wastewater treatments plants are also being designed to include screening to remove solids in order to prevent damage to equipment. Future regulation from government agencies and the defining of "flushable" materials is essential to prevent further detrimental impacts to sewage infrastructure. Most recently, the state of California put forward legislation to address the issue of labelling these wipes clearly as "non-flushable" (Bloom 2020). Along these lines, our study demonstrates that these wipes are prevalent and will not break down in the sewage system, even if they are labeled as "flushable". Recent studies on wet wipe dispersibility (Harter et al. 2021), and presence of non-flushable and flushable wipes in marine sediments highlight the importance of additional research needed on this issue (Briain et al. 2020). The presence of wipes in marine sediments are particularly alarming given the concern of increasing microplastics being found in aquatic habitats. Although, the generation of microplastics from wipes was outside the scope of this work, others have conclusively demonstrated that wipes are a source of microplastic fibers (Briain et al. 2020). Wipes consisting of 80-90% wood pulp, vicose, and lyocell are known to be highly biodegradable in the current literature (Kim and Hergett, 2012; Mango, 2017) however, most brands of wipes do not list their major structural components which presents difficulty when studying their suitability for the sewer system. The composition of wipes varies and might consist of natural biopolymers combined with synthetic fibers. It is accepted that natural biopolymers eventually fully degrade such as toilet paper, which is made of cellulosic pulp, however wipes do not exhibit the same characteristics of toilet paper when flushed into the sewer as shown in our work. The individual components of wipes may degrade differently since the natural biopolymers should degrade via biological methods while the synthetic fibers may persist longer and possibly never degrade to a satisfactory level that prevents fatbergs and other blockages in the sewer system.

### *Future Directions*

This study and others have shown that the labelling of wipes as "flushable" and "non-flushable" is flawed. In a recent study, 23 products that were labelled "flushable" failed the test of being flushable and contained at least one man-made material (Joksimovic et al. 2020). Joksimovic et al. 2020 recommend removing the term "flushable" from all products except toilet paper. More public education and legislation is needed to change the marketing of wipes so that consumers are strongly advised not to flush these items. An interdisciplinary approach including chemists, physicists, engineers and biologists is needed to research the emergence of wipe-related problems. Convergent research is needed to design and produce wipes that can degrade, as well as methods to test the current wipes being used, so that government authorities can update antiquated legislation that was established before widespread use of wipes.

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## Data Availability Statement

The data that supports the findings of this study is available in graphs in this article. Any additional data that support the findings of this study are available from the corresponding author upon reasonable request.

## Author Contributions

TRB is the senior author; TRB and CJM conceived the project; TRB, CJM, AFP, JST conceptualized the content; AFP, JST, MG, and AP were involved in the investigation; AFP, JST, MG, AP and AAV performed the data analysis and wrote the manuscript; All authors edited the manuscript; Funding and resources were provided by TRB and CJM.

## Literature Cited

Alda-Vidal, C., A. L. Browne and C. Hoolohan, 2020. "Unflushables": Establishing a global agenda for action on everyday practices associated with sewer blockages, water quality, and plastic pollution. *Wiley Interdisciplinary Reviews-Water* 10.1002/wat2.1452.

Atasagˇun, H.G and G.S. Bhat, 2020. Advancement in flushable wipes: Modern technologies and characterization. *Journal of Industrial Textile* **49**(6) 722–747.

Bloom, R., 2020. Solid waste: premoistened nonwoven disposable wipes.

Briain, O. O., A. R. M. Mendes, S. McCarron, M. G. Healy and L. Morrison, 2020. The role of wet wipes and sanitary towels as a source of white microplastic fibres in the marine environment. *Water Research* **182**.

Bresse, R.R, 1986. General Effects of Ageing on Textiles. *Journal of the American Institute for Conservation*, **25**:1, 39-48.

Chamas, A., H. Moon, J. Zheng, Y. Qiu, T. Tabassum, J. H. Jang, M. Abu-Omar, S. L. Scott and S. Suh, 2020. Degradation Rates of Plastics in the Environment. *Acs Sustainable Chemistry & Engineering* **8**:3494-3511.

Dong, Y., S. I. Safferman, J. Ostahowski, T. Herold and R. Panter, 2017. Enzyme pretreatment of fats, oil and grease from restaurant waste to prolong septic soil treatment system effectiveness. *Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering* **52**:55-63.

Engelhaupt, E., 2017. Huge Blobs of Fat and Trash Are Filling the World's Sewers.

Environmental Protection Agency, 2004. Report to Congress on Impacts and Control of Combined Sewer Overflows and Sanitary Sewer Overflows.

Harter, T., I. Bernt, S. Winkler and U. Hirn, 2021. Reduced dispersibility of flushable wet wipes after wet storage (vol 11, pg 7942, 2021). *Scientific Reports* **11**.

He, X., F. L. de los Reyes, III, M. L. Leming, L. O. Dean, S. E. Lappi and J. J. Ducoste, 2013. Mechanisms of Fat, Oil and Grease (FOG) deposit formation in sewer lines. *Water Research* **47**:4451-4459.

He, X., M. Iasmin, L. O. Dean, S. E. Lappi, J. J. Ducoste and F. L. de los Reyes, III, 2011. Evidence for Fat, Oil, and Grease (FOG) Deposit Formation Mechanisms in Sewer Lines. *Environmental Science & Technology* **45**:4385-4391.

Husain, I. A. F., M. a. F. Alkhatib, M. S. Jammi, M. E. S. Mirghani, Z. Bin Zainudin and A. Hoda, 2014. Problems, Control, and Treatment of Fat, Oil, and Grease (FOG): A Review. *Journal of Oleo Science* **63**:747-752.

Jensen, A. L., H. Sorensen, L. Rosendahl and P. U. Thamsen, 2018. Characterisation of textile shape and position upstream of a wastewater pump under different part load conditions. *Urban Water Journal* **15**:132-137.

Joksimovic D., A. Khan, and B. Orr, 2020. Inappropriate disposal of 'flushable' consumer products – reasons for concern. *Water Sci Technol* 81 (1): 102–108.

Karadagli, F., D. C. McAvoy and B. E. Rittmann, 2009. Development of a Mathematical Model for Physical Disintegration of Flushable Consumer Products in Wastewater Systems. *Water Environment Research* **81**:459-465.

Kim, M.J and H.H Hergett, 2012. Technology roadmap for flushable nonwoven wipes. *Journal of the Textile Institute* **103:**200-209.

Levenson, M., 2020. Americans Coping With the Coronavirus Are Clogging Toilets.

Mango, P. Flushable wipes – past, present and future. Nonwovens Industry, 2004

Mattsson, J., A. Hedstroem, M. Viklander and G.-T. Blecken, 2014. Fat, Oil, and Grease Accumulation in Sewer Systems: Comprehensive Survey of Experiences of Scandinavian Municipalities. *Journal of Environmental Engineering* **140**.

Mayberry, P., 2016. Flush ability standards could go global. Nonwovens Industry

McIntyre, K. To flush or not to flush. Nonwovens Industry, 18 February 2014.

Mitchell, R.-L., P. U. Thamsen, M. Gunkel and J. Waschnewski, 2017. Investigations into wastewater composition focusing on nonwoven wet wipes. **10**:125.

Molina, B., 2019. A 'fatberg' made of grease and wet wipes found in English sewer.

Munoz, L.P., A.G. Baez, D. McKinney, and H. Garelick, 2018. Characterization of "flushable" and "non-flushable" commercial wet wipes using microRaman, FTIR spectroscopy and flouresence microscopy: to flush or not to flush. *Environmental Science and Poluttion Research* **25**(20)-20268-20279.

Ramirez, C. E., 2018. Fatberg's removal from Macomb sewer cost $100K.

Schaverien, A., 2019. Scientists Solve a Puzzle: What's Really in a Fatberg.

Spence, K. J., C. Digman, D. Balmforth, J. Houldsworth, A. Saul and J. Meadowcroft, 2016. Gross solids from combined sewers in dry weather and storms, elucidating production, storage and social factors. *Urban Water Journal* **13**:773-789.

Smithers, A. The next steps for flushable wipes. Nonwovens Industry, www.nonwovens-industry.com/issues/2014-04-02/view_features/the-next-steps-for-flushable-wipes/13594

Wallace, T., D. Gibbons, M. O'Dwyer and T. P. Curran, 2017. International evolution of fat, oil and grease (FOG) waste management - A review. *Journal of Environmental Management* **187**:424-435.

Water Research Foundation, 2003. Protocol to determine the flushability of disposable products.

Williams, J. B., C. Clarkson, C. Mant, A. Drinkwater and E. May, 2012. Fat, oil and grease deposits in sewers: Characterisation of deposits and formation mechanisms. *Water Research* **46**:6319-6328.

WWJ News, 2020. Macomb Co. Reports 400% Spike In Items That Shouldn't Be Flushed Down The Toilet.

Zhang, B., D. Ning, Y. Yang, J. D. Van Nostrand, J. Zhou and X. Wen, 2020. Biodegradability of wastewater determines microbial assembly mechanisms in full-scale wastewater treatment plants. *Water Research* **169**.

**Figure Legends:**

***Figure 1:*** *Clintondale Pumping Station and fatberg location*

***Figure 2****: Screening Debris*

***Figure 3****.(A) Dried solids collected from the CPS bin. (B), Weighing process of the wipes.*

***Figure 4****: Single run of wipe degradation analysis*

***Figure 5****: Weekly solids accumulation (by weight) and rainfall depth*

***Figure 6****: Weekly solids accumulation (by volume) and rainfall depth*

***Figure 7****: Weekly solids accumulation (by weight) and average flow rate at CPS*

***Figure 8****: Weekly solids accumulation (by volume) and average flow rate at CPS*
***Figure 9:*** *Percent of flushable wipes (A-C), nonflushable wipes (D-F) and toilet paper*

*(G) retained in each sieve size fraction after 2 hours (gray) and 48 hours (black) under kinetic conditions in tap water*

***Figure 10****: Percent of the original wipe completely intact after 48 hours* ***in tap water*** *under static and kinetic conditions. Toilet paper (TP) degrades significantly greater than both the flushable wipe (FW) and nonflushable wipe (NFW). Asterisks (*) represent significant differences ($p<0.05$) relative to the control as determined by ANOVA by Tukey Post-Hoc test.*

***Figure 11****: Percent of the original wipe completely intact after 48 hours* ***in raw sewage water*** *under static and kinetic conditions. Toilet paper (TP) degrades significantly greater than each flushable wipe (FW) and nonflushable wipe (NFW). Asterisks (*) represent significant differences ($p<0.05$) relative to the control as determined by ANOVA with Tukey Post-Hoc test.*

***Figure 12****: Wipe degradation after 48 hours in tap water and kinetic conditions (blue), tap water and static conditions (orange), and raw water and kinetic conditions (gray)*

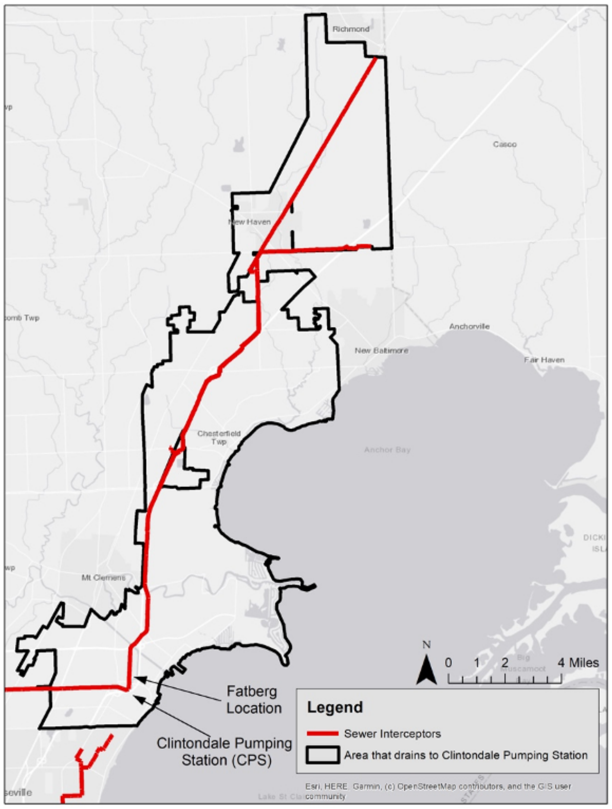

***Figure 1:*** Clintondale Pumping Station (CPS) and fatberg location

***Figure 2***: Screening Debris

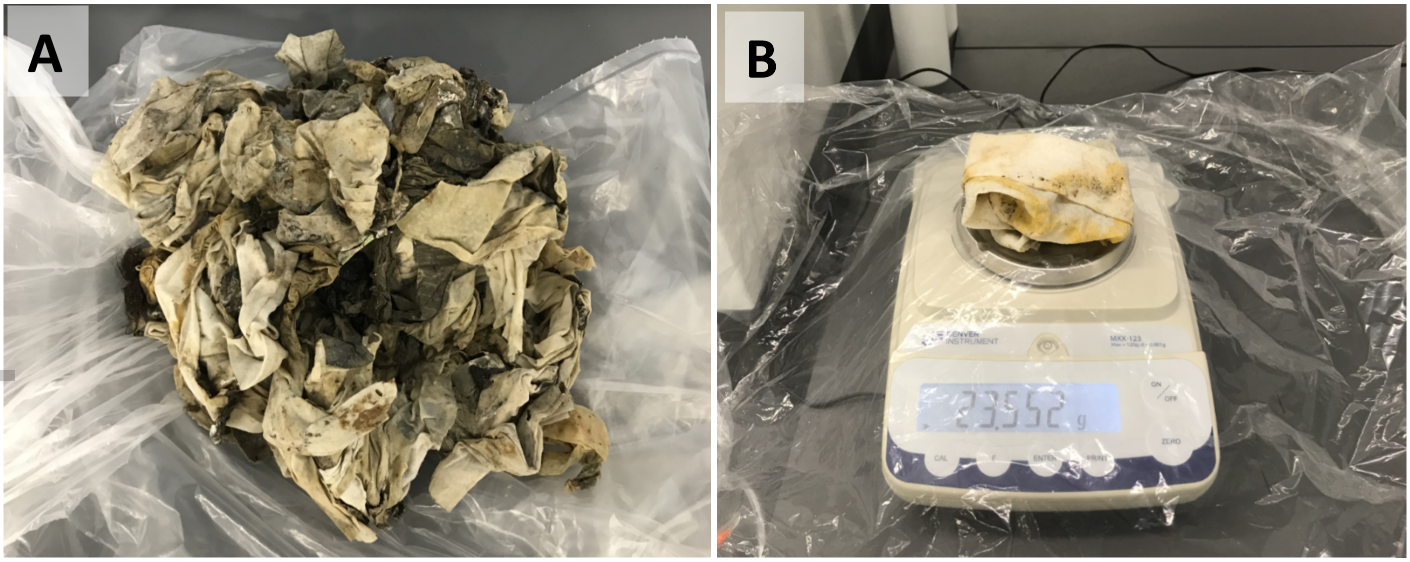

***Figure 3.*** (A) Dried solids collected from Clintondale Pumping Station (CPS) bins. (B) Weighing process of wipes

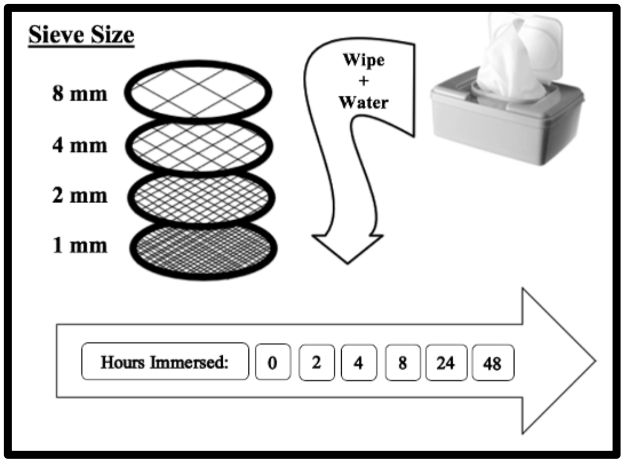

*Figure 4*: Single run of wipe degradation analysis

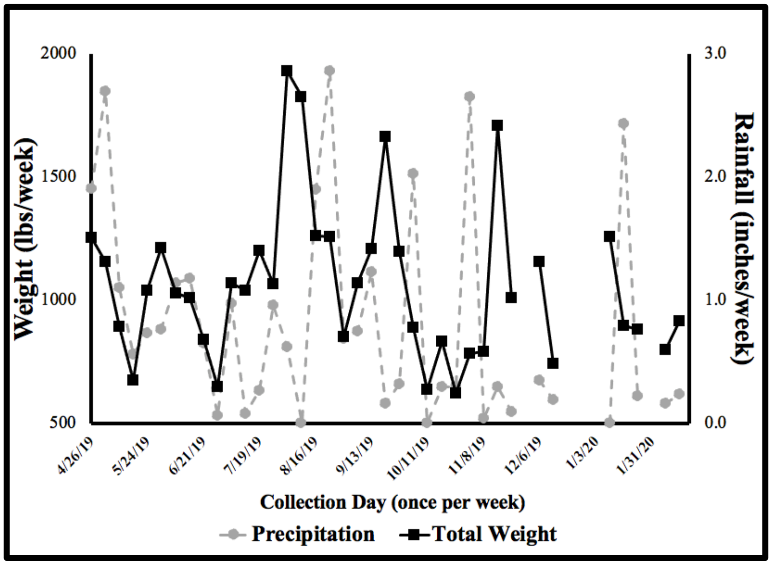

***Figure 5****:* Weekly solids accumulation (by weight) and rainfall depth

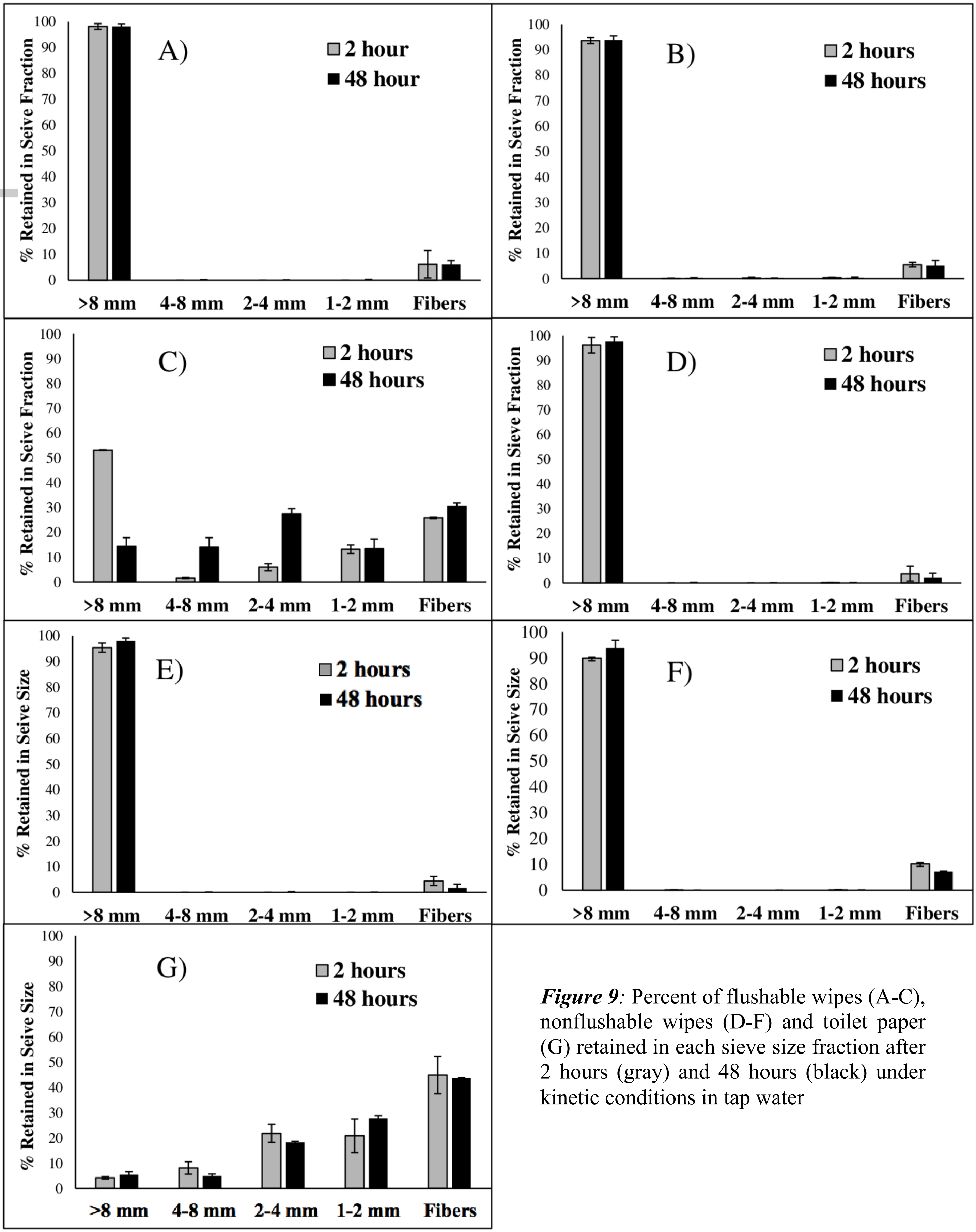

***Figure 9**:* Percent of flushable wipes (A-C), nonflushable wipes (D-F) and toilet paper (G) retained in each sieve size fraction after 2 hours (gray) and 48 hours (black) under kinetic conditions in tap water

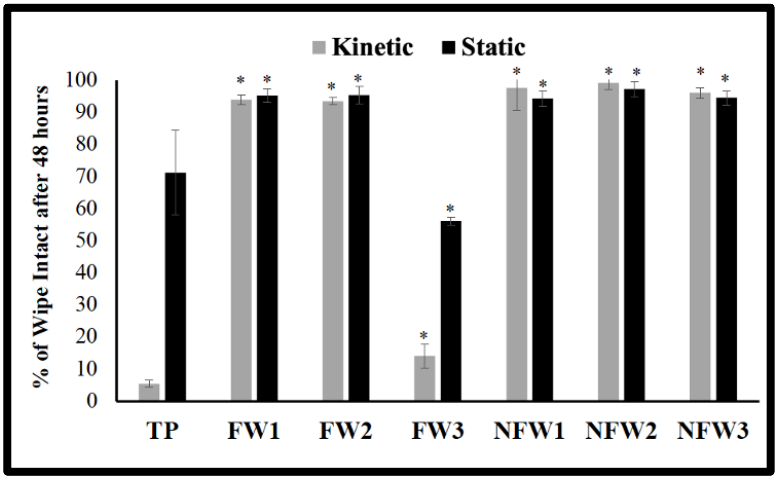

***Figure 10:*** Percent of the original wipe completely intact after 48 hours **in tap water** under static and kinetic conditions. Toilet paper (TP) degrades significantly greater than both the flushable wipes (FW) and nonflushable wipes (NFW). Asterisks (*) represent significant differences ($p<0.05$) relative to the control as determined by ANOVA by Tukey Post-Hoc test.

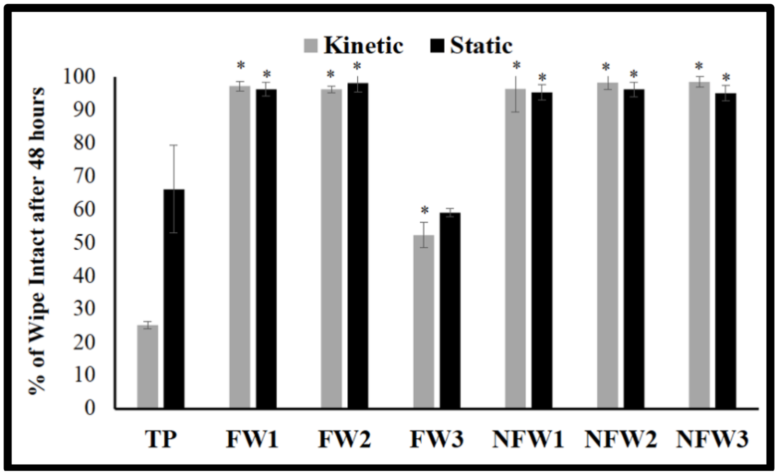

***Figure 11**: Percent of the original wipe completely intact after 48 hours **in raw sewage water** under static and kinetic conditions. Toilet paper (TP) degrades significantly greater than each flushable wipe (FW) and nonflushable wipe (NFW). Asterisks (*) represent significant differences ($p<0.05$) relative to the control as determined by ANOVA with Tukey Post-Hoc test.*

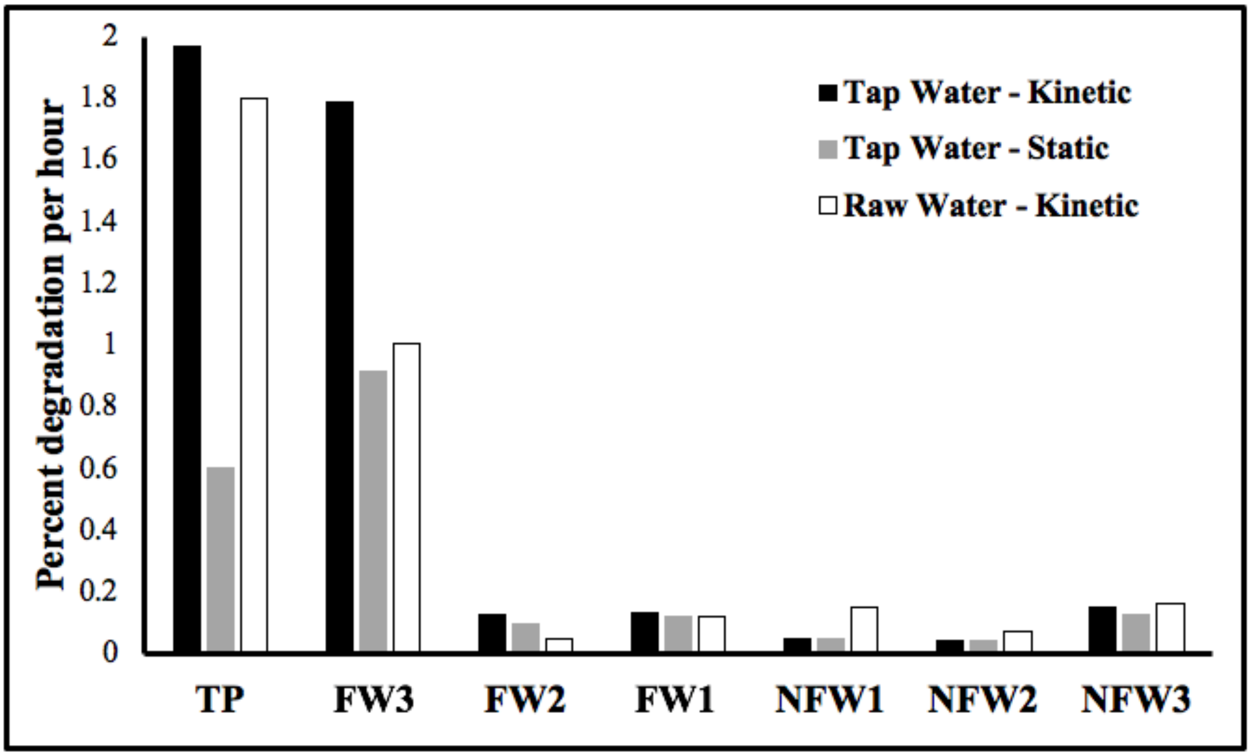

***Figure 12****:* Wipe degradation after 48 hours in tap water and kinetic conditions (blue), tap water and static conditions (orange), and raw water and kinetic conditions (gray)

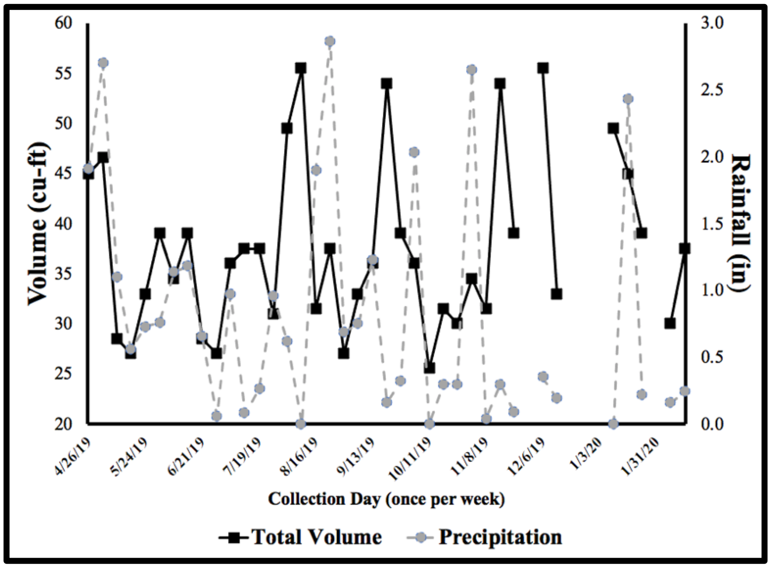

***Figure 6**:* Weekly solids accumulation (by volume) and rainfall depth

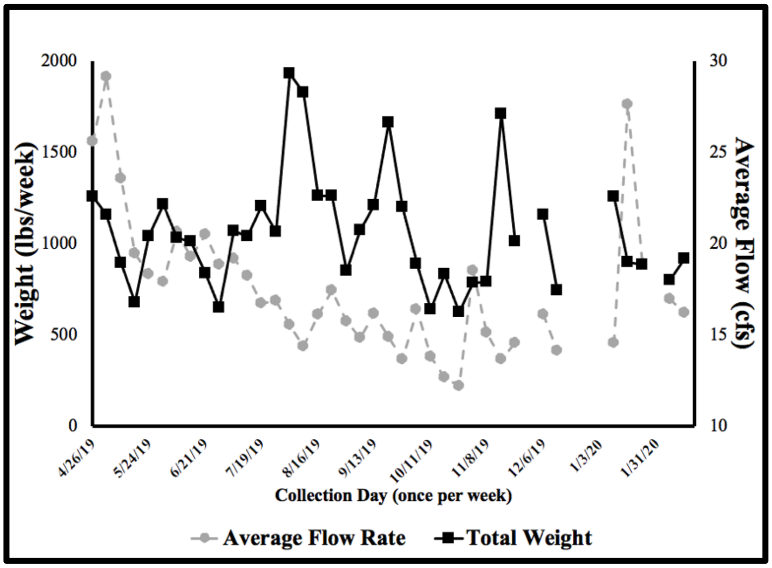

***Figure** 7:* Weekly solids accumulation (by weight) and average flow rate at Clintondale Pumping Station (CPS)

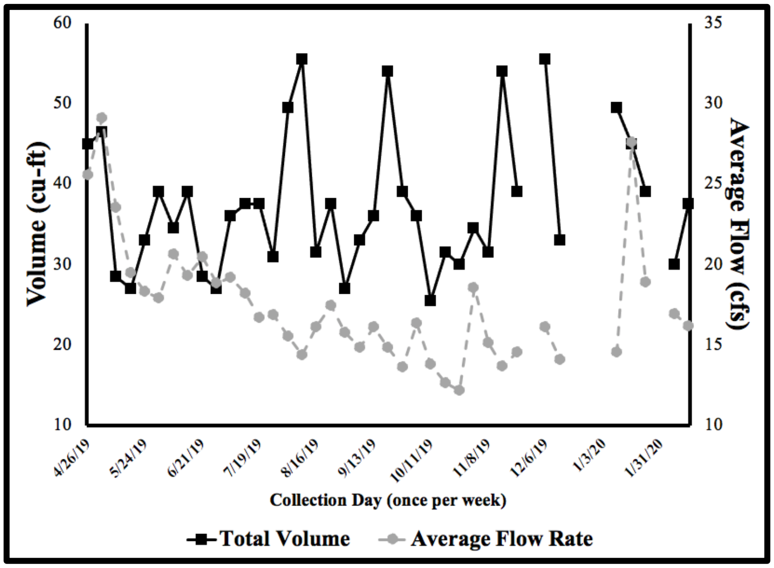

***Figure 8**:* Weekly solids accumulation (by volume) and average flow rate at Clintondale Pumping Station (CPS)