Quantifying Plastic Debris Loading and Accumulation in Corpus Christi Bay to Improve Stakeholder Awareness

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Prepared by:
Jeremy L. Conkle, Principal Investigator
Coastal Health & Water Quality Laboratory
Texas A&M University-Corpus Christi
6300 Ocean Drive, Unit 5892
Corpus Christi, Texas 78412
(361) 825-2862

Submitted to:
Coastal Bend Bays & Estuaries Program
615 N. Upper Broadway, Suite 1200
Corpus Christi, Texas 78401-0749

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Jeremy L. Conkle, Principal Investigator

Coastal Health & Water Quality Laboratory
Texas A&M University-Corpus Christi
6300 Ocean Drive, Unit 5892
Corpus Christi, Texas 78412
Corpus Christi, Texas 78412

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We owe a huge debt of gratitude to Tony Wood and the National Oil Spill School for their guidance and help with designing stormwater aspects of the project as well as troubleshooting and sampling.

Executive Summary

Corpus Christi was established because of the ecosystem services provided by the local environment. The bay was ideal for a port, which established the city as a center of commerce in the region. This port has benefited significantly due to nearby deposits of oil and gas. The community continues to grow due to the natural resource and beauty of the area that attracts new residents but also drives tourism, which is a major part of the local economy. However, today the waters and shoreline of Corpus Christi Bay are heavily impacted by litter. This study sought to quantify the amounts of macro (cups, bags, wrappers, etc.) and microplastics entering and accumulating in Corpus Christi Bay. To do this, wastewater effluent, stormwater and bay sediment were sampled. Wastewater effluent was sampled for microplastics at three Corpus Christi wastewater treatment plants (WWTP) at semi-monthly intervals and at one WWTP to examine weekly, daily and hourly discharge of microplastics. Stormwater discharge was sampled for macroplastics at two locations in Corpus Christi Bay (Cole Park and Oleander Point) and in the Schanen Ditch that flows into Oso Creek and eventually the bay. Lastly, sediment samples were collected at 15 sites distributed around the bay to determine where plastic accumulation may be occurring. Due to the time required to process and sort samples, results for wastewater and sediment samples are not yet complete. Preliminary results for microplastics in wastewater indicate that millions of microplastic fibers and particles are discharged daily from the three WWTPs studied which equates to billions or 10s of billions annually. Further processing of the samples must occur, so these numbers should be considered a rough estimate. The impacts of microplastics in Corpus Christi Bay is also unknown, but future studies by the PI and additional collaborators are planned to begin addressing these issues. For sediment sampling, preliminary results indicate that between 160 and 450 microplastics Kg^{-1} of sediment can be found in the top 20 cm of Corpus Christi Bay sediment. These results are in line with and slightly higher than a study that examined concentrations near Hong Kong. With stormwater discharge, the methods used to capture debris did not work as planned. Unpredictable rains, strong winds, choppy water and spring tides made sampling at Cole Park, Oleander Point, and Schanen Ditch challenging. Debris was captured at Cole Park for one rain event, but the wind and tides pushed the debris onshore, where the maintenance crew removed most of the material before it could be collected by our researchers. The fraction of material collected weighed ~4.5 kg, with the most numerous items being bottle caps (614), cigarette butts (186), "other plastic" (168), straws (147) and plastic food wrappers (100). While efforts to quantify litter in stormwater discharge are disappointing, it is obvious that there is a major problem with plastic debris entering Corpus Christi Bay. What this study has proven, despite only having preliminary data so far, is that microplastic is also a major contaminant of our surface waters. Although, its impacts still need to be assessed. Broadly speaking, efforts must continue to address the plastic litter problems facing our community, which involve determining the underlying causes and addressing them, improving waste infrastructure, adding litter capturing infrastructure and continuing to grow community buy-in to reduce litter in our environment.

Introduction

Corpus Christi is nicknamed the "Texas Riviera" or the "Sparkling City by the Sea," with Corpus Christi Bay being the centerpiece of this city. Unfortunately, Corpus Christi Bay is developing a reputation for its trash/plastic debris and littered shorelines (see "All the Cups" on YouTube: https://youtu.be/LhlBSOlTYdQ). This "reputation" could have economic consequences in the broader region, with $1.5 billion and $5.4 million in local revenues tied to nature tourism and fisheries.[1, 2] Unfortunately, this problem is not unique to Corpus Christi, with plastic debris estimates in the ocean at ~268,000 tons[3] and 4.8-12.7 million tons loaded annually.[4] The fate of plastic debris is also largely unknown, as estimates for total annual plastic loading[4] do not match observed concentrations.[3] The first step in understanding the problem locally is quantifying its scale and studying sources. This project quantifies and characterizes (types, sources, sizes) plastic (i.e., polyethylene terephthalate, polyethylene, polypropylene, polystyrene, etc.) loading from stormwater and wastewater as well as its accumulation in Corpus Christi Bay sediment. These results provide the City of Corpus Christi with the baseline data needed to justify funding requests and grants that will tackle the problem through education, outreach, and mitigation. Additionally, the data collected will assist researchers locally and globally in assessing the impact of aquatic plastic debris on ecosystem function and health.

Methods

The quantification and characterization of plastic debris, particularly microplastics, in aquatic systems is a rapidly growing field of research. This increase in research has led to the development of numerous methods for the collection of macro and microplastics in wastewater, stormwater, and sediment. Currently, there are no standardized methods approved by the USEPA or TCEQ for the sampling of plastic debris in wastewater effluent, stormwater discharges, and sediment. Therefore, the methods employed in this research adapt those published in peer-reviewed literature or QAPPs from other areas of the country if available.

Wastewater Effluent

Sample Collection

Tertiary treated (UV disinfected) wastewater was collected at three of the largest Corpus Christi wastewater treatment plants (WWTPs), Greenwood, Oso, and Allison, which account for ~73% of the city's 26 Mgal d -1 effluent (Figure 1). Wastewater effluent was sampled across 4 temporal scales to account for variations in microplastic discharge. Effluent was sampled semi-monthly for 3 months at each WWTP (Semi-monthly). Then at only the Greenwood WWTP, samples were collected weekly for one month (Weekly), daily for one week (Daily) and as 3-hr composite samples for a 24 hr period over 3 days (Hourly). Attempts were made to collect samples at the same time of day for the Semi-monthly, Weekly and Daily samples to reduce sources of variation in the data. Sampling dates are showing in Table 1.

Table 1. Sampling dates for wastewater effluent

Semi-monthly (3 WWTPs)	Weekly (Greenwood)	Daily (Greenwood)	Hourly (Greenwood)
8/16/17	8/16/17	10/1/17	1/22/18
*9/13/17	8/23/17	10/2/17	1/23/18
9/27/17	9/6/17	10/3/17	1/24/18
10/11/17	9/13/17	10/4/17	
10/25/17	9/20/17	10/5/17	
11/8/17	9/27/17	10/6/17	
⍋11/22/17	10/4/17	10/7/17	
	10/11/17		

*Sampling was suspended from 08/23 to 09/06 due to Hurricane Harvey

[⊼]Policies at the Corpus Christi WWTPs underwent changes in late November limiting access for sampling

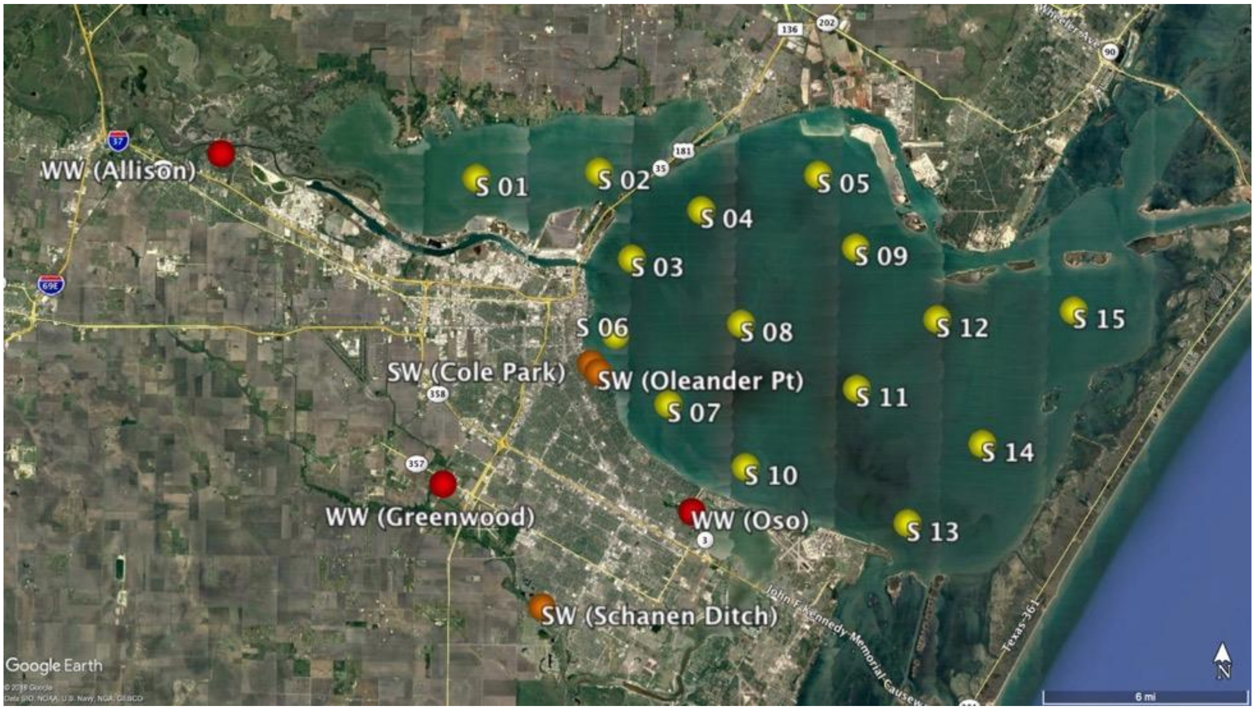


Figure 1. Wastewater (red, n=3), stormwater (orange, n=3) and bay sediment sample collection sites (yellow, n=15).

The Semi-monthly, Weekly and Daily samples were collected using pre-cleaned 4 L amber bottles. Each bottle was rinsed onsite with sample water (~0.5L) 3x prior to sample collection. Sample volumes of ~2 L were collected for each sampling event in triplicate using on-site sampling devices. The three, 24-hour effluent sampling events at the Greenwood WWTP were conducted with two Teledyne ISCO Avalanche Portable Auto-Sampler. The Auto-Samplers were programmed to collect 8, 3-hr composite samples over 24-hr. Each composite contained 4 L of wastewater effluent.

Sample Processing

Prior to sample processing, all wastewater samples were autoclaved at 121 ^{o}C for 30 minutes and then stored at 4 ^{o}C. Next, samples were vacuum filtered with a 0.8 µm membrane filter. The filter membrane was then transferred to a petri dish, covered with aluminum foil and dried overnight at 60-75 ^{o}C. Dried membranes were stored in a closed petri dish until visual sorting of suspected microplastic particles and fibers under a microscope. Suspected fiber and particle characteristics were logged, and the materials were consolidated in a 3mL vial containing ~2mL ethanol (70%).

Storm Water

Boom Installation

Three stormwater sampling sites were monitored for plastic debris in discharges (Cole Park, Oleander Point, and Schanen Ditch; Figure 1) after with rain events. To collect debris, harbor class booms were deployed 2-3 days before storm events when weather permitted (Figure 2). After storms, dip nets were used to collect the debris captured by booms and if necessary boats were also used. Booms in Corpus Christi Bay (Cole Park and Oleander Point stormwater basins) were anchored to the shoreline and extend out 30 and 15 m from the shore for Cole Park and Oleander Point (Figure 3). The Schanen Ditch boom stretched across the drainage channel (~30 m; Figure 3). The Schanen Ditch site was not originally a planned sampling site. The original sampling site

Figure 2. Boom installation at Cole Park (09/01/2017)

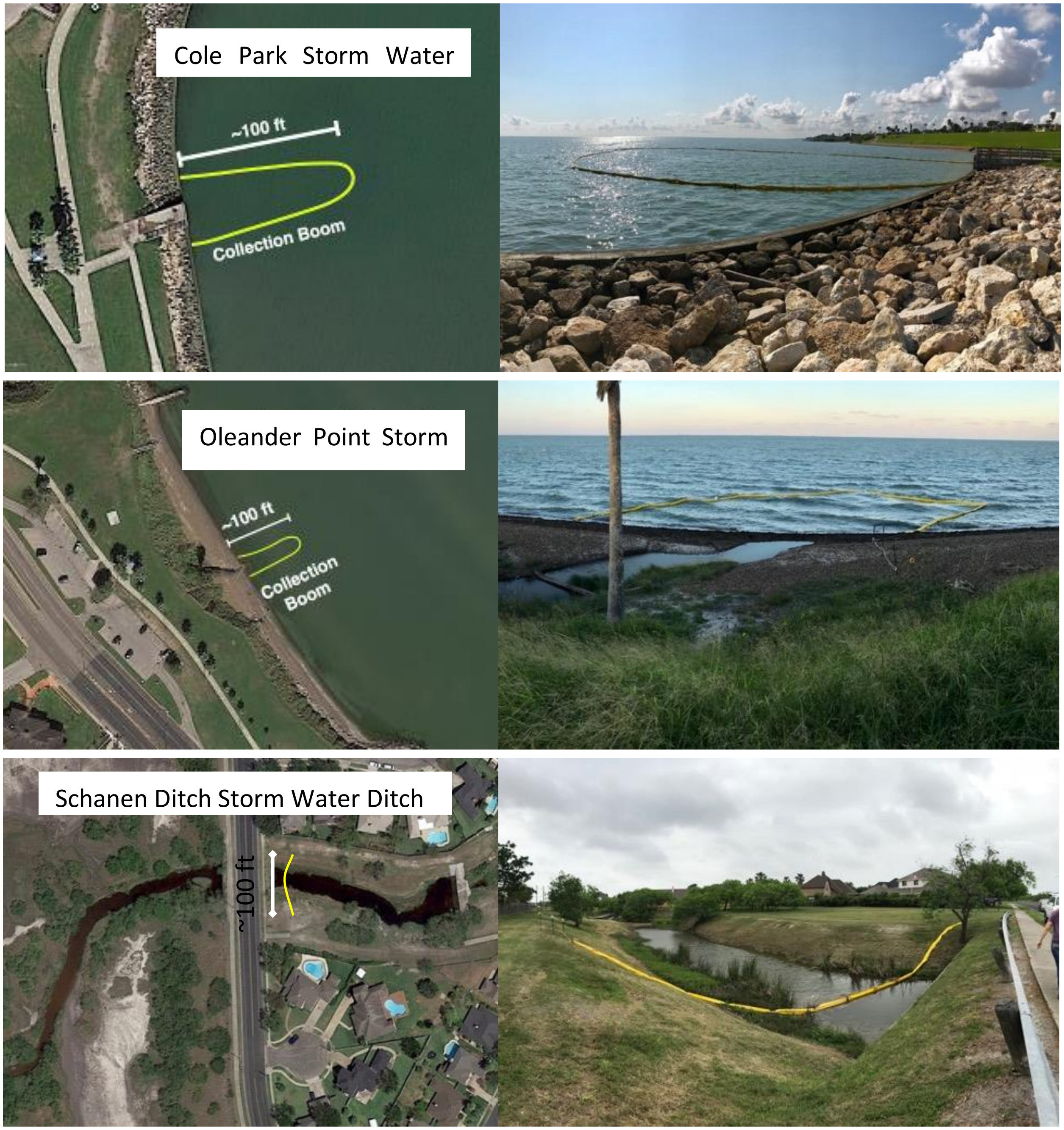


Figure 3. Stormwater collection sites.

was planned for Oso Creek, just north of the Staples Street bridge. This site was scouted prior to the development of the project QAPP. However, in the summer of 2017 construction on the road south of the Staples Street bridge prohibited access to the original sample collection area. A meeting was held with representatives from the City of Corpus Christi and the Texas Department of Transpiration (TXDOT) to gain access through the site contractor. However, shortly after this meeting, Hurricane Harvey occurred. All communications with TXDOT after that were never returned and we begin looking into alternative sampling sites along Oso Creek. While awaiting word from TXDOT we were made aware of Schanen Ditch as a potential sampling site. The site was scouted in February and an amendment to the original QAPP to use Schanen Ditch instead of Oso Creek was submitted shortly thereafter.

The floating debris collection system utilized standard harbor class oil spill response boom extending 30 to 60 m (100 to 200 ft) into the bay from the shoreline at Cole Park and Oleander Point in an open trapezoidal configuration (Figure 3). This configuration allowed for potentially strong discharge currents to flow under the boom while capturing floating debris.

The harbor class booms to be used in this study have the following characteristics:

- Plastic skirt that extends 0.5 m (18”) into the water column
- Yellow color, making them easily visible from shore
- Booms deployed in shallow water with dive lights attached to alter boaters at night
- 0.2 m (8”) foam flotation chamber with >0.15 m (6”) of freeboard
- Chain ballast
- Cable (steel or aramid) top tension member
- Z-Type end connectors

Onshore, booms were anchored on each side of the outfall using a series of three T-posts. In the water, booms were secured with a standard anchor system consisting of:

- 9 kg (20 lbs) Danforth Anchors
- Tripline with small floats

- Anchor chain
- Anchor lines 5 to 7 times the depth of the water in length

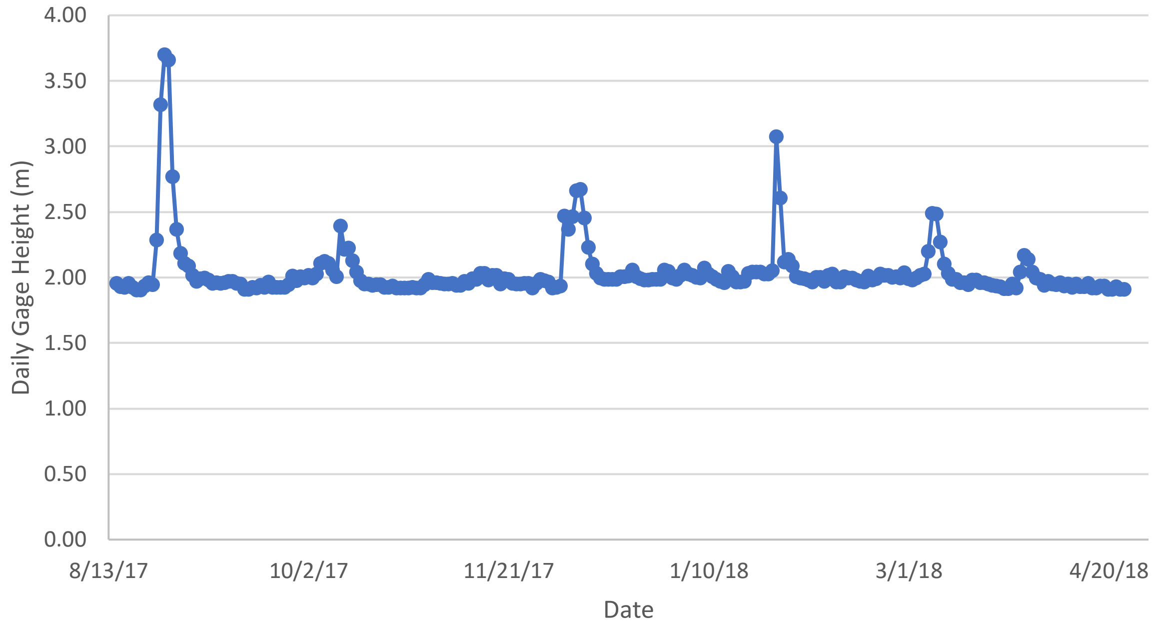
Where additional holding strength is required to stabilize the boom due to waves and current, a tandem anchor system was employed. A second anchor and chain were positioned in-line between the trip line and the hilt of the first anchor. All anchors were removed when booms were collected after each storm event.

In Schanen Ditch, a 30 m length of boom was stretched across the sampling area at a ~30^{o} angle with the water flow path. With the boom angled slightly upstream, across streamflow, debris captured by the boom will move with the flow of water to the apex where it can more easily be collected.

For safety reasons, prior to boom deployment at Cole Park and Oleander Point, Lee Schroer, Coastal Field Biologist at the Texas General Land Office, Peter Davidson, Corpus Christi Marina Superintendent, and the United States Coast Guard (USCG) Waterways Management were notified. Contact information for our lab was also attached to multiple locations on the booms deployed at each site.

Boom deployment was attempted on numerous occasions from 09/01/17 through 04/24/18. A log of stormwater sampling efforts are detailed in Table 2 and rain events the sampling period is shown in Figure 5. Rainfall data is from the Conrad Blucher Institute (CBI; http://cbi.tamucc.edu/cbi/data/) for the Corpus Christi Meteorological Del-Mar East site (#278; 27.773522, -97.440144), which is located within the large Cole Park storm watershed. Wind data (Figure 4) is from the CBI Corpus Christi Meteorological site at Texas A&M University-Corpus Christi (#236; 27.867836,-97.631822; http://cbi.tamucc.edu/dnr/station/). Water flows in Oso

Creek (Figure 6) were obtained from USGS site 08211520 (https://waterdata.usgs.gov/tx/nwis/uv?site_no=08211520).



8/3/17 9/22/17 11/11/17 12/31/17 2/19/18 4/10/18

Figure 6. Maximum daily gage height for water in Oso Creek from 08/15/17 to 04/24/18.

Figure 5. Daily rainfall data from the Corpus Christi Meteorological Del-Mar East weather station from 08/15/17 to 04/24/18.

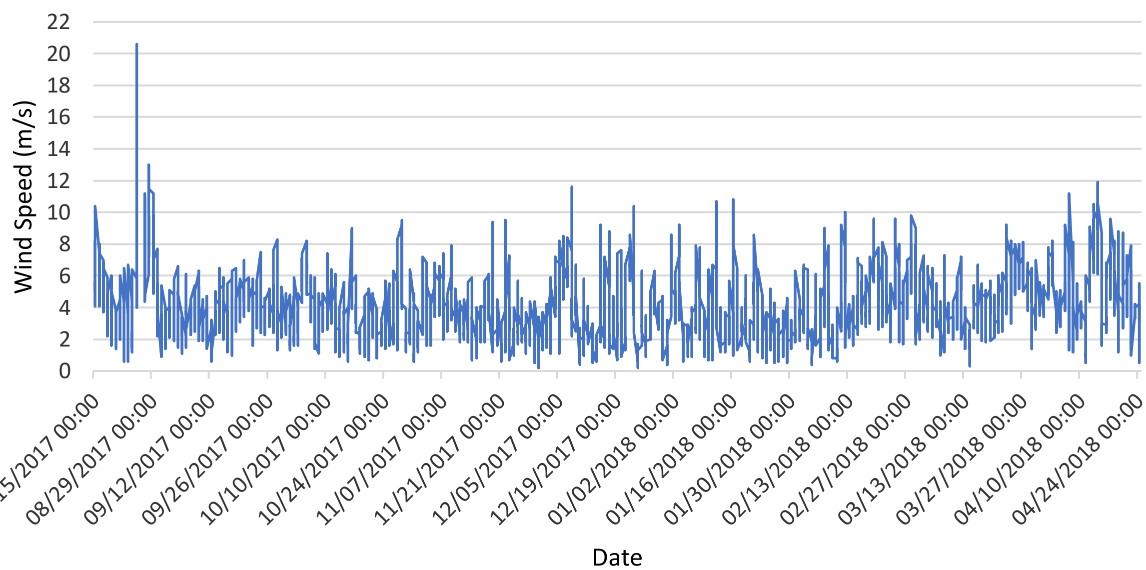


Figure 4. Wind speed data from the Corpus Christi Meteorological weather station at Texas A&M University-Corpus Christi from 08/15/17 to 04/24/18. When the wind speed was ≥6 m s^{-1}, boats could not be launched to deploy booms at Cole Park.

Table 2. Log of efforts to deploy booms as well as rain events >8 mm from 09/01/17 to 04/24/18.

Date	Deploy/Recover	Weather	Location	Debris?	Notes
8/25/17	STANDBY	Hurricane Harvey (160 mm)			
9/1/17	Deploy	No Rain	CP, OP	No	
9/13/17	Recover				Wood/Oil Spill School helped with recovery
9/28/17		Rain (15 mm)			Conkle out of town
9/29/17		Rain (16 mm)			Unexpected rain event
10/2/17	Deploy		CP, OP		Oil Spill Control Association Installation.
10/5/17		Rain (9 mm)			Some debris collected, but high winds pushing onshore coupled with a "King" tide blew debris onto grounds at Cole Park. Collection of debris occurred on 10/5/17, but the park grounds crew had already removed a significant amount of debris. Both booms failed (ropes/chains attached to shore partially or fully broke/came undone) due to high winds that resulted in rough waters. Attempts were made to recover boom on 10/09/17, 10/11/17 and 10/16/17. Booms were finally reset 10/18/17.
10/9/17	Unable to recover	Wind >13 mph	CP, OP		
10/16/17	Unable to recover	Wind >13 mph	CP, OP		Event was Cancelled because FEMA requested boats to survey Hurricane Harvey damage
10/18/17	Reset Booms		CP, OP		Helped by Oil Spill School
10/19/17			CP, OP		Rough seas resulted in Cole Park ropes/chains coming undone again
10/23/17	Recover		CP, OP		
10/31/17	STANDBY	Nothing materialized	CP, OP		Rain never occurred
11/10/17	STANDBY	Rain never materialized (11/11)	CP, OP		Reservation cancelled due to no rain
11/13/17		Rain (17 mm)			Conkle out of town for conference

11/17/17		Rain (11 mm)			Conkle out of town for conference
12/4/17	Deploy		OP		Winds > 13mph could not deploy at CP
12/6/17		Rain (22 mm)		No	
12/7/17		Rain (15 mm)		No	No debris was found in booms at Oleander Point. Reasons unknown.
12/8/17		Rain (17 mm)		No	
12/9/17		Rain (12 mm)		No	
12/11/17	Recover		OP		
12/12/17	Start Winter Break				
1/20/18	End Winter Break				
1/28/18		Rain (65 mm)			Missed Event; Conkle out of town for meeting
2/6/18	STANDBY	Rain never materialized	CP, OP		
2/13/18	STANDBY	Rain never materialized (2/14/18)	CP, OP		
2/20/18	STANDBY	Rain never materialized	CP, OP		
2/22/18	STANDBY	Rain (9 mm)	CP, OP		Expected rain was very low, no booms deployed
3/3/18	STANDBY				
3/7/18	STANDBY	Rain (38 mm)	CP, OP		Wind >13mph for several days prior to rain event. Unable to deploy
3/12/18	STANDBY	Rain never materialized	CP, OP, SD		No trucks or boats available for field work
3/28/18	Deploy		SD		Wind >13 mph for several days before rain on 3/28/18. Could not deploy booms in Bay
3/29/18		Rain (14 mm)			
3/30/18	Recover		SD	Yes	Very little material collected by booms
4/9/18	STANDBY	Rain never materialized	CP, OP, SD		
4/20/18	Deploy	Rain never materialized (4/21/18)	SD	No	
4/24/18	Recover		SD		

Sample Collection and Processing

All materials captured by booms were collected by hand or with dip nets, either from the shore, by boat or in the water using waders (Schanen Ditch). The debris was consolidated into heavy duty trash bags, labeled and secured so that no loss or augmentation of material occurs during transportation to the TAMUCC campus. Next, the bags were stored in a secure, covered exterior location. Drain holes (<1.5 cm diameter) were placed in the bottom corners of the bag and ventilation slits (<2.5 cm) were cut in various locations of the bag to allow water vapor to escape. After allowing time to dry for at least 2 weeks, bag contents were weighed (VWR 3002E; max load of 3000 g) and sorted. All plastics (and suspected plastics) collected were recorded by hand and then typed into a Google Docs Spreadsheet. Pictures of the debris were also taken.

Sediment

Sediment samples were collected at 15 sites in Corpus Christi and Nueces Bay from boats using a piston push corer during November 2017 (Figure 1, Table 3). Each sample was collected from 0-20 cm and then sectioned in the field to 0-5, 5-10 and 10-20 cm subsamples. In the lab, sediment samples were homogenized and then extracted using density separation. This is accomplished by adding sodium iodide (NaI) to aliquots of each sample, thoroughly mixing, initially by shaking and then with a vortex. Next, the samples are centrifuged. After mixing and centrifuging, all plastic particles and fibers, which are less dense than NaI, should float at or near the surface of the solution. The supernatant is then decanted, and the process repeated twice for a total of three extractions. The combined extracts are then filtered through a 0.45 µm membrane filter to capture plastic particles and fibers, which are then manually sorted using a stereomicroscope. Suspected fiber and particle characteristics were logged, and the materials were consolidated in a 3 mL vial containing ~2 mL ethanol (70%).

Table 3. Sediment sample collection dates and locations

ID	Sampling Date	Coordinates
S01	11/28/17	27.848435, -97.444370
S02*	11/28/17	27.852112, -97.317346
S03	11/28/17	27.815726, -97.369765
S04	11/15/17	27.836616, -97.337117
S05	11/15/17	27.852259, -97.281803
S06	11/28/17	27.778046, -97.373956
S07	11/7/17	24.754765, -97.351300
S08*	11/15/17	27.789152, -97.317346
S09	11/15/17	27.821908, -97.263419
S10	11/7/17	27.728865, -97.314122
S11	11/14/17	27.762560, -97.261804
S12*	11/14/17	27.792306, -97.224045
S13	11/7/17	27.706271, -97.236667
S14	11/14/17	27.740181, -97.201631
S15	11/14/17	27.796891, -97.159098

Fourier Transform Infrared (FTIR) Analysis

This aspect of the project has not been completed. However, when it is performed suspected microplastic polymer types will be analyzed using Fourier Transform Infrared Spectroscopy (FTIR; Thermo Nicolet iS10) for larger particles (>2mm diameter) or FTIR microscopy (μ-FTIR, Thermo Nicolet iN5 microscope paired with the Thermo Nicolet iS10) for smaller (<1 mm to 2 μm diameter). Due to time constraints, suspected microplastics will be randomly sub-sampled at 10% of the total for analysis with FTIR or μ-FTIR.

Quality Analysis & Quality Control

Contamination of samples, specifically by microplastic fibers, is a major concern. Therefore, blanks are used during various phases of the research to assess potential contamination.

Wastewater Effluent

Field and lab blanks were used during wastewater sample collection and processing in the lab. Field blanks consisted of a 0.5 L of DI water in a 1 L amber jar that is opened for the collection of one sample for each sample collection trip. Lab blanks consisted of 0.5 L of DI water in a 1 L amber jar and was opened and left in proximity to samples being filtered and sorted by stereomicroscope at a rate of one per 20 samples. For sample sorting under a stereomicroscope in the lab, 20% of samples were examined by 2 individuals to ensure consistent plastic sorting and identification across all samples. If these results were not within 10% agreement, they were re-sorted by both individuals.

Storm Water

Characterization of stormwater materials was performed by teams of 2, where one person sorted debris and the second recorded observations. Quality control checks were performed by reversing roles of the personnel and comparing data sheets for one out of every 10 trash bags collected.

Sediment

Lab blanks consisted of 0.5 L of DI water in a 1 L amber jar and was opened and left in proximity to samples being filtered and sorted by stereomicroscope at a rate of one per 20 samples. For sample sorting under a stereomicroscope, 20% of samples were examined by 2 individuals to ensure consistent plastic sorting and identification across all samples. If these results were not within 10% agreement, they were re-sorted by both individuals.

FTIR

The night prior to analysis, a System Performance Verification will be run on the FTIR. If the system was outside of the manufacturer suggested parameters, the instrument was checked, and the issues resolved prior to analysis. Additionally, prior to sample analysis, National Institute of Standards and Technology (NIST) standards (if available) or a known polymer/plastic type will be analyzed for QC to determine the instrument and software are working properly. Polymers are determined by matching the sample spectrum with FTIR libraries provided with the instrument's OMNIC Spectra Software. When comparing samples to the library, an 80% match was the material type verification criteria. If the sample database match was between 60 and 79%, samples were recorded as "suspected" for the highest database match.

Results

Wastewater Effluent

Samples of wastewater effluent are in the process of being manually sorting for suspected microplastics under the microscope. Currently, 18 of the 21 Allison (7 sampling events taken in triplicate), 20 of 21 of the Oso and 67 of the 75 Greenwood WWTP samples have been sorted. Two of the 8 remaining samples (hourly samples taken 1/22/18) from Greenwood were lost when their bottles broke during storage. No samples have been analyzed using FTIR.

Among all samples collected, filtered and sorted so far, there is high variation (Table 4), but generally suspected microplastic fibers were found at higher concentrations than particles. These values are preliminary estimates of possible microplastics discharged by these three WWTPs. In one sense, these values are moderately conservative. This is due to the small size of the particles and fibers that are visually sorted; it is likely that some amount was not found by technicians and are therefore not included in the counts presented in Table 4. However, any underestimation is likely overshadowed by the number of false positives within the suspected microplastics. Determination of actual plastics will be determined by μ-FTIR analysis, which has not yet been performed with this study. In the literature, one study stated that of their suspected microplastics, only 36% were actually plastic.[5] Additionally, in an ongoing study in our lab examining the Mississippi River, we have found that fully synthetic plastics constitute ~13% of our suspected microplastics. A large portion of the materials that we originally suspected as microplastics are "semi-synthetic", meaning they are made from natural materials (mostly cellulose from cotton or wood) but are chemically altered so that they are no longer considered "natural". To account for suspected microplastics that are not plastic, additional calculations for 36 and 13% confirmation rates are included in Table 4.

Estimates for daily and annual discharge based on grab samples from WWTP effluent for all suspected microplastic particles and fibers from each of the three WWTPs is Table 5 and Table 6 for daily discharge of microplastics range from the low millions to over a billion. Annually, values range from low billions to over a trillion. However, these values have high variation due to bundles of fibers, some containing hundreds of individuals, found in various samples and general variation with regards to the particles observed.

Until sample processing, sorting and confirmation is finished for the microplastic samples, it is ***stressed*** that while these numbers are large, they are preliminary findings that require blank adjustments and confirmation with μ-FTIR.

Table 4. Estimated average suspected microplastic concentrations (number per liter) across all samples processed to date as well as well as values assuming that only 36 or 13% of suspected microplastics are confirmed as plastic using µ-FTIR.

	All Suspected	36% Confirmation	13% Confirmation
		#/L	
Particle	7 ± 20	2 ± 7	1 ± 3
Fiber	101 ± 172	37 ± 62	13 ± 22
All	108 ± 175	39 ± 63	14 ± 23

Table 5. Estimated daily discharge of all suspected microplastics as well as values assuming that only 36 or 13% of suspected microplastics are confirmed as plastic using µ-FTIR.

	Particles	Fibers	All
		#	
All Suspected Microplastics			
Allison	26,500,000 ± 54,600,000	505,300,000 ± 461,000,000	531,600,000 ± 488,700,000
Oso	224,900,000 ± 194,300,000	2,276,400,000 ± 2,168,000,000	2,501,300,000 ± 2,184,400,000
Greenwood	56,800,000 ± 45,000,000	1,292,500,000 ± 1,672,600,000	1,349,200,000 ± 1,665,500,000
Total	308,000,000 ± 294,000,000	4,074,100,000 ± 4,301,600,000	4,382,100,000 ± 4,338,500,000
36% of Suspected Microplastics			
Allison	9,500,000 ± 19,700,000	181,900,000 ± 166,000,000	191,400,000 ± 176,000,000
Oso	81,000,000 ± 70,000,000	819,500,000 ± 780,500,000	900,500,000 ± 786,400,000
Greenwood	20,400,000 ± 16,000,000	465,300,000 ± 602,100,000	485,700,000 ± 599,600,000
Total	111,000,000 ± 106,000,000	1,466,700,000 ± 1,548,600,000	1,577,600,000 ± 1,561,900,000
13% of Suspected Microplastics			
Allison	3,400,000 ± 7,100,000	65,700,000 ± 60,000,000	69,100,000 ± 63,500,000
Oso	29,200,000 ± 25,300,000	295,900,000 ± 281,800,000	325,200,000 ± 284,000,000
Greenwood	7,400,000 ± 5,800,000	168,000,000 ± 217,400,000	175,400,000 ± 216,500,000
Total	40,100,000 ± 38,200,000	529,600,000 ± 559,200,000	569,700,000 ± 564,000,000

Table 6. Estimated annual discharge of all suspected microplastics as well as values assuming that only 36 or 13% of suspected microplastics are confirmed as plastic using µ-FTIR.

	Particles	Fibers	All
		#	
All Suspected Microplastics			
Allison	9,668,600,000 ± 19,932,300,000	184,433,400,000 ± 168,256,100,000	194,021,200,000 ± 178,362,000,000
Oso	82,097,400,000 ± 70,937,400,000	830,880,500,000 ± 791,317,500,000	912,977,900,000 ± 797,303,900,000
Greenwood	20,720,200,000 ± 16,410,800,000	471,749,700,000 ± 610,499,300,000	492,469,900,000 ± 607,900,700,000
Total	112,486,216,000 ± 107,280,500,000	1,487,063,700,000 ± 1,570,072,800,000	1,599,469,100,000 ± 1,583,566,600,000
36% of Suspected Microplastics			
Allison	3,480,700,000 ± 7,175,600,000	66,396,000,000 ± 60,572,200,000	69,847,600,000 ± 64,210,300,000
Oso	29,555,100,000 ± 25,537,500,000	299,117,000,000 ± 284,874,300,000	328,672,100,000 ± 287,029,400,000
Greenwood	7,459,300,000 ± 5,907,900,000	169,829,900,000 ± 219,779,700,000	177,289,200,000 ± 218,844,300,000
Total	40,495,000,000 ± 38,621,000,000	535,342,900,000 ± 565,226,200,000	575,808,900,000 ± 570,084,000,000
13% of Suspected Microplastics			
Allison	1,256,900,000 ± 2,591,200,000	23,976,300,000 ± 21,873,300,000	25,222,800,000 ± 23,187,100,000
Oso	10,672,700,000 ± 9,221,900,000	108,014,500,000 ± 102,871,300,000	118,687,100,000 ± 103,649,500,000
Greenwood	2,693,600,000 ± 2,133,400,000	61,327,500,000 ± 79,364,900,000	64,021,100,000 ± 79,027,100,000
Total	14,623,200,000 ± 13,946,500,000	193,318,300,000 ± 204,109,500,000	207,931,000,000 ± 205,863,700,000

Semi-Monthly Sampling

Semi-monthly sampling took place at all three WWTPs from 08/16/17 to 11/22/17. The results for suspected microplastics reported here have not undergone confirmation with μ-FTIR. Currently, the preliminary results reported are highly variable (Table 7). This high variation, particularly for fibers, is due to the presence of fiber clusters in a few samples. No trend is observed for either particles or fibers (Figure 7). With suspected particles, average concentrations across the three WWTPs are <10 # L^{-1}. Suspected fiber concentrations range from 0-133 # L^{-1}, with averages between 47 and 55 across the three WWTPs. There is no significant difference between the concentration of fibers or particles at either of the three WWTPs for the semi-monthly sampling.

Weekly Sampling

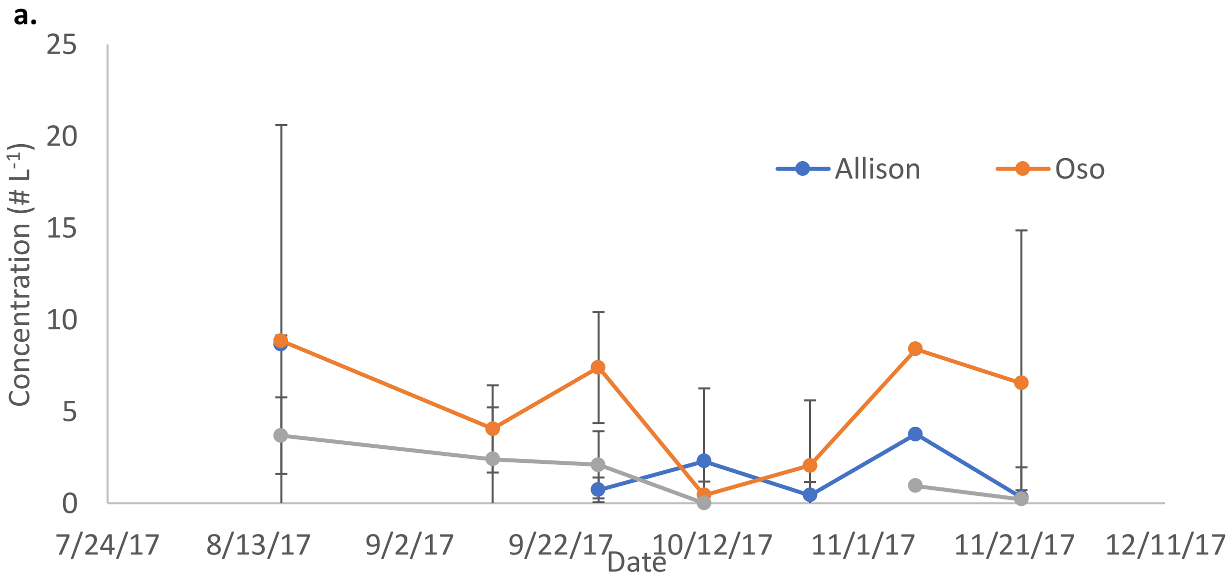
Weekly sampling was performed once a week at roughly the same time of day from 8/16/17 to 10/11/17 at the Greenwood WWTP. No noticeable trend is observed (Figure 8), although there is high variation with fibers for a couple of samples due to bundles of fibers. Suspected microplastic particles ranged from 1-5 # L^{-1} with an average of 3, while suspected microplastic fibers ranged from 20 to 96 with an average of 40.

Daily Sampling

Daily sampling was performed from 10/01/17 (Sunday) to 10/07/17 (Saturday) at the Greenwood WWTP. Daily samples for suspected particles averaged between 1-4 with the exception of Friday, which was 9 (Figure 9). For suspected microplastic fibers, averages ranged between 31 and 58, with the exception of Thursday at 384 (Figure 9). Confirmation of suspected plastics with μ-FTIR is needed to further assess whether spikes in concentrations are real and potentially associated with a delay between water use on the weekend (higher rates of laundry cleaning), its treatment and subsequent release.

Table 7. Semi-monthly concentration averages.

	Particles	Fibers	Total
		# L^{-1}	
Allison	2 ± 5	47 ± 43	49 ± 45
Oso	5 ± 5	55 ± 52	60 ± 52
Greenwood	1 ± 2	55 ± 78	57 ± 78



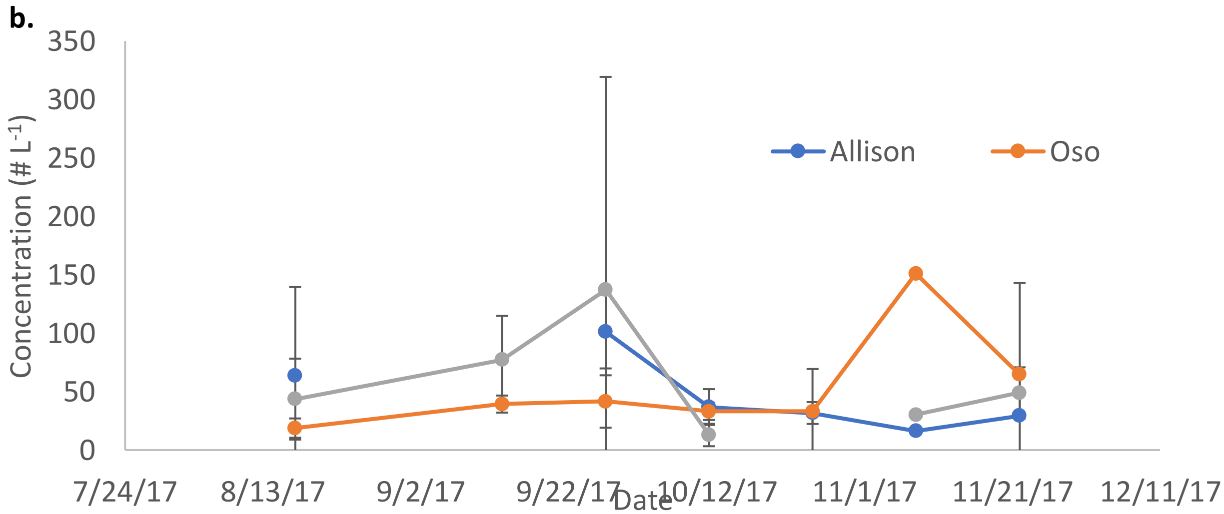


Figure 7. Preliminary semi-monthly suspected microplastic a) particles and b) fibers.

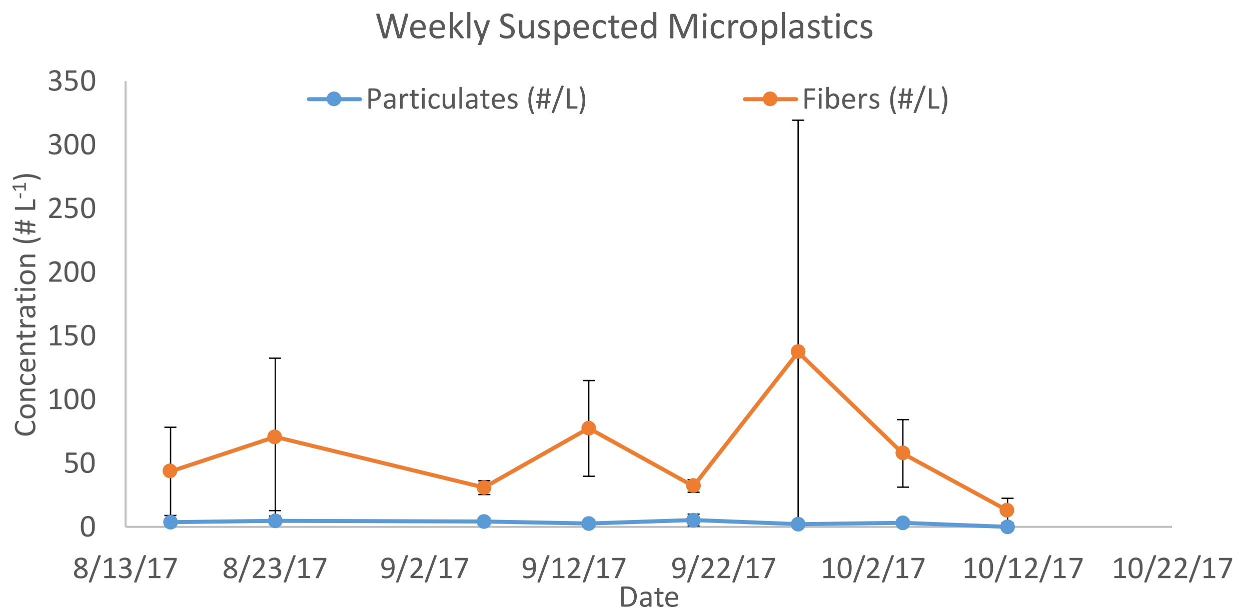


Figure 8. Preliminary weekly suspected microplastic results.

Hourly Sampling

Hourly sampling consisted of 3 hr composites taken by an auto-sample over three days (12/02/18 to 12/04/18). The results are presented in Figure 10, but it is important to note that the 2-5 and 5-8 pm samples on Day 1 were lost when their containers broke. Additionally, there are 3 other samples that are still being processed. Therefore, these results are incomplete but provide a general understanding of the trends in suspected microplastics over a 24 hour period. In general, the concentrations remain steady throughout the 24 hour cycle, with the exception of the 5-8 pm samples. However, one of the 5-8 pm samples has been analyzed and the other was lost. Therefore, this spike may disappear when the second sample is analyzed.

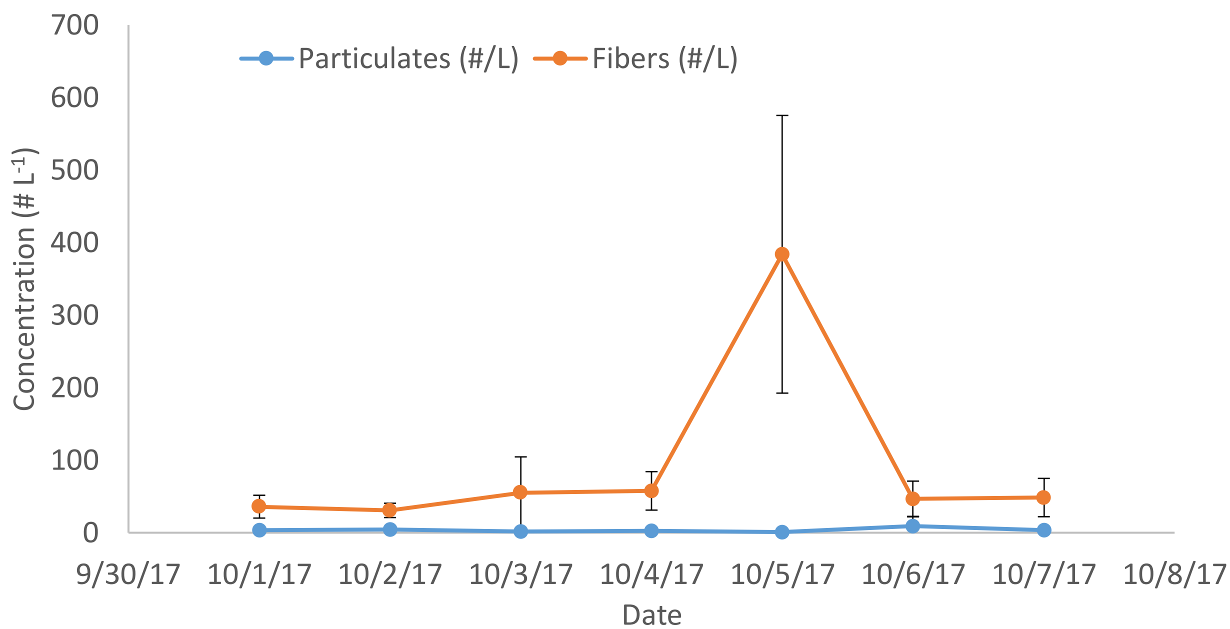


Figure 9. Daily suspected microplastics sampled at the Greenwood WWTP.

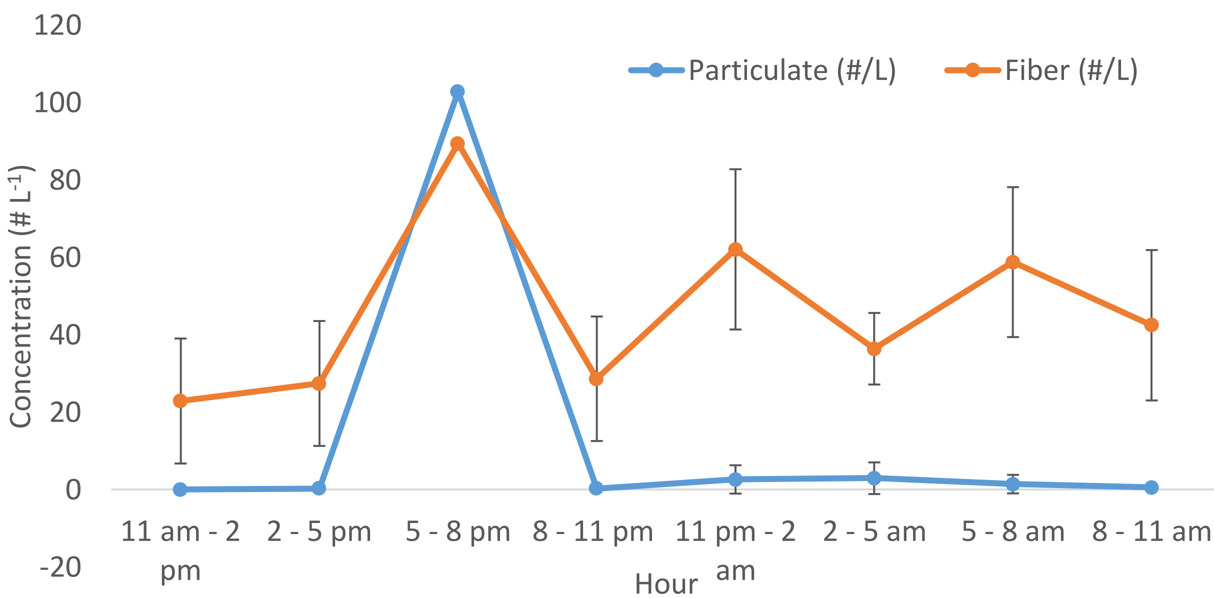


Figure 10. Hourly suspected microplastics sampled at the Greenwood WWTP.

Storm Water

From August 15 to April 24th weather forecasts were monitored for events where there was a 50% chance of 8 mm (0.3”) of rainfall. During this period there were 16 Standby events, where we monitored the weather more closely and were prepared for potential boom deployment

(Table 2). Of these, Hurricane Harvey prevented the first attempt at sampling, 9 potential storms never moved past the "Standby" stage as the forecasts shifted (although 2/22/18 still received 9 mm of rain) and booms could not be deployed for the 3/7/18 storm due to high winds (>6 m s^{-1}; >13 mph) for multiple days leading up to the event. For the remaining 5 events (2 at both Cole Park and Oleander Point, 1 at only Oleander Point and 2 at Schanen Ditch), booms were deployed, with no rain occurring for deployments on 9/01/17 and 4/20/18. Booms were deployed at Cole Park for a total of 33 days and for one rain event (10/5/17); Oleander Point for 40 days and five rain events; Schanen Ditch for 7 days and one rain event. There were 5 rain events where rain was unexpected and therefore not captured. Plastic debris was only captured during 2 of the boom deployments, 10/2/17 (only Cole Park) and 3/28/18 (Schanen Ditch). Debris was captured after the 10/5/17 rain event for Cole Park is only a partial sample of the materials captured by booms (Table 8). Due to a strong on-shore wind out of the East and a slightly elevated spring tide (when the Moon and Sun are in line with the Earth) water was topping the seawall and reaching land at Cole Park. This resulted in any floating debris that was captured by the boom being washed or blown onto land. Materials were collected from land 10/5/2017 after the rain finished. However, maintenance crews at Cole Park had already collected and disposed of most debris that was on the grass. The materials presented in Table 8 represent what was not yet removed by the maintenance crew, which was smaller materials that had accumulated in the riprap of the Cole Park sea wall. It is stressed that the maintenance crews stated they had removed over 10 bags of materials and that not all materials that accumulated in the riprap were able to be collected due to safety concerns. Therefore, the information presented in Table 8 is only a small portion of the materials that were captured by booms during this storm event. In total for 10/5/2017 sample collection, 1,569 pieces of anthropogenic litter were collected that weighed ~4.5 kg (10 lbs; Table 8). Bottle caps were the most common item found and were ~3x more numerous than the next most common item. The next 4 most common items, cigarette butts, other plastic, straws and food wrappers were all ≥100. Since this material was collected after it washed up on shore at Cole Park, some material had fragmented and was not able to be identified. This debris is listed as "Fragments" and was not counted individually but is reported by mass for each color of material found. There are additional materials listed in Table 8 that were collected at Cole Park, which include fabric, paper, and a flip-plot. Debris was also captured 3/30/18 in Schanen Ditch and is shown in Table 9. Despite the 14 mm rain event (Figure 4) and a small pulse in Oso Creek (Figure 6), little material was captured by the boom. The materials collected were foam fragments, food packaging or beverage containers (cups, bottles, caps).

Table 8. Debris collected 10/05/2017 at Cole Park.

	Quantity	Mass (g)	Characteristics	Branding	Description
Plastic					
Bottle/Container Caps	614	784			
Cigarette	186	46			
Other Plastic	168	975			Unidentifiable
Straws	147	150			
Plastic Food Wrapper	100	79			
Foam Fragment	95	72			
Disposable Cigar Tips	72	57		Black & Mild	Mostly white with some black
Packaging	27	122			
Plastic Bottle	22	568			
Personal Care Product	21	143			
Pens + Lids	20	41			
Foam Cup	16	68			
Utensils	15	29			
Rope/Net pieces	15	31			
Bullet Case	15	50			
Cup	12	111			

Balloon/String	5	6		
Plastic Jug	3	131		
Plastic Bag	2	32		
Fragments				
White		377		
Black		101		
Blue		85		
Green		56		
Red		43		
Yellow		30		
Orange		29		
Pink/Purple		28		
Paper				
Other	8	41		
Cloth				
Misc. Fabric	1	6	black	black strap
Rubber				
Baseball	1	140		
Flip-flops	1	94		only the base
Other	1	9		
Processed Lumber				
Other	1	2		popsicle stick
Unknown				
White bundle	1	4		
Totals	1,569	4,540		

Table 9. Debris collected 03/30/2018 at Schanen Ditch.

	Quantity	Mass (g)	Characteristics	Branding	Description
Plastic					
Foam Fragment	3	0.7			
Packaging	2	2.8			Fragmented
Plastic Bottle	1	9.8		Great Value	
Foam Cup	1	3.8		Chick-fil-a	
Bottle/Container Caps	1	0.7			
Metal					
Aluminum/tin can	1	15.1		Mike's Hard Lemonade	
Totals	9	32.9			

Sediment

Sediment processing was slowed due to the need to the need to develop methods different than those proposed in the original project plan. Due to this delay and the need to have it approved before use, of the 63 total samples (15 sites with 3 depths and 3 triplicates), only 10 samples have been fully sorted. While results on inconclusive, preliminary numbers suggest that sediment in Corpus Christi Bay has 1250 ± 460 suspected microplastics Kg^{-1} of sediment (Table 10). These numbers will evolve as more samples are processed and confirmation is performed using µ-FTIR. As was done with wastewater samples, values, if 36% or 13% of suspected microplastics are confirmed, is also shown in Table 10. These values demonstrate that between 450 and 160 microplastics Kg^{-1} may be in the sediment of Corpus Christi Bay.

Table 10. Preliminary results for suspected microplastics in sediment from Corpus Christi Bay.

	Particles	Fibers # Kg^{-1}	Total
Suspected Microplastics	370 ± 360	880 ± 500	1250 ± 460
36 % Confirmation	130 ± 130	320 ± 180	450 ± 170
13% Confirmation	50 ± 50	120 ± 70	160 ± 60

Discussion

It is again emphasized that the results presented in this report are preliminary in nature. Prior to establishing any concrete conclusions, the remaining samples must be processed, sorted and confirmed using μ-FTIR. However, the results presented in this report paint a general, but still incomplete, picture of the extent of plastic contamination in Corpus Christi Bay, which is broadly discussed in the subsections below.

Wastewater Effluent

While no concrete conclusions can be drawn from the preliminary data included in this report, it is likely that 10s of millions of microplastic particles and fibers are released daily from our local WWTPs. Over the course of a year, this equates to billions or even 10s of billions of these materials going into local watersheds that drain into Corpus Christi Bay.

There is a growing body of research on the release of microplastics (particles and fibers) in wastewater effluent. A few recent studies found that in tertiary wastewater treatment, between 0.28 and 2 Microplastics (MP) L^{-1} are discharged.[6-8] These confirmed microplastic discharge values are lower than the average of "suspected" or even the adjusted suspected values from this work (although there is a high variation in these calculations). If 36% of suspected plastics are confirmed, there would be 39 ± 63 or for 13% confirmed, 14 ± 23. When examining the trends in semi-monthly, weekly, daily and hourly sampling, no significant trends were observed. Additional future work will attempt to establish a mass for the amount of microplastic fibers and particles being discharged in an effort to provide broader context to these results.

Storm Water

This boom collection strategy was developed based on knowledge and experience collecting floating oil, with the expectation that it would also capture floating materials (plastics, Styrofoam and organic debris). This approach allowed for the opportunity to capture, characterize, and quantify these materials. In theory, this was the best approach available for this project. However, as noted in project planning documents, there was a concern that "excessively large wind, waves, or current flows could have an adverse impact on the boom performance." The wind and subsequent waves, especially at the Cole Park site, presented safety hazards when installing and removing booms as well as for sample collection. There were three times when high winds (>6 m s^{-1}; ~13 mph) prevented boom deployment before potential rain events: 12/4/17 at Cole Park; 3/6/18 and 3/28/18 at Cole Park Oleander Point. There were also three failed attempts (10/9, 10/11 and 10/16/17) to recover boom from Cole Park and Oleander Point due to high winds. When deployed at Cole Park and Oleander Point, these high wind and wave events also caused frayed ropes, lost shackles and loose anchors that resulted in failed booms that needed to be re-secured on multiple occasions between 10/2 and 10/23/17. Attempts were made to use chains instead of ropes (when possible) and better secure shackles. However, boom failures prevented sample collection on 10/11/17. Material was captured for the rain event on 10/5/17, but the steady onshore winds, as well as moderate spring tide during this period, pushed floating debris onto land. Attempts were made to collect the debris after the rain subsided 10/5/17, but maintenance crews at Cole Park had already removed the majority of this material. Material left on seawall was collected and cataloged.

Despite a moderate rain event (14 mm) on 3/30/18, little debris was captured by the boom on Schanen Ditch. It is not known why so little material was captured, but it could have moved under the boom as water receded if there was any gap between the boom and the shoreline. It is possible that this is all the material that flowed down Schanen Ditch during this event, but at least one neighbor stopped to tell us about a large amount of debris they witness going down the ditch due to rain events.

In the future, stormwater sampling to quantify debris flowing out of Cole Park may be best suited to high definition video recordings and digital characterization of these materials. Regular strong winds, constant chop (waves reflecting off the curved shoreline), shallow waters and a concrete seawall make installation of the booms difficult but also a safety hazard. As image recognition algorithms are improved, digital recording of materials discharged to Cole Park will likely be the best solution to documenting plastic debris at this site. There may also be alternative locations to attempt debris collection, one being at the Art's Apartments on Ocean Drive just north of Airline Drive. At Oleander Point, a smaller sample collection system would have likely worked better. This would have been something that is placed on-shore near the mouth of the discharge, rather than a boom in Corpus Christi Bay. In Schanen Ditch, more attempts to collect debris where runoff could be monitored in person would help to determine why no materials were collected 3/30/18.

Sediment

Sediment samples processing is ongoing, but preliminary results indicate that there could be between 160 to 450 microplastics Kg^{-1} in the top 20 cm of sediment. These values are in the upper range of and higher than the49 to 279 particles Kg^{-1} range found in a study conducted near Hong Kong. While further data processing is necessary, it is obvious that plastic debris accumulates in the sediment of Corpus Christi Bay.

Preliminary expectations were that sediment samples would contain larger debris that has sunk to the bottom, but mostly microplastics are found in sediment. This indicates that the larger materials that float out of stormwater drains and into the bay are mostly deposited on shorelines where they are known to accumulate and fragment over time. When the remaining samples are processed it is hoped that the data will help to understand where materials are accumulating in the bay so that if mitigation efforts are planned, they can target deposition hot spots.

What does it mean for Corpus Christi Bay?

While concrete conclusions cannot yet be made from this work, it is obvious from this project, observations around the bay and documentation of others, that there is a lot of micro and macroplastic debris in Corpus Christi Bay. The potential amount of microplastic particles and fibers that discharge into Corpus Christi Bay is likely in the millions daily and billions of 10s of billions annually. However, their impacts on the broader environment as well as Corpus Christi Bay is unknown. The field of microplastic effects research is rapidly evolving, but still needs further study to assess potential impacts on systems like Corpus Christi Bay. Numerous aquatic organisms are known to either deliberately or unintentionally ingest or uptake microplastics, while most organisms are exposed to these materials during normal activity.[9-12] The actual impacts of microplastic exposure are variable, with some studies finding impacts, while other seeing nothing noticeable. For example, the consumption of microplastics, which have no nutritional value, can be stuck in the gut of an organism, resulting in pseudo-satiation (feeling full).[13, 14] This would result in less foraging and potentially starvation if the organism cannot egest the microplastic.[13, 14] To assess the potential impacts of microplastics in Corpus Christi Bay and other estuaries of the Texas coast, multiple studies are planned to examine concentrations of microplastics and their potential consumption by juvenile organisms.

Microplastics are often created by the breakdown of larger, macroplastic debris (cups, bags, bottles, etc.) that enters the environment, which is also a problem in Corpus Christi Bay. The issue has been known for a long time and the city, as well as the community, are exploring solutions and starting to make an impact. The data collected from this project would have furthered those efforts by providing concrete data to the community and local government. Unfortunately, the approach used was not sufficient and similar efforts in the future must try a different approach.

To reduce litter in Corpus Christi Bay, the problem must be approached on multiple fronts. First, we have to find a way to get our community to take more pride in the cleanliness of the city. I've witnessed but also heard stories of littering around the city. I do not know how to achieve this goal but believe it would require research to determine factors that make someone more likely to litter and then using that knowledge to change habits and improve infrastructure. Second, infrastructure for trash disposal must be improved, properly maintained and regularly emptied. This will probably help the first point as it is known that the longer the distance to a trash bin the less likely someone will walk to it and throw away their waste. Distance to a bin is likely a problem in our community as the greater Corpus Christi area contains >325,000 residents with most living in sprawl outside of the city's downtown. It would be cost prohibitive for the city to install and service the number bins necessary to stop all littering. However, where waste bins exist or should be installed, the appropriate infrastructure is essential. Our region experiences more wind than most, but also has large wild and feral animal populations. Therefore, waste bins must be animal and wind resistant, but also quickly accessible and easy to use. Third, the community must continue to test and install litter capture devices that work best with our existing infrastructure. This will reduce the amount of materials that reach the bay if properly maintained. Last, there needs to be more community buy-in. There are numerous cleanup efforts organized locally that make a huge difference in the amount of litter found around the bay, but more work is needed. One program that could be brought to Corpus Christi is the Adopt-A-Drain program where residents take responsibility for a storm drain and regularly clean street gutters nearby. Capturing and removing debris in the environment, which is the goal of the last two approaches, is necessary and must continue, but they only address symptoms of the problem. It is essential that the first two approaches are assessed and implemented if our community is to make the necessary strides towards a cleaner Corpus Christi Bay.

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