Michigan Waste & Recycling Association
Statewide Study on Landfill Leachate PFOA and PFOS Impact on Water Resource Recovery Facility Influent

TECHNICAL REPORT

Completed in Collaboration with Michigan Department of Environmental Quality
March 1, 2019
(Second Revision March 6, 2019)

1.0 INTRODUCTION & OVERVIEW

This report summarizes the results of a statewide study completed on behalf of the Michigan Waste & Recycling Association (MWRA) to determine levels of PFOA and PFOS in the leachate of those landfills participating in the study, and to estimate the leachate's relative contribution to the total amount found in wastewater influent at water resource recovery facilities (WRRFs) (aka POTWs or publicly owned treatment works, or sewage or wastewater treatment plants). The study involved testing leachate at 32 active municipal solid waste landfills (Type II landfills) located throughout the state. This report presents general background information on PFAS, summarizes testing results, and summarizes available PFAS information from WRRFs that receive leachate and those that do not.

PFOA and PFOS are two compounds in a class of compounds known as Per- and polyfluoroalkyl substances (PFAS). They have been used for over 50 years in household products such as non-stick coatings in cookware, in stain and water-resistant coatings and fabrics, and in industrial products such as firefighting foam. More recently, certain PFAS compounds were identified as having potentially adverse effects on human health and the environment. In general, PFAS compounds are resistant to natural degradation, and can therefore persist in the environment for a long time.

Each solid waste landfill in the study is licensed by the State of Michigan to accept household, commercial, and industrial solid waste generated by the communities they serve. Some of the wastes received for disposal contain PFAS. Leachate is the liquid that occurs in landfills when rainwater combines with moisture contained within the waste. Chemicals present in the waste may be present in the leachate. The leachate is effectively captured by utilizing engineered liner and active liquid collection systems. A common method of leachate management is through discharge to a local WRRF where it is handled with other household, commercial, and various industrial wastewaters. In this way, leachate is managed in a closed system where there is no direct exposure to the public.

Landfill leachate sent to a WRRF is typically directly discharged via pipeline or stored in onsite tanks prior to being transferred to tanker trucks and hauled to the treatment facility. WRRFs are engineered structures that apply various technologies to treat wastewater to meet certain regulatory criteria prior to discharge of these waters.

In 2018, the Michigan Department of Environmental Quality (MDEQ) and various WRRFs requested that landfills test for PFAS in leachate as part of a statewide effort to better understand the presence of PFAS in the environment and to work toward plans for PFAS reduction, where needed. The information was also useful to examine the interdependent cycle of waste disposal, leachate generation, wastewater treatment, and wastewater sludge disposal.

Rather than participating landfills sampling and reporting individually, the MWRA (with MDEQ concurrence) conducted a collective study involving 32 active municipal solid waste landfills (Type II landfills) located throughout the state. This effort represents one of the largest studies conducted on active landfill leachate to-date. The main objective of the study was to gather information on PFOA and PFOS concentration in leachate at individual landfills and to examine its potential significance to WRRF influent across the state.

NTH Consultants, Ltd, (NTH), a Michigan-based professional environmental and engineering consulting firm, conducted the MWRA study. NTH prepared this technical report that provides testing results for individual landfills, details of the sampling and analysis procedures, characteristic leachate discharge volumes, and available flow and PFAS testing information from the potentially-affected WRRFs.

2.1 Status Of Regulatory Action In Michigan

Information on various adverse health effects associated with certain PFAS compounds has been evolving since the early 2000's. Two of the most widely-utilized PFAS compounds, PFOA and PFOS, have received early environmental regulatory focus. These and related compounds have been used in thousands of applications worldwide. Largely for these reasons, the manufacture of PFOA and PFOS has been voluntarily phased-out in the United States.

In response to concerns regarding the increasingly common detection of PFAS in the environment, the Michigan PFAS Action Response Team (MPART) was formed by an Executive Directive issued by then-Governor Snyder in November 2017. MPART, a multiagency group, is comprised of a team of local, state, and federal agencies that are working to understand the exposure risks and ways to mitigate PFAS impacts to the environment.

MPART emphasizes the need for cooperation and coordination among agencies at all levels of government charged with identifying PFAS contaminants, informing the public, and mitigating the potential effects.

The EPA established a drinking water health advisory (HA) for PFOA and PFOS of 70 ppt in 2016. Although the HA is not an enforceable drinking water standard, it was established as a protective guidance for the most sensitive subpopulations over a lifetime of exposure. In January of 2018, the MDEQ incorporated the information contained in the HA and established the same 70 ppt value as groundwater cleanup criteria under Part 201, Environmental Remediation, of the Natural Resources and Environmental Protection Act, 1994 P.A. 451, as amended (Act 451). Currently, this value is used by the Michigan Department of Health and Human Services (DHHS) as guidance when evaluating PFAS concentrations in public and private drinking water supplies.

The MDEQ also promulgated Water Quality Standards (WQS) for PFOA and PFOS in surface water in May 2011 and March 2014, respectively. These WQS values were developed for use by MDEQ when evaluating permits for discharge to surface water and were promulgated in accordance with the Part 4 Rule 57 administrative rules (Rule 57) pursuant to Water Resources Protection (Part 31) of Act 451. Michigan's WQS values include chemical-specific values that represent the water quality values protective of aquatic life, human health, or wildlife; and acute chemical-specific values protective of aquatic life. The applicable most restrictive WQS values developed by the State are listed in below in Table 2-1, Rule 57 Values.

Table 2-1 – Rule 57 Values

Chemicals	HNV (non-drinking water*)	HNV (drinking water**)
PFOS	12 ppt	11 ppt
PFOA	12,000 ppt	420 ppt

HNV: Human Non-cancer Value

ppt: parts per trillion (laboratory reports in nanograms per liter (ng/L)

* "non-drinking water" means the surface water body receiving the discharge is not designated as a public drinking water source

** "drinking water" means the surface water body receiving the discharge is used as a public drinking water source

Other states have or are considering establishing regulatory limits for PFAS compounds. The variability in existing values between states is generally attributable to differences in the selection and interpretation of the choice of uncertainty factors, and the approach used for animal-to-human extrapolation mostly using the same key toxicity data. Differences in values between regulatory agencies may also be due to the choice of exposure assumptions, including the amount of water consumed, life stage used, and the relative source contributions (percentage exposure assumed to come from non-drinking water sources). All of this contributes to the overall uncertainty across the US in how to most appropriately establish risk-based criteria for these compounds and more consistency is needed in this important area.

2.2 Literature Summary Of PFOA & PFOS Concentrations In Landfill Leachate

To provide a basis for comparison of the results of the MRWA landfill leachate study, NTH completed a review of current literature regarding PFOA and PFOS concentrations in landfill leachate. Sources include professional journals, regulatory documents, and government agency websites. A summary of the information we reviewed is presented below.

2.2.1 Worldwide PFOA and PFOS

Literature review focused on documents published over the past 15 years. Two recent and comprehensive publications regarding PFAS concentrations in leachate includes a worldwide perspective by Hamid, et al (2018) and its associated multiple references, and the US-focused paper by Lang, et al (2017).

Unlike Hamid, et al (2018), Lang, et al (2017) focused on an evaluation of climatic effects on leachate PFAS concentrations and associated mass loading to municipal wastewater treatment plants located in the US. This study, which included 87 samples from 18 landfills, representing one of the largest databases of any similar investigation to date, demonstrates PFOA and PFOS concentrations in leachate generally have been decreasing over time, with greater rates of decline in humid regions (i.e., precipitation greater than 75 cm/year), which is where landfills that contain nearly half the annual volume of solid waste disposed in the US are located.

Hamid, et al (2018) compiled data from 11 selected literature sources, published between 2004 to 2017, that include PFAS leachate concentrations from landfills located in Australia, Canada, China, Denmark, Germany, Norway, Spain , Sweden, and the USA . Together, these sources comprise dozens of landfills with a total of more than 162 leachate samples.

To summarize the PFOA and PFOS leachate results from these various studies, we prepared Table 2-2, Study of Literature Study derived from Hamid, et al.'s database (Supplemental Information Table 1) and information from the Lang (2017) et al. study. This information is graphically depicted on Figure 2-1, PFOA & PFOS Concentration in Landfill Leachate (Worldwide – Separate Studies).

Figure 2-2, PFOA & PFOS Concentrations in Landfill Leachate (By Region) summarizes the PFOA and PFOS ranges observed in each of the world regions. As shown, PFOA and PFOS concentrations in landfill leachate vary considerably in different regions of the world and likely reflect the nature of the consumer products and industrial materials used, produced, and disposed in each country. The age of waste materials, as well as climatic conditions to which landfills are subject, appear important factors that govern the rate of degradation of PFAS materials to PFOA and PFOS, both considered "terminal" products of precursor compounds.

In summary, the preceding information reveals a wide range of leachate PFOA and PFOS concentrations worldwide including the United States. China's values are much higher than elsewhere in the world, likely a result of their continued production of consumer goods (as well as industrial waste associated with related manufacturing processes) with PFAS compounds. These products are then distributed throughout the world for purchase, including in the US and eventually disposed.

Figure 2-1
PFOA & PFOS Concentrations in Landfill Leachate
(Worldwide - Separate Studies)

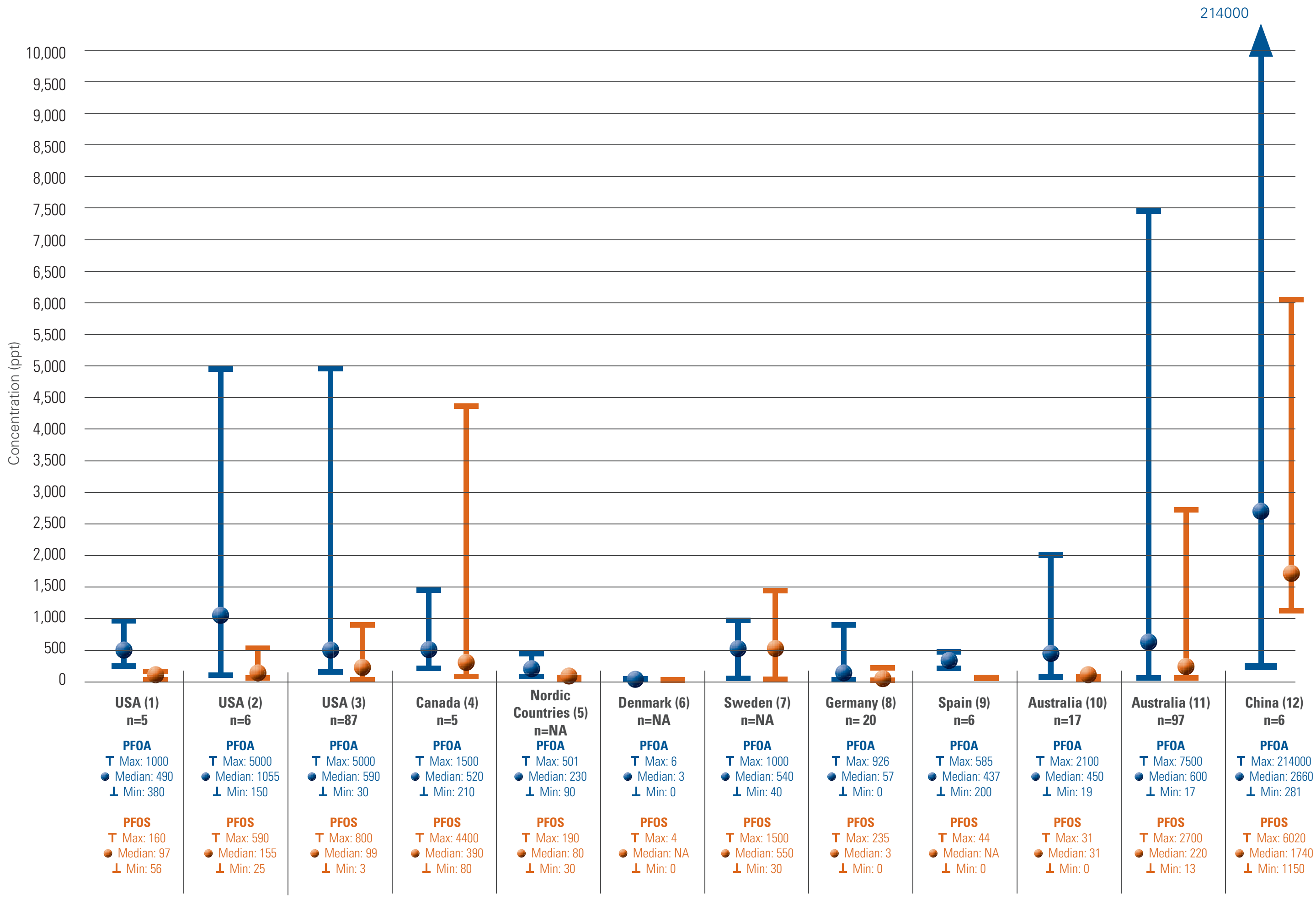
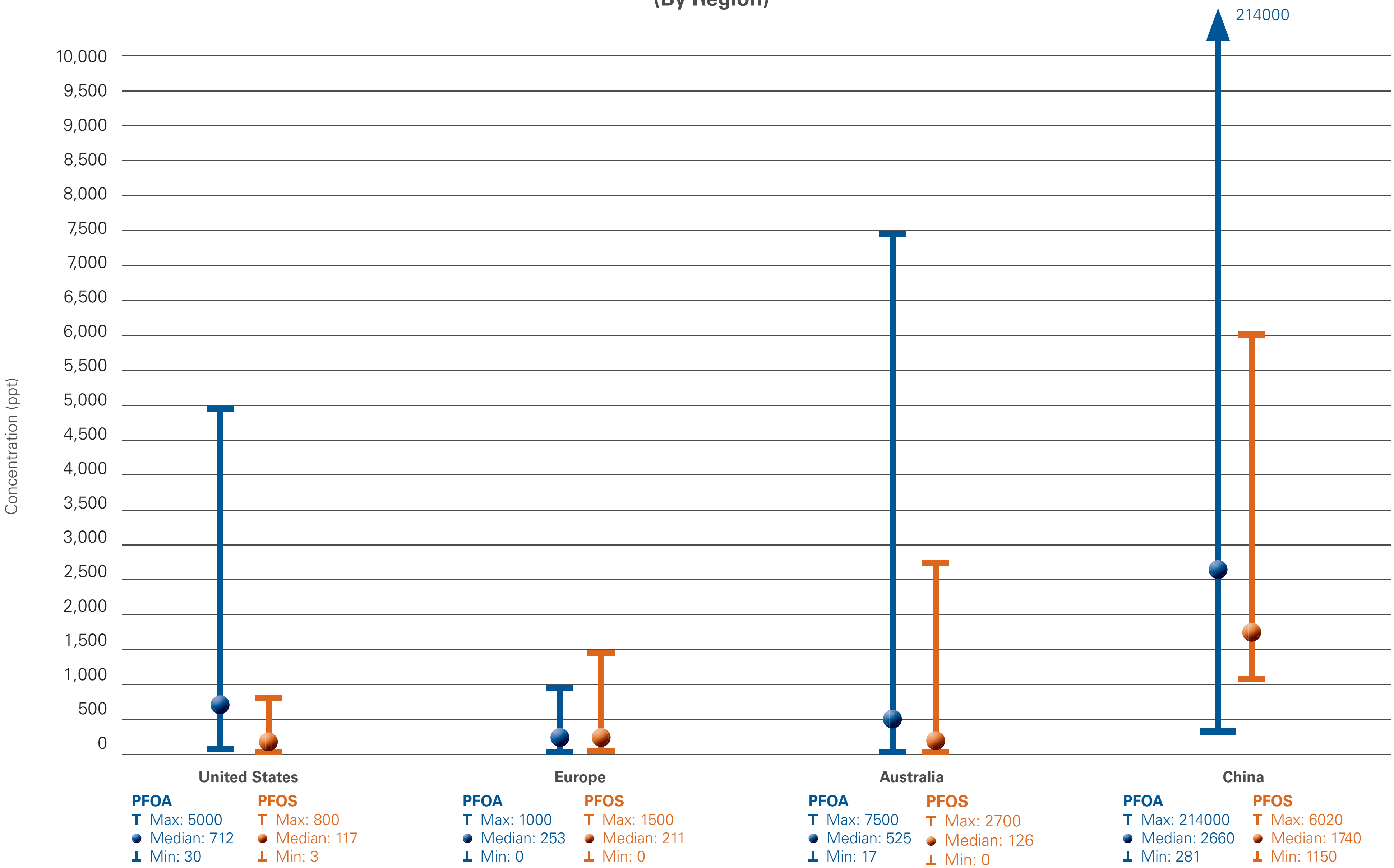


Table 2.2: Summary of Literature Study - PFOA & PFOS Concentrations in Landfill Leachate

Source Cited	Location/ Region	Sample Size	PFOA			PFOS		
			Detection Frequency %	Concentration Range (ng/l)	Median (ng/l)	Detection Frequency %	Concentration Range (ng/l)	Median (ng/l)
1. Huset, et al (2011)	USA	5	100	380 - 1,000	490	100	56 -160	97
2. Allred, et al (2015)	USA	6	100	150 - 5,000	1,055	100	25 - 590	155
3. Lang, et al (2017)	USA	87	100	30 - 5,000	590	96	3-800	99
4. Benskin, et al (2012)	Canada	5	100	210 - 1,500	520	100	80 - 4,400	390
5. Kallenborn, et al (2004)	Nordic Countries	NA	NA	90-501	230	NA	30 - 190	80
6. Bossi, et al (2008)	Denmark	NA	NA	0 - 6	3	NA	0 - 4	NA
7. Woldegiorgis, et al (2008)	Sweden	NA	NA	40 - 1,000	540	NA	30 - 1,500	550
8. Busch, et al (2010)	Germany	20	95	0 - 926	57	100	0 - 235	3
9. Fuertes, et al (2017)	Spain	6	100	200 - 585	437	17	0 - 44	NA
10. Gullen, et al (2016)	Australia	17	100	19 - 2,100	450	89	0 - 100	31
11. Gullen, et al (2017)	Australia	97	64	17 - 7,500	600	65	13 - 2,700	220
12. Yan, et al (2015)	China	6	100	281 - 214,000	2,260	100	1,150 - 6,020	1,740

Figure 2-2
PFOA & PFOS Concentrations in Landfill Leachate (By Region)



3.0 LEACHATE SAMPLING PROGRAM

This section includes information regarding the statewide PFAS sampling program participants, along with sample collection methods and analytical techniques. The sampling program included 32 sites located in the Lower and Upper Peninsulas of Michigan, as shown on the attached Figure 3-1, Site Location Map. Each site is an active, Type II, municipal solid waste landfill. As explained later in this report, we included three additional landfills with leachate data available for comparison as part of our overall evaluation. The locations of these three disposal facilities (i.e., City of Riverview Landfill, South Kent County Landfill, and Smiths Creek Landfill) are also shown on Figure 3-1.

3.1 Field Methods

3.1.1 Site Sampling Planning & Coordination

NTH working with Test America Laboratories (TAL) sampled leachate at the 32 MWRA-member landfills over a period of 14 days, beginning on Monday, November 19, 2018, and concluding on Wednesday, December 12, 2018. NTH accompanied TA staff during the first 5 days of sampling to verify TAL followed MDEQ-recommended sampling methods and protocol in the guidance documents referenced below.

NTH contacted each of the 32 participating facilities and requested information including site contacts, leachate system discharge configuration, access limitations, specialized site requirements, pretreatment installations, leachate discharge volume, and receiving WRRF locations. The relevant information from the sites is summarized on Table 3-1, Landfill Leachate Discharge Information.

Additionally, NTH prepared and distributed a sampling schedule based on logistical groupings to maximize efficiency and coordinate acceptable sampling times at each site. NTH remained in contact with TAL to maintain the established schedule according to site-specific approvals. NTH provided TAL the compiled site information for use as a guide during the sampling to help streamline and prepare for the field work.

3.1.2 Sampling Collection Overview

Experienced TAL field staff completed leachate sampling with oversight by Mr. Michael McNamara (NTH) during the first 5 sampling days. Mr. McNamara previously completed PFAS sampling training conducted by the MDEQ in April 2018. The MDEQ training included field-sampling of leachate and groundwater along with the collection equipment blanks using laboratory-supplied PFAS-free water (LSPFW). MDEQ has issued a number of draft guidance documents for PFAS sample collection, including:

- "Standard Operating Procedure – Collection of Landfill Leachate Samples for Analysis of Polyfluorinated Alkyl Substances (draft)," dated April 2018,
- "Wastewater PFAS Sampling Guidance," dated October 2018, and
- "General PFAS Sampling Checklist," dated October 2018.

Both NTH and TAL reviewed and followed these documents during sampling activities. To maintain consistency and uniformity with the program sampling, TAL dedicated two experienced representatives (Gary Schafer and Zachary Nelson) to this project, who remained involved for the duration of the entire 32-site program, as indicated in Table 3-1. During the first five days of sampling, which included 14 of the 32 sites, NTH accompanied the designated TAL sampling crew and verified that TAL followed the MDEQ PFAS-sampling protocols. A summary of the sampling procedures is included in Appendix A, Sampling and Testing Methods.

3.1.3 Sample Analysis

Consistent with MWRA's agreement with MDEQ, the sample analysis for this study included PFOA and PFOS using EPA Method 537 (modified). This was done to focus the study on the two compounds with Michigan Part 201 and Rule 57 standards. TA analyzed the samples at their Sacramento laboratory following their US EPA Method 537 (modified) standard operating procedures (SOPs).

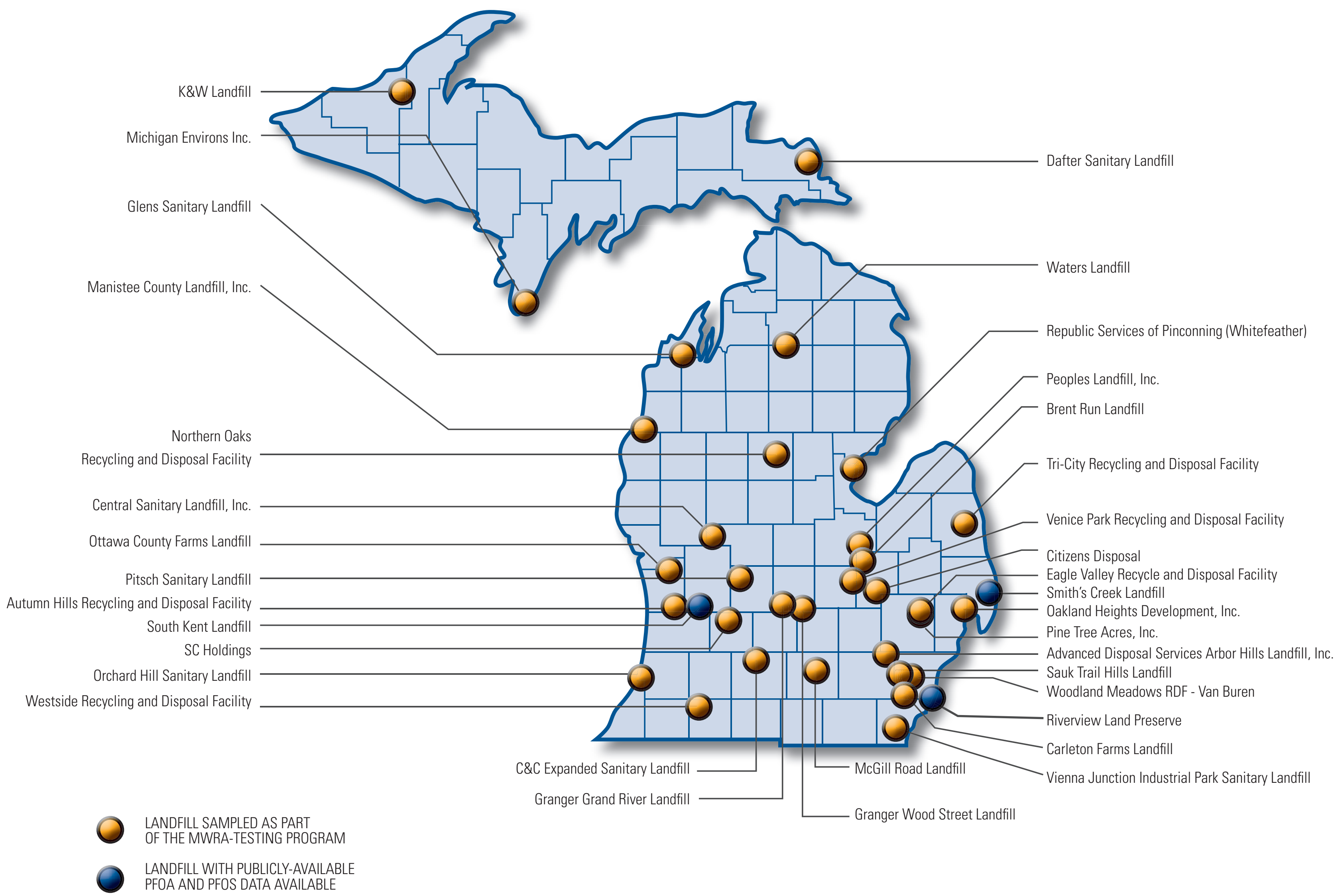

K&W Landfill
Michigan Environs Inc.
Glens Sanitary Landfill
Manistee County Landfill, Inc.
Northern Oaks Recycling and Disposal Facility
Central Sanitary Landfill, Inc.
Ottawa County Farms Landfill
Pitsch Sanitary Landfill
Autumn Hills Recycling and Disposal Facility
South Kent Landfill
SC Holdings
Orchard Hill Sanitary Landfill
Westside Recycling and Disposal Facility
C&C Expanded Sanitary Landfill
Granger Grand River Landfill
McGill Road Landfill
Granger Wood Street Landfill
Dafter Sanitary Landfill
Waters Landfill
Republic Services of Pinconning (Whitefeather)
Peoples Landfill, Inc.
Brent Run Landfill
Tri-City Recycling and Disposal Facility
Venice Park Recycling and Disposal Facility
Citizens Disposal
Eagle Valley Recycle and Disposal Facility
Smith's Creek Landfill
Oakland Heights Development, Inc.
Pine Tree Acres, Inc.
Advanced Disposal Services Arbor Hills Landfill, Inc.
Sauk Trail Hills Landfill
Woodland Meadows RDF - Van Buren
Riverview Land Preserve
Carleton Farms Landfill
Vienna Junction Industrial Park Sanitary Landfill
LANDFILL SAMPLED AS PART OF THE MWRA-TESTING PROGRAM
LANDFILL WITH PUBLICLY-AVAILABLE PFOA AND PFOS DATA AVAILABLE

Table 3-1

Landfill Leachate Generation & Disposal Methods

MWRA-Member Landfill Designation	Leachate Treatment Facility	LEACHATE DISCHARGE INFORMATION		
		Discharge Configuration	Pretreatment	Approximate Daily Disposal Volume at WRRF (Gallons)
Discharge to Sanitary Sewer				
ADVANCED DISPOSAL SERVICES ARBOR HILLS LANDFILL INC	Ypsilanti Community Utilities Authority (YCUA) Pump and Haul to CWT eventually discharges to GLWA (~38,000 gpd)	Manhole to Sewer	N/A	60,400
BRENT RUN LANDFILL	Anthony Ragnone WWTP (Genesee County)	Manhole to Sewer	N/A	16,400
CITIZENS DISPOSAL	Anthony Ragnone WWTP (Genesee County)	Manhole to Sewer	N/A	32,900
EAGLE VALLEY RECYCLE & DISPOSAL FACILITY	Great Lakes Water Authroity WRRF (GLWA)	Forcemain to Sewer	N/A	32,900
GRANGER GRAND RIVER LANDFILL	Southern Clinton County Utilities Authority (SCCMUA)	Manhole to Sewer	N/A	64,400
GRANGER WOOD STREET LANDFILL	City of Lansing WWTP (Lansing)	Manhole to Sewer	N/A	19,200
OAKLAND HEIGHTS DEVELOPMENT INC	Clinton River Water Resource Recovery Facility in Pontiac (CRWRRF)	Manhole to Sewer	N/A	17,800
PINE TREE ACRES INC	Great Lakes Water Authroity WRRF (GLWA)	Manhole to Sewer	N/A	74,000
SAUK TRAIL HILLS LANDFILL	Ypsilanti Community Utilities Authority (YCUA)	Manhole to Sewer	N/A	20,500
SC HOLDINGS	City of Hastings WWTP (Hastings)	Direct Discharge	Ammonia Treatment	16,000
VENICE PARK RECYCLING & DISPOSAL FACILITY	Anthony Ragnone WWTP (Genesee County)	Two Manholes to Sewer	N/A	32,900
WESTSIDE RECYCLING & DISPOSAL FACILITY	City of Three Rivers WWTP (Three Rivers)	Direct Discharge	N/A	60,800
WOODLAND MEADOWS RDF-VAN BUREN	Great Lakes Water Authroity WRRF (GLWA)	Manhole to Sewer	N/A	54,800
Pump and Haul to WRRF				
AUTUMN HILLS RECYCLING AND DISPOSAL FACILITY	City of Grand Rapids WWTP (Grand Rapids)	Loadout Pad	N/A	54,800
DAFTER SANITARY LANDFILL	City of Sault Ste. Marie WWTP (Sault St. Marie)	Loadout Pad	N/A	16,500
GLENS SANITARY LANDFILL	Betsie Lake Utility Authority (BLUA)	Loadout Pad	Site Evaporator	3,800
K & W LANDFILL	Portage Lake Water and Sewage Authority's WWTF (Portage Lake) Iron-Gogebic Wastewater Authority's Treatment Facility (Ironwood)	Loadout Pad	N/A	17,500
MANISTEE COUNTY LANDFILL INC	City of Ludington WWTP (Ludington) (approx 4,700 gpd)	Loadout Pad	N/A	4,700
	Packaging Corporation of America (PCA) - approx 30,000 gpd	Loadout Pad	N/A	
MICHIGAN ENVIRONS INC	City of Menominee WWTF (Menominee)	Loadout Pad	N/A	13,100
PITSCH SANITARY LANDFILL	Belding WRRF (Belding), with Grand Rapids as a backup	Loadout Pad	N/A	15,000
TRI-CITY RECYCLING AND DISPOSAL FACILITY	City of Sandusky WWTP (Sandusky)	Loadout Pad	N/A	9,600
Pump and Haul to Centralized Waste Treatment				
ADVANCED DISPOSAL SERVICES ARBOR HILLS LANDFILL INC	YCUA (60,400 gpd) Pump and Haul to CWT eventually discharges to GLWA	Loadout Pad	N/A	38,000
C & C EXPANDED SANITARY LANDFILL	Dart/Clean Earth in Detroit (DART) - GLWA	Loadout Pad	N/A	42,000
CARLETON FARMS LANDFILL	Dart/Clean Earth in Detroit (DART) - GLWA	Loadout Pad	N/A	123,300
CENTRAL SANITARY LANDFILL INC	SET Environmental Inc - Grand Rapids	Loadout Pad	N/A	30,100
MCGILL ROAD LANDFILL	Usher Oil (Detroit) (Usher) - GLWA	Loadout Pad	N/A	13,700
NORTHERN OAKS RECYCLING AND DISPOSAL FACILITY	Plummer's Environmental Services - Wyoming, MI (Plummer's)	Loadout Pad	Site Evaporator	12,300
ORCHARD HILL SANITARY LANDFILL	Third Party Pretreatment Facility in Holland, MI - Holland WRRF"	Loadout Pad	Reverse Osmosis	12,500
OTTAWA COUNTY FARMS LANDFILL	SET Environmental Inc - Grand Rapids	Loadout Pad	N/A	82,200
PEOPLES LANDFILL INC	Usher - GLWA	Loadout Pad	N/A	21,900
VIENNA JUNCTION INDUSTRIAL PARK SANITARY LANDFILL	Half to City of Toledo - Toledo (Out of state so not included in total) Half to Usher in Romulus, MI - GLWA	Loadout Pad	N/A	13,700
Pump and Haul to Deep Injection Well for Disposal				
WHITEFEATHER LANDFILL	Deep Injection Well In Pinconning -approx 12,600 gpd	Loadout Pad	N/A	Deep Well Disposal - No offsite leachate disposal
WATERS LANDFILL	Northeastern Exploration (Deep Well) in Johannesburg, MI-approx 8,200 gpd	Loadout Pad	Site Evaporator	Deep Well Disposal - No offsite leachate disposal

3.2 Leachate Disposal Methods, Daily Leachate Volume, & Receiving WRRFs

In this section, we present details regarding leachate disposal methods, annual leachate volumes, and the water resource recovery facilities (WRRFs) that treat leachate generated by the participating landfills, including relevant summary tables and graphics.

3.2.1 Disposal Methods

We obtained disposal information from a pre-sampling questionnaire completed by each facility owner representative. Based on the compiled data included in Table 3-1, the participating landfills manage leachate either by direct sanitary sewer discharge (DSD); pump-and-haul (PAH) for discharge; deep well injection (DWI); or a combination of these three methods. One site, Orchard Hill Landfill, primarily treats leachate for direct discharge to surface water using a reverse-osmosis (RO) system or whenever necessary, manages leachate by PAH. Figure 3-2, Statewide Leachate Disposal Methods illustrates the percentage by leachate volume of each disposal method utilized by the participating landfills.

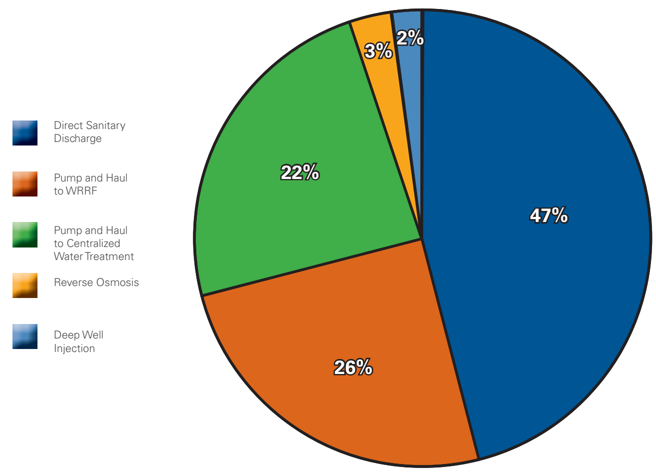
3.2.2 Daily Leachate Volumes

Each site representative accessed their respective site Operating Records that include leachate flow measurements. The average daily leachate volumes by site, are included on Table 3-1. As indicated on Table 3-1 and graphed on Figure 3-3, Average Daily Leachate Volume Managed at Michigan WRRFs, the leachate volume discharged to WRRFs varies, ranging from approximately 3,800 gallons per day (gpd) at Glen's Sanitary Landfill to approximately 123,000 gpd at Carleton Farms Landfill. The daily flow from all 32 landfills is just over 1 million gallons. In general, the larger landfills produce more leachate than smaller ones, but other factors affect leachate generation including timing of cell closures, new cell development, leachate minimization practices, precipitation and recirculation.

3.2.3 Receiving WRRFs

As summarized on Table 3-1, with the exception of DWI, leachate from the original 32 MWRA-member landfills participating in this study are ultimately discharged to a WRRF, regardless of disposal/conveyance/pretreatment method employed. Statewide, the leachate from 18 facilities (more than half the participating sites) is managed at one of the five following, relatively large, regional WRRFs located in the southern half of Michigan's Lower Peninsula

Figure 3-2
Statewide Leachate Disposal Methods
(Percentage based on gallons treated)



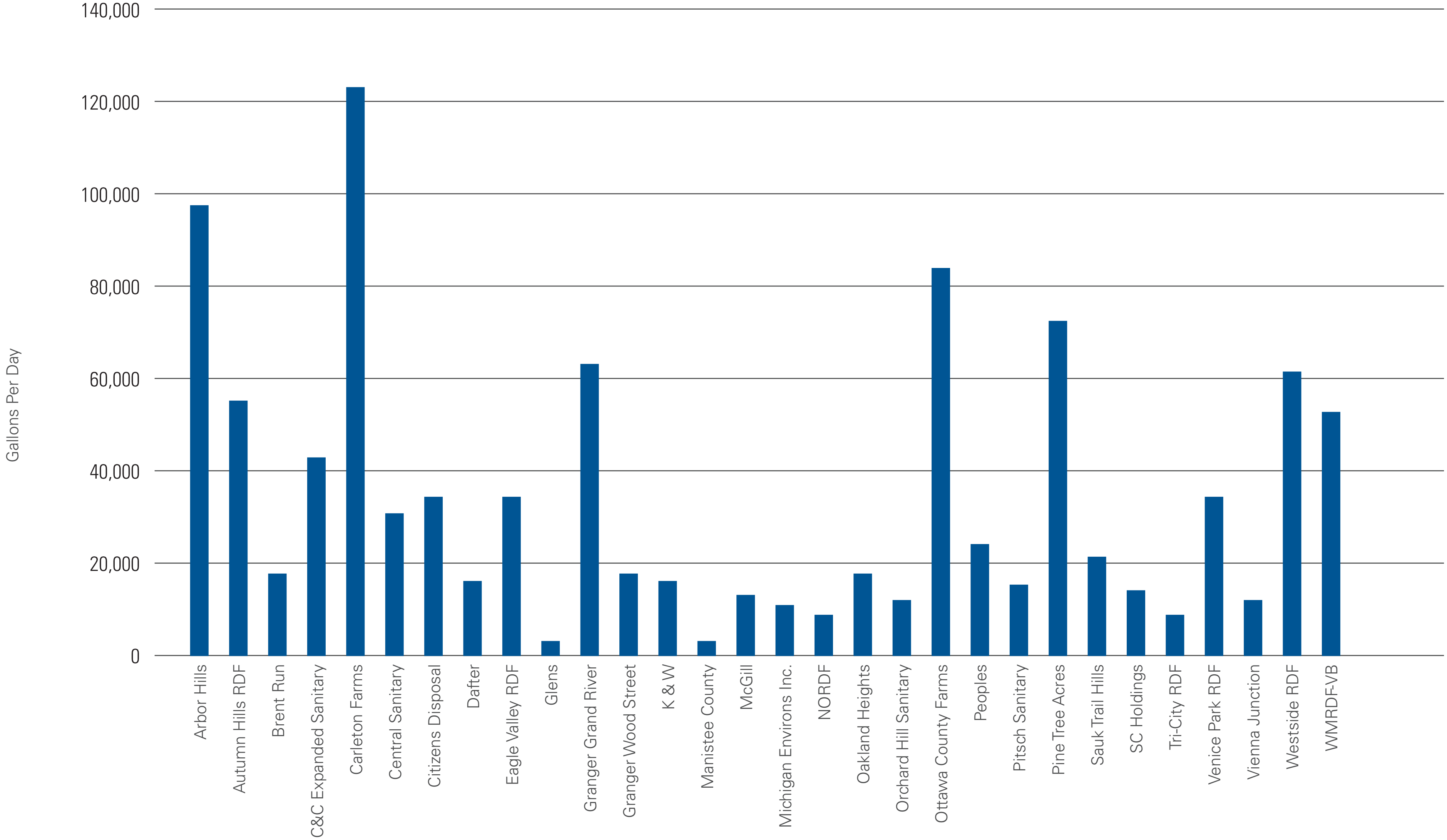
1. Great Lakes Water Authority in Detroit (GLWA), used by nine landfills,
2. Clinton River Water Resource Recovery in Pontiac (CRWRR), used by one landfill;
3. Grand Rapids Water Resource Recovery (GRWRR), used by four landfills
4. Anthony Ragnone Wastewater Treatment Plant near Flint (Ragnone), used by three landfills
5. Ypsilanti Community Utilities Authority (YUCA), used by two landfills (one of these landfills also PAH to GLWA).

Leachate from the remaining 12 participating landfills is managed at individual, local and generally smaller-scale WRRFs, primarily located in less-densely populated regions of the state (e.g., Mid-Michigan, SW-Michigan, Northern-Michigan, and various locations in the Upper Peninsula), as indicated in Table 3-1.

Figure 3-3

Average Daily Leachate Volume Managed at Michigan WRRFs.

Note: Leachate volumes provided by MWRA members



4.0 LABORATORY RESULTS, DATA ANALYSES AND EVALUATION

This section includes the leachate laboratory results and our analyses and evaluation of the leachate PFOA and PFOS concentrations from samples collected during this study. As mentioned previously, PFOA and PFOS data were publicly available in MiWaters.com (MiWaters) for three landfills outside of this study; for completeness, we also evaluated those data below. This results in 35 landfills that represent the majority of the 45 active solid waste disposal facilities in Michigan. We focus our presentation on statewide summary statistics, comparisons to worldwide leachate concentrations, and the total leachate PFOA and PFOS discharged to WRRFs to estimate the percentage of the total mass of these compounds contributed to WRRFs statewide.

A discussion of the laboratory sample processing and analytical methods, quality control protocol, and data validation process are summarized in Appendix A.

4.1 Summary of All Landfills and Water Resource Recovery Facilities Included in this Study

As indicated previously, the original scope of this study included evaluating the leachate PFOA and PFOS content and their effect on the overall influent concentrations and mass at receiving WRRFs for the 32 participating landfills. For completeness, the scope was expanded to evaluate available PFOA and PFOS data for all active Type II landfills and all Michigan WRRFs (those that accept leachate and those that do not). The resulting database used as part of NTH's analyses and evaluation presented in this section is summarized in Table 4-1A, Summary of Landfill Data Utilized and Table 4-1B, Summary of WRRF Data Utilized, below.

For additional details and reference, we prepared a schematic, or flowchart (presented in Appendix B: Source Data Flowchart), which combines the information provided in Tables 4-1A and 4-1B related to the source of all data used in this report and the basis of our analyses and evaluations in this section.

Taken together, as indicated on Table 4-1A, the study considers 35 landfills with available data (out of the 45 active Type II Michigan landfills). [For reference the remaining 10 Type II landfills are listed in a table included in Appendix B.]

For WRRF data, we relied on publicly available information provided by MiWaters. Some WRRFs accept leachate from several landfills and others only a single disposal facility, and some do not accept any leachate. We also note that MiWaters' influent PFOA and PFOS data set is incomplete; not all WRRFs included information for both compounds. As indicated in Table 4-1B, WRRF PFOA and or PFOS influent data are available for 39 (out of Michigan's 95 total operating treatment facilities with industrial pretreatment programs). As also indicated in Table 4-1B, 68 of these WRRFs do not accept landfill leachate and 27 WRRFs do accept leachate. Of the 27 WRRFs accepting leachate, 13 had available influent data.

Table 4-1A
Summary of Landfill PFOA/PFOS Data Utilized

MWRA-member Landfills Included in this study	Other Active Type II Landfills included in this study	Total No. of Active Type II Landfills include in this study	TType II Active Landfills without PFAS data - not evaluated in this study
32	3	35	10

Table 4-1B
Summary of WRRF PFOA/PFOS With Influent Data Evaluated in This Study

WRRFs with PFOA/PFOS data that manage MWRA-member landfill leachate	Total WRRFs with PFOA/PFOS data that manage leachate from other active Type II Landfills	WRRFs with PFOA/PFOS data that do not manage Leachate from active Type II Landfills	Total WRRFs with PFOA/PFOS data included in this Study
11	7	16	34

4.2 Statewide PFOA and PFOS Leachate Concentrations

Analytical data reports prepared by TAL, are contained in Appendix C, Analytical Data Reports. Table 4-2A, PFOA and PFOS Concentrations and Mass in Active Type II Landfills Leachate presents the concentrations of these PFAS compounds detected in 39 separate leachate samples collected from 35 active Type II landfills located in Michigan. We note three landfills included two or more leachate samples/locations (Venice Park, two samples; Riverview LF, three samples; and South Kent County LF, two samples).

As shown on Table 4-2A, PFOA concentrations for the MWRA participating landfills ranged from 240 ppt to 3,200 ppt. For all 35 Michigan active Type II landfills with data the PFOA concentration ranged from 16 ppt to 3,200 ppt with the lowest concentration in leachate detected in a Western-Michigan landfill and greatest concentration at a SE-Michigan landfill. The median PFOA leachate concentration was 1,000 ppt and the "average" concentration was approximately 1,187 ppt.

For PFOS, the leachate concentrations ranged from 100 to 710 ppt for the MWRA 32 participating landfills. For all 35 Michigan active Type II landfills with data the PFOS concentration ranged from 9 to 960 ppt, and the median value is 220 ppt. The lowest PFOS concentration was detected in leachate from a SE-Michigan landfill; the greatest from a Western-Michigan landfill. The average PFOS concentration was 287 ppt and the median concentration was 220 ppt.

4.3 MWRA Landfill Leachate PFOA & PFOS Concentrations Compared To Other Studies

Table 4-3, Michigan vs. Worldwide PFOA and PFOS Leachate Concentration Ranges compares ranges of PFOA and PFOS leachate concentrations observed as part of this study ("Michigan") to the ranges reported for other areas, based on the literature review discussed in Section 2.1. As shown, the worldwide leachate range for PFOA concentrations, is non-detect to 214,000 ppt and the corresponding PFOS range is non-detect to 6,020 ppt.

As indicated in Table 4-3, Michigan's PFOA and PFOS ranges are within those observed in the US based on available published literature. The Michigan PFOS concentration range is consistent with that reported in other Western world regions, but nearly an order-of-magnitude lower than what is reported for China. The apparent reason China's concentrations are greater is their continued use of PFAS compounds in consumer-goods manufacturing.

Table 4-3
Michigan vs. Worldwide PFOA and PFOS Leachate Concentrations Ranges

Region	PFOA (ppt)	PFOS (ppt)
Michigan*	16 to 3,200	9 to 960
United States	30 to 5,000	3 to 800
Europe	ND to 1,000	ND to 1,500
Australia	17 to7,500	13 to 2,700
China	281 to 214,000	1,150 to 6,020
Worldwide Range	**ND to 214,000**	**ND to 6,020**

* Based on leachate analyses from 32 MWRA-member landfills participating in this statewide study and leachate data obtained on MiWaters.com.

4.4 Leachate PFOA And PFOS Concentrations vs. MDEQ Criteria

As indicated in Section 2.1, Michigan has established both groundwater clean-up criteria and surface water quality standards (WQS) for PFOA and PFOS. The Michigan Part 201 groundwater cleanup criteria for PFOA and PFOS is 70 ppt, either individually or as a combined limit. This is not an enforceable standard for public drinking water supplies but has been used in Michigan as a protective guideline during site investigations.

The Rule 57 PFOA WQS is 420 ppt for surface water that may be used as a drinking water (DW) source and 12,000 ppt for non-drinking water (NDW) sources. For PFOS, the WQS for drinking and non-drinking water sources are 11 ppt and 12 ppt, respectively.

It is not appropriate regulatory policy to compare the leachate results to surface water quality standards (WQS) because leachate is not being discharged to surface water. Nevertheless, the WQS are used as a means of putting the leachate results in some context.

Individually, as shown on Table 4-2A, the concentration of PFOA in leachate collected from two landfills during this study are below the 420 ppt DW WQS as are the concentrations from two samples from two separate landfills with data obtained from MiWaters. The other samples are above the 420 ppt value. The concentration of PFOA in the leachate from all sites was considerably lower than the 12,000 ppt NDW WQS. The concentration of PFOS at all locations exceeded the DW and NDW WQS.

Table 4-2A

Concentrations and Mass of PFOA AND PFOS
Michigan Active Type II Landfills' Leachate

MWRA Participating Landfill Designation	Average Leachate Volume GPD	PFOA (ppt)	PFOS (ppt)	"PFOA Daily Mass (lb/day)"	"PFOS Daily Mass (lb/day)"
Arbor Hills Landfill	98,400	3200	220	0.0026	0.00018
Autumn Hills RDF	54,800	1300	380	0.0006	0.00017
Brent Run Landfill	16,400	540	110	0.0001	0.00002
C&C Expanded Sanitary Landfill	42,000	1300	450	0.0004	0.00015
Carleton Farms Landfill	123,300	1800	250	0.0018	0.00026
Central Sanitary Landfill	30,100	2500	470	0.0006	0.00012
Citizen's Disposal Inc.	32,900	1100	180	0.0003	0.00005
Dafter Sanitary Landfill	16,500	680	130	0.0001	0.00002
Eagle Valley RDF	32,900	490	170	0.0001	0.00005
Glens Sanitary Landfill	3,800	770	210	0.00002	0.00001
Granger Grand River Landfill	64,400	240	160	0.0001	0.00009
Granger Wood Street Landfill	19,200	470	110	0.0001	0.00002
K&W Landfill	17,500	830	170	0.0001	0.00002
Manistee County Landfill	4,700	420	220	0.000016	0.000009
McGill Road Landfill	13,700	760	170	0.0001	0.00002
Michigan Environs Inc. (Menominee)	13,100	1400	100	0.0002	0.00001
Northern Oaks RDF	12,300	1000	220	0.0001	0.00002
Oakland Heights Development	17,800	780	230	0.0001	0.00003
Orchard Hill Sanitary Landfill	12,500	650	110	0.0001	0.00001
Ottawa County Farms Landfill	82,200	1800	530	0.0012	0.0004
People's Landfill	21,900	2500	710	0.0005	0.00013
Pine Tree Acres RDF	74,000	1800	430	0.001	0.0003
Pitsch Sanitary Landfill	15,000	1300	260	0.0002	0.00003
Sauk Trail Hills Landfill	20,500	2800	610	0.0005	0.00010
SC Holdings	16,000	960	410	0.0001	0.00005
Tri-City RDF	9,600	1200	160	0.0001	0.00001
Venice Park RDF MH#20*	32,900	910	190	0.0007	0.0002
Venice Park RDF MH#21*		1500	630		
Vienna Junction Industrial Park Sanitary Landfill	13,700	1300	130	0.0001	0.00001
Waters Landfill	NONE	930	230	NONE	NONE
Westside RDF	60,800	1300	160	0.0007	0.00008
Whitefeather Landfill	NONE	1700	550	NONE	NONE
Woodland Meadows RDF -Van Buren	54,800	2000	510	0.0009	0.00023
Other Active Type II Landfill Leachate Data Obtained from MIWaters		**PFOA (ppt)**	**PFOS (ppt)**	**PFOA Daily Mass (lb/day)**	**PFOS Daily Mass (lb/day)**
Riverview 003* Riverview 004* Riverview 007*	37,400	1900 860 38	270 140 8.5	0.0003	0.00004
South Kent Outfall* South Kent Hauled*	48,000	725 16	960 130	0.0001	0.0002
Smith's Creek Landfill*	32,900	510	120	0.0001	0.00003
	minimum maximum median average n	16 3200 1000 1186 39	9 960 220 287 39	0.000016 0.003 0.0001 0.0004 33	0.000007 0.0004 0.00005 0.0001 33

Notes:
1. There are a total 45 Active Type II Landfills in Michigan; 35 are represented in this table.
* - These facilities reported multiple laboratory results. In these cases, we calculated mass based on the averaged concentrations for PFOA and PFOS.
2. Riverview, South Kent, and Smith's Creek leachate are managed by the Downriver, Wyoming, and Port Huron WRRFs, respectively.

4.5: Statewide PFOA and PFOS WRRF Influent Concentrations

WRRFs serve all users within their respective service areas. Landfill leachate mixes with other wastewater from homes and workplaces, as well as public and private facilities (e.g., churches, restaurants and stores), that is delivered via municipal sanitary sewer networks. The WRRF treats the combined wastewater before adequately-treated water is discharged to a local surface water body or via infiltration beds.

Although very effective at removing bacteria, pathogens, and most undesirable chemicals present in wastewater, most WRRFs are not currently designed to significantly remove PFOA and PFOS.

Table 4-2B, WRRF Influent PFOA & PFOS Concentrations & Daily Mass, summarizes available data obtained from MiWaters organized by three groups. "Group A" includes the 14 (11 with available data) WRRFs that accept leachate from MWRA-member landfills; "Group B" nine (8 with data) that represent WRRF's that accept leachate from other active Type II landfills; and "Group C" 39 (20 with data) identify WRRFs that do not accept leachate from active Type II landfills.

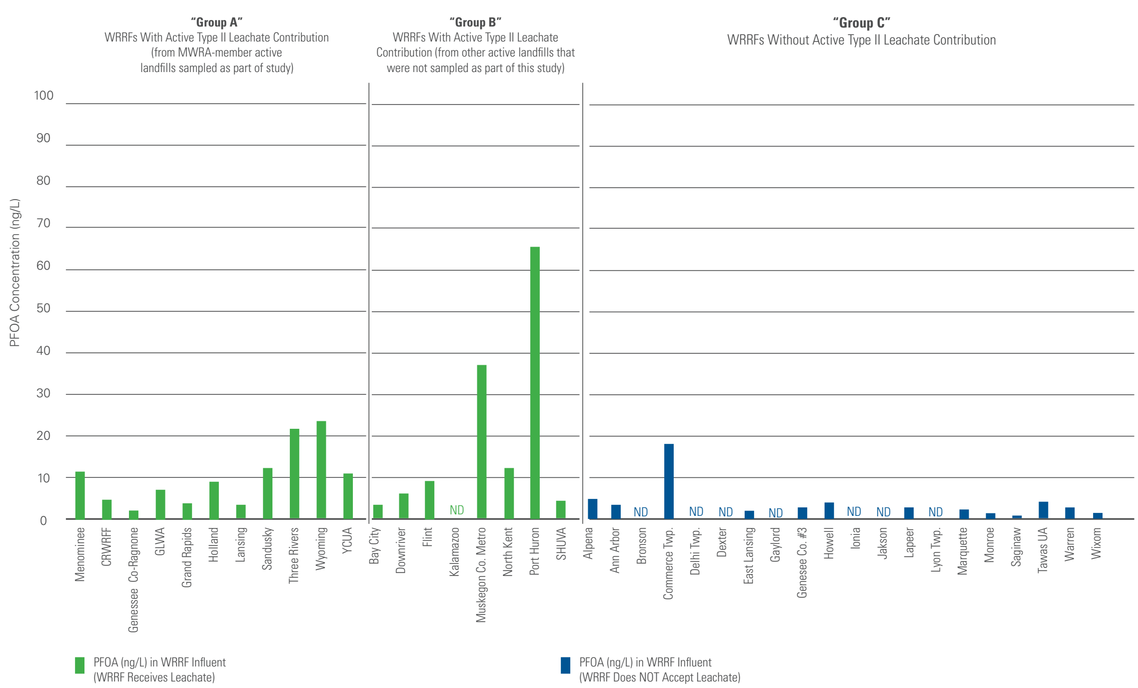
Reviewing all three groups, PFOA influent concentrations ranged from non-detect (ND) at eight WRRFs to 64.6 ppt. The median PFOA influent concentration was 5.06 ppt and the average was 10.3 ppt, based on 31 sample with reported detections.

For PFOS in all groups, influent concentrations ranged from ND (at the same six WRRFs as before) to approximately 500 ppt. The median and average PFOS influent concentrations were 8.6 ppt and 34.5 ppt respectively, based on 29 samples with results above the method detection limit (MDL).

Figure 4-1A, WRRF Gross Influent PFOA Concentrations, graphically depicts available data for influent PFOA concentrations at WRRFs that accept leachate from active Type II landfills and those that do not, categorized by the groupings described above and on the graphic. Based on visual analyses of Figure 4-1A, we note that all influent values (Group A, Group B, and Group C) were below the most stringent 420 ppt PFOA WQS.

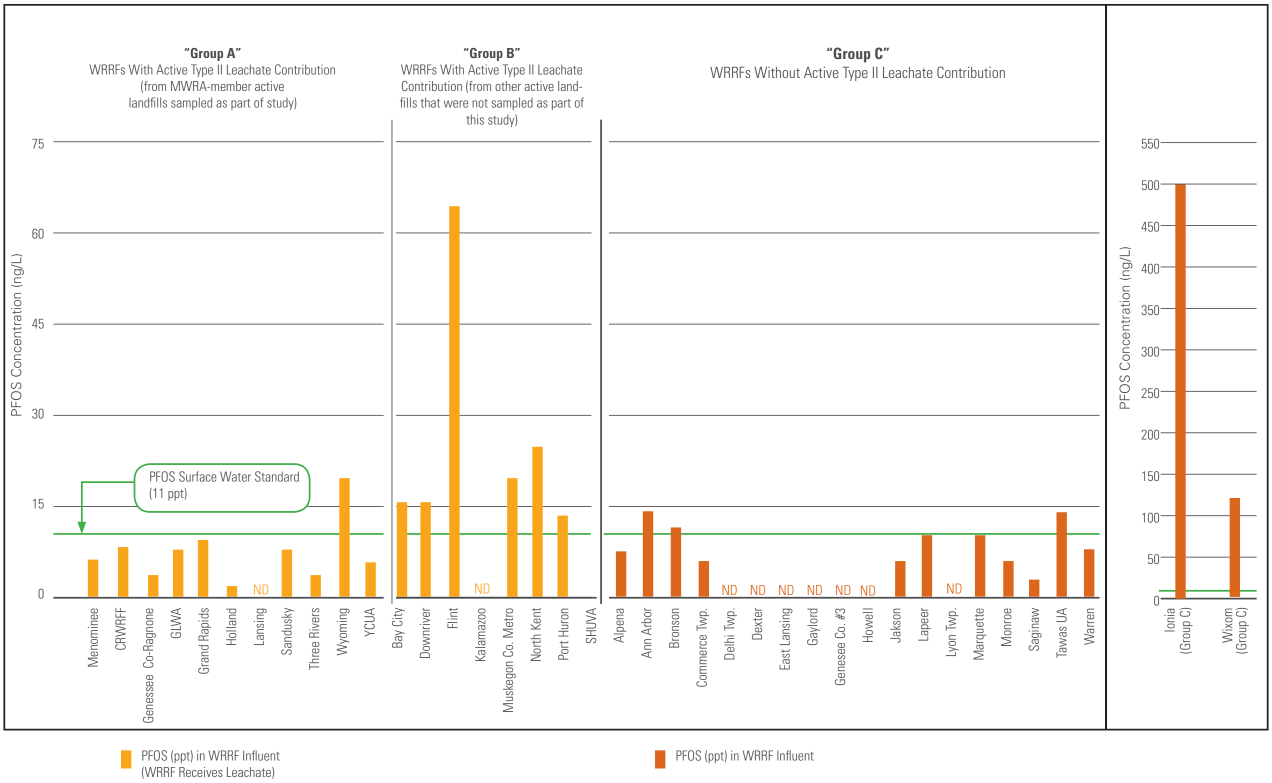
Figure 4-1B, WRRF Gross Influent PFOS Concentrations, depicts available data for influent PFOS concentrations at WRRFs that accept leachate from active Type II landfills and those that do not, categorized by the groupings described above and on the graphic. Based on visual analyses of Figure 4-1B, we note that more than half (12 of 19) of the WRRFs that accept landfill leachate (Group A and Group B) were below 11 ppt, the most stringent WQS for PFOS.

Figure 4-1A
WRRF Gross Influent PFOA Concentrations
At WRRFs that Accept and Do Not Accept Active Type II Leachate



Notes
1. PFOS influent concentrations obtained from MIWaters.com.
2. ND = Not detected above laboratory reporting limit.
3. PFOA surface water standard is 420 ppt (not depicted on this chart).

Figure 4-1B
WRRF Gross Influent PFOS Concentrations
At WRRFs that Accept and Do Not Accept Active Type II Leachate



Notes 1. PFOS influent concentrations obtained from MIWaters.com
2. ND = Not detected above laboratory reporting limit

4.6 PFOA & PFOS Leachate and WRRF Mass Comparison

In order to estimate the mass contribution of PFOA and PFOS in landfill leachate to the total WRRFs influent mass that were evaluated in the study, we again relied on information available from MWRA-member landfills (combined with data available for other landfills) and data provided via MiWaters (for influent and WRRF design flows). This information was used to calculate an estimated mass contribution of PFOA and PFOS from each landfill to their associated WRRF. We also estimated the total mass contribution of PFOA and PFOS from all study landfills and other wastewater sources that contribute to WRRF influent.

4.6.1: Influent Leachate PFOA and PFOS Mass

Table 4-2A, summarizes the calculated daily mass of PFOA in leachate from 33 landfills (2 landfills do not discharge to WRRFs) included in this study. The total daily PFOA estimated mass from all 33 landfills' leachate was 0.014 lb. Daily mass for PFOA was from a low of 0.000016 lb. (Northern-Michigan landfill) to a high of 0.0026 lb. (SE-Michigan landfill). The median daily PFOA mass was 0.0001 lb. and the average daily PFOA mass was 0.0004 lb. These small mass values illustrate that although some of the concentration results appear high when viewed in parts per trillion values, the mass contributions are actually quite low.

The calculated daily mass of PFOS in leachate from the 33 landfills is also include on Table 4-2A. The total daily PFOS estimated mass in leachate from all 33 landfills' leachate was 0.0031 lb. The daily mass ranged from a low of 0.000007 lb. (Northern-Michigan landfill) to a high of 0.0004 lb. (Western Michigan Landfill). The median daily PFOS mass was 0.00005 lb. and the average daily mass for PFOS was 0.0001 lb.

4.6.2: WRRF PFOA and PFOS Mass

Table 4-2B, provides a summary of all WRRFs used in our analyses. We note that the influent flow calculation is based on the WRRF design flow capacity provided in each WRRF's NPDES permit. This design flow was used since actual flow information is not known or published via MiWaters. Further, we note that most of the WRRF influent mass calculations rely on a single or very limited number of samples. Based on these considerations, the calculated masses are provided as estimates and actual mass may fluctuate over time, depending on a number of inter-related factors (e.g., precipitation, seasonality, etc.)

From Table 4-2B, based on 27 results, estimated daily WRRF influent PFOA mass ranged from non-detect (at 10 facilities) to 0.03 lb., with a median of 0.0007 lb. and average of 0.003 lb. For PFOS, based on 25 results, estimated daily WRRF influent ranged from non-detect (at several locations) to 0.04 lb.; the associated median and average values were 0.0019 lb. and 0.005 lb., respectively.

Figure 4-2A, PFOA Mass: Influent Leachate vs. Overall WRRF Influent, depicts the total PFOA mass contribution from leachate versus overall estimated WRRF influent mass on a daily basis for the 13 facilities that receive leachate and have PFOA and/or PFOS data. Review of this graphic reveals the following:

- PFOA mass from leachate represents a relatively minor proportion of the individual WRRFs estimated influent mass at a majority of the WRRFs.
- GLWA's PFOA influent mass is at least twice that of any of the other 12 WRRFs, which is based on its permitted treatment capacity and large area served including many industrial facilities; and
- The influent PFOA mass for the other WRRFs that serve large, densely-populated metropolitan areas are generally greater than observed at smaller WRRFs that serve less-populated areas.

Figure 4-2B, PFOS Mass: Influent Leachate vs. Overall WRRF Influent, depicts the total PFOS mass contribution from leachate versus overall estimated WRRF influent mass on a daily basis for the 13 facilities that receive leachate and have PFOA and or PFOS data. Visual evaluation of this stacked bar chart graph reveals the following:

- PFOS mass from leachate represents a relatively minor proportion of most the individual WRRFs and overall;
- GLWA's PFOS influent mass is at least twice that of any of the other WRRFs, based on its large permitted treatment capacity and large area served including many industrial facilities; and
- Other than Lansing, which did not detect PFOS in their influent, the influent PFOS mass for the WRRFs that serve large, metropolitan areas are generally greater than smaller WRRFs that serve less populated areas.

Table 4-2B

WRRF Influent PFOA and PFOS Concentrations (Page 1 of 2)

Leachate Disposal/WRRF Facility	WRRF Permitted Capicity (MGD)*	Influent Concentration		Influent Mass	
		PFOA (ppt)	PFOS (ppt)	PFOA (lb/ day	PFOS (lb/day)
		Min to Max	Min to Max		
Group A: WRRFs Utilized by MWRA-member Active, Type II Landfills Participating in this Study					
Belding	3.07	NA	NA	NA	NA
Menominee	3.2	12	5.6	0.0003	0.0001
Clinton River	30.6	4.94	7.68	0.0013	0.0019
Genesee Co-Ragnone	25.9	4	5.22	0.0009	0.0012
GLWA	650	6.02	7.54	0.0324	0.0406
Grand Rapids	61.1	5.06	12.7	0.0026	0.0066
Hastings	2	NA	NA	NA	NA
Holland	12	8.93	3.79	0.0009	0.0004
Lansing	35	4.98	ND	0.0014	ND
Ludington	4.5	NA	NA	NA	NA
Sandusky	2.55	12.2	7.98	0.0003	0.0002
Three Rivers	2.75	21.44	7.39	0.0005	0.0002
Wyoming	22	5.08 to 25	6.2 to 26.4	0.0046	0.0048
YCUA	51.2	12	4.8 to 7.51	0.0051	0.0032
Group B: WRRFs Utilized to Dispose Leachate from Other Active, Type II Landfills					
Bay City	18	4.87	18.2	0.0007	0.0027
Downriver	125	7.2	22.2	0.0075	0.0230
Flint	50	10.3	62.4	0.0043	0.0258
Kalamazoo	53.5	ND	ND	ND	ND
KI Sawyer	0.65	NA	NA	NA	NA
Muskegon Co Metro	43	11.7 to 36.9	10.5 to 24.3	0.0131	0.0086
North Kent S A	8	11.2	31.1	0.0007	0.0021
Port Huron	20	64.6	19.5	0.0107	0.0032
S Huron Valley UA (SHUVA)	24	3.76	ND	0.0007	ND

* WRRF permitted daily flow and PFOA and PFOS data provided by MIWaters.com.

Influent mass calculated using the single sample or the maximum value where multiple data are available.

NA: data not available

ND : Not detected. Detection limit unknown. Excluded from average and median calculations.

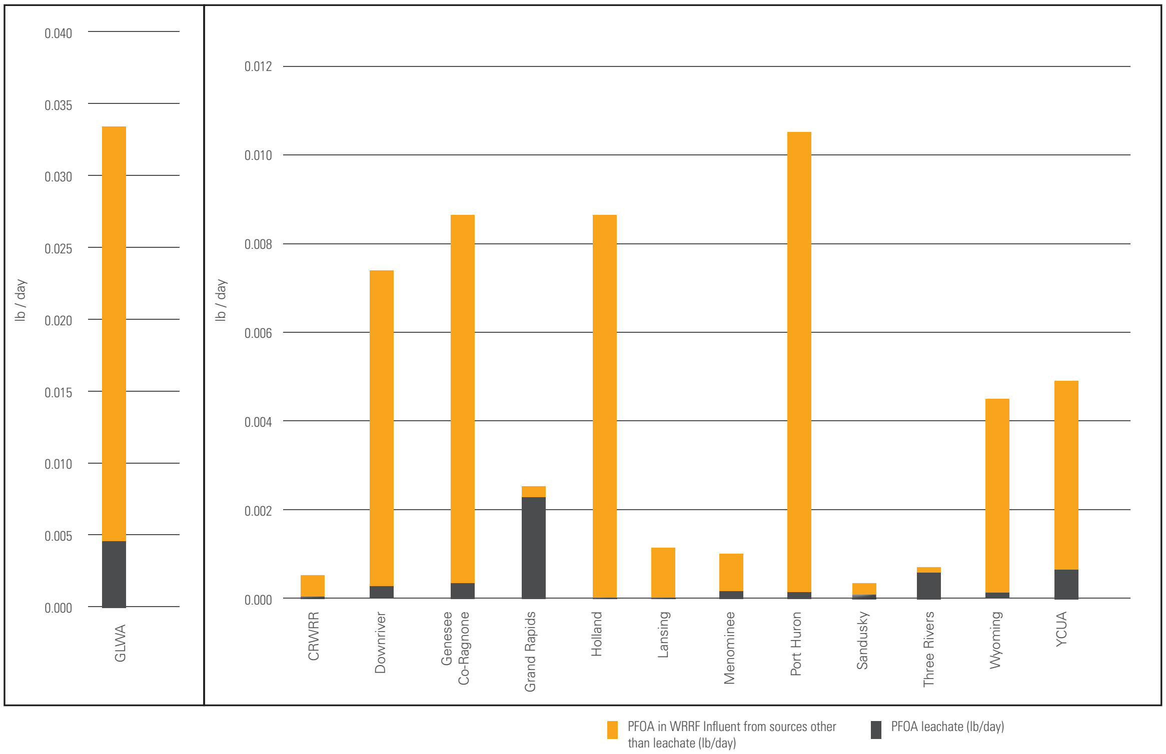
Table 4-2B

WRRF Influent PFOA and PFOS Concentrations (Page 2 of 2)

Leachate Disposal/WRRF Facility	WRRF Permitted Capicity (MGD)*	Influent Concentration		Influent Mass	
		PFOA (ppt)	PFOS (ppt)	PFOA (lb/ day	PFOS (lb/day)
		Min to Max	Min to Max		
Group C: WRRFs that do not Treat Active Type II Leachate					
Adrian	7	NA	NA	NA	NA
Alpena	5.5	5.94	5.44	0.0003	0.0002
Ann Arbor	29.5	2.91 to 4.3	16.5 to 20	0.0011	0.0049
AuGres	0.221	NA	NA	NA	NA
Battle Creek	18	NA	NA	NA	NA
Benton Harbor - St. Joseph	15.3	NA	NA	NA	NA
Boyne City	0.9	NA	NA	NA	NA
Bronson	0.5	ND	12	ND	0.0001
Charlotte	1.8	NA	NA	NA	NA
Commerce Twp	8.5	17.9	6.38	0.0013	0.0004
Delhi Twp	4	ND	ND	ND	ND
Dexter	0.58	ND	ND	ND	ND
East Lansing	18.75	2.21	ND	0.0004	ND
Gaylord	2.2	ND	ND	ND	ND
Genesee Co #3	11	2.6	ND	0.0002	ND
Gladwin	0.65	NA	NA	NA	NA
Greenville	1.75	NA	NA	NA	NA
Holly	1.35	NA	NA	NA	NA
Howell	2.4	4.42	ND	0.0001	ND
Ionia	4	ND	499.36	ND	0.0165
Jackson	18	ND	5.98	ND	0.0009
Lapeer	1.5	4.2	8.6	0.0001	0.0001
Lyon Twp	1.095	ND	ND	ND	ND
Marquette	3.85	3.27	10.3	0.0001	0.0003
Marysville	2.4	NA	NA	NA	NA
Milan WWTP	2.5	NA	NA	NA	NA
Monroe	24	2.89	5.5	0.0006	0.0011
Mt Clemens	6	NA	NA	NA	NA
Petoskey	2.5	NA	NA	NA	NA
Saginaw Twp	4.8	NA	NA	NA	NA
Saginaw	32	2.56	4.19	0.0007	0.0011
Saline	1.81	NA	NA	NA	NA
South Lyon	2.5	NA	NA	NA	NA
Sturgis	2.8	NA	NA	NA	NA
Tawas Utility Authority	2.4	6.2	17	0.0001	0.0004
Warren	36	4.61	7.31	0.0014	0.0022
West Bay County Regional	10.28	NA	NA	NA	NA
Wixom	2.8	3.07	128	0.0001	0.0029
Zeeland	1.65	NA	NA	NA	NA
Summary Statistics - all Groups (A, B, C)	minimum maximum median average n	ND 64.6 5.06 10.3 31	ND 499.36 8.6 34.5 29	ND 0.03 0.0007 0.003 31	ND 0.04 0.0019 0.005 29

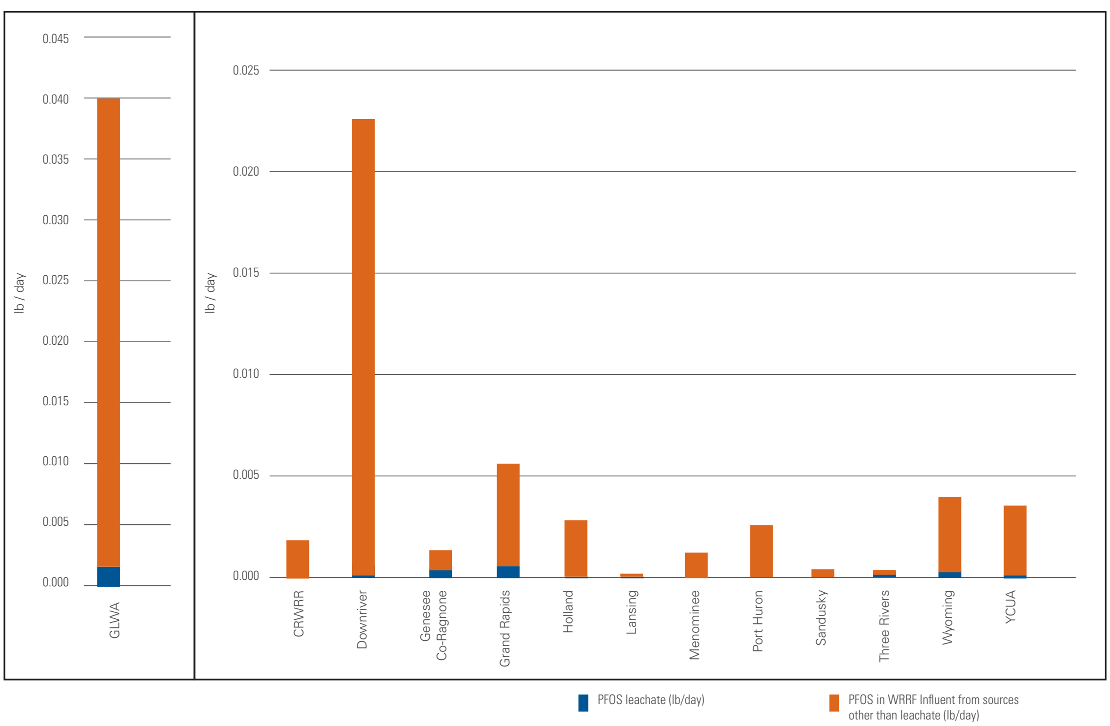
* WRRF permitted daily flow and PFOA and PFOS data provided by MIWaters.com
Influent mass calculated using the single sample or the maximum value where multiple data are available.
NA: data not available
ND : Not detected. Detection limit unknown. Excluded from average and median calculations.

Figure 4-2A
PFOA Mass: Influent Leachate vs. Overall WRRF Influent



Note: Gray shading indicates active Type II landfill leachate loading to WWRF for PFOA mass. This graph includes a total of 13 WRRFs utilized by 26 landfills. Eleven of the WRRFs treat 24 active landfills (23 which were sampled as part of this study and South Kent landfill). Two of the WRRFs are utilized by two additional active landfills that were not sampled as part of this study. PFOA and PFOS influent concentrations were unavailable from the WRRFs that treat other active Type II landfills. The mass represents a calculated value on a single sample, permitted discharge volume, and average daily leachate discharge.

Figure 4-2B
PFOS Mass: Influent Leachate vs. Overall WRRF Influent



Note : Blue shading represents active Type II landfill leachate loading for PFOS mass at each WRRF. This graph includes a total of 13 WRRFs utilized by 26 landfills. Eleven of the WRRFs treat 24 active landfills (23 which were sampled as part of this study and South Kent landfill). Two of the WRRFs are utilized by two additional active landfills that were not sampled as part of this study. PFOS influent concentrations were unavailable for the WRRFs that treat other active Type II landfills. The mass represents a calculated value on a single sample, permitted discharge volume, and average daily leachate discharge.

5.0: OTHER CONSIDERATIONS

In this section, we discuss other concerns related to the current understanding of PFOA and PFOS in the environment that need to be addressed to help guide future regulatory, toxicological, and best-management practices (BMPs).

5.1: WRRF Influent, Effluent, and Biosolids

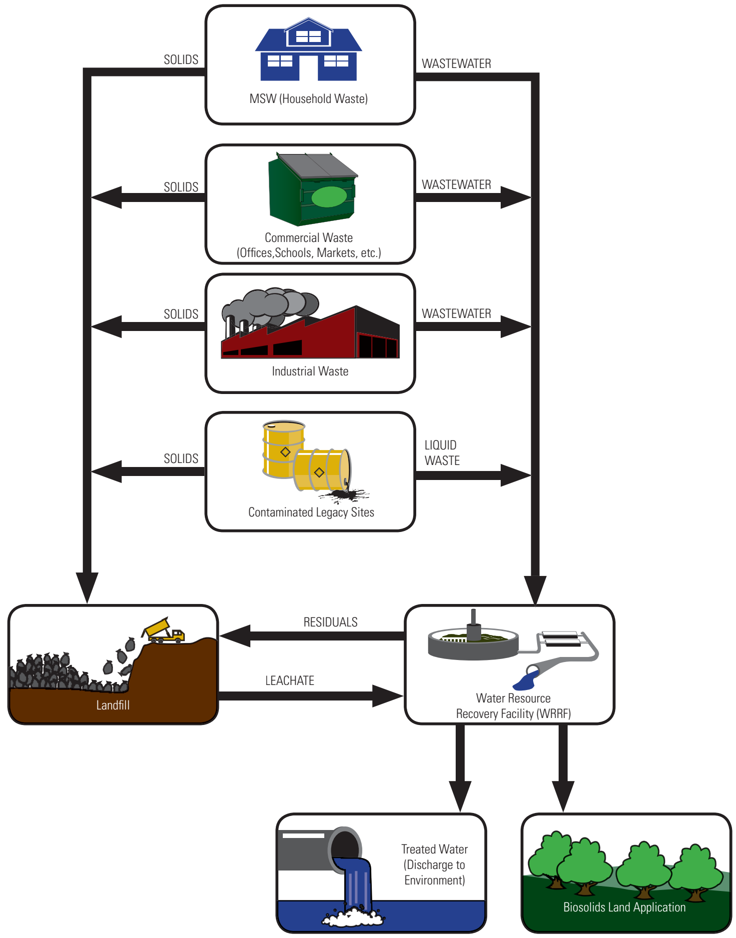
It is documented that WRRF biosolids typically contain PFAS (NEBRA, 2018). A recent comprehensive study was completed for the North East Biosolids and Residuals Association (NEBRA) that examined PFOA and PFOS concentrations in WRRF biosolids. Although the biosolids data are reported for solid/sludge samples and leachate samples are liquids, based on our review, the biosolids concentrations were typically two orders-of-magnitude greater than observed in active, Type II landfill leachate on a ppt basis.

Related specifically to PFOA and PFOS mass in leachate and WRRF biosolids, there are complexities between these two media that need evaluation to optimize future management of these two waste streams:

- the role of biochemical processes in WRRFs;
- fate and transport of PFOA/PFOS contained in biosolids
- temporal and spatial variation effects;
- waste age and state of decomposition in landfills;
- impact of equipment and infrastructure residual contamination; and
- appropriate and effective current BMPs.

While beyond the scope of this study to assess these factors, recent and ongoing research by others may provide direction. For example, work by Hamid (2018) and Lang (2017) indicate some PFAS compounds typically increase in WRRF effluent as compared to influent from biochemical degradation of related PFAS chemicals within the waste stream. Other factors could include residual PFAS from WRRF processing equipment.

For landfills, the existing literature (Lang, et al, and related references) indicates that PFOA+PFOA leachate mass decreases over time with more rapid declines observed in temperate, humid climates. This observation is significant with respect to long-term PFAS leachate management and reduction.



5.2: Proper PFAS Waste Management: Interdependence between Landfills, WRRFs, and General Public

Our study and previous investigations confirm PFAS presence in LF leachate – it comes from many sources that cannot be easily identified or eliminated including various consumer products disposed in landfills. As indicated throughout this report, PFAS have been used for over 50 years in household products. Managing PFAS-containing waste is a challenge that touches all sectors of the economy, including the solid waste industry, manufacturing and commercial sectors, and the general public. It is a societal concern that we need to work together to effectively address.

The leachate is effectively managed at landfills through active leachate collection via engineered liner systems. In Michigan, the most viable method for leachate management is its discharge to a local WRRF where it is handled with other household, commercial, and various industrial wastewaters. In this way, leachate is managed in a closed system where there is no direct exposure to the public. WRRFs treat wastewater to meet certain regulatory criteria prior to discharge of the treated water.

Considering data collected and evaluated during this study, the impact that PFOA and PFOS in landfill leachate has on WRRFs influent concentrations is presented on Figures 4-2A and 4-2B. These data indicate that:
:

a. leachate provides a relatively minor contribution to the overall PFOA and PFOS concentration/mass in most WRRF influent because of the relatively low leachate discharge volumes;

b. non-leachate sources of PFOA and PFOS significantly contribute to WRRF influent and at higher volumes. It is noteworthy that the WRRF influent that have no landfill leachate contribution show a similar concentration range for PFOA and PFOS as WRRF influent that has leachate contribution; and

c. although reduction of landfill leachate concentrations of PFOA and PFOS to the WRRF influent could be beneficial to meeting WQS in the WRRF effluent, the impact may be minor in most cases since leachate typically contributes a relatively small volume to the overall WRRF influent.

As discussed above, WRRFs also produce biosolids (i.e., "sewage sludge") with elevated concentrations of PFAS. These biosolids are normally either land applied as fertilizer or incinerated (which potentially create separate environmental exposures), or are disposed at landfills (which likely contributes to higher PFAS concentrations in leachate at those landfills).

Each of these WRRF biosolids management methods have potential unintended adverse consequences. Incineration emissions may contribute to airborne PFAS, although this is largely un-studied. Similar cross-media impacts may be related to land application. Disposing of biosolids in landfills likely increases the concentrations of PFAS in leachate discharged to WRRFs. However, of the three disposal methods, landfilling in properly built and managed landfills appears to pose the least risk because landfills have engineering controls and environmental monitoring systems.
Accordingly, landfills and WRRFs have an important and mutually-beneficial relationship: landfills need to dispose of leachate and WRRFs need to safely manage society's biosolids. Together, these two critical environmental infrastructure components would benefit from enhanced cooperation to manage PFAS to serve the needs of both industries and protect the environment.

6.0: CONCLUSIONS

PFOA and PFOS were detected in all of the leachate samples taken in the study. The concentration ranges were similar to previous leachate studies conducted elsewhere in the US. The variability from landfill to landfill may reflect variations in waste-types, waste age, size of landfills in the study, and the relative state of decomposition. In summary:

- In leachate sampled from MWRA member landfills that participated in this study, PFOA ranged from 240 to 3,200 ppt and PFOS ranged from 100 to 710 ppt.

- In published studies of landfill leachate in the United States, PFOA ranged from 30 to 5,000 ppt and PFOS ranged from 3 to 800 ppt.

- Michigan leachate concentrations were substantially lower than some other countries, such as China, where published studies show PFOA ranged from 281 to 214,000 ppt and PFOS ranged from 1,150 to 6,020 ppt.

Comparing leachate volume and mass contribution from the 35 landfills examined to the total influent mass at the 39 WRRFs shows that the contribution of PFOA and PFOS is mostly from non-landfill sources.

- On a statewide basis, available data indicates that the 35 landfills contribute approximately one million gallons of leachate to WRRF influent, with approximately 0.01 lbs / day of PFOA and 0.003 lbs / day of PFOS.

- On a statewide basis, available data indicates that the 34 WRRFs that have influent data receive approximately 1.4 billion gallons of influent daily (based on design capacity), with approximately 0.09 lbs / day of PFOA and 0.15 lbs / day of PFOS.

The ranges of PFOA and PFOS concentrations in WRRF influent that do not accept leachate show overlap with those that do accept leachate.

- In WRRFs that do not accept landfill leachate, influent levels of PFOA range from non-detect to 17.9 ppt while PFOS ranges from non-detect to 499 ppt (next highest value is 128 ppt).

- In WRRFs that accept landfill leachate, influent levels of PFOA range from non-detect to 64.6 ppt while PFOS ranges from non-detect to 62.4 ppt.

- Available data show that PFOA levels in WRRF influent are well below Michigan's most conservative surface water criteria (420 ppt) at all WRRFs examined, and that PFOS levels in WRRF influent are below Michigan's most conservative surface water criteria (11 ppt) at approximately two-thirds of the WRRFs examined.

- The data collected during this study indicate that leachate provides a relatively minor contribution to the overall PFOA and PFOS concentration in most WRRF influent; non-leachate sources of PFOA and PFOS contribute greater mass to WRRF influent than leachate.

7.0: RECOMMENDATIONS

Based on the results of this study, we present the following recommendations:

- The solid waste industry in Michigan (and nationally) must continue working to understand the significance of the contribution of leachate to PFOA and PFOS received by WRRFs and work towards reduction solutions.

- The conclusions of this study are based mainly on a single leachate sample from each landfill and limited available data for WRRFs. Therefore, calculated mass values are estimates and more data and information are needed. This should include additional leachate data, WRRF influent data, and biosolids data.

- Facilities will need to present and discuss their individual results with the WRRF receiving their leachate to help evaluate any appropriate solutions on a local basis.

The information gathered during this study and other research can be used to develop, where needed, improved practices for management of waste that contains PFAS within and between landfills and WRRFs. Future collaboration should involve forming a workgroup consisting of MWRA members, MDEQ, MPART, and WRRFs. Discussions should take into consideration the unique aspects of landfills as a component of PFAS management and their interdependence with WRRFs in providing an important function to society. Further, the stakeholder parties need to work with toxicologists and other environmental scientists to better understand the potential impacts of PFOA and PFOS on human health in the context of landfill leachate and in general.

MWRA is committed to continue playing an active role in this process, as demonstrated by its funding of this statewide leachate report and ongoing participation with state and federal technical and scientific committees working toward solutions that follows sound scientific principles and implements best management practices where needed.

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