Source Identification of Per- and Poly-fluoroalkyl Substances (PFAS) in Cedar Lake, Alcona and Iosco County, Michigan.

by
David William Craig

North Carolina State University

in partial fulfillment of the
requirements for the degree of
Master of Environmental Assessment

Under the direction of Dr. Elizabeth Guthrie Nichols

Raleigh, North Carolina

2022

ABSTRACT

CRAIG, DAVID WILLIAM. Source Identification of Per- and Poly-fluoroalkyl Substances (PFAS) in Cedar Lake, Alcona and Iosco County, Michigan. (Under the direction of Dr. Elizabeth Guthrie Nichols).

Per- and poly-fluoroalkyl Substances (PFAS) are a large group of organic chemicals produced for the use in a variety of consumer, commercial, industrial, and military applications. In 2017, Michigan formed the Michigan PFAS Action Response Team (MPART) whose goal was to be proactive in its responsiveness to the mitigation of PFAS type chemicals in the state and establish state specific drinking water and groundwater criteria for seven PFAS chemicals. The purpose of this project was to investigate Cedar Lake, Michigan which has had concentrations of PFAS detected to determine a potential source of these chemicals.

In total, two surface water samples and two surface water foam sample analytical results from Cedar Lake were compared to ten other surface water body PFAS analytical results with no known PFAS source. The results from Cedar Lake were consistent with the analytical results from the ten surface water bodies, indicating that the PFAS detected at Cedar Lake may not be part of a local contamination plume, but background PFAS levels in surface water bodies in Michigan. The Cedar Lake analytical results were reinforced by comparing them to the surface water and surface water foam results from Van Etten Lake, a local lake in the vicinity of Cedar Lake that is considered a PFAS Site in Michigan. Cedar Lake PFAS concentrations were consistently lower for each analyte compared to Van Etten Lake. Additionally, groundwater monitoring wells and localized groundwater flow indicate that the PFAS detected at Cedar Lake was not caused by groundwater contamination, but likely from background sources like atmospheric deposition, surface runoff from the residential areas surrounding Cedar Lake, including recreational vehicle use

BIOGRAPHY

David Craig was born in Lapeer, Michigan. After graduating high school, he attended Mott Community College and the University of Michigan – Flint where he earned a Bachelor of Science in Environmental Science and Planning in 2010. After completing this degree, David was a project coordinator for a large chemical company before moving to his current position as an environmental consultant and staff scientist. Working on major remediation projects in Michigan prompted him to pursue projects with contaminated sites and motivated him to return to college to pursue his master's degree in environmental assessment at North Carolina State University.

ACKNOWLEDGMENTS

I would like to thank Dr. Elizabeth Guthrie Nichols for all her support and guidance while working on this project. I was struggling to find a topic for a project until I took Dr. Nichols EA-504 class and worked on a smaller, similar version of this and found something that not only interests me but is close to home as well. I've spent my entire life vacationing in the area this thesis talks about so it's almost as if I'm working on my second home. I also want to thank my family, friends, and work colleagues that have had to put up with me through these challenging years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

Background on Perfluoroalkyl and Polyfluoroalkyl Substances

Per- and poly-fluoroalkyl Substances (PFAS) are a large group of organic chemicals produced for the use in a variety of consumer, commercial, industrial, and military applications including but not limited to non-stick cookware, fire-fighting foams, food contact materials, carpets, textiles, paints (Renner, 2001). Two of the most common and studied chemicals within this group are perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA). Chemical companies have started to phase out certain compounds based on public pressure and the concern over their toxicity and persistence in humans and the environment (Wang et al., 2017). Popularity of these chemicals was gained by their ability reduce surface tension, reduce friction, and resist temperature extremes; however, due to their unique structure, these chemicals are highly soluble, transport easily through soil and groundwater, making them persistent in the environment, and according to 3M, resistant to biodegradation (3M, 2000).

PFAS chemicals are so widespread that the United States Centers for Disease Control (CDC) and Prevention's National Health and Nutrition Examination Survey (NHANES) found PFAS chemicals in the blood of 97% of Americans (Lewis et al., 2015). The C8 Health Project, an epidemiological study of 69,030 people who may have been ingesting PFAS contaminated water in West Virginia, found probable links between elevated levels of PFOA and high cholesterol (hypercholesteremia), ulcerative colitis, thyroid function, testicular cancer, kidney cancer, preeclampsia, as well as elevated blood pressure during pregnancy (Frisbee, et al., 2009). On average, the level of PFOA in the blood of the members of the study was 32.91 nanograms per milliliter (ng/mL) (Frisbee, et al., 2009), while the general population background blood

levels are approximately 4 ng/mL (Post, et al., 2012) with a half-life of approximately 3.8 to 8.5 years (Frisbee, et al., 2009).

PFOA and PFOS, and most PFAS chemicals that are commonly detected in the environment, have a hydrophobic carbon-fluorine chain or "tail" and a hydrophilic polar functional group or "head" (Interstate Technology and Regulatory Council, 2020). Because of this partitioning, PFAS chemicals have a tendency to form at the air-water and / or water-water interface. The hydrophilic head would be dissolved in water while the hydrophobic tail would be positioned towards the air or soil (Interstate Technology and Regulatory Council, 2020).

State of Michigan Regulatory Efforts

Recent studies have elevated concerns about the effects of PFAS chemicals on human health, animals, and the environment. In 2017, to help reinforce these recent studies, former Michigan governor Rick Snyder signed Executive Directive 2017-4 which formed the Michigan PFAS Action Response Team (MPART) (State of Michigan, 2017). The purpose of this group is to be proactive in its responsiveness to the mitigation of PFAS type chemicals in the state and is made up of the Michigan Department of Environment, Great Lakes, and Energy (EGLE), Michigan Department of Health and Human Services (DHHS), Michigan Department of Agriculture and Rural Development (MDARD), Michigan Department of Natural Resources (DNR), Michigan Department of Transportation (MDOT), Michigan Department of Licensing and Regulatory Affairs (LARA), Michigan Department of Military and Veterans Affairs (DMVA), PFAS Technical Advisory Workgroups including Science Advisory Workgroup, Local Health Department Advisory Workgroup, Citizens Advisory Workgroup, Treatment Technology Roundtable, and Regional and Site Leads. The goal of MPART is to coordinate

together at all levels of government, include outside sources to develop evidence-based recommendations, and implement changes or provide recommendations to law more quickly.

In January 2018, shortly after the formation of MPART, the state of Michigan established a state criterion for PFOA and PFOS by utilizing the previously established United States Environmental Protection Agency (EPA) healthy advisory level of 70 parts per trillion (ppt), or 0.07 micrograms per liter (μg/L) for the combined concentrations of PFOA and PFOS in groundwater used for drinking water (Michigan Department of Environmental Quality, 2018a). After the new criteria was established, in May 2018, a statewide sampling campaign began to assess all public water supplies, as the major pathway of exposure to most humans and animals is ingestion via groundwater. More than 1,500 public, school, and tribal water systems were sampled for PFOA and PFOS for exceedances of the newly established standard of 70 ppt (Michigan PFAS Action Response Team, 2018). Private residential wells were not sampled during this event. The study ended in February of 2019, and the results found that only two drinking water systems, the City of Parchment, and Robinson Elementary School, had PFOA and PFOS detections exceeding the regulatory criteria (Michigan Department of Environmental Quality, 2019).

In March of 2019, Governor Gretchen Whitmer directed MPART to form a science advisory team to review national PFAS drinking water standards and provide Maximum Contaminant Levels (MCL) for PFAS chemicals (Michigan PFAS Action Response Team, 2019). The deadline to develop such MCLs was July 1, 2019, with draft rules expected to be developed by October 2019 and adopted sometime in the spring of 2020. Following the deadline to develop MCLs, EGLE published drafts on October 11, 2019, that would set the drinking water standards for the following seven PFAS chemicals. The seven chemicals (Table 1) are

perfluorononanoic acid (PFNA), PFOA, perfluorohexanoic acid (PFHxA), PFOS, perfluorohexanesulfonic acid (PFHxS), perfluorobutanesulfonic acid (PFBS), and GenX (HFPO-DA) (Michigan Department of Environment, Great Lakes, and Energy, 2019b).

Table 1. Michigan Residential and Nonresidential PFAS groundwater and drinking water MCLs

Contaminant	CASRN	Drinking Water (ng/L)	Groundwater (ppt)
PFNA	375-95-1	6	6
PFOA	335-67-1	8	8
PFOS	1763-23-1	16	16
PFHxS	355-46-4	51	51
HFPO-DA	13252-13-6	370	370
PFBS	375-73-5	420	420
PFHxS	307-24-4	400,000	400,000

CASRN – Chemical Abstract Services Registry Number; ng/L – nanogram per liter

Michigan adopted the proposed MCLs in Table 1 for drinking water in July 2020, which took effect in August 2020 (Michigan Department of Environment, Great Lakes, and Energy, 2020b). Both the drinking water criteria and the groundwater criteria were published at this time. With these changes, the number of sites that had PFAS exceedances in either groundwater or drinking water increased from 100 to 140 (LeBlanc & Burke, 2020). In December 2020, the five PFAS chemicals that were just added to the drinking water criteria, were added to groundwater cleanup criteria (Michigan Department of Environment, Great Lakes, and Energy, 2020c).

EGLE states that a “PFAS Site” is defined as “a property where EGLE has a valid groundwater monitoring well sample result that exceeds one or more of Michigan's seven PFAS groundwater cleanup criteria, and based on data, EGLE has determined the property is the location of the source of PFAS contamination (e.g., fire training area where PFAS-containing foam was used)” (EGLE MPART, n.d.). At the time this paper was written, 199 sites have been identified in Michigan (EGLE MPART, n.d.).

Known Oscoda Area PFAS Contamination

Nine individual PFAS Sites have been identified in the area of Cedar Lake, and the surrounding Oscoda area. These nine PFAS Sites located in Figure 1 have been identified from the ongoing Oscoda area PFAS investigation resulting from the former activities associated at Wurtsmith (Michigan PFAS Action Response Team, 2021b). Details regarding the history of the surrounding area of each PFAS Site are below, starting with Wurtsmith. The summaries below for each of the nine individual Oscoda area PFAS Site is referenced from the Oscoda Area Historical Timeline (Michigan PFAS Action Response Team, n.d.-a).

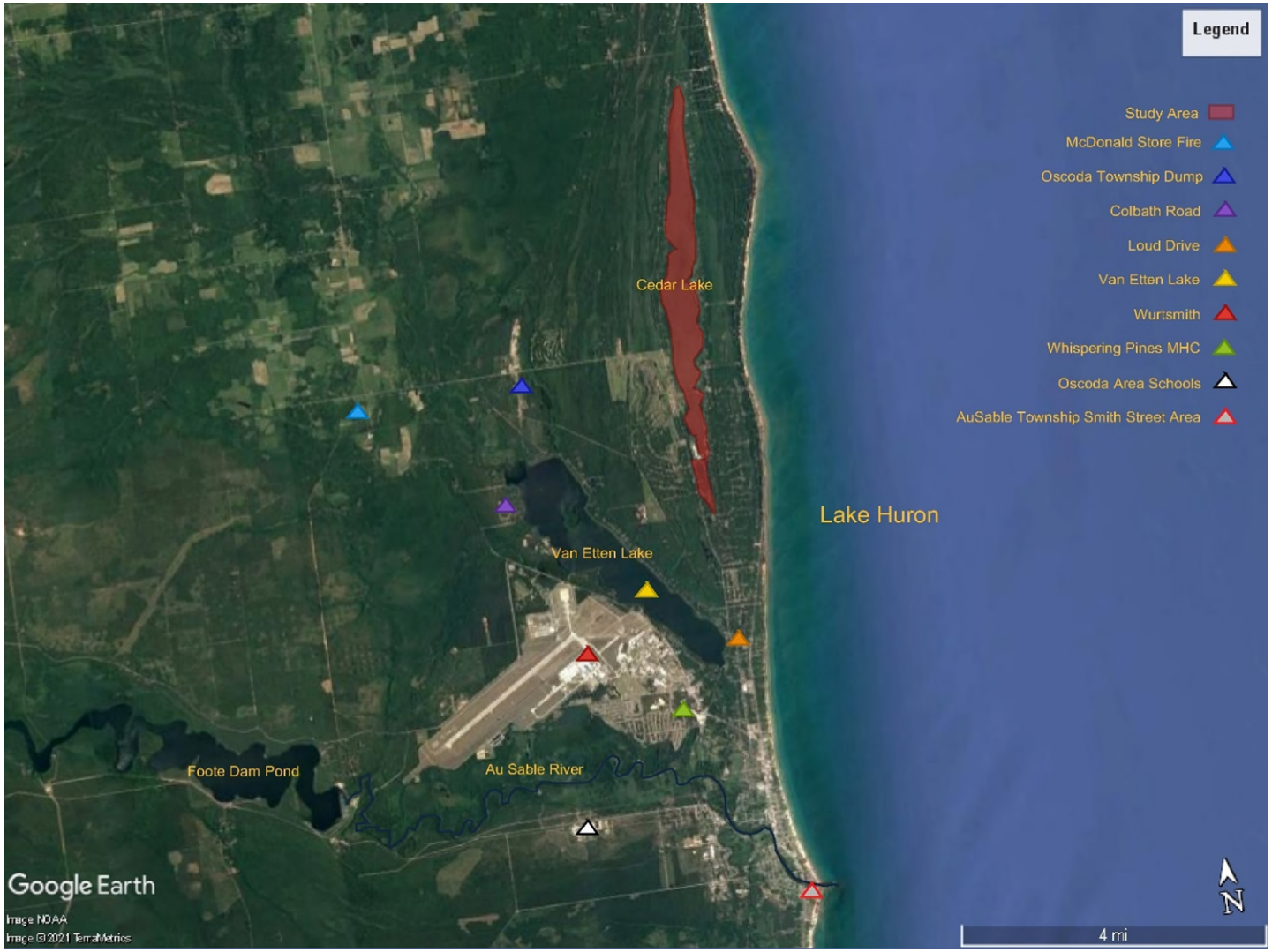

Figure 1. A map showing the nine identified PFAS Sites identified by EGLE in proximity to the Study Area (Michigan PFAS Action Response Team, 2021b)

1. **Former Wurtsmith Air Force Base**

Wurtsmith operated as a military base from 1923 to 1993 when it ceased military operations and was converted to civilian use (The WAFB Historical Site, n.d.). During operations, Wurtsmith Air Force Base (Wurtsmith) utilized firefighting foams because of their effectiveness against hydrocarbon fires in the event of an aircraft crash or accident. Developed and utilized in the late 1950s, aqueous film-forming foam (AFFF) is made up of fluorosurfactants which are PFAS type substances, hydrocarbon surfactants, solvents, inorganic salts, corrosion inhibitors, and water. (Eberly, 2018). After AFFF is sprayed on a fire, the liquid in the foam drains to the bottom via gravity and forms a blanket over the surface effectively blocking the supply of oxygen to the fire (CHEMGUARD, n.d.).

PFAS contamination was discovered at Wurtsmith in March 2010 when EGLE (formally the Michigan Department of Environmental Quality (MDEQ)) installed monitoring wells at the former firefighting training area on the base. Large plumes of PFAS contamination have been found in numerous areas at the base, some at least eight square miles, resulting from the firefighting training area, as well as base fires and crashes (Michigan PFAS Action Response Team, 2021a). One notable crash at Wurtsmith was in October 1988 when a KC-135 Stratotanker used to refuel other planes crashed during a landing. The Wurtsmith firefighters just finished a training exercise and were ready to go extinguishing the fire with AFFF (Tanker Plane Crashes At Wurtsmith Air Force Base; Six Killed, 1988).

2. **AuSable Township Smith Street Area**

In 2019, a subsurface investigation was kicked off near the DNR boat launch on the mouth of the Au Sable River where it enters near Lake Huron. Numerous analytical results detected PFAS chemicals above EGLE MCLs. Further groundwater sampling is currently being evaluated for the site.

3. **Colbath Road**

   In 2016, a subsurface investigation was conducted in the Colbath Road area to investigate the possible presence of PFAS chemicals from the alleged use of AFFF used to extinguish fires in the area, which was learned from historical documentation review. Analytical results ranging from non-detect to above EGLE MCLs for select PFAS chemicals were found, and quarterly groundwater monitoring is continued in the area.

4. **Loud Drive**

   In 2016, a Loud Drive resident took a drinking water sample from her home which contained tetrachloroethylene above drinking water criteria. This information prompted additional drinking water samples to be taken from this resident's home which were then found to include PFAS chemicals. Numerous subsurface investigations were conducted, with analytical results ranging from non-detect to above EGLE MCLs for select PFAS chemicals. In 2020, Oscoda Township constructed a watermain near Loud Drive that is proposed to serve 139 homes but was not finished. Construction of the watermain to connect to the homes started in 2021 and quarterly groundwater monitoring is continued in the area.

5. **McDonald Store Fire**

   In 1992, firefighters from Wurtsmith extinguished a fire at the McDonald store using AFFF. In 2018, a subsurface investigation was conducted to assess the extent of the

PFAS contamination in the area. Analytical results showed the presence of PFAS chemicals in excess of EGLE MCLs in soil, sediments, and surface water. Further sampling is currently being evaluated for the site.

6. **Oscoda Township Dump**

   A historical 1968 letter stated that waste from Wurtsmith was being disposed of at the Oscoda area dump. Like most local historical dumps of the time period, the Oscoda dump was essentially an open pit with no permits, no control of entry, and no material restrictions. In 2018, a subsurface investigation was conducted to obtain the extent of possible PFAS contamination at the site. Analytical results showed the presence of PFAS in excess of EGLE MCLs, with the most significant exceedances in the southeast corner of the site. Further sampling is currently being evaluated for the site.

7. **Oscoda Area Schools**

   In 1995, a bus garage fire was extinguished utilizing AFFF when the local area fire department was unable to control the fire. In 2016, a subsurface investigation commenced in the vicinity of the bus garage fire. Analytical results showed high concentrations of PFAS in the groundwater surrounding the school. The school utilized a potable water well for its drinking water, and by 2018 municipal water service was connected to the school. Quarterly groundwater monitoring is continued in the area.

8. **Van Etten Lake**

   In 2017, surface water foam sampling kicked off from complaints by residents of excessive foam around the lake (Ebbs, 2019). Analytical results detected excess PFAS above EGLE MCLs. Numerous investigations have been conducted including surface

water foam, surface water, ice, and sediment in the area (Michigan PFAS Action Response Team, n.d.-d).

9. **Whispering Pines MHC**

   In 2016, District Health Department 2 started providing bottled water to the residents of Whispering Pines due to detected levels of PFAS chemicals in their drinking water wells. Then, in 2018, Oscoda Township attempted to connect the residents to municipal water, but a dispute with the contractor has halted construction which was not completed until 2020.

Cedar Lake, Michigan (Figure 2) has had concentrations of PFAS chemicals detected in its surface water and surface water foam but is not listed as a PFAS Site based on the EGLE definition because EGLE has not determined the source of the PFAS chemicals. Cedar Lake is in the vicinity of the most studied area of PFAS chemicals in Michigan, including nine PFAS Sites, all resulting from the historical activities associated with the former Wurtsmith. The purpose of this project is to investigate the Study Area to determine a potential source of the detected PFAS chemicals found in the surface water and surface water foam at Cedar Lake.

Figure 2. A map outlining Cedar Lake, Michigan (Study Area) as well as Greenbush and Oscoda Townships, Van Etten Lake, and Lake Huron.

CHAPTER 2. METHODS

Study Area and Local Area Description

Cedar Lake, Michigan, is located 0.5 miles west of Lake Huron and one mile north of Oscoda, Michigan in the northeast Lower Peninsula of Michigan. Cedar Lake is 1,075 acres in size, approximately 5.9 miles long, approximately 0.2 miles wide, and on average, about five feet deep (Cwalinski, n.d.-a). Wurtsmith was constructed northwest of Oscoda in 1923, which ceased military operations in 1993. The former air force base remains, mostly transferred to either the Township of Oscoda, Oscoda Wurtsmith Airport Authority, which currently operates a civilian airport, U.S. Forest Service, and Kalitta Air who service large civilian aircraft at the airport. During its peak, the base housed around 6,500 people. (The WAFB Historical Site, n.d.).

Currently, there are approximately 700 private properties around the shoreline of Cedar Lake (Rouse, 2018). Cedar Lake is cut almost in half by county line jurisdictions, with Alcona County to the north which houses Greenbush Township. The southern portion is in Iosco County which houses Oscoda Township. The properties that reside to the north in Greenbush Township utilize potable water well and septic. The properties to the south surrounding Cedar Lake utilize municipal water for drinking water and septic for waste (R. Vaughn, personal communication, October 17, 2021).

The legal lake water level for Cedar Lake was set at 608.5 feet above mean sea level (AMSL) by a court order in 1954, which is maintained by a spillway at its northern most point (Kieser & Associates, LLC, 2011). Most of the water recharge Cedar Lake receives in the summer and fall is from rainfall (53.3%), while the remainder comes from groundwater (46.7%) (Kieser & Associates, LLC, 2011). The main sources of groundwater are Sherman Creek and Jones Creek which reside northwest of Cedar Lake. These creeks provide water to Cedar Lake

from the wetland area northwest of Cedar Lake (Kieser & Associates, LLC, 2011). As shown in Figure 3, groundwater flows east, southeast, south, and southwest away from Cedar Lake (Kieser & Associates, LLC, 2011; Michigan Department of Environment, Great Lakes, and Energy, 2020a).

Figure 3. A map showing the Cedar Lake Watershed and localized groundwater flow near Cedar Lake and Wurtsmith (Kieser & Associates, LLC, 2011; Michigan Department of Environment, Great Lakes, and Energy, 2020a)

Sample Collection

Surface water samples are collected in part through EGLE's Water Chemistry Program (Michigan Department of Environment, Great Lakes, and Energy, n.d.) and the Water Resources Division (WRD) mission strategy (Roush, 2017) of protecting Michigan's water bodies. The first 21 surface water body samples were taken for PFAS in 2001 (Michigan PFAS Action Response Team, n.d.-b). The Cedar Lake surface water and surface water foam samples plus the additional 10 surface water bodies are samples from part of that strategy. Van Etten Lake surface water and surface water foam samples plus the groundwater samples were collected as part of an ongoing investigation in the former activities associated with Wurtsmith.

To ensure accuracy and precision with the collection of samples, samples would have been collected and prepared following the methods detailed in the following ELGE Technical Guides:

- MDEQ General PFAS Sampling Guidance – October 2018 (Michigan Department of Environmental Quality, 2018c)
- MDEQ Groundwater PFAS Sampling Guidance – October 2018 (Michigan Department of Environmental Quality, 2018b)

- EGLE PFAS Sampling Quick Reference Field Guide – October 2018 (Michigan Department of Environment, Great Lakes, and Energy, 2018)

- MDEQ Surface Water PFAS Sampling Guidance – November 2018 (Michigan Department of Environmental Quality, 2018d)
- EGLE Surface Water Foam PFAS Sampling Guidance – August 2019 (Michigan Department of Environment, Great Lakes, and Energy, 2019a)

Laboratory Analyses

Cedar Lake surface water and surface water foam samples, plus all ten surface water body locations that were selected for analysis for this project had samples collected for EGLE for the laboratory analysis of PFAS utilizing EPA Method 8327 - Per-and Polyfluoroalkyl Substances (PFAS) by Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS) that includes 31 PFAS analytes (Michigan Department of Environment, Great Lakes, and Energy, 2022).

Van Etten Lake, as well as all of the groundwater monitoring wells located in the Oscoda area are part of the ongoing Wurtsmith investigation. These surface water, surface water foam, and groundwater samples also utilized EPA Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS) (AECOM, 2020).

Project Description

Cedar Lake, Michigan has had concentrations of PFAS chemicals detected in its surface water and surface water foam (A. Armbruster, personal communication, September 10, 2021) but is not listed as a PFAS Site based on the EGLE definition because EGLE has not determined the source of the PFAS chemicals. Cedar Lake is in the vicinity of the most studied area of PFAS chemicals in Michigan, including nine PFAS Sites, all resulting from the historical activities

associated with the Wurtsmith. The purpose of this project was to investigate the Study Area to determine a potential source of the detected PFAS chemicals found in the surface water and surface water foam at Cedar Lake. Utilizing Freedom of Information Act (FOIA) requests, interviews, and utilizing public information, data was acquired including but not limited to all Cedar Lake surface water and surface water foam results, Van Etten Lake surface water and surface water foam results, groundwater monitoring well result data, as well as analytical data from additional surface water bodies throughout the state of Michigan. Additional information was utilized from watershed and groundwater studies in the area of Cedar Lake. From there the data was characterized and converted into ppt to compare the surface water and surface water foam results at Cedar Lake to Van Etten Lake and the ten surface water bodies without a PFAS source. Groundwater flow data as well as groundwater monitoring well data was utilized to see if there was an impact from the nine PFAS Sites in the vicinity of Cedar Lake.

CHAPTER 3. RESULTS

Surface Water

In total, two surface water samples have been taken at Cedar Lake. One surface water sample was taken from the causeway area (Figure 4) in July 2019 (EGLE MPART, n.d.), with another taken in April of 2020 (Michigan PFAS Action Response Team, n.d.-c). None of the surface water samples for Cedar Lake were above EGLE's MCLs for the seven PFAS chemicals outlined earlier in Table 1. The summary of the statistical data for Cedar Lake is outlined in Table 2.

Table 2. Statistical Summary of Detected PFAS Concentrations in Cedar Lake Surface Water

	Waterbody	Cedar Lake	Cedar Lake
	Media	Surface Water	Surface Water
	Location	Causeway	Causeway
	Season	Summer	Spring
	Sample Date	7/23/2019	4/8/2020
Compound	**Unit**	**Michigan Part 201 Drinking Water Criteria**	41 Analytes Analyzed	41 Analytes Analyzed
PFOA	ppt	8	1.8	ND
PFOS	ppt	16	0.85	5.43
PFNA	ppt	6	0.64	1.46
PFHxS	ppt	51	0.47	ND
HFPO-DA	ppt	370	ND	ND
PFBS	ppt	420	0.57	ND
PFHxA	ppt	400,000	1.4	ND
PFOA+PFOS	ppt	N/A	2.65	5.43
Total PFAS	ppt	N/A	18.66	17.02

ND – Not detected; Source: (EGLE MPART, n.d.; Michigan PFAS Action Response Team, n.d.-c).

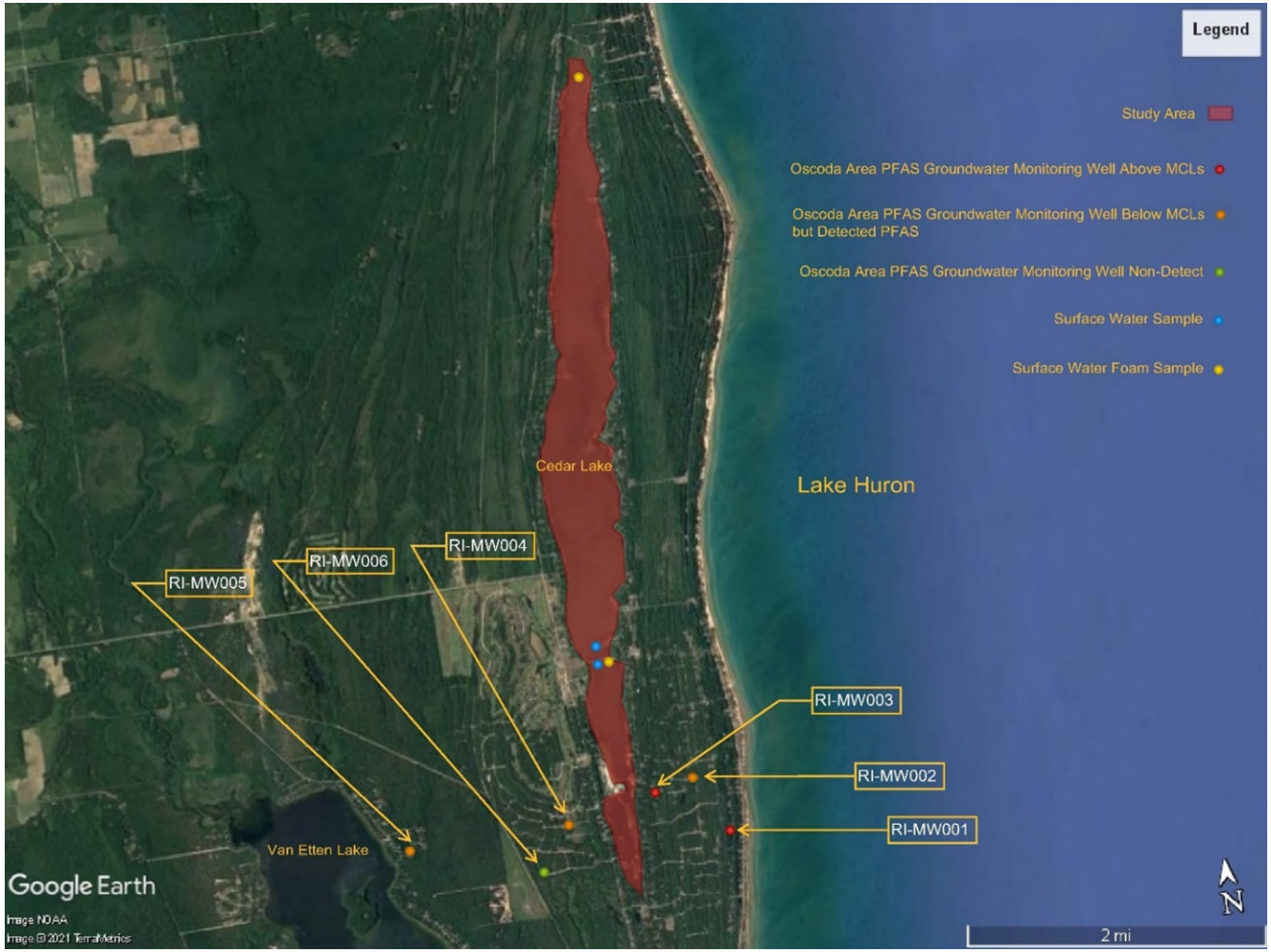

Figure 4. A map showing the Cedar Lake surface water, surface water foam, and groundwater monitoring wells sample locations (Michigan Department of Environment, Great Lakes, and Energy, 2020a; EGLE MPART, n.d.; AECOM, 2020; AECOM, 2021

In comparison, Van Etten Lake, which is located approximately one and a quarter mile southwest of the Study Area and is 21.5 feet below the lake level elevation of Cedar Lake (Cwalinski, n.d.-b). Van Etten Lake is considered a PFAS Site by EGLE because of its proximity to Wurtsmith and being hydraulically connected, (Michigan Department of Environment, Great Lakes, and Energy, 2021). Between July 2013 and March 2021, 20 surface water samples have been collected from Van Etten Lake (EGLE MPART, n.d.), Michigan PFAS Action Response Team, n.d.-c). PFAS chemicals were detected in all 20 samples analyzed, with PFOA being present in every sample, and PFOS being present in every sample but one. PFOA, PFOS, and / or PFHxS were detected in 8 of the 20 samples above EGLE MCLs. PFOA results ranged from 1.1 to 50.3 ppt, while PFOS results ranged from non-detect to 254 ppt. Total PFAS detected in all 20 samples ranged from 9.19 to 733.26.

The two surface samples from Cedar Lake and 20 from the Van Etten Lake surface water sampling events were averaged per each applicable PFAS chemical and compared to each other in Table 3.

Table 3. Statistical Average Comparison of all Van Etten Lake PFAS Surface Water Analytical Results to all Cedar Lake Surface Water Analytical Results

Location Compound	Unit	Criteria	Cedar Lake	Van Etten Lake	% Difference
PFOA	ppt	8	0.9	9.015	1002%
PFOS	ppt	16	3.14	34.55	1100%
PFNA	ppt	6	1.05	0.6327	60%
PFHxS	ppt	51	0.235	30.95	13170%
HFPO-DA	ppt	370	0	0	0%
PFBS	ppt	420	0.285	0.524	183.90%
PFHxA	ppt	400,000	0.7	6.3385	905.50%
PFOA+PFOS	ppt	N/A	4.04	43.565	1078.30%
Total PFAS	ppt	N/A	17.84	116.926	655%

On average, the analytical results for Van Etten Lake were 2017% higher than that of Cedar Lake for the applicable PFAS chemicals.

To better understand the surface water analytical data at Cedar Lake, additional surface water sample locations were selected at random in Michigan that do not have an apparent source of PFAS chemicals. The types and locations of these samples are summarized in Table 4.

Table 4. Sample Location Descriptions for the selected Michigan Surface Water locations with no known PFAS sources for comparison to Cedar Lake

Name	Watershed	# Of Samples	Waterbody Type
Nester Creek	Au Gres-Rifle	4	Creek
Johnson Creek	Au Gres-Rifle	4	Creek
Picket Creek	Aus Gres-Rifle	4	Creek
Buck Creek	Au Gres-Rifle	4	Creek
South Branch Pine River	Pine	4	River
Saginaw Bay	Lake Huron	4	Lake
Tamarack Lake	Muskegon	1	Lake
Grand Traverse Bay	Lake Michigan	3	Lake
Flint Park Lake	Flint	1	Lake
Saginaw River	Saginaw	1	River

Source: EGLE MPART, n.d.

The values from the ten surface water locations selected from the EGLE database for PFAS sampling are similar to that of Cedar Lake. These locations according to the database (EGLE MPART, n.d.) do not have a source of PFAS chemicals and are based on a statewide sampling plan. The only outlier in Table 5 is the May 26, 2020, sampling event for Nester Creek, which presented values slightly over the average but well below the maximum values for PFOA and PFOS at 7.8 and 4.9, respectively.

Table 5. PFOA and PFOS Analytical Results in Surface Water locations with no known PFAS sources for comparison to Cedar Lake and Van Etten Lake

Name	Location	# of Samples	Dates	PFOA	PFOS	Total PFAS
Nester Creek	44.2989, -83.9638	4	5/26/2020 - 11/10/2020	0.81 - 7.8	0.5 - 4.9	15.62 - 99.1
Johnson Creek	44.19122, -83.85406	4	5/1/2019 - 11/4/2019	0.81 - 1.1	0.5 - 0.85	9.29 - 16.11
Picket Creek	44.34587, -83.68142	4	5/1/2019 - 11/4/2019	0.84 - 3.5	0.52 - 1.4	9.23 - 27.93
Buck Creek	44.4194, -83.5695	4	5/1/2019 - 11/4/2019	0.71 - 0.84	0.45 - 0.58	7.00 - 8.31
South Branch Pine River	44.5771, -83.4937	4	5/26/2020 - 11/10/2020	0.71 - 0.98	0.45 - 0.55	9.35 - 13.94
Saginaw Bay	43.83805, -83.7927	4	5/16/2019 - 11/19/2019	1.4 - 1.6	1.3 - 2.7	14.51 - 16.1
Tamarack Lake	43.44412, -85.2708	1	4/13/2021	1.13	1.03	23.33
Grand Traverse Bay	44.77444, -85.53583	3	5/14/2019 - 9/11/2019	1.8 - 2	1.9 - 2.2	12.83 - 14.37
Flint Park Lake	43.058597, -83.719	1	10/18/2018	2.6	8.5	30.11
Saginaw River	43.613, -83.854	1	10/29/2019	1.4	2	18.82
Cedar Lake	N/A	2	7/29/2019 - 4/8/2020	ND - 1.8	0.85 - 5.43	17.02 - 18.66
Van Etten Lake	N/A	20	7/1/2013 - 3/31/2021	0.8 - 50.3	ND - 254	9.19 - 733.26

Source: EGLE MPART, n.d.; ND – Non-Detect, N/A – Not Applicable

Surface Water Foam

In total, two surface water foam samples have been taken at Cedar Lake. One surface water foam sample was taken from the north end of Cedar Lake in December 2017, and one surface water foam sample was taken from the causeway in March 2020 (Michigan PFAS Action Response Team, n.d.-c). The summary of the statistical data for Cedar Lake surface water foam samples is outlined in Table 6.

Table 6. Statistical Summary of Detected PFAS Concentrations in Cedar Lake Surface Water Foam

		Waterbody	Cedar Lake	Cedar Lake
		Media	Foam	Foam
		Location	North	Causeway
		Season	Winter	Summer
		Sample Date	12/7/2017	4/8/2020
Compound	**Unit**	**Michigan Part 201 Drinking Water Criteria**	21 Analytes Analyzed	39 Analytes Analyzed
PFOA	ppt	8	7.82	76.2
PFOS	ppt	16	158	7260
PFNA	ppt	6	32.5	956
PFHxS	ppt	51	ND	ND
HFPO-DA	ppt	370	N/A	ND
PFBS	ppt	420	ND	ND
PFHxA	ppt	400,000	ND	ND
PFOA+PFOS	ppt	N/A	165.82	7336.2
Total PFAS	ppt	N/A	242.54	19267.5

ND – No Data; N/A – Not Applicable; Source: (Michigan PFAS Action Response Team, n.d.-c).

In comparison to Van Etten Lakes surface water foam results, Cedar Lake's are significantly less as noted in Table 7. This aligns with the surface water results being significantly lower as well.

Table 7. Statistical Summary of Detected PFAS Concentrations in Van Etten Lake Surface Water Foam

Sample Date	PFOA	PFOS	PFOA + PFOS	Total PFAS
7/13/2017	30.8	910	940.8	1161.3
7/27/2017	97.1	12100	12197.1	13028.44
7/27/2017	253	17200	17453	18988.67
7/27/2017	513	48000	48513	51997.89
8/3/2017	1.18	165	166	170
9/19/2017	830	110000	110830	117625
10/3/2017	79.3	10600	10679.3	11574.13
10/12/2017	149	23100	23249	24571.53
12/7/2017	10.5	651	661.5	714.11
9/26/2018	71.9	7120	7191.9	7990.2
9/26/2018	102	14900	15002	16742.65
10/1/2018	1210	82300	83510	90828.4
10/1/2018	830	86500	87330	94394.5
10/2/2018	443	40800	41243	45096.5
10/2/2018	1600	134000	135600	150386.4
10/2/2018	1640	148000	149640	164113
3/31/2020	869	31500	32369	34769
3/31/2020	1730	43100	44830	49607
3/31/2020	2730	222000	224730	242430

Source: (EGLE MPART, n.d.) Results in ppt

Groundwater

There are numerous groundwater monitoring wells installed all over the Oscoda area to monitor the PFAS groundwater contamination from the former activities associated with Wurtsmith (Michigan Department of Environment, Great Lakes, and Energy, 2021). Three monitoring wells, RI-MW001, RI-MW002, and RI-MW003 were installed in August 2017 in the southeast portion of the Study Area (Table 8). Three monitoring wells, RI-MW004, RI-MW005, and RI-MW006 were also installed in August 2017 and are located southwest of the Study Area (Figure 4) (AECOM, 2020).

Of the six groundwater monitoring wells located near the Study Area, 59 groundwater (EGLE MPART, n.d.) samples have been analyzed for the PFAS chemicals identified in Table 10. Of the 59 samples, groundwater monitoring wells RI-MW001 and RI-MW003 had the two highest Total PFAS averages of 24.17 and 22.00 ppt respectively, as well as the only samples exceeding the EGLE MCL for PFOA at 8.43 and 8.7 ppt in the shallowest screen intervals (Table 8).

Table 8. EGLE Groundwater Monitoring Wells Near Study Area

Well ID	Date of Completion	Surface Elevation (ft AMSL)	Screen Interval 1 (bgs)	Screen Interval 2 (bgs)	Screen Interval 3 (bgs)	Screen Interval 4 (bgs)	Screen Interval 5 (bgs)	Screen Interval 6 (bgs)
RI-MW001	8/22/2017	589.04	3-8ft	17-18ft	n/a	n/a	n/a	n/a
RI-MW002	8/18/2017	593.03	2-7ft	12-13ft	17-18ft	n/a	n/a	n/a
RI-MW003	8/15/2017	603.27	2-7ft	16-17ft	26-27ft	36-37ft	46-47ft	n/a
RI-MW004	8/2/2017	607.51	5-10ft	19-20ft	29-30ft	39-40ft	49-50ft	59-60ft
RI-MW005	8/9/2017	602.17	7-12ft	20-21ft	30-31ft	40-41ft	51-52ft	60-61ft
RI-MW006	8/3/2017	608.04	5-10ft	20-21ft	30-31ft	40-41ft	50-51ft	n/a

Source: (AECOM, 2020)
Notes: ft - Feet AMSL - Above Mean Sea Level; bgs - Below Ground Surface; n/a - Not Applicable

The analytical results from both of those samples are located in Table 9. Although this coincides with an area of water loss from Cedar Lake (Kieser & Associates, LLC, 2011), the PFOA groundwater monitoring well results are generally higher than that of the surface water results at Cedar Lake.

Table 9. Monitoring Well Sample Results Above EGLE MCLs

		Location	RI-MW001	RI-MW003
		Well Screen Interval (bgs)	3-8 feet	2-7 feet
		Sample	GW2010281655RL	GW1910091430RAP
		Sample Date	10/28/2020	10/9/2019
	Lab Report		2002372	1903624
Compound	Unit	Michigan Part 201 Drinking Water Criteria		
PFOA	ppt	8	8.43	8.7
PFOS	ppt	16	5.2	3.75
PFNA	ppt	6	ND	1.59
PFHxS	ppt	51	2.87	4.55
HFPO-DA	ppt	370	ND	ND
PFBS	ppt	420	3.99	3.05
PFHxA	ppt	400,000	6.42	8.7
PFOA+PFOS	ppt	NC	13.63	12.45
Total PFAS	ppt	NC	47.98	49.37

Source: (AECOM, 2021)

Table 10. PFAS Nomenclature

Chemical Name	Abbreviation	CAS #
Perfluorobutanoic acid	PFBA	375-22-4
Perfluoropentanoic acid	PFPeA	2706-90-3
Perfluorohexanoic acid	PFHxA	307-24-4
Perfluoroheptanoic acid	PFHpA	375-85-9
Perfluorooctanoic acid	PFOA	335-67-1
Perfluorononanoic acid	PFNA	375-95-1
Perfluorodecanoic acid	PFDA	335-76-2
Perfluoroundecanoic acid	PFUnA	2058-94-8
Perfluorododecanoic acid	PFDoA	307-55-1
Perfluorotridecanoic acid	PFTrDA	72629-94-8
Perfluorotetradecanoic acid	PFTeDA	376-06-7
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	11Cl-PF3OUdS	763051-92-9
9-Chlorohexadecafluoro-3-oxanone-1-sulfonic acid	9Cl-PF3ONS	756426-58-1
4,8-Dioxa-3H-perfluorononanoic acid	ADONA	919005-14-4
Perfluoro-2-propoxypropanoic acid	HFPO-DA	13252-13-6
Perfluorodecane sulfonic acid	PFDS	335-77-3
Perfluorobutane sulfonic acid	PFBS	375-73-5
Perfluoropentane sulfonic acid	PFPeS	2706-91-4
Perfluorohexane sulfonic acid	PFHxS	355-46-4
Perfluoroheptane sulfonic acid	PFHpS	375-92-8
Perfluorooctane sulfonic acid	PFOS	1763-23-1
Perfluorononane sulfonic acid	PFNS	68259-12-1
Perfluorooctanesulfonamide	PFOSA	754-91-6
4:2 Fluorotelomer sulfonic acid	4:2 FTS	757124-72-4
6:2 Fluorotelomer sulfonic acid	6:2 FTS	27619-97-2
8:2 Fluorotelomer sulfonic acid	8:2FTS	39108-34-4
N-Ethyl Perfluorooctane sulfonamindo acetic acid	EtFOSAA	2991-50-6
N-Methyl Perfluorooctane sulfonamide	MeFOSAA	2355-31-9

	Perfluoroalkyl Carboxylic Acids (PFCAs)
	Perfluoropolyether carboxylic acids (PFPE)
	Perfluoroalkane Sulfonic Acids (PFSAs)
	Perfluoroalkane Sulfonamides (FASAs)
	Fluorotelomer Sulfonic Acids (FTSAs)
	N-Ethyl Perfluoroalkane Sulfonamidoacetic Acids (EtFASAAs)
	N-Methyl Perfluoroalkane Sulfonamidoacetic Acids (MeFASAAs)

Source: (AECOM, 2021)

CHAPTER 4. DISCUSSION

Surface Water

At the time of this project, 2,047 PFAS surface water samples have been taken in Michigan (EGLE MPART, n.d.). Ten surface water bodies in Michigan with no known direct sources of PFAS pollution were selected for a PFAS concentration comparison to the two surface water samples taken from Cedar Lake. The two surface water samples at Cedar Lake had PFOA concentrations of 1.8 ppt and non-detect, PFOS concentrations of 0.85 ppt and 5.43 ppt, and Total PFAS of 18.66 ppt and 17.02 ppt respectively.

The 10 surface water bodies represent 30 total samples collectively and had PFOA concentrations between 0.81 – 7.8 ppt, PFOS concentrations between 0.45 – 8.5 ppt, and Total PFAS between 7.00 – 99.1 ppt. The 99.1 ppt Total PFAS was from one of the 30 samples and came from one of the four samples taken from Nester Creek on May 26, 2020. The next highest Total PFAS was 30.11, which is closer to the analytical results at Cedar Lake. The results from the Cedar Lake PFAS surface water samples reside inside the ranges from the ten surface water bodies, significantly lower than the surface water body samples taken from Van Etten Lake. This could indicate that the PFAS chemicals found within the Cedar Lake could be from background sources like atmospheric deposition, surface runoff from the residential areas surrounding Cedar Lake, including recreational vehicle use and not from one of the PFAS Sites in the vicinity of Cedar Lake.

Surface Water Foam

On Cedar Lake, surface water foam accumulates down-wind near and along the shorelines when there's a strong northerly wind. Cedar Lake runs almost directly north / south in

orientation and at no point is it further than .80 miles from Lake Huron. Because of the distance from Lake Huron to the east, localized weather in the area is more dependent on onshore and offshore breezes. Cedar Lake does not appear to be wide enough to cause enough wind fetch to create the environment needed to create and transport PFAS surface water foam. The foam observed on Cedar Lake forms when strong northerly winds off Lake Huron have enough distance and space to create enough wind fetch.

The two surface water foam samples at Cedar Lake had PFOA concentrations of 7.82 ppt and 76.2 ppt, PFOS concentrations of 158 ppt and 7260 ppt, and Total PFAS of 242.54 ppt and 19267.5 ppt respectively. By comparison, Van Etten Lake's nineteen samples averaged a PFOA concentration of 694.20 ppt, PFOS of 54365.58, and Total PFAS of 59799.40 ppt. The results from the Cedar Lake PFAS surface water foam samples are significantly lower than the surface water body foam samples taken from Van Etten Lake. Similar to the surface water samples at Cedar Lake, this could indicate that the PFAS chemicals found within Cedar Lake could be from background levels associated with Michigan surface waters and not from the PFAS Sites in the vicinity of Cedar Lake.

Groundwater

At 608.5 feet AMSL, Cedar Lake is maintained by a spillway at the north end of the lake and is the highest water body elevation in the area. Van Etten Lake, which is at 587 feet AMSL, while Lake Huron is at 577 feet AMSL, respectively (Cwalinski, n.d.-a, Cwalinski, n.d.-b). Cedar Lake resides higher than any other local water body including Van Etten Lake, which is a PFAS Site by EGLE definition. Cedar Lake is 21.5 feet higher in elevation than Van Etten Lake, and 31.5 higher in elevation than Lake Huron. There are numerous groundwater monitoring wells installed all over the Oscoda area to monitor the PFAS plume from the former activities

associated with Wurtsmith. Hydrological studies have been conducted in the area of Cedar Lake and surrounding the Oscoda area and are well established (Michigan Department of Environment, Great Lakes, and Energy, 2020a; Kieser & Associates, LLC, 2011).

Because of the unique location of Cedar Lake and its elevation, nearly all surrounding lands drain away from the lake, except for the western shoreline and wetland area to the northwest. Groundwater recharge through the northwest wetland occurs mostly in the spring through snowmelt and fall through extended rain periods and is assisted by Sherman and Jones Creek (Kieser & Associates, LLC, 2011). In the summer months, lake recharge is mostly attributed to rainfall and runoff from the shorelines on the western side of the lake (Kieser & Associates, LLC, 2011).

Of the monitoring wells, RI-MW001, RI-MW002, RI-MW003, RI-MW004, RI-MW005, and RI-MW006 near Cedar Lake, only RI-MW001 and RI0MW003 had criteria above Michigan Part 201 Drinking Water Criteria at 8.43 ppt and 8.7 ppt respectively for PFOA. The total PFAS in each of the groundwater monitoring wells samples were 47.98 and 49.37 respectively. RI-MW002, RI-MW004, and RI-MW005 had detectable levels of PFAS in the monitoring well sample results but under EGLE MCLs while RI-MW006 has had no detectable results at all. The two surface water samples at Cedar Lake had PFOA concentrations of 1.8 ppt and non-detect and Total PFAS of 18.66 ppt and 17.02 ppt respectively. The groundwater in the area of RI-MW001 and RI-MW003 is hydraulicly connected to Cedar Lake, in either groundwater discharge, or surface water runoff (Kieser & Associates, LLC, 2011), but this trend does not match the surface water sample results compiled in this report as the concentration of the groundwater sample results is exponentially higher than that of the surface water.

CHAPTER 5. CONCLUSIONS

Conclusions

The purpose of this project was to investigate the Study Area to determine a potential source of the detected PFAS chemicals found in the surface water and surface water foam at Cedar Lake. Results suggest that the PFAS chemicals found within the surface water and surface water foam at Cedar Lake may be from background sources like atmospheric deposition, surface runoff from the residential areas surrounding Cedar Lake, including recreational vehicle use.

Based on surface level elevation and groundwater movement within the area, the results of this project suggest that Cedar Lake is hydraulicly disconnected from the Au Sable Watershed, and therefore from the nine PFAS Sites within the vicinity of the area as the groundwater from the nine PFAS Sites locally move to the south-southeast. Further, the detectable amounts of PFAS chemicals found in the surface water at Cedar Lake appear to be similar in composition and amounts to other surface water bodies in Michigan that have been sampled, but do not have a PFAS source or Site. This suggests a normal background level of PFAS on surface water bodies in Michigan, and what is detected at Cedar Lake is background and not related to the Wurtsmith investigation. This was reinforced by the surface water and surface water foam samples from Van Etten Lake compared to Cedar Lake.

The groundwater monitoring wells near the southern portion of Cedar Lake have had detectable levels of PFAS chemicals, most notably from two groundwater monitoring wells to the southeast of Cedar Lake but higher than the surface water levels. This could be an indicator of surface runoff and / or groundwater discharge from Cedar Lake that has accumulated over time and not part of the yearly water gains and losses for Cedar Lake.

CHAPTER 6. FUTURE RESEARCH

Future Research

The purpose of this project was to investigate the Study Area to determine a potential source of the detected PFAS chemicals found in the surface water and surface water foam at Cedar Lake. Future research surrounding Cedar Lake could incorporate more surface water sampling results from around the state of Michigan for a better analysis. This project only used 10 of the 2,047 surface water samples in the state sampled for PFAS chemicals and using more data and samples could reinforce that PFAS is a widespread contaminant in the state of Michigan's surface water ecosystem and that the background levels of PFAS detected at Cedar Lake are found all over the state.

Additional avenues of research would focus on wildlife studies that have been conducted in the area. If fish studies exist for Cedar Lake relating to PFAS chemicals, a comparison could be made to other surface water bodies including the Au Sable River and Van Etten Lake, known areas for do not eat fish advisories. Further, health risks through the drinking water pathway should be conducted for the 700 properties surrounding Cedar Lake as well as a majority of the residents utilize potable water wells for their drinking water.

REFERENCES

3M. 2000. Biodegradation study of PFOS. US Environmental Protection Agency Administrative Record Number AR226-0057.

A. Armbruster, personal communication, September 10, 2021

AECOM. (2020, July 23). *Oscoda Area PFAS Groundwater Investigation Data Summary Report.* Retrieved September 10, 2021 from personal communication

AECOM. (2021, April). PFAS Nomenclature GSU Monitoring Well Sampling Analytical Results, April 2021, Iosco County, Michigan 60612721. Retrieved September 10, 2021 from personal communication

CHEMGUARD. (n.d.). *Aqueous Film-Forming Concentrates (AFFF).* Retrieved November 27, 2021, from https://www.chemguard.com/fire-suppression/catalog/foam-concentrates/aqueous-film-forming-foam-afff/

Cwalinski, T.A. (n.d-a). *Cedar Lake Alcona and Iosco counties Lake Huron watershed, last surveyed 2011.* Michigan Dept. of Natural Resources Status of the Fishery Resource Report. Retrieved October 27, 2021 from https://www.michigan.gov/documents/dnr/CedarLake-Alc-Ios-Co_696269_7.pdf

Cwalinski, T.A. (n.d-b). *Van Etten Lake Iosco County, T24N, R09E, many sections Au Sable/Pine River watersheds, last surveyed 2018.* Michigan Dept. of Natural Resources Status of the Fishery Resource Report. Retrieved February 11, 2022 from https://www.michigan.gov/documents/dnr/VanEttenLake_SFR_2020-284_687776_7.pdf

Eberly, C. (2018, June). *Wastewater and Fire Fighting Foam.* ParkUSA. https://parkusa.com/index.php/tech-art/white-paper/af3-whitepaper

EGLE MPART. (n.d.). *PFAS Geographic Information System*. Retrieved January 11, 2022, from https://egle.maps.arcgis.com/apps/webappviewer/index.html?id=bdec7880220d4ccf943aea13eba102db

Frisbee, S. J., Brooks, A. P., Jr, Maher, A., Flensborg, P., Arnold, S., Fletcher, T., Steenland, K., Shankar, A., Knox, S. S., Pollard, C., Halverson, J. A., Vieira, V. M., Jin, C., Leyden, K. M., & Ducatman, A. M. (2009). The C8 health project: design, methods, and participants. Environmental health perspectives, 117(12), 1873–1882. https://doi.org/10.1289/ehp.0800379

Interstate Technology and Regulatory Council. (August 2020). *Fate and Transport of Per- and Polyfluoroalkyl Substances (PFAS).* https://pfas-1.itrcweb.org/wp-content/uploads/2020/10/f_and_t_508_2020Aug.pdf

Kieser & Associates, LLC. (2011, May). *Cedar Lake Watershed Management Plan. http://kieser-associates.com/uploaded/final_cedar_lake_wmp_9_15_11.pdf*

LeBlanc, B., & Burke, M.N. (2020, July 23). New PFAS rules set to take effect Aug. 3, among nation's strictest. *The Detroit News.* https://www.detroitnews.com/story/news/local/michigan/2020/07/23/new-pfas-rules-take-effect-aug-3-standards-some-strictest-nation/5493618002/

Lewis, R. C., Johns, L. E., & Meeker, J. D. (2015). Serum Biomarkers of Exposure to Perfluoroalkyl Substances in Relation to Serum Testosterone and Measures of Thyroid Function among Adults and Adolescents from NHANES 2011-2012. *International journal of environmental research and public health*, 12(6), 6098–6114. https://doi.org/10.3390/ijerph120606098

Michigan Department of Environment, Great Lakes, and Energy. (n.d.). *Water Chemistry.* Retrieved March 6, 2022, from https://www.michigan.gov/egle/0,9429,7-135-3313_3681_3686_3728-32361--,00.html

Michigan Department of Environment, Great Lakes, and Energy. (2018, October 17). *EGLE PFAS Sampling Quick Reference Field Guide.* https://www.michigan.gov/documents/pfasresponse/PFAS_Sampling_Quick_Reference_Field_Guide_662170_7.pdf

Michigan Department of Environment, Great Lakes, and Energy. (2019a, July). *Surface Water Foam PFAS Sampling.* https://www.michigan.gov/documents/pfasresponse/Surface_Water_Foam_PFAS_Sampling_Guidance_+_Quick_Reference_Field_Guide_662168_7.pdf

Michigan Department of Environment, Great Lakes, and Energy. (2019b, October 11). *Michigan moves forward on drinking water standards for PFAS.* https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-509831--,00.html

Michigan Department of Environment, Great Lakes, and Energy. (2020a, July 21). *Oscoda Area Conceptual Site Model.*

https://www.michigan.gov/documents/pfasresponse/Oscoda_Area_Conceptual_Site_Model_July_21_2020_Presentation_697071_7.pdf

Michigan Department of Environment, Great Lakes, and Energy. (2020b, July 22). *Michigan adopts strict PFAS in drinking water standards.* https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-534663--y_2020,00.html

Michigan Department of Environment, Great Lakes, and Energy. (2020c, December 21). *EGLE updates PFAS cleanup standards, adding five new compounds.* https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-548012--y_2020,00.html

Michigan Department of Environment, Great Lakes, and Energy. (2021, January 19). *Oscoda Area and Former Wurtsmith Air Force Base PFAS Update Meeting.* https://www.michigan.gov/documents/pfasresponse/Oscoda_Area_and_Former_Wurtsmith_Air_Force_Base_PFAS_Update_Meeting_Presentation_January_19_2021_713535_7.pdf

Michigan Department of Environment, Great Lakes, and Energy. (2022, January). *Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) Minimum Laboratory Analyte List.* https://www.michigan.gov/documents/pfasresponse/EGLE_Minimum_Laboratory_Analyte_List_for_PFAS_667668_7.pdf

Michigan Department of Environmental Quality. (2018a, January 9). *State Takes Action to Strengthen Environmental Criteria in Response to PFAS Contamination.*

https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-470182--y_2018,00.html

Michigan Department of Environmental Quality. (2018b, October). *Groundwater PFAS Sampling Guidance.* *https://www.michigan.gov/documents/pfasresponse/Groundwater_PFAS_Sampling_Guidance_637871_7.pdf*

Michigan Department of Environmental Quality. (2018c, October 16). *General PFAS Sampling Guidance.* *h*ttps://www.michigan.gov/documents/pfasresponse/General_PFAS_Sampling_Guidance_634597_7.pdf

Michigan Department of Environmental Quality. (2018d, November). *Surface Water PFAS Sampling Guidance.* *https://www.michigan.gov/documents/pfasresponse/Surface_Water_PFAS_Sampling_Guidance_639408_7.pdf*

Michigan Department of Environmental Quality. (2019, February 25). *Michigan completes first statewide study of PFAS in water supply.* https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-490378--,00.html

Michigan PFAS Action Response Team. (n.d.-a). *Oscoda Area Historical Timeline*. Retrieved October 15, 2021, from https://www.michigan.gov/pfasresponse/0,9038,7-365-86511_82704_97100_97106---,00.html

Michigan PFAS Action Response Team. (n.d.-b). *PFAS Sampling in Lakes and Streams.* Retrieved March 6, 2022, from https://www.michigan.gov/pfasresponse/0,9038,7-365-88059_91300---,00.html

Michigan PFAS Action Response Team. (n.d.-c). Surface Water and Foam Results. Retrieved October 29, 2021, from https://www.michigan.gov/pfasresponse/0,9038,7-365-88059_91295_104144-545645--,00.html

Michigan PFAS Action Response Team. (n.d.-d). *Van Etten Lake.* Retrieved January 21, 2022, from https://www.michigan.gov/pfasresponse/0,9038,7-365-86511_82704_83952-512946--,00.html

Michigan PFAS Action Response Team. (2018, May 18). *Michigan embarks on statewide study of PFAS in water supplies.* https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-470190--y_2018,00.html

Michigan PFAS Action Response Team. (2019, April 4). *MPART Meets to Take Action on Developing PFAS MCL.* https://www.michigan.gov/pfasresponse/0,9038,7-365-86513_96296-495065--,00.html

Michigan PFAS Action Response Team. (2021a, August 30, 2021). *Former Wurtsmith Air Force Base, Iosco County. https://www.michigan.gov/pfasresponse/0,9038,7-365-86511_82704_83952---,00.html*

Michigan PFAS Action Response Team. (2021b, October 21). *Oscoda Area, Oscoda, Iosco County.* https://www.michigan.gov/pfasresponse/0,9038,7-365-86511_82704_97100---,00.html

Post, G. B., Cohn, P. D., & Cooper, K. R. (2012). Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: a critical review of recent literature. Environmental research, 116, 93–117. https://doi.org/10.1016/j.envres.2012.03.007

Renner, R. (2001). Growing Concern Over Perfluorinated Chemicals. *Environmental Science & Technology,* 35, (7), 154A-160A. https://doi.org/10.1021/es012317k

Rouse, K. (2018, January 3). Cedar Lake levels, special assessment district discussed. *Oscoda Press.* https://www.iosconews.com/oscoda_press/news/article_d295178e-f0ae-11e7-ae84-73385fc6d385.html

Roush, D. (2017, January). Michigan Surface Water Monitoring Strategy Update 2017. *Michigan Department of Environmental Quality Water Resources Division. https://www.michigan.gov/documents/deq/wrd-swas-strategy-2017_556101_7.pdf*

State of Michigan. (2017, November 13). Gov. *Rick Snyder creates action team to enhance coordination in statewide response to nationally emerging contaminant.* https://www.michigan.gov/formergovernors/0,4584,7-212-96477_90815_57657-452191--,00.html

Tanker Plane Crashes At Wurtsmith Air Force Base; Six Killed. (1988, October 11). *Associated Press News.* https://apnews.com/article/b9faccb954a02e8fc0f5805ea1c60512

The WAFB Historical Site. (n.d.). *A brief history of Wurtsmith Air Force Base.* Retrieved October 15, 2021, from https://wafb.net/Main-Gate/WAFB-History

R. Vaughn, personal communication, October 17, 2021

Wang, Z., DeWitt, J.C., Higgins, C.P., & Cousins, I.T. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)?. *Environmental Science & Technology,* 51(5), 2508-2518. https://doi.org/10.1021/acs.est.6b04806