Addendum for

Per- and Polyfluoroalkyl Substances (PFAS) in Michigan

Current State of Knowledge and

Recommendations for Future Actions

<u>August 2017</u>

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Note this document provides information up to August 2017 only

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Introduction

PFAS Workgroup Consensus Statement and Department-Wide Recommendations

The Toxics Steering Group (TSG) PFAS Workgroup was originally tasked by the Michigan Department of Environmental Quality (MDEQ) executive management to provide departmental recommendations towards establishing an environmental monitoring plan for PFAS in Michigan following the contamination detected at the former Wurtsmith Air Force Base (WAFB). The original White Paper titled, *Perfluorinated Compounds in Michigan - Current State of Knowledge and Recommendations for Future Actions* (hereinafter as the "White Paper") was completed September 1, 2011, by the PFAS Workgroup. Note: the present document serves strictly as an addendum to the original 2011 White Paper and provides updates to information first posed in the White Paper through August 2017.

As described in the White Paper, PFAS have been detected in fish and wildlife as well as in humans throughout the United States and around the world. The widespread detection of PFAS in the environment and humans continues to be documented and presented in published research papers (Ahrens et al., 2011; Ahrens 2011; Cai et al., 2011; Gebbink et al., 2011; Houde et al., 2011; Reiner et al., 2011; Thompson et al., 2011; Asher et al., 2012; Benskin et al., 2012a and 2012b; Gewurtz et al., 2012; Guo et al., 2012; Lee et al., 2012; Myers et al., 2012; Yu et al., 2013; Aas et al., 2014; Gonzalez-Gaya et al., 2014; Stahl et al., 2014; Lescord et al., 2015; Wang et al., 2015 and 2016; De Silva et al., 2016; Lam et al., 2016; Munoz et al., 2017). Sampling in Michigan, to date, has shown that some residents and wildlife are being exposed to PFAS.

<u>August 2017 Addendum Consensus Statement</u>

The MDEQ has information to initiate regulatory and public health-protective actions; however, the department needs to increase its understanding of the toxicity of this group of chemicals and determine their sources in Michigan's environment. Investigations to identify potential PFAS sources and areas of contamination in Michigan along with monitoring (fish sampling, exposure assessments, effluent sampling, and evaluating other potential environmental releases) are critical to protect Michigan's human and environmental health.

<u>Workgroup Recommendations to MDEQ Management</u>

- Recognize that PFAS have emerged as ubiquitous human, wildlife, and environmental contaminants and take appropriate measures to assure adequate protection of Michigan residents and environmental resources from their adverse effects.
- Work towards the goal of identifying all sources of PFAS contributing to environmental contamination in Michigan.
- Continue to support all ongoing investigations of sites of known environmental PFAS contamination in Michigan.
- Initiate investigations into the source(s) of PFAS drinking water contamination in Michigan as identified from the third federal Unregulated Contaminant Monitoring Rule (UCMR 3) or any other drinking water quality monitoring programs.
- Continue to support the establishment of PFAS-based fish consumption advisories as well as identifying the underlying PFAS source(s) responsible for these advisories.
- Support the development of in-house MDEQ laboratory testing capabilities for PFAS in water and soil samples in order to improve access to and reduce costs associated with PFAS environmental media testing in Michigan.

- Initiate training of field staff on PFAS investigations in Michigan, including identification of known industrial sources of environmental contamination, appropriate environmental investigation practices for suspected PFAS contamination, and remediation best practices.
- Complete the promulgation of the draft Part 201 environmental remediation administrative rules inclusive of PFAS cleanup criteria.

New Key Information Presented within the 2017 Addendum

- In May 2016, the United States Environmental Protection Agency (USEPA) established lifetime health advisory values for drinking water of 70 nanograms per liter (ng/L or parts per trillion) for both the individual and combined total of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA). The lifetime health advisory addresses short-term exposure (protecting against developmental effects) as well as long-term exposure (cancer effects) to these PFAS.
- In May 2017, the Minnesota Department of Health (MDH) issued updated values for PFOA (35 ppt) and PFOS (27 ppt) that are more restrictive than the current 2016 USEPA health advisory levels.
- PFAS have been detected in Type 1 (provides year-round service to at least 25 residents or at least 15 living units) public water supply and private residential wells in Oscoda (the known source is the contaminated groundwater migrating off-site from the WAFB).
- PFAS contamination has been identified at other Department of Defense (DOD) and non-DOD sites in Michigan.
- PFAS contamination has been identified in public drinking water systems in Plainfield Township (North of Grand Rapids) and Ann Arbor.
- Rule 57 human health and aquatic life surface water quality values have been developed for PFOS and PFOA. The human health and aquatic life values for PFOS were derived in 2014, whereas, the human health and aquatic life values for PFOA were derived in 2011 and 2010, respectively.
- PFAS have been detected in Michigan surface water bodies and in some species of fish inhabiting those waters.
- Fish consumption guidelines driven by PFAS contamination are reported in at least 13 Michigan water bodies, including a “do not eat” advisory for fish from several water bodies near the former WAFB in Oscoda.
- Other states have determined that PFAS in groundwater can result from atmospheric deposition.
- Results from the C8 Health Project study (further information can be found at http://www.c8sciencepanel.org/index.html) investigating human exposures to PFOA released from DuPont’s West Virginia work plant established probable links between PFOA exposure and kidney cancer, high cholesterol, thyroid disease, ulcerative colitis, testicular cancer, and pregnancy-induced hypertension.

Background

PFAS are ubiquitous contaminants in the environment. The term PFAS is attributed to a very large class of chemicals composed of many different families that have different physical, chemical, and biological properties (Buck et al., 2011). Due to their unique chemical properties, PFAS production grew as these chemicals were incorporated into components of inks, varnishes, waxes, firefighting foams, metal plating and cleaning solutions, coating formulations, lubricants, water and oil repellents, paper, and textiles (Paul et al., 2009). Examples of industries that are using PFAS include automotive, aviation, aerospace and defense, biocides, cable and wiring, construction, electronics, energy, firefighting, food processing, household products, oil and mining production, metal plating, medical articles, paper and packaging, semiconductors, textiles, leather goods, and apparel (OECD, 2013).

A survey by the Swedish Chemicals Agency (KEMI) identified the existence of over 1,000 PFAS that are composed of short fragments of perfluorinated carbons, which are much less persistent than other PFAS. A total of 2,060 highly fluorinated PFAS were identified during a survey of the global market and as many as 4,000 PFAS were estimated to be in use. Many of these compounds do not have a Chemical Abstract Service number (KEMI, 2015). The use of PFAS in aqueous film-forming foam (AFFF) was found to be less than 5% (Prevedouros et al., 2006) or 1% (KEMI, 2015) of the total PFAS global market. While some PFAS have been phased out of production, other PFAS are still manufactured and used throughout the United States with little environmental regulation (Wang et al. 2017). Environmental exposure to these chemicals have been associated with adverse effects to humans and wildlife globally. Some PFAS may partially degrade in the environment and biota. However, the degradation will ultimately lead to other very stable end product PFAS that are usually highly persistent in the environment (Wang et al., 2017). As a result, these man-made chemicals will continue to be detected for decades.

The White Paper provided a background on PFAS chemicals and a summary of the state of knowledge of Michigan's PFAS environmental contamination in 2011, and made numerous recommendations to further our understanding of these pervasive and ubiquitous chemicals in Michigan's environment. Since 2011, the general descriptive names of these chemicals have been updated from PFCs (defined then as perfluorinated chemicals) to PFAS (per- and polyfluoroalkyl substances) because it is a more comprehensive terminology and is less confused with perfluorocarbons (also abbreviated as PFCs), which are greenhouse gases. This addendum will refer to per- and polyfluoroalkyl substances as PFAS.

This addendum's primary focus is to provide the MDEQ, Michigan Department of Health and Human Services (MDHHS), and the Michigan Department of Agriculture and Rural Development (MDARD) management with the latest science on the toxicity and sources of PFAS in the environment, an update on Michigan state agency activities that have occurred, new environmental data collected since completion of the 2011 White Paper, and recommendations for future PFAS-related activities.

2011 White Paper PFAS Workgroup Recommendations:

In 2011, the TSG PFAS Workgroup recommended that the MDEQ take the actions listed below. Recommendations are listed in order of importance, to be undertaken in a tiered approach as funding allowed. Note that the environmental samples mentioned should be analyzed for PFOS and PFOA at a minimum, with perfluorobutanoic acid (PFBA) and perfluorohexane sulfonate (PFHxS) analyses performed where possible and appropriate.

Department-Wide

- Support the development of in-house PFAS analytical capabilities at the MDEQ Environmental Laboratory.
- Send at least one staff person to the annual USEPA PFAS conference.
- Establish external collaboration with the "research corridor" of Michigan State University, the University of Michigan, and Wayne State University.

Water

Objective 1: Determine the scope and extent of PFAS contamination in surface water and fish in the area of the WAFB. It is possible that the WAFB is the worst-case scenario in the state, thus, results from the site could inform other decisions regarding PFAS in the state.

Tasks:

- Obtain paired fish tissue and surface water samples from the Au Sable River and Van Etten Lake.
- Obtain groundwater samples from existing on-site monitoring wells.

Objective 2: Obtain data to test the hypothesis that the conditions at the WAFB represent the most severe PFC contamination in the state.

Tasks:

- Collect groundwater, surface water, fish, mink, bald eagle, and herring gull samples from:
  - An area likely to be minimally impacted by PFAS (e.g., Keweenaw, Luce, and Mackinac Counties).
  - An area likely to be significantly impacted by PFAS (e.g., certain locations in Kent and Ottawa Counties and Southeast Michigan Counties near known or suspected environmental releases).
  - The Kalamazoo River watershed, as discussed by Kannan et al. (2005).

If the data collected to satisfy Objective 2 reveal “hot spots” of elevated ambient levels of PFAS, it may be necessary to identify specific sources of PFAS entry into Michigan’s environment and develop a long-term monitoring plan. Potential sources are discussed in the text of this report.

Air

- Conduct outdoor air sampling in identified urban centers to determine current ambient air levels.
- Identify industrial manufacturing emission sources and assess feasibility of stack testing as part of the permitting program under the 1990 Clean Air Act Amendments.
- Assess overall impact to ambient outdoor air from elevated indoor air concentrations when data are available by encouraging the scientific community to quantitate PFAS adsorbtion/desorbtion to dust and exchange rates of indoor PFAS to outdoor PFAS. Speciation and degradation information would also help to determine this as a source/reservoir for environmental concentrations.

ANALYTICAL UPDATES

MDEQ Analytical Laboratory Capabilities

To date, the MDEQ Drinking Water Laboratory does not analyze water samples for PFAS. Similarly, the MDEQ Environmental Laboratory does not analyze soil or sediment samples for PFAS.

<u>MDHHS Analytical Laboratory Capabilities</u>

In 2012, the MDHHS Analytical Chemistry Laboratory developed and validated an analytical method for analyzing for PFAS in a variety of tissue samples. Examples of tissues include fish, deer, and waterfowl.

WATER UPDATES

<u>USEPA Drinking Water Health Advisory Levels for PFOA and PFOS</u>

In May 2016, the USEPA, Office of Water, published drinking water health advisory levels for PFOA and PFOS. The new health advisory levels are 70 ng/L (parts per trillion) for PFOA and PFOS, either individually or when found in combination in drinking water. These new advisory levels replace the USEPA's January 2009 provisional health advisory levels for PFOA (400 ng/L) and PFOS (200 ng/L) and reflect the evolution of the science regarding exposure and toxicity of these chemicals. Drinking water health advisories are non-regulatory and non-enforceable; rather, they provide drinking water system operators with technical information on the health risks of chemicals, so they can take the appropriate actions to protect and inform their customers in accordance with the Safe Drinking Water Act.

The USEPA's health advisories are based on the best available peer-reviewed studies on the adverse health effects caused by exposure to PFOA and PFOS in laboratory animals and are also informed by epidemiological studies of human populations that have been exposed to these chemicals. These studies indicate that exposure to PFOA and PFOS in exceedance of certain levels may result in adverse health effects, including developmental effects to the fetus during pregnancy exposure or to breastfed infants, cancer, liver effects, immune effects, thyroid effects, and other effects. The USEPA's health advisory levels offer a margin of protection against adverse health effects to the most sensitive populations; i.e., fetuses and breastfed infants.

The drinking water health advisory levels for PFOA and PFOS only apply to exposure scenarios involving drinking water, specifically drinking water consumption and household use of drinking water during food preparation. The health advisory levels are calculated based on the drinking water intake rate of lactating women, who drink more water than other people and can pass these chemicals along to nursing infants through breastmilk. The health advisory levels do not address exposure resulting from either skin contact or inhalation of PFOA or PFOS.

The USEPA is currently evaluating PFOA and PFOS as drinking water contaminants in accordance with the process required by the Safe Drinking Water Act (USEPA, 2016a). PFOA and PFOS were included by the USEPA among the list of contaminants that water systems are required to monitor under the UCMR 3 in 2012 (see the USEPA UCMR 3 site for further Michigan-specific PFOA and PFOS monitoring results). In accordance with the Safe Drinking Water Act, the USEPA will consider the occurrence data from the UCMR 3, along with the peer-reviewed health effects assessments supporting the PFOA and PFOS health advisories, to make a regulatory determination on whether to initiate the process to develop a national primary drinking water regulation for these chemicals.

Minnesota Department of Health (MDH) Issues More Restrictive PFC Values than the USEPA

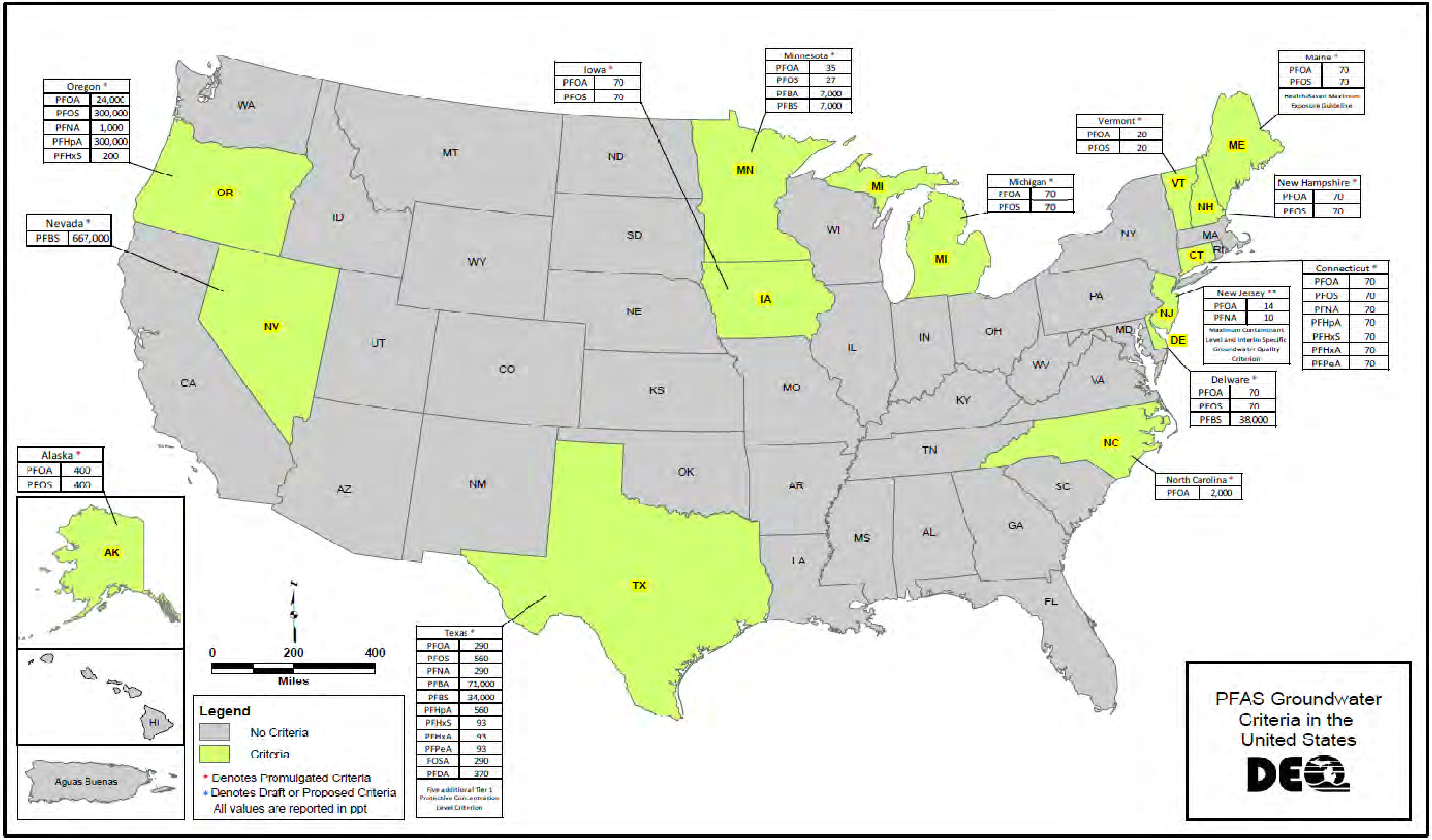
In May 2017, the MDH issued updated values for PFOA and PFOS that are more restrictive than the current 2016 USEPA lifetime health advisory levels. The MDH's updated values are 35 ng/L (parts per trillion) for PFOA and 27 ng/L for PFOS. The updated MDH values apply to both short-term exposure during pregnancy and breastfeeding and lifetime exposure and represent a Minnesota state-level analysis for the mother-to-fetus or nursing infant exposure route. These values are the health recommendations to local public water supply facilities and private well owners with PFAS in groundwater. The MDH also recommended using the PFOS value of 27 ng/L as a surrogate for PFHxS until more conclusive toxicological data become available. The Minnesota Pollution Control Agency and other local Minnesota agencies are also using the MDH updated values as action levels to ensure public health and to hold the responsible parties accountable for contaminated site cleanup. Note the MDH still uses the term "perfluorochemicals" and the abbreviation "PFCs" in its reference materials.

In addition to the federal drinking water health advisories for PFOS and PFOA and recent MDH values, other state regulatory agencies have released drinking water values for these chemicals, as presented in Table 1. PFAS groundwater criteria concentrations are presented in Figure 1.

Table 1. Federal and State Agency PFAS Drinking Water Criteria Levels.

	Agency	**Drinking Water Criteria**	**Year**	**PFAS (ng/L)**
FEDERAL				
USEPA	Office of Water	Drinking Water Lifetime Health Advisory	2016	PFOA - 70 PFOS - 70
STATE				
DE	Department of Natural Resources and Environmental Control	Groundwater Screening Level (ingestion)	2016	PFOA - 70 PFOS - 70
ME	Department of Health and Humans Services	Maximum Exposure Guideline	2014	PFOA - 100
MI	Department of Environmental Quality	Proposed Drinking Water Criterion	2017	PFOA - 70 PFOS - 70
MN	Department of Health	Health-based Value	2017	PFOA - 35 PFOS - 27
NC	Division of Water Quality	Interim Max Allowable Concentration	2006	PFOA - 2,000
NJ	Department of Environmental Protection	Health-based Drinking Water Value	2017	PFOA - 14
TX	Commission of Environmental Quality	Groundwater Protective Concentration Level	2016	PFOA - 290 PFOS - 560
VT	Department of Health	Drinking Water Health Advisory	2016	PFOA - 20 PFOS - 20

Figure 1. Per- and polyfluoroalkyl substances (PFAS) groundwater criteria in the United States as of August 2017.



PFAS Drinking Water Contamination at the WAFB[1]

Type 1 and private drinking water wells near the former WAFB in Oscoda have been found to be contaminated with PFAS coming from the WAFB. One home was found to have PFAS concentrations much higher (19,733 ng/L total PFAS and 3,396 ng/L PFOS+PFOA) than the USEPA lifetime health advisory level (USEPA, 2016a and 2016b). The U.S. Air Force has connected that home to city water. A second home, not downgradient from the WAFB but in an area where PFAS-containing fire-fighting foam was used to extinguish a forest fire, had 78 ng/L PFOS+PFOA in its well; that home has been provided a reverse-osmosis filter[1]. The MDHHS and the District Health Department No. 2 have issued drinking water advisories in areas downgradient from the WAFB and are providing reverse-osmosis filters or water coolers to homes in those areas. Buildings and housing at the former WAFB are already connected to city water, which is obtained from Lake Huron. The MDEQ is continuing its investigations at the WAFB, sampling drinking water and monitoring groundwater. The U.S. Air Force is beginning a Remedial Investigation in 2017. Plumes from the former WAFB have impacted approximately 10 square miles of groundwater. Three other PFAS plumes have been detected away from the base during investigation of Base contamination.

PFAS in Groundwater Venting to Surface Water at the WAFB

The MDEQ issued two Substantive Requirements Documents that contain discharge limits/monitoring requirements for PFAS at the WAFB. The Substantive Requirements Documents include treatment technology-based limits for PFAS. Since the start of operations at the primary groundwater treatment facility, the WAFB treatment operator has demonstrated compliance with the discharge limits or effluent limitations in the Substantive Requirements Documents. A detailed description of the history of PFAS contamination at the WAFB can be found in Appendix A.

PFAS Detections in Groundwater at Other Michigan DOD Sites

The U.S. Air Force is in the process of conducting site inspections at other Michigan DOD installations (including the former K.I. Sawyer Air Force Base and the Alpena, Selfridge, and Battle Creek Air National Guard bases) and has identified PFAS contamination of groundwater at the K.I. Sawyer Air Force Base. The MDEQ is awaiting completion of the investigations at the other sites. It may be reasonable to expect that PFAS contamination will be detected at these other bases as well due to the historical use of AFFF. In the spring of 2017, PFAS contamination of groundwater from both the Camp Grayling Airfield and at Camp Grayling itself have been shown to have PFAS plumes[2]. The plumes at K.I. Sawyer, Camp Grayling, and Camp Grayling Airfield contain PFAS above the USEPA health advisory levels. The extent of the plumes has not been characterized at these bases as of May 2017 and who or what receptors might be impacted is still unknown. Further investigations are being conducted at those bases.

PFAS Detections in Michigan Public Drinking Water Systems

The MDEQ, Remediation and Redevelopment Division, Superfund Section, is investigating the State Disposal National Priorities List site in Grand Rapids as a potential source of PFAS contamination to two of the drinking water wells for Plainfield Township. The wells are down

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[1] For further information refer to www.mi.gov/wurtsmith

[2] For further information refer to www.mi.gov/campgrayling

gradient from the State Disposal National Priorities List site, a former landfill. The contamination of the community water system was discovered in the UCMR 3. Follow-up sampling conducted by Plainfield Township showed two wells exceeding the USEPA 2016 70 ppt lifetime health advisory level; these wells have been taken off-line by the township.

The UCMR 3 also identified a PFOS detections in a community water system in Ann Arbor. The potential source of the PFAS in the Ann Arbor water system (a mixture of groundwater and surface water) has not yet been identified.

MDEQ Rule 57 Water Quality Values for Human Health and Aquatic Life

Michigan's Part 4 Water Quality Values require that all designated uses of the receiving water be protected. Designated uses include: agriculture, navigation, industrial water supply, public water supply at the point of water intake, warmwater or coldwater fish, other indigenous aquatic life and wildlife, fish consumption, partial body contact recreation, and total body contact recreation from May 1 to October 31.

Table 2 provides the human health (Human Noncancer Values (HNVs)) and aquatic life values (Final Chronic Value (FCV), Final Acute Value (FAV), and Aquatic Maximum Value (AMV)) derived for PFOS and PFOA using the methodology provided in Rule 57 (R 323.1057) of the Part 4 Rules, Water Quality Standards, promulgated under Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended.

Table 2. Rule 57 Nondrinking and Drinking Water HNVs for PFOS and PFOA.

PFAS	HNV (nondrinking)	HNV (drinking)	FCV	FAV	AMV
PFOS (ng/L)	12	11	140,000	1,600,000	780,000
PFOA (ng/L)	12,000	420	880,000	15,000,000	7,700,000

As can be seen from Table 2, PFOS and PFOA are more of a human health concern than an aquatic life concern. In addition, the PFOS HNVs are much lower than the PFOA HNVs because the Bioaccumulation Factors (BAFs) used to derive the HNVs for PFOS are much higher than the BAFs used to derive the values for PFOA, and the surface water criteria for human health protection account for recreational fish consumption as well as drinking water consumption. Specifically, the Trophic Levels 3 and 4 fish BAFs used to derive the HNVs for PFOS are 2,329 and 5,047, respectively, whereas, both BAFs are 4 for PFOA.

Surface Water and Fish Tissue Sampling

The MDHHS was awarded a Great Lakes Restoration Initiative (GLRI) grant to assess the levels of PFAS in Michigan surface waters and fish. Specifically, the project was designed to reassess some of the surface waters that were initially sampled in 2001, determine the extent of PFAS contamination throughout the state, and attempt to correlate surface water concentrations of PFAS with those found in fish tissue. Table 3 provides the summarized surface water sampling results for PFOS and PFOA, two of the more studied PFAS (Michigan Department of Community Health, 2015).

Table 3. Geometric Mean Concentration (ng/L) of PFOS and PFOA in Michigan Surface Water Samples.

Surface Water Location	Collection Date	PFOS (ng/L)	PFOA (ng/L)
Au Sable River	2013	3.23	1.86
Clark's Marsh	2011	5,099	1,309
Flint River – M13	2013	41	4.19
Flint River – Montrose	2013	50.70	2.29
Kalamazoo River – New Richmond	2013	ND*	6.82
Kalamazoo River – Lake Allegan	2013	6.73	3.92
Kalamazoo River – upstream Lake Allegan	2013	7.62	4.26
Muskegon River	2013	ND	1.20
Saginaw River	2013	9.53	3.34
St. Joseph River	2013	1.70	1.45
Tahquamenon River	2013	ND	ND
Thunder Bay River	2013	ND	ND
Van Etten Lake	2013	1.40	1.34

*ND = not detected.

Surface water samples collected from Clark's Marsh, Flint River-M13, and Flint River-Montrose exceeded the human health surface water values for PFOS. No surface water samples exceeded the human health surface water values for PFOA and no surface water samples exceeded the aquatic life values for either PFOS or PFOA.

Table 4 provides the fish tissue results for PFOS for all of the samples collected as part of the GLRI grant (Bush et al., 2015) plus additional samples analyzed for other purposes. At least ten fish were analyzed per species except for some of the species collected from the Au Sable, Tahquamenon, and St. Marys Rivers. The results of the PFOA analyses are not provided in the table because this particular PFAS is not expected to accumulate in fish tissue.

Table 4. Mean concentrations (µg/kg; ppb) of PFOS measured in fish fillets collected from Michigan waters between 2011 and 2016.

Sample Site	Arithmetic Mean PFOS in Fish Fillets (µg/kg; ppb)										
	All Species Combined	Carp	Largemouth / Smallmouth Bass	Black Crappie	Bluegill / Pumpkinseed	Northern Pike	Rainbow Trout	Rock Bass	Walleye	White Sucker	Yellow Perch
Allen Lake	1.6	--	3.6	--	1.3	--	--	--	--	--	--
Au Sable River - Mill Street	61.3	7.8	80.1	--	165.9	--	--	20.1	20.6	34.0	11.3
Clark's Marsh	5100	--	--	--	5100	--	--	--	--	--	--
Dead River/Hoist Basin	0.8	--	--	--	--	--	--	--	0.8	--	--
Flint River-Montrose	92.8	51.6	132.1	--	--	--	--	94.8	--	--	--
Kalamazoo River-New Richmond	61.6	28.1	111.2	--	45.4	--	--	--	--	--	--
Kalamazoo-Lake Allegan	52.2	36.4	82.5	--	37.5	--	--	--	--	--	--
Lake Erie/Monroe	17.7	--	--	--	--	--	--	--	17.7	--	--
Lake Huron/Oscoda	14.0	--	--	--	--	--	14.0	--	--	--	--
Lake Michigan/Little Bay De Noc	9.6	--	--	--	--	--	--	--	9.6	--	--
Lake St. Helen/Roscommon County	2.0	--	--	--	--	--	--	--	2.0	--	--
Muskegon River-Hersey	1.8	1.0	1.3	--	3.1	--	--	--	--	--	--
Otter Lake/Houghton County	4.2	--	--	--	--	--	--	--	4.2	--	--
Rogue River/Rockford Impoundment	25.7	--	32.2	--	--	--	--	--	--	19.2	--
Saginaw River-Essexville	22.8	13.8	31	--	23.4	--	--	--	--	--	--
St. Joseph River-Riverview Park	31.1	21.0	21.7	--	--	--	--	50.7	--	--	--
St. Marys River/Munuscong Bay	5.3	--	--	--	--	--	--	--	5.3	--	--
Tahquamenon River-mouth	1.8	0.6	2.2	--	--	--	--	2.3	--	--	--
Thunder Bay River-Lake Besser	1.7	0.4	2.7	--	--	--	--	1.7	--	--	--
Van Etten Lake	10.6	--	--	--	8.4	--	--	10.6	23.7	12.6	--
Versluis Lake	28.6	--	47.7	67.2	10.5	27.7	--	4.9	--	--	--

Fish Consumption Advisories

Table 5 presents fish consumption advisories for PFOS for the fish species collected from the waterbodies identified in Table 3. A total of 46 fish tissue sample sets were analyzed. PFOS was the primary cause of the fish consumption advisory in 13 (28.3%) of the sample sets, the secondary cause in 18 (39.1%) of the sample sets, and did not result in an advisory in 15 (32.6%) of the sample sets. A primary cause is the reason for a fish consumption guideline while a secondary cause is not the guideline driver, but still present in the fish.

Table 5. Michigan Water Bodies, Fish Species Analyzed for PFOS, and Status of Fish Consumption Advisories.

Water Body	Location	Species	Status*
Tahquamenon River	d/s Lower Falls	Carp	
		Rock Bass	
		Smallmouth Bass	
		Yellow Perch	
Otter Lake	Houghton County	Walleye	
Dead River	Hoist Basin/Marquette Co	Walleye	
Thunder Bay River	d/s Fletcher Dam	Carp	
		Largemouth Bass	
		Rock Bass	
Au Sable River	d/s Foote Dam	Bluegill/Pumpkinseed	X
		Rock Bass	X
		Smallmouth Bass	X
		White Sucker	X
		Yellow Perch	X
Allen Lake	near Oscoda	Sunfish	
Clark's Marsh	near Oscoda	Sunfish	X
Van Etten Lake	near Oscoda	Pumpkinseed	+
		Rock Bass	+
		Walleye	+
		White Sucker	+
Lake St. Helen		Walleye	
Rogue River	Rockford Dam Pond	Largemouth Bass	X
		White Sucker	X
Kalamazoo River	Morrow to Allegan Lake Dam	Bluegill/Sunfish	+
		Carp	+
		Largemouth Bass	+
	d/s Allegan Lake	Bluegill	+
		Carp	+
		Smallmouth Bass	+
Muskegon River	u/s Rogers Dam	Bluegill	
		Carp	
		Smallmouth Bass	
St. Joseph River	d/s Berrien Springs	Carp	+
		Rock Bass	X
		Smallmouth Bass	+
Saginaw River	Essexville	Pumpkinseed	X
		Smallmouth Bass	X
Flint River	d/s Flint	Carp	+
		Rock Bass	X
		Smallmouth Bass	X
St. Marys River		Walleye	
Lake Michigan		Walleye	+
Lake Huron		Carp	+
		Rainbow Trout	+
		Walleye	+
Lake Erie		Walleye	+
	Number of Sample Sets Analyzed		46
	Primary Cause		13
	as % of Sets analyzed		28.3
	Secondary Cause		18
	as % of Sets analyzed		39.1
	Not a Cause		15

d/s = downstream, u/s = upstream

*X = primary cause of advisory, + = secondary cause of advisory, blank = does not cause advisory

In 2014, the MDHHS finalized the report titled, *Technical Support Document for Assessment of Perfluorinated Chemicals and Selection of a Perfluorooctane Sulfonate (PFOS) Reference Dose as the basis for Michigan Fish Consumption Screening Values (FCSVs).* This document preceded the USEPA's release of the lifetime health advisories for drinking water and their supporting documentation. The MDHHS's and USEPA's reference doses were similar.

AIR UPDATES

Source Identification

The New Hampshire Department of Environmental Services (NHDES) has been investigating sources that are contributing to contaminated drinking water in their state. https://www4des.state.nh.us/nh-pfas-investigation/. NHDES determined that PFAS chemicals can be emitted from stacks at facilities that manufacture oil/water/stain-resistant fabrics. A coating containing PFAS is applied to the glass fabric which then goes through a heated drying phase. NHDES's research has shown the drying phase is the primary source of PFAS air emissions. The emissions occur when the fabric is heated and the PFAS is emitted as particulate matter. Also, some PFAS chemicals are not listed on safety data sheets since they may not be used as raw material also specific names may not be listed because the names are considered confidential business information. Further, some PFAS can break down and create PFOA during manufacturing processes; therefore, PFOA would not be listed on Safety Data Sheet, which makes it further challenging for identifying PFOA emission sources (personal communication from Mr. Gary Milbury, Permitting and Environmental Health Bureau Administrator, NHDES, Air Resources Division, to Joy Taylor Morgan; January 4, 2017). For example, ammonium perfluorooctanoate (APFO), if used as a raw material, can release PFOA. The NHDES regulates APFO as a state air toxic via the inhalation exposure route.

To identify potential sources in Michigan, the MDEQ, Air Quality Division did a search of their air emission inventory system using the same North American Industrial Classification System (NAICS) and the Source Classification Codes (SCCs) as those facilities found to emit PFAS in New Hampshire. The NAICS codes identify a company's primary business, such as fabric coating, while the SCCs are used to categorize sources of air emissions. Based upon the 2015 data, four fabric coating facilities with similar NAICS codes and 20 facilities with similar SCCs were identified. Further investigation is needed to determine if these facilities use PFAS. No air emission source has been verified in the state.

Stack Testing

Stack test data is very limited. The state of New Jersey conducted limited stack testing at a PFAS manufacturer and detected PFOA being emitted, while the NHDES conducted stack testing utilizing a modified USEPA Method 5 sampling train for one facility that manufactures stain-resistant fabric and found PFOA emitted into the ambient air at 1.5 ounces per year. The NHDES is evaluating what amount emitted could result in elevated groundwater contamination as the PFOA quickly migrates through the soil. The New York State Department of Environmental Conservation required one of their facilities to test for 13 PFAS chemicals from their polytetrafluorethylene (Teflon) coating lines in December 2016. Because the source is controlled with a wet scrubber/packed bed fiber filter device, the emissions were all less than 4 grams per year for each PFAS chemical (Tom Gentile, New York State Department of Environmental Conservation, personal communication with Joy Taylor Morgan; June 1, 2017). To MDEQ's knowledge, no stack sampling for PFAS has been conducted in Michigan.

Ambient Air Monitoring

There is no USEPA protocol developed for air monitoring of PFAS. While methods exist, few states are currently conducting air monitoring. Since the 2011 White Paper, ambient air monitoring data for PFAS chemicals have been published for several areas in the world. This data suggests highly populated urban areas have been found to have the highest PFAS concentrations. To the MDEQ's knowledge, no ambient air monitoring for PFAS chemicals have been conducted in Michigan.

Deposition Modeling

Some states are conducting dispersion modeling to estimate the atmospheric deposition of PFAS. The states of New Hampshire and New York are currently addressing deposition of PFAS by conducting stack testing, atmospheric modeling and monitoring groundwater. Deposition modeling conducted by the NHDES, New Jersey Department of Environmental Protection, and the C8 Health Project study (discussed below) found that atmospheric deposition of PFAS can be the primary source contributing to contaminated groundwater. For NHDES, the emission information utilized included raw material usage, stack test data and information from EPA.

Focus of monitoring efforts

The NHDES recommends focusing investigation efforts where data indicates the potential presence of PFAS such as around facilities that make oil/water/stain-resistant materials. Because of what has been found in NH, the NHDES is considering developing legislation to address air deposition of these chemicals to soil and subsequent groundwater contamination since their current standards (for APFO) are based on ambient air inhalation exposure only.

Michigan's monitoring efforts have been focused on water and fish rather than air because of the greater chance for significant exposure to the public.

C8 STUDY DETERMINATIONS

From the 1950s until early 2000s there were releases of C8, also known as PFOA, by DuPont's West Virginia Washington Works Plant into the air and the Ohio River and, subsequently, into the area's drinking water supply. Air emissions and releases into the Ohio River have since been eliminated; however, a class action lawsuit was brought against DuPont. As a result of this lawsuit, an independent company was tasked with a yearlong survey focused on the affected surrounding community. This survey effort is called the C8 Health Project. The C8 Health Project was tasked to collect information and blood samples from the approximately 69,000 residents living in the Washington Works Plant area. Data gathered by the C8 Health Project, as part of the lawsuit settlement, was assessed by a science panel comprised of public health scientists. This panel was charged with determining any probable links between PFOA exposure and disease in the community.

The science panel defined a probable link in the DuPont settlement agreement to mean "that given the available scientific evidence, it is more likely than not that among class members a connection exists between PFOA exposure and a particular human disease." Probable links are summarized below by study release date beginning with the most recent October 2012 reports. Further detail for all probable link evaluations and studies used can be found on the C8 Science Panel Probable Link Evaluation web site. A summary of findings can be found in Table 6.

Table 6. Summaries, by date, of probable link study conclusions following long-term PFOA human exposure in West Virginia.

Study Date	Probable Link	No Probable Link
October 2012	high cholesterol	coronary artery disease; hypertension; chronic kidney disease; liver disease; osteoarthritis; Parkinson's disease
July 2012	ulcerative colitis; thyroid disease	autoimmune diseases; common infections; neurodevelopment disorder in children; asthma; chronic obstructive pulmonary disease; stroke
April 2012	testicular cancer; kidney cancer	thyroid cancer; melanoma; type II diabetes
December 2011	pregnancy-induced hypertension	Birth defects; miscarriage/stillbirth; preterm birth/low birth weight

STAFF CONFERENCE PARTICIPATION AND TRAINING

- National Environmental Health Association Annual Education Conference (July 11, 2017; MDHHS presentation)
- Highly Fluorinated Compounds – Social and Scientific Discovery (June 14-15, 2017; MDHHS presentations)
- Michigan Premier Public Health Conference (October 22, 2014; MDHHS presentation)
- Agency for Toxic Substance and Disease Registry (ATSDR) Region 5 Regional Meeting (October 21, 2015; MDHHS presentation)
- Visit to Michigan by 3M scientists Dr. Sue Chang and Dr. Geary Olsen, with presentations to the MDEQ Toxics Steering Group (December 16, 2015)
- Emerging Contaminants Summit (Denver, CO; March 1-2, 2016)

- Michigan Environmental Health Association Annual Education Conference (March 16, 2016; MDHHS presentation)
- PFAS Workgroup members attended several NEWMOA PFAS webinars over the last several years
- Joint Engineer Training Conference and Expo (May 20-23, 2014; MDEQ presentation)
- 251st American Chemical Society National Meeting and Exposition (March 13-17, 2016; MDEQ presentation)

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Appendix A - Case Study: The Former Wurtsmith Air Force Base (WAFB)

1. Introduction

The unique chemical properties of per- and polyfluoroalkyl substances (PFAS) resulted in many different industries using them in industrial processes and in the manufacture of commercial products. During the development of firefighting agents to replace protein foams, PFAS were identified to be ideal chemicals and have been used as a component of military-specific aqueous film forming foams (AFFF) for fighting class B fires (flammable liquids) since 1965 (Prevedouros et al., 2006). In 1969, the Department of Defense (DOD) published a new military-specification, MIL-F-24385, that identified requirements for diluting AFFF with either fresh or seawater for use as fire extinguishing solutions. Performance testing of AFFF from 1968 through 1972 showed superior performance of AFFF compared to earlier protein foams (Breen, 1973). Replacement of protein foams with AFFF did not occur at all the facilities at the same time. A preliminary assessment conducted at DOD facilities identified 1970 as the year when it is believed that any use and/or release of AFFF could have occurred at any DOD facility (Administrative Record [AR] 471539, 2016; Anderson, 2017). Once an AFFF was demonstrated to meet performance requirements, the product was listed on the DOD Qualified Products Listing. AFFF are now used by the U.S. Armed Forces, including all U.S. Navy ships and submarines, and North Atlantic Treaty Organization members. Additionally, AFFF have been used by many fire departments and all major U.S. airports.

PFAS were identified in groundwater samples collected at former DOD bases, such as WAFB, in the late 1990s (Moody, 2000). The DOD started to investigate the possible occurrence of PFAS through its Emerging Contaminants Program in 2009 at fire training areas and in 2014 for non-fire training areas. Recently, program-wide preliminary assessments and site inspections have been completed for a total of 1,775 discrete areas and are currently ongoing (Anderson, 2017).

2. The Former WAFB

2.1 Site History and Description

The former WAFB is located in Oscoda (Iosco County), Michigan, approximately 170 miles north of Detroit (Figure 1). The 5,221-acre site is located less than one mile west of Lake Huron. The WAFB is bounded by Van Etten Lake (to the north and northeast), Van Etten Creek (to the east), the Au Sable River (to the south), and the Alpena State Forest (to the west) (AR 1261, 2001).

The elevation on the base ranges between 600 and 645 feet above mean sea level (AR 1275, 1993). An aquifer lies below the Base and extends beyond the Base's boundaries. The principal aquifer consists of a medium to coarse sand containing some gravel that extends from the land surface to an average depth of 65 feet (AR 27, 1986; AR 1261, 2001). The groundwater flow is eastward towards Van Etten Lake and Van Etten Creek. There is a groundwater divide that extends diagonally across the Base, which directs the groundwater south of the divide toward the Au Sable River (AR 27, 1986). The subsurface geology influences how the groundwater flows; however, the pumping activities from several on-base purge wells and former drinking water supply wells also influence groundwater flow at the site (AR 27, 1986; AR 1261, 2001).

Figure 1: The Former WAFB Location in Oscoda, MI.

2.2 Past Remedial Activities

The WAFB was used as an aircraft maintenance and fueling facility; training facility, gunnery practice range; weapon maintenance, processing, testing, and storage facility; and air field housing. Base activities over several decades involved hazardous materials such as aviation and motor fuels; various grades of petroleum, oils, and lubricants; hydraulic fluids, solvents, paints, thinners, pesticides, and compressed gases (AR 1275, 1993).

Operations at the Base resulted in numerous releases of hazardous substances to the environment. Large groundwater plumes resulted from these releases. Chlorinated solvent, fuel constituents, and landfill leachates constituted the major types of plumes that were created by leakage from the storage, disposal, and conveyance infrastructure.

The U.S. Air Force (USAF) began evaluating WAFB through its Installation Restoration Program in 1984. During site inspection activities completed between 1983 and 2009, 62 Installation Restoration Program sites were identified at WAFB for further investigation under the Base Realignment and Closure Program (AR 462688, 2013). As of 2017, remedial actions have been implemented at about 25 Installation Restoration Program sites at the Base.

2.3 Timeline of PFAS Sampling at the WAFB

PFAS were first discovered at the WAFB in groundwater samples collected in 1999 at a former fire training area (FT-02) and a KC-135 airplane crash site (Schultz et al., 2004). In an effort to understand the possible impacts of PFAS to surface waters, the MDEQ Water Resources Division collected 41 samples from 23 monitoring stations in 2001 (Aiello, 2005). Surface water samples collected from the Au Sable River upgradient of WAFB had the lowest PFOA concentration of 1.16 nanograms per liter (ng/L) while the PFOS concentration was 6.34 ng/L. Based on the understanding of PFAS at that time, it was later concluded that the levels of PFOA and PFOS in Michigan surface waters were not a statewide concern (MDEQ, 2015). The same location upgradient of the WAFB on the Au Sable River was resampled by the MDEQ in 2011 and 2014. PFOS and PFOA were not detected during either sampling event; however, in 2014, using a longer PFAS analyte list, perfluorobutanoic acid (PFBA) was detected at a concentration of 2.5 ng/L.

The MDEQ performed PFAS screening at WAFB from 2010 through 2013, collecting soil, groundwater, and surface water samples. The MDEQ, in collaboration with the Michigan Department of Health and Human Services (MDHHS), also collected fish samples from Van Etten Lake, Clark's Marsh, and the Au Sable River. In 2012, a "Do Not Eat" fish advisory was issued by the MDHHS for Clark's Marsh and the Au Sable River due to high PFOS concentrations in fish filets (as high as 9,580 micrograms per kilogram [µg/kg]). From the fall of 2012 through the spring of 2013, the USAF conducted initial base-wide PFAS sampling by collecting samples from FT-02, Clark's Marsh, and 24 other Installation Restoration Program sites. Environmental media collected included soil, sediment, sludge, seeps, groundwater, and surface water. The USAF confirmed the widespread PFAS contamination across WAFB that was identified by the MDEQ (AR 470965, 2013). The highest PFAS concentration plume emanated from the FT-02 fire training area, discharged south of the base into Clark's Marsh, and eventually reached the Au Sable River south of the Base. The MDEQ has continued to collect fish and surface water samples from the Au Sable River and surface water samples from Van Etten Lake.

In 2014 and 2015, the MDEQ and the United States Geological Survey collected tree swallow and muskrat tissue samples to evaluate the possibility of PFAS accumulation in other Clark's Marsh biota. The PFAS concentrations found in the eggs and plasma samples from Clark's Marsh tree swallow nestlings were twice the highest concentrations found among 69 other sites in the Great Lakes Basin (Custer et al., 2016). The geometric mean concentration of PFOS in the tree swallow plasma from the WAFB was 1,649 ng/mL, which was more than twice the second highest concentration of 582 ng/mL found at Wild Rice Lake in Minnesota, another known PFAS hotspot (Custer et al., 2016). The MDEQ also collected surface water samples from the Au Sable River, Van Etten Lake, and Van Etten Creek, as well as small streams, and seeps surrounding WAFB during these sampling events. All of the surface water bodies located downgradient of WAFB were found to be impacted with PFAS. The 2015 preliminary assessment conducted at WAFB identified a total of 20 areas where PFAS-containing AFFF was stored, handled, and/or released. Based on field investigations and current site inspections, a fire training area, the base operation apron, a fire station, hangars, an AFFF pump station, a crash site, former wastewater treatment plant seepage lagoons, sludge disposal areas, historic landfills, and the former defense reutilization and marketing office were identified as PFAS sources at the WAFB.

The MDEQ and USAF initiated a residential well survey downgradient of the former WAFB boundaries in order to determine whether they had been impacted by PFAS (AR 541373, 2017). A total of 54 samples were collected from 50 properties. One residential well was found to exceed the USEPA drinking water health advisory with the highest PFOS+PFOA concentration of 2,923 ng/L (AR 541373, 2017). The MDEQ confirmed the USAF results by collecting split samples.

The MDHHS conducted an evaluation of the first round of residential well sampling from December 2015. Even though the concentrations did not exceed any criteria or the provisional USEPA health advisory available at that time, the MDHHS issued a "Do Not Drink" advisory for the area downgradient of the WAFB because the PFAS concentrations were found to be higher than those found in the municipal system (MDHHS, 2016). The MDHHS cited several reasons for placing the advisory, including: lack of full characterization of all PFAS releases, bioaccumulation in the food chain, and long half-lives in humans.

Residents east of Van Etten Creek and Van Etten Lake requested that their wells be sampled. Initial United States Geological Survey investigations found that groundwater from the shallow aquifer under the Base discharged towards the surface waters surrounding the WAFB. The conceptual site model in the past has always been that any offsite contaminant migration from the Base would discharge into the surface waters surrounding the Base, preventing further migration (AR 15, 1983). However, due to the shallow water level of Van Etten Creek, the MDEQ sampled several residential wells in order to determine if PFAS could have migrated across Van Etten Creek. PFAS were found in all of the residential wells across Van Etten Creek and the MDEQ continued to expand the sampling area as more residential wells were found to be impacted with PFAS.

The MDEQ collected water samples from an old water heater and a water softener tank, believed to contain water from the time when the Base was operational. During this process, the MDEQ learned that certain hydrants on the Base were not flushed frequently, especially in areas where buildings were demolished. The MDEQ also sampled water from selected WAFB hydrants. A total of 20 hydrant water samples were collected and analyzed for PFAS. PFOA and PFOS were detected in ten hydrant water samples at concentrations above the USEPA drinking water health advisories, with the highest PFOS+PFOA combined concentration of 7,400 ng/L.

In 2016 the MDEQ continued to sample residential wells east of Van Etten Creek and Van Etten Lake and south of the Au Sable River. By the end of 2016 a total of 265 residential wells had been sampled for PFAS. The USAF informed the residents that they could not provide assistance unless the PFAS concentrations in the wells exceeded the USEPA drinking water health advisory combined PFOS+PFOA concentration of 70 ng/L. The MDHHS provided alternate water, even when the PFAS concentrations were not exceeding the USEPA drinking water health advisory, due to lack of PFAS plume delineation and possible historic exposure to higher concentrations.

The MDEQ concluded that the Colbath Road area north of the Base and the high school area south of the Au Sable River were impacted by the use of AFFF or contaminated water due to AFFF use. The MDHHS provided reverse osmosis or bottled water to those that were located within the “Do Not Drink” advisory area. At this time the Colbath Road and high school areas were not believed to have a hydrogeological connection to the PFAS contamination from WAFB. The MDHHS decided not to offer alternative water at the Colbath Road area locations, as none of the samples had PFAS concentrations above the USEPA drinking water health advisory. However, one residence in the high school area was provided alternative water as PFOS+PFOA was detected above the USEPA health advisory level. The MDEQ believes that the PFAS contamination east of Van Etten Lake and Van Etten Creek originated from the WAFB. The MDEQ is still investigating the hydrology at WAFB in order to understand off-site PFAS plume migration. PFAS detection east of Van Etten Lake prompted the MDEQ to further investigate groundwater across Van Etten Lake and Van Etten Creek, Colbath Road Area, and High School Area.

In 2017, the MDEQ competed two phases of remedial investigation downgradient of WAFB and conducted an investigation to determine the possible presence of paleo channels (a remnant of an inactive river or stream channel that has been filled or buried by younger sediment) and

PFAS preferential flow through them. The MDEQ confirmed the presence of one paleo channel close to the Au Sable River and the detection of PFAS in it. The MDEQ is currently conducting a full remedial investigation in order to define the lateral and horizontal extent of the PFAS plume east of Van Etten Lake and south of the Au Sable River from the WAFB. The extent of PFAS groundwater contamination surrounding WAFB is presented in Figure 2. The MDEQ and MDHHS continue to respond to residential requests to sample their wells.

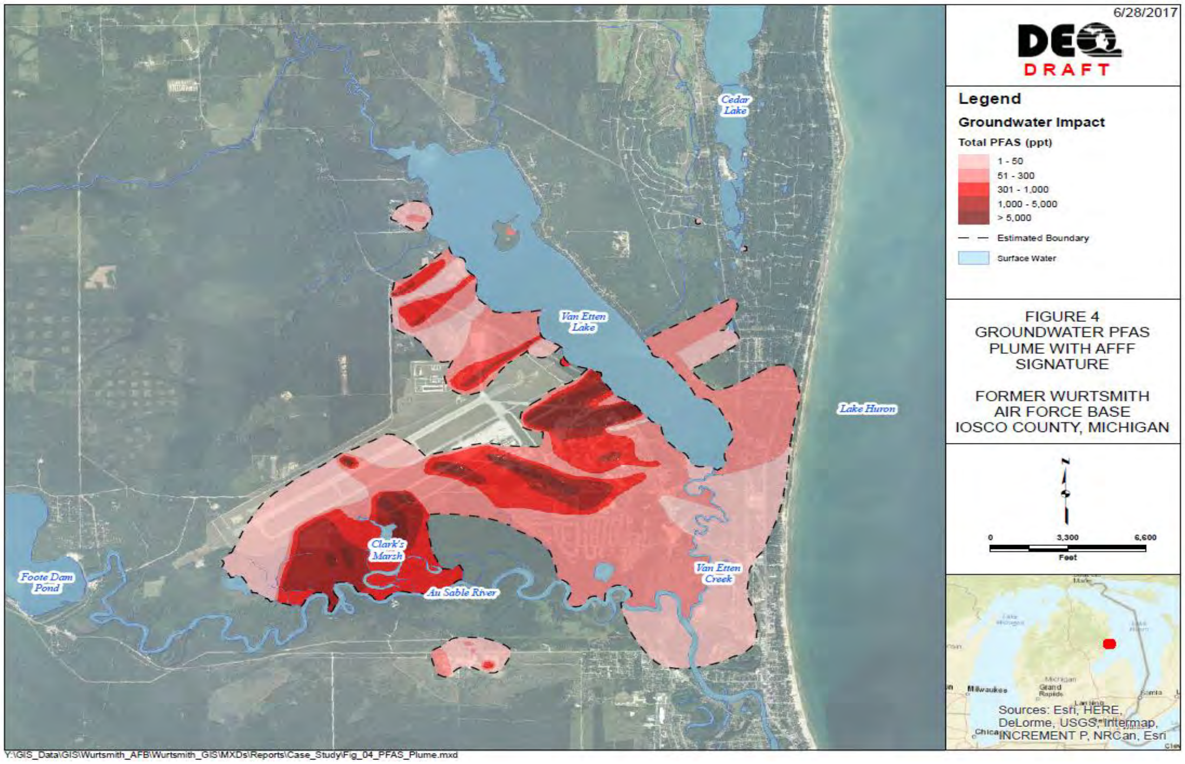

Figure 2: Groundwater PFAS Plume with AFFF Signature at WAFB.

3. Discussion and Conclusions

The use of AFFF at WAFB resulted in widespread PFAS groundwater contamination. In some areas the total PFAS concentration was determined to be as high as 1,000,000 ng/L. Historic landfill contamination and the spreading of sludge (biosolids) from the WAFB wastewater treatment plant have also been identified as being sources of PFAS. The PFAS plume crosses surface water bodies that were previously believed to act as barriers to plume migration. PFAS contamination has impacted groundwater, surface water, and biota (fish, muskrats, and tree swallows). PFAS plumes exceeding the MDEQ groundwater surface water interface (GSI) criterion for PFOS (12 ng/L) continue to discharge to surface waters. Figure 3 shows all of the groundwater or surface water samples that exceed the GSI criterion. With the exception of Van Etten Lake, all of the surface waters surrounding WAFB have a PFAS-based fish advisory. Van Etten Lake has a fish advisory for other contaminants that also addresses PFAS.

Although most scientific and regulatory focus has been on PFOA and PFOS contamination, at least 20 different PFAS have been detected at WAFB. PFHxS is the most prevalent PFAS detected in large areas of the PFAS plumes and residential wells found downgradient of the WAFB. During a recent evaluation of ten DOD installations PFHxS was detected in 95% of groundwater samples and in every media that was tested. PFHxS was detected in all of the biota samples collected around WAFB. These other PFAS should not be ignored during site characterization and risk evaluation.

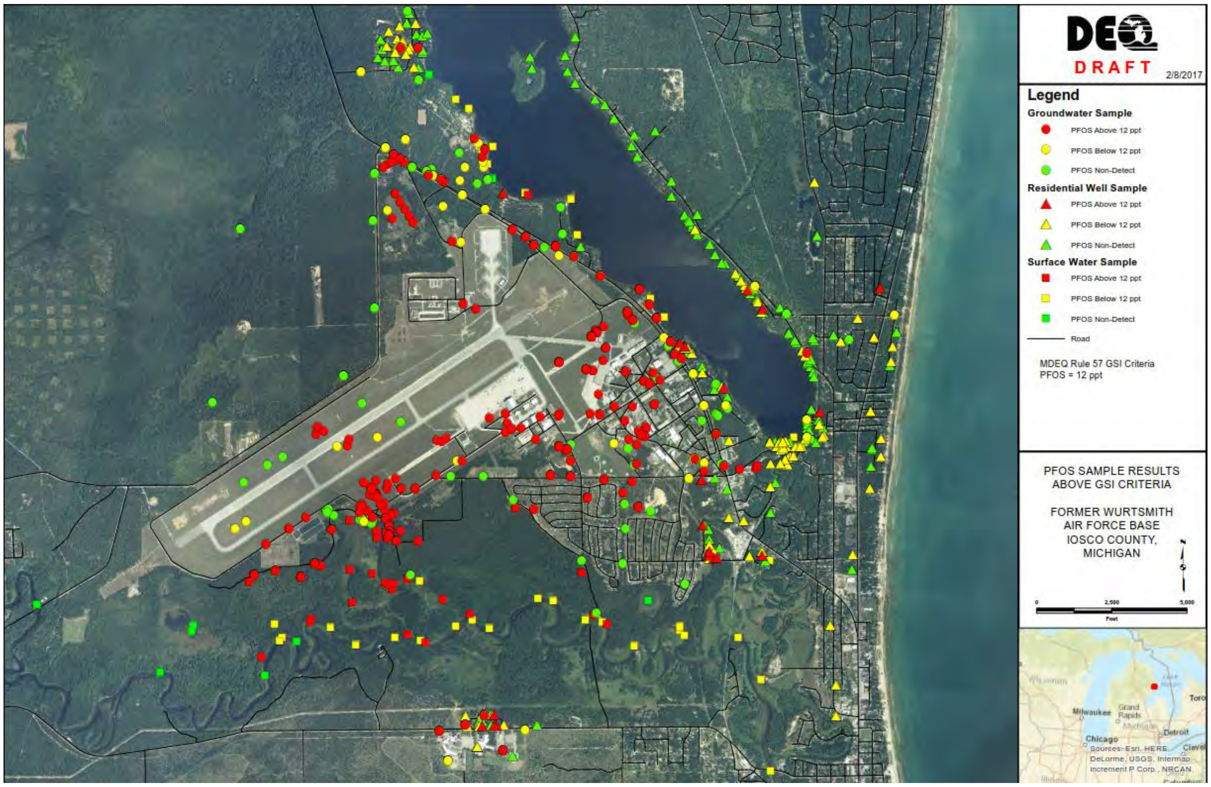

Figure 3: PFOS Sample Results above Michigan GSI Criteria

PFAS release at WAFB has resulted in historical and on-going human and ecological exposures to these chemicals. The current remedial actions have not been sufficient to prevent ecological exposure or human exposure through drinking water or fish consumption. Even though the USAF installed a pump and treat system to reduce the PFAS plume migration from the fire training area into Clark's Marsh, tree swallow egg samples collected in 2016 had the highest PFAS concentrations to date.

In order to better understand the environmental fate of the PFAS at WAFB, a robust sampling plan and characterization of the marsh sediments should be performed. A comprehensive analysis of the fate of PFAS would enable better planning and application of environmental remediation measures at the Base and off-site. PFAS distribution in the food web should be more thoroughly evaluated. Sampling of wild game species, such as deer, should also be conducted, in order to evaluate this potential route of human exposure.

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