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Native American and First-Nations Canadian and Physical PFAS Accumulations: A Literature Review

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Authors Note:

Hello,

My name is Laurel Liebeseller, I am a student at Portland State University finishing my bachelor's in environmental science with a minor in Indigenous Nations Studies. I come to you humbly and respectfully with an understanding that this article is missing information as no one piece of literature can inhabit all conversations, ideas, perspectives, or understandings. I am a queer, white, female author from Germanic, Hungarian, and Scots-Irish Heritage raised in Iowa on Ioway, Sauk, Meškwahki, and Oceti Sakowin territories, and now reside in Portland, Oregon primarily in the Multnomah, Kalapuya, and Cowlitz territories. I understand that untangling and learning about the power and privilege I hold as a white colonial, and the disparities between my own communities and Native/Indigenous/Metis/First Nations communities, is a life-long lesson I need to continuously subscribe to. I am also aware of the atrocities my ancestors and current community place on marginalized communities and claim my heritage and peoples with the intent to be a part of the resistance systematic oppression that myself, and other white people gain power from.

I am writing this thesis with the hopes of pointing out important topics within Per- and Polyfluoroalkyl Substances (PFAS) literature through the consolidation of data to help us all move forward and better support Native/Indigenous/Metis/First-Nations peoples. I cannot speak, nor do I wish to speak, for Native/Indigenous/Metis/First-Nations communities and this document should not be taken as such. The word "Indian" is used in this document only as it is needed to describe a governmental policy that is still labeled as such and not as a descriptor I personally use for Native American (American Indian) (USA) / Inuit, Red River Metis, and First Nations (Canada) peoples. This comes with the understanding that the term "Indian" is used and has been used to subjugate, misclassify, and colonize American (American Indian) (USA) / Inuit, Red River Metis, and First Nations (Canada) peoples by Conqueror governments and communities. I understand that there is a wide range of feelings about outsiders using this term and this will not encompass all people's perspectives. For the sake of brevity, I will be using the word "Native" to describe American (American Indian) (USA) / Inuit, Red River Metis, and First Nations (Canada) peoples to respect different communal and individual labels as was taught to me by Native people around me. If these label's context changes and this term no longer applies or becomes dated, know it comes from a place of respect and learning, I ask for patience during my continual growing process.

Readers will also note that I have chosen to focus on PFAS accumulated in Native individual's blood serum, I recognize the trauma associated with discussing such a topic and the rightful mistrust and conflicts some Native people have with giving parts of their body to a scientific and medical endeavors and of myself – a non-Native person disseminating this information. We do not need to focus on Native bodies to generate an accurate picture of contaminants on Native land or within Native people, but I do think that understanding specific bioaccumulations within communities made vulnerable by a colonial system who want to be tested is important to understand how individuals and communities can move forward.

I heavily advocate for Native-led science due to the need for a Native perspective that I cannot give. With this, I have consulted with a multitude of people including Native individuals to help round out the perspectives in this document and to make sure I am including Native perspectives that I cannot replace. You may find the names of those who collaborated with me in the acknowledgement section of this article. I apologize if there is missing information, or my lens impedes my ability to disseminate this information. You will also note that I use the terms "biological female" and "biological male" when discussing data within the literature. Unfortunately, I did not find any data that referenced transgender, non-binary/other, or intersex people and therefore I can't speak to those communities. This shows us a large hole in PFAS literature and may be a path explored in the future.

Finally, within this document, I refer to the dominant white culture as a conqueror or colonizing culture because, as myself a part of this community, we must speak our truth. This is not to make people feel guilt or shame, but simply to be honest about our history of colonization of Native peoples around the globe that continues to this day. If you find you are struggling with the terminology or have not interacted with the ideas we are about to discuss, I recommend reading "Becoming Kin: An Indigenous Call to Unforgetting the Past and Reimagining Our Future" by Patty Krawek (Anishinaabe from the Lac Seul First Nation) or "White Fragility" by Robin DiAngelo (colonizer settler) that provides a more in-depth introduction than what I will present here. Finally, directly below you will find a brief synopsis of Native American Subjugation in the U.S. and Canada as I think it is important to understand this foundational knowledge to grasp the importance of equitable movements for Native people in the U.S. and Canada. To gain a deeper knowledge I recommend the book *An Indigenous Peoples' History of the United States: For Young People* by Roxanne Dunbar-Ortiz.

Native Subjugation and Genocide in the U.S. and Canada *(trigger warning: this section will discuss Native American relocation, genocide of food sources, removal of children from families, and warfare)*

The history of colonization in the U.S. and Canada is long and traumatic and continues to this day. Due to the capacity of this article, only a short history of the Native genocide and assimilation and erasure tactics conducted by the U.S. and Canadian governments will be discussed. Understanding the basic history of colonization of Native peoples in the U.S. and Canada is important to understand this article's information and why so little data exists on the physical accumulation of PFAS in Native communities.

Native communities have endured multiple types of genocide for hundreds of years, beginning with the Taínos people (now known as Luyacan) peoples – who found the lost explorers, Christopher Columbus and his crew. The enslavement of and brutality (torture, rape, and murder) against the Taínos people by Columbus and his country made way for the enslavement of many other Native people in the United States and Canada throughout history (Keegan and Carlson 2008). The difference between enslaved Native communities and others, such as enslaved Africans', is land over labor. Contemporary genocide of Native peoples uses cultural assimilation and erasure tactics for this reason. Important laws and regulations that shape contemporary lives and the oppression of Native people and uplifting of whites are;

- The Canadian "Indian Act"(1876) that includes larger policies like the Potlach Law of 1884 (Hanson).
  - Outlawed traditional practices including potlatches.
- The Indian Removal Act of 1830 – more commonly associated with the Trail of Tears of which there were many.
  - Removed many people from their traditional lands often onto unwanted "sacrificial" lands. It is common for a community to have been moved more than once.
- The mass genocide of spiritually, culturally, and physically important animals such as Bison.
  - By the 1880s nearly all Bison were killed often for sport or trade. Photos of thousands of stacked bison skulls are easy to find on the internet.

  - The building of dams and diversion of waterways makes Salmon migration extremely difficult or impossible. This has resulted in degradation of river systems, extirpated Salmon from many native streams, and endangered whole populations of Salmon.
- The invention of on-reservation boarding schools in Oregon in 1819 and off reservation Indian Residential Schools opened in Canada in 1831.
  - Children were not permitted to speak their own language, were forced to convert to Christianity, were beaten or verbally abused for practicing their own cultural norms, and in many cases left the boarding schools traumatized by sexual, physical, emotional, and verbal abuse or a combination of the four.
  - Many children never left the boarding schools, how many children died in these schools is still unknown. Mass graves of children who died at boarding schools continue to be found and exhumed.
- The Dawes Act of 1887 (A.K.A the Allotment Act or Blood Quantum Act – from which the census was derived).
  - Native reservations were split into allotments. A Native family or individual was given an allotment if they could prove they had high enough blood quantum to be considered Native American. *Those who did not have high enough blood quantum were documented as white.* This further destroyed Native commons as those who were allotted land often lost it due to government taxation created to steal the land.
  - Blood quantum is still a factor when deciding who gets federal resources and who does not.
- Native Americans gained U.S. Citizenship – June 3rd, 1924
- Indian Reorganization Act – June 18th, 1934
  - Federal control over "American Indian" affairs decreased and gave greater autonomy and self-governance to recognized Native Nations.
- The 1950s out-adoption
  - Adoption and fostering techniques that deemed Native parents "unfit" and placed Native children with predominantly white families.
- The U.S. Termination Era 1950s – 1960s

    - Removed treaty responsibilities from the U.S. government and removed land from tribes. Native people were no longer considered Native American – they were considered a part of the white majority.
- The Indian Child Welfare Act of 1978: Made it harder for out-adoption or fostering to occur.
    - Native children could no longer be as easily taken from their families. If Native children are taken, family must first be contacted for fostering, followed by placement with a Native family, and last effort with a family of another ethnicity/race.
- American Indian Religious Freedom Act of 1978
    - Allowed for Native peoples to perform, pass down, and act out their religions free of persecution.
- The forced and coerced sterilization of Native women by the Indian Health Services.
    - Note that this continues to this day, an example is the U.S. border where immigrant women from Mexico and South America were looking for refuge.
- The mass murder, assault, and kidnapping of Native women and two-spirit people.
    - The matriarchs of Native communities have been violently deconstructed since the beginning of colonization. This continues; Native women are 12x more likely to go missing or are murdered compared to white women. By removing the matriarchal colonial governments and culture, and through the enforcement of dominant patriarchal culture, Native cultures were/are disenfranchised (Dunbar-Ortiz 2014; Krawec 2022).

Abstract

Native communities' exposure to anthropogenic Per- and Polyfluoroalkyl Substances or Per- and Polyfluoroalkyl Chemicals (PFAS, PFCS: "Forever Chemicals") are not demographically or geographically evenly distributed. Those who live near or on contaminated land or water are the most likely to accumulate dangerous amounts of PFAS that may have serious health consequences (Tribal PFAS Working Group 2021). Areas that tend to be most contaminated include landfills, airports, and military bases. Often Black, Indigenous People of Color (BIPOC) and low-income communities are placed near these "sacrificial zones" due to historic and current policies that segregate and marginalize people and families to polluted lands creating great environmental injustices (Bullard 1990). In this thesis I will

discuss 14 articles that delve into PFAS bodily accumulations in Native communities North of the 40th meridian in the U.S. and Canada and will come to understand that food and general practices deeply effect PFAS accumulation from community to community. Though there is overlap in some of the data found in this review, generalized understandings about Native peoples' bodily accumulations of PFAS in the region are hard to determine, and should be approached cautiously. I therefore conclude that to truly understand PFAS in Native communities, first-foods, first-medicines, and drinking water need to be tested. Native food, medicine, and water sovereignty should be centered, and Native leadership is paramount.

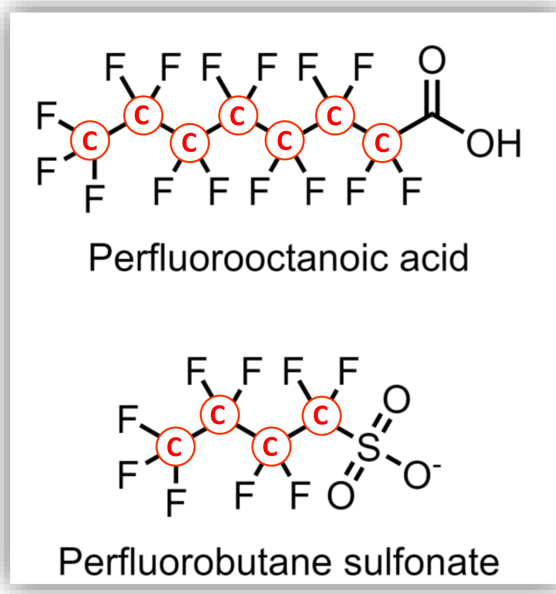
Introduction

Termed Forever Chemicals by mainstream media, anthropogenic-PFAS are primarily created using electrochemical fluorination (ECF) and telomerization. These processes create chains of carbon fluoride bonds that are incredibly strong. For various PFAS chemicals, also known as PFAS constituents, these bonds are so strong that they may take over a millennia to break down. PFAS are polar molecules, meaning that they can easily bond with water molecules, allowing them to move easily through our hydrosphere (Meegoda et al. 2022; Renfrew and Pearson 2021; Zhuikov 2023). This allows them to be transported through our atmosphere and later deposited in even the most remote places on earth including in the bodies of wolves, porcupines, and caribou in northern Canada (Müller et al. 2011). By moving through the hydrosphere, PFAS can accumulate in food and medicines and are shown to accumulate in human bodies with varying half-lives depending on the specific constituent. PFAS are split into long- and short-chain forms based on the number of fluoride-carbon bonds present as seen in Figure 1. The most researched PFAS constituents are Perfluorooctanesulfonic acid (PFOS) and Perfluorooctanoic Acid (PFOA) due to their historic relevance and persistence in our environments.

Native communities North of the 40th meridian demonstrate a large variation of Per-and Polyfluoroalkyl Substances (PFAS: "forever chemicals") accumulation in their bodies. PFAS bodily accumulation differences, based on the literature reviewed for this thesis, are due to rural and urban Native communities, differing expressions of culture on communal and individual levels, and arctic versus sub arctic communities. In total there are over 4,000 anthropogenic PFAS constituents. Only a handful of which have been heavily studied due to their high rates of accumulation in our ecosystems and plant and animal bodies (Environmental Protection Agency 2019). It is estimated that 98% of residents in the United States (Michigan Department of Health and Human Services) and 90 – 100% of Canadian residents have some amount of PFAS in their bodies (Environmental Climate Change Canada and Health Canada 2023). The articles I have listed in this thesis are only a starting point, as the diversity of Native peoples needs greater recognition than what these studies and this thesis itself are able to provide. However, they do serve as a good jumping off point for future questions and studies.

Native people and communities at the highest risk of PFAS exposure live near or on PFAS contaminated lands and participate in the consumption of untested traditional foods, medicines, or water. Concerns about PFAS in food, medicines, and drinking water has been echoed through many Native communities, and these voices have been at the forefront, demanding testing for their communities (Fond du Lac Human Services Division et al. 2015; National Tribal Water Council; News Center Maine 2022; Tribal PFAS Working Group 2021, Zhuikov 2023). Currently there is some funding for public and private drinking water testing for Native communities from the federal government in the United States and NGOs, but the funds are not enough to test every drinking water resource that affects Native peoples. There is even less funding for traditional food and medicine PFAS testing (US EPA 2014; US EPA 2023).

This thesis aims to disseminate the key takeaways found in 14 articles regarding Native communities North of the 40th meridian in the U.S. and Canada, describe the history of PFAS in the United States and Canada, describe the routes of exposure for many Native peoples, summarize toxicological effects that these chemicals can have on the body, and finally conclude with ways to move forward to understand what testing and actions may be best to support Native communities in this region and promote food, medicine, and water sovereignty.



- Long Chain PFAS >=6 Fluoride-Carbon bonds.

- Short Chain PFAs =<5 Fluoride-Carbon bonds.

Figure 1: Long and short chain PFAS.

Methodology

In this work I reviewed 14 articles that directly studied the accumulation of PFAS in Native people's bodies. This includes: Aker, Ayotte, Élyse Caron-Beaudoin, Amila De Silva, et al. 2023; Aker, Ayotte, Élyse Caron-Beaudoin, Ricard, et al. 2023; Aker, Ayotte, Élyse Caron-Beaudoin, Silva, et al. 2023; Aker et al. 2022; Byrne et al. 2022; Byrne et al. 2018; Caron-Beaudoin et al. 2020; Caron-Beaudoin et al. 2019; Château-Degat et al. 2010; Dallaire et al. 2009; Garcia-Barrios et al. 2021; La Corte and Wuttke 2012; Wen et al. 2013; Wielsøe et al. 2022. The remaining 42 sources were used to help compare PFAS accumulations in different populations, understand the health effects of PFAS constituent accumulations, provide PFAS chemical origins, and help to disseminate the science found in the 14 directly related articles. Literature cited includes government-based documents, credible news articles, and peer-reviewed research. Any non-peer-reviewed material is from credible government agencies, news agencies, or non-profits. Google Scholar was first used to help define preferable key search terms and to understand a larger picture of the analyses. Any articles found on Google Scholar were checked for peer review and funding sources. The databases I used included "Web of Science", "Health Source: Consumer Edition", "Health Source: Nurse/Academic Edition", and "Indigenous Peoples of North America". Key phrases included, "American Indian or Native American or Metis or Indigenous AND PFAS or Per- and Polyfluoroalkyl Substances". These key search terms were helpful, but too many unrelated articles were found. I narrowed search terms to specific nations' names to try to reduce the number of unrelated articles found. Community names were chosen based on communities within the region of interest and included but were not limited to: “Blackfoot AND Per- and Polyfluoroalkyl Substances”, “Chinook AND Per- and Polyfluoroalkyl Substances”, “Navajo or Dinè AND Per- and Polyfluoroalkyl Substances”, “Lakota or Sioux AND Per- and Polyfluoroalkyl Substances”, “Salish AND Per- and Polyfluoroalkyl Substances”. Reference lists from identified sources were reviewed and those that were accessible were included in this review. All articles identified for this review were included without additional selection criteria due to the limited number of studies on Native communities’ exposure to PFAS in the selected region. Finally, a review of this thesis’s work was performed by experts in the field. They read through the thesis content and gave critiques of my work based on their own expertise 14 articles I supplied them with; names of these kind individuals can be seen in the Acknowledgements section of this article.

PFAS History

PFAS were originally created in the 1930s, becoming popular after industrial production in the 1950s. 3M built the first large-scale PFAS production and research laboratory in Minnesota and was followed closely by DuPont de Nemours Inc. that began production of PFOA in 1951. PFAS were first used as surfactants for industrial goods production, becoming commercially popular between the mid-1950s to 1960s in the forms of non-stick cookware, water-resistant/proof clothing and cosmetics, grease resistant food wrappers, and stain-resistant/proof sprays. Names like Teflon and Scotchguard became generic trademarks and use of the chemicals slowly became ubiquitous throughout the United States helping to usher in what was deemed the “chemical century” (Renfrew and Pearson 2021).

Military interest in PFAS grew after commercial production began, using the chemicals in several high-profile military endeavors including the creation and components of the atomic bombs. Military use of PFAS skyrocketed after the advent of Aqueous Film Forming Foam (AFFF), used to extinguish intense liquid fires such as jet fuel fires. AFFF is still used at airports, military sites, and firefighting houses and training areas and has become one of the largest sources of PFAS exposure throughout the United States and Canada (Interstate Technology Regulatory Council 2020; Renfrew and Pearson 2021). Dupont and 3M began testing the potential toxicological effects of Polytetrafluoroethylene (PTFE; A.K.A. Teflon) in 1961. DuPont's research team observed that when rats were exposed to PTFE their livers enlarged, endocrine disruption occurred, pups had lowered birth weights, and at high doses, was fatal (Arenson 1961).

DuPont and 3M omitted the toxic nature and cumulative effects of PFAS from regulatory officials, lying to the government and public about the harm that was produced (Rich 2016). Public awareness of PFAS toxins, and more specifically PFOS, increased in 2000. Brought to light by cattle farmer Wilbur Earl Tennant and lawyer, Rob Billot PFOS showed to sicken and kill some of Tennant's cattle who drank water from a creek that had been polluted by Dupont dumping industrial waste upstream (Rich 2016). Public outcry against the manufacturing and distribution of PFOS and PFOA was nearly immediate and broader research began on the toxicological nature of PFOS and PFOA, later followed by several other PFAS chemicals. PFAS manufacturers voluntarily phased out PFOS by 2002 and PFOA by 2015 (Renfrew and Pearson 2021). Global guidance on the use of PFAS began in 2009 during the Stockholm Convention (an international collaboration aiming to protect human health against persistent organic pollutants) beginning with PFOS and later would add in PFOA and Perfluorohexane sulfonate (PFHxS) in 2019 and 2022 respectively (Agency for Toxic Substances and Disease Registry 2020). In place of PFOS and PFOA other chemicals were created including hexafluoropropylene oxide dimer acid and associated ammonium acids(GenX) – first used in production in 2009 to replace PFOA. GenX chemicals have since been shown to break down into PFOA and Perfluorononanoic acid (PFNA). PFOA and PFNA are two of the most highly accumulated PFAS discussed in this thesis. Publicly broadcasted as safer than PFOS or PFOA, GenX chemicals have been shown to cause a myriad of negative health effects that will be discussed further later in this document (Environmental Protection Agency 2022; Interstate Technology Regulatory Council 2020).

Mainstream public bodily accumulations of PFOS and PFOA have decreased since the two chemicals were phased out of production but continue to be prevalent due to their slow breakdown times and use of precursor chemicals (e.g. GenX chemicals and FTOHs) (Byrne et al. 2018). In 2021 the U.S. EPA set guidelines at for PFOS and PFOA at 70 parts per trillion in one liter of drinking water (ppt/L), but no regulatory actions were taken. However, six PFAS constituents will be regulated PFOS, PFOA, PFNA, GenX chemicals, PFHxS, perfluoobutane sulfonic acid (PFBS), and combinations of these six hopefully starting in 2024. The EPA has proposed regulations set limits of detection for PFOS and PFOA at 4ppt/L, all other constituents will follow 1 unit under the Hazard Index in ppt (EPA PPT). Regulations for these chemicals will fall under the Safe Drinking Water Act and are hoped to be completed by the end of 2023 and publicly regulated in public water supplies by 2025 (Environmental Protection Agency 2019). As of 2024, PFAS drinking water regulations have not been fully implemented on a federal level but are regulated in some states and cities.

Funding for Testing Water

The Reclamation Water Settlement Fund under the 2022 federal Bipartisan Infrastructure Law includes a tentative 2 billion dollars designated for front-line communities to build drinking water infrastructure, and an additional 5 billion dollars over the following five years to help relieve PFAS drinking water burdens. Of the 2 billion, $238,627,000 will be allotted to Native communities for Drinking Water Infrastructure in 2022, followed by $965,020,000 dollars for general drinking water infrastructure between 2022 and 2026. This is the largest amount of money the federal government has ever allotted to Native communities for water infrastructure. Funds will be divided based on grant applications and analysis. Initial amounts are shown in Table 1 and Table 2 but may be subject to change post 2023. This fund does not include funding for testing of traditional foods, medicines, or soils (Environmental Protection Agency 2019; US EPA 2014; US EPA 2023). Concerns over how grants will be awarded and who will administer them are common and valid concerns among Native communities regarding this new funding.

Table 1: Bipartisan Infrastructure Law Funding for Tribal Water Infrastructure FY 2022 – 2026

Appropriation*	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026	5-Year Total
Clean Water Indian Set-Aside (CWISA) BIL General Supplemental	$38,040,000	$44,040,000	$48,060,000	$52,060,000	$52,060,000	**$234,260,000**
CWISA Emerging Contaminants	$2,000,000	$4,500,000	$4,500,000	$4,500,000	$4,500,000	**$20,000,000**
Drinking Water Infrastructure Grants – Tribal Set-Aside (DWIG-TSA) BIL General Supplemental	$38,040,000	$44,040,000	$48,060,000	$52,060,000	$52,060,000	**$234,260,000**
DWIG-TSA Emerging Contaminants	$16,000,000	$16,000,000	$16,000,000	$16,000,000	$16,000,000	**$80,000,000**
DWIG-TSA Lead Service Line Replacement	$60,000,000	$60,000,000	$60,000,000	$60,000,000	$60,000,000	**$300,000,000**
Subtotal – CWISA and DWIG-TSA Appropriations	**$154,080,000**	**$168,580,000**	**$176,620,000**	**$184,620,000**	**$184,620,000**	**$868,520,000**
Emerging Contaminants in Small or Disadvantaged Communities Tribal**	$19,300,000	$19,300,000	$19,300,000	$19,300,000	$19,300,000	**96,500,000**
Total for all Appropriations	**$173,380,000**	**$187,880,000**	**$195,920,000**	**$203,920,000**	**$203,920,00**	**$965,020,000**

(US EPA 2023)

Table 2: Summary of 2023 Tribal Funding Allocations

Program	Total Funds Available
Drinking Water Bipartisan Infrastructure Law Funding (BIL)	
Drinking Water Infrastructure Grants – Tribal Set-Aside (DWIG-TSA) General Supplemental	$44,040,000
DWIG-TSA Emerging Contaminants	$16,000,000
DWIG-TSA Lead Service Line Replacement	$60,000,000
Emerging Contaminants in Small or Disadvantaged Communities (EC-SDC) Tribal Grant Program	$38,600,000*
Drinking Water BIL Total	***$158,640,000***
Clean Water Bipartisan Infrastructure Law Funding (BIL)	
Clean Water Indian Set-Aside (CWISA) General Supplemental	$44,040,000
CWISA Emerging Contaminants (EC)	$4,500,000
Clean Water BIL Total	***$48,540,000***
Drinking Water Consolidated Appropriations Act Funding (Base)	
DWIG-TSA Base	$10,332,000
Assistance to Small, Underserved, and Disadvantaged Communities (SUDC) Tribal Grant Program	$5,600,000*
Drinking Water Base Total	***$15,932,000***
Clean Water Consolidated Appropriations Act Funding (Base)	
CWISA Base	$15,515,000
Clean Water Base Total	***$15,515,000***
Total BIL and Base Tribal Drinking Water and Clean Water Funding	**$238,627,000**

(US EPA 2023)

PFAS testing is extremely expensive and time intensive. Due to the ubiquity of PFAS chemicals special PFAS-free laboratories and trained personnel are needed for optimal results. PFAS-free laboratories are expensive to run due to their specific filtration requirements, specially trained staff, and dedicated equipment such Liquid Chromatography – Mass Spectrometry instruments. Native peoples have been supporting PFAS testing of water for a long period of time, continuously supporting their communities in need. Some organizations that perform or help to have testing done are Great Lakes Tribal Council Inc. Free Drinking Water Testing Program and work being done by the National Tribal Water Council.

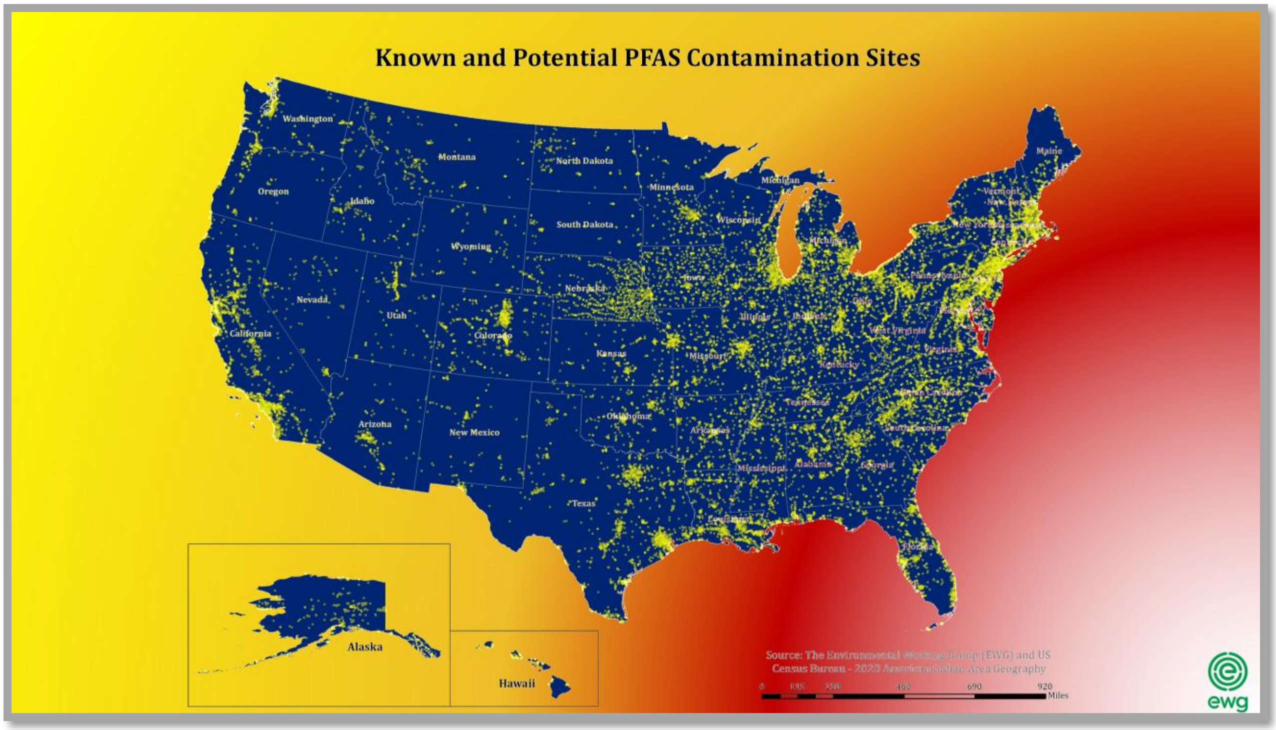


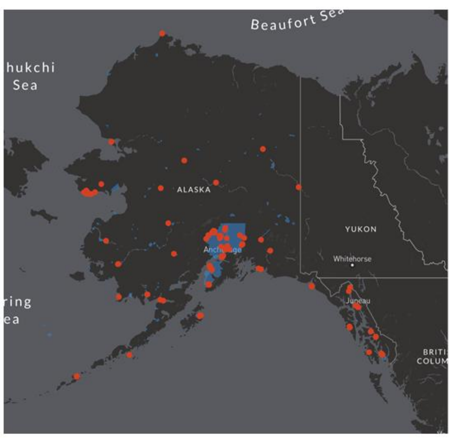
Figure 2: Suspected PFAS contamination sites in the United States (Tribal PFAS Working Group 2021).

PFAS Exposure

Ingestion of contaminated food/water, inhalation of PFAS chemicals, living near or on contaminated land, and using products that are made of or have PFAS in them (Gore-Tex, cosmetics, stain-resistant sprays, non-stick cookware, fire-resistant mattresses, PFAS treated food packaging, fire extinguishing sprays, etc.) are the most common types of PFAS exposure. Due to federal policies in both the U.S. and Canada that place Native communities near “sacrificial zones”, such as redlining, Native peoples are at higher risk of living near or on contaminated land or water. It is estimated that nearly 3,000 tribal lands (7%) are within five miles of PFAS contamination sites in the U.S. as demonstrated in Table 3 (Tribal PFAS Working Group 2021), but Native people only make up 2.6% of the United States population according to the U.S. census. Native people in Canada make up 5% of the population (Government of Canada 2022), but to my knowledge it is unknown how many Native people live within 5 miles of PFAS contaminated sites. A map of this relationship is shown in Figure 3. To my knowledge, no relational maps between Native communities and PFAS-contaminated sites have been produced in Canada. To help give some relative understanding, a map of First Nations and Tribal Councils in Canada are represented above are known or suspected PFAS contamination sites in Figure 4. It is not known if either of these maps account for ubiquitous FTOH or GenX chemicals.

Table 3: Statistics of the number of tribal lands near or on suspected PFAS-contaminated land (Tribal PFAS Working Group 2021).

PFAS Contamination	Locations within 5 Miles of Tribal Lands	Total Locations	Percent of Total Locations in Indian Country
Drinking Water Detection	91	1,660	5%
Other Known Users	11	57	19%
Military Facilities	91	1,660	5%
Suspected Industry Release	11	57	19%
Suspected Sewage Release	38	327	12%
Suspected Landfill Release	1,921	29,960	6%
Suspected Airport Release	356	4,901	7%
Total	470	6,393	7%



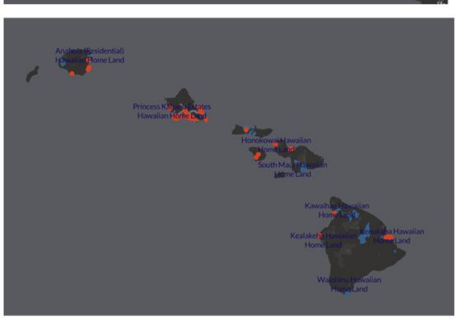


Photo credit: PFAS contamination across Tribal Lands (August 16, 2021).

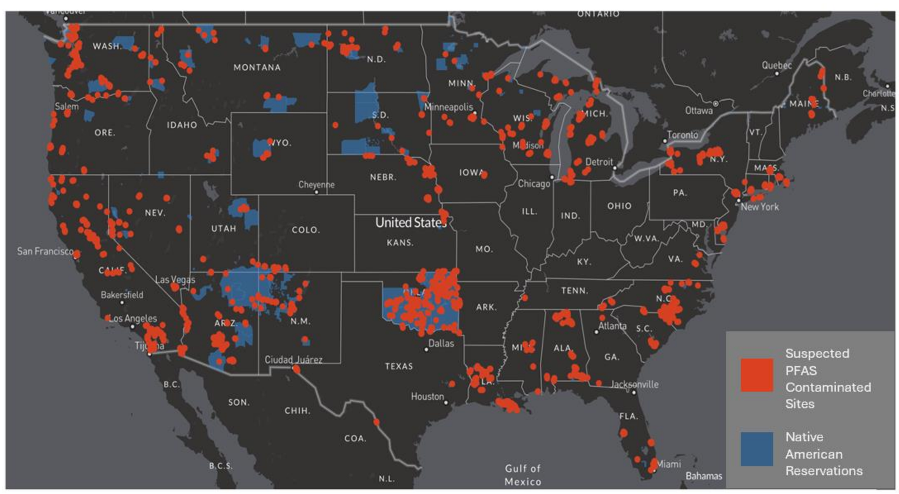


Figure 3: Suspected PFAS-contaminated sites near or on Native American reservations in the United States.

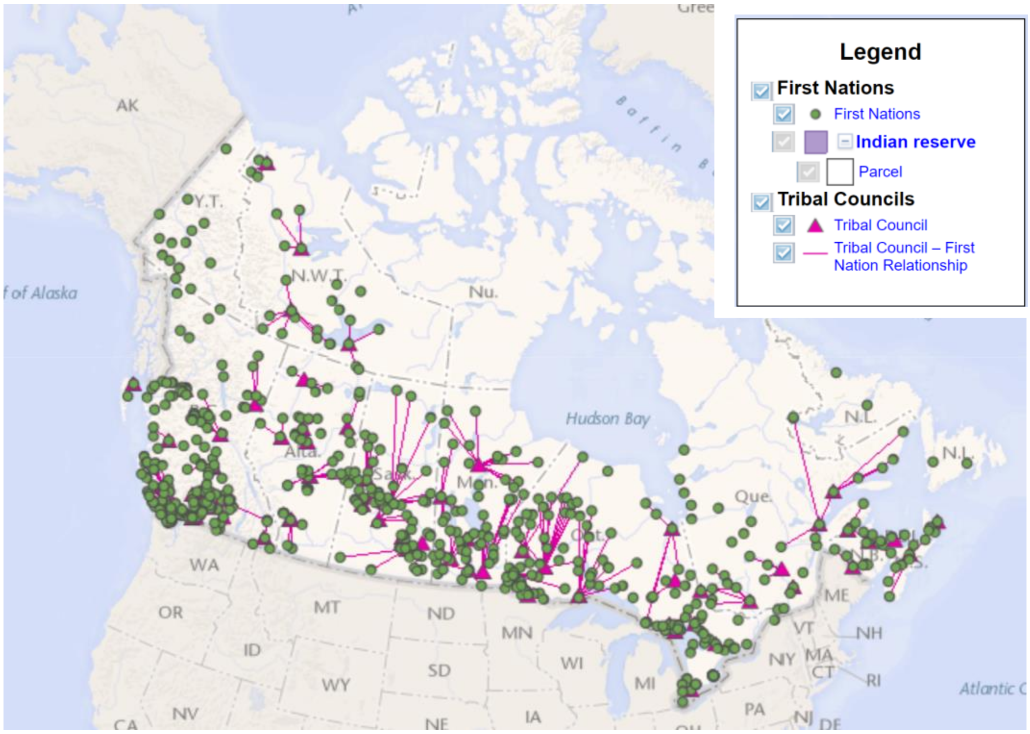


Photo credit: Government of Canada

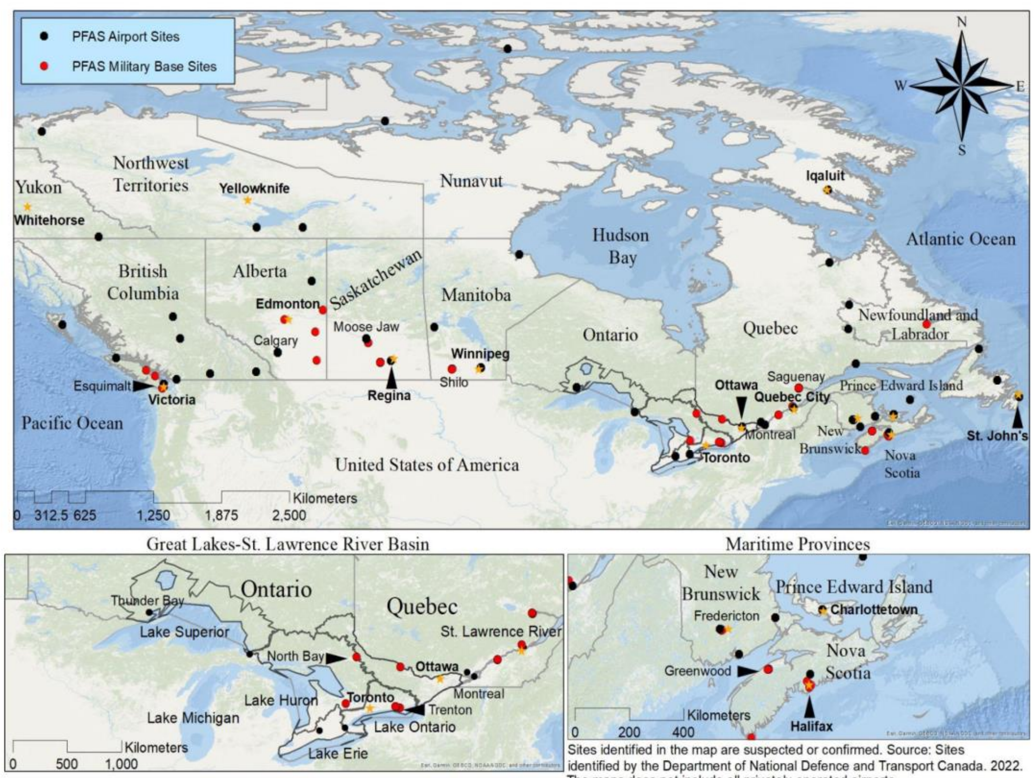


Figure 4: Examples of tribal locations near or on suspected PFAS-contaminated sites in Canada.

PFAS chemicals range in size from course particles, 10 - 2.5µm, to ultra-fine particles 0.1 to 0.056µm. In an article conducted by Huiju et al., the most common aerosolized PFAS particle sizes found were between 0.056– 0.1µm with another less significant spike at 3.2 – 10µm. This study demonstrates the variability of aerosolized PFAS particles. An example of particle sizes to understand the above numbers can be seen in Figure 5. Little is known about the bioavailability of PFAS but we do understand that the highest accumulation of PFAS come from the ingestion of contaminated food or water. Food and water may be contaminated by PFAS treated packaging (such as microwave popcorn bags), dumping or runoff of PFAS into water bodies, or through prolonged exposure – such as a glass of water being left out over night in a space that has a high load of aerosolized PFAS. Inhalation of contaminated indoor air and dermal exposure are likely the second and third most important pathways into the body respectively as seen in Table 4. Analysis of PFAS bioavailability is hard to understand because of how many variables affect PFAS uptake in the body. Examples of this are how few anthropogenic PFAS have been studied compared to how many there are, how PFAS precursors such as GENX and FTOHs may skew results, and how PFAS accumulations are different from person to person (Poothong et al. 2020). Living near or on contaminated land or water may increase a person's chance of ingesting contaminated food or water through dust accumulation over time or working or recreating within the contaminated zone.

Figure 5: Relative particle sizes (PFAS 0.056µm to 10µm)

https://www.visualcapitalist.com/visualizing-relative-size-of-particles/

Table 4: Estimated intakes of PFAS by body weight in Norway (pg/kg) (Poothong et al. 2020)

	PFHxS	PFHpS	PFOS	PFDS	PFHxA	PPHpA	PFOA	PFNA	PFDA	PFUnDA	PFDoDA	PFTrDA	PFOPA
Dietary intake													
Mean	11	N/A	156	N/A	90	47	269	38	72	45	5.4	10	N/A
Min	0.9	N/A	12	N/A	8.8	3.3	41	4	11	0.76	0	0	N/A
Max	63	N/A	845	N/A	464	136	866	137	244	792	79	127	N/A
House dust ingestion													
Mean	3.4	N/A	27	2.2	14	3	66	15	22	3.9	12	0.39	1.2
Min	0.005	N/A	0.005	0.07	0.31	0.05	0.21	0.04	0.01	0.01	0.01	0.01	0.02
Max	192	N/A	1480	50	308	109	1570	182	701	94	486	11	22
Indoor air inhalation													
Mean	N/A	N/A	N/A	N/A	4.7	0.47	17	1.7	7	0.7	0.39	N/A	N/A
Min	N/A	N/A	N/A	N/A	0.38	0.04	0.84	0.08	0.41	0.04	0.01	N/A	N/A
Max	N/A	N/A	N/A	N/A	46	4.6	217	22	124	0.18	11	N/A	N/A
Dermal absorption													
Mean	0.33	3.7	N/A	0.17	0.15	0.02	1.4	0.35	N/A	N/A	N/A	N/A	N/A
Min	0.01	0.02	N/A	0.01	0	0	0	0	N/A	N/A	N/A	N/A	N/A
Max	13	52	N/A	3.6	3.3	0.33	20	2.5	N/A	N/A	N/A	N/A	N/A

Native people who consume untested traditional foods and medicines may be at higher risk of PFAS exposure due to the lack of available information of pollution in vulnerable communities. Testing for PFAS in food and water is often cost prohibitive and therefore many consume PFAS without knowing. While there is more funding for testing PFAS concentrations in water from the federal government and NGOs, there is comparatively very little assistance for food and medicinal PFAS testing. Avoiding traditional foods and medicines is not an option for some Native communities or individuals due to the close relationships and ties they have with the land that not only inform identity, but provide people with physical, mental, and spiritual health, without which many people die (News Center Maine 2022). Additionally, accessing store (market/grocery) foods may not be available for some in communities because of the extremely high grocery prices in rural sites (Aker et al. 2022).

Which PFAS constituent(s) and the amount(s) that are accumulated varies based on traditional food, medicine, or drinking water sources. For example, Dallaire et al. (2009) that Inuit individuals in Nunavik that consumed high rates of fish and marine mammals had higher rates of PFOS in their blood serum than those who did not. Comparatively, similar articles within the same region show higher rates of other chemical constituents including PFNA, PFUnDA, and PFOA compared to PFOS(Aker et al. 2023; Aker, Ayotte et al. 2023; Aker et al. 2022). Fond du Lac Human Services Division et al. (2015) found PFOS and PFNA levels were both higher in biological males in the Fond du Lac Band of Lake Superior Chippewa who consumed fish from Lake Winnebago compared to those who did not (Fond du Lac Human Services Division et al. 2015). Complicating this topic further, trophic bioaccumulation (accumulation of chemicals up the food chain) is also species dependent. In a recent Alaskan study, fish, sediments, and macroalgae tended to accumulate Perfluoroalkyl carboxylic acids (e.g. PFUnDA, PFNA, PFOA) and PFOSA compared to other species including ringed seals, moose, and polar bears that tended to accumulate PFOS (Kelly et al. 2009).

This finding is corroborated in urban spaces. In Fond Du Lac there were no correlations drawn between consumption of wild terrestrial game or Native wild rice in the area (Fond du Lac Human Services Division et al. 2015). PFAS have been found in the organs, muscles, and fatty tissues of different species, including humans. It is suspected that these differences are caused by being lower on the trophic scale and the differences in aquatic versus, semi-aquatic, and terrestrial species (e.g. water over gills filtering water may have higher exposure rates than lungs breathing air) (Kelly et al. 2009). In many articles found there were more correlations to traditional food consumption and PFAS such as PFNA, PFOS, PFUnDA, and PFDA – however these chemicals varied greatly from community to community.

Comparatively, in the same studies those who consumed grocery foods tended to have higher rates of PFOA similar to the general public (Aker et al. 2023; Breyers 2009; Conard et al. 2022; Kelly et al. 2009; National Tribal Water Council ; Wielsøe et al. 2022).

Calls for PFAS testing of traditional food, medicine, and drinking water by Native people has become common as concerns about communal safety increase. Examples of these calls can be seen from the Penobscot Nation (News Center Maine 2022) and 10 of the 11 Ojibwe tribes a part of the Voigt Intertribal Task Force that use ceded territories in Minnesota, Wisconsin, and Michigan for harvesting, among many others (Zhuikov 2023). Testing foods, medicines, and drinking waters is especially important for those who live near pollution sources or have had releases of PFAS chemicals near them because of the higher potential of PFAS pollution in these spaces. However, it is sometimes hard to know when PFAS have been released due to the ubiquity of PFAS in consumer goods. An example of this is from Caron-Beaudoin et al. (2019) in which the researchers conducted a pilot study that included Anishinaabe and Innu youth who participated in the Jes!-Yeh! project. The average age of study participants was 10 years old. Surprisingly, a section of Anishinaabe participants had eight times higher PFNA serum concentrations ranging from 9.44 – 3.01µm/L, compared to neighboring Innu participants that had PFNA levels ranging from 0.89 – 0.45µm/L. Anishinaabe participants with the highest accumulations were between 6 – 11 years old. Food and drinking water sources were quickly tested after the initial results without significant findings. Later it was revealed that a fire extinguisher had been released in the public school and is believed to be the most likely cause of the higher levels of PFNA in the children's blood serum, demonstrating the variability and need for tailored analyses of individual communities and general practices and education about PFAS materials in "safe" products (Caron-Beaudoin et al. 2019; Zhuikov 2023).

PFOS, PFNA, PFUnDA, and PFOA may continue to be a concern in Native communities due to the breakdown of unregulated emerging contaminants such as 8:2 FTOH and 10:2 FTOH into Perfluoroalkyl acids such as PFNA are suspected to be a main cause of high accumulations in Native communities in the arctic (Aker et al. 2023)**.** To my knowledge, there is only one temporal study that has collected data for FTOHs. Caron-Beaudoin et al. discussed their findings within Nunivuik Native populations between 2004 to 2017 that displayed significant decreases in PFOS (66%), PFOA (44%), and PFHxS (49%). However, PFOS, PFNA, and PFDA continue to be higher than Canadian Health Measure Survey (CHMS) groups taken at the same time (1.8, 6.3, and 3.3 times respectively). PFNA levels unfortunately increased by 19% since 2011 within the focus group with higher rates in those who consumed country foods (also known as subsistence foods or hunted and gathered foods) – regularly (p=<0.01). Higher accumulations of PFNA may also be associated with PFAS transportation to the arctic and calls attention to the need for greater global regulation of PFAS (Caron-Beaudoin et al. 2020; Zhuikov 2023).

PFAS by Demographic

Three demographic differences that trended across the articles are biological sex, age, and ethnicity. Biological sex plays a significant role in PFAS accumulation because menstruation, fluids lost during childbirth, and breastfeeding are suspected pathways of bodily PFAS excretion. Biological sex also heavily impacts PFAS accumulation seen in national studies including CHMS and the National Health and Nutrition Examination Survey (NHANES) (Cakmak et al. 2022; Ye et al. 2018). This is confirmed in all but one article from this literature review. Aker et al. 2023, found similar PFAS accumulation rates between biological females and biological males, but interestingly biological females had higher rates of PFDA and PFUnDA compared to biological males who had higher accumulation of PFOA and Perfluorohexane sulfonate (PFHxS). Comparatively, biological sex does not seem to affect PFAS accumulation in prepubescent children and has a significantly reduced role in post-menopausal individuals who no longer menstruate, give birth, or breastfeed. An example of this sex dichotomy is from Château-Degat et al. (2010) that states,

> In the 18–24 yrs group, mean levels (geometric mean [95% CI]) were significantly lower in women (12.5 mg/L [11.2–13.9]) than in men (16.7 mg/L [14.9–18.7]). These values were very close to those observed in the 25–44 yrs group (14.6 mg/L [13.5–16.0] for women and 18.1 mg/L [16.6–19.7] for men), but much lower than those observed in the older age group (29.1 mg/L [25.0–33.8] for women, 31.4 mg/L [27.1–36.6] for men), where the gender difference was no longer significant. Although PFOS levels increased with age, levels were significantly higher only in people aged above 45 yrs old, in both genders.

This emphasizes the relationship between menstruation, childbirth, and breastfeeding and lower physical PFAS accumulations. Age as an isolated variable away from biological sex may also help to understand what demographics are participating in greater amounts of traditional food and medicinal practices than others. While many participate in traditional foods and medicines for cultural, physical, and spiritual reasons, others participate because they are not able to access market-based foods. Aker et al. (2023), found that Native Nunavik individuals, between 16-29 and 50-82, and who made less than

$20,000 annually were more likely to have a country food dominant diet (Male identified: 72.6%, female-identified: 27.4%, 16-29yrs: 51.3% and 50-82yrs: 28.0%, 55.8% who make <$20,000/year). Those who participated in country food had significantly higher concentrations of, "PFNA [percent change in concentration (%Δ) 43.91, 95 % CI 20.39–72.02], PFDA (%Δ 49.53, 95 % CI 20.49–85.56), PFUnDA (%Δ 57.55, 95 % CI 27.35–94.90), and PFOS (%Δ 50.41, 95 % CI 21.65–85.97), compared to participants in the Market Food Dominant group." 30 – 49 year olds making >$60,000 were more likely to partake in grocery-based foods and had significant differences in PFOA accumulations with a 10.69% difference between those who regularly participated in market-based foods and those who did not (Garcia-Barrios et al. 2021; Haozous et al. 2014). No information regarding transgender or intersex individuals was found from any of the articles in this document, and therefore cannot speak to these communities.

PFAS Toxicokinetics

PFAS enters the bloodstream through ingestion, inhalation, or dermal absorption, with rates of exposure from greatest to least respectively. Binding to albumin proteins in blood, they are transported through our bodies and bioaccumulate most often in protein-dense tissues, but PFAS constituents act differently and may accumulate in non-protein-dense areas such as PFOS in bone (Zhao et al. 2022). Accumulation of PFAS in human bodies can affect fertility, create high blood pressure in pregnant people, increase low birth weights, increase bone variations, accelerate puberty, create behavioral changes, increase the risk of prostate, kidney, and testicular cancer, suppress immune responses, act as an endocrine (hormone) disrupter, and increase the risk of high cholesterol and obesity (United States Environmental Protection Agency 2021). Understanding the health effects of PFAS is hard due to the number of PFAS (>4,000 anthropogenic chemicals), PFAS precursors, and variability of contamination levels from person to person.

PFOS and PFOA are the most well understood PFAS, but there continues to be debate regarding their health effects. PFNA and PFUnDA comparatively have fewer human health assessments, but are believed to be "main contributors driving associations with lipid profiles and prediabetes" (Aker et al. 2023). How these chemicals interact in the body together is still not well understood by PFAS experts, but Aker et al. 2023 found that mixtures of Perfluoroalkyl Acids (PFAAs: e.g. PFOA and PFNA) heavily affected total cholesterol, low density lipoproteins, high density lipoproteins, apolipoprotein B-100 tests, and prediabetes in Inuit Nunavik populations, and most particularly those identified as male. Interestingly other long-chain PFAS, such as PFOS, may not have the same bodily effects. Château-Degat et al. (2010), explains that while there did seem to be associations between lipid levels and PFOS accumulation there was a level of uncertainty in the results because the effects they observed may have been caused by a mixture of PFAS and could not determine causality. The two studies' different conclusions may be explained by the expansion of PFAS constituents performed by Aker et al. 2023.

PFAS have also been shown to change hormone chemistry in the body. In Byrne et al. (2022), Byrne et al. (2018), and Caron-Beaudoin et al. (2019) PFNA accumulations affected Thyroxine levels (T4/T3– a hormone that affects metabolism) in the body. PFNA works to disrupt T4 and T3 hormone levels by bonding to protein receptors in the body. Though there were associations between thyroxine levels and PFNA no article was able to make correlations between T4/T3 rates and thyroid disease. However, the lack of a clinical diagnosis does not mean that there isn't the potential for harm,

> "sub-clinical thyroid disruption is associated with morbidity. Osteoporosis and changes in cardiac anatomy and physiology are more common among individuals with sub-clinical hyperthyroidism, … while subclinical hypothyroidism is associated with overweight and obesity … adverse cardiovascular outcomes … and impaired cognitive function." (Byrne et al. 2018).

Interestingly hormonal T3/T4 hormones may be affected differently based on biologic sex. PFOS and PFNA have shown positive associations with T3 hormones in women and negative associations with T3 hormones in men (Byrne et al. 2018). Why biological sex plays a role in the expression of PFAS in bodies is not understood, but the results from this study were consistent with larger studies including a 2007–2010 NHANES study (Wen et al. 2013). While most of the articles regarding Native peoples in this review do have higher rates of at least one PFAS constituents compared to the general populous an overarching study called the First Nations Biomonitoring Initiative from 2013 found that on average First peoples that participated in the initiative had lower accumulations of PFAS than the mainstream public, as documented in the Canadian Health Measures Survey (CHMS). Average differences between the FNBI and the CHMS can be seen in Table 5 (La Corte and Wuttke 2012).

Perfluorooctane sulfonate (PFOS)- Arithmetic and geometric means of Plasma concentrations (µg/L) for on-reserve and crown land population aged 20 years old and older, FNBI 2011

Population	Sex	n	% < LOD	A.M. 95%CI	G.M. 95%CI	10th 95%CI	25th 95%CI	50th 95%CI	75th 95%CI	90th 95%CI	95th 95%CI	Compared to CHMS G.M.
FNBI Total	Total	473	1.10	5.06 4.13 - 6.00	3.12 2.63 - 3.71	0.77 0.55 - 1.00	1.57 1.24 - 1.90	3.20 2.38 - 4.02	6.35 4.87 - 7.83	10.68 9.04 - 12.31	16.61E 10.02 - 23.20	↓
	F	285	1.80	3.51 3.02 - 4.01	2.14 1.87 - 2.44	0.55 0.41 - 0.70	0.97E 0.57 - 1.37	1.90 1.51 - 2.30	3.78 3.11 - 4.45	9.20 7.20 - 11.20	11.02 9.10 - 12.93	↓
	M	188	0.00	6.55 4.96 - 8.14	4.50 3.48 - 5.80	1.39E 0.68 - 2.10	2.27E 1.06 - 3.49	4.30 3.48 - 5.13	8.31 6.63 - 9.98	12.97E 8.25 - 17.69	22.67E 13.08 - 32.27	↓
CHMS	Total	2880	0.14	11.31 10.02 - 12.60	8.85 7.97 - 9.82	3.62 3.08 - 4.16	5.71 5.01 - 6.40	9.17 8.08 - 10.25	13.89 12.34 - 15.44	19.81 16.92 - 22.69	27.53 22.77 - 32.29	
	F	1504	0.20	8.86 7.83 - 9.89	7.07 6.30 - 7.93	3.08 2.68 - 3.47	4.51 3.96 - 5.06	7.42 6.45 - 8.39	11.24 9.84 - 12.64	15.98 14.05 - 17.91	20.05 15.85 - 24.25	
	M	1376	0.07	13.81 11.96 - 15.66	11.13 10.03 - 12.36	5.19 4.33 - 6.05	7.67 6.72 - 8.63	11.28 9.90 - 12.65	16.48 14.66 - 18.30	23.67 18.16 - 29.18	31.31 23.68 - 38.94	

Note: If >40% of samples were below LOD, the percentile distribution is reported but means were not calculated
E means that the survey estimates should be used with caution. Their associated coefficient of variation are between 16.6% and 33.3%
F means that the survey estimates were too unreliable to be published. Their associated coefficient of variation were above 33.3%
"-" or "." means that the survey estimates or their coefficient of variation couldn't be calculated.

Table 5: First Nations Biomonitoring Initiative PFOS total amount (2008-2013). For First-Nations people in Canada on reserve south of the 40th˚. (La Corte and Wuttke 2012).

The differences in study outcomes from individual and overarching populations point to the need for individual community assessment beginning with populations that would like their foods, medicines, waters, and lands or combination thereof tested to understand the risks associated with consuming traditional foods, medicines, or drinking water.

Conclusion

Physical PFAS accumulations in Native communities north of the 40th meridian in the United States and Canada were discussed in this document. In total, 14 articles directly regarding Native PFAS bodily accumulations north of the 40^{th} meridian were found. The following 42 documents were used to help readers understand the health ramifications, what the need for testing first-foods, first-medicines, and drinking water are, help draw comparisons, and understand the history of PFAS and Native communities in the U.S. and Canada. All 14 articles were kept for interpretation due to the small sample size. PFAS accumulation in bodies is hard to understand due to the diversity of PFAS chemical constituents and use and lack of regulation of precursor chemicals such as 8:2 FTOH, 10:2 FTOH, and GenX chemicals that can break down or can be metabolized into PFAS chemicals such as PFOS, PFOA, and PFNA. Some Native peoples may be at higher risk of PFAS exposure due to historic and current policies and actions that oppress and subjugate these communities and continue to deplete opportunities for Native people, including healthy living spaces. Though there were some overlapping findings between studies regarding what PFAS chemicals were physically accumulated, the results varied greatly from large accumulations of PFOS, to PFNA, to a combination thereof. PFAS have shown to accumulate differently per biological sex with average higher rates typically found in biological males due to biological female's expulsion of PFAS chemicals through menstrual blood, fluids during childbirth, and milk while breastfeeding. PFDA and PFUnDA, as discussed by Aker et al. (2023), have been shown to accumulate at higher rates in biological females than biological males, why this is, is still unknown. Increased country food consumption based on gender roles or socioeconomic ability may also play a significant role in PFAS accumulation but cannot be generalized due to the cultural and financial differences between Native communities and individuals. Interestingly PFAS do not exhibit similarly based on biological sex. It has been found that T3/T4 levels have a positive relationship with PFAS in biological females and a negative relationship with biological males, why this occurs and repeats across populations is not well understood. Unfortunately, there was no information about people who are intersex, or transgender found in any of the reviewed literature, and so this thesis cannot speak to bodily accumulations based on physical intersexual or transgender expression.

Variations in how PFAS is expressed based on biological sex reflects the significant food and medicinal consumption differences that can be present between and within Native communities. Differences in food, medicine, and water consumption are important to understand due to the differences in PFAS accumulation based on species, as seen by the different bodily PFAS accumulations between seal, elk, and wild rice. High trophic aquatic to semi-aquatic species such as seals showed the highest accumulation of PFAS in their protein rich organs. Other aquatic animals or semi-aquatic species may have higher rates of PFAS due to water filtration through their gills and prolonged exposure compared to terrestrial animals. Traditional foods such as elk in the great plains and wild rice have not been shown to heavily bioaccumulate PFAS. However, to reduce the risk of PFAS consumption, it is recommended that protein-rich organs be avoided, regardless of an animal's trophic status.

Other sources of contamination may be through the inhalation or consumption of fine dust particles, for those who live near landfills, military bases, firefighting training facilities, or use PFAS materials in their homes. To deter anxiety related to PFAS bodily accumulations individuals can reduce their exposure to PFAS by educating their family, friends, and communities about where PFAS can be found and avoid PFAS coated or contaminated items in the household. Examples of items to avoid are grease/water resistant packaging, water or other drinkable liquids left out for a significant amount of time (such as overnight), carpet or furniture stain resistant or proof sprays, brands like Gore-Tex, water resistant or proof camping gear, and Teflon non-stick pans. Alternative materials for these goods are reusable glass containers for food, Gore-Tex-free or PFAS-free rain resistant or proof water camping gear, and cast-iron pots and pans that can build up a non-stick surface with proper care over time.

Monolithic treatment of PFAS across Native lands is not achievable. While there may be overlap based on foods, medicines, and drinking water sources the ubiquity of PFAS in our world makes it hard to create blanket plans that span whole regions. This means that culturally appropriate testing needs to be made available for all Native communities who wish to have their foods, medicines, and waters tested. Testing would hopefully help increase communities' access to knowledge on how to reduce risk while still participating in traditional lifeways – directly allowing for communities and individuals to perform food, medicine, and water sovereignty – as is their right. The U.S. government has invested some money into Native drinking water infrastructure, but more needs to be done to increase funds, make access to funds available to those who most need it, and create true accountability for industrial polluters. State and Federal self-accountability is needed for sites that affect Native communities' foods, waters, and medicines that have been polluted by state or federal entities – such as landfills and military bases. These actions may be accomplished by having fewer restrictions on PFAS testing financial assistance applications, scholarships for education of Native youth and adults who are interested in toxicological research – especially in culturally appropriate settings, and greater legally binding agreements with current polluters to clean-up and phase out pollutants. PFAS are likely to be around for hundreds of years, but action needs to be taken now to help ensure the health and safety of Native communities for current and future generations.

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