MEMORANDUM

Date: January 29, 2020

To: The Honorable Chairman and Members
Pima County Board of Supervisors

From: C.H. Huckelberry
County Administrator

Re: **Environmental Toxic Substance Assessment for Per- and Polyfluoroalkyl Substances (PFAS) in Pima County Water prepared under Contract with Pima County Health Department**

Intermittently since 2018, the Pima County Health Department received community inquiries regarding the health implication of exposures to Per- and Polyfluoroalkyl Substances (PFAS). At that time, upon consultation with the Health Board, the County commissioned a report to summarize the state of the sciences in the areas and available local information regarding this subject. The attached final report dated December 20, 2019 is a result of this activity. I have asked Deputy County Administrator Dr. Francisco Garcia to brief each of your offices on this matter.

The report was authored by Dr. Paloma Beamer and Dr. Marc Verhougstraete of Environment, Exposure Science and Risk of Assessment Center of The University of Arizona, College of Public Health. The report details the impact and ubiquity of human-made PFAS contamination and details the impact on Pima County and other communities in Arizona in drinking water and more generally in the environment. It also summarizes the limited scientific knowledge of the human health consequences of such exposure and identifies some mitigation strategies.

Although the County is not a water provider, we are interested in understanding the consequences of human exposure to these substances. Given the present lack of information and regulatory standards for exposure to these products by the US Environmental Protection Agency, the County will take actions to reduce human and environmental exposure to these chemicals.

CHH/lab

Attachment

c: Jan Lesher, Chief Deputy County Administrator
Francisco Garcia, MD, MPH, Deputy County Administrator and Chief Medical Officer, Health and Community Services

Environmental Toxic Substance Assessment
Per- and Polyfluoroalkyl Substances (PFAS) in Pima County Water

Pima County, Arizona

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December 20, 2019

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EXECUTIVE SUMMARY
PFAS Environmental Toxic Substance Assessment

Purpose

Beginning in March 2018, the Pima County Health Department received community inquiries regarding exposures to per- and polyfluoroalkyl substances (PFAS) via drinking water in Pima County. There are historical local community concerns about man-made groundwater contamination and the role of local government in addressing these concerns. This report seeks to summarize the available local information and place it in the context of available research.

PFAS are a class of over 3,000 man-made chemicals historically widely used in industrial production of common household items such as non-stick pans, stain protection on fabrics, upholstery, carpets, and even dental floss. PFAS is widely used in military applications and is a key component of petroleum-firefighting foams. Due to these practices, PFAS has contaminated surface and groundwater across the nation.

Ingestion is the primary route of exposure for PFAS and it is estimated that 72% of the total exposure is from food ingestion, 22% is from water consumption, and 6% is from dust ingestion. Although food ingestion associated with consumer products typically accounts for the highest exposure route, the purpose of this report is to discuss PFAS in the local public drinking water systems, including a review of background information, presence in Pima County drinking water systems, health effects, and mitigation strategies for personal exposure.

PFAS in Local Water Systems and Safety Regulation

PFAS are recognized by the US Environmental Protection Agency (US EPA) as emerging contaminants of concern. Emerging contaminants are usually synthetic chemicals or pharmaceuticals that are being detected in the environment due to improved analytical methods or new uses. They can also be contaminants that are naturally occurring or that have been measured in the environment for a long time, but due to research that are more recent developing health concerns. In recent years, the US EPA has conducted environmental monitoring of PFAS in drinking water sources and the Agency for Toxic Substances and Disease Registry (ATSDR) conducted a toxicological profile for PFAS in 2018.

PFAS' presence in drinking water is a widespread issue that is not limited to a single county or water provider. Even within Pima County, it is a complex picture built from reporting information from multiple entities, local and federal government, including Marana Water, Tucson Water, the Arizona Department of Environmental Quality, Davis-Monthan Air Force Base, Arizona Air National Guard, Pima County Regional Wastewater Reclamation District, and the US EPA. PFAS has been detected in local groundwater by these entities in concentrations from 12 to >10,000 parts per trillion, yet *none* of these wells are being served to the public directly. Efforts are being made, even without federal regulation, to address these concerns.

There are no PFAS national drinking water regulatory standards, known as a Maximum Contaminant Level (MCL), which specifies the level at which these contaminants may be acceptable in potable water. The US EPA has established a drinking water health advisory level for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) (two substances in the PFAS group) in drinking

water, either individually or in combination, of 70 parts per trillion (ppt). Health advisories are non-enforceable and non-regulatory concentration recommendations below which consumption is thought to be acceptable and not pose an elevated risk. Health advisories are intended to inform local officials on the health risk based on US EPA review of scientific studies.

The City of Tucson Water Department has adopted the internal operating target level of 18 ppt for PFOA and PFOS combined, and 47 ppt for PFHxA and PFHxS combined. It is important to note that private drinking water wells are not regulated by US EPA and therefore those who rely on a private well are encouraged to have their water tested for PFAS by an US EPA-approved laboratory.

PFAS Health Concerns

PFAS is of high environmental and health concern because it is highly persistent in the human body, has high potential for exposure, and has many known or suggested adverse health effects. PFAS exposures can occur through ingestion of contaminated drinking water, food, dust, and the use of consumer products in our homes or at work that contain PFAS. The relationship between PFAS exposure and adverse health outcomes is complex and continues to be researched. To date, PFAS exposure has been associated increased risk cardiovascular, gastrointestinal, musculoskeletal, endocrine, immune, developmental, diabetes, cancer, hepatic, renal, and reproductive disease, as well as adverse pregnancy and birth outcomes. This report summarizes ninety-nine studies that suggest significant relationships between exposure to a PFAS substance and a health outcome in humans.

Vulnerable Populations and Risk Mitigation

Populations that are especially vulnerable to PFAS include fetuses, infants, and immunocompromised individuals.

Individuals can take precautionary steps to protect themselves from PFAS exposure by avoiding or replacing water sources above the health advisory level or using a home water treatment option to reduce the concentration of PFAS in their drinking water. Replacement options should be utilized with caution because alternative sources, like bottled water, are rarely monitored for PFAS, meaning that the exposure is unknown. Some home treatment systems are certified to remove PFAS from drinking water. These devices are most commonly granular activated carbon (GAC) or reverse osmosis (RO). At this time, it is uncommon for stock refrigerator filters to remove PFAS. Before purchasing a point-of-use device, confirm that the product is certified by the National Sanitation Foundation (NSF) for NSF Protocol P473. Additional information is available through Good Housekeeping and NSF International.

Individuals can also reduce their exposures to PFAS by avoiding fabrics treated with water-resistant treatments like Polartec, and Gore-tex, using stainless steel and cast iron cookware instead of non-stick cookware like Teflon, skipping optional stain-repellant treatment on new carpets and furniture like Scotchguard, avoiding personal care products with PTFE or “fluoro” ingredients, and eating less fast food and microwave popcorn as the wrappers and bags are often coated in PFAS[1].

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List of Acronyms

ADEQ Arizona Department of Environmental Quality
ADHD attention deficit hyperactive disorder
AEC absolute eosinophil counts
AFCEC Air Force Civil Engineer Center
AFFF aqueous film forming foam
ANSI American National Standards Institute
AST aspartate aminotransferase
ATSDR Agency for Toxic Substances and Disease Registry
CAP Central Arizona Project
CERCLA Comprehensive Environmental Response, Compensation and Liability Act
CCL Contaminant Candidate List
DMAFB Davis Monthan Air Force Base
DWHA Drinking Water Health Advisory
ECP eosinophilic cationic protein
eGFR/GFR glomerular filtrate rates
GAC granular activated carbon
HDL "good" cholesterol
HR higher risk
LDL "bad" cholesterol
LR lower risk
MCL Maximum Contaminant Level
MRLs Minimal Risk Levels
Me-PFOSA-AcOH 2-(N-Methyl-perfluorooctane sulfonamido) acetic acid
NC risk not clear
NCP New Chemicals Program
NPDWR National Primary Drinking Water Regulations
NSF National Sanitation Foundation
PFAS Per- and Polyfluoroalkyl Substances
PFBuS Perfluorobutane sulfonic acid
PFDeA Perfluorodecanoic acid
PFDoA Perfluorododecanoic acid
PFHpA Perfluoroheptanoic acid
PFHxA Perfluorohexanoic acid
PFHxS Perfluorohexane sulfonic acid
PFNA Perfluorononanoic acid
PFOA Perfluorooctanoic acid
PFOS Perfluorooctane sulfonic acid
PFUA Perfluoroundecanoic acid
ppt parts per trillion
PTFE Polytetrafluoroethylene
PWS public water system
RO reverse osmosis
SDWA Safe Drinking Water Act
SNUR Significant New Use Rule
T3 triiodothyronine
T4 thyroxine

TARP Tucson Airport Remediation Project
TSCA Toxic Substances Control Act
TSH thyroid stimulating hormone
UCMR Unregulated Contaminant Monitoring Rule
US EPA US Environmental Protection Agency
WWTP wastewater treatment plant

Acknowledgments

The authors wish to thank the employees of Pima County Health Department, Pima County Department of Environmental Quality, and the City of Tucson-Tucson Water Department for their critical review and expert knowledge contributions to this report.

Introduction: PFAS Background, Pima County Water Sources, and Drinking Water Safety Strategies

Pima County Water Sources and Contaminants

Contaminants in drinking water sources may come from the natural environment, human activity, or a combination of both. In Pima County, most drinking water comes from groundwater, surface water, or a combination of the two. Surface water from the Colorado River travels to Pima County via the Central Arizona Project (CAP) to supplement local groundwater sources.[2] Contaminants can enter these source waters through point-source pollution (pollution inputs that have discrete, identifiable sources) or non-point-source pollution (pollution inputs with no concentrated, clearly identifiable source such as storm water runoff).[3] Source water contaminants may exist naturally, exist naturally but increase due to human activity, or exist solely from human activity.[3,4]

When considering chemical contaminants in drinking water sources, it is important to remember that being a natural or man-made contaminant has no direct bearing on the potential health impacts of such contamination.[5] Contaminants found in groundwater may be of natural origin (*e.g.* dissolution of environmental lead or manganese into water sources) or result from human activity (*e.g.* leaking underground tanks, such as septic or fuel tanks, contaminants leaching from landfills, pesticide and fertilizer use, or contaminants discharged in municipal wastewater streams).[6] Purely human-produced chemical pollutants are synthetic and have usually been produced by manufacturing processes, industrial practices, and similar human activities.[4] Chemicals that can cause adverse health effects may be of natural or man-made origin and, therefore, it cannot be determined simply using source information what the level of concern should be surrounding a potential contaminant.

Many unregulated chemicals may occur in drinking water systems. The concentration of these chemicals, the dose, personal vulnerability, and other sources of exposure are essential to prioritizing hazardous chemicals. Contaminants of emerging concern are unregulated chemicals that have recently entered the public awareness as more research and laboratory detection methods become available. This does not imply that contaminants were absent prior to public awareness since any chemical widely produced and used will likely be released into the environment.[6] The US Toxic Substances Control Act allows 84,000 chemicals on the market but has only tested the toxicity of around 1,000 of those chemicals and when a chemical is determined to be dangerous to humans it is often replaced by another untested chemical.[7] This has resulted in thousands of chemicals in our environment with very little information about their safety. Similarly, we do not have methods for measuring many of these chemicals in water. Methods for prioritizing emerging contaminants of concern are being developed based on a wide range of factors including contaminant properties, water safety context, health concerns, detectable levels and input from experts and stakeholders.[8] **It is important to remember that advances in research will continue to identify emerging contaminants as time moves forward. Municipalities and individuals must take the most informed steps possible to face these challenges as they arise.**

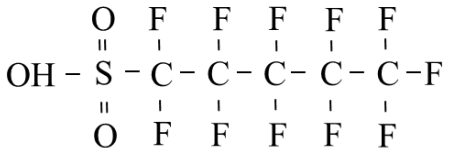
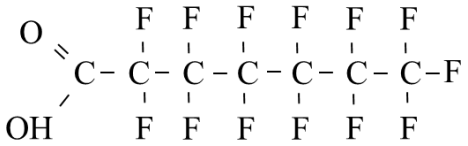
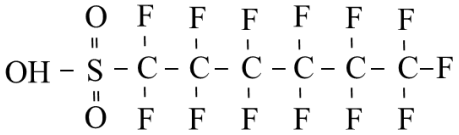
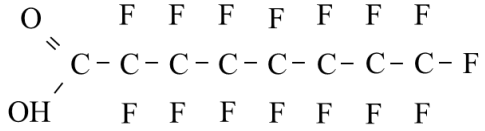
Per-and Polyfluoroalkyl Substances

Per- and polyfluoroalkyl substances (PFAS) are a class of human produced chemicals which can enter the environment from many sources. The PFAS class is a highly prioritized

environmental concern because it is highly persistent in the human body and in the environment, has high potential for exposure, and has many known/suggested adverse health effects. There are over 3,000 individual chemicals within the PFAS family.[9] PFAS were first produced in 1947 for industrial use to create foams, including firefighting foams, and slick coatings.[10] Home uses for PFAS include non-stick pans, stain protection on upholstery, and coated dental floss.[11] PFAS were designed specifically to not break down and to be water and oil repellant in order to protect consumer products. However, these same qualities are what make PFAS so persistent in the environment and allow PFAS to travel through the environment indefinitely without breaking down.[12] **PFAS are mobile in the environment, do not degrade readily under natural conditions, and bioaccumulate and biomagnify (meaning it may accumulate in a living organism over time and move upwards through the food chain)[13] in wildlife and humans.[10]** PFAS have been detected in 98% of human serum samples in widespread population studies and in remote environments such as the Arctic.[14,15]

PFAS chemicals are sorted into short and long chain structures. Long chain PFAS are persistent in the body and environment, can bioaccumulate, and include two of the most-studied PFAS substances: perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS).[16] Shorter chain structures are often selected as the replacement chemicals for long chain PFAS that have been banned or phased-out; however, the short chain PFAS are mobile and extremely persistent in the environment, are even more difficult to remove from water, and uncertainty surrounds their health impacts.[16] Short chain PFAS include perfluoroalkane sulfonic acids with carbon chain lengths of five or fewer and perfluorocarboxylic acids with carbon chains lengths of six or fewer. Long chain PFAS include perfluoroalkane sulfonic acids with carbon chain lengths of six or greater and perfluorocarboxylic acids with carbon chain length of seven or greater.[16] These structural differences are shown below in Table 1.

Table 1. Short and long chain PFAS chemical structures

	Perfluoroalkane Sulfonic Acids	Perfluorocarboxylic Acids
Short Chain	 (or shorter)	 (or shorter)
Long Chain	 (or longer)	 (or longer)

PFAS are released to the environment during industrial production, firefighting foam application, wastewater treatment plant discharge, biosolids land application, and surface waste (i.e. landfills) leaching into groundwater.[17] PFAS can be found in wastewater treatment plant (WWTP) effluent if PFAS chemicals are present in the influent. Evidence suggests that PFAS associated biotransformation can occur under multiple conditions, including in wastewater treatment process,

aerobic soils, humans, animals, plants, and marine and freshwater systems.[18–21] Vulnerable drinking water systems are typically in close proximity to land contamination sites surrounding facilities using PFAS, firefighting training areas, military bases, and wastewater treatment plants.[14,22,23] PFAS has also been detected in water with no obvious contaminant source.[24]

Drinking water is just one source of PFAS exposure in day-to-day life. A person can be exposed to PFAS in food, household products, the workplace, and animals used as food sources.[25] For example, Egeghy and Lorber created a scientific model based on extensive real-world data which estimated that a typical adult intakes 160 ng PFOS/day with 72% of exposure due to food ingestion, 6% from dust ingestion, 22% due to water ingestion.[26] Another study determined PFAS exposure primarily occurs through direct ingestion of food and water, indirect dust ingestion, and hand-to-mouth transfer from treated carpets.[27] Skin absorption and outdoor and indoor inhalation each accounted for less than 1% of PFOS exposure. Evidence is too limited to draw meaningful conclusions; however, it was found that in regions with known PFAS environmental contamination some milk, cheese, and produce samples had detectable PFAS present. In other testing, not limited strictly to contaminated areas, produce, meat, seafood, cake, and raw milk had PFAS concentrations above the lower limit of quantification.[28] A detailed summary of the sources of PFAS exposure was produced by the Agency for Toxic Substances and Disease Registry and can be found here. To most effectively reduce PFAS exposure overall it is also important to consider reducing PFAS exposure through limiting home use of products that contain PFAS. Although this report focuses on man-made water contamination, other methods to reduce PFAS exposure are briefly addressed in the risk mitigation section of this report.

Drinking water regulations are established by the US EPA and enforced locally by the Arizona Department of Environmental Quality (ADEQ).[4] PFAS is currently unregulated in drinking water, but the US EPA has already taken precautionary measures to address the growing concern regarding PFAS in drinking water, including a drinking water health advisory, described in the "US Environmental Protection Agency - Drinking Water Health Advisories (DWHA)" section of this report.[29] In 2002, the US EPA published a Significant New Use Rule (SNUR) regarding 13 chemicals in the PFAS group to be included under the Toxic Substances Control Act (TSCA).[30] Under TSCA, manufacturing and importation of PFAS must be reported. Additionally, part of the SNUR development process involved the US EPA working with 3M Corporation to voluntarily discontinue the production of PFOS in 2002.[30] The US EPA also developed another SNUR to have additional PFAS, including PFOA, reported similarly to PFOS.[30,31] The US EPA 2010/2015 PFOA Stewardship Program was established by the US EPA in 2006 to work with eight leading PFAS-producing companies to commit to a 95% reduction of PFOA by 2010 and eliminate PFOA from emissions and products by 2015.[32] Globally, China is one of the few remaining producers and consumers of PFOS.[33] With research ongoing, there is some evidence to suggest that import and use of goods from countries with ongoing PFAS production can lead to PFAS exposure and environmental release in countries that have discontinued its production.[34] Following the original phasing out of certain PFAS, manufacturers developed replacement perfluorinated compounds that are similar but have structural differences to decrease bioaccumulation and environmental persistence.[14] The US EPA's New Chemicals Program (NCP) under the TSCA reviews PFAS substitutes and restricts PFAS use to improve understanding of the chemicals' fate and effects.[35]

Overall, the reduction in the manufacturing and importation of PFAS in the United States has been effective in reducing human serum PFOS and PFOA levels.[15,31] Surveys have studied certain sub-populations and identified the following PFAS types in human serum: PFOA, PFAS, PFOS,

PFDeA, PFHxS, Me-PFOSA-AcOH, PFBuS, PFHpA, PFNA, PFUA, and PFDoA.[36–39] Reductions of PFOS and PFOA levels in human serum have been reported as production has been phased out.[15,31]

PFAS and Water Safety Guidelines

Safe Drinking Water Act (SDWA) and Unregulated Contaminant Monitoring Rule (UCMR)

Beyond the SNUR, the US EPA uses the Safe Drinking Water Act (SDWA) to propose potential contaminants for regulation.[40] The process to get a contaminant regulated using the SDWA happens under the National Primary Drinking Water Regulations (NPDWR). Step one of a NPDWR establishment is to identify contaminants. The SDWA specifies that the US EPA must find that the contaminant is possibly linked to adverse health effects, occurs frequently, and there must be a feasible plan for health risk reduction for Public Water Systems (PWS).[31] Contaminants under consideration are placed on a Contaminant Candidate List (CCL). The US EPA uses the CCL in its selection of contaminants for a particular Unregulated Contaminant Monitoring Rule (UCMR) cycle.[41]

The UCMR is a tool to collect data for suspected drinking water contaminants that do not have current health-based regulations.[41] The reports from the UCMR program provide drinking water occurrence data for monitored contaminants and is a primary source of occurrence and exposure information that the US EPA uses to make regulatory decisions for emerging contaminants.[41] Different contaminants are monitored in each UCMR cycle. The UCMR Cycle 3 monitored, among other contaminants, PFOA, PFOS, PFNA, PFHxS, PFHpA, PFBS from 2013 to 2015. A breakdown of relevant data from the UCMR 3 is included in the "PFOA, PFOS, PFHpA, and PFHxS Detection in Public Water Systems in Pima County and Across Arizona" section of this report.

US Environmental Protection Agency - Drinking Water Health Advisories (DWHA)

The US EPA publishes non-regulatory, non-enforceable health advisories under authority of the SDWA.[42] The US EPA health advisories are meant to provide technical information about contaminants that are known to occur in drinking water and can cause human health effects.[31] Scientifically supported acceptable concentrations of PFAS in drinking water have evolved over time as more evidence becomes available. Provisional US EPA health advisories for drinking water levels of PFOA and PFOS were 400 and 200 ppt, respectively.[43–45] As research evolved, those advisory levels have decreased.

PFAS do not have an established national or state drinking water standards but the US EPA has created a DWHA for water containing PFOA and PFOS, either individually or in combination, of 70 ppt. The US EPA DWHA of 70 ppt was chosen based on experiments which gave increasing doses of PFOA to pregnant mice, monitored health outcomes, and found evidence of pregnancy loss, reduced offspring survival, developmental delays, bone development issues, and premature puberty in males.[46]

Agency for Toxic Substances and Disease Registry (ATSDR) – Minimal Risk Levels

ATSDR is a federal public health agency under the US Department of Health and Human Services which focuses on the public health effect of hazardous substances in the environment.[47]

In June of 2018, the ATSDR published a draft toxicological profile for perfluoroalkyls. This thorough document provides detailed background, toxicological and epidemiological studies findings, environmental studies, and other relevant information about PFAS (including PFOA and PFOS). The ATSDR health-based Minimal Risk Levels (MRLs) provide an estimate of the amount of a chemical a person can eat, drink, or breathe each day without detectable risk to health.[48] **The ATSDR has set MRLs, the dose (mg/kg/day) that a person can ingest or inhale each day without a likely risk to health, for multiple PFAS chemicals.** Of the many substances in the PFAS class, some have oral MRLs for intermediate risk levels, which are summarized in Table 2. Based upon the size of and average child and an average adult, and average drinking water consumption these MRLs can be converted into drinking water guideline levels.[49]

Table 2. Oral MRLs for intermediate risk levels for select substances within the PFAS class as defined by ATSDR[48] These values have been converted to suggested drinking water guidelines based upon the size of an average child and an adult and their consumption.[49]

PFAS Substance	MRL (mg/kg/day)	Child (ppt)	Adult (ppt)
Perfluorooctanoic acid (PFOA)	3×10^{-6}	21	78
Perfluorooctane sulfonic acid (PFOS)	2×10^{-6}	14	52
Perfluorohexane sulfonic acid (PFHxS)	2×10^{-5}	140	517
Perfluorononanoic acid (PFNA)	3×10^{-6}	21	78

These MRLs are based on two additional studies incorporated into the ATSDR toxicological profile that were not used in setting the US EPA DWHA. The first exposed pregnant mice to 0.3 mg/kg/day PFOS or PFOA during pregnancy which resulted in affected motor function in offspring.[50] The second study examined in-utero and postnatal exposure to PFOA in mice and demonstrated that PFOA accumulated in bones, affected bones cells, and indirectly impacted bones through increased body weight and lessened activity.[51]

At this point in time, there is no federal government requirement to regulate PFAS in drinking water. However, as the evidence suggesting that PFAS can cause serious adverse health effects increases, many states have or are in the process of creating PFAS standards. Arizona has taken no such action. Our local municipalities are voluntarily setting targets for PFAS concentration in their drinking water. **Tucson Water has voluntarily chosen an interim internal operating target of 18 ppt for PFOA and PFOS and 47 ppt PFHxS and PFHxA, individually or in combination**. This target is largely based on the evidence contained in the ATSDR report and the utility's conservative approach to protect consumers' health. For reference, when thinking about the concentration targets, 1 ppt is equal to one drop of water into a pool as big as a football field and three stories (43 feet) deep.[52]

Potential Adverse Health Effects Associated with PFAS

Adverse Health Outcomes

While much research still needs to be conducted, there have been an increasing number of studies documenting adverse health effects among the US population associated with exposure to PFAS. Of greatest concern are studies suggesting that PFAS exposure may cause cancer and developmental effects in humans. Animal studies have also shown adverse health effects at ever-lower levels of PFAS exposure. While the human health evidence is not clear, there is enough to warrant larger epidemiological investigations and for the establishment of drinking water health advisories while the more detailed studies are being conducted.

The associations between PFAS contaminated drinking water and adverse human health effects are still being assessed including very large epidemiological investigations currently being conducted by ATSDR.[53] Most studies to date have focused on assessing the associations between human serum levels of PFAS and health outcomes, and not necessarily the associations between drinking water exposures and health outcomes. However, it is well documented that drinking water is an important source of human exposure to PFAS particularly following the phase out of PFOA and PFOS from consumer products.[54–56] The ATSDR toxicological profile for PFAS summarizes possible health outcomes resulting from PFAS exposure.[14] A brief overview of the adverse health effects associated with some PFAS substances based on the ATSDR profile is illustrated in Table 3 and accompanied by a written summary. According to the ATSDR toxicological profile, there are 99 human studies that document a statistically significant association between PFAS levels in serum and health outcomes in humans. The majority of these studies are based upon PFAS levels measured in serum.

Table 3 shows each health outcome category and each of the 14 specific PFAS chemicals summarized in the ATSDR report. Under each PFAS chemical, the number of studies that found a significant association between the amount of that PFAS chemical measured in serum and harmful health effects are marked by “HR” (i.e., greater PFAS levels in blood correlated with increased risk bad health outcomes). The number of articles that found a significant association between the amount of that PFAS type in the body and a lower risk of the health outcome are marked by LR. In some cases, significant associations were determined between PFAS levels in the body and certain health markers like hormone levels, but it is not clear if this is harmful or not harmful for your health and this depends on the particular study. The number of these studies is indicated by “NC”. Associations do not necessarily equate with certainty to causal relationship. However, as evidence of correlations are built up over time, the causal relationship becomes more strongly supported. A more detailed table and the list of references are included in Appendix 1.

Table 3. *Summary of human health outcomes associated with some PFAS chemicals*

	PFAS Type											
	Long-Chain								Short-Chain			
	PFOA	PFOS	PFHxS	PFNA	PFDeA	PFUA	PFDoA	PFOSA	PFHpA	PFBuS	PFBA	PFHxA
Cardiovascular disease	9 HR	3 HR				1 LR			1 HR			
Gastrointestinal		1 HR										
Musculoskeletal	5 HR	1 HR 1 LR	1 HR	2 HR								
Endocrine	2 HR 6 NC 1 LR	2 HR 7 LR	2 HR 1 NC	2 NC	2 NC	3 NC	4 NC					
Immune	13 HR	7 HR	6 HR	8 HR	6 HR	2 HR	5 HR			3 HR		
Reproductive	5 NC 6 HR	5 NC 3 HR	2 HR	1 NC		1 NC						
Pregnancy and Birth Outcomes		3 HR		1 HR	1 HR							
Developmental	5 LR 6 HR	3 HR	2 HR	1 HR	1 HR			1 HR				
Diabetes	2 LR 2 HR	4 HR		2 LR		3 LR						
Cancer	4 HR 2 LR	2 HR 1 LR	2 HR			1 HR		1 HR				
Hepatic	39 HR 1 LR	21 HR	3 HR	4 HR	3 HR	1 HR				1 HR		
Renal	16 HR	9 HR	2 HR	1 HR								

The numbers in each column represents the number of studies found to have a significant association between PFAS type and the indicated health outcome

HR (Higher risk): greater PFAS levels in blood correlated with significantly increased risk bad health outcomes

LR (Lower risk): greater PFAS levels in blood correlated with significantly lower risk of health outcomes

NC (not clear): PFAS levels are significantly associated with other health measurements (e.g., hormone levels) but it is not clear if is this is harmful or not harmful for your health.

Potential Carcinogenic Health Outcomes

Exposure to various PFAS chemicals has been associated with cancer outcomes in human populations.[42,57,58] While a direct causal relationship between PFAS and cancer has not been determined, many studies have found strong evidence supporting a connection between the two. PFOA exposure has been positively associated with testicular cancer,[59] kidney cancer deaths,[60,61] and prostate cancer deaths (i.e., greater PFOA exposure will result in a greater likelihood of these cancers).[62] PFOA has been negatively associated with colorectal cancer[63] and bladder cancer (i.e., greater PFOA exposure levels have been associated with decreased likelihood of these cancers).[64] PFOS exposure has been with increased risk of bladder cancer[65] and breast cancer[66] and has been associated with decreased risk of colorectal cancer.[63] PFHxS exposure has been associated with increased prostate cancer deaths[67] and breast cancer.[68] PFUA exposure has also been associated with increased prostate cancer deaths.[67] PFOSA exposure has been positively associated with breast cancer.[68] Given these conflicting results and that we are exposed to mixtures of these compounds, not

just one PFAS chemical at a time, makes it difficult to establish causality. However, these results are suggestive that PFAS exposures likely increase the rates of some cancers in the population.

Potential Non-Carcinogenic Health Outcomes

Various PFAS chemicals have been associated with certain kidney outcomes. Increased levels of serum uric acid (a potential marker of kidney disease) has been associated with exposure to PFOA,[69–74] PFOS,[71,72,74] and PFHxS.[73] PFOA[70,71,73,75,76] and PFOS[70,75] exposure has been positively associated with increased hyperuricemia (elevated uric acid in blood) risk. PFOA,[72,75,77] PFOS, [72,75,77] PFHxS,[77] PFNA[77] exposure have been associated with reduced glomerular filtration rates (i.e., eGFR/GFR). PFOA[60,75] and PFOS[75] have been associated with increased chronic kidney disease.

Certain PFAS have been associated with possible endocrine effects. Triiodothyronine (T3), thyroxine (T4), and thyroid stimulating hormone (TSH) are markers tested to indicate thyroid health.[78] In some studies PFOA[79] and PFOS[80] exposure has been associated with increased TSH, however, other studies have found PFOS,[81,82] PFNA,[82] PFDeA,[82] PFUA,[82] and PFDoA[82] to be associated with decreased TSH. Certain studies have shown an association between PFOA[79,83] and PFOS[84] exposure and increased T3, FT3, or T3 uptake. Alternatively, other studies have found PFOA,[85] PFOS,[81] PFDeA,[80] PFUA,[80] and PFDoA[82] exposure to be associated with decreased T3, FT3, or T3 uptake. PFOA exposure was associated with increased risk of thyroid disease in women in one study.[86] The same study found increased thyroid medication use in men.[86] Another study found an association between PFOS and PFHxS exposure and increased risk of subclinical hypothyroidism, an association between PFHxS exposure and increased risk of subclinical hyperthyroidism, and an association between PFOA exposure and decreased risk of subclinical hyperthyroidism.[87] Yet another study found an association with increased risk of functional thyroid disease and PFOA exposure.[88] Because both increased levels and decreased levels of hormones in the body can affect your health, it is not clear what the significant associations between PFAS exposures and these hormone levels mean for long-term health risk. It is clear, from these group of studies, that PFAS exposure is associated with changes to hormone levels in the body.

PFAS exposure has been associated with many aspects of immune health. PFOA,[89,90] PFOS,[89–91] PFHxS,[89,90] PFNA,[89,90] PFDeA,[89,90] PFDoA,[89] and PFBuS[90] have been associated with increased asthma diagnosis or severity. One study found associations between PFOA, PFOS, PFNA, PFDeA, and PFDoA exposure with increased levels of serum immunoglobulin E concentrations, absolute eosinophil counts (AEC), and eosinophilic cationic protein (ECP) concentrations and an association between PFHxS exposures and increased AEC and ECP concentrations.[89] Decreased levels of tetanus antibodies following vaccination were associated with and PFOA,[92] PFHxS,[93] PFUA,[94] and PFDoA concentrations.[94] One study saw an association between PFOA and PFNA exposures and number of common cold episodes, as well as an association between PFOA and PFHxS exposures and number of gastroenteritis episodes, and associations between PFOA, PFOS, PFHxS, and PFNA exposure and decreased rubella antibody levels following vaccintation.[95] PFOA is associated with reduced seroprotection from influenza A H3N2 virus.[38] Higher IL-4 or IL-5 T-helper cytokine levels are associated with PFOA,[90] PFNA,[90] PFBuS exposure.[90,96]

PFAS exposure has been associated with developmental effects in children. Lower levels of mental development indices in 6 month old female infants was associated with prenatal PFOA exposure.[97] A separate study found that increased PFOA exposure was associated with increased full-scale IQ along with decreased ADHD indicators.[98] Interestingly, PFOA exposure has been associated

with increased executive function scores when evaluated by the mother but decreased scores when evaluated by the teacher.[99] One study found an association between PFOA, PFOS, and PFHxS exposure and increased risk of ADHD[100] but another study found PFOA exposure was associated with decreased risk of ADHD.[101] One study found an association between prenatal PFOA exposure and being categorized as hypotonic which includes infant qualities such as reduced muscle tone.[102] PFOA exposure was associated with reduced rates of externalizing behavior (negative outward behavior in response to their environment) in boys.[103] Prenatal exposure to PFOS and PFOA had an association with increased rates of hyperactive behavior.[104] A separate study found that infants born to mothers with greater PFOS levels were slightly more likely to sit independently later.[105] PFOS, PFHxS, PFNA, PFDeA, and PFOSA have been associated with lower scores of children's performance when performing a task that requires behavioral inhibition.[106] PFOS has been associated with reduced rates of learning problems.[101]

Multiple PFAS chemicals have been linked with reproductive and pregnancy outcomes. PFOA,[107,108] PFOS,[107] and PFHxS[108] exposure have been associated with reduced fecundity. PFOA,[107–109] PFOS,[107,109] and PFHxS[108] exposure have also been associated with increased infertility. PFOA is associated with higher levels of prolactin (the hormone which triggers breast milk production) in serum of males.[110] A separate study reported associations in males between PFOA exposure in utero and lower sperm count and concentration as well as higher levels of two reproductive hormones: LH and FSH. The same study found no association PFOS exposure or any of the mentioned parameters.[111] Another study found an association between PFOS and PFUA exposure and lower levels of FSH hormone.[112] Increased testosterone levels are associated with increased PFOA[113] exposure and decreased PFOS exposure.[112,114] There was an association between PFOA exposure and higher levels of the sex hormone-binding globulin.[112] There were associations between increased rates of the hormone estradiol and PFOA[113] and PFNA[115] exposures and an association between lower levels of estradiol and PFOS exposure.[114,116] PFOS exposure has been associated with increased rates of pre-term birth, small size for gestational age, and low birth weight and associated with decreased gestational age, birth weight, and head circunference.[117,118] PFNA and PFDeA exposures were both associated with increased rates of miscarriage before 12 weeks.[119]

There are mixed results on the risk of various musculoskeletal outcomes and PFAS exposures. One study found associations between PFOA exposure and increased osteoarthritis risk and PFOA, PFHxS, and PFNA exposures with increased osteoporosis risk. The same study found associations between PFOS exposure and decreased osteoarthritis risk as well as PFOA, PFOS, and PFNA exposure and lower bone mineral density.[120] Another study found associations between PFOA exposure and osteoarthritis risk and osteoporosis risk.[121]

Multiple studies link PFAS exposures with hepatic health outcomes. PFOA,[69,96,113,122–130131] PFOS,[84,96,126,132,133] PFHxS,[127] PFNA,[96,129] PFDeA,[129] and PFUA[96] are all positively associated with total cholesterol.[131] PFOA,[96,113,122,123,128–130,132] PFOS,[96,132,133] PFHxS,[127] and PFNA[129] exposure have been associated with increasing levels of LDL ("bad" cholesterol). PFOS[122] and PFDeA[123] exposure have been associated with higher levels of HDL ("good" cholesterol). At the same time, PFOA[135] and PFOS[133] exposure have been reported to have an association with lower levels of PFOS levels have been associated with lower ratios of total cholesterol to HDL levels.[134] PFOA,[96,123,136] PFOS,[84,136] and PFNA[96] exposures have all been associated with higher triglyceride levels. PFOA has been associated with both increased[125] and decreased[137] associated with bilirubin levels (increased bilirubin can be a marker of liver issues). PFOA[113,138,139] and PFOS[139] exposure have been associated with increased levels of gamma-glutamyl transferase, an enzyme that can be elevated in blood when lever or bile

duct disease is present. PFOA has been positively associated with α2 globulins (used as markers of many types of disease).[69] PFOA[125,135,139] and PFOS[84,139] exposure have also been associated with higher levels of aspartate aminotransferase (AST); elevated AST in the blood can be a marker of liver damage. Finally, PFOA[137–140] and PFOS[84,139,140] exposures have been associated with increased levels of alanine aminotransferase (a marker of liver disease).

Multiple studies have reported PFAS exposures associated with cardiovascular effects. Two studies have reported that PFOA exposure was associated with increased risk of cardiovascular disease.[53,74] PFOA[141] and PFOS[142,143] exposures have been associated with increased risk of stroke and increased carotid intima media thickness (a measure used to assist in diagnosis of carotid atherosclerotic vascular disease[144]). PFOA exposure has been positively associated with increased risk of angina, myocardial infarction, peripheral arterial disease, systolic blood pressure, hypertension risk,[53,145,146] cerebrovascular disease,[62] and pregnancy-induced hypertension.[147] PFOS[118] and PFUA[148] exposures have been associated with increased and decreased risk of pre-eclampsia, respectively. Lastly, PFHpA exposure has been associated with increased risk of coronary artery disease.[149]

PFAS exposure has been associated with various diabetes-related outcomes. One study found associations between PFOS exposure and increased glucose intolerance, fasting blood glucose, diabetes, and glycated hemoglobin. Decreased glucose intolerance was associated with exposure to PFOA, PFNA, and PFUA. [150] Decreased fasting blood glucose was associated with PFOA and PFUA and decreased risk of diabetes was associated with PFNA and PFUA. [150] Two separate studies found PFOA to be associated with increased rates of diabetes deaths.[60,62]

One study demonstrated an association between PFOS exposure and increased gallstone formation and gallbladder inflamation.[151]

Vulnerable Populations and Risk Mitigation

Vulnerable Populations

Most people have been exposed to PFAS due to its environmental persistence and wide-spread occurrence.[31] PFAS can have very long half-lives in human tissue ranging between <1 to 8.5 years.[14] Numerous studies are currently being conducted to assess and monitor human and environmental health outcomes following PFAS exposure.[31] **Currently known vulnerable populations include those living near or working in a PFAS manufacturer, fetuses, infants, and immunocompromised individuals.**[15,31,49,152] PFAS can cross the placenta and have been tentatively linked to adverse health outcomes, including low birth weight, in fetuses of pregnant women.[153] Infants are also identified as a vulnerable population because PFAS can enter breast milk or infant formula may be mixed with PFAS-contaminated drinking water.[154] Infants and young children are also at a higher risk due to increased intakes of food and water per pound of body weight, exposure pathways through breast milk, mouthing and ingestion of non-food items and dust as well as increased contact with the floor, particularly treated carpets.[27,155] Most recently, immunological effects are being identified in PFAS exposure and health effects studies.[49] Associations have been assessed between PFAS exposure and decreased serum concentrations of antibodies following vaccinations.[93] For this reason, immunocompromised individuals are now also listed as a sensitive population for PFAS exposures.

PFOA, PFOS, PFHpA, and PFHxS Detection in Public Water Systems in Pima County and Across Arizona

PFAS presence in drinking water or its sources is a widespread issue that is not limited to a single county or water provider. Even within Pima County, it is a complex picture built from reporting information from multiple entities, including Marana Water, the Arizona Department of Environmental Quality, Davis-Monthan Air Force Base, Tucson Water, Arizona Air National Guard, and Pima County Regional Wastewater Reclamation District, and the federal government.

A recent report included a map of PFAS (PFOA and PFOS) detections in various local water sources (including but not limited to production wells) and documented 1, 27, and 20 locations in Metro Water, Tucson Water, and Marana Water districts, respectively.[156] Each location may have had one or more positive detection events. While not all detections were above the US EPA DWHA, it further emphasizes that PFAS presence is not limited to individual water providers and could potentially be present in local private wells. A map of wells where PFAS has been measured can be found here (https://www.tucsonaz.gov/files/water/docs/Map_Detects_July_2019_web.pdf). For the vast majority of monitored wells in the Tucson Metro area, PFAS was not detected in any of the samples.

Pima County Waste Water released a thorough review of emerging contaminant concerns in the region. [157] It included a summary of PFOS and PFOA measurements in December 2016 from Pima County Water Reclamation Facilities, all of which were well below DWHA suggestions. The report additionally details local media coverage of PFAS in regional waters and provides a few maps of local water sampling points. It then covers some available information surrounding DMAFB and Tucson International Airport. Finally, the report provides a copy of the Arizona Department of Environmental Quality status report on Emerging Contaminants in Arizona Water from September 2016.[157]

In 2016, PFAS was measured above the health advisory in seven supply wells for the Picture Rocks and Airline/Lambert Water Systems served by Marana Water (Table 4).[156]

Table 4. Wells and the respective concentration for PFAS that serve Marana Water and are above the US EPA DWHA.

Well Name	Sample Date	Combined PFOA and PFOS concentration (ppt)
Continental Reserve 1	12/13/2016	80
Continental Reserve 2	12/13/2016	92
Airline	12/13/2016	102
La Puerta	12/13/2016	90
Lambert	12/13/2016	90
Saguaro Bloom	12/13/2016	109
Falstaff	12/13/2016	87

The Water Infrastructure Finance Authority awarded a $15 million loan to Marana to build two new plants designed to remove PFAS from the affected water and, as of May 2019, the draft preliminary design report is complete.[158] In the meantime, Marana Water has mentioned at-home water treatment systems as a temporary solution including home treatment systems reviewed by Good Housekeeping

and that granular activated carbon has been utilized to reduce PFAS.[159] These home-treatment systems should be certified by the National Sanitation Foundation (NSF) for NSF Protocol P473.

A report produced by the Arizona Department of Environmental Quality summarized 109 samples from 68 of the 1,500 PWSs in Arizona.[160] Twenty samples were positive and six (five in Pima County) were above the current US EPA DWHA of 70 ppt.

Tucson Water has monitored for PFAS in its system since 2009 as part of its internal Sentry Water Quality Monitoring Program, a voluntary program to proactively look for unregulated compounds in its water supplies. Between 2009 and 2016, PFAS were found in wells on the northwest side near the Santa Cruz River, at levels below EPA's DWHA at the time was set at 600 ppt for combined PFOA and PFOS. When EPA revised this DWHA to 70 ppt in late 2016, Tucson Water shut off six of these northwest-side wells, and initiated testing of the rest of its system. At that time, two new wells adjacent to Davis-Monthan Air Force Base were found to have high levels of PFAS and were shut down. As of October 2019, Tucson Water had shut down 19 groundwater wells due to the presence of PFAS.

In 2018, Tucson Water noticed a discrepancy in samples of water coming from the Tucson Airport Remediation Project (TARP), a treatment facility the utility operates to clean trichloroethylene (TCE) and 1,4-Dioxane from a plume of industrial groundwater contamination. It was discovered that some samples had been taken from a sampling spigot installed to test a water main that was receiving water from non-TARP sources. Therefore, samples were then taken from the correct TARP water main and other locations throughout the TARP-served area. Sampling for PFAS showed concentrations in this service area were < 30 ppt. Upon this discovery, the utility flushed the system using water from its central distribution system, shut down TARP wells with the highest PFAS concentrations, and blended TARP plant water with water from the main distribution system. In addition to these remediation steps, Tucson Water has replaced the carbon used in the TARP treatment process to specifically remove PFAS (the plant was not originally designed to remove these contaminants). Following this step, the utility has been able to reduce PFAS in water distributed from TARP to below its operational targets of 18 ppt PFOS+PFOA and 47 ppt for PFHxS +PFHxA.

Tucson Water conducted sampling for PFAS in its distribution system in 2018 and modified its internal operational target to 18 ppt as a voluntary, proactive operational strategy to protect public health. As a result, it has removed 17 groundwater production wells from service where PFOA and PFOS have been found. Tucson Water has created a set of frequently asked questions regarding PFAS presence in local water sources here.[162] The City of Tucson maintains a website summarizing wells that have been tested for PFAS and efforts being made to inform the public here.

PFAS was detected in soil, sediment, and groundwater from Davis-Monthan Air Force Base in concentrations above the US EPA Health Advisory levels.[163] Davis-Monthan Air Force Base recently released a report summarizing PFOS and PFOA, the Air Forces' response to emerging contaminant concerns, and Davis-Monthan-specific information.[164] The report explains that aqueous film forming foam (AFFF) containing PFOS and PFOA has been used by the Air Force when fighting petroleum fires since 1970. Based on a 2009 policy established by the Department of Defense requiring assessment of emerging contaminants, in 2010 the Air Force Civil Engineer Center (AFCEC) determined that AFFF may have been released at active bases, reserve bases, Air National Guard bases, closed bases, fire training areas, emergency response areas, aircraft crash sites, or other release areas. The AFCEC is guided by the Comprehensive Environmental Response, Compensation and

Liability Act (CERCLA) when addressing emerging contaminants. The Site Inspection of AFFF Release Areas Environmental Programs Worldwide- Davis-Monthan Air Force Base, Arizona report summarized local efforts to identify PFAS in drinking water. PFOS and PFOA, individually and in combination, were found above the US EPA DWHA throughout vertical aquifer samples and PFBS (a PFAS replacement chemical) was detected below the US EPA Tap Water Regional Screening Level at AFFF Release Area 3. Combined PFOA and PFOS concentrations in one well reached 14,400 ppt while PFOS concentrations had a maximum concentration of 13,000 ppt. The Davis-Monthan Air Force Base is continuing to work with AFCEC to identify further studies or surveys that may be needed. The Air Force makes public reports available here.

Pima County has created a comprehensive report summarizing PFAS in Pima County water here. The Pima County Regional Wastewater Reclamation Department has detected PFAS in wastewater effluent and local surface water, but all values were below EPA's DWHA. This online tracker provides PFAS contamination information for national and international sources. Residents may contact their water utility for more information on how PFAS are being addressed in their community water supply. Residences and others using private wells are encouraged to test individual sources for possible contamination. For more information and a list of certified drinking water laboratories, visit: https://www.epa.gov/dwlabcert.

Federally, during the US EPA's UCMR 3 collection period of 2013 to 2015 some drinking water sources in Arizona were found to have PFAS concentrations above the UCMR 3 Minimum Reporting Levels. While less current, UCMR 3 data further contributes to the context and knowledge surrounding PFAS in local drinking water sources. UCMR 3 samples were taken at the entry point to the distribution system.[165] The full UCMR 3 data set is available online here.[166] The data set shows 6,648 samples tested for PFAS from 75 PWSs in Arizona, eight of which were in Pima County. Forty-seven samples had PFAS results above the Minimum Reporting Levels in Arizona with 6 samples coming from two Pima County PWSs. Select UCMR 3 data has been summarized below in Table 5 which shows average PFAS concentration results above Minimum Reporting Levels in Arizona PWSs and in Table 6 which shows the six samples above Minimum Reporting Levels in Pima County. The next cycle, UCMR 4 is currently underway.[167]

Table 5. Summary of PFAS detections above Minimum Reporting Levels in Arizona during UCMR 3

	Average Reported PFAS Chemical Result (ppt)[1,2]			
PWS Name	**PFOA**	**PFOS**	**PFHpA**	**PFHxS**
Oatman Water Company	31	265	14.5	710
City of Tempe	37	78.6	12	62.5
Liberty Water LPSCO	50	205	30	67.5
Town of Payson	38	*	*	*
City of Tucson	*	56	*	340
Metropolitan DWID	*	52	*	*

Table 6. Summary of PFAS detections above Minimum Reporting Levels in Pima County during UCMR 3

PWS Name	PFAS Chemical[1]	Sample Date	PFAS Chemical Concentration (ppt)
Metropolitan DWID[2]	PFOS	08/20/2014	51
Metropolitan DWID[2]	PFOS	03/23/2015	53
City of Tucson[3]	PFOS	04/16/2013	56
City of Tucson[3]	PFOS	11/20/2013	56
City of Tucson[3]	PFHxS	11/20/2013	260
City of Tucson[3]	PFHxS	04/16/2013	420

[1]: Minimum Reporting Levels for PFOS and PFHxS are 0.04 µg/L and 0.03 µg/L, respectively.
[2]: Metropolitan DWID PWS is associated with zip code 85704 based on data available through the US EPA regarding zip codes served by PWSs.
[3]: City of Tucson PWS is associated with zip codes 85629, 85641, 85658, 85701, 85704, 85705, 85706, 85707, 85708, 85709, 85710, 85711, 85712, 85713, 85714, 85715, 85716, 85718, 85719, 85726, 85730, 85735, 85736, 85737, 85739, 85741, 85742, 85743, 85745, 85746, 85747, 85748, 85749, 85750, 85756, and 85757 based on data available through the US EPA regarding zip codes served by PWSs.

Risk Mitigation

While this report emphasized ingestion exposure to PFAS via drinking water, it is important to note that PFAS occurs from other pathways as well. The Agency for Toxic Substance and Disease Registry makes the following recommendations to reduce overall PFAS exposure: 1) if drinking water is contaminated, use alternative sources for all activities where water may be swallowed such as a certified home treatment system, 2) avoid eating contaminated fish per local health advisories, and 3) avoid using household products containing PFAS (contact Consumer Product Safety Commission at (800) 638-2772 for more information).[54]

The Environmental Working Group has been providing the public with recommendations on how to reduce PFAS exposure for almost 20 years. They recommend that individuals can reduce their exposures to by avoiding fabrics treated with water-resistant treatments like Polartec, and Gore-tex, using stainless steel and cast iron cookware instead of non-stick cookware like Teflon, skipping optional stain-repellant treatment on new carpets and furniture like Scotchguard, avoiding personal care products with PTFE or “fluoro” ingredients, and eating less fast food and microwave popcorn as the wrappers and bags are often coated in PFAS.[1]

Studies have seen that PFAS concentration in dust was positively correlated with carpeting in the home.[168] Further studies have found that PFAS found in household dust were significantly related to floor type, number of occupants of the home, and age of the home.[169] These studies begin to explain potential sources of PFAS in household dust however more research is needed to clearly define steps to reduce PFAS exposure via dust.

Consuming PFAS-containing drinking water through direct water ingestion or cooking are established routes of exposure to PFAS.[42,170] Although PFAS are persistent in the environment, precautions can be taken on an individual level to decrease exposure through drinking water. Options include use of drinking water treatment and alternative drinking water sources. Various systems, ranging from point-of-use filters to point-of-entry reverse osmosis water treatment strategies are effective in reducing

PFAS from drinking water. A first step in selecting risk mitigation strategies is to determine the existing level of PFAS contamination, and whether mitigation is required.

Drinking tap water is often a good option because it is held highly accountable by regulatory agencies and routinely monitored. Municipalities aim to be proactive in addressing water quality concerns when serving the public. Based on size, they may be mandated to monitor for PFAS even though it is an unregulated chemical substance and smaller water systems may elect to monitor for PFAS even if it is not mandated. Municipalities are a part of a collective, nationwide knowledge base regarding emerging contaminants and treatment options to deal with them. **Alternative sources, such as bottled water, are often either not monitored for PFAS or extremely limited in the information they provide about emerging contaminants, so the potential for exposure is unknown.** If a municipal water source is serving water above health advisory limits, implementing a mitigation technique such as a home treatment system may be recommended to reduce PFAS exposure.

Residential Water and Private Wells

Municipal water systems may be tested for perfluorinated compounds and municipalities regularly publish water quality reports. **However, if a private well is the home drinking water source, the US EPA recommends sending water samples to certified laboratories.**[171] For more information and a list of certified drinking water laboratories, visit: https://www.epa.gov/dwlabcert.

It is suggested to periodically monitor private residential drinking water wells. If the residential drinking water sample results from a US EPA certified drinking water laboratory have PFOA and PFOS levels higher than 70 ppt, additional sampling is recommended.[42] If additional sampling results confirm that residential drinking water contains PFOA and PFOS concentrations above the 70 ppt health advisory, treatment measures are recommended. The Arizona Department of Health Services maintains detailed information for private well owners regarding regulations, testing information, and who to reach out to with any questions.[172] The Arizona Department of Health Services and the US EPA can provide relevant information and recommendations for remediation strategies for those using private wells for residential water supplies. PFAS levels have been measured above the US EPA DWHA in private wells in southern Arizona.[173]

Mitigation Choices and Options

Boiling water may concentrate the PFAS in water.[174]

Mitigation measures can always be taken if there is any concern about drinking water safety. This may include water above or below the DWHA of 70 ppt. One solution is to substitute personal drinking water in the home. If utilizing substitution options, this water should also be used for food-preparation purposes. Bottled water producers are required to produce water under sanitary conditions, protect water sources from contaminants, use quality control processes, and sample and test source water and final product for contaminants.[175] If using bottled water, it is important to ensure its safety by taking precautions such as using bottled water relatively quickly after opening and storing bottled water in a cool place.[176] **Please note that bottled water is not regulated for PFAS, there is very limited data regarding PFAS levels in bottled water and therefore it is unknown if it is a good substitution.** Bottled water should only be used as a substitute when there is known PFAS contamination of the original water source and other mitigation approaches are not available.

Residential water treatment options exist for individuals with water quality issues or concerns. [177–180] At-home treatment typically occurs at the "point-of-use" (meaning that water treatment happens wherever you are directly using the water such as attached to the faucet or in a pitcher before you drink the water) or "point-of-entry" (meaning water treatment occurs as water enters the property and therefore all water outlets in the home are putting out treated water). Water treatment system type, treatment system location, homeownership or renting status, water usage amount, and cost are all factors to consider when selecting a residential water treatment system. Treatment methods have been identified as successful in removing some PFAS compounds, including PFOA and PFOS. These methods include Granular Activated Carbon (GAC), Powdered Activated Carbon, ion exchange resins, reverse osmosis (RO), and nanofiltration.[180,181] GAC and RO are likely the most feasible options for residential water treatment. Proper maintenance of the residential treatment system is critical to reducing contaminant breakthrough or concentration.

To assist in making informed choices for PFAS drinking water removal systems, several third party, non-government organizations have developed accreditation standards and protocols for water processing materials. **The American National Standards Institute (ANSI) and the National Sanitation Foundation (NSF) are the two leaders in testing products and setting treatment standards for aesthetics, health effects, emerging compounds, incidental contaminants, microbial contaminants, chemicals metals, and PFOA/PFOS**.[182,183] The ANSI-NSF P473 is the standard for PFOA and PFOS reduction in drinking water. The NSF completes rigorous product testing to determine if a system complies with the ANSI-NSF P473 standard. Some home treatment systems are certified to remove PFAS from drinking water.[177–180] The point-of-use devices are most commonly Granular Activated Carbon (GAC) or Reverse osmosis (RO). At this time, it is uncommon for stock refrigerator filters to remove PFAS. Before purchasing a point-of-use device, confirm that the product is NSF Certified for P473. Additional information is available through Good Housekeeping and NSF International.[179] Another great resource for PFAS information was recently published by the University of Arizona Cooperative Extension and is available here.[184]

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Appendix 1. Further detail regarding negative human health outcomes association with each PFAS type discussed including references used in creation of Table 3 in the report.

*The reference numbers presented in Appendix 1 coincide with the reference numbers in Appendix 2. The appendices references do not correspond to the reference numbers in the main report.

		PFAS Type											
		Long-Chain								Short-Chain			
		PFOA	**PFOS**	**PFHxS**	**PFNA**	**PFDeA**	**PFUA**	**PFDoA**	**PFOSA**	**PFHpA**	**PFBuS**	**PFBA**	**PFHxA**
Cardiovascular	Cardiovascular disease	+ (1, 7)											
	Stroke; Coratid intima media thickness	+ (1)	+ (3, 8)										
	Angina; myocardial infarction; peripheral arterial disease; systolic blood pressure; hypertension risk	+ (1, 6, 7)											
	Cerebrovascular disease	+ (4, 59)											
	Pregnancy induced hypertension	+ (2)											
	Pre-eclampsia		+ (10)				- (9)						
	Coronary artery disease									+ (5)			
Gastrointestinal	Cholelithiasis or acute cholecystitis		+ (11)										
Musculoskeletal	Osteoarthritis risk	+ (12, 14)	- (12)										
	Bone mineral density	- (12)	- (12)		- (12)								
	Osteoporosis risk	+ (12, 14)		+ (12)	+ (12)								
Endocrine	TSH	+ (18)	+ (15); (16, 27)		- (27)	- (27)	- (27)	- (27)					
	T3; FT3; T3 uptake	+ (18, 24) - (17)	+ (21) - (16)			- (15)	- (15)	- (27)					
	T4; T4 binding globulin; Free T4	+ (17, 18)	+ (16, 22)	+ (25)	- (23)		- (23)	- (23, 27)					
	Thyroid disease risk (female)	+ (20)											
	Taking thyroid medication (male)		+ (20)										
	Subclinical hypothyroidism		+ (25)	+ (25)									
	Subclinical hyperthyroidism	- (25)		+ (25)									
	Functional thyroid disease	+ (26)											
Immune	Asthma diagnosis; asthma severity	+ (28, 36)	+ (28, 32, 36)	+ (28, 36)	+ (28, 36)	+ (28, 36)		+ (28)			+ (36)		
	IgE	+ (28)	+ (28)		+ (28)	+ (28)		+ (28)					
	Absolute eosinophil counts; Eosinophil cationic protein	+ (28)	+ (28)	+ (28)	+ (28)	+ (28)		+ (28)					
	Tetanus antibody levels	- (29)		- (35)			- (33)	- (33)					
	Diptheria antibody levels	- (29, 30, 35)	- (33)		- (33)	- (30, 33)	- (33)	- (33)					
	Common cold (# of episodes)	+ (31)			+ (31)								
	Rubella antibody levels	- (31)	- (31)	- (31)	- (31)								
	Gastroenteritis (# of episodes)	+ (31)		+ (31)									
	Seroprotection from influenza A H3N2 virus	- (34)											
	IL-4 or IL-5 T-helper cytokine	+ (36)			+ (36)						+ (36, 90)		
Reproductive	Fecundability	- (37, 38)	- (37)	- (38)									
	Infertility	+ (37, 38, 39)	+ (37, 39)	+ (38)									
	Prolactin	+ (40)											
	FSH	+ (41)	- (42)				- (42)						
	LH	+ (41)											
	Testosterone	+ (82)	- (42, 43)										
	SHGB	+ (42)											
	Estradiol	+ (82)	- (43, 45)		+ (44)								
Pregnancy and Birth Outcomes	Pre-term birth; small for gestational age; low birth weight		+ (10, 46)										
	Gestational age; birth weight; head circumference		- (46)										
	Miscarriage before gestation week 12				+ (47)	+ (47)							
Developmental	Mental development indices, 6-month old female infants	- (48)											
	Full-scale IQ	+ (49)											
	Scores on tests of ADHD (lower scores favorable)	- (49)											
	Executive function scores (mother completed survey)	+ (50)											
	Executive function scores (teacher completed survey)	- (50)											
	ADHD	+ (53) - (51)	+ (53)	+ (53)									
	Hypotonic	+ (52)											
	Scores on tests evaluating externalizing behavior	- (54)											
	Abnormal behavior and hyperactivity	+ (55)											
	Delay in age of sitting and earlier use of word-like sounds		+ (56)										
	Performance on task requiring behavioral inhibition		- (57)	- (57)	- (57)	- (57)			- (57)				
Diabetes	Glucose tolerance	- (58)	+ (58)		- (58)		- (58)						
	Fasting blood glucose	- (58)	+ (58)				- (58)						
	Diabetes		+ (58)		- (58)		- (58)						
	Diabetes deaths	+ (59, 62)											
	Glycated hemoglobin		+ (58)										
Cancer	Prostate cancer deaths	+ (59)		+ (65)			+ (65)						
	Colorectal cancer	- (60)	- (60)										
	Bladder cancer	- (61)	+ (66)										
	Kidney cancer deaths	+ (62, 64)											
	Testicular cancer	+ (63)											
	Breast cancer		+ (67)	+ (68)					+ (68)				

		PFAS Type											
		Long-Chain								Short-Chain			
		PFOA	**PFOS**	**PFHxS**	**PFNA**	**PFDeA**	**PFUA**	**PFDoA**	**PFOSA**	**PFHpA**	**PFBuS**	**PFBA**	**PFHxA**
Hepatic	HDL	- (87)	+ (69) - (80)			+ (76)							
	LDL	+ (74-77, 79, 82, 85, 90)	+ (74, 80, 90)	+ (73)	+ (76)								
	TC/HDL-C ratio		- (69)										
	Total cholesterol	+ (70, 72, 73, 75-77, 79, 81-84, 85, 90)	+ (21, 74, 80, 83, 84, 90)	+ (73, 84)	+ (76, 84, 90)	+ (76, 84)	+ (84)				+ (90)		
	Elevated cholesterol	+ (77, 88)	+ (77)										
	Elevated LDL		+ (77)										
	Triglycerides	+ (85, 86, 90)	+ (21, 86)		+ (90)								
	Bilirubin	+ (81) - (71)											
	GGT	+ (78, 82, 89)	+ (89)										
	AST	+ (81, 87, 89)	+ (21, 89)										
	ALT	+ (71, 78, 89, 91	+ (21, 89, 91)										
	α2 globulins	+ (70)											
Renal	Serum uric acid	+ (70, 92-95, 97)	+ (93, 94, 97)	+ (95)									
	Hyperuricemia risk	+ (92, 93, 95, 97, 98)	+ (92, 97)										
	eGFR; GFR	- (94, 96, 99)	- (94, 96, 99)	- (99)	- (99)								
	Chronic kidney disease	+ (62, 96)	+ (96)										

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children/ adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
1	Renal; Respiratory; Endocrine; Metabolic; Cardiovascular	2008	Anderson-Mahoney, P., Kotlerman, J., Takhar, H., Gray, D., & Dahlgren, J.	Self-reported health effects among community residents exposed to perfluorooctanoate.	New Solutions	Cross-sectional comparison study of self-reported health history and symptoms	US; near a Teflon manufacturing plant located along the Ohio River in Wood County, West Virginia.	Adults	N=566 residents and occupational	Renal	Kidney disease (self-reported)	PFOA	+
										Respiratory	Chronic bronchitis	PFOA	+
										Endocrine	Thyroid problems (self-reported)	PFOA	+
										Metabolic	Diabetes (Self-reported)	PFOA	+
										Respiratory	Asthma	PFOA	+
										Respiratory	Shortness of breath on stairs	PFOA	+
										Cardiovascular	Cardiovascular disease (self-reporte	PFOA	+
										Cardiovascular	Angina (self-reported)	PFOA	+
										Cardiovascular	Myocardial infarction	PFOA	+
										Cardiovascular	Stroke	PFOA	+
2	Cardiovascular	2013	Darrow, L. A., Stein, C. R., &Steenland, K.	Serum Perfluorooctanoic Acid and Perfluorooctane Sulfonate Concentrations in Relation to Birth Outcomes in the Mid-Ohio Valley, 2005–2010	Environmental Health Perspectives, 121(10),	Cross-sectional	US; mid-Ohio valley	Adults	N=1,330; C8 Health project	Cardiovascular	Pregnancy-induced hypertension	PFOA	+
3	Cardiovascular	2013	Lin, C.-Y., Lin, L.-Y., Wen, T.-W., Lien, G.-W., Chien, K.-L., Hsu,	Association between levels of serum perfluorooctane sulfate and carotid artery intima-media thickness in adolescents and young adults	International Journal of Cardiology, 168, 3309–3316.	Cross-sectional	Taiwan	Both	N=644; general population ages 12-30	Cardiovascular	Carotid intima media thickness	PFOS	+
4	Cardiovascular	2009	Lundin, J. I., Alexander, B. H., Olsen, G. W., & Church, T. R	Ammonium Perfluorooctanoate Production and Occupational Mortality	Epidemiology, 20(6), 921–928.	Occupational; prospective	US; Cottage Grove, Minnesota	Adults	N=3,993; Occupational	Cardiovascular	Cerebrovascular disease risk	PFOA	+
5	Cardiovascular	2015	Mattsson K, Rignell-Hydbom A, Holmberg S, et al.	Levels of perfluoroalkyl substances and risk of coronary heart disease: Findings from a population-based longitudinal study	Environ Res 142:148-154	Case-control; longitudinal	US	Adults	N=231 cases with CHD, 231 controls	Cardiovascular	Coronary artery disease	PFHpA	+
6	Cardiovascular	2012	Min, JY., Lee, KJ., Park, JB., et al.	Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults.	Occupational and environmental medicine	Cross-sectional	US	Adults	N=2,208; NHANES	Cardiovascular	Systolic blood pressure	PFOA	+
7	Cardiovascular	2012	Shankar, A., Xiao, J., & Ducatman, A.	Perfluorooctanoic Acid and Cardiovascular Disease in US Adults.	Archives of Internal Medicine, 172(18), 1397.	Cross-sectional	US	Adults	N=1,216; NHANES	Cardiovascular	Cardiovascular disease	PFOA	+
											Peripheral arterial disease	PFOA	+
											Hypertension risk	PFOA	+
8	Cardiovascular	2013	Simpson, C., Winquist, A., Lally, C., & Steenland, K.	Relation between perfluorooctanoic acid exposure and strokes in a large cohort living near a chemical plant.	Environmental Research, 127, 22–28.	Cross-sectional	US	Adults	N=28,541; 11% also had occupational exposure; C8 Health Project	Cardiovascular	Stroke	PFOA	+
9	Cardiovascular	2014	Starling, A. P., Engel, S. M., Richardson, D. B., Baird, D. D., Haug,	Perfluoroalkyl Substances During Pregnancy and Validated Preeclampsia Among Nulliparous Women in the Norwegian Mother and Child Cohort Study.	American Journal of Epidemiology, 179(7), 824–833.	Cross-sectional	Norway	Adults	N=976; pregnant women	Cardiovascular	Pre-eclampsia	PFUA	-
10	Cardiovascular; Pregnancy; Birth outcomes	2009	Stein CR, Savitz DA, Dougan M	Serum levels of perfluorooctanoic acid and perfluorooctane sulfonate and pregnancy outcome	Am J Epidemiol 170(7):837-846.	Cross-sectional	US	Adults	N=5,652 pregnant women and infants; C8 participants	Cardiovascular	Pre-eclampsia	PFOS	+
										Pregnancy	Pre-term birth	PFOS	+
										Birth outcomes	Low birth weight	PFOS	+
11	Gastrointestinal	2004	Olsen, G. W., Burlew, M. M., Marshall, J. C., Burris, J. M., & Mandel, J. H.	Analysis of episodes of care in a perfluorooctanesulfonyl fluoride production facility	Journal of Occupational and Environmental Medicine, 46(8), 837–846	Occupational; Cross-sectional	US	Adults	N=652 exposed, N=659 for non-exposed	Gastrointestinal	Cholelithiasis or acute cholecystitis	PFOS	+
12	Musculoskeletal	2011	Innes, K. E., Ducatman, A. M., Luster, M. I., &	Association of Osteoarthritis with Serum Levels of the Environmental Contaminants Perfluorooctanoate and Perfluorooctane Sulfonate in a Large Appalachian Population	American Journal of Epidemiology, 174(4), 440–450.	Cross-sectional	US	Adults	N=49,432 C8 Health Project	Musculoskeletal	Osteoarthritis risk (physician diagno	PFOA	+
											Osteoarthritis risk (physician diagno	PFOS	-

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children/ adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
13	Musculoskeletal	2016	Khalil, N., Chen, A., & Lee, M.	Association of perfluoroalkyl substances, bone mineral density, and osteoporosis in the U.S. Population in NHANES 2009-2010	Environ Health Perspect 124(1):81-87	Cross-sectional	US	Adults	N=1,914 NHANES	Musculoskeletal	bone mineral density at total femur	PFOS	-
											femoral neck (FNBMD)	PFOS	-
											bone mineral density at total femur	PFOA	-
											Osteoporosis risk; self-reported phy	PFOA	+
											bone mineral density at total femur	PFNA	-
											femoral neck (FNBMD)	PFNA	-
											lumbar spine (LSBMD)	PFNA	-
											Osteoporosis; self-reported physicia	PFNA	+
											Osteoporosis; self-reported physicia	PFHxS	+
14	Musculoskeletal	2013	Uhl, S. A., James- Todd, T., & Bell, M. L.	Association of Osteoarthritis with Perfluorooctanoate and Perfluorooctane Sulfonate in NHANES 2003-2008.	Environmental Health Perspectives , 121(4), 447–452.	Cross-sectional	US	Adults	N=1,888 male and 1,921 female adults; NHANES	Musculoskeletal	Osteoarthritis risk; self-reported	PFOA	+
15	Endocrine	2015	Berg, V., Nøst, T., Hansen, S., Elverland, A., Veyhe, A., Jorde, R., … Sandanger, T	Assessing the relationship between perfluoroalkyl substances, thyroid hormones and binding proteins in pregnant women; a longitudinal mixed effects approach	Environment International, 77, 63–69	Cross-sectional	Norway	Adults	N=391; The Northern Norway Mother-and- Child Contaminant Cohort Study	Endocrine	TSH	PFOS	+
											T3	PFDA	-
											FT3	PFUnDA	-
16	Endocrine	2009	Dallaire, Renée Dewailly, Éric Pereg, Daria Dery, Serge Ayotte, Pierre	Thyroid Function and Plasma Concentrations of Polyhalogenated Compounds in Inuit Adults	Environmental Health Perspectives, 117(9), 1380-1386.	Cross-sectional	Inuit adults	Adults	N=623 Inuit adult population of Nunavik	Endocrine	TSH	PFOS	-
											T3	PFOS	-
											T4-binding globulin	PFOS	-
											Free T4	PFOS	+
17	Endocrine	2011	Knox, S. S., Jackson, T., Frisbee, S. J., Javins, B., & Ducatman, A. M.	Perfluorocarbon exposure, gender and thyroid function in the C8 Health Project	The Journal of Toxicological Sciences 36(4):403-410	Cross-sectional	US	Adults	N=50,113; C8 Health Project; ≥20 years of age	Endocrine	T4	PFOA	+
											T3 uptake	PFOA	-
18	Endocrine	2015	Lewis, R. C., Johns, L. E., & Meeker, J. D.	Serum Biomarkers of Exposure to Perfluoroalkyl Substances in Relation to Serum Testosterone and Measures of Thyroid Function among Adults and Adolescents from NHANES 2011-2012	Int. J. Environ. Res. Public Health, 12, 12	Cross-sectional	US	Both	N=1,682; NHANES	Endocrine	TSH	PFOA	+
											Free T4	PFOA	+
											Free T3	PFOA	+
											Total T3	PFOA	+
											Free T4	PFOS	+
19	Endocrine	2012	Lopez-Espinosa, M.-J., Mondal, D., Armstrong, B., Bloom, M. S., & Fletcher, T.	Thyroid Function and Perfluoroalkyl Acids in Children Living Near a Chemical Plant	Environmental Health Perspectives, 120(7), 1036–1041.	Cross-sectional	US; mid-Ohio valley	CA	N=10,725 children aged 1–17 years; community affected by the Washington Works facility	Endocrine	Thyroid disease	PFOA	+
											Hypothyroidism	PFOA	+
20	Endocrine	2010	Melzer, D., Rice, N., Depledge, M. H., Henley, W. E., & Galloway, T. S.	Association between serum perfluorooctanoic acid (PFOA) and thyroid disease in the NHANES study	Environmental Health Perspectives , 118(5), 686–692.	Cross-sectional	US	Adults	N=3,966; NHANES	Endocrine	Thyroid disease risk; female	PFOA	+
											Taking thyroid medication; male	PFOS	+
21	Hepatic; Endocrine	2003	Olsen, G. W., Burris, J. M., Burlew, M. M., &Mandel, J. H.	Epidemiologic assessment of worker serum perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) concentrations and medical surveillance examinations	Journal of Occupational and Environmental Medicine, 45(3), 260–270	Occupational; longitudinal and cross-sectional	US and Belgium	Adults	N=518; 421 male and 97 female	Hepatic	ALT (alanine aminotransferase)	PFOS	+
											GGT (female only)	PFOS	+
											Total cholesterol	PFOS	+
											Triglycerides; males	PFOS	+
										Endocrine	T3	PFOS	+

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children/ adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
22	Endocrine	2015	Shrestha, S., Bloom, M. S., Yucel, R., Seegal, R. F., Wu, Q., Kannan, K., … Fitzgerald, E. F.	Perfluoroalkyl substances and thyroid function in older adults. *Environment International, 75,* 206–214.	Environment International, 75, 206–214.	Cross-sectional	US; Hudson Valley, NY	Adults	N=87 men and women aged 54-74 years, w/o clinical diagnosis of thyroid disease	Endocrine	Free T4	PFOS	+
											T4	PFOS	+
23	Endocrine	2014	Wang, Y., Rogan, W. J., Chen, P.-C., Lien, G.-W., Chen, H.-Y., Tseng, Y.-C., … Wang, S.-L.	Association between maternal serum perfluoroalkyl substances during pregnancy and maternal and cord thyroid hormones: Taiwan maternal and infant cohort study.	Environmental Health Perspectives, 122(5), 529–534.	Cohort	Taiwan	Both	N=285 pregnant women	Endocrine	Free T4	PFNA	-
											Total T4	PFNA	-
											Free T4	PFUA	-
											Total T4	PFUA	-
											Free T4	PFDoA	-
											Total T4	PFDoA	-
24	Endocrine	2016	Webster, G. M., Rauch, S. A., Ste Marie, N., Mattman, A., Lanphear, B. P., & Venners, S. A.	Cross-Sectional Associations of Serum Perfluoroalkyl Acids and Thyroid Hormones in U.S. Adults: Variation According to TPOAb and Iodine Status (NHANES 2007–2008).	Environmental Health Perspectives 124(7):935-942	Cross-sectional	US	Adults	N=1,525	Endocrine	Free T3	PFOA	+
25	Endocrine	2013	Wen, L.-L., Lin, L.-Y., Su, T.-C., Chen, P.-C., & Lin, C.-Y.	Association Between Serum Perfluorinated Chemicals and Thyroid Function in U.S. Adults: The National Health and Nutrition Examination Survey 2007-2010.	J Clin Endocrinol Metab, 98(9), E1456-1464.	Cross-sectional	US	Adults	N=1,181; NHANES	Endocrine	Subclinical **hypo**thyroidism risk	PFOA	+
											Subclinical **hyper**thyroidism risk	PFOA	-
											Subclinical **hypo**thyroidism risk	PFOS	+
											Subclinical **hypo**thyroidism risk	PFHxS	+
											Subclinical **hyper**thyroidism risk	PFHxS	+
											Total T4	PFHxS	+
											Total T3	PFHxS	+
26	Endocrine	2014	Winquist, A., & Steenland, K.	Perfluorooctanoic acid exposure and thyroid disease in community and worker cohorts.	Epidemiology, 25(2), 255–264.	Cohort	Ohio Valley workers and community	Adults	N=28,541	Endocrine	Functional thyroid disease	PFOA	+
27	Endocrine	2016	Yang, L., Li, J., Lai, J., Luan, H., Cai, Z., Wang, Y., … Wu, Y.	Placental Transfer of Perfluoroalkyl Substances and Associations with Thyroid Hormones: Beijing Prenatal Exposure Study	Scientific Reports, 6:21699	Cohort	China; Beijing	Adults	N=157 pregnant women	Endocrine	TSH	PFOS	-
											TSH	PFNA	-
											TSH	PFDeA	-
											TSH	PFUA	-
											TSH	PFDoA	-
											Free T3	PFDoA	-
											Total T3	PFDoA	-
											Free T4	PFDoA	-
											Total T4	PFDoA	-
28	Immune	2013	Dong, G.-H., Tung, K.-Y., Tsai, C.-H., Liu, M.-M., Wang, D., Liu, W., … Chen, P.-C.	Serum polyfluoroalkyl concentrations, asthma outcomes, and immunological markers in a case-control study of Taiwanese children	Environmental Health Perspectives, 121(4), 507–513	Case-control	Taiwain; Taipei City	CA	N=231 asthmatic and 225 non-asthmatic children	Immune	Asthma diagnosis	PFOA	+
											IgE	PFOA	+
											Absolute eosinophil counts	PFOA	+
											Eosinophil cationic protein	PFOA	+
											Asthma diagnosis	PFOS	+
											Asthma severity	PFOS	+
											IgE	PFOS	+
											Absolute eosinophil counts	PFOS	+
											Eosinophil cationic protein	PFOS	+
											Asthma diagnosis	PFHxS	+
											Absolute eosinophil counts	PFHxS	+
											Eosinophil cationic protein	PFHxS	+
											Asthma diagnosis	PFNA	+
											IgE	PFNA	+
											Absolute eosinophil counts	PFNA	+
											Eosinophil cationic protein	PFNA	+

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children/ adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
											Asthma diagnosis	PFDeA	+
											Asthma severity	PFDeA	+
											IgE	PFDeA	+
											Absolute eosinophil counts	PFDeA	+
											Eosinophil cationic protein	PFDeA	+
											Asthma diagnosis	PFBuS	+
											Absolute eosinophil counts	PFBuS	+
											Asthma diagnosis	PFDoA	+
											Asthma severity	PFDoA	+
											IgE	PFDoA	+
											Absolute eosinophil counts	PFDoA	+
											Eosinophil cationic protein	PFDoA	+
29	Immune	2012	Grandjean, P., Andersen, E. W., Budtz-Jørgensen, E., Nielsen, F., Mølbak, K., Weihe, P., & Heilmann, C.	Serum Vaccine Antibody Concentrations in Children Exposed to Perfluorinated Compounds.	JAMA, 307(4), 391–397	Prospective study of a birth cohort	Faroe Islands	CA	N=587	Immune	Tetanus antibody levels at age 5	PFOA	-
											Diptheria antibody levels at age 7	PFOA	-
30	Immune	2017	Grandjean, P., Heilmann, C., Weihe, P., Nielsen, F., Mogensen, U. B., & Budtz-	Serum Vaccine Antibody Concentrations in Adolescents Exposed to Perfluorinated Compounds	Environmental Health Perspectives, 125(7), 077018	Prospective cohort	Faroe Islands	CA	N=516; General population (children examined at age 7 and 13 years)	Immune	Diptheria antibody levels at age 13	PFOA	-
											Diphtheria antibody levels at age 7	PFDeA	-
31	Immune	2013	Granum, B., Haug, L. S., Namork, E., Stølevik, S. B., Thomsen, C., Aaberge, I. S., … Nygaard, U. C.	Pre-natal exposure to perfluoroalkyl substances may be associated with altered vaccine antibody levels and immune-related health outcomes in early childhood.	Journal of Immunotoxicology, 10(4), 373–379	Prospective and cross-sectional	Norway	CA	N=56; General population; children age 3 years	Immune	Common cold (# of episodes)	PFOA	+
											Rubella antibody levels	PFOA	-
											Gastroenteritis (# of episodes)	PFOA	+
											Rubella antibody levels	PFOS	-
											Rubella antibody levels	PFHxS	-
											Gastroenteritis (# of episodes)	PFHxS	+
											Common cold (# of episodes)	PFNA	+
											Rubella antibody levels	PFNA	-
32	Immune	2014	Humblet, O., Diaz- Ramirez, L. G., Balmes, J. R., Pinney, S. M., & Hiatt, R. A.	Perfluoroalkyl chemicals and asthma among children 12-19 years of age: Nhanes (1999-2008).	Environmental Health Perspectives, 122(10), 1129–1133.	Cross-sectional	US	CA	N=1,877 adolescents; General population (NHANES)	Immune	Ever diagnosed with asthma	PFOS	+
33	Immune	2016	Kielsen, K., Shamim, Z., Ryder, L. P., Nielsen, F., Grandjean, P., Budtz-Jørgensen, E., & Heilmann, C.	Antibody response to booster vaccination with tetanus and diphtheria in adults exposed to perfluorinated alkylates.	Journal of Immunotoxicology, 13(2), 270–273.	Prospective	Denmark; Copenhagen	Adults	N=12; general population	Immune	Diphtheria antibody levels	PFOS	-
											Diphtheria antibody levels	PFNA	-
											Diphtheria antibody levels	PFDeA	-
											Diphtheria antibody levels	PFUA	-
											Tetanus antibody levels	PFUA	-
											Diphtheria antibody levels	PFDoA	-
											Tetanus antibody levels	PFDoA	-
34	Immune	2014	Looker, C., Luster, M. I., Calafat, A. M., Johnson, V. J., Burleson, G. R., Burleson, F. G., & Fletcher, T.	Influenza Vaccine Response in Adults Exposed to Perfluorooctanoate and Perfluorooctanesulfonate.	Toxicological Sciences, 138(1), 76–88	Cross-sectional	US; mid-Ohio and West Virginia	Adults	N=411; C8 Health Project	Immune	Seroprotection from influenza A H3N2 virus	PFOA	-
			Mogensen, U. B., Grandjean, P.,								Diphtheria antibody levels	PFOA	-

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children/ adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
35	Immune	2015	Heilmann, C., Nielsen, F., Weihe, P., & Budtz-Jørgensen, E.	Structural equation modeling of immunotoxicity associated with exposure to perfluorinated alkylates.	Environmental Health 14:47	Cross-sectional	Denmark	CA	N=464; children 7 years of age	Immune	Tetanus antibody levels at age 7	PFHsX	-
36	Immune	2016	Zhu, Y., Qin, X.-D., Zeng, X.-W., Paul, G., Morawska, L., Su, M.-W., … Dong, G.-H.	Associations of serum perfluoroalkyl acid levels with T-helper cell-specific cytokines in children: By gender and asthma status.	Science of the Total Environment, 559, 166–173.	Case-control	Taiwan; Taipei City	CA	N=231 asthmatic and 225 non-asthmatic children	Immune	Asthma diagnosis	PFOA	+
											IL-4 T-helper cytokine	PFOA	+
											IL-5 T-helper cytokine	PFOA	+
											Asthma diagnosis	PFOS	+
											Asthma diagnosis	PFHxS	+
											Asthma diagnosis	PFNA	+
											IL-4 T-helper cytokine	PFNA	+
											IL-5 T-helper cytokine	PFNA	+
											Serum IgE	PFNA	+
											Asthma diagnosis	PFDeA	+
											Serum IgE	PFDeA	+
											Asthma diagnosis	PFBuS	+
											IL-5 T-helper cytokine	PFBuS	+
37	Reproductive	2009	Fei, C., McLaughlin, J. K., Lipworth, L., & Olsen, J.	Maternal levels of perfluorinated chemicals and subfecundity	Human Reproduction, 24(5), 1200–1205	Cross-sectional	Denmark	Adults	N=1240 women from the Danish National Birth Cohort recruited from 1996 to 2002	Reproductive	Fecundability	PFOA, PFOS	-
											Infertility	PFOA, PFOS	+
38	Reproductive	2015	Velez, M. P., Arbuckle, T. E., & Fraser, W. D.	Maternal exposure to perfluorinated chemicals and reduced fecundity: the MIREC study.	Human Reproduction, 30(3), 701–709.	Cohort	Canada	Adults	N=1,743 pregnant women	Reproductive	Fecundability	PFOA	-
											Infertility	PFOA	+
											Fecundability	PFHxS	-
											Infertility	PFHxS	+
39	Reproductive	2012	Whitworth, K. W., Haug, L. S., Baird, D. D., Becher, G., Hoppin, J. A., Skjaerven, R., … Longnecker, M. P.	Perfluorinated compounds and subfecundity in pregnant women.	Epidemiology, 23(2), 257–263.	Case-Control	Norway	Adults	N=416 subfecund pregnant women and 474 controls	Reproductive	Infertility	PFOA	+
											Infertility	PFOS	+
40	Reproductive	1998	Olsen GW, Gilliland FD, Burlew MM, et al.	An epidemiologic investigation of reproductive hormones in men with occupational exposure to perfluorooctanoic acid	J Occup Environ Med 40(7):614-622	Cross-sectional	US	Adults	N=111 males in 1993 and 80 in 1995)	Reproductive	Prolactin; 1993	PFOA	+
41	Reproductive	2013	Vested A, Ramlau- Hansen CH, Olsen SF, et al.	Associations of *in utero* exposure to perfluorinated alkyl acids with human semen quality and reproductive hormones in adult men.	Environ Health Perspect 121(4):453-458.	Cross-sectional	Denmark	Adults	N=169 males aged 19–21 years	Reproductive	LH	PFOA	+
											FSH	PFOA	+
42	Reproductive	2015	Tsai MS, Lin CY, Lin CC, et al.	Association between perfluoroalkyl substances and reproductive hormones in adolescents and young adults	Int J Hyg Environ Health 218(5):437-443.	Cross-sectional	Taiwan	Both	N=540 adolescents and young adults aged 12–30 years	Reproductive	SHGB	PFOA	+
											FSH	PFOS	-
											Testosterone	PFOS	-
											FSH	PFUA	-
43	Reproductive	2015	Barrett ES, Chen C, Thurston SW, et al.	Perfluoroalkyl substances and ovarian hormone concentrations in naturally cycling women	Fertil Steril 103(5):1261-1270 e1263.	Cohort	Norway	Adults	N=178 women	Reproductive	Follicular estradiol	PFOS	-
44	Reproductive	2013	Joensen UN, Veyrand B, Antignac JP, et al.	PFOS (perfluorooctanesulfonate) in serum is negatively associated with testosterone levels, but not with semen quality, in healthy men	Hum Reprod 28(3):599-608	Cross-sectional	Denmark	Adults	N=247 men; mean age 19.6 years	Reproductive	Total testosterone	PFOS	-
											Free testosterone	PFOS	-
											Free androgen index	PFOS	-
											Estradiol	PFNA	+

References for PFAS Health Outcomes from ATSDR's Toxicological Profile for Perfluoroalkyls (June 2018): Studies of human subjects only with statistical significance of < 0.05

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children/ adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
45	Reproductive	2011	Knox, S., Jackson, T., Javins, B., Frisbee, S., Shankar, A., & Ducatman, A	Implications of Early Menopause in Women Exposed to Perfluorocarbons	The Journal of Clinical Endocrinology & Metabolism, *96* (6), 1747-1753.	Cross-sectional	US	Adults	N=25,957 women; C8 Health Project	Endocrine	Estradiol concentration (perimenopausal and menopausal subgroups)	PFOS	-
46	Reproductive	2012	Chen MH, Ha EH, Wen TW, et al.	Perfluorinated compounds in umbilical cord blood and adverse birth outcomes.	PLoS ONE 7(8):e42474.	Prospective cohort	Taiwan;Taiwan Birth Panel Study	CA	N=429 infants	Reproductive	Preterm birth	PFOS	+
											Gestational age	PFOS	-
											Birth weight	PFOS	-
											Head circumference	PFOS	-
											Small for gestational age	PFOS	+
47	Reproductive	2015	Jensen TK, Andersen LB, Kyhl HB, et al.	Association between perfluorinated compound exposure and miscarriage in Danish pregnant women.	PLoS ONE 10(4):e0123496.	Case-control	Denmark	Adults	N=56 cases and 336 controls	Reproductive	Miscarriage before gestation week 12	PFNA	+
											Miscarriage before gestation week 12	PFDeA	+
48	Developmental	2016	Goudarzi, H., Nakajima, S., Ikeno, T., Sasaki, S., Kobayashi, S., Miyashita, C., … Kishi, R.	Prenatal exposure to perfluorinated chemicals and neurodevelopment in early infancy: The Hokkaido Study.	Science of the Total Environment, 541, 1002–1010	Prospective birth-cohort	Japan	Both	N=514 (infants at 6 (n = 173) and 18 (n = 133) months of age) Hokkaido Study on Environment and Children's Health	Neurodevelopment	Mental development indices in 6-month old female infants	PFOA	-
49	Developmental	2013	Stein CR, Savitz DA, Bellinger DC.	Perfluorooctanoate and neuropsychological outcomes in children.	Epidemiology 24(4):590-599.	Cross-sectional	US; mid-Ohio valley	CA	N=320 children 6-12 years old; C8 Health Project	Neurodevelopment	Full scale IQ	PFOA	+
											Scores on tests of ADHD (improvement)	PFOA	+
50	Developmental	2014	Stein CR, Savitz DA, Bellinger DC.	Perfluorooctanoate exposure in a highly exposed community and parent and teacher reports of behaviour in 6-12-year-old children.	Paediatr Perinat Epidemiol 28(2):146-156.	Cross-sectional	US	CA	N=321 children 6–12 years	Neurodevelopment	Executive function scores (mother completed survey)	PFOA	+
											Executive function scores (teacher completed survey)	PFOA	-
51	Developmental	2011	Stein CR, Savitz DA.	Serum perfluorinated compound concentration and attention deficit/hyperactivity disorder in children 5-18 years of age.	Environ Health Perspect 119(10):1466-1471.	Cross-sectional	US; mid-Ohio valley	CA	N=10,546 children aged 5-18 years; C8 Health Project	Neurodevelopment	ADHD	PFOA	-
52	Developmental	2015	Donauer S, Chen A, Xu Y, et al.	Prenatal exposure to polybrominated diphenyl ethers and polyfluoroalkyl chemicals and infant neurobehavior.	J Pediatr 166(3):736-742.	Cohort	US	Both	N=349 infants at 5 weeks of age	Neurodevelopment	Hypotonic	PFOA	+
53	Developmental	2010	Hoffman K, Webster TF, Weisskopf MG, et al.	Exposure to polyfluoroalkyl chemicals and attention deficit/hyperactivity disorder in U.S. children 12-15 years of age.	Environ Health Perspect 118(12):1762-1767.	Cross-sectional	US	CA	N=571 children aged 12-15 years; NHANES	Neurodevelopment	ADHD (parent reported)	PFOA	+
											ADHD (parent reported)	PFHxS	+
											ADHD (parent reported)	PFOS	+
54	Developmental	2016	Quaak I, de Cock M, de Boer M, et al.	Prenatal exposure to perfluoroalkyl substances and behavioral development in children.	Int J Environ Res Public Health 13(5).	Cross-sectional	Amsterdam	CA	N=76 infants 18 months of age	Neurodevelopment	Scores on test evaluating externalizing behavior	PFOA	-
55	Developmental	2015	Høyer BB, Ramlau- Hansen CH, Obel C, et al.	Pregnancy serum concentrations of perfluorinated alkyl substances and offspring behaviour and motor development at age 5-9 years--a prospective study.	Environ Health 14:2.	Prospective cohort	Poland and Ukraine	CA	N=1,106 children aged 5-9 years	Neurodevelopment	Abnormal behavior	PFOA	+
											Hyperactivity	PFOA	+
56	Developmental	2008	Fei C, McLaughlin JK, Lipworth L, et al.	Prenatal exposure to perfluorooctanoate (PFOA) and perfluorooctanesulfonate (PFOS) and maternally reported developmental milestones in infancy.	Environ Health Perspect 116(10):1391-1395.	Cross-sectional	Denmark	CA	N=1400 infants	Neurodevelopment	Delay in age of sitting	PFOS	+
											Earlier use of word-like sounds	PFOS	+

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57	Developmental	2011	Gump BB, Wu Q, Dumas AK, et al.	Perfluorochemical (PFC) exposure in children: Associations with impaired response inhibition.	Environ Sci Technol 45(19):8151-8159.	Cross-sectional	US	CA	N=83 children aged 9-11 years	Neurodevelopment	Performance on task requiring behavioral inhibition	PFOS	-
											Performance on task requiring behavioral inhibition	PFHxS	-
											Performance on task requiring behavioral inhibition	PFNA	-
											Performance on task requiring behavioral inhibition	PFDeA	-
											Performance on task requiring behavioral inhibition	PFOSA	-
58	Diabetes	2016	Su TC, Kuo CC, Hwang JJ, et al.	Serum perfluorinated chemicals, glucose homeostasis and the risk of diabetes in working-aged Taiwanese adults.	Environ Int 88:15-22.	Cross-sectional	Taiwan	Adults	N=571	Diabetes	Fasting blood glucose	PFOA	-
											Glucose tolerance	PFOA	-
											Diabetes	PFOS	+
											Fasting blood glucose	PFOS	+
											Glucose tolerance	PFOS	+
											Glycated hemoglobin	PFOS	+
											Diabetes	PFNA	-
											Glucose tolerance	PFNA	-
											Diabetes	PFUA	-
											Fasting blood glucose	PFUA	-
											Glucose tolerance	PFUA	-
59	Cardiovascular; Diabetes; Cancer	2009	Lundin JI, Alexander BH, Olsen GW, et al.	Ammonium perfluorooctanoate production and occupational mortality.	Epidemiology 20(6):921-928.	Cohort; Occupational	US; Cottage Grove, Minnesota	Adults	N=3993	Cardiovascular	Cerebrovascular disease risk	PFOA	+
										Diabetes	Diabetes deaths	PFOA	+
										Cancer	Prostate cancer deaths	PFOA	+
60	Cancer	2014	Innes, K., Wimsatt, J., Frisbee, S., & Ducatman, A.	Inverse association of colorectal cancer prevalence to serum levels of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) in a large Appalachian population	BMC Cancer, 14(1), 45	Cross-sectional	US; mid-Ohio Valley	Adults	N=47,359	Cancer	Colorectal cancer	PFOA	-
											Colorectal cancer	PFOS	-
61	Cancer	2015	Steenland K, Zhao L, Winquist A.	A cohort incidence study of workers exposed to perfluorooctanoic acid (PFOA).	Occup Environ Med 72(5):373-380.	Cross-sectional; Occupational	US; West Virginia	Adults	N=3713	Cancer	Bladder cancer	PFOA	-
62	Cancer; renal; diabetes	2012	Steenland K, Woskie S.	Cohort mortality study of workers exposed to perfluorooctanoic acid.	Am J Epidemiol 176(10):909-917.	Retrospective; Occupational	US; West Virginia	Adults	N=1088	Renal	Chronic kidney disease deaths	PFOA	+
										Diabetes	Diabetes deaths	PFOA	+
										Cancer	Kidney cancer deaths	PFOA	+
63	Cancer	2013	Barry V, Winquist A, Steenland K.	Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant.	Environ Health Perspect 121(11-12):1313-1318.	Retrospective' Occupational	US; West Virginia	Adults	N=32,254	Cancer	Testicular cancer	PFOA	+
64	Cancer	2013	Vieira VM, Hoffman K, Shin M, et al.	Perfluorooctanoic acid exposure and cancer outcomes in a contaminated community: A geographic analysis.	Environ Health Perspect 121(3):318 323.	Cross-sectional	US; West Virginia	Adults	N=25,107	Cancer	Kidney cancer	PFOA	+
65	Cancer	2014	Hardell E, Karrman A, van Bavel B, et al.	Case-control study on perfluorinated alkyl acids (PFAAs) and the risk of prostate cancer.	Environ Int 63:35-39.	Case-control	Sweden	Adults	N=201 cases, 186 controls	Cancer	Prostate Cancer	PFHxS	+
											Prostate Cancer	PFUA	+
66	Cancer	2003	Alexander BH, Olsen GW, Burris JM, et al.	Mortality of employees of a perfluorooctanesulphonyl fluoride manufacturing facility.	Occup Environ Med 60:722-729.	ctive; Occupation	US; Alabama	Adults	N=2083; 145 deaths	Cancer	Bladder and other urinary organs cancer	PFOS	+
67	Cancer	2011	Bonefeld-Jorgensen EC, Long M, Bossi R, et al.	Perfluorinated compounds are related to breast cancer risk in Greenlandic Inuit: A case control study.	Environ Health 10:88.	Case-control	Greenland	Adults	N=31 breast cancer cases and 115 matched controls	Cancer	Breast cancer	PFOS	+

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68	Cancer	2014	Bonefeld-Jorgensen EC, Long M, Fredslund SO, et al.	Breast cancer risk after exposure to perfluorinated compounds in Danish women: A case-control study nested in the Danish National Birth Cohort.	Cancer Causes Control 25(11):1439-1448.	Case-control	Greenland	Adults	N=250 breast cancer cases and 115 matched controls	Cancer	Breast cancer	PFHxS	+
											Breast cancer	PFOSA	+
69	Hepatic	2010	Château-Degat, M.-L., Pereg, D., Dallaire, R. E., Ayotte, P., Dery, S., & Dewailly, R.	Effects of perfluorooctanesulfonate exposure on plasma lipid levels in the Inuit population of Nunavik (Northern Quebec)	Environmental Research 110(7): 710-717	Cross-sectional	Northern Quebec, Canada	Adults	N=723; Inuit residents of Nunavik	Hepatic	Plasma lipid levels (HDL-C)	PFOS	+
											TC/HDL-C ratio	PFOS	-
70	Hepatic; Renal	2009	Costa, G., Sartori, S., & Consonni, D.	Thirty years of medical surveillance in perfluooctanoic acid production workers	Journal of Occupational and Environmental Medicine, 51(3), 364–372	Cross-sectional	Miteni, Trissino, Italy	Adults	N=53 male workers engaged in a perfluooctanoic acid (PFOA) production plant (1978-2007)	Hepatic	Total cholesterol	PFOA	+
											α2 globulins	PFOA	+
										Renal	Uric acid	PFOA	+
71	Hepatic	2016	Darrow, L. A., Groth, A. C., Winquist, A., Shin, H. M., Bartell, S. M., & Steenland, K.	Modeled perfluorooctanoic acid (PFOA) exposure and liver function in a Mid-Ohio Valley community	Environmental Health Perspectives, 124(8)	Cross-sectional	US; mid-Ohio valley	Adults	N=28,831; C8 Health Project	Hepatic	ALT	PFOA	+
											Bilirubin	PFOA	-
72	Hepatic	2013	Eriksen, K. T., Raaschou-Nielsen, O., Mclaughlin, J. K., Lipworth, L., Tjønneland, A., Overvad, K., & Sørensen, M.	Association between Plasma PFOA and PFOS Levels and Total Cholesterol in a Middle-Aged Danish Population	PLoS ONE 8(2):e56969	Cross-sectional	Denmark	Adults	N=57,053 enrolled in the prospective Danish Diet, Cancer and Health (DCH) cohort	Hepatic	Total cholesterol	PFOA, PFOS	+
73	Hepatic	2013	Fisher, M., Arbuckle, T. E., Wade, M., & Haines Health Canada, D. A.	Do perfluoroalkyl substances affect metabolic function and plasma lipids?-Analysis of the 2007-2009, Canadian Health Measures Survey (CHMS) Cycle 1	Environmental Research 121:95-103	Cross-sectional	Canada	Adults	N=2368 Canadian adults, Canadian Health Measures Survey (CHMS)	Hepatic	Total cholesterol	PFOA	+
											Total cholesterol	PFHxS	+
											Non HDL cholesterol	PFHxS	+
											LDL cholesterol	PFHxS	+
74	Hepatic	2013	Fitz-Simon, N., Fletcher, T., Luster, M. I., Steenland, K., Calafat, A. M., Kato, K., & Armstrong, B.	Reductions in serum lipids with a 4-year decline in serum perfluorooctanoic acid and perfluorooctanesulfonic acid	Epidemiology, 24(4), 569–576	Longitudinal	US	Adults	N=560 adults; Community; living in parts of Ohio and West Virginia where public drinking water had been contaminated with PFOA; C8 Science Panel	Hepatic	LDL cholesterol	PFOS	+
											Total cholesterol	PFOS	+
											LDL cholesterol	PFOA	+
75	Hepatic	2010	Frisbee, S. J., Shankar, A., Knox, S. S., Steenland, K., Savitz, D. A., Fletcher, T., & Ducatman, A. M.	Perfluorooctanoic acid, perfluorooctanesulfonate, and serum lipids in children and adolescents: results from the C8 Health Project	Archives of Pediatrics & Adolescent Medicine, 164(9), 860–869	Cross-sectional community-based study	US; Mid-Ohio river valley	CA	N=12,476 children included in the C8 Health Project	Hepatic	Total cholesterol	PFOA	+
											LDL cholesterol	PFOA	+
											Total cholesterol	PFOS	+
											LDL cholesterol	PFOS	+
											HDL cholesterol	PFOS	+
			Fu Y Wang T		Ecotoxicology and				N=133; randomly selected community		LDL cholesterol	PFOA	+
											Total cholesterol	PFOA	+

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76	Hepatic	2014	Fu, Q., Wang, P., & Lu, Y.	Associations between serum concentrations of perfluoroalkyl acids and serum lipid levels in a Chinese population	Environmental Safety, 106, 246–252	Cross-sectional	Henan, China	Adults	members coming in to clinic for health check-ups	Hepatic	LDL cholesterol	PFNA	+
											Total cholesterol	PFNA	+
											HDL cholesterol	PFDeA	+
											Total cholesterol	PFDeA	+
77	Hepatic	2014	Dee Geiger, S., Xiao, J., Ducatman, A., Frisbee, S., Innes, K., & Shankar, A.	The association between PFOA, PFOS and serum lipid levels in adolescents.	Chemosphere, 98, 78–83	Cross-sectional	US	CA	N=815 participants; at least 18 years of age; NHANES 1999–2008.	Hepatic	Total cholesterol	PFOA	+
											LDL cholesterol	PFOA	+
											Elevated cholesterol	PFOA	+
											Elevated cholesterol	PFOS	+
											Elevated LDL	PFOS	+
78	Hepatic	2010	Lin, C.-Y., Lin, L.-Y., Chiang, C.-K., Wang, W.-J., Su, Y.-N., Hung, K.-Y., & Chen, P.-C.	Investigation of the associations between low-dose serum perfluorinated chemicals and liver enzymes in US adults.	The American Journal of Gastroenterology, 105(6), 1354–1363	Cross-sectional	US	Adults	N=2,216; NHANES	Hepatic	ALT (alanine aminotransferase)	PFOA	+
											GGT	PFOA	+
79	Hepatic	2015	Maisonet, M., Näyhä, S., Lawlor, D. A., & Marcus, M.	Prenatal exposures to perfluoroalkyl acids and serum lipids at ages 7 and 15 in females.	Environment International, 82, 49–60	Retrospective	UK	CA	N=111 for 7-year-old and N=88 for 15-year- old girls	Hepatic	Total cholesterol	PFOA	+
											LDL cholesterol	PFOA	+
80	Hepatic	1999	Olsen, G. W., Burris, J. M., Mandel, J. H., & Zobel, L. R.	Serum Perfluorooctane Sulfonate and Hepatic and Lipid Clinical Chemistry Tests in Fluorochemical Production Employees	Journal of Occupational and Environmental Medicine, 41(9), 799–806	Occupational; Cross-sectional	US and Belgium	Adults	N=178 in 1995; N=149 in 1997	Hepatic	Total cholesterol	PFOS	+
											LDL cholesterol	PFOS	+
											HDL cholesterol	PFOS	-
81	Hepatic	2007	Sakr, C. J., Leonard, R. C., Kreckmann, K. H., Slade, M. D., & Cullen, M. R.	Longitudinal study of serum lipids and liver enzymes in workers with occupational exposure to ammonium perfluorooctanoate.	Journal of Occupational and Environmental Medicine, 49:872-879	Longitudinal; Occupational	US; Washington Works facility, West Virginia	Adults	N=454	Hepatic	Total bilirubin	PFOA	+
											AST	PFOA	+
											Total cholesterol	PFOA	+
82	Hepatic; Reproductive	2007	Sakr, C. J., Kreckmann, K. H., Green, J. W., Gillies, P. J., Reynolds, J. L., &Leonard, R. C.	Cross-sectional study of lipids and liver enzymes related to a serum biomarker of exposure (ammonium perfluorooctanoate or APFO) as part of a general health survey in a cohort of occupationally exposed workers.	Journal of Occupational and Environmental Medicine, 49(10), 1086–1096.	Cross-sectional	US; Washington Works facility, West Virginia	Adults	N=1,025	Hepatic	GGT	PFOA	+
											Total cholesterol	PFOA	+
											LDL cholesterol	PFOA	+
											VLDL cholesterol	PFOA	+
										Reproductive	Estradiol	PFOA	+
											Testosterone	PFOA	+
83	Hepatic	2015	Skuladottir, M., Ramel, A., Rytter, D., Haug, S., Sabaredzovic, A., Hammer Bech, B., … Halldorsson, I.	Examining confounding by diet in the association between perfluoroalkyl acids and serum cholesterol in pregnancy.	Environmental Research, 143, 33–38.	Cross-sectional	Denmark	Adults	N=854; pregnant women	Hepatic	Total cholesterol	PFOA	+
											Total cholesterol	PFOS	+
84	Hepatic	2014	Starling, A. P., Engel, S. M., Whitworth, K. W., Richardson, D. B., Stuebe, A. M., Daniels, J. L., … Longnecker, M. P.	Perfluoroalkyl substances and lipid concentrations in plasma during pregnancy among women in the Norwegian Mother and Child Cohort Study.	Environment International, 62, 104–112.	Cross-sectional	Norway	Adults	N=854; pregnant women	Hepatic	Total cholesterol	PFOA	+
											Total cholesterol	PFOS	+
											Total cholesterol	PFHxS	+
											Total cholesterol	PFNA	+
											Total cholesterol	PFDeA	+
											Total cholesterol	PFUA	+
85	Hepatic	2009	Steenland, K., Tinker, S., Frisbee, S., Ducatman, A., &	Association of Perfluorooctanoic Acid and Perfluorooctane Sulfonate With Serum Lipids Among Adults Living Near a Chemical Plant.	American Journal of Epidemiology, 170(10), 1268–1278.	Cross-sectional	US	Adults	N=46,294; Community (C8) living near chemical plant; Ohio and West	Hepatic	Total cholesterol	PFOA	+
											Total cholesterol	PFOS	+
											LDL cholesterol	PFOA	+

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children/ adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
			Vaccarino, V.										
									Virginia		Triglycerides	PFOA	+
86	Hepatic	2014	Timmermann, AC. G., Rossing, L. I., Grøntved, A., Ried- Larsen, M., Dalgård, C., Andersen, L. B., … Jensen, T. K.	Adiposity and Glycemic Control in Children Exposed to Perfluorinated Compounds.	J Clin Endocrinol Metab, 99(4), E608-614.	Cross-sectional	Denmark	CA	N=499; 8-10 years old; European Youth Heart Study, Danish component	Hepatic	Triglycerides; significant in obese children only	PFOA	+
											Triglycerides; significant in obese children only	PFOS	+
87	Hepatic	2012	Wang, J., Zhang, Y., Zhang, W., Jin, Y., & Dai, J.	Association of Perfluorooctanoic Acid with HDL Cholesterol and Circulating miR-26b and miR-199−3p in Workers of a Fluorochemical Plant and Nearby Residents.	Environmental Science and Technology, 46(17)9274-9281.	Occupational; cross-sectional	China; Changshu City, Jiangsu Province	Adults	N=55	Hepatic	AST	PFOA	+
											HDL cholesterol	PFOA	-
88	Hepatic	2014	Winquist, A., & Steenland, K.	Modeled PFOA exposure and coronary artery disease, hypertension, and high cholesterol in community and worker cohorts.	Environmental Health Perspectives, 122(12), 1299–1305.	Cohort	US; mid-Ohio valley workers and residents	Adults	N=28,541	Hepatic	Hypercholesterolemia	PFOA	+
89	Hepatic	2013	Yamaguchi, M., Arisawa, K., Uemura, H., Katsuura-Kamano, S., Takami, H., Sawachika, F., … Satoh, H.	Consumption of Seafood, Serum Liver Enzymes, and Blood Levels of PFOS and PFOA in the Japanese Population.	Journal of Occupational Health, 55, 184–194.	Cross-sectional	Japan	Both	N=608; aged 16-76 years	Hepatic	ALT	PFOA	+
											AST	PFOA	+
											GGT	PFOA	+
											ALT	PFOS	+
											AST	PFOS	+
											GGT	PFOS	+
90	Hepatic; Immune	2015	Zeng, X.-W., Qian, Z., Emo, B., Vaughn, M., Bao, J., Qin, X.-D., … Dong, G.-H.	Association of polyfluoroalkyl chemical exposure with serum lipids in children.	Science of The Total Environment, 512–513, 364–370.	Cross-sectional	Taiwan	CA	N=225 adolescents, 12-15 year olds	Hepatic	Total cholesterol	PFOA	+
											LDL cholesterol	PFOA	+
											Triglycerides	PFOA	+
											Total cholesterol	PFOS	+
											LDL cholesterol	PFOS	+
											Total cholesterol	PFNA	+
											Triglycerides	PFNA	+
											Total cholesterol	PFBuS	+
										Immune	IL-5 T-helper cytokine	PFBuS	+
91	Hepatic	2012	Gallo, V., Leonardi, G., Genser, B., Lopez- Espinosa, M.-J., Frisbee, S. J., Karlsson, L., … Fletcher, T.	Serum Perfluorooctanoate (PFOA) and Perfluorooctane Sulfonate (PFOS) Concentrations and Liver Function Biomarkers in a Population with Elevated PFOA Exposure	Environmental Health Perspectives, 120(5), 655–660	Cross-sectional	US	Adults	N=47,092 adults; C8 Health Project,	Hepatic	ALT level (alanine aminotransferase)	PFOA	+
											ALT level (alanine aminotransferase)	PFOS	+
92	Renal	2013	Geiger, S. D., Xiao, J., & Shankar, A.	Positive Association Between Perfluoroalkyl Chemicals and Hyperuricemia in Children	American Journal of Epidemiology, 177(11), 1255–1262	Cross-sectional	US	CA	N=1,772 ≤18 years of age from the National Health and Nutrition Examination Survey 1999–2000 and 2003–2008.	Renal	Serum uric acid	PFOA	+
											Hyperuricemia risk	PFOA	+
											Hyperuricemia risk	PFOS	+
93	Renal	2015	Gleason, J. A., Post, G. B., & Fagliano, J. A.	Associations of perfluorinated chemical serum concentrations and biomarkers of liver function and uric acid in the US population (NHANES), 2007-2010	Environmental Research, 136, 8–14	Cross-sectional	US	Both	N=4,333; NHANES, at least 12 years of age	Renal	Serum uric acid	PFOA	+
											Hyperuricemia risk	PFOA	+
											Serum uric acid	PFOS	+
											Serum uric acid	PFNA	+

Ref #	Health Category	Date	Authors	Title	Journal	Study design	Location	Adults; CA=children / adolescent; Both	Population	Health Category	Outcome measured	PFAS Type	Association (+, -)
94	Renal	2015	Kataria, A., Trachtman, H., Malaga-Dieguez, L., & Trasande, L.	Association between perfluoroalkyl acids and kidney function in a cross-sectional study of adolescents.	Environmental Health 14:89	Cross-sectional	US	CA	N= 1960; aged 12-19 years of the 2003-2010 NHANES	Renal	eGFR (Estimated glomerular filtration rate)	PFOA	-
											Serum uric acid	PFOA	+
											eGFR (Estimated glomerular filtration rate)	PFOS	-
											Serum uric acid	PFOS	+
95	Renal	2016	Qin, X.-D., Qian, Z., Vaughn, M. G., Huang, J., Ward, P., Zeng, X.-W., … Lee, Y. L.	Positive associations of serum perfluoroalkyl substances with uric acid and hyperuricemia in children from Taiwan.	Environmental Pollution, 212, 519–524.	Cross-sectional	Taiwan	CA	N=225	Renal	Serum uric acid	PFOA	+
											Hyperuricemia risk	PFOA	+
											Serum uric acid	PFHxS	+
96	Renal	2011	Shankar, A., Xiao, J., & Ducatman, A.	Perfluoroalkyl Chemicals and Chronic Kidney Disease in US Adults.	American Journal of Epidemiology, 174(8), 893–900.	Cross-sectional	US	Adults	N=4,587; NHANES	Renal	GFR	PFOA	-
											Chronic kidney disease	PFOA	+
											GFR	PFOS	-
											Chronic kidney disease	PFOS	+
97	Renal	2011	Shankar, A., Xiao, J., & Ducatman, A.	Perfluoroalkyl chemicals and elevated serum uric acid in US adults.	Clinical Epidemiology, 3, 251–258.	Cross-sectional	US	Adults	N=3,883; NHANES	Renal	Serum uric acid	PFOA	+
											Hyperuricemia risk	PFOA	+
											Serum uric acid	PFOS	+
											Hyperuricemia risk	PFOS	+
98	Renal	2010	Steenland, K., Tinker, S., Shankar, A., & Ducatman, A.	Association of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) with uric acid among adults with elevated community exposure to PFOA.	Environmental Health Perspectives, 118(2), 229–233.	Cross-sectional	US	Adults	N=54,591; Ohio and West Virginia community	Renal	Hyperuricemia risk	PFOA	+
99	Renal	2013	Watkins, D. J., Josson, J., Elston, B., Bartell, S. M., Shin, H.-M., Vieira, V. M., … Wellenius, G. A.	Exposure to Perfluoroalkyl Acids and Markers of Kidney Function among Children and Adolescents Living near a Chemical Plant.	Environmental Health Perspectives, 121(5), 625–630.	Cross-sectional	US	CA	N=9,660 children; C8 Health Project	Renal	GFR	PFOA	-
											GFR	PFOS	-
											GFR	PFHxS	-
											GFR	PFNA	-