Environmental Toxic Substance Assessment 2022 Update

Per- and Polyfluoroalkyl Substances (PFAS) in Pima County Water

Pima County, Arizona

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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.

Pima County Health Department has requested an update to the original report. This updated version seeks to summarize new local information and available research as of October 2019 to August 2022.

PFAS are a class of over 12,000 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. More recent studies have demonstrated potential detection in cosmetics, food, and clothing including in "green" products. 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. PFAS contamination has been identified in all 50 states.

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 are associated with emerging 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 that was last updated in 2021. The National Academies of Sciences, Engineering and Medicine (NASEM) released a report on guidance for PFAS exposure, testing and clinical follow-up in 2022. Ongoing research has linked PFAS exposure with adverse health effects.

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 Department, 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 legal level at which these contaminants may be acceptable in potable water. In March 2021, US EPA published a final determination to regulate perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) in drinking water. They will propose the regulation by the end of 2022 with final rule anticipated for 2023. This regulation will include both the enforceable MCL and non-enforceable Maximum Contaminant Level Goal (MCLG).

On June 15, 2022 the US EPA published updated drinking water health advisory levels for PFOA and PFOS (two substances in the PFAS group) in drinking water and established final health advisories for additional substances from the PFAS group. These are hexafluoropropylene oxide (HFPO) dimer acid and its ammonium salt (together referred to as "GenX chemicals") and perfluorobutane sulfonic acid and its related compound potassium perfluorobutane sulfonate (together referred to as "PFBS")
(two additional substances from the PFAS group). Health advisories are non-enforceable and non-regulatory concentration recommendations below which consumption is thought to be acceptable and not pose an elevated health risk. Health advisories are intended to inform local officials on the health risk based on US EPA review of scientific studies. The current health advisories are: 0.004 ppt, 0.02 ppt, 10 ppt, and 2,000 ppt for PFOA, PFOS, GenX and PFBS, respectively.

The City of Tucson Water Department has adopted the internal operating target level of non – detect (less than 2 ppt) for PFOA, non-detect (less than 2 ppt) for PFOS, 7 ppt for PFHxS, 7 ppt for PFHpA, 420 ppt for PFBS, 200,000 ppt for PFHxA, and 10 ppt for GenX. 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 or by the Arizona Department of Environmental Quality Monitoring Assistance Program.

PFAS Health Concerns

PFAS are of high environmental and health concern because they are highly persistent in the human body, have high potential for exposure, and have 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 with increased risk cardiovascular, gastrointestinal, musculoskeletal, hematological, dermal, endocrine, immune, developmental, diabetes, cancer, hepatic, renal, and reproductive disease, as well as adverse pregnancy and birth outcomes. An analysis of disease burden and related costs has quantified the PFAS-attributable disease costs in the US at $5.5 billion across five disease endpoints, with an upper estimate of $62.6 billion. This report summarizes two hundred and sixty-six studies that suggest significant relationships between exposure to PFAS substance(s) and a health outcome in humans.

Biomonitoring

A technique used to indicate exposure or effect of exposure to environmental contaminants is biomonitoring. Biomonitoring measures chemicals, metabolites, and other proteins in bodily fluids like whole blood, urine, breastmilk, and hair. Though it tends to be measure in serum and plasma. PFOA and PFOS have been measured in serums as apart of US national health surveys as early as 1999, and additional PFAS compounds have been added in more recent surveys. Only the German Human Biomonitoring Commission has risk-based guidance levels for PFOA and PFOS in plasma (comparable to serum). Results from US national surveys indicate that 99% of the general US population has detectable PFAS levels in their blood and that levels of PFOA and PFOS have decreased over the last 20 years. In the most recent survey, 70% and 55% of the participants had levels of PFOA and PFOS below any level of concern. Recommended levels are dependent on individual susceptibility. Though individual testing is not yet widely accessible for the general public, ATSDR has developed PFAS exposure assessment technical tools that can help local, tribal, territorial and state health departments to conduct PFAS biomonitoring activities.

Clinical Guidelines

NASEM has created a report that provides clinicians with informed care recommendations, exposure reduction and options/ considerations for patient testing for PFAS at the request of ATSDR and NIEHS. The NASEM report provides a stepwise guide for clinicians that covers identifying primary sources of exposure, staying up to date with local consumption advisories and work alongside local occupational and safety professionals. Clinicians should prioritize testing via serum or plasma concentration for patients that are determined to have elevated levels of PFAS exposures. It is recommended that local governments continue to give guidance and education materials for health authorities.

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 with detectable levels of PFAS or using a home water treatment options 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. A few studies have measured PFAS in bottled water at concentrations above the drinking water health advisories (range: 0.17-18.87 ppt). 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) and can range in cost from $65-$400. At this time, it is uncommon for stock refrigerator filters to remove PFAS, however a few aftermarket refrigerator filters, and some pitcher and faucet-mounted filters do remove PFAS. Effectiveness of these devices is based upon overall drinking water quality and users maintaining the systems and changing the filters. Before purchasing a point-of-use device, confirm that the product is certified by the National Sanitation Foundation (NSF) for NSF/ANSI Protocol 53 or Protocol 58 for reverse osmosis. 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. ATSDR also recommends avoiding using water contaminated with PFAS for any drinking, cooking, or activities where swallowing water may occur and avoiding contaminated fish and game meat.

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List of Acronyms

11Cl-PF3OUdS 11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
4:2FTS 1H,1H, 2H, 2H-perfluorohexane sulfonic acid
6:2FTS 1H,1H, 2H, 2H-perfluorooctane sulfonic acid
8:2FTS 1H,1H, 2H, 2H-perfluorodecane sulfonic acid
9Cl-PF3ONS 9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid
AC Activated Carbon
ADEQ Arizona Department of Environmental Quality
ADHD attention deficit hyperactive disorder
ADONA 4,8-dioxa-3H-perfluorononanoic acid
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
CLIA Clinical Laboratory Improvement Amendments
DMAFB Davis Monthan Air Force Base
DWHA Drinking Water Health Advisory
ECP eosinophilic cationic protein
eGFR/GFR glomerular filtrate rates
GAC granular activated carbon
GenX hexafluoropropylene oxide (HFPO) dimer acid and its ammonium salt
HBM Human Biomonitoring **HDL** “good” cholesterol
HFPO DA hexafluoropropylene oxide dimer acid
HR higher risk
I – HBM International Human Biomonitoring Workgroup
LDL “bad” cholesterol
LR lower risk
MCL Maximum Contaminant Level
MCLG Maximum Contaminant Level Goal
MRLs Minimal Risk Levels
Me-PFOSA-AcOH 2-(N-Methyl-perfluorooctane sulfonamido) acetic acid
MSS Multi-site Study
NASEM National Academies of Sciences, Engineering, and Medicine
NC risk not clear
NCP New Chemicals Program
NEtFOSAA N-ethyl perfluorooctanesulfonamidoacetic acid
NFDHA nonafluoro-3,6-dioxaheptanoic acid
NHANES National Health and Nutrition Examination Survey
NIEHS National Institute of Environmental Health Sciences

NIST National Institute of Science and Technology
NMeFOSAA N-methyl perfluorooctanesulfonamidoacetic acid
NPDWR National Primary Drinking Water Regulations
NSF National Sanitation Foundation
PEATT PFAS Exposure Assessment Technical Tools
PFAS Per- and Polyfluoroalkyl Substances
PFBA Perfluorobutanoic acid
PFBS perfluorobutane sulfonic acid and its potassium salt
PFBuS Perfluorobutane sulfonic acid
PFDA Perfluorodecanoic acid
PFDeA Perfluorodecanoic acid
PFDoA Perfluorododecanoic acid
PFEESA Perfluoro(2-ethoxyethane) sulfonic acid
PFHpA Perfluoroheptanoic acid
PFHpS Perfluoroheptanesulfonic acid
PFHxA Perfluorohexanoic acid
PFHxS Perfluorohexane sulfonic acid
PFMBA Perfluoro-4-methoxybutanoic acid
PFMPA Perfluoro-3-methoxypropanoic acid
PFNA Perfluorononanoic acid
PFOA Perfluorooctanoic acid
PFOS Perfluorooctane sulfonic acid
PFPeA Perfluoropentanoic acid
PFPeS Perfluoropentanesulfonic acid
PFTA Perfluorotetradecanoic acid
PFTrDA Perfluorotridecanoic acid
PFUA Perfluoroundecanoic acid
PFUnA Perfluoroundecanoic acid
ppt parts per trillion
PTFE Polytetrafluoroethylene
PWS public water system
RO reverse osmosis
RWRD Regional Wastewater Reclamation Department
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
WRF Water Reclamation Facilities
WWTP wastewater treatment plant

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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.[1] 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).[2] Source water contaminants may exist naturally, exist naturally but increase due to human activity, or exist solely from human activity.[2,3]

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.[4] 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.[3] 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.

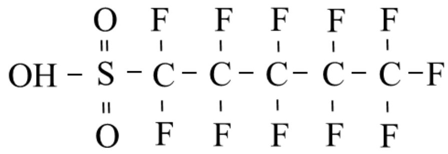
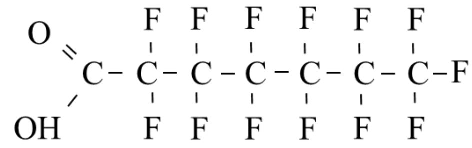
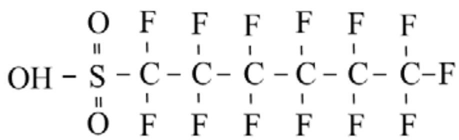
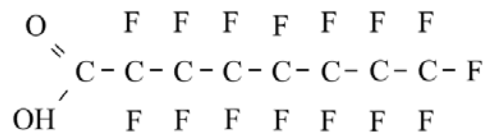
Many unregulated chemicals may occur in drinking water systems. The concentration of these chemicals, the dose, duration of exposure, personal vulnerability, and other sources of exposure are essential to prioritizing hazardous chemicals. Contaminants of emerging concern are unregulated chemicals that have increasingly 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.[5] 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.[6] 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.[7] **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 12,000 individual chemicals within the PFAS family.[8,9] 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] Recently, PFAS have been measured in a wide range of consumer products (e.g., clothing, food, cosmetics), including "green" products, where they may have been intentionally added or are present due to contamination during the manufacturing process.[12] 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.[13] Currently there is no single solution for breaking down PFAS. A group of researchers at Northwestern University developed a process that causes two classes of PFAS compounds to fall apart by using a combination of low temperatures, dimethyl sulfoxide and sodium hydroxide.[14] The researchers are still studying ways to make this work outside of the lab at a larger scale.[14] **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)[15] in wildlife and humans.**[10] PFAS have been detected in 98% of human serum samples in widespread population studies in the US and in remote environments such as the Arctic[16,17]. There is environmental contamination in all 50 US states.[9]

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).[18] Shorter chain structures are often selected as the replacement chemicals for long chain PFAS that have been banned or phased-out; however, some short chain PFAS such as perfluoroalkyl acids (PFAAS) are mobile and extremely persistent in the environment, are even more difficult to remove from water, and uncertainty surrounds their health impacts.[18] Recently, some FDA studies indicate that the toxicity of short-chain PFAS may have been under estimated.[19,20] 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.[18] 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)

Short chain replacement PFAS in manufacturing include GenX as a replacement for PFOA, and PFBS as a replacement for PFOS.[21] GenX chemicals may be used in similar ways as PFOA by manufacturers, but EPA does not have information from manufacturers on which commercial products rely on GenX chemicals. GenX chemicals have been detected in surface water, groundwater, drinking water, rainwater, and air emissions.[21] Following the voluntary phase out by US manufacturers of PFOS in 2002, PFBS was used as the replacement. PFBS have been detected in surface water, wastewater, drinking water, dust, floor wax, carpeting and carpet cleaner, and more.[22]

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.[23] 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.[24–27] Vulnerable drinking water systems are typically in close proximity to land contamination sites surrounding facilities using or manufacturing PFAS, firefighting training areas, military bases, and wastewater treatment plants.[16,28,29] PFAS has also been detected in water with no obvious contaminant source.[30,31] A 2020 study conducted in Pima and Pinal County found that soils amended with Class B sewage biosolids had PFAS concentrations, including large long-chain PFAS, that were fairly low and ranged from non-detect to a mean concentration of 4.1 μg/kg. PFAS detected in biosolids are not always detected in soil. The authors from the study also found that biosolids had PFOS concentrations ranging from 14-36 μg/kg, and PFOA concentrations less than 1.2 μg/kg. However, if biosolids with a much larger concentration of PFAS are used, such as from an industrial facility, there could be concern related to long-term application to soil.

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, cosmetics, clothing, the workplace, and animals used as food sources.[32] PFAS are also present in pharmaceuticals and medical devices.[33] 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.[34] 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.[35] 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.[36] Food packaging, including grease-resistant paper, fast food containers/wrappers, microwave popcorn bags, pizza boxes, and candy wrappers, commonly contains PFAS. 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).[3] 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.[37] In March 2021, US EPA published a final determination to regulate perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) in drinking water. They will propose the regulation by the end of 2022 with final rule anticipated for 2023. This regulation will include both the enforceable MCL and non-enforceable Maximum Contaminant Level Goal (MCLG).[38,39]

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).[40] 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.[40] The US EPA also developed another SNUR to have additional PFAS, including PFOA, reported similarly to PFOS.[40,41] 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.[42] Globally, China is one of the few remaining producers and consumers of PFOS.[43] 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.[44] 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.[16] 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.[45] On October 18, 2021, the EPA released its PFAS Strategic Roadmap: EPA's Commitments to Action (Strategic Roadmap) which outlines future actions and timelines that will safeguard public health, protect the environment and hold polluters accountable. The three main guides of the Strategic Roadmap are to **research** PFAS, **restrict** PFAS from entering our air, water and land and to **clean up** PFAS contamination where it already exists.[46] Key actions that have already been completed under the roadmap include: issuing the fifth Unregulated Contaminant Monitoring Rule (UCMR) including 29 PFAS; issuing the first Toxic Substances Control Act PFAS test order; adding five PFAS to EPA's contaminated site cleanup tables; publishing draft aquatic life water quality criteria for PFOA and PFOS and a memo to proactively address PFAS in Clean Water Act permitting; and publishing a new draft total absorbable fluorine wastewater method.[46] On April 27, 2021, the EPA established the Council on PFAS which aims to better understand and reduce the risks of PFAS.

In addition to the Strategic Roadmap, on June 15, 2022, EPA announced that it is inviting states and territories to apply for $1 billion, the first of $5 billion in Bipartisan Infrastructure Law grant funding.[47] This funding can be used to address PFAS and other emerging contaminants in drinking water, specifically in small or disadvantaged communities through actions such as technical assistance, water quality testing, contractor training, and installation of centralized treatment technologies and systems.

On August 26, 2022 under the Strategic Roadmap, the EPA announced a proposal to designate two of the most widely uses PFAS as hazardous substances under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).[48] This designation will increase transparency around the release of PFAS and will help hold polluters accountable for cleaning up their contamination.

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.[17,41] 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.[49–52] Reductions of PFOS and PFOA levels in human serum have been reported as production has been phased out.[17,41]

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.[53] 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).[41] 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.[54]

The UCMR is a tool to collect data for suspected drinking water contaminants that do not have current health-based regulations.[54] 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.[54] 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. PFAS were not included in UCMR Cycle 4. UCMR Cycle 5 will begin in 2023 and includes 29 PFAS, including: 11Cl-PF3OUdS, 9Cl-PF3ONS, ADONA, HFPO DA, NFDHA, PFBA, PFBS, 8:2FTS, PFDA, PFDoA, PFEESA, PFHpS, PFHpA, 4:2FTS, PFHxS, PFHxA, PFMPA, PFMBA, PFNA, 6:2FTS, PFOS, PFOA, PFPeA, PFPeS, PFUnA, NEtFOSAA, NMeFOSAA, PFTA, and PFTrDA.[55]

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

The US EPA publishes non-regulatory, non-enforceable health advisories under authority of the SDWA.[56] 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.[41] 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.[57–59] 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 DWHAs for PFAS. On June 15, 2022, the EPA announced four drinking water health advisories for PFAS substances.[60] The release of these new health advisories is part of the PFAS Strategic Roadmap. EPA's updated drinking water health advisories for PFOA and PFOS to replace the health advisories issued back in 2016. The health advisory of 2016 was based on evidence available at the time. However, new studies and toxicity values have indicated that the levels at which negative health outcomes could occur are much lower than previously understood.[60] The new health advisories are based on analyses conducted by US EPA that determined that the most sensitive non-cancer health effect is decreased immunity (i.e., decreased serum antibody concentrations after vaccination) in children in a human epidemiology study.[61,62] The new health advisory for PFOA is based upon suppression of tetanus vaccination in seven year old children, while the new health advisory for PFOS is based upon suppression of diptheria vaccination in seven year old children.[61,62]

EPA issued new health advisories for perflurobutane sulfonic acid and its potassium salt (PFBS) and for hexafluoropropylene oxide (HFPO) dimer acid and its ammonium salt (GenX Chemicals).[60]

Table 2. 2022 Health Advisories for the four PFAS

Chemical	Health Advisory Value	Type of health advisory
PFOA	$4x10^{-9}$/L or 0.004 ppt	Interim updated health advisory
PFOS	$2x10^{-8}$/L or 0.02 ppt	Interim updated health advisory
GenX Chemicals	0.00001 mg/L or 10ppt	Final lifetime health advisory
PFBS	0.002 mg/L or 2,000 ppt	Final lifetime health advisory

The current minimum reporting limits from EPA Analytical Method 533 are 4,4,5 and 3 ppt for PFOA, PFOS, GenX and PFBS, respectively.[39] It is important to remember that the lower the level of PFAS concentrations, the lower the risk. Therefore, the risk of drinking water with PFAS below the minimum report limit is lower than drinking water with PFAS above the minimum reporting limit, even if it is above the health advisory.

It is anticipated that US EPA will finalize a regulation in 2023 that will include both the enforceable MCL and non-enforceable MCLG.[38] The MCLG is the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, allowing an adequate margin of safety.[38] It is anticipated that this will be set close to the current health advisories. The enforceable MCL is set as close as feasible to MCLG. US EPA considers the ability to measure and treat a contaminant as well as costs and benefits in setting the enforceable standard, and it is likely to be above the minimum reporting limits.[39]

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.[63] In May of 2021, the ATSDR released a final toxicological profile for perfluoroalkyls.[64] 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 report focuses on twelve specific PFAS compounds. 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.[65] **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 some PFAS chemicals.**[64] MRLs are intended to serve as screening levels and do not represent regulatory or action levels for ATSDR. Of the many substances in the PFAS class, some have oral MRLs for intermediate risk levels, which are summarized in Table 3. 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.[66]

Table 3. Oral MRLs for intermediate risk levels for select substances within the PFAS class as defined by ATSDR[65] These values have been converted to suggested drinking water guidelines based upon the size of an average child and an adult and their consumption.[66]

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 a study incorporated into the ATSDR toxicological profile that 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.[67]

At this point in time, there is no federal government requirement to regulate PFAS in drinking water. In June of 2022, the EPA released health advisories for four PFAS compounds in drinking water. However, the health advisories are non-enforceable and non-regulatory levels that represent the concentration of a contaminant that are not expected to cause adverse health effects when at or below the advisory value. 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 had originally volunteered an interim internal operating target of 18 ppt for PFOA and PFOS and 47 ppt PFHxS and PFHxA, individually or in combination. Since the new EPA health advisory was released in June 2022 they have responded by updating their internal targets. These new targets are non –detect (less than 2 ppt) for PFOA, non-detect (less than 2ppt) for PFOS, 7 ppt for PFHxS, 7 ppt for PFHpA, 420 ppt for PFBS, 200,000 ppt for PFHxA, and 10 ppt for GenX.[68] Town of Marana’s operational target at both of their water treatment campuses (Picture Rocks and Airline/Lambert) is 17.5 ppt. This target did not change after the updated health advisory was released in June 2022. Samples taken from entry point into the distribution are consistently reported as non-detect, which means they are below the practical quantitation limit of 2 ppt using EPA Analytical Method 537.1. For reference, when thinking about the concentration targets, 1 ppt is equal to one drop of water in a pool as big as a football field and three stories (43 feet) deep.[69]

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 regulations while the more detailed studies are being conducted. Recently researchers quantified disease burdens and economic costs associated with PFAS exposures in the US in 2018.[70] They estimated that the PFAS-attributable disease costs in the US to be $5.5 billion across five primary disease endpoints with an upper estimate of $62.6 billion.[70] While there are some uncertainties in their work, this is likely to be an underestimate of the potential economic implications from this disease burden as the analysis does not include COVID or reduction of vaccine effectiveness in children with is the primary endpoint for the drinking water health advisories.[70]

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.[71] 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.[72–74] The ATSDR toxicological profile for PFAS summarizes possible health outcomes resulting from PFAS exposure.[16] Following publication of the ATSDR Toxicological Profile in 2021, the National Academies of Sciences, Engineering and Medicine (NASEM) published "Guidance for PFAS Exposure, Testing, and Clinical Follow-up (2022)."[9] A brief overview of the adverse health effects associated with some PFAS substances based on the ATSDR profile and the NASEM report is illustrated in Table 4 and accompanied by a written summary. According to the ATSDR toxicological profile and the NASEM report, there are 266 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 4 shows each health outcome category and each of the 12 specific PFAS chemicals summarized in the ATSDR report or the NASEM 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 for 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.

The NASEM committee reviewed epidemiological studies published after 2018 in addition to those in the ATSDR report and synthesized the data into four categories of association: sufficient evidence of an association, limited suggestive evidence of an association, inadequate or insufficient evidence of an association, and limited suggestive evidence of no association.[9] The committee found sufficient evidence of an association for the following diseases and health outcomes:

- Decreased antibody response (in adults and children)
- Dyslipidemia (abnormally elevated cholesterol or lipids in blood) (in adults and children)
- Decreased infant and fetal growth
- Increased risk of kidney cancer (in adults)

The committee found limited or suggestive evidence of an association for the following diseases and health outcomes:

- Increased risk of breast cancer (in adults)
- Liver enzyme alterations (in adults and children)
- Increased risk of pregnancy-induced hypertension (gestational hypertension and preeclampsia)
- Increased risk of testicular cancer (in adults)
- Thyroid disease and dysfunction (in adults)
- Increased risk of ulcerative colitis (in adults)

Table 4. Summary of human health outcomes associated with short- and long- chain PFAS chemicals

	PFAS Type											
	Long-Chain								**Short-Chain**			
	PFOA	PFOS	PFHxS	PFNA	PFDeA	PFUA	PFDoA	PFOSA	PFHpA	PFBS	PFBA	PFHxA
Cardiovascular disease	16 HR 1 LR	8 HR	3 HR 1 LR	5 HR 3 LR	3 HR	2 HR 1 LR	4 HR	3 HR	3 HR 1 LR	3 HR	1 HR	
Gastrointestinal		1 HR										
Musculoskeletal	6 HR	5 HR 1 LR	2 HR	4 HR	2 HR							
Endocrine	7 HR 19 NC 2 LR	3 HR 17 NC	3 HR 6 NC	10 NC	1 HR 5 NC	5 NC	6 NC		1 NC	1 NC		
Immune	30 HR 5 LR	14 HR 4 LR	11 HR 1 LR	1 HR 1 LR	7 HR 1 LR	4 HR 4 LR	6 HR 1 LR	1 HR	1 HR	3 HR	1 HR	
Reproductive	20 HR 13 NC 3 LR	19 HR 8 NC	7 HR 1 NC 2 LR	10 HR 2 NC 1 LR	5 HR 1 NC	4 HR 1 NC	1 HR 1 NC	1 HR	1 LR	1HR		1 NC
Pregnancy and Birth Outcomes	19 HR 6 NC 2 LR	21 HR 8 NC 2 LR	5 HR 3 NC 3 LR	5 HR 4 NC 1 LR	4 HR 2 NC 1 LR	1 HR 2 NC 2 LR	2 HR 1 NC 1 LR	1 HR 1 LR	1 HR 2 NC	1 LR	1 HR	
Developmental	7 HR 2 LR	6 HR	4 HR	4 HR	3 HR	1 HR		1 HR				
Diabetes	20 HR 4 LR	14 HR 4 LR	5 HR 2 LR	6 HR 2 LR	2 HR	1 HR 2 LR	1 HR		1 HR	1 HR		
Cancer	12 HR 2 LR	6 HR 2 LR	3 HR	1 HR	2 HR	2 HR		2 HR				
Hepatic	60 HR 3 NC 4 LR	29 HR 5 NC 3 LR	10 HR 2 NC 1 LR	125H R 2 NC 1 LR	7 HR 3 NC 1 LR	2 HR 2 NC 1 LR			1 HR	1 HR		
Renal	17 HR	9 HR	3 HR	3 HR	1 HR			1 HR				
Respiratory	7 HR	5 HR 1 LR	3 HR	5 HR	2 HR		1 HR			2 HR		
Neurological	1 HR 2 NC	1 HR 1 LR	1 HR	1HR								

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 of 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 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.[56,75,76] 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,[77] kidney cancer deaths,[78,79] and prostate cancer deaths (i.e., greater PFOA exposure will result in a greater likelihood of these cancers).[80] PFOA has been negatively associated with colorectal cancer[81] and bladder cancer (i.e., greater PFOA exposure levels have been associated with decreased likelihood of these cancers).[82] PFOS exposure has been associated with increased risk of bladder cancer[83] and breast cancer[84] and has been associated with decreased risk of colorectal cancer.[81] PFHxS exposure has been associated with increased prostate cancer deaths[85] and breast cancer.[86] PFUA exposure has also been associated with increased prostate cancer deaths.[85] PFOSA exposure has been positively associated with breast cancer.[86] 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,[87–92] PFOS,[89,90,92] and PFHxS.[91] PFOA[88,89,91,93,94] and PFOS[88,93] exposure has been positively associated with increased hyperuricemia (elevated uric acid in blood) risk. PFOA,[90,93,95] PFOS, [90,93,95] PFHxS,[95] PFNA[95] exposure have been associated with reduced glomerular filtration rates (i.e., eGFR/GFR). PFOA[78,93] and PFOS[93] 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.[96] In some studies, PFOA[97] and PFOS[98] exposures have been associated with increased TSH, however, other studies have found PFOS, PFNA,[99] PFDeA,[99] PFUA,[99] and PFDoA[99] to be associated with decreased TSH. Certain studies have shown an association between PFOA and PFOS exposure and increased T3, FT3, or T3 uptake. Alternatively, other studies have found PFOA,[100] PFOS,[101] PFDeA,[98] PFUA,[98] and PFDoA[99] 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.[102] The same study found increased thyroid medication use in men.[102] 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.[103] Yet another study found an association with increased risk of functional thyroid disease and PFOA exposure.[104] 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 groups 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,[105,106] PFOS,[105–107] PFHxS,[105,106] PFNA,[105,106] PFDeA,[105,106] PFDoA,[105] and PFBuS[106] 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.[105] Decreased levels of tetanus antibodies following vaccination were associated with and PFOA,[108] PFHxS,[109] PFUA,[110] and PFDoA concentrations.[110] 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 vaccination.[111] PFOA is associated with reduced seroprotection from influenza A H3N2 virus.[51] Higher IL-4 or IL-5 T-helper cytokine levels are associated with PFOA,[106] PFNA,[106] PFBuS exposure.[106,112] In light of the COVID-19 pandemic, many studies looked at the associations between PFAS exposure and COVID-19 outcomes. Higher PFBA plasma levels have been associated with a more severe disease outcome, elevated risk of hospitalization, and admission to the ICU.[113] The NASEM report highlighted studies establishing links between COVID-19 and PFAS exposure. This exposure was associated with a slightly increased risk of infection rates and disease severity, while significant findings were not found for COVID-19 mortality. All listed studies were ecological, therefore more should be conducted to establish the impact of exposure on infection response.[9]

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.[114] A separate study found that increased PFOA exposure was associated with increased full-scale IQ along with decreased ADHD indicators.[115] Interestingly, PFOA exposure has been associated with increased executive function scores when evaluated by the mother but decreased scores when evaluated by the teacher.[116] One study found an association between PFOA, PFOS, and PFHxS exposure and increased risk of ADHD[117] but another study found PFOA exposure was associated with decreased risk of ADHD.[118] One study found an association between prenatal PFOA exposure and being categorized as hypotonic which includes infant qualities such as reduced muscle tone.[119] PFOA exposure was associated with reduced rates of externalizing behavior (negative outward behavior in response to their environment) in boys.[120] Prenatal exposure to PFOS and PFOA had an association with increased rates of hyperactive behavior.[121] A separate study found that infants born to mothers with greater PFOS levels were slightly more likely to sit independently later.[122] PFOS, PFHxS, PFNA, PFDeA, and PFOSA have been associated with lower scores of children's performance when performing a task that requires behavioral inhibition.[123] PFOS has been associated with reduced rates of learning problems.[118]

Multiple PFAS chemicals have been linked with reproductive and pregnancy outcomes. PFOA, [124,125] PFOS,[124] and PFHxS[125] exposure have been associated with reduced fecundity. PFOA,[124–126] PFOS,[124,126] and PFHxS[125] 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.[127] 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.[128] Another study found an association between PFOS and PFUA exposure and lower levels of FSH hormone.[129] Increased testosterone levels are associated with increased PFOA[130] exposure and decreased PFOS exposure.[129,131] There was an association between PFOA exposure and higher levels of the sex hormone-binding globulin.[129] There were associations between increased rates of the hormone estradiol and PFOA[130] and PFNA[132] exposures and an association between lower levels of estradiol and PFOS exposure.[131,133] 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 circumference.[134,135] PFNA and PFDeA exposures were both associated with increased rates of miscarriage before 12 weeks.[136]

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.[137] Another study found associations between PFOA exposure and osteoarthritis risk and osteoporosis risk.[138]

Multiple studies link PFAS exposures with hepatic health outcomes. PFOA,[87,112,130,139–147148] PFOS,[112,141,149–151] PFHxS,[142] PFNA,[112,144] PFDeA,[144] and PFUA[112] are all positively associated with total cholesterol.[148] PFOA,[112,130,143–147,149] PFOS,[112,149,150] PFHxS,[142] and PFNA[144] exposure have been associated with increasing levels of LDL ("bad" cholesterol). PFOS[148,152] and PFDeA[144,148] exposure have been associated with higher levels of HDL ("good" cholesterol). At the same time, PFOA[153] and PFOS[150] 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.[152] PFOA,[112,147,154] PFOS,[151,154] and PFNA[112] exposures have all been associated with higher triglyceride levels. PFOA has been associated with both increased[140] and decreased[155] associated with bilirubin levels (increased bilirubin can be a marker of liver issues). PFOA[130,156,157] and PFOS[157] exposure have been associated with increased levels of gamma-glutamyl transferase, an enzyme that can be elevated in blood when liver or bile duct disease is present. PFOA has been positively associated with α2 globulins (used as markers of many types of disease).[87] PFOA[140,153,157] and PFOS[151,157] 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[155–158] and PFOS[151,157,158] 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.[71,92] PFOA[159] and PFOS[160,161] 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[162]). PFOA exposure has been positively associated with increased risk of angina, myocardial infarction, peripheral arterial disease, systolic blood pressure, hypertension risk,[71,163,164] cerebrovascular disease,[80] and pregnancy-induced hypertension.[165] PFOS[135] and PFUA[166] 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.[167]

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. [168] Decreased fasting blood glucose was associated with PFOA and PFUA and decreased risk of diabetes was associated with PFNA and PFUA. [168] Two separate studies found PFOA to be associated with increased rates of diabetes deaths.[78,80]

One study demonstrated an association between PFOS exposure and increased gallstone formation and gallbladder inflammation.[169]

Current On-going PFAS Epidemiological Studies

The University of Arizona's HEROES research project includes thousands of adult essential workers and children across the state of Arizona, with more than half from Pima County. From blood collected primarily for SARS-CoV-2 (COVID-19) antibody analysis, a separate aliquot is set aside following each blood draw for potential PFAS analysis. Selected sera from at least 2000 HEROES participants will be analyzed for PFAS concentrations. The New Jersey Department of Health is the laboratory used by HEROES-RECOVER for PFAS analyses, but additional laboratories may be selected based on special analytic needs. The association of serum PFAS concentrations with COVID-19 endpoints such as but not limited to severity of illness, antibody concentrations and vaccine effectiveness will be evaluated.

The Pease Study is the first site of the Multi-Site study. This study examines the human health effects of PFAS exposure through drinking contaminated water at the Pease International Tradeport in Portsmouth, New Hampshire.[170] According to ATSDR, the Pease Study findings will provide a better understanding between PFAS exposure and health outcomes and will be applied to other communities across the nation. As of December 2021, the study enrollment has ended; The CDC and ATSDR are writing the final report, processing and analyzing blood and urine samples and mailing individual results to participants.[170]

The Multi-Site Health Study (MSS) is a coordinated study by the CDC and ATSDR to examine the health effects of exposure to PFAS in communities across the United States.[171] According to ATSDR, the expected outcome of the MSS is to provide a better scientific understading about the relationships between PFAS exposure via drinking water and certain health outcomes among differing populations. The MSS is expanding on the work that began with the Pease Study in 2019. The data collected at each of the 7 MSS sites will be combined with data from the Pease Study to allow researchers to explore health outcomes from PFAS exposure.[171] Recruitment for this study began in fall 2021 with a target sample size of 2,100 children and 7,000 adults across all sites (Table 5).[171]

Table 5. Multi-Site Health Study Partners and Locations

Partner	Site Location
Colorado School of Public Health, University of Colorado, Anschutz Medical Campus	El Paso County, Colorado
Michigan Department of Health and Human Services	Parchment/Cooper Township, Michigan Belmont, Rockford area, Michigan
Research Triangle Institute International and Pennsylvania Department of Health	Montgomery County, Pennylvania Bucks County, Pennsylvania
Rutgers Biomedical and Health Sciences, School of Public Health	Gloucester County, New Jersey
Silent Spring Institute	Hyannis, Massachusetts Ayer, Massachusetts
University at Albany, State University of New York and New York State Department of Health	Hoosick Falls, New York Newburgh, New York
University of California, Irvine	Communities near the University of California, Irvine Medical Center, California

Biomonitoring

Biomonitoring is the measurement of chemicals, metabolites, and/or proteins in bodily fluids or tissues that can indicate exposure or effect of exposure to environmental contaminants. PFAS have been measured in whole blood, urine, breastmilk, and hair, however they are primarily measured in serum or plasma.[172] Some methods use a finger prick to measure PFAS in capilllary blood.

PFOA and PFOS have been measured in serum as part of the National Health and Nutrition Examination Survey (NHANES) since the 1999-2000 cycle. Exposures in the general US population have steadily decreased since the early 2000s (Figures 1 and 2).[172] NHANES has also measured exposures to other PFAS substances over time, however PFOA and PFOS have been

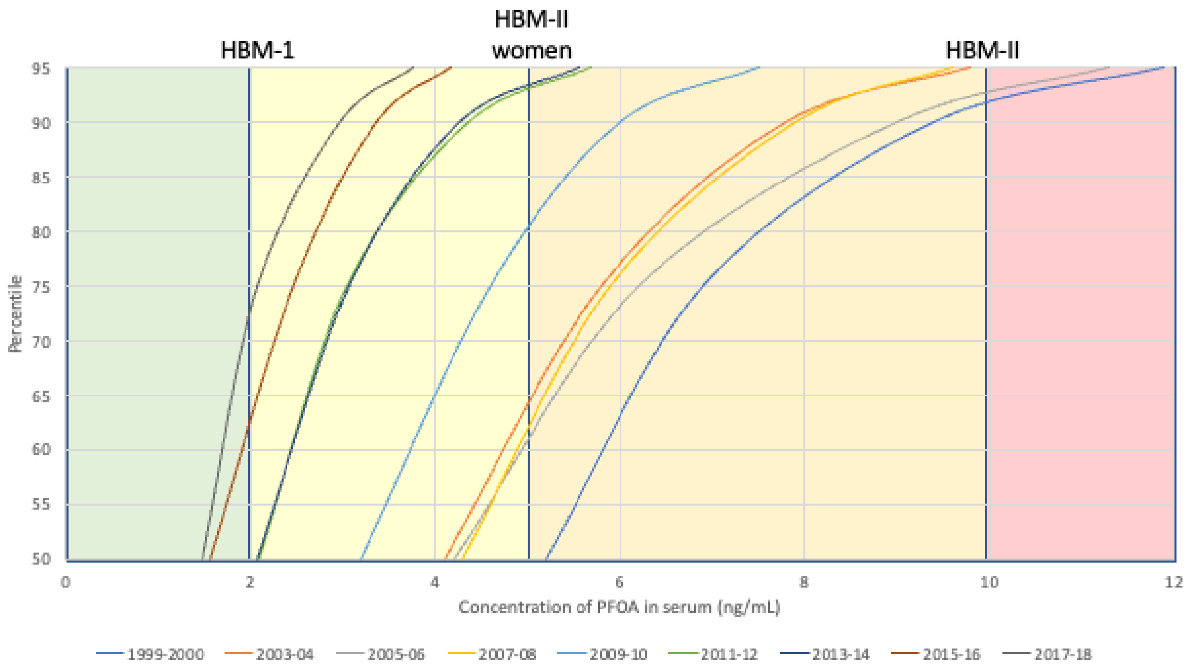


Figure 1. Percentiles of PFOA serum concentrations for the US population from NHANES survey years 1999-2018 and HBM-I and HBM-II guidelines for the general population and women of childbearing age from the German Human Biomonitoring Commission.

monitored the longest.[9] The International Human Biomonitoring Workgroup (i-HBM) of the International Society of Exposure Science, maintains an online database of biomonitoring guidelines from multiple countries (e.g., US, Japan, Germany, Canada) and can be accessed here. Currently, only the German Human Biomonitoring Commission has risk-based guidance levels for PFOA and PFOS in plasma, which is assumed to be comparable to serum. They report a value for which below no adverse effects are expected (HBM-1) and a separate value for which adverse effects may be possible (HBM-II).[173] The current HBM-1 values are 2 and 5 ng/mL for PFOA and PFOS in plasma, respectively.[174] The HBM-II values for the general population are 10 and 20 ng/ml for PFOA and PFOS in plasma, respectively.[175] The HBM-II levels for women of childbearing age are 5 and 10 ng/ml for PFOA and PFOS in plasma, respectively.[175] These are based on studies that have demonstrated potential for developmental toxicity, reduced fertility, and increased incidence of gestational diabetes. These are compared to the US general population levels in Figures 1 and 2. As of 2017-2018 NHANES cycle, it appears that 70% and 55% of the general US population are below the HBM-I for PFOA and PFOS, respectively.[175] The NASEM committee estimated that according to the most recent NHANES report 2 and 1 percent of women of childbearing age (15-49 years) in the US populations may have PFOA and PFOS levels above the comparable HBM-II values.[9]

The European Food Safety Authority has a guidance level of 6.9 ng/mL for the sum of PFOA, PFOS, PFHxS, and PFNA in serum based upon there efforts to understand a tolerable daily intake of PFAS.[9]

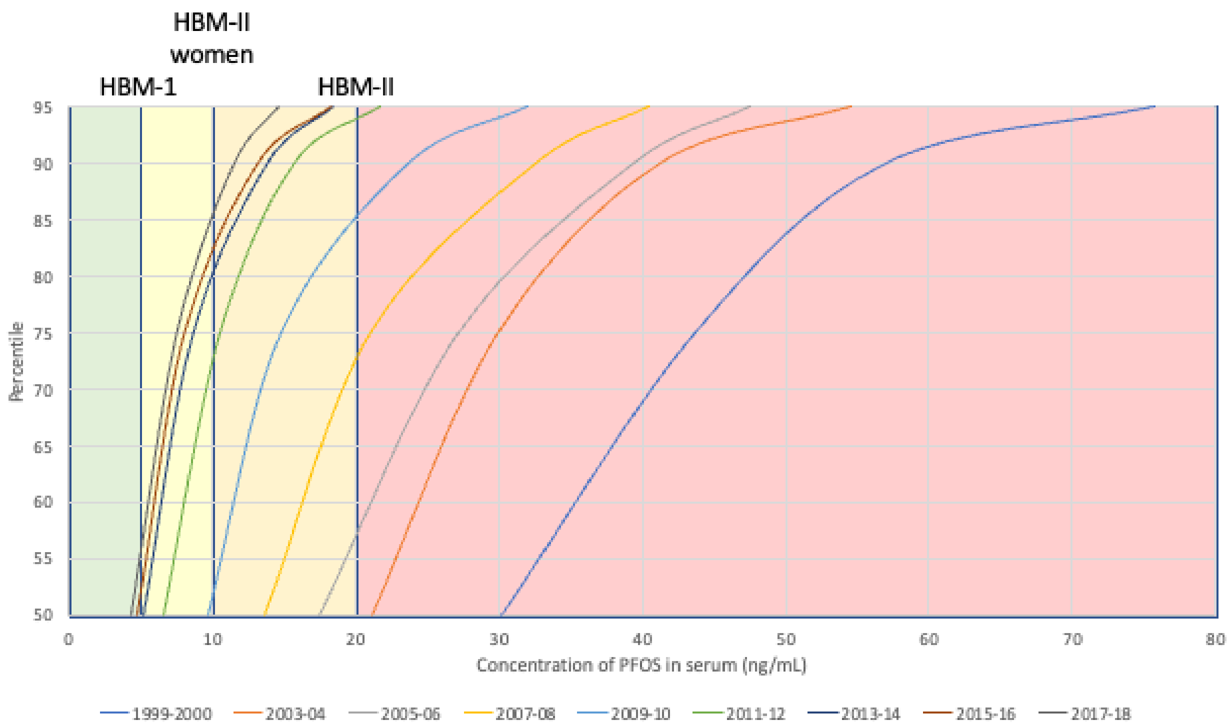


Figure 2. Percentiles of PFOA serum concentrations for the US population from NHANES survey years 1999-2018 and HBM-I and HBM-II guidelines for the general population and women of childbearing age from the German Human Biomonitoring Commission.

Currently, NMS labs in Pennsylvania offers PFAS testing, but requies a clinican request, costs are >$600.[9] EMPower DX in Massachusetts, a subsidiary of Eurofins Scientific in Luxembourg, recently began offering direct-to-consumer testing for $399. While they can measure over 40 PFAS from a finger-prick care should be taken comparing results to recommendations for serum and plasma samples.[9]

The ATSDR developed the PFAS Exposure Assessment Technical Tools (PEATT) to help local, tribal, territorial and state health departments conduct PFAS biomonitoring activities, assuming that drinking water is the primary source of PFAS exposure. The PEATT includes resources such as statistically-based representative sampling, risk communication materials, questionnaires, US EPA's water sampling protocol to help characterize PFAS exposure in communities. If requested the CDC/ATSDR will provide technical assistance to health departments in developing and carrying out PFAS exposure assessments.[176]

PFAS Testing and Laboratory Methods

Currently, there are no standard methods for PFAS testing in blood, although many laboratories follow the CDC protocols used for NHANES. Labs that test for PFAS may also not have clinical certifications such as Clinical Laboratory Improvement Amendments (CLIA).[9] Laboratories used for testing PFAS in blood should have evidence of an extensive quality assurance/quality control (QA/QC) program, use standard reference materials from the National Institute of Science and Technology (NIST), and employ laboratory methods with relative standard deviations and limits of detection comparable to CDC methods.[9,177–179] It is necessary for the lab to follow these methods in order to interpret the results with the biomonitoring and clinical guidelines. Methods used by a lab that does not follow these methods may provide results that are difficult to interpret. As relevant PFAS concentrations are very low, great care should be taken to avoid using equipment or sampling supplies that may contaminante the sample such as those that contain Teflon.[9]

Clinical Guidelines

The ATSDR and the NIEHS (National Institute of Environmental Health Sciences) asked the NASEM for a committee to: "develop principles for biological testing and clinical evaluation, given substantial scientific uncertainty about the health effects or the value of such measures in informing care; review the human health literature for the health effects of PFAS; and characterize human exposure pathways and develop principles for exposure reduction."[9] They also asked the committee to recommend: "options and considerations to guide decision making for PFAS testing in a patient's blood or urine; PFAS concentrations that could inform clinical care of exposed patients, and appropriate patient follow-up and care specific to PFAS-associated health endpoints for those patients known or suspected to be exposed to PFAS." Their report was published on July 28, 2022.[9]

The NASEM report provides several recommendations for clinicans advising patients on PFAS exposure reduction.[9] Their primary recommendations are to first do an environmental exposure assessment to determine the potential primary sources of exposure such as occupation (e.g., firefighter, military), drinking water, living near certain industries , or consumption of fish and game from contaminated areas.[9] If necessary clinicans should consult with occupational health and safety professionals. Clinicans should advise patients that they can filter their drinking water if it has elevated levels of PFAS.[9] Clinicans should stay up to date on any local consumption advisories for fish, game, dairy and meat from areas with PFAS contamination. Currently, there does not appear to be any local consumption adivsories for Pima County. However, it is not clear if fish or game have been tested for PFAS. Special care should be given regarding breastfeeding. Although PFAS can be present in breastmilk, there are numerous benefits for child development from breastfeeding. PFAS may also be present in the infant food packaging or water used to make formula and it is not clear which would provide a greater exposure.[9]

If clinicians determine that their patient may have elevated levels of PFAS exposure they should consider offering PFAS testing.[9] They should provide their patients with an overview of the potential benefits and harms of testing and subsequent clinical consequences as well as limitations of the testing.[9] Patients that should be prioritized for testing include those who may have had occupational exposures (e.g., firefighters, military), live in areas with documented PFAS contamination, or live in areas where PFAS contamination may have occurred such as near industrial facilities that use fluorochemicals, airports, military bases, wastewater treatment plants, sewage sludge applications, landfills or incinerators.[9]

The NASEM recommends that clinicans should use serum or plasma concentrations of the sum of PFAS to inform clinical care for exposed patients.[9] The sum of PFAS should include PFOA, PFOS, MeFOSAA, PFHxS, PFDA, PFUnDA, and PFNA measured in serum or plasma, care should be taken with interpretation of capillary blood samples.[9] They recommend that clinicians use serum or plasma concentrations and the following guidelines to inform clinical care of exposed patients[9]:

- "Adverse health effects related to PFAS exposure are not expected at less than 2 nanograms per milliliter (ng/mL).
- There is a potential for adverse effects, especially in sensitive populations, between 2 and 20 ng/mL.
- There is an increased risk of adverse effects above 20 ng/mL."

The NASEM report provides detailed guidance for clinical follow-up for each of these categories. It is recommended that ATSDR and local governemnt agencies provide local clinicans and healthcare providers with educational materials about PFAS exposure and PFAS testing[9]. The NASEM committee recommended that labs that conduct PFAS testing be required to report results to public health authorities following local reporting requirements. There is some limited evidence that phlebotomy may help reduce PFAS levels in blood, but more research is needed to determine at which level of PFAS do the benefits outweigh the potential risks.[9]

Vulnerable Populations and Risk Mitigation

Vulnerable Populations

Most people have been exposed to PFAS due to its environmental persistence and wide-spread occurrence.[41] PFAS can have very long half-lives in human tissue ranging between <1 to 8.5 years.[16] Numerous studies are currently being conducted to assess and monitor human and environmental health outcomes following PFAS exposure.[41] **Currently known vulnerable populations include those living near or working in a PFAS manufacturer, pregnant and nursing women, fetuses, infants, and immunocompromised individuals.**[9,17,41,66,180] PFAS can cross the placenta and have been tentatively linked to adverse health outcomes, including low birth weight, in fetuses of pregnant women.[181] 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.[182] 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.[35,183] Formula feeding can also lead to PFAS exposure through contaminated formula or formula mixed with contaminated drinking water.[9] Most recently, immunological effects are being identified in PFAS exposure and health effects studies.[66]

Associations have been assessed between PFAS exposure and decreased serum concentrations of antibodies following vaccinations.[109] For this reason, immunocompromised individuals are now also listed as a sensitive population for PFAS exposures.[109]

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 Department, 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.[184] Each location may have had one or more positive detection events, which 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. For the vast majority of monitored wells in the Tucson Metro area, PFAS was not detected in any of the samples. However, the method detection limit is higher the revised 2022 US EPA DWHA. Therefore, all measured concentrations from water samples are likely to be above the current 2022 DWHA for PFOA and PFOS. For those wells that have been tested but have never had a sample concentration reported above the current method detection limit it is possible they may not have any PFAS contamination especially if they are far from the current known contaminated areas.

Pima County Wastewater released a thorough review of emerging contaminant concerns in the region. [185] It included a summary of PFOS and PFOA measurements in December 2016 from Pima County Water Reclamation Facilities. 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.[185]

In 2016, PFAS was measured above the previous health advisory in seven supply wells for the Picture Rocks and Airline/Lambert Water Systems served by Marana Water (Table 6).[184]

Table 6. 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)	2022 Update
Continental Reserve 1	12/13/2016	80	Treated at Picture Rocks Treatment Campus
Continental Reserve 2	12/13/2016	92	Treated at Picture Rocks Treatment Campus
Airline	12/13/2016	102	Off – Line (Not Active)
La Puerta	12/13/2016	90	In "lag position" may only run during peak water demand or under fire flow
Lambert	12/13/2016	90	In "lag position" may only run during peak water demand or under fire flow
Saguaro Bloom	12/13/2016	109	Treated at Airline/Lambert Treatment Campus
Falstaff	12/13/2016	87	No longer owned by Town of Marana, private owner

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.[186] 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.[187] Previously, these home-treatment systems should have been certified by the National Sanitation Foundation (NSF) for NSF Protocol P473. This protocol was designed for EPA's 2016 DWHA of 70 ppt but was retired in 2019 and the NSF/ANSI 53 and 58 protocols were established by the NSF. Home treatment systems for PFOA and PFOS should now be certified according to NSF/ANSI 53: *Drinking Water Treatment Units-Health Effects* or NSF/ANSI 58: *Reverse Osmosis Drinking Water Treatment Systems* protocols.[188,189]

The Picture Rocks Water Treatment Campus and the Airline/Lambert Water Treatment Campus reached operational status on March 12, 2021.[190] Sampling results of the water being introduced into the respective systems from both treatment facilities continue to show successful removal of both of these non-regulated compounds (i.e., PFOS and 1,4-dioxane).[190]

The Arizona Department of Environmental Quality produced a report that summarized 109 samples from 68 of the 1,500 PWSs in Arizona.[191] Twenty samples had PFAS detected and therefore are above the current 2022 DWHA and six (five in Pima County) were above the previous 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 which was 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 June 2022, Tucson Water had shut down 25 groundwater wells due to the presence of PFAS.[192]

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 was 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.

PFAS was detected in soil, sediment, and groundwater from Davis-Monthan Air Force Base in concentrations above the US EPA Health Advisory levels.[193] 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.[194] 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.

In 2019, screening of nine wells identified a mobile home park with PFAS concentrations above 70 ppt. Bottled water continues to be delivered to this mobile home park.

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, which was still 70 ppt when the report was released. In addition, the comprehensive report includes an October 2021 memorandum from PDEQ, stating that the most recent discovery of PFAS in groundwater occurred in August 2021 in a well near Houghton Road and Tanque Verde Wash.[195] The well had PFAS concentrations less than 10 ppt and is one of the 25 that has been shut off.[195] This residential area is an unlikely location for PFAS to be discovered. This online tracker provides PFAS contamination information for national and international sources.[196] 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 here. In December 2020, ADEQ committed $3.3 million from the state's Water Quality Assurance Revolving Fund to stop PFAS from impacting Tucson drinking water sources.[197]

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.[198] The full UCMR 3 data set is available online here.[199] 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 7 which shows average PFAS concentration results above Minimum Reporting Levels in Arizona PWSs and in Table 8 which shows the six samples above Minimum Reporting Levels in Pima County. PFAS were not included in UCMR Cycle 4. UCMR Cycle 5 will begin in 2023 and will include 29 PFAS, including: 11Cl-PF3OUdS, 9Cl-PF3ONS, ADONA, HFPO DA, NFDHA, PFBA, PFBS, 8:2FTS, PFDA, PFDoA, PFEESA, PFHpS, PFHpA, 4:2FTS, PFHxS, PFHxA, PFMPA, PFMBA, PFNA, 6:2FTS, PFOS, PFOA, PFPeA, PFPeS, PFUnA, NEtFOSAA, NMeFOSAA, PFTA, and PFTrDA.[55]

Table 7. 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 8. 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.

On June 8, 2021, Tucson Water announced that out of an abundance of caution and due to rising levels of newer contaminants in the area groundwater (like PFAS), also emanating from the airport area), it would suspend TARP operations on June 21, 2021 as it seeks alternative end-uses for the treated water.[200] These alternatives include discharge to the Santa Cruz River and/or Tucson Water's reclaimed water system, which is used for landscape irrigation.[200] Similar to drinking water which is regulated through the Safe Drinking Water Act, these alternatives will need to be assessed for potential regulatory implications under the Clean Water Act. While currently PFAS is not regulated yet under the Clean Water Act, US EPA is working towards establishing water quality criteria, updated analytical methods and a new rule under the Clean Water Act.[201]

On June 21, 2021 Governor Doug Ducey and the Arizona Department of Environmental Quality (ADEQ) announced that $2 million in state funding would be used to help Tucson Water restart the treatment plant and construct a State-funded temporary pipeline and permanent outfall structure to convey treated water to the Santa Cruz River north of Irvington Road.[202] This announcement marked the second time that the state deployed fund to address PFAS in Tucson's groundwater supply. In November 2021, the TARP began operating to remove PFAS from groundwater and discharge the treated water into the Santa Cruz River.[202,203] In addition, the Central Tucson PFAS Project began operating in January 2022 to remove PFAS from groundwater.[202] Tucson Water is also constructing the TARP Recycled System Source Water Infrastructure Project, which will discharge treated TARP/AOP water into the Tucson Water Recycled Water System.[203] This is expected to be complete in May 2023.[68]

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 25 groundwater production wells from service where PFOA and PFOS have been found. Since the new EPA health advisory was announced in June 2022, the City of Tucson Water Department has adopted the internal operating target level of non –detect (less than 2 ppt) for PFOA, non-detect (less than 2ppt) for PFOS, 7 ppt for PFHxS, 7 ppt for PFHpA, 420 ppt for PFBS, 200,000 ppt for PFHxA, and 10 ppt for GenX.[68] Tucson Water has created a set of frequently asked questions regarding PFAS presence in local water sources here.[204] The City of Tucson maintains a website summarizing wells that have been tested for PFAS and efforts being made to inform the public here.

On February 5, 2020 Regional Wastewater Reclamation Department (RWRD) provided sample data to the Pima County Board of Supervisors for PFOA and PFOS influent and effluent (Table 9).[205] Due to the consistently low levels of PFOA and PFAS at the Water Reclamation Facilities (WRF), there was no further analyses.[205]

Table 9. Water Reclamation Facility PFOS and PFOA Sample Data

Water Reclamation Facility	Location	Sample Date	PFOS ng/L	PFOA ng/L	Total ng/L
Agua Nueva	Influent	12/8/16	7.5	4.6	12.1
	Effluent	12/8/16	6.6	8	14.6
	Effluent	12/29/16	9.9	11	20.9
	Effluent	6/21/17	5.4	7.7	13.1
	Influent	8/29/18	19	3.9	22.9
	Effluent	8/29/18	5.1	6.6	11.7
Avra Valley	Effluent	12/29/16	1.6	9.2	10.8
	Influent	8/29/18	4.8	1.9	6.7
	Effluent	8/29/18	2.5	8.8	11.3
Corona de Tucson	Effluent	12/29/16	ND	18	18
	Influent	8/29/18	ND	ND	ND
	Effluent	8/29/18	ND	14	14
Green Valley	Effluent	12/29/16	2.8	26	28.8
	Influent	8/29/18	ND	4	4
	Effluent	8/29/18	4.5	28	32.5
Tres Rios	Effluent	12/29/16	8.6	9	17.6
	Influent	8/29/18	5.5	5.1	10.6
	Effluent	8/29/18	4.2	6.1	10.3

In June 2017, the ADEQ contracted with Hargis + Associates to conduct water sampling and analysis for the presence of PFAS in surface water at various locations along the Santa Cruz River and in groundwater samples from various monitor and irrigation wells. Results showed that PFOS and PFOA were detected in all eleven ADEQ surface water samples from the Santa Cruz River with concentrations less than 30 ng/L except for location SC-07 approximated seven miles downstream of the Tres Rios WRF which had a concentration of 47 ng/L. In addition, PFOS and PFOA were detected in all four ADEQ groundwater samples along the Santa Cruz in concentrations ranging from 17 to 60 ng/L.

RWRD has also taken measures as it relates to PFAS and land application of biosolids. Biosolids are no longer applied to agricultural land and is instead disposed in landfills as of December 31, 2019. RWRD is also working with the University of Arizona National Science Foundation Water and Environmental Technology Center on a project that aims to assess the human and ecological health risks related to land application of municipal biosolids containing PFAS.

In Spring of 2022, well screening for PFOA and PFOS was conducted at Marana School District and Tucson Medical Center (TMC). TMC had no detectable levels and levels at Marana School District were below the previous EPA DWHA of 70 ppt.[206]

In June 2022, PDEQ provided the operational data from four PFAS removal plants in Pima County (Table 10).[206]

Table 10. Pima County PFAS Removal Plant Operational Data

Reclamation Plants	Average PFOA+PFOS Influent (ppt)	Average PFOA+PFOS Effluent (ppt)	Volume of water treated (MG)
Airline/Lambert Water Treatment Campus	76.1	<1.70	11
Central Tucson PFAS Project (CTPP)	1,785	<1.80	19.4
Picture Rocks Water Treatment Campus	49.4	<1.70	31
Tucson Airport Area Remediation Project (TARP)	38.7	<2.0	270.7
Summary	-	<1.7 to <2.0	332.1

In 2021, the University of Arizona has received a $1.3 million grant from Department of Defense to study how PFAS behaves underground and moves from the soil to the groundwater.[207] They have found that at defense sites, PFAS can be present at very high concentrations in the soil, much higher than the groundwater, and thus, there is a reservoir that can have long-term potential for contaminating the groundwater.[207]On April 5, 2022 the Arizona Board of Regents awarded $1.5 million to team members from the University of Arizona, Northern Arizona, and Arizona State University to address cost effective technology to remediate PFAS in water and a cost-effective way to replace AFFF.[208] The University of Arizona and Northern Arizona

University researchers that received 1.5 million from the Arizona Board of Regents are working to develop specialized, reusable sponges to remove PFAS from drinking water.[209]

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. ATSDR 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).[72] Currently, there are not any health advisories regarding consumption of fish with respect to PFAS in Arizona. However, it does not appear that fish have been tested for PFAS in Arizona.

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.[210]

Studies have seen that PFAS concentration in dust was positively correlated with carpeting in the home.[211] 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.[212] 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.[56,213] 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 using available analytical methods. Since current analytical methods cannot measure down to the new DWHAs for PFOA and PFOS, risk mitigation should be considered if PFOA or PFOS are detected in the drinking water.[9]

The NASEM report includes information from behavioral intervention studies focused on reducing PFAS exposure.[9] The studies demonstrate the effectiveness of water filtration at reducing levels of certain PFAS. The authors from the report mention that consumers have a variety of options to reduce PFAS exposure, such as whole-house, under-sink, and filtering-pitcher devices.[9] Funded by NIEHS, the PFAS- REACH (Research, Education, and Action for Community Health) project develops guidance materials and data interpretation tools for communities to use if they have been impacted by PFAS-contaminated water.[9] PFAS-REACH provide "in your personal life recommendations," such as filtering your drinking water with an activated carbon or RO filtration system, and "in your community recommendations," such as urging your local water utility to test for PFAS.[9]

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 or filtering at the point-of-use (POU) may be recommended to reduce PFAS exposure. However, it is important to note that some treatment technologies, such as high-pressure membrane technologies like nanofiltration and RO, may produce waste streams or filters with concentrated levels of PFAS that require proper disposal.[188,189] Before implementing treatment technologies, it is advised to understand and follow the recommended use guidelines to prevent increased PFAS concentrations (e.g., some treatment processes have been shown to increase PFOS concentrations, likely through precursor oxidation), and other unintended effects.[189]

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.**[214] For more information and a list of certified drinking water laboratories, visit: https://www.epa.gov/dwlabcert. To find a list of the Arizona Certified Commercial Drinking Water Laboratories, visit https://ells-lab search.azdhs.gov/DrinkingWaterTestingLabs/drinkingwatersearchcontentpage. US EPA also provides additional information on how to protect and maintain your well for contaminants of concern here: www.epa.gov/safewater

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 detectable PFOA and PFOS levels, additional sampling is recommended.[56] If additional sampling results confirm that residential drinking water contains PFOA and PFOS concentrations, treatment measures are recommended.[9] 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.[215] 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. PFOS and PFOA levels have been measured in private wells in southern Arizona during dry and wet seasons.[216] The combined concentration for

PFOS and PFOA exceeded the previous DWHA level in three samples during the wet seasons (maximum concentration reported was 1.38e-5 mg/L), and all measured concentrations for PFOS and PFOA exceeded the current DWHAs (maximum concentrations were 3.47e-5 mg/L for PFOS and 8.66e-5 mg/L for PFAS).[216]

Mitigation Choices and Options

Boiling water may concentrate the PFAS in water.[188,189,217]

Mitigation measures can always be taken if there is any concern about drinking water safety due to the presence of PFAS. 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.[218] 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.[219] **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. Authors from the NASEM report state that using bottled water as a replacement for tap water can be expensive and inconvenient, thus understanding local water conditions in comparison with PFAS levels in specific types of water bottled is needed to be confident of reduced PFAS exposure from drinking water.[9]

Appendix E from the NASEM report provides an overview of studies on personal behavior modifications that may reduce PFAS exposure.[9] They primarily focus on two types of drinking water interventions: 1) whether the use of purchased water bottle results in lower PFAS exposure compared to the use of tap water, and 2) whether-and the extent to which water filters at point of entry (POE) into the home, point of use (POU), or in water pitchers reduce PFAS exposure.[9]

Bottled Water

Just a few studies have measured PFAS in bottled water. In one study, median concentrations in tap water, filtered water, and bottled water were 4.44 ng/L, 3.13 ng/L, and 2.36 ng/L, respectively and there was no significant difference between them.[220] A different study found higher PFAS tap water (41.3 ng/L) compared to bottled water (0.48 ng/L).[220] In a survey of 101 non-carbonated, non-nutritional and unflavored bottled water products from 19 retail food and beverage chains, PFAS was detected in 55.6%, 40%, 11.4% and 66.6% of the samples from spring water, alkaline water, purified water and distilled water, respectively.[221] The median measured concentration of the sum of 32 PFAS in these bottled water samples was 0.98 ng/L with a range of 0.17 ng/L to 18.87 ng/L.[221] Collectively, this indicates that bottled water should be considered for substitution of tap water to reduce PFAS exposure, only in areas where tap water is documented to regularly be above these concentrations.

Filtration mitigation

Residential water treatment options exist for individuals with water quality issues or concerns.[222–225] 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.[225,226] 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, and other unintended effects such as metal corrosion.[227] Metal corrosion can occur due to changes in the water pH or alkalinity levels, like what happened with lead in Flint, Michigan. Detailed information regarding treatment technologies and considerations is available for each PFAS (i.e., PFOA, PFOS, PFBS, and GenX) in their respective Health Advisory documents.[60,188,189]

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**.[228,229] The NSF/ANSI 53 (sorption) and 58 (RO) are the standards for PFOA and PFOS reduction in drinking water. The NSF completes rigorous product testing to determine if a system complies with the NSF/ANSI 53 and 58 standards. To comply with the standards, the device must reduce PFOA and PFOS concentrations in water below the previous DWHA of 70 ppt and comply with NSF/ANSI 53: *Drinking Water Treatment Units- Health Effects* or NSF/ANSI 58: *Reverse Osmosis Drinking Water Treatment Systems.*[230] Some home treatment systems are certified to remove PFAS from drinking water.[222–225] The point-of-use devices are most commonly Granular Activated Carbon (GAC) or Reverse Osmosis (RO). Before purchasing a point-of-use device, confirm that the product is NSF/ANSI Certified for Protocol 53 or 58. A complete list of the Drinking Water Treatment Units certified under NSF/ANSI 53 can be found here. The NSF advises people that wish to implement a home water treatment to find out what is in their water, decide what contaminants they want to reduce, and compare options for water treatment.[231] For links to NSF certified point-of-use filters and whole-house filters, visit: https://www.nsf.org/consumer-resources/articles/home-water-treatment. Before purchasing a water treatment system for PFAS removal that is NSF certified, make sure to check packaging or NSF's website for the standard (such as NSF/ANSI 53 or 58), and for a claim such as PFAS reduction.[231]. Examples of refrigerator filters that are NSF/ANSI 53 certified and that remove PFOA and PFOS include the LG Electronics ADQ747937 filter, the A.O Smith AO-US-100-R filter, and Samsung Electronics RWP70010TWW filter.[232] At this time, it is uncommon for stock refrigerator filters to remove PFAS. Additional information is available through Good Housekeeping.[224] Another resource for PFAS information was published by the University of Arizona Cooperative Extension and is available here.[233]

Costs for treatment technologies intended for PFAS removal will vary based on the type of PFAS that consumers wish to reduce, size of the system (single household vs. community), and other factors. On April 18, 2022, Cyclopure released Purefast filters. The home filter is compatible with Brita pitchers and is priced at $45 with a capacity of 65 gallons.[234] The company has validated the removal of 11 PFAS compounds including PFOS, PFOA, GenX and PFNA to non-detect throughout the duration of the 65-gallon filter cycle.[234] Examples of NSF certified filtration systems include Hydroviv Under Sink Water Filter, A.O. Smith AO-CMW Clean Water Machine Pitcher-Filter, AOW-3000 Under Sink Reverse Osmosis Water Filter System, which range in cost from $140-400. Detailed treatment technologies specific for PFOA, PFOS, GenX and PFBS are available in their respective health advisory documents.[235]

NSF certifies treatment technologies under laboratory conditions. A few studies have been conducted have tested POU and POE technologies in real-world conditions. In one study, RO and dual-stage filters removed most measured PFAS compounds at an average of ≥90% efficiency. Activated carbon POU filters (including countertop, faucet, pitcher, fridge, and single stage under-sink filters) had greater variability and 73% of the filters still showed significant removal.[9] Other studies have demonstrated that AC pitcher-type water filters and faucet-mounted filters were able to reduce PFAS to below the detectable range.[9] However, the effectiveness decreased with filter age. Additional studies have been conducted by US EPA, that demonstrate that homeowner installed RO and GAC systems are effective at removing PFAS, however differing water qualities may change the effectiveness in PFAS reduction of these treatment systems.[236] Based on these and other studies cited in the NASEM report, the authors concluded that household water purifiers are effective at reducing PFAS levels in drinking water, and that pitcher-type, POE, and POU filtration systems can reduce PFAS exposure, but that optimal filtration depends on users maintaining the devices and replacing filters according to manufacture directions.[9]

References

1. Central Arizona Project (CAP) Water. Central Arizona Project. Accessed July 12, 2022. https://www.cap-az.com/water/

2. Ritter L, Solomon K, Sibley P, et al. Sources, Pathways, and Relative Risks of Contaminants in Surface Water and Groundwater: A Perspective Prepared for the Walkerton Inquiry. *Journal of Toxicology and Environmental Health*. 2002;65(1):1-142. doi:10.1080/152873902753338572

3. Artiola JF, Farrell-Poe KL, Moxley JC. *Arizona: Know Your Water: A Consumer's Guide to Water Sources, Quality, Regulations,and Home Water Treatment Options*.; 2012. https://clu-in.org/conf/tio/srpwir4_072116/Arizona-Know-Your-Water-UAz.pdf

4. Tracey Brown. *Making Sense of Chemical Stories: A Guide for the Lifestyle Sector and Anybody with Questions about Chemical Stories*.; 2014. https://senseaboutscience.org/wp-content/uploads/2014/05/MakingSenseofChemicalStories2.pdf

5. Glassmeyer ST, Furlong ET, Kolpin DW, et al. Nationwide reconnaissance of contaminants of emerging concern in source and treated drinking waters of the United States. *Science of The Total Environment*. 2017;581-582:909-922. doi:10.1016/J.SCITOTENV.2016.12.004

6. Beamer P. Other worries in addition to lead in the water. The Hill. Published 2016. https://thehill.com/blogs/congress-blog/energy-environment/269769-other-worries-in-addition-to-lead-in-the-water/

7. Olson G, Wilczak A, Boozarpour M, DeGraca A, Weintraub JM. Evaluating and Prioritizing Contaminants of Emerging Concern in Drinking Water. *Journal – American Water Works Association*. 2017;109(12):54-63.

8. PFAS | NIOSH | CDC. Published July 8, 2021. Accessed September 1, 2022. https://www.cdc.gov/niosh/topics/pfas/default.html

9. National Academies Sciences, Engineering, Medicine. *"Guidance on PFAS Exposure, Testing, and Clinical Follow-Up" at NAP.Edu*. The National Academies Press doi:10.17226/26156

10. Prevedouros K, Cousins IT, Buck RC, Korzeniowski SH. Sources, Fate and Transport of Perfluorocarboxylates. Published online 2005. doi:10.1021/ES0512475

11. Chen H, Zhang C, Han J, Yu Y, Zhang P. PFOS and PFOA in influents, effluents, and biosolids of Chinese wastewater treatment plants and effluent-receiving marine environments. *Environmental Pollution*. 2012;170:26-31. doi:10.1016/J.ENVPOL.2012.06.016

12. PFAS: Hard to escape in food, clothes, and makeup. EHN. Published July 7, 2022. Accessed August 24, 2022. https://www.ehn.org/pfas-summary-2657611806/some-highlights

13. Bossi R, Strand J, Sortkjær O, Larsen MM. Perfluoroalkyl compounds in Danish wastewater treatment plants and aquatic environments. *Environment International*. 2008;34(4):443-450. doi:10.1016/J.ENVINT.2007.10.002

14. Zimmer C. Forever Chemicals No More? PFAS Are Destroyed With New Technique. *The New York Times*. https://www.nytimes.com/2022/08/18/science/pfas-forever-chemicals.html. Published August 18, 2022. Accessed September 1, 2022.

15. Definition of Bioaccumulation by Merriam-Webster. https://www.merriam-webster.com/dictionary/bioaccumulation

16. Atsdr. *Toxicological Profile for Perfluoroalkyls, Draft for Public Comment*.; 2018. https://www.atsdr.cdc.gov/toxprofiles/tp200.pdf

17. Calafat AM, Wong LY, Kuklenyik Z, Reidy JA, Needham LL. Polyfluoroalkyl chemicals in the U.S. population: data from the National Health and Nutrition Examination Survey (NHANES) 2003-2004 and comparisons with NHANES 1999-2000. *Environmental health perspectives*. 2007;115(11):1596-1602. doi:10.1289/ehp.10598

18. Brendel S, Fetter É, Staude C, Vierke L, Biegel-Engler A. Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. *Environmental sciences Europe*. 2018;30(1):9. doi:10.1186/s12302-018-0134-4

19. Kabadi SV, Fisher JW, Doerge DR, Mehta D, Aungst J, Rice P. Characterizing biopersistence potential of the metabolite 5:3 fluorotelomer carboxylic acid after repeated oral exposure to the 6:2 fluorotelomer alcohol. *Toxicology and Applied Pharmacology*. 2020;388:114878. doi:10.1016/j.taap.2020.114878

20. Rice PA, Aungst J, Cooper J, Bandele O, Kabadi SV. Comparative analysis of the toxicological databases for 6:2 fluorotelomer alcohol (6:2 FTOH) and perfluorohexanoic acid (PFHxA). *Food and Chemical Toxicology*. 2020;138:111210. doi:10.1016/j.fct.2020.111210

21. US EPA O. Drinking Water Health Advisories for GenX Chemicals and PFBS. Published June 13, 2022. Accessed August 26, 2022. https://www.epa.gov/sdwa/drinking-water-health-advisories-genx-chemicals-and-pfbs

22. US EPA O. Learn about the Human Health Toxicity Assessment for PFBS. Published February 24, 2021. Accessed August 26, 2022. https://www.epa.gov/chemical-research/learn-about-human-health-toxicity-assessment-pfbs

23. Post GB, Gleason JA, Cooper KR. Key scientific issues in developing drinking water guidelines for perfluoroalkyl acids: Contaminants of emerging concern. Birnbaum LS, ed. *PLOS Biology*. 2017;15(12):e2002855. doi:10.1371/journal.pbio.2002855

24. Xiao F, Halbach TR, Simcik MF, Gulliver JS. Input characterization of perfluoroalkyl substances in wastewater treatment plants: Source discrimination by exploratory data analysis. *Water Research*. 2012;46(9):3101-3109. doi:10.1016/J.WATRES.2012.03.027

25. Interstate Technology Regulatory Council. *Environmental Fate and Transport for Per-and Polyfluoroalkyl Substances Continued*.; 2018. https://pfas-1.itrcweb.org/fact_sheets_page/PFASFact_Sheet_Fate_and_Transport_April2020.pdf

26. Eriksson U, Haglund P, Kärrman A. Contribution of precursor compounds to the release of per- and polyfluoroalkyl substances (PFASs) from waste water treatment plants (WWTPs). *Journal of Environmental Sciences*. 2017;61:80-90. doi:10.1016/J.JES.2017.05.004

27. Arvaniti OS, Stasinakis AS. Review on the occurrence, fate and removal of perfluorinated compounds during wastewater treatment. *Science of The Total Environment*. 2015;524-525:81-92. doi:10.1016/J.SCITOTENV.2015.04.023

28. Li Y, Fletcher T, Mucs D, et al. Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water. *Occupational and environmental medicine*. 2018;75(1):46-51. doi:10.1136/oemed-2017-104651

29. United States Environmental Protection Agency. The Challenges of PFAS Remediation. Science Inventory. Published 2018. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=339749&Lab=NRMRL

30. Post GB, Cohn PD, Cooper KR. Perfluorooctanoic acid (PFOA), an emerging drinking water contaminant: A critical review of recent literature. *Environmental Research*. 2012;116:93-117. doi:10.1016/J.ENVRES.2012.03.007

31. Pepper IL, Brusseau ML, Prevatt FJ, Escobar BA. Incidence of Pfas in soil following long-term application of class B biosolids. *Science of The Total Environment*. 2021;793:148449. doi:10.1016/j.scitotenv.2021.148449

32. United States Environmental Protection Agency. Basic Information on PFAS. PFOA, PFOS and Other PFASs. Published 2018. https://www.epa.gov/pfas/pfas-explained?mod=article_inline

33. Glüge J, Scheringer M, T. Cousins I, et al. An overview of the uses of per- and polyfluoroalkyl substances (PFAS). *Environmental Science: Processes & Impacts*. 2020;22(12):2345-2373. doi:10.1039/D0EM00291G

34. Egeghy PP, Lorber M. An assessment of the exposure of Americans to perfluorooctane sulfonate: A comparison of estimated intake with values inferred from NHANES data. *Journal of Exposure Science & Environmental Epidemiology*. 2011;21(2):150-168. doi:10.1038/jes.2009.73

35. Trudel D, Horowitz L, Wormuth M, Scheringer M, Cousins IT, Hungerbühler K. Estimating Consumer Exposure to PFOS and PFOA. *Risk Analysis*. 2008;28(2):251-269. doi:10.1111/j.1539-6924.2008.01017.x

36. USFDA. Per and Polyfluoroalkyl Substances (PFAS). Chemicals, Metals & Pesticides in Food. Published 2019. https://www.fda.gov/food/chemical-contaminants-food/and-polyfluoroalkyl-substances-pfas

37. US EPA. *National Primary Drinking Water Regulations*.; 2009. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulation-table

38. US EPA O. Per- and Polyfluoroalkyl Substances (PFAS). Published November 16, 2021. Accessed September 6, 2022. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas

39. US EPA O of W. Webinar on Drinking Water Health Advisories for Four PFAS (GenX, PFBS, PFOA, PFOS) and Bipartisan Infrastructure Law Announcement. PowerPoint presented at: June 2022. Accessed July 20, 2022. https://www.epa.gov/system/files/documents/2022-07/PFAS%20HAs%20for%20Water%20Utility%20Briefing%20-%20June%2022Final.pdf

40. Environmental Protection Agency. Perfluoroalkyl Sulfonates; Significant New Use Rule. Published online 2002. https://www.federalregister.gov/d/02-31011

41. US EPA. *FACT SHEET PFOA & PFOS Drinking Water Health Advisories*.; 2016:1-5. https://19january2021snapshot.epa.gov/sites/static/files/2016-05/documents/drinkingwaterhealthadvisories_pfoa_pfos_5_19_16.final_.1.pdf#:~:text=FACT%20SHEET%20PFOA%20%26%20PFOS%20Drinking%20Water%20Health,health%20advisory%20levels%20at%2070%20parts%20per%20trillion.

42. US EPA O. Fact Sheet: 2010/2015 PFOA Stewardship Program. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program

43. Lim TC, Wang B, Huang J, Deng S, Yu G. Emission inventory for PFOS in China: review of past methodologies and suggestions. *TheScientificWorldJournal*. 2011;11:1963-1980. doi:10.1100/2011/868156

44. Vestergren R, Herzke D, Wang T, Cousins IT. Are imported consumer products an important diffuse source of PFASs to the Norwegian environment? *Environmental Pollution*. 2015;198:223-230. doi:10.1016/J.ENVPOL.2014.12.034

45. US EPA O. New Chemicals Program Review of Alternatives for PFOA and Related Chemicals. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/new-chemicals-program-review-alternatives-pfoa-and

46. Environmental Protection Agency. PFAS Strategic Roadmap: EPA’s Commitments to Action 2021—2024. https://www.epa.gov/pfas/pfas-strategic-roadmap-epas-commitments-action-2021-2024

47. US EPA O. EPA Announces New Drinking Water Health Advisories for PFAS Chemicals, $1 Billion in Bipartisan Infrastructure Law Funding to Strengthen Health Protections. Published June 15, 2022. Accessed August 26, 2022. https://www.epa.gov/newsreleases/epa-announces-new-drinking-water-health-advisories-pfas-chemicals-1-billion-bipartisan

48. US EPA O. EPA Proposes Designating Certain PFAS Chemicals as Hazardous Substances Under Superfund to Protect People's Health. Published August 26, 2022. Accessed September 1, 2022. https://www.epa.gov/newsreleases/epa-proposes-designating-certain-pfas-chemicals-hazardous-substances-under-superfund

49. Vestergren R, Cousins IT, Trudel D, Wormuth M, Scheringer M. Estimating the contribution of precursor compounds in consumer exposure to PFOS and PFOA. *Chemosphere*. 2008;73(10):1617-1624. doi:10.1016/j.chemosphere.2008.08.011

50. National Health and Nutrition Examination Survey. NHANES 2013-2014: Perfluoroalkyl and Polyfluoroalkyl Substances (formerly Polyfluoroalkyl Chemicals - PFC) Data Documentation, Codebook, and Frequencies. Published 2016. https://wwwn.cdc.gov/Nchs/Nhanes/2013-2014/PFAS_H.htm

51. Looker C, Luster MI, Calafat AM, et al. Influenza Vaccine Response in Adults Exposed to Perfluorooctanoate and Perfluorooctanesulfonate. *Toxicological Sciences*. 2014;138(1):76-88. doi:10.1093/toxsci/kft269

52. Agency for Toxic Substances and Disease Registry. Additional Resources. Per- and Polyfluoroalkyl Substances (PFAS) and Your Health. https://www.atsdr.cdc.gov/pfas/index.html

53. USEPA. *Understanding How EPA DEVELOPS NEW DRINKING WATER REGULATIONS*. https://www.epa.gov/sdwa/infographic-how-epa-develops-drinking-water-regulations

54. US EPA. Learn About the Unregulated Contaminant Monitoring Rule. Monitoring Unregulated Drinking Water Contaminants. Published 2018. https://www.epa.gov/dwucmr/learn-about-unregulated-contaminant-monitoring-rule

55. US EPA O. Fifth Unregulated Contaminant Monitoring Rule. Published January 11, 2021. Accessed August 26, 2022. https://www.epa.gov/dwucmr/fifth-unregulated-contaminant-monitoring-rule

56. Environmental Protection Agency U. *Drinking Water Health Advisory for Perfluorooctanoic Acid (PFOA).*; 2016. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100OM4O.PDF?Dockey=P100OM4O.PDF

57. Llorca M, Farré M, Picó Y, Müller J, Knepper TP, Barceló D. Analysis of perfluoroalkyl substances in waters from Germany and Spain. *Science of The Total Environment*. 2012;431:139-150. doi:10.1016/J.SCITOTENV.2012.05.011

58. U. S. GEOLOGICAL SURVEY CIRCULAR 1133. CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS. Contaminants in the Mississippi River. Published 1995. https://pubs.usgs.gov/circ/circ1133/conversion-factors.html

59. Davis T. Tucson Water: PFAS levels below EPA recommendations make drinking water safe. Arizona Daily Star. Published 2018. https://tucson.com/news/local/tucson-water-pfas-

levels-below-epa-recommendations-make-drinking-water-safe/article_d064395e-0a2b-5990-b7d4-c6b23a72cfbb.html

60. EPA U. Technical Fact Sheet: Drinking Water Health Advisories for Four PFAS (PFOA, PFOS, GenX chemicals, and PFBS). Published online June 2022. https://www.epa.gov/system/files/documents/2022-06/technical-factsheet-four-PFAS.pdf

61. US EPA. EXTERNAL PEER REVIEW DRAFT: Proposed Approaches to the Derivation of a Draft Maximum Contaminant Level Goal for Perfluorooctanoic Acid (PFOA) (CASRN 335-67-1) in Drinking Water. Published online 2021a. Accessed July 12, 2022. https://sab.epa.gov/ords/sab/f?p=100:18:16490947993:::RP,18:P18_ID:2601.

62. US EPA. EXTERNAL PEER REVIEW DRAFT: Proposed Approaches to the Derivation of a Draft Maximum Contaminant Level Goal for Perfluorooctane Sulfonic Acid (PFOS) (CASRN 1763-23-1) in Drinking Water. Published online 2021b. Accessed July 12, 2022. https://sab.epa.gov/ords/sab/f?p=100:18:16490947993:::RP,18:P18_ID:2601.

63. Registry A for TS and D. About ATSDR. Agency for Toxic Substances and Disease Registry. Published 2018. https://www.atsdr.cdc.gov/about/index.html

64. ATSDR (Agency for Toxic Substances and Disease Registry). *Toxicological Profile for Perfluoroalkyls*.; 2021. Accessed July 12, 2022. https://www.atsdr.cdc.gov/toxprofiles/tp200.pdf

65. Agency for Toxic Substances and Disease Registry. Minimal Risk Levels (MRLs). Priority List of Hazardous Substances. Published 2018. https://wwwn.cdc.gov/TSP/MRLS/mrlsListing.aspx

66. Registry A for TS and D. ATSDR's Minimal Risk Levels (MRLs) and Environmental Media Evaluation Guides (EMEGs) for PFAS. Per- and Polyfluoroalkyl Substances (PFAS) and Your Health.

67. Koskela A, Finnilä MA, Korkalainen M, et al. Effects of developmental exposure to perfluorooctanoic acid (PFOA) on long bone morphology and bone cell differentiation. *Toxicology and Applied Pharmacology*. 2016;301:14-21. doi:10.1016/j.taap.2016.04.002

68. Tucson Water. Quarterly Update to UCAB TARP - Tucson Water. PowerPoint presented at: UCAB Quarterly Meeting; July 20, 2022; Unified Community Advisory Board - Tucson International Airport Area Superfund Site Quarterly Meeting.

69. Stubbs HS. Parts per Million, Billion, Trillion. *Science Activities Projects and Curriculum Ideas in STEM Classrooms*. 1992;29(1):17-20. doi:10.1080/00368121.1992.10113008

70. Obsekov V, Kahn LG, Trasande L. Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Expo Health*. Published online July 26, 2022. doi:10.1007/s12403-022-00496-y

71. Anderson-Mahoney P, Kotlerman J, Takhar H, Gray D, Dahlgren J. Scientific Solutions-Self-Reported Health Effects Among Community Residents Exposed To Perfluorooctanoate. *NEW SOLUTIONS*. 2008;18(2):129-143. doi:10.2190/NS.18.2.d

72. Agency for Toxic Substances and Disease Registry. How can I be exposed to PFAS? Per- and Polyfluoroalkyl Substances (PFAS) and Your Health. Published 2018. https://www.atsdr.cdc.gov/pfas/health-effects/exposure.html

73. Steenland K, Fletcher T, Savitz DA. Epidemiologic evidence on the health effects of perfluorooctanoic acid (PFOA). *Environmental health perspectives*. 2010;118(8):1100-1108. doi:10.1289/ehp.0901827

74. Xiao F, Simcik MF, Gulliver JS. Mechanisms for removal of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) from drinking water by conventional and enhanced coagulation. *Water Research*. 2013;47(1):49-56. doi:10.1016/J.WATRES.2012.09.024

75. International Agency for Research on Cancer. *Agents Classified by the IARC Monographs, Volumes 1–123*.; 2017. https://monographs.iarc.who.int/agents-classified-by-the-iarc/

76. United States Environmental Protection Agency. *Drinking Water Health Advisory for Perfluorooctane Sulfonate (PFOS)*.; 2016. https://www.epa.gov/sites/default/files/2016-05/documents/pfos_health_advisory_final-plain.pdf.

77. Barry V, Winquist A, Steenland K. Perfluorooctanoic Acid (PFOA) Exposures and Incident Cancers among Adults Living Near a Chemical Plant. *Environmental Health Perspectives*. 2013;121(11-12):1313-1318. doi:10.1289/ehp.1306615

78. Steenland K, Woskie S. Cohort Mortality Study of Workers Exposed to Perfluorooctanoic Acid. *American Journal of Epidemiology*. 2012;176(10):909-917. doi:10.1093/aje/kws171

79. Vieira VM, Hoffman K, Shin HM, Weinberg JM, Webster TF, Fletcher T. Perfluorooctanoic Acid Exposure and Cancer Outcomes in a Contaminated Community: A Geographic Analysis. *Environmental Health Perspectives*. 2013;121(3):318-323. doi:10.1289/ehp.1205829

80. Lundin JI, Alexander BH, Olsen GW, Church TR. Ammonium Perfluorooctanoate Production and Occupational Mortality. *Epidemiology*. 2009;20(6):921-928. doi:10.1097/EDE.0b013e3181b5f395

81. Innes KE, Wimsatt JH, Frisbee S, Ducatman AM. Inverse association of colorectal cancer prevalence to serum levels of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) in a large Appalachian population. *BMC Cancer*. 2014;14(1):45. doi:10.1186/1471-2407-14-45

82. Steenland K, Zhao L, Winquist A. A cohort incidence study of workers exposed to perfluorooctanoic acid (PFOA). *Occupational and Environmental Medicine*. 2015;72(5):373-380. doi:10.1136/oemed-2014-102364

83. Alexander BH, Olsen GW, Burris JM, Mandel JH, Mandel JS. Mortality of employees of a perfluorooctanesulphonyl fluoride manufacturing facility. *Occupational and Environmental Medicine*. 2003;60(10):722-729. doi:10.1136/oem.60.10.722

84. Bonefeld-Jorgensen EC, Long M, Bossi R, et al. Perfluorinated compounds are related to breast cancer risk in greenlandic inuit: A case control study. *Environmental Health*. 2011;10(1):88. doi:10.1186/1476-069X-10-88

85. Hardell E, Kärrman A, van Bavel B, Bao J, Carlberg M, Hardell L. Case–control study on perfluorinated alkyl acids (PFAAs) and the risk of prostate cancer. *Environment International*. 2014;63:35-39. doi:10.1016/J.ENVINT.2013.10.005

86. Bonefeld-Jørgensen EC, Long M, Fredslund SO, Bossi R, Olsen J. 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*. 2014;25(11):1439-1448. doi:10.1007/s10552-014-0446-7

87. Costa G, Sartori S, Consonni D. Thirty Years of Medical Surveillance in Perfluooctanoic Acid Production Workers. *Journal of Occupational and Environmental Medicine*. 2009;51(3):364-372. doi:10.1097/JOM.0b013e3181965d80

88. Geiger SD, Xiao J, Shankar A. Positive Association Between Perfluoroalkyl Chemicals and Hyperuricemia in Children. *American Journal of Epidemiology*. 2013;177(11):1255-1262. doi:10.1093/aje/kws392

89. Gleason JA, Post GB, Fagliano JA. Associations of perfluorinated chemical serum concentrations and biomarkers of liver function and uric acid in the US population (NHANES), 2007–2010. *Environmental Research*. 2015;136:8-14. doi:10.1016/j.envres.2014.10.004

90. 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*. 2015;14(1):89. doi:10.1186/s12940-015-0077-9

91. Qin XD, Qian Z, Vaughn MG, et al. Positive associations of serum perfluoroalkyl substances with uric acid and hyperuricemia in children from Taiwan. *Environmental Pollution*. 2016;212:519-524. doi:10.1016/J.ENVPOL.2016.02.050

92. Shankar A, Jie Xiao J, Alan Ducatman A. Perfluoroalkyl chemicals and elevated serum uric acid in US adults. *Clinical Epidemiology*. 2011;3:251. doi:10.2147/CLEP.S21677

93. Shankar A, Xiao J, Ducatman A. Perfluoroalkyl Chemicals and Chronic Kidney Disease in US Adults. *American Journal of Epidemiology*. 2011;174(8):893-900. doi:10.1093/aje/kwr171

94. 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*. 2010;118(2):229-233. doi:10.1289/ehp.0900940

95. Watkins DJ, Josson J, Elston B, et al. Exposure to Perfluoroalkyl Acids and Markers of Kidney Function among Children and Adolescents Living near a Chemical Plant. *Environmental Health Perspectives*. 2013;121(5):625-630. doi:10.1289/ehp.1205838

96. US Department of Health and Human Services. Thyroid Tests. National Institute of Diabetes and Digestive and Kidney Disease. https://www.niddk.nih.gov/health-information/diagnostic-tests/thyroid

97. Lewis RC, Johns LE, Meeker JD. Serum Biomarkers of Exposure to Perfluoroalkyl Substances in Relation to Serum Testosterone and Measures of Thyroid Function among Adults and Adolescents from NHANES 2011-2012. *International journal of environmental research and public health*. 2015;12(6):6098-6114. doi:10.3390/ijerph120606098

98. Berg V, Nøst TH, Hansen S, et al. Assessing the relationship between perfluoroalkyl substances, thyroid hormones and binding proteins in pregnant women; a longitudinal mixed effects approach. *Environment International*. 2015;77:63-69. doi:10.1016/j.envint.2015.01.007

99. Yang L, Li J, Lai J, et al. Placental Transfer of Perfluoroalkyl Substances and Associations with Thyroid Hormones: Beijing Prenatal Exposure Study. *Scientific Reports*. 2016;6(1):21699. doi:10.1038/srep21699

100. Knox SS, Jackson T, Frisbee SJ, Javins B, Ducatman AM. Perfluorocarbon exposure, gender and thyroid function in the C8 Health Project. *The Journal of toxicological sciences*. 2011;36(4):403-410.

101. Dallaire R, Ayotte P, Pereg D, et al. Determinants of Plasma Concentrations of Perfluorooctanesulfonate and Brominated Organic Compounds in Nunavik Inuit Adults (Canada). *Environmental Science & Technology*. 2009;43(13):5130-5136. doi:10.1021/es9001604

102. Melzer D, Rice N, Depledge MH, Henley WE, Galloway TS. Association between Serum Perfluorooctanoic Acid (PFOA) and Thyroid Disease in the U.S. National Health and Nutrition Examination Survey. *Environmental Health Perspectives*. 2010;118(5):686-692. doi:10.1289/ehp.0901584

103. Wen LL, Lin LY, Su TC, Chen PC, Lin CY. Association Between Serum Perfluorinated Chemicals and Thyroid Function in U.S. Adults: The National Health and Nutrition Examination Survey 2007–2010. *The Journal of Clinical Endocrinology & Metabolism*. 2013;98(9):E1456-E1464. doi:10.1210/jc.2013-1282

104. Winquist A, Steenland K. Perfluorooctanoic Acid Exposure and Thyroid Disease in Community and Worker Cohorts. *Epidemiology*. 2014;25(2):255-264. doi:10.1097/EDE.0000000000000040

105. Dong GH, Tung KY, Tsai CH, et al. Serum Polyfluoroalkyl Concentrations, Asthma Outcomes, and Immunological Markers in a Case–Control Study of Taiwanese Children. *Environmental Health Perspectives*. 2013;121(4):507-513. doi:10.1289/ehp.1205351

106. Zhu Y, Qin XD, Zeng XW, et al. Associations of serum perfluoroalkyl acid levels with T-helper cell-specific cytokines in children: By gender and asthma status. *Science of The Total Environment*. 2016;559:166-173. doi:10.1016/j.scitotenv.2016.03.187

107. Humblet O, Diaz-Ramirez LG, Balmes JR, Pinney SM, Hiatt RA. Perfluoroalkyl Chemicals and Asthma among Children 12–19 Years of Age: NHANES (1999–2008). *Environmental Health Perspectives*. 2014;122(10):1129-1133. doi:10.1289/ehp.1306606

108. Grandjean P, Heilmann C, Weihe P, Nielsen F, Mogensen UB, Budtz-Jørgensen E. Serum Vaccine Antibody Concentrations in Adolescents Exposed to Perfluorinated Compounds. *Environmental Health Perspectives*. 2017;125(7):077018. doi:10.1289/EHP275

109. Mogensen UB, Grandjean P, Heilmann C, Nielsen F, Weihe P, Budtz-Jørgensen E. Structural equation modeling of immunotoxicity associated with exposure to perfluorinated alkylates. *Environmental Health*. 2015;14(1):47. doi:10.1186/s12940-015-0032-9

110. Kielsen K, Shamim Z, Ryder LP, et al. Antibody response to booster vaccination with tetanus and diphtheria in adults exposed to perfluorinated alkylates. *Journal of Immunotoxicology*. 2016;13(2):270-273. doi:10.3109/1547691X.2015.1067259

111. Granum B, Haug LS, Namork E, et al. 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*. 2013;10(4):373-379. doi:10.3109/1547691X.2012.755580

112. Zeng XW, Qian Z, Emo B, et al. Association of polyfluoroalkyl chemical exposure with serum lipids in children. *Science of The Total Environment*. 2015;512-513:364-370. doi:10.1016/j.scitotenv.2015.01.042

113. Grandjean P, Timmermann CAG, Kruse M, et al. Severity of COVID-19 at elevated exposure to perfluorinated alkylates. *medRxiv*. Published online October 26, 2020:2020.10.22.20217562. doi:10.1101/2020.10.22.20217562

114. Goudarzi H, Nakajima S, Ikeno T, et al. Prenatal exposure to perfluorinated chemicals and neurodevelopment in early infancy: The Hokkaido Study. *Science of The Total Environment*. 2016;541:1002-1010. doi:10.1016/j.scitotenv.2015.10.017

115. Stein CR, Savitz DA, Bellinger DC. Perfluorooctanoate and Neuropsychological Outcomes in Children. *Epidemiology*. 2013;24(4):590-599. doi:10.1097/EDE.0b013e3182944432

116. 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. *Paediatric and Perinatal Epidemiology*. 2014;28(2):146-156. doi:10.1111/ppe.12097

117. Hoffman K, Webster TF, Weisskopf MG, Weinberg J, Vieira VM. Exposure to Polyfluoroalkyl Chemicals and Attention Deficit/Hyperactivity Disorder in U.S. Children 12–15 Years of Age. *Environmental Health Perspectives*. 2010;118(12):1762-1767. doi:10.1289/ehp.1001898

118. Stein CR, Savitz DA. Serum Perfluorinated Compound Concentration and Attention Deficit/Hyperactivity Disorder in Children 5–18 Years of Age. *Environmental Health Perspectives*. 2011;119(10):1466-1471. doi:10.1289/ehp.1003538

119. Donauer S, Chen A, Xu Y, Calafat AM, Sjodin A, Yolton K. Prenatal Exposure to Polybrominated Diphenyl Ethers and Polyfluoroalkyl Chemicals and Infant Neurobehavior. Published online 2015. doi:10.1016/j.jpeds.2014.11.021

120. Quaak I, de Cock M, de Boer M, Lamoree M, Leonards P, van de Bor M. Prenatal Exposure to Perfluoroalkyl Substances and Behavioral Development in Children. *International Journal of Environmental Research and Public Health*. 2016;13(5):511. doi:10.3390/ijerph13050511

121. 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. *Environmental Health*. 2015;14(1):2. doi:10.1186/1476-069X-14-2

122. Fei C, McLaughlin JK, Lipworth L, Olsen J. Prenatal Exposure to Perfluorooctanoate (PFOA) and Perfluorooctanesulfonate (PFOS) and Maternally Reported Developmental Milestones in Infancy. *Environmental Health Perspectives*. 2008;116(10):1391-1395. doi:10.1289/ehp.11277

123. Gump BB, Wu Q, Dumas AK, Kannan K. Perfluorochemical (PFC) Exposure in Children: Associations with Impaired Response Inhibition. *Environmental Science & Technology*. 2011;45(19):8151-8159. doi:10.1021/es103712g

124. Fei C, McLaughlin JK, Lipworth L, Olsen J. Maternal levels of perfluorinated chemicals and subfecundity. *Human Reproduction*. 2009;24(5):1200-1205. doi:10.1093/humrep/den490

125. Velez MP, Arbuckle TE, Fraser WD. Maternal exposure to perfluorinated chemicals and reduced fecundity: the MIREC study. *Human Reproduction*. 2015;30(3):701-709. doi:10.1093/humrep/deu350

126. Whitworth KW, Haug LS, Baird DD, et al. Perfluorinated Compounds and Subfecundity in Pregnant Women. *Epidemiology*. 2012;23(2):257-263. doi:10.1097/EDE.0b013e31823b5031

127. Olsen GW, Gilliland FD, Burlew MM, Burris JM, Mandel JS, Mandel JH. An epidemiologic investigation of reproductive hormones in men with occupational exposure to perfluorooctanoic acid. *Journal of occupational and environmental medicine*. 1998;40(7):614-622.

128. 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. *Environmental health perspectives*. 2013;121(4):453-458. doi:10.1289/ehp.1205118

129. Tsai MS, Lin CY, Lin CC, et al. Association between perfluoroalkyl substances and reproductive hormones in adolescents and young adults. *International Journal of Hygiene and Environmental Health*. 2015;218(5):437-443. doi:10.1016/j.ijheh.2015.03.008

130. Sakr CJ, Kreckmann KH, Green JW, Gillies PJ, Reynolds JL, Leonard RC. 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*. 2007;49(10):1086-1096. doi:10.1097/JOM.0b013e318156eca3

131. Barrett ES, Chen C, Thurston SW, et al. Perfluoroalkyl substances and ovarian hormone concentrations in naturally cycling women. *Fertility and Sterility*. 2015;103(5):1261-1270.e3. doi:10.1016/j.fertnstert.2015.02.001

132. 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. *Human Reproduction*. 2013;28(3):599-608. doi:10.1093/humrep/des425

133. Knox SS, Jackson T, Javins B, Frisbee SJ, Shankar A, Ducatman AM. Implications of Early Menopause in Women Exposed to Perfluorocarbons. *The Journal of Clinical Endocrinology & Metabolism*. 2011;96(6):1747-1753. doi:10.1210/jc.2010-2401

134. Chen MH, Ha EH, Wen TW, et al. Perfluorinated Compounds in Umbilical Cord Blood and Adverse Birth Outcomes. Meliker J, ed. *PLoS ONE*. 2012;7(8):e42474. doi:10.1371/journal.pone.0042474

135. Stein CR, Savitz DA, Dougan M. Serum Levels of Perfluorooctanoic Acid and Perfluorooctane Sulfonate and Pregnancy Outcome. *American Journal of Epidemiology*. 2009;170(7):837-846. doi:10.1093/aje/kwp212

136. Jensen TK, Andersen LB, Kyhl HB, Nielsen F, Christesen HT, Grandjean P. Association between Perfluorinated Compound Exposure and Miscarriage in Danish Pregnant Women. Szecsi PB, ed. *PLOS ONE*. 2015;10(4):e0123496. doi:10.1371/journal.pone.0123496

137. Innes KE, Ducatman AM, Luster MI, Shankar A. Association of Osteoarthritis With Serum Levels of the Environmental Contaminants Perfluorooctanoate and Perfluorooctane Sulfonate in a Large Appalachian Population. *American Journal of Epidemiology*. 2011;174(4):440-450. doi:10.1093/aje/kwr107

138. Uhl SA, James-Todd T, Bell ML. Association of Osteoarthritis with Perfluorooctanoate and Perfluorooctane Sulfonate in NHANES 2003-2008. *Environmental health perspectives*. 2013;121(4):447-452. doi:10.1289/ehp.1205673

139. Eriksen KT, Raaschou-Nielsen O, McLaughlin JK, et al. Association between Plasma PFOA and PFOS Levels and Total Cholesterol in a Middle-Aged Danish Population. Pant AB, ed. *PLoS ONE*. 2013;8(2):e56969. doi:10.1371/journal.pone.0056969

140. Sakr CJ, Leonard RC, Kreckmann KH, Slade MD, Cullen MR. Longitudinal Study of Serum Lipids and Liver Enzymes in Workers With Occupational Exposure to Ammonium Perfluorooctanoate. *Journal of Occupational and Environmental Medicine*. 2007;49(8):872-879. doi:10.1097/JOM.0b013e318124a93f

141. Skuladottir M, Ramel A, Rytter D, et al. Examining confounding by diet in the association between perfluoroalkyl acids and serum cholesterol in pregnancy. *Environmental Research*. 2015;143(Pt A):33-38. doi:10.1016/j.envres.2015.09.001

142. Fisher M, Arbuckle TE, Wade M, Haines DA. Do perfluoroalkyl substances affect metabolic function and plasma lipids?—Analysis of the 2007–2009, Canadian Health Measures Survey (CHMS) Cycle 1. *Environmental Research*. 2013;121:95-103. doi:10.1016/j.envres.2012.11.006

143. Frisbee SJ, Shankar A, Knox SS, et al. Perfluorooctanoic Acid, Perfluorooctanesulfonate, and Serum Lipids in Children and Adolescents. *Archives of Pediatrics & Adolescent Medicine*. 2010;164(9):860-869. doi:10.1001/archpediatrics.2010.163

144. Fu Y, Wang T, Fu Q, Wang P, Lu Y. Associations between serum concentrations of perfluoroalkyl acids and serum lipid levels in a Chinese population. *Ecotoxicology and Environmental Safety*. 2014;106:246-252. doi:10.1016/j.ecoenv.2014.04.039

145. Geiger SD, Xiao J, Ducatman A, Frisbee S, Innes K, Shankar A. The association between PFOA, PFOS and serum lipid levels in adolescents. *Chemosphere*. 2014;98:78-83. doi:10.1016/j.chemosphere.2013.10.005

146. Maisonet M, Näyhä S, Lawlor DA, Marcus M. Prenatal exposures to perfluoroalkyl acids and serum lipids at ages 7 and 15 in females. *Environment International*. 2015;82:49-60. doi:10.1016/j.envint.2015.05.001

147. Steenland K, Tinker S, Frisbee S, Ducatman A, Vaccarino V. Association of Perfluorooctanoic Acid and Perfluorooctane Sulfonate With Serum Lipids Among Adults Living Near a Chemical Plant. *American Journal of Epidemiology*. 2009;170(10):1268-1278. doi:10.1093/aje/kwp279

148. Starling AP, Engel SM, Whitworth KW, et al. Perfluoroalkyl substances and lipid concentrations in plasma during pregnancy among women in the Norwegian Mother and Child Cohort Study. *Environment International*. 2014;62:104-112. doi:10.1016/j.envint.2013.10.004

149. Fitz-Simon N, Fletcher T, Luster MI, et al. Reductions in Serum Lipids with a 4-year Decline in Serum Perfluorooctanoic Acid and Perfluorooctanesulfonic Acid. *Epidemiology*. 2013;24(4):569-576. doi:10.1097/EDE.0b013e31829443ee

150. Olsen GW, Burris JM, Mandel JH, Zobel LR. Serum perfluorooctane sulfonate and hepatic and lipid clinical chemistry tests in fluorochemical production employees. *Journal of occupational and environmental medicine*. 1999;41(9):799-806.

151. Olsen GW, Burris JM, Burlew MM, Mandel JH. Epidemiologic assessment of worker serum perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) concentrations and medical surveillance examinations. *Journal of occupational and environmental medicine*. 2003;45(3):260-270.

152. Château-Degat ML, Pereg D, Dallaire R, Ayotte P, Dery S, Dewailly É. Effects of perfluorooctanesulfonate exposure on plasma lipid levels in the Inuit population of Nunavik (Northern Quebec). *Environmental Research*. 2010;110(7):710-717.

153. 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 & technology*. 2012;46(17):9274-9281. doi:10.1021/es300906q

154. Timmermann CAG, Rossing LI, Grøntved A, et al. Adiposity and Glycemic Control in Children Exposed to Perfluorinated Compounds. *The Journal of Clinical Endocrinology & Metabolism*. 2014;99(4):E608-E614. doi:10.1210/jc.2013-3460

155. Darrow LA, Groth AC, Winquist A, Shin HM, Bartell SM, Steenland K. Modeled Perfluorooctanoic Acid (PFOA) Exposure and Liver Function in a Mid-Ohio Valley Community. *Environmental health perspectives*. 2016;124(8):1227-1233. doi:10.1289/ehp.1510391

156. Lin CY, Lin LY, Chiang CK, et al. Investigation of the Associations Between Low-Dose Serum Perfluorinated Chemicals and Liver Enzymes in US Adults. *American Journal of Gastroenterology*. 2010;105(6):1354-1363. doi:10.1038/ajg.2009.707

157. Yamaguchi M, Arisawa K, Uemura H, et al. Consumption of seafood, serum liver enzymes, and blood levels of PFOS and PFOA in the Japanese population. *Journal of occupational health*. 2013;55(3):184-194. doi:10.1539/joh.12-0264-oa

158. Gallo V, Leonardi G, Genser B, et al. Serum Perfluorooctanoate (PFOA) and Perfluorooctane Sulfonate (PFOS) Concentrations and Liver Function Biomarkers in a Population with Elevated PFOA Exposure. *Environmental Health Perspectives*. 2012;120(5):655-660. doi:10.1289/ehp.1104436

159. Anderson-Mahoney P, Kotlerman J, Takhar H, Gray D, Dahlgren J. No Title. 2008;18(2):129-143. doi:10.2190/NS.18.2.d

160. Lin CY, Lin LY, Wen TW, et al. Association between levels of serum perfluorooctane sulfate and carotid artery intima–media thickness in adolescents and young adults. *International Journal of Cardiology*. 2013;168(4):3309-3316. doi:10.1016/j.ijcard.2013.04.042

161. 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*. 2013;127:22-28. doi:10.1016/j.envres.2013.10.002

162. Carotid Intima-Media Thickness Test (CIMT) | Cedars-Sinai. https://www.cedars-sinai.org/programs/heart/clinical/womens-heart/conditions/cimt-carotid-intima-media-thickness-test.html#:~:text=The%20carotid%20intima%2Dmedia%20thickness,when%20patients%20are%20still%20asymptomatic.

163. Shankar A, Xiao J, Ducatman A. Perfluorooctanoic Acid and Cardiovascular Disease in US Adults. *Archives of Internal Medicine*. 2012;172(18):1397. doi:10.1001/archinternmed.2012.3393

164. Min JY, Lee KJ, Park JB, Min KB. Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults. *Occupational and Environmental Medicine*. 2012;69(9):658-662. doi:10.1136/oemed-2011-100288

165. Darrow LA, Stein CR, Steenland K. Serum Perfluorooctanoic Acid and Perfluorooctane Sulfonate Concentrations in Relation to Birth Outcomes in the Mid-Ohio Valley, 2005–2010. *Environmental Health Perspectives*. 2013;121(10):1207-1213. doi:10.1289/ehp.1206372

166. Starling AP, Engel SM, Richardson DB, et al. Perfluoroalkyl Substances During Pregnancy and Validated Preeclampsia Among Nulliparous Women in the Norwegian Mother and Child Cohort Study. *American Journal of Epidemiology*. 2014;179(7):824-833. doi:10.1093/aje/kwt432

167. 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. *Environmental Research*. 2015;142:148-154. doi:10.1016/j.envres.2015.06.033

168. Su TC, Kuo CC, Hwang JJ, Lien GW, Chen MF, Chen PC. Serum perfluorinated chemicals, glucose homeostasis and the risk of diabetes in working-aged Taiwanese adults. *Environment International*. 2016;88:15-22. doi:10.1016/j.envint.2015.11.016

169. Olsen GW, Burlew MM, Marshall JC, Burris JM, Mandel JH. Analysis of episodes of care in a perfluorooctanesulfonyl fluoride production facility. *Journal of occupational and environmental medicine*. 2004;46(8):837-846.

170. PFAS Pease Study | ATSDR. Published August 24, 2022. Accessed August 26, 2022. https://www.atsdr.cdc.gov/pfas/activities/pease.html

171. PFAS Multi-site Study (MSS) | Per- and Polyfluoroalkyl Substances (PFAS) and Your Health | ATSDR. Published August 11, 2022. Accessed August 26, 2022. https://www.atsdr.cdc.gov/pfas/activities/studies/multi-site.html

172. Alves A, Jacobs G, Vanermen G, Covaci A, Voorspoels S. New approach for assessing human perfluoroalkyl exposure via hair. *Talanta*. 2015;144:574-583. doi:10.1016/j.talanta.2015.07.009

173. Schulz C, Wilhelm M, Heudorf U, Kolossa-Gehring M, Human Biomonitoring Commission of the German Federal Environment Agency. Update of the reference and HBM values derived by the German Human Biomonitoring Commission. *Int J Hyg Environ Health*. 2011;215(1):26-35. doi:10.1016/j.ijheh.2011.06.007

174. Hölzer J, Lilienthal H, Schümann M. Human Biomonitoring (HBM)-I values for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) - Description, derivation and discussion. *Regul Toxicol Pharmacol*. 2021;121:104862. doi:10.1016/j.yrtph.2021.104862

175. Schümann M, Lilienthal H, Hölzer J. Human biomonitoring (HBM)-II values for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) - Description, derivation and discussion. *Regulatory Toxicology and Pharmacology*. 2021;121:104868. doi:10.1016/j.yrtph.2021.104868

176. PFAS Exposure Assessment Technical Tools | ATSDR. Published June 24, 2020. Accessed September 6, 2022. https://www.atsdr.cdc.gov/pfas/activities/assessments/peatt.html

177. Bioanalytical Method Validation Guidance for Industry. Published online 2018:44.

178. Scientific Working Group for Forensic Toxicology (SWGTOX) Standard Practices for Method Validation in Forensic Toxicology. *Journal of Analytical Toxicology*. 2013;37(7):452-474. doi:10.1093/jat/bkt054

179. Kannan K, Stathis A, Mazzella MJ, et al. Quality assurance and harmonization for targeted biomonitoring measurements of environmental organic chemicals across the Children's Health Exposure Analysis Resource laboratory network. *International Journal of Hygiene and Environmental Health*. 2021;234:113741. doi:10.1016/j.ijheh.2021.113741

180. Landsteiner A, Huset C, Williams A, Johnson J. Biomonitoring for Perfluorochemicals in a Minnesota Community With Known Drinking Water Contamination. *National Environmental Health Association (NEHA) Source: Journal of Environmental Health*. 2014;77(5):14-19. doi:10.2307/26330157

181. Agency for Toxic Substances and Disease, National Center for Environmental Health. *An Overview of Perfluoroalkyl and Polyfluoroalkyl Substances and Interim Guidance for Clinicians Responding to Patient Exposure Concerns Interim Guidance*.; 2018. https://stacks.cdc.gov/view/cdc/77114

182. Lankova D, Lacina O, Pulkrabova J, Hajslova J. The determination of perfluoroalkyl substances, brominated flame retardants and their metabolites in human breast milk and infant formula. *Talanta*. 2013;117:318-325. doi:10.1016/j.talanta.2013.08.040

183. US EPA, Oppt. *Long-Chain Perfluorinated Chemicals (PFCs) Action Plan*.; 2009. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/long-chain-perfluorinated-chemicals-pfcs-action-plan

184. Engineers C. *Groundwater Quality Improvements: Alternatives Evaluation and Implementation Plan*.; 2017.

185. Jenkins J. RWRD Efforts on Identifying Perfluorinated Compounds (PFCs) and 1,4-Dioxane Contamination. Published online 2018. https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Administration/CHHmemosFor%20Web/2018/October/Perflourinated%20Compounds%20(PFCs)%20and%201,4-Dioxane%20in%20Regional%20Wastewater%20Reclamation%20Effluent%20and%20Sludge%20.pdf

186. MARANA WATER - Project Water. Town of Marana. Accessed August, 2019. https://www.maranaaz.gov/water-project-water

187. Davis T. Marana gets $15 million loan to build water treatment plants. Arizona Daily Star. Published 2018. https://tucson.com/news/local/marana-gets-15-million-loan-to-build-water-treatment-plants/article_c5cf6aa7-d2c9-5640-a474-2c353f1ab0b2.html

188. Interim Drinking Water Health Advisory: Perfluorooctanoic Acid (PFOA) CASRN 335-67-1. :33. https://www.epa.gov/system/files/documents/2022-06/interim-pfoa-2022.pdf

189. Interim Drinking Water Health Advisory: Perfluorooctane Sulfonic Acid (PFOS) CASRN 1763-23-1. :34.https://www.epa.gov/system/files/documents/2022-06/interim-pfos-2022.pdf

190. MARANA WATER - Project Water. Town of Marana. Accessed September 1, 2022. https://www.maranaaz.gov/water-project-water

191. Arizona Department of Environmental Quality. *Arizona's Public Water System Screening for Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) Final Report*.; 2018. https://static.azdeq.gov/wqd/reports/pfoapfosepareport_final.pdf

192. Davis T. Tucson officials hope new EPA guidelines speed groundwater cleanup. Arizona Daily Star. Accessed September 6, 2022. https://tucson.com/news/local/tucson-officials-hope-new-epa-guidelines-speed-groundwater-cleanup/article_8f9a169e-ece1-11ec-bcff-5335eb0176fd.html

193. Davis-Monthan Air Force Base. ADEQ Arizona Department of Environmental Quality. Published 2019. https://azdeq.gov/DOD/DavisMonthan

194. AFWP. *Site Inspection of Aqueous Film Forming Foam (AFFF) Release AREAS Environmental Programs Worldwide*.; 2019. http://www.cpeo.org/lists/military/2019/pdfWNgAeyWNJH.pdf

195. Pima County. Re: Quarterly Update on Per- and Polyfluoroalkyl Substances (PFAS). Published online April 27, 2022. Accessed August 2, 2022. https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Administration/AdminMemosForWeb/April/2022-april-27-quarterly-update-on-per-and-polyfluoroalkyl-substances-pfas.pdf

196. PFAS Sites and Community Resources. The PFAS Project Lab. Published January 20, 2017. Accessed September 6, 2022. https://pfasproject.com/pfas-sites-and-community-resources/

197. PRESS RELEASE | ADEQ is Committed to Protecting Arizonans and Assisting Public Water Systems in Addressing PFAS | ADEQ Arizona Department of Environmental Quality. Accessed September 1, 2022. https://azdeq.gov/press-releases/press-release-adeq-committed-protecting-arizonans-and-assisting-public-water-systems

198. USEPA. *The Third Unregulated Contaminant Monitoring Rule (UCMR 3) Fact Sheet for Screening Survey Monitoring (List 2 Contaminants).*; 2012.

199. USEPA. UCMR 3 (2013-2015) Occurrence Data. Monitoring Unregulated Drinking Water Contaminants. Published 2017. https://www.epa.gov/dwucmr/data-summary-third-unregulated-contaminant-monitoring-rule

200. Tucson Water to suspend operations of Tucson Airport Remediation Project treatment facility | Local | kvoa.com. Accessed September 6, 2022. https://www.kvoa.com/news/local/tucson-water-to-suspend-operations-of-tucson-airport-remediation-project-treatment-facility/article_a3033e80-a33e-554a-8968-e1e2b30d4c7d.html

201. US EPA O. EPA Actions to Address PFAS. Published March 13, 2018. Accessed September 1, 2022. https://www.epa.gov/pfas/epa-actions-address-pfas

202. Governor Doug Ducey Announces $2 Million In State Funding To Restart Tucson Water Treatment Plant. Office of the Arizona Governor. Published June 21, 2021. Accessed September 1, 2022. https://azgovernor.gov/governor/news/2021/06/governor-doug-ducey-announces-2-million-state-funding-restart-tucson-water

203. Tucson Water. Quarterly Update to UCAB TARP - Tucson Water - Jan.2022. Presented at: January 19, 2022.

204. City of Tucson. Tucson Water FAQ’s on Water Quality. Official website of the City of Tucson. Published 2018. https://www.tucsonaz.gov/water/pfcs_tarp_faq

205. Huckelberry - County Administrator CH. Memorandum: Per- and Polyfluoroalkyl Substances Received and Conveyed by the Pima County Sanitary Sewerage System. Published online February 5, 2020. Accessed July 28, 2022. https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Administration/CHHmemosFor%20Web/2020/February/PFAS%20Substances%20Received%20and%20Conveyed%20by%20the%20Pima%20County%20Sanitary%20Sewerage%20System.pdf

206. Pima County. Re: Quarterly Update on Per- and Polyfluoroalkyl Substances (PFAS) - June. Published online June 23, 2022. Accessed August 2, 2022. https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Administration/AdminMemosForWeb/2022/June/2022-june-23-quarterly-update-on-per-and-polyflouroalkyl-substances-pfas.pdf

207. UArizona Receives $1.3M Federal Grant to Study Synthetic Chemicals Posing Risk to Regional Aquifer. University of Arizona News. Published July 6, 2021. Accessed August 30, 2022. https://news.arizona.edu/story/uarizona-receives-13m-federal-grant-study-synthetic-chemicals-posing-risk-regional-aquifer

208. Delivering solutions for Arizona through innovative partnerships | Arizona Board of Regents. Accessed September 1, 2022. https://www.azregents.edu/news-releases/delivering-solutions-arizona-through-innovative-partnerships

209. $1.4M effort develops reusable sponges to soak up harmful chemicals from water. University of Arizona News. Published August 16, 2022. Accessed August 30, 2022. https://news.arizona.edu/story/14m-effort-develops-reusable-sponges-soak-harmful-chemicals-water

210. EWG. EWG’S GUIDE TO AVOIDING PFAS CHEMICALS. Published 2017. https://www.ewg.org/consumer-guides/ewgs-guide-avoiding-pfas-chemicals

211. Strynar MJ, Lindstrom AB. Perfluorinated Compounds in House Dust from Ohio and North Carolina, USA. *Environmental Science & Technology*. 2008;42(10):3751-3756. doi:10.1021/es7032058

212. Karásková P, Venier M, Melymuk L, et al. Perfluorinated alkyl substances (PFASs) in household dust in Central Europe and North America. *Environment International*. 2016;94:315-324. doi:10.1016/J.ENVINT.2016.05.031

213. Vestergren R, Cousins IT. Tracking the Pathways of Human Exposure to Perfluorocarboxylates. *Environmental Science & Technology*. 2009;43(15):5565-5575. doi:10.1021/es900228k

214. US EPA. Certification of Laboratories that Analyze Drinking Water Samples to Ensure Compliance with Regulations. https://www.epa.gov/dwlabcert

215. Arizona Department of Health Services. Well Water Quality - Home. Environmental Toxicology. https://www.azdhs.gov/preparedness/epidemiology-disease-control/environmental-toxicology/well-water/index.php

216. Van Horne YO, Parks J, Tran T, Abrell L, Reynolds KA, Beamer PI. Seasonal variation of water quality in unregulated domestic wells. *International Journal of Environmental Research and Public Health*. 2019;16(9). doi:10.3390/ijerph16091569

217. International NSF. PFOA/PFOS In Drinking Water. Drinking Water. Published 2019. https://www.nsf.org/consumer-resources/articles/pfoa-pfos-drinking-water

218. United States Department of Health and Human Services. FDA Regulates the Safety of Bottled Water Beverages Including Flavored Water and Nutrient-Added Water Beverages. Published 2018. https://www.fda.gov/food/buy-store-serve-safe-food/fda-regulates-safety-bottled-water-beverages-including-flavored-water-and-nutrient-added-water

219. Raj SD. Bottled Water: How Safe Is It? *Water Environment Research*. 2005;77(7):3013-3018. doi:10.2175/106143005x73893. PMID: 16381148.

220. Heo JJ, Lee JW, Kim SK, Oh JE. Foodstuff analyses show that seafood and water are major perfluoroalkyl acids (PFAAs) sources to humans in Korea. *Journal of Hazardous Materials*. 2014;279:402-409. doi:10.1016/j.jhazmat.2014.07.004

221. Chow SJ, Ojeda N, Jacangelo JG, Schwab KJ. Detection of ultrashort-chain and other per- and polyfluoroalkyl substances (PFAS) in U.S. bottled water. *Water Research*. 2021;201:117292. doi:10.1016/j.watres.2021.117292

222. The Good Housekeeping Institute. Filters That Really Work. Good Housekeeping.com. https://www.goodhousekeeping.com/home-products/g29609739/best-water-filters/

223. Envirotek Laboratories Inc. Perfluorinated Chemicals Reduction Test Report. Berkey Water Filter Lab Test Results - What does it remove? Published 2016. https://berkeywaterkb.com/wp-content/uploads/2016/09/Black-Berkey_Perfluorinated-Chemical-Removal-Test-Report.pdf

224. NSF International. NSF Protocol P473 Drinking Water Treatment Units - PFOA & PFOS. NSF Product and Service Listings. Published 2019. https://www.wcponline.com/wp-content/uploads/2016/11/12-01_NSF-P473.pdf

225. Michigan Department of Environmental Quality. *PFAS In-Home Filtration Systems*.; 2017. https://www.michigan.gov/pfasresponse/drinking-water/filters

226. United States Environmental Protection Agency. Treating PFAS in Drinking Water. PFOA, PFOS and Other PFASs. Published 2018. https://19january2021snapshot.epa.gov/pfas/treating-pfas-drinking-water_.html#:~:text=Treating%20PFAS%20in%20Drinking%20Water%20EPA%20has%20found,high%20pressure%20membranes%2C%20like%20nanofiltration%20or%20reverse%20osmosis

227. US EPA. Technologies for Reducing PFAS in Drinking Water. Published online April 18, 2019. Accessed August 5, 2022. https://www.epa.gov/sites/default/files/2019-10/documents/pfas_drinking_water_treatment_technology_options_fact_sheet_04182019.pdf

228. GRAVER TECHNOLOGIES. *Understanding USP, FDA and NSF*. https://help.filtersource.com/hc/en-us/articles/115005487068-Understanding-USP-FDA-and-NSF

229. ANSI. Introduction to ANSI. About ANSI.https://www.ansi.org/about/introduction

230. PFOA/PFOS Reduction Claims Requirements Added to NSF Standards for…. NSF. Accessed September 1, 2022. https://www.nsf.org/news/pfoa-pfos-reduction-claims-requirements-added-to-nsf-standards

231. Home Water Treatment. NSF. Accessed September 1, 2022. https://www.nsf.org/consumer-resources/articles/home-water-treatment

232. NSF/ANSI 53 Drinking Water Treatment Units - Health Effects - Listing Category Search Page | NSF International. Accessed September 9, 2022. https://info.nsf.org/Certified/DWTU/Listings.asp?ProductFunction=053%7CPFOA+Reduction&ProductFunction=053%7CPFOS+Reduction&ProductFunction=P473%7CPFOA+Reduction&ProductFunction=P473%7CPFOS+Reduction&ProductType=&submit2=Search

233. Dery JL, Gerrity D, Rock CM. *Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS): What Consumers Need to Know*.; 2019. https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1794-2019.pdf

234. Inc C. Cyclopure Announces Purefast™ Home Filter for PFAS! Accessed September 1, 2022. https://www.prnewswire.com/news-releases/cyclopure-announces-purefast-home-filter-for-pfas-301520029.html

235. Final Progress Reports: CycloPure, Inc.: Remediation of Perfluorinated Chemicals in Water Using Novel High-Affinity Polymer Adsorbents (Superfund Research Program). National Institute of Environmental Health Sciences. Accessed September 1, 2022. https://tools.niehs.nih.gov/srp/programs/progress_report.cfm?Project_ID=R43ES029401

236. Brown KW, Gessesse B, Butler LJ, MacIntosh DL. Potential Effectiveness of Point-of-Use Filtration to Address Risks to Drinking Water in the United States. *Environmental Health Insights*. 2017;11:117863021774699. doi:10.1177/1178630217746997

Appendix 1. Further detail regarding negative human health outcomes association with each PFAS type discussed including references used in creation of Table 4 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	PFBS	PFBA	PFHxA
Cardiovascular	Cardiovascular disease	+ (1, 7, 59)					+(101)	+(101)	+(101)		+(101)		
	Stroke; Carotid intima media thickness	+ (1, 8)	+ (3, 233)		+(115) -(233)	+(233)			+(115)	-(233)			
	Angina; myocardial infarction; peripheral arterial disease; systolic blood pressure; diastolic blood pressure; hypertension risk	+ (1, 6, 7, 100, 201, 235)	+(100, 201, 233)	+(201)	+(100, 101) -(233)	+(100, 233)		+(100, 101)	+(201)	+(100) -(233)		+(100)	
	Cerebrovascular disease; microvascular disease	+ (4, 59)	+(204)										
	Pregnancy induced hypertension	+ (2)	+(201)	+(201)									
	Pre-eclampsia	+(114) -(154)	+ (10)	+(201) -(154)	-(154)		- (9)				+(219)		
	Coronary artery disease; Coronary heart disease				+(101)		+(101)			+ (5)	+(219)		
	Congestive heart failure							+(101)					
	Arterial Wall Stiffness	+(102)			+(102)								
Gastrointestinal	Cholelithiasis or acute cholecystitis		+ (11)										
Musculoskeletal	Osteoarthritis risk	+ (12, 14)	- (12)										
	Bone mineral density	- (13, 218)	- (13, 117, 218)		- (13, 218)	- (218)							
	Osteoporosis risk	+ (13)		+ (13)	+ (13)								
	Serum calcium	(+222)	+(222)	+(222)	+(222)	+(222)							
Endocrine	TSH	+ (18, 122, 163, 231) -(164)	+ (15, 200, 221, 230) -(16, 27, 107, 108)	+(164)	- (27, 231)	+(221) - (27, 221)	- (27)	- (27, 221)					
	T3; FT3; T3 uptake	+ (18, 24, 109, 118, 122) - (17, 221, 231)	+ (21)- (16, 163)	+(25, 221)	+(109, 221) -(231)	- (15)	-(15, 221)	- (27)					
	T4; T4 binding globulin; Free T4	+ (17, 18, 118, 221) -(107, 108, 250)	+(16, 18, 22) -(16, 107, 108)	+ (25) –(107, 250)	+ (105, 107, 108, 109, 221) - (23)		- (23, 252)	- (23, 27, 221)					
	Thyroid disease; thyroid peroxidase antibody; thyroglobulin	+ (1, 19, 20) -(221)				+(221)							
	Taking thyroid medication		+ (20)										
	Hypothyroidism including subclinical	+(19, 25, 106)	+ (25, 106)	+ (25)									
	Subclinical hyperthyroidism	- (25)		+ (25)									
	Functional thyroid disease	+ (26)											
	Germ cell tumor			+(234)									
	Adrenal steroid metabolites					-(224)							
	Fetal sex hormone									-(245)	-(245)		
Immune	Infectious Diseases (Total, risk of hospitalization)	+(131) –(131)	+(111, 131)	+(111)									
	IgE	+ (28) –(125)	+ (28)		+ (28, 36)	+ (28, 36)		+ (28)					
	Absolute eosinophil counts; Eosinophil cationic protein	+ (28)	+ (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)					
	Lower Respiratory Infections, Common cold (# of episodes), rhino-conjunctivitis, chicken pox, pneumonia, bronchitis, ear infection	+ (31, 110, 196, 220, 229) -(220)	+ (110, 220, 229) -(220)	+(220)	+ (31, 110, 220) -(220)		+ (110, 220) -(220)	+(196)	+(110)	+(229)			
	COVID severity; COVID risk		+(225, 246)	+(246)								+(215)	
	Urinary tract infection	-(220)	-(220)	-(220)									
	Rubella antibody levels	- (31, 130)	- (31, 130)	- (31, 130)	- (31)								
	Mumps antibody levels	-(130)	-(130)										
	Gastroenteritis (# of episodes); Diarrhea/gastric flu	+ (31, 220)		+ (31, 220)	+(220)	- (266)							
	Seroprotection from influenza A H3N2 virus	- (34)											
	IL-4 or IL-5 T-helper cytokine	+ (36)			+ (36)						+ (36, 90)		
	Allergies, Eczema, rhinitis, sensitization, dermatitis	+(124, 126, 130, 206, 188) - (196, 171)	+(131), -(131, 196)	+(206)	+(126)	+(206)	-(196, 220)	+(206) -(196)					
	MHC I, PF4			(+260)		+(260)							
	Ulcerative Colitis	+(61, 128, 261)											
	Rheumatoid Arthritis; RA markers or factors	+(61, 205)											

		PFAS Type											
		Long-Chain								Short-Chain			
		PFOA	PFOS	PFHxS	PFNA	PFDeA	PFUA	PFDoA	PFOSA	PFHpA	PFBS	PFBA	PFHxA
Reproductive	Fecundability	+(148) -(37, 38)	- (37)	+(149) - (38)	-(148)				-(151)				
	Infertility	+ (37, 38, 39)	+ (37, 39)	+ (38) -(150)	+(148) – (150)					-(150)	+(150)		
	Premature ovarian insufficiency	+(198)	+(198)	+(198)									
	Prolactin	+ (40)											
	FSH	+ (41)	- (42)				- (42)						
	LH	+ (41, 135)											
	Testosterone	+ (82, 116, 135)	- (42, 44, 135)		-(135)	-(135)		-(135)					-(135)
	SHGB	+ (42)											
	Estradiol	+ (82, 116, 136)	- (43, 45)	+(135)	+ (44)								
	P450 Aromatase	+(116)											
	Reduced breastfeeding duration, breastfeeding cessation	+ (131, 144, 146)	+(131, 146)		+(146, 254)	+(146, 254)							
	Anogenital distance	+(197) -(264)				-(264)	-(264)	-(264)					
	Androgen Index		-(44)										
	PCOS	+147)	+(147)										
	Early puberty; Early Menopause	+(45, 145, 210)	+(45, 210, 213)	+(145, 213)	+(145, 213)	+ 212							
	Later puberty				+(213)								
	Hysterectomy	+(145)	+(145)	(+145)	+(145)								
	Altered sperm morphology or motility; percent abnormal sperm	+(137) -(138)	+(137, 138)	+(138)	+(137)	+(137)							
	y-X chromosome ratio		+(139)										
	IVF outcomes (embryo quality, 2 PN zygote)	-(239)											
	Endometriosis	+(140, 142)	+(140)		+(140)								
	Menstrual irregularity	+(143)											
Pregnancy and Birth Outcomes	Pre-term birth; small for gestational age; low birth weight	+(113, 114) -(152)	+ (10, 46, 154, 208) -(152)	-(156)		+(176)	+(176)						
	Gestational age; birth weight; head circumference, birth length, abdominal circumference, adiposity at birth, umbilical circumference	+(177) -(112, 113, 153, 157, 161, 162, 165, 166, 167, 168, 169, 203, 258)	+(112) - (10, 46, 112, 113, 156, 158, 166, 169, 174, 202, 216)	+(161, 166) – (168, 175, 202, 203, 216)	+(223) -(155, 168, 176)	+(223) - (176) -203	+(161, 176)	+(207) -(112, 176)	+(203) -(178)	-(112)	+ (207)	-(214)	
	Childhood BMI	-(141, 227)	-(141, 227)	+(227)	+(227)	+(227)	+(227)			+(227)			
	Childhood growth trajectories	-(227)		-(227)	-(227)	-(227)	-(227)	-(227)		(-227)			
	Ponderal Index	-(159, 169)	-(159, 167, 169, 170, 171)										
	Cord total adiponectin		+(167)										
	Gestational weight gain; Maternal weight gain; upper arm circumference; skinfold thickness postpartum	+(160, 241, 253)	+(160, 214, 241, 253)		+(253)								
	Congenital cerebral palsy		+(173)										
	Cord DNA methylation	+(244, 260)	+(244)	+(244)	+(244, 260)								
	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 (improvement)	+ (49)											
	Executive function scores (mother completed survey)	+ (50)											
	Executive function scores (teacher completed survey)	- (50)											
	ADHD	+ (53) -(51)	+ (53)	+ (53)	+(217)	+(217)							
	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)				
	Negative impact on personal social skills	-(247)	-(247)	-(247)	-(247)	-(247)	-(247)						
	Autism spectrum disorder	+(248)	+(257)	+(257)	+(248)								
	Learning problems		+ (51)										
Diabetes/ Metabolic	Glucose tolerance	- (58)	+ (58) -(249, 182)		- (58)		- (58)						
	Fasting blood glucose; Fasting insulin; maternal glucose levels	+(184, 188) - (58, 103)	+ (58, 184, 185, 191, 188, 269) -(103)	+(188, 192, 269)	+(188, 191, 192)	+(184)	- (58)						
	Diabetes; gestational diabetes	+(1, 187, 189, 190, 204, 251) -(183)	+ (58, 189) -(183)	-(183)	+(251) - (58, 183)		- (58)	+(129)		+(251)	+(129)		
	Diabetes deaths	+ (59, 62, 179, 180, 181, 182)											
	Central adiposity, risk of obesity	+(237)		+(237)									
	Glycated hemoglobin (HbA1C)	+(103)	+ (58)										
	β cell function; HOMA- β; HOMA–IP	+(103, 184, 185) -(186)	+(184, 191, 188) -(186)	+(192) -(193)	+(192)	-(186)							

		PFAS Type											
		Long-Chain								Short-Chain			
		PFOA	**PFOS**	**PFHxS**	**PFNA**	**PFDeA**	**PFUA**	**PFDoA**	**PFOSA**	**PFHpA**	**PFBS**	**PFBA**	**PFHxA**
Cancer	Prostate cancer; prostate cancer deaths	+ (59, 65, 181, 194)	+(65)	+ (65)		+ (65)	+ (65)						
	Colorectal cancer	- (60)	- (60)										
	Bladder cancer	- (61)	+ (66)										
	Kidney cancer deaths; renal cell carcinoma	+ (62, 64, 182, 256)											
	Testicular cancer	+ (63)											
	Breast cancer	+(63, 195, 240)	+ (67, 195, 240, 188) -(209)	+ (68, 188)	+(195)	+ (195)	+ (195)		+ (67, 68)				
Hepatic	HDL	+(84, 118, 243) - (87)	+ (69, 75, 84, 102, 243) - (80)	+(84,104)	+(84, 104)	+ (76, 84, 102, 243)	+ (84, 102)						
	LDL	+ (74-77, 79, 82, 85, 90, 102)	+ (74, 75, 80, 90, 102)	+ (73, 102)	+ (76, 102, 243)	+(102)	+(105)						
	TC/HDL-C ratio		- (69)										
	Total cholesterol	+ (70, 72, 73, 75-77, 79, 81-83, 85, 90, 102, 120, 232)	+ (21, 74,75 80, 83, 85, 90, 102)	+ (73, 84, 102, 232)	+ (76, 90, 102, 232, 243)	+ (76, 102)	+(104)				+ (90)		
	Elevated cholesterol	+ (77, 88)	+ (77)										
	Non-HDL cholesterol	+(120, 121)											
	Elevated LDL		+ (77)										
	Triglycerides, free fatty acids, triglycerides with saturated fatty acids	+ (85, 86, 90, 102, 104, 118, 264) -(212)	+ (21, 86, 265) -(212, 243)	+(104, 265) -(212)	+ (90, 104, 265) -(212)	- (212)	-(212)						
	NASH, NAFLD, Liver fibrosis		+(226)	+(226)									
	Bilirubin	+ (81, 118) -(71)											
	GGT	+ (78, 82, 89, 118, 222)	+ (21, 89, 222)		+(222, 255)	+(222)							
	AST	+ (81, 87, 89) -(119)	+ (21, 89)										
	ALT	+ (71, 78, 89, 91, 255)	+ (21, 89, 91, 255)							+(255)			
	ALP	+(255)			+(255)	+(255)							
	Lipid metabolism biomarkers	+(222)	+(222)	+(222)	+(222)	+(222)							
	α2 globulins	+ (70)											
Renal	Serum uric acid	+ (70, 92-95, 97)	+ (93, 94, 97)	+ (95)	+ (93)								
	Hyperuricemia risk	+ (92, 93, 95, 97, 98,)	+ (92, 97)										
	eGFR; GFR	- (94, 96, 99)	- (94, 96, 99)	- (99, 200)	- (99, 200)	- (200)			+(200)				
	Kidney disease	+ (1, 96)	+ (96)										
	Chronic kidney disease deaths	+(62)											
Respiratory	Chronic Bronchitis	+(1)											
	Asthma diagnosis; asthma severity	+ (1, 28, 36, 61, 127)	+ (28, 32, 36, 127)	+ (28, 36, 127)	+ (28, 36, 127, 199)	+ (28, 36)		+ (28)			+ (28, 36)		
	Lung Function		-(228)										
	Cardiorespiratory fitness				-(259)								
	Shortness of Breath, wheezing	+(1)	-(132)										
Neurological	Memory loss	-(133)	-(133)	-(133)	-(133)								
	Memory and Learning scores, executive function, visual and spatial function scores	+(134) -(134)	+(134)										

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; Cardiovascular; Diabetes	2008	Anderson-Mahoney, P., Kotlerman, J., Takhar, H., et al.	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	+
										Respiratory	Asthma	PFOA	+
										Respiratory	Shortness of breath on stairs	PFOA	+
										Cardiovascular	Cardiovascular disease (self-reported)	PFOA	+
										Cardiovascular	Angina (self-reported)	PFOA	+
										Cardiovascular	Myocardial infarction	PFOA	+
										Cardiovascular	Stroke	PFOA	+
										Diabetes	Self Reported diabetes	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), 1207–1213.	Cross-sectional	US; mid-Ohio valley	Adults	N=1,330; C8 Health project	Cardiovascular	Pregnancy-induced hypertension	PFOA	+
										Birth Outcome	Birth weight	PFOS	-
3	Cardiovascular	2013	Lin, C.-Y., Lin, L.-Y., Wen, T.-W., et al.	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, et al.	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., et al.	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., et al.	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., et al.	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 diagnosed)	PFOA	+
											Osteoarthritis risk (physician diagnosed)	PFOS	-
											bone mineral density at total femur (TFBMD)	PFOS	-
											femoral neck (FNBMD)	PFOS	-

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 (TFBMD)	PFOA	-
											Osteoporosis risk; self-reported physician-diagnosed	PFOA	+
											bone mineral density at total femur (TFBMD)	PFNA	-
											femoral neck (FNBMD)	PFNA	-
											lumbar spine (LSBMD)	PFNA	-
											Osteoporosis; self-reported physician-diagnosed	PFNA	+
											Osteoporosis; self-reported physician-diagnosed	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., et al.	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	PFDeA	-
											FT3	PFUA	-
16	Endocrine	2009	Dallaire, R., Ayotte, P., Pereg, D., et al.	Determinants of Plasma Concentrations of Perfluorooctanesulfonate and Brominated Organic Compounds in Nunavik Inuit Adults (Canada).	Environmental Science & Technology, 43(13), 5130–5136.	Cross-sectional	Northern Quebec, Canada	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., et al.	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., et al.	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., et al.	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 aminostransferase)	PFOS	+
											GGT	PFOS	+
											Total cholesterol	PFOS	+
											Triglycerides; males	PFOS	+
										Endocrine	T3	PFOS	+
22	Endocrine	2015	Shrestha, S., Bloom, M. S., Yucel, R.,et al.	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., et al.	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., et al.	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., et al.	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	US; mid-Ohio valley workers and residents	Adults	N=28,541	Endocrine	Functional thyroid disease	PFOA	+
27	Endocrine	2016	Yang, L., Li, J., Lai, J., et al.	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., et al.	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	+
											Asthma diagnosis	PFDeA	+
											Asthma severity	PFDeA	+
											IgE	PFDeA	+
											Absolute eosinophil counts	PFDeA	+
											Eosinophil cationic protein	PFDeA	+
											Asthma diagnosis	PFBS	+
											Absolute eosinophil counts	PFBS	+
											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., et al.	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., et al.	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., et al.	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., et al.	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., et al.	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., et al.	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	-
35	Immune	2015	Mogensen, U. B., Grandjean, P., Heilmann, C., et al.	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	Diphtheria antibody levels	PFOA	-
											Tetanus antibody levels at age 7	PFHxX	-
36	Immune	2016	Zhu, Y., Qin, X.-D., Zeng, X.-W., et al.	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	Taiwain; 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	PFBS	+
											IL-5 T-helper cytokine	PFBS	+
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	-
											Fecundability	PFOS	-
											Infertility	PFOA	+
											Infertility	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., et al.	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	+
45	Reproductive	2011	Knox, S., Jackson, T., Javins, B., et al.	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	-
											Early Menopause Risk (Menopausal subgroup)	PFOA	+
												PFOS	+
											Early Menopause Risk (Perinenopausal subgroup)	PFOA	+
												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., et al.	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 total, n=173 (infants at 6 months), n=133 (infants at 18 months of age)	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	-
											Learning problems	PFOS	-
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	+
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; Immune	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	-
										Immune	Asthma	PFOA	+
											Ulcerative Colitis	PFOA	+
											Rheumatoid Arthritis	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	+
											Breast 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	+
											Prostate Cancer	PFOA	+
											Prostate Cancer	PFOS	+
											Prostate Cancer	PFDeA	+
											Prostate Cancer	PFUaA	+
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.	Retrospective; Occupational cohort	US; Alabama	Adults	N=2083; 145 deaths	Cancer	Bladder and other urinary organs cancer	PFOS	+
			Bonefeld-						N=31 breast cancer			PFOS	+

67	Cancer	2011	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	PFOSA	+
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.,et al.	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	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 PFOA production plant (1978-2007)	Hepatic	Total cholesterol	PFOA	+
										Renal	α2 globulins	PFOA	+
											Uric acid	PFOA	+
71	Hepatic	2016	Darrow, L. A., Groth, A. C., Winquist, A., et al.	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., et al.	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 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., et al.	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 , Ohio and West Virginia residents where public drinking water was contaminated by 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, et al.	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	+
76	Hepatic	2014	Fu, Y., Wang, T., Fu, Q., et al.	Associations between serum concentrations of perfluoroalkyl acids and serum lipid levels in a Chinese population	Ecotoxicology and Environmental Safety, 106, 246–252	Cross-sectional	Henan, China	Adults	N=133; randomly selected community members coming in to clinic for health check-ups	Hepatic	LDL cholesterol	PFOA	+
											Total cholesterol	PFOA	+
											LDL cholesterol	PFNA	+
											Total cholesterol	PFNA	+
											HDL cholesterol	PFDeA	+
											Total cholesterol	PFDeA	+
77	Hepatic	2014	Dee Geiger, S., Xiao, J., Ducatman, A., et al.	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., et al.	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 aminostransferase)	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., et al.	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., et al.	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., et al.	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., et al.	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	HDL cholesterol	PFOA	+
											HDL cholesterol	PFOS	+
											HDL cholesterol	PFHxS	+
											HDL cholesterol	PFNA	+
											HDL cholesterol	PFDeA	+
											HDL cholesterol	PFUA	+
85	Hepatic	2009	Steenland, K., Tinker, S., Frisbee, S., et al.	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 Virginia	Hepatic	Total cholesterol	PFOA	+
											Total cholesterol	PFOS	+
											LDL cholesterol	PFOA	+
											Triglycerides	PFOA	+
86	Hepatic	2014	Timmermann, AC. G., Rossing, L. I., Grøntved, A., et al.	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., et al.	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., et al.	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	+
											Total cholesterol	PFOA	+
											LDL cholesterol	PFOA	+
											Triglycerides	PFOA	+

90	Hepatic; Immune	2015	Zeng, X.-W., Qian, Z., Emo, B., et al.	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	PFOS	+
											LDL cholesterol	PFOS	+
											Total cholesterol	PFNA	+
											Triglycerides	PFNA	+
											Total cholesterol	PFBS	+
										Immune	IL-5 T-helper cytokine	PFBS	+
91	Hepatic	2012	Gallo, V., Leonardi, G., Genser, B., et al.	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 aminostransferase)	PFOA	+
											ALT level (alanine aminostransferase)	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	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	+
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., et al.	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 pcid (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.,et al.	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	-
100	Cardiovascular	2017	Bao WW, Qian ZM, Geiger SD, et al.	Gender-specific associations between serum isomers of perfluoroalkyl substances and blood pressure among Chinese: Isomers of C8 Health Project in China	Sci Total Environ 607-608:1304-1312.	Cross-sectional	China	Adults	N=1612 adults	Cardiovascular	Systolic Blood Pressure	PFOA	+
											Diastolic Blood Pressure	PFOA	+
											Risk of Hypertension	PFOS	+
											Systolic Blood Pressure	PFOS	+
											Diastolic Blood Pressure	PFOS	+
											Risk of Hypertension	PFNA	+
											Systolic Blood Pressure	PFNA	+
											Diastolic Blood Pressure	PFNA	+
											Diastolic Blood Pressure	PFDeA	+
											Systolic Blood Pressure	PFHpA	+
											Diastolic Blood Pressure (males only)	PFHpA	+
											Risk of Hypertension	PFBA	+
											Systolic Blood Pressure	PFBA	+
											Systolic Blood Pressure (females only)	PFDoA	+
											Diastolic Blood Pressure	PFDoA	+

101	Cardiovascular	2018	Huang M, Jiao J, Zhuang P, et al.	Serum polyfluoroalkyl chemicals are associated with risk of cardiovascular diseases in national US population	Environ Int 119:37-46	Cross-sectional	NHANES	Adults	N=10859	Cardiovascular	Risk of Coronary Heart Disease	PFNA	+
											Risk of Heart Attack	PFNA	+
											Risk of Cardiovascular Disease	PFUA	+
											Risk of Coronary Heart Disease	PFUA	+
											Risk of Angina Pectoris	PFUA	+
											Risk of Cardiovascular Disease	PFBS	+
											Risk of Cardiovascular Disease	PFDoA	+
											Risk of Congestive Heart Failure	PFDoA	+
											Risk of Angina Pectoris	PFDoA	+
											Risk of Cardiovascular Disease	PFOSA	+
102	Cardiovascular; Hepatic	2017	Koshy TT, Attina TM, Ghassabian A, et al.	Serum perfluoroalkyl substances and cardiometabolic consequences in adolescents exposed to the World Trade Center disaster and a matched comparison group	Environ Int 109:128-135	Case-control	US	CA	N=123 in WTCHR group and 185 in comparison	Cardiovascular	Arterial Wall Stiffness	PFOA	+
											Arterial Wall Stiffness	PFNA	+
										Hepatic	Total Cholesterol	PFOA	+
											LDL Cholesterol	PFOA	+
											Triglycerides	PFOA	+
											Total Cholesterol	PFOS	+
											LDL Cholesterol	PFOS	+
											HDL Cholesterol	PFOS	+
											Total Cholesterol	PFHxS	+
											LDL Cholesterol	PFHxS	+
											Total Cholesterol	PFNA	+
											LDL Cholesterol	PFNA	+
											Total Cholesterol	PFDeA	+
											LDL Cholesterol	PFDeA	+
											HDL Cholesterol	PFDeA	+
											HDL Cholesterol	PFUA	+
103	Diabetes	2018	Liu HS, Wen LL, Chu PL, et al.	Association among total serum isomers of perfluorinated chemicals, glucose homeostasis, lipid profiles, serum protein and metabolic syndrome in adults: NHANES, 2013-2014	Environ Pollut 232:73-79	Cross-sectional	US	Adults	N=1871	Metabolic	Fasting Glucose	PFOA	-
											HbA1C	PFOA	+
											β cell function	PFOA	+
										Diabetes	HbA1C	PFOA	+
											β-cell function	PFOA	+
											Fasting Glucose	PFOS	-
104	Hepatic; Diabetes	2018	Yang Q, Guo X, Sun P, et al.	Association of serum levels of perfluoroalkyl substances (PFASs) with the metabolic syndrome (MetS) in Chinese male adults: A cross-sectional study	Sci Total Environ 621:1542-1549	Cross-sectional	China	Adults	N=148 males diagnosed with Metabolic Syndrome	Hepatic	Triglycerides	PFOA	+
											HDL Cholesterol	PFHxS	+
											Triglycerides	PFHxS	+
											HDL Cholesterol	PFNA	+
											Triglycerides	PFNA	+
105	Hepatic; Endocrine	2018	Kang H, Lee H, Moon HB, et al.	Perfluoroalkyl acids in serum of Korean children: Occurrences, related sources, and associated health outcomes	Sci Total Environ 645:958-965	Cohort	Korea	CA	N=150 children	Hepatic	Total Cholesterol	PFUA	+
											LDL Cholesterol	PFUA	+
										Endocrine	Free T4	PFNA	+
106	Endocrine	2018	Dufour P, Pirard C, Seghaye MC, et al	Association between organohalogenated pollutants in cord blood and thyroid function in newborns and mothers from Belgian population	Environ Pollut 238:389-396	Cohort	Belgium	Both	N=214 cord blood samples from pregnant women	Endocrine	Hypothyroidism	PFOA	+
											Hypothyroidism	PFOS	+
107	Endocrine	2018	Preston EV, Webster TF, Oken E, et al.	Maternal plasma per- and polyfluoroalkyl substance concentrations in early pregnancy and maternal and neonatal thyroid function in a prospective birth cohort: Project Viva (USA)	Environ Health Perspect 126(2):027013	Prebirth Cohort	US	Both	N= 732 mothers and 480 neonates	Endocrine	Free T4 in mother	PFOA	-
											Neonatal T4	PFOA	-
											TSH (TPOAb positive mothers)	PFOS	-
											Neonatal T4	PFOS	-
											Neonatal T4	PFHxS	-
108	Endocrine	2017	Tsai MS, Lin CC, Chen MH, et al	Perfluoroalkyl substances and thyroid hormones in cord blood	Environ Pollut 222:543-548	Prospective Birth Cohort	Taiwan	Both	N=118 mother-infant pairs	Endocrine	Cord Blood T4	PFOS	-
											Cord Blood TSH	PFOS	+
											Free T4 levels	PFNA	+
109	Endocrine	2017	Crawford NM, Fenton SE, Strynar M, et al	Effects of perfluorinated chemicals on thyroid function, markers of ovarian reserve, and natural fertility	Reprod Toxicol 69:53-59	Cohort	US	Adults	N=99 women	Endocrine	T3 levels	PFOA	+
											T3 levels	PFNA	+
											Free T4 levels	PFNA	+
											Number of lower respiratory infections (0-10 years of age)	PFOA	+
											Number of lower respiratory infections (0-10 years of age)	PFOS	+

110	Immune	2018	Impinen A, Nygaard UC, Lodrup Carlsen KC, et al	Prenatal exposure to perfluoralkyl substances (PFASs) associated with respiratory tract infections but not allergy- and asthma-related health outcomes in childhood	Environ Res 160:518-523	Birth Cohort	Oslo	CA	N=641 infants	Immune	Number of lower respiratory infections (0-10 years of age)	PFNA	+
											Number of lower respiratory infections (0-10 years of age)	PFUA	+
											Number of common colds (0-2 years of age)	PFUA	+
											Number of lower respiratory infections (0-10 years of age)	PFOSA	+
111	Immune	2017	Goudarzi H, Miyashita C, Okada E, et al.	Prenatal exposure to perfluoroalkyl acids and prevalence of infectious diseases up to 4years of age	Environ Int 104:132-138	Prospective cohort	Japan	Both	N=1558 mother-child pairs	Immune	Risk of total infectious disease	PFOS	+
											Risk of total infectious diseases (females only)	PFHxS	+
112	Developmental	2017	Li M, Zeng XW, Qian ZM, et al	Isomers of perfluorooctanesulfonate (PFOS) in cord serum and birth outcomes in China: Guangzhou Birth Cohort Study	Environ Int 102:1-8	Cohort	China	Both	n=321 mother-infant pairs	Developmental	Gestational Age (boys only)	PFOS	+
											Birth Weight	PFOA	-
											Birth Weight	PFOS	-
											Birth Weight (boys only)	PFOS	-
											Birth Weight (boys only)	PFHpA	-
											Birth Weight (girls only)	PFDoA	-
113	Developmental	2017	Lauritzen HB, Larose TL, Oien T, et al	Maternal serum levels of perfluoroalkyl substances and organochlorines and indices of fetal growth: A Scandinavian case-cohort study	Pediatr Res 81(1-1):33-42	Case-cohort	Sweden	Both	n=424 mother-child pairs	Developmental	Birth Length	PFOA	-
											Small for Gestational Age	PFOA	+
											Small for Gestational Age (boys only)	PFOA	+
											Birth Weight	PFOS	-
											Birth Length	PFOS	-
114	Cardiovascular; Birth Outcomes	2012	Savitz DA, Stein CR, Bartell SM, et al	Perfluorooctanoic acid exposure and pregnancy outcome in a highly exposed community	Epidemiology 23(3):386-392	Cohort	US	Both	n=11737	Cardiovascular	Pre-eclampsia	PFOA	+
										Developmental	Low Birth Weight	PFOA	-
115	Cardiovascular	2012	Lind PM, Salihovic S, van Bavel B, et al	Circulating levels of perfluoroalkyl substances (PFASs) and carotid artery atherosclerosis	Environ Res 152:157-164	Cross-sectional	Sweden	Adults	n=1016 70 year olds	Cardiovascular	Echogenicity of intima media complex (females only)	PFNA	+
											Intima Media Thickness in Common Carotid Artery (combined population)	PFOSA	+
116	Endocrine function	2019	Yao, Q., R. Shi, C. Wang, W. Han, et al.	Cord blood per- and polyfluoroalkyl substances, placental steroidogenic enzyme, and cord blood reproductive hormone	Environment International 129:573–582.	Cohort study	Laizhou Wan (Bay) of the Bohai Sea, Shandong province, China	Adults	N=351	endocrine	Increased etradiol levels	PFOA	+
											lower mean birth weight	PFAS	+
											Testosterone	PFOA	+
											P450aromatase	PFUA	+
117	Musculoskeletal	2014	Lin LY, Wen LL, Su TC, et al	Negative association between serum perfluorooctane sulfate concentration and bone mineral density in US premenopausal women: NHANES, 2005-2008	The Journal of clinical endocrinology and metabolism 99(6):2173-2180	Cross-sectional	US	Both; NHANES	N=2339	Musculoskeletal	Total lumbar spine bone mineral density	PFOS	-
118	Hepatic; Endocrine	2007	Olsen GW, Zobel LR	Assessment of lipid, hepatic, and thyroid parameters with serum perfluorooctanoate (PFOA) concentrations in fluorochemical production workers	Int Arch Occup Environ Health 81:231-246	Cross-sectional	Belgium and US	Adults	N=552	Hepatic	GGT	PFOA	+
											Total Bilirubin	PFOA	-
											HDL Cholesterol	PFOA	+
											Triglycerides	PFOA	+
										Endocrine	Free T4	PFOA	+
											T3	PFOA	+
119	Hepatic	2006	Emmett EA, Zhang H, Shofer FS, et al	Community exposure to perfluorooctanoate: Relationships between serum levels and certain health parameters	J Occup Environ Med 48(8):771-779	Cross-sectional	US	Both	N=371	Hepatic	Abnormal AST	PFOA	-
120	Hepatic	2004	Costa G	Report on the meeting held on Friday 20th and Saturday 21st 2004 at the Inn at Montchanin Village (Wilmington, USA) with 3M and DuPont delegations	U.S. Environmental Protection Agency. AR226-1866	Cross-sectional	Italy	Adults	N=35	Hepatic	Total Cholesterol	PFOA	+
											Non-HDL Cholesterol	PFOA	+
121	Hepatic	2010	Nelson JW, Hatch EE, Webster TF	Exposure to polyfluoroalkyl chemicals and cholesterol, body weight, and insulin resistance in the general U.S. population	Environ Health Perspect 118(2):197- 202	Cross-sectional	US	Both; NHANES	N=860	Hepatic	Non-HDL Cholesterol	PFOA	+
122	Endocrine	1992	Gilliland FD	Fluorocarbons and human health: Studies in an occupational cohort: A thesis	University of Minnesota, 29-229	Retrospective Cohort	US	Adults	N=115	Endocrine	TSH	PFOA	+

123	Endocrine	2013	Jain RB	Association between thyroid profile and perfluoroalkyl acids: Data from NHNAES 2007-2008	Environ Res 126:51-59	Cross-sectional	US	Both; NHANES	N=1525	Endocrine	Total T3	PFOA	+
124	Immune	2016	Buser MC, Scinicariello F	Perfluoroalkyl substances and food allergies in adolescents	Environ Int 88:74-79	Cross-sectional	US	CA; NHANES	N=637 (2005-2006) N=701 (2007-2010)	Immune	Food allergies	PFOA	+
125	Immune	2012	Okada E, Sasaki S, Saijo Y, et al	Prenatal exposure to perfluorinated chemicals and relationship with allergies and infectious diseases in infants	Environ Res 112:118-125	Prospective cohort	Japan	Both	N=343 pregnant women	Immune	Cord IgE levels (females only)	PFOA	-
126	Immune	2014	Okada E, Sasaki S, Kashino I, et al	Prenatal exposure to perfluoroalkyl acids and allergic diseases in early childhood	Environ Int 65:127-134	Prospective cohort	Japan	Both	N=2603 infants	Immune	Risk of Allergic Diseases (females only)	PFOA	-
											Risk of Allergic Diseases (females only)	PFNA	-
											Risk of Allergic Diseases (females only)	PFUA	-
											Eczema (females only)	PFUA	-
127	Immune	2017	Qin XD, Qian ZM, Dharmage SC, et al	Association of perfluoroalkyl substances exposure with impaired lung function in children	Environ Res 155:15-21	Cross-sectional Case-control	Taiwan	CA	N=132 children and 168 matched controls	Immune	Asthma	PFOA	+
											Asthma	PFOS	+
											Asthma	PFHxS	+
											Asthma	PFNA	+
128	Immune	2013	Steenland K, Zhao L, Winquist A, et al	Ulcerative colitis and perfluorooctanoic acid (PFOA) in a highly exposed population of community residents and workers in the Mid-Ohio Valley	Environ Health Perspect 121(8):900-905	Cohort	US	Both; C8 Community	N=28441	Immune	Ulcerative Colitis	PFOA	+
129	Diabetes	2020	Xu, H., Q. Zhou, J. Zhang, X. Chen, H. Zhao, H. Lu, et al.	Exposure to elevated per- and polyfluoroalkyl substances in early pregnancy is related to increased risk of gestational diabetes mellitus: A nested case-control study in Shanghai, China.	Environment International 143:105952.	Case Control study	Shanghai, China	Adults	N=2,460	Diabetes	Gestational diabetes mellitus	PFBS	+
											Gestational diabetes mellitus	PFDoA	+
130	Immune	2016	Stein CR, McGovern KJ, Pajak AM, et al	Perfluoroalkyl and polyfluoroalkyl substances and indicators of immune function in children aged 12-19 y: National Health and Nutrition Examination Survey	Pediatr Res 79(2):348-357	Cross-sectional	US	CA; NHANES	N=1191 adolescents (NHANES 1999-2000 and 2003 2004) and N=640 adolescents (NHANES 2005-2006)	Immune	Mumps Antibody Titers	PFOA	-
											Rubella Antibody Titers	PFOA	-
											Rhinitis	PFOA	+
											Mumps Antibody Titers (whole cohort)	PFOS	-
											Mumps Antibody Titers (seropositive subcohort)	PFOS	-
											Rubella Antibody Titers (seropositive subcohort)	PFOS	-
											Allergic Sensitization Plants	PFOS	-
											Allergic Sensitization Cockroach or Shrimp	PFOS	-
											Allergic Sensitization Mold	PFOS	+
											Rubella Antibody Titers (seropositive subcohort)	PFHxS	-
131	Immune; Reproductive	2010	Fei C, McLaughlin JK, Lipworth L, et al	Prenatal exposure to PFOA and PFOS and risk of hospitalization for infectious diseases in early childhood	Environ Res 110(8):773-777	Cohort	Denmark	Both	N=1400 pregnant women and young children	Immune	Risk of Hospitalization for Infectious Disease in Young Children (girls only)	PFOA	+
											Risk of Hospitalization for Infectious Disease in Young Children (boys only)	PFOA	-
											Risk of Hospitalization for Infectious Disease in Young Children (girls only)	PFOS	+
									N=1347 pregnant women	Reproductive	Breastfeeding Duration ≤ 3 months	PFOA	+
											Breastfeeding Duration ≤ 6 months	PFOA	+
											Breastfeeding Duration ≤ 3 months	PFOS	+
											Breastfeeding Duration ≤ 6 months	PFOS	+
132	Respiratory	2015	Smit LA, Lenters V, Hoyer BB, et al	Prenatal exposure to environmental chemical contaminants and asthma and eczema in school age children	Allergy 70(6):653-660	Cohort	Greenland and Ukraine	CA	N=1024 children	Respiratory	Current Wheezing (Ukraine cohort)	PFOS	-
133	Neurological	2013	Gallo V, Leonardi	Serum perfluoroalkyl acids concentrations and memory impairment in a large cross-sectional	BMJ Open	Cross-sectional	US	Adults; C8	N=21024 adults over	Neurological	Memory Loss (self-reported)	PFOA	-
											Memory Loss (self-reported)	PFOS	-

133	Neurological	2013	G, Brayne C, et al	study	3(6):e002414	Cross-sectional	US	Community	50 years of age	Neurological	Memory Loss (self-reported)	PFHxS	-
											Memory Loss (self-reported)	PFNA	-
134	Neurological	2017	Shrestha S, Bloom MS, Yucel R, et al	Perfluoroalkyl substances, thyroid hormones, and neuropsychological status in older adults	Int J Hyg Environ Health 220(4):679-685	Cross-sectional	US	Adults	N=126 older adults aged 55-74 years old	Neurological	Memory and Learning Scores	PFOA	+
											Executive Function Scores	PFOA	-
											Memory and Learning Scores	PFOS	+
											Visual and Spatial Function Scores	PFOS	+
135	Reproductive	2012	Raymer JH, Michael LC, Studabaker WB, et al	Concentrations of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) and their associations with human semen quality measurements	Reprod Toxicol 33(4):419-427	Cross-sectional	US	Adults	N=256 men	Reproductive	LH	PFOA	+
											Free Testosterone	PFOA	+
136	Reproductive	2016	Zhou Y, Hu LW, Qian ZM, et al	Association of perfluoroalkyl substances exposure with reproductive hormone levels in adolescents: By sex status	Environ Int 94:189-195	Cohort	Taiwan	CA	N=225 adolescents 13-15 years old	Reproductive	Estradiol (boys only)	PFOA	+
											Testosterone (boys only)	PFOS	-
											Estradiol (boys only)	PFHxS	+
											Testosterone (boys only)	PFNA	-
											Testosterone (boys only)	PFDeA	-
											Testosterone (girls only)	PFDoA	-
											Testosterone (boys only)	PFHxA	-
137	Reproductive	2015	Buck Louis GM, Chen Z, Schisterman EF, et al	Perfluorochemicals and human semen quality: The LIFE study	Environ Health Perspect 123(1):57-63	Cohort	US	Adults; LIFE study	N=96 in Michigan N=366 in Texas	Reproductive	Sperm Motility: Increased Curvilinear Velocity	PFOA	+
											Sperm Morphology: Increased Percentage of Sperm Head Acrosome Area	PFOA	+
											Sperm Morphology: Decreased Percentage Sperm with Coiled Tails	PFOA	+
											Sperm Motility: Increased Distance Traveled	PFOS	+
											Sperm Morphology: Increased Percentage of Normal Sperm	PFNA	+
											Sperm Morphology: Decreased Percentage Sperm with Coiled Tails	PFNA	+
											Sperm Morphology: Increased Sperm Head Length	PFDeA	+
											Sperm Morphology: Decreased Percentage Sperm with Coiled Tails	PFDeA	+
138	Reproductive	2012	Toft G, Jonsson BA, Lindh CH, et al	Exposure to perfluorinated compounds and human semen quality in Arctic and European populations	Hum Reprod 27(8):2532-2540	Cohort	Greenland, Poland, and Ukraine	Adults	N=588 males	Reproductive	Increased Percent Motile Sperm	PFOA	+
											Percent Normal Sperm	PFOS	-
											Percent Normal Sperm	PFHxS	-
139	Reproductive	2012	Kvist L, Giwercman YL, Jonsson BA, et al	Serum levels of perfluorinated compounds and sperm Y:X chromosome ratio in two European populations and in Inuit from Greenland	Reprod Toxicol 34(4):644-650	Cross-sectional	Greenland, Poland, and Ukraine	Adults	N=588 men	Reproductive	Y-X Chromosome Ratio (whole cohort)	PFOS	+
											Y-X Chromosome Ratio (Greenland cohort)	PFOS	-
140	Reproductive	2012	Buck Louis GM, Peterson CM, Chen Z, et al	Perfluorochemicals and endometriosis. The ENDO study	Epidemiology 23(6):799-805	Matched exposure cohort	US	Adults	N=473	Reproductive	Endometriosis	PFOA	+
											Risk of Moderate to Severe Endometriosis	PFOA	+
											Risk of Moderate to Severe Endometriosis	PFOS	+
											Endometriosis	PFNA	+
141	Endocrine function	2019	Yeung, E. H., E. M. Bell, R. Sundaram, et al.	Examining endocrine disruptors measured in newborn dried blood spots and early childhood growth in a prospective cohort.	Obesity (Silver Spring, MD) 27(1):145–151.	longitudinal cohort study	New york, USA	CA	N=3111	Endocrine	Lower BMI level	PFOS	+
											Lower BMI level	PFOA	+
142	Reproductive	2016	Campbell S, Raza M, Pollack AZ	Perfluoroalkyl substances and endometriosis in US women in NHANES 2003-2006	Reprod Toxicol 65:230-235	Cross-sectional	US	Adults; NHANES	N=753 women aged 20-50 years old	Reproductive	Self-reported Endometriosis	PFOA	+
143	Reproductive	2014	Lyngsø J, Ramlau-Hansen CH, Hoyer BB, et al	Menstrual cycle characteristics in fertile women from Greenland, Poland and Ukraine exposed to perfluorinated chemicals: A cross-sectional study	Hum Reprod 29(2):359-367	Cross-sectional	Greenland, Poland, and Ukraine	Adults	N=1623 pregnant women	Reproductive	Long Menstrual Cycle	PFOA	+

144	Reproductive	2016	Romano ME, Xu Y, Calafat AM, et al	Maternal serum perfluoroalkyl substances during pregnancy and duration of breastfeeding	Environ Res 10.1016/j.envres.2016.04.034	Longitudinal Cohort	US	Both	N=336 women; HOME study	Reproductive	Breastfeeding Duration ≤3 months	PFOA	+
											Breastfeeding Duration ≤6 months	PFOA	+
145	Reproductive	2014	Taylor KW, Hoffman K, Thayer KA, et al	Polyfluoroalkyl chemicals and menopause among women 20-65 years of age (NHANES)	Environ Health Perspect 122(2):145-150	Cross-sectional	US	Adults; NHANES	N=2151 women	Reproductive	Early Menopause	PFOA	+
											Hysterectomy	PFOA	+
											Hysterectomy	PFOS	+
											Early Menopause	PFHxS	+
											Hysterectomy	PFHxS	+
											Early Menopause	PFNA	+
											Hysterectomy	PFNA	+
146	Reproductive	2017	Timmermann CA, Budtz-Jorgensen E, Petersen MS, et al	Shorter duration of breastfeeding at elevated exposures to perfluoroalkyl substances	Reprod Toxicol 68:164-170	Cohort	Faroe Islands	Both	N=1130 women	Reproductive	Breastfeeding Duration (in months)	PFOA	-
											Exclusive Breastfeeding (in months)	PFOA	-
											Breastfeeding Duration (in months)	PFOS	-
											Exclusive Breastfeeding (in months)	PFOS	-
											Breastfeeding Duration (in months)	PFNA	-
											Exclusive Breastfeeding (in months)	PFNA	-
											Breastfeeding Duration (in months)	PFDeA	-
147	Reproductive	2014	Vagi SJ, Azziz-Baumgartner E, Sjodin A, et al	Exploring the potential association between brominated diphenyl ethers, polychlorinated biphenyls, organochlorine pesticides, perfluorinated compounds, phthalates, and bisphenol A in polycystic ovary syndrome: A case-control study	BMC Endocr Disord 14:86	Case-control	US	Adults	N=52 cases n=50 controls	Reproductive	Polycystic Ovary Syndrome Risk	PFOA	+
											Polycystic Ovary Syndrome Risk	PFOS	+
148	Reproductive	2014	Jørgensen KT, Specht IO, Lenters V, et al	Supplemental files to "Perfluoroalkyl substances and time to pregnancy in couples from Greenland, Poland and Ukraine	Environ Health 13:116.10.1186/1476-069x-13-116	Cohort	Greenland, Poland, and Ukraine	Adults	n=938 pregnant women	Reproductive	Fecundability (Primiparous subgroup)	PFOA	+
											Fecundability	PFNA	-
											Infertility	PFNA	+
149	Reproductive	2012	Vestergaard S, Nielsen F, Andersson AM, et al	Association between perfluorinated compounds and time to pregnancy in a prospective cohort of Danish couples attempting to conceive	Hum Reprod 27(3):873-880	Prospective cohort	Denmark	Adults	n=222 nulliparous couples	Reproductive	Fecundability	PFHxS	+
150	Reproductive	2017	Wang B, Zhang R, Jin F, et al	Perfluoroalkyl substances and endometriosis-related infertility in Chinese women	Environ Int 102:207-212	Case-control	China	Adults	N= 157 women with endometriosis-related infertility and 178 controls	Reproductive	Endometriosis-related infertility	PFHxS	-
											Endometriosis-related infertility	PFNA	-
											Endometriosis-related infertility	PFHpA	-
											Endometriosis-related infertility	PFBS	+
151	Reproductive	2013	Buck Louis GM, Sundaram R, Schisterman EF, et al	Persistent environmental pollutants and couple fecundity: The LIFE Study	Environ Health Perspect 121:231-236	Prospective cohort	US	Adults	N=501 couples; LIFE study	Reproductive	Fecundability: Female serum PFOSA	PFOSA	-
152	Pregnancy	2012	Whitworth KW, Haug LS, Baird DD, et al	Perfluorinated compounds in relation to birth weight in the Norwegian Mother and Child Cohort Study	Am J Epidemiol 175(12):1209-1216	Cohort	Norway	Both	N=901 infants	Developmental	Preterm Birth	PFOA	-
											Preterm Birth	PFOS	-
153	Pregnancy	2012	Wu K, Xu X, Peng L, et al	Association between maternal exposure to perfluorooctanoic acid (PFOA) from electronic waste recycling and neonatal outcomes	Environ Int 48:1-8	Case-control	China	Both	N=167 pregnant women at each hospital (2 hospitals)	Developmental	Gestational Age	PFOA	-
											Birth Weight	PFOA	-
											Birth Length	PFOA	-
154	Pregnancy	2019	Wikstrom, S., C. H. Lindh, H. Shu, and C.-G. Bornehag.	Early pregnancy serum levels of perfluoroalkyl substances and risk of preeclampsia in Swedish women	Scientific Reports 9(1):9179.	Case Control study	Sweden	Adults	n=1773	Pregnancy	Preeclampsia	PFOS	+
											Preeclampsia	PFNA	+
155	Pregnancy	2018	Sagiv SK, Rifas-Shiman SL, Fleisch AF, et al	Early-pregnancy plasma concentrations of perfluoroalkyl substances and birth outcomes in Project Viva: Confounded by pregnancy hemodynamics?	Am J Epidemiol 187(4):793-802	Prospective cohort	US	Both	N=1645 pregnant women	Developmental	Preterm	PFOS	+
											Birth Weight for Gestational Age	PFNA	-

156	Pregnancy	2010	Hamm MP, Cherry NM, Chan E, et al	Maternal exposure to perfluorinated acids and fetal growth	J Expo Sci Environ Epidemiol 20(7):589-597	Cohort	Canada	Both	N=252 pregnant women	Developmental	Preterm Birth	PFHxS	-
											Small for Gestational Age	PFOS	-
157	Birth Outcomes	2009	Nolan LA, Nolan JM, Shofer FS, et al	The relationship between birth weight, gestational age and perfluorooctanoic acid (PFOA)-contaminated public drinking water	Reprod Toxicol 27:231-238	Cross-sectional	US	CA	N=1555 singleton infants	Developmental	Low Birth Weight	PFOA	-
158	Birth Outcomes	2012	Savitz DA, Stein CR, Elston B, et al	Relationship of perfluorooctanoic acid exposure to pregnancy outcome based on birth records in the Mid-Ohio Valley	Environ Health Perspect 120(8):1201-1207	Case-control	US	CA	N=4547 infants	Developmental	Small for Gestational Age	PFOA	+
159	Birth Outcomes	2016	Alkhalawi E, Kasper-Sonnenberg M, Wilhelm M, et al	Perfluoroalkyl acids (PFAAs) and anthropometric measures in the first year of life: Results from the Duisburg Birth Cohort	J Toxicol Environ Health A 79(22-23):1041-1049	Retrospective cohort	Germany	Both	N=156 mother-infant pairs	Developmental	Ponderal index	PFOA	-
											Ponderal index	PFOS	-
160	Birth Outcomes	2016	Ashley-Martin J, Dodds L, Arbuckle TE, et al	Maternal and neonatal levels of perfluoroalkyl substances in relation to gestational weight gain	Int J Environ Res Public Health 13(1):146	Cohort	Canada	Both	N=1723 pregnant women; MIREC study	Developmental	Gestational Weight Gain	PFOA	+
											Gestational Weight Gain	PFOS	+
161	Birth Outcomes	2018	Cao W, Liu X, Liu X, et al	Perfluoroalkyl substances in umbilical cord serum and gestational and postnatal growth in a Chinese birth cohort	Environ Int 116:197-205	Longitudinal Birth Cohort	China	CA	N=337 newborns	Developmental	Birth Length	PFOA	-
											Head Circumference	PFHxS	+
											Birth Length	PFUA	+
162	Birth Outcomes	2007	Fei C, McLaughlin JK, Tarone RE, et al.	Perfluorinated chemicals and fetal growth: A study within the Danish National Birth Cohort	Environ Health Perspect 115:1677-1682	Birth Cohort	Denmark	Both	N=1400 pregnant women	Developmental	Birth Weight	PFOA	-
											Birth Length	PFOA	-
											Abdominal Circumference	PFOA	-
163	Birth Outcomes	2011	Kim SK, Lee KT, Kang CS, et al	Distribution of perfluorochemicals between sera and milk from the same mothers and implications for prenatal and postnatal exposures	Environ Pollut 159(1):169- 174	Cross-sectional	South Korea	Both	n=44 pregnant women	Developmental	Cord TSH	PFOA	+
											Cord T3	PFOS	-
164	Birth Outcomes	2016	Kim DH, Kim UJ, Kim HY, et al	Perfluoroalkyl substances in serum from South Korean infants with congenital hypothyroidism and healthy infants - Its relationship with thyroid hormones	Environ Res 147:399-404	Case-control	South Korea	CA	N=27 infants with congenital hypothyroidism n=13 controls	Developmental	Thyroid Stimulating Immunoglobulin Levels	PFOA	-
											Thyroid Stimulating Immunoglobulin Levels	PFHxS	+
165	Birth Outcomes	2016	Lenters V, Portengen L, Rignell-Hydbom A, et al	Prenatal phthalate, perfluoroalkyl acid, and organochlorine exposures and term birth weight in three birth cohorts: Multi-pollutant models based on elastic net regression	Environ Health Perspect 124(3):365-372	Cohort	Greenland, Poland, and Ukraine	Both	n=513 infants in Greenland subcohort n=557 infants in Ukraine subcohort n=180 infants in Poland subcohort	Developmental	Birth Weight	PFOA	-
166	Birth Outcomes	2012	Maisonet M, Terrell ML, McGeehin MA, et al	Maternal concentrations of polyfluoroalkyl compounds during pregnancy and fetal and postnatal growth in British girls	Environ Health Perspect 120(10):1432-1437	Cohort	Great Britain	Both	N=447 girls	Developmental	Birth Weight	PFOA	-
											Birth Weight	PFOS	-
											Birth Length	PFOS	-
											Birth Weight	PFHxS	-
											Birth Length	PFHxS	-
167	Birth Outcomes	2017	Minatoya M, Itoh S, Miyashita C, et al	Association of prenatal exposure to perfluoroalkyl substances with cord blood adipokines and birth size: The Hokkaido Study on environment and children's health	Environ Res 156:175-182	Prospective Cohort	Japan	Both	N=168 mother-infant pairs	Developmental	Birth Weight	PFOA	-
											Ponderal Index	PFOS	-
											Cord Total Adiponectin	PFOS	+
168	Birth Outcomes; Diabetes	2017	Starling AP, Adgate JL, Hamman RF, et al	Perfluoroalkyl substances during pregnancy and offspring weight and adiposity at birth: Examining mediation by maternal fasting glucose in the Healthy Start Study	Environ Health Perspect 125(6):067016	Prospective Cohort	US	Both	N=604 mother-infant pairs	Developmental	Birth Weight	PFOA	-
											Adiposity at Birth	PFHxS	-
											Birth Weight	PFNA	-
											Adiposity at Birth	PFNA	-
										Diabetes	Maternal glucose levels	PFOA	+
											Maternal glucose levels	PFHxS	+
											Maternal glucose levels	PFNA	+
											Maternal glucose levels	PFDeA	+

169	Birth Outcomes	2007	Apelberg FJ, Witter FR, Herbstman JB, et al	Cord serum concentrations of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) in relation to weight and size at birth	Environ Health Perspect 115:1670-1676	Cross-sectional	US	CA	N=341 singleton births	Developmental	Head Circumference	PFOA	-
											Ponderal Index	PFOA	-
											Head Circumference	PFOS	-
											Ponderal Index	PFOS	-
170	Birth Outcomes	2017	Kobayashi S, Azumi K, Goudarzi H, et al	Effects of prenatal perfluoroalkyl acid exposure on cord blood IGF2/H19 methylation and ponderal index: The Hokkaido Study	Expo Sci Environ Epidemiol 27(3):251-259	Cohort	Japan	Both	N=177 mother-infant pairs	Developmental	Ponderal index	PFOS	-
171	Immune	2019	Wen, H. J., S. L.Wang, Y. C. Chuang, et al.	Prenatal perfluorooctanoic acid exposure is associated with early onset atopic dermatitis in 5-year-old children.	Chemosphere 231:25–31. https://doi.org/10.1016/j.chemosphere.2019.05.100.	Prospective Cohort	Taiwan	both	N=863 mother-infant pairs	Immune	early onset atopic dermatitis	PFOA	+
172	Birth Outcomes	2013	Lee YJ, Kim M-K, Bae J, et al	Concentrations of perfluoroalkyl compounds in maternal and umbilical cord sera and birth outcomes in Korea	Chemosphere 90(5):1603-1609	Cross-sectional	South Korea	Both	N=59 pregnant women	Developmental	Ponderal Index	PFOS	-
173	Birth Outcomes	2014	Liew Z, Ritz B, Bonefeld-Jorgensen EC, et al	Prenatal exposure to perfluoroalkyl substances and the risk of congenital cerebral palsy in children	Am J Epidemiol 180(6):574-581	Case-Cohort	Denmark	Both	n=156 children diagnosed with congenital cerebral palsy (cases) n=550 controls	Developmental	Congenital Cerebral Palsy (boys only)	PFOS	+
174	Birth Outcomes	2009	Washino N, Saijo Y, Sasaki S, et al	Correlations between prenatal exposure to perfluorinated chemicals and reduced fetal growth	Environ Health Perspect 117:660-667	Prospective Cohort	Japan	Both	N=428 women and infants	Developmental	Birth Weight (males only)	PFOS	-
											Birth Weight (females only)	PFOS	-
175	Birth Outcomes	2016	Bach CC, Bech BH, Nohr EA, et al	Perfluoroalkyl acids in maternal serum and indices of fetal growth: The Aarhus Birth Cohort	Environ Health Perspect 10.1289/ehp.1510046	Cohort	Denmark	Both	N=1,507 nulliparous women	Developmental	Birth Weight	PFHxS	-
176	Birth Outcomes	2016	Wang Y, Adgent M, Su PH, et al	Prenatal exposure to perfluorocarboxylic acids (PFCAs) and fetal and postnatal growth in the Taiwan maternal and infant cohort study	Environ Health Perspect 10.1289/ehp.1509998	Cohort	Taiwan	Both	n=117 boys and 106 girls examined at 2, 5, 8, and 11 years of age	Developmental	Birth Weight (girls only)	PFNA	-
											Birth Weight (girls only)	PFDeA	-
											Small for Gestational Age (girls only)	PFDeA	+
											Birth Weight (girls only)	PFUA	-
											Small for Gestational Age (girls only)	PFUA	+
											Birth Weight (girls only)	PFDoA	-
											Head Circumference (girls only)	PFDoA	-
177	Birth Outcomes	2016	Callan AC, Rotander A, Thompson K, et al	Maternal exposure to perfluoroalkyl acids measured in whole blood and birth outcomes in offspring	Sci Total Environ 569-570:1107-1113	Cross-sectional	Australia	Both	N=98 pregnant women	Developmental	Optimal Body Weight	PFUA	+
178	Birth Outcomes	2015	Robledo CA, Yeung E, Mendola P, et al	Preconception maternal and paternal exposure to persistent organic pollutants and birth size: The LIFE study	Environ Health Perspect 123(1):88-94	Prospective Cohort	US	Both	N=234 couples	Developmental	Birth Weight (boys only) (only maternal association)	PFOSA	-
179	Diabetes	2018	Wang, Y., L. Zhang, Y. Teng, et al.	Association of serum levels of perfluoroalkyl substances with gestational diabetes mellitus and postpartum blood glucose.	Journal of Environmental Sciences (China) 69:5–11	Case Control study	Beijing, China	Adult	N=252	Diabetes	Increased blood glucose	PFHxS	+
											Increased blood glucose	PFOS	+
180	Diabetes	2008	Leonard RC, Kreckmann KH, Sakr CJ, et al.	Retrospective cohort mortality study of workers in a polymer production plant including a reference population of regional workers	Ann Epidemiol 18:15-22.	Retrospective cohort	U.S. polymer manufacturing facility	Adults	Occupational (n=6,027)	Diabetes	Diabetes deaths	PFOA	+
181	Diabetes; Cancer	2009	Lundin JI, Alexander BH, Olsen GW, et al.	Ammonium perfluorooctanoate production and occupational mortality.	Epidemiology 20(6):921-928.	Retrospective Cohort	3M Company plant in Cottage Grove Minnesota	Adults	Occupational (n=3,993)	Diabetes	Diabetes deaths	PFOA	+
										Cancer	Prostate Cancer Deaths	PFOA	+
182	Endocrine	2021	Valvi, D., K. Højlund, B. A. Coull, et al.	Life-course exposure to perfluoroalkyl substances in relation to markers of glucose homeostasis in early adulthood.	Journal of Clinical Endocrinology & Metabolism 106(8):2495–2504.	prospective cohort	Faroes Islands	Both	N=699	Endocrine	altered glucose homeostasis	PFOS	+
											increased beta-cell function	PFOS	+
											insulin sensitivity	PFOS	+

183	Diabetes	2016	Conway B, Innes KE, Long D. 2	Perfluoroalkyl substances and beta cell deficient diabetes.	J Diabetes Complications 30(6):993-998.	Cohort	West Virginia and Ohio	Both	n=820 with type 1 diabetes, 4,291 with type 2 diabetes, 1,349 with uncategorized, and 60,439 with no diabetes	Diabetes	Type 1 diabetes (all)	PFOA	-
											Adults (>20 years)	PFOA	-
											Youth (≤20 years)	PFOA	-
											Type 2 diabetes	PFOA	-
											Adults (>20 years)	PFOA	-
											Youth (≤20 years)	PFOA	-
											Uncategorized diabetes	PFOA	-
											Type 1 diabetes (all)	PFOS	-
											Type 2 diabetes	PFOS	-
											Uncategorized diabetes	PFHxS	-
											Type 1 diabetes (all)	PFHxS	-
											Type 2 diabetes	PFHxS	-
											Type 1 diabetes (all)	PFNA	-
											Type 2 diabetes	PFNA	-
184	Diabetes	2017	Cardenas A, Gold DR, Hauser R, et al.	Plasma concentrations of per- and polyfluoroalkyl substances at baseline and associations with glycemic indicators and diabetes incidence among high risk adults in the diabetes prevention program trial	Environ Health Perspect 125(10):107001.	Cross sectional	United States	Adults	General population (n=957) adults at high risk of developing type 2 diabetes	Diabetes	Fasting blood glucose	PFOA	+
											Fasting insulin	PFOA	+
											HOMA-IR	PFOA	+
											HOMA-β	PFOA	+
											HbA1c	PFOA	+
											Fasting blood glucose	PFOS	+
											Fasting insulin	PFOS	+
											HOMA-IR	PFOS	+
											HOMA-β	PFOS	+
											HbA1c	PFOS	+
											Fasting blood glucose	PFNA	+
185	Diabetes	2016	Domazet SL, Grontved A, Timmermann AG, et al.	Longitudinal associations of exposure to perfluoroalkylated substances in childhood and adolescence and indicators of adiposity and glucose metabolism 6 and 12 years later: The European youth heart study.	Diabetes Care 39(10):1745-1751	Longitudinal	Denmark (from the European Youth Heart Study)	CA	n=501	Diabetes	HOMA-β At age 15	PFOA	+
											Glucose at age 15	PFOS	+
186	Diabetes	2017	Fleisch AF, Rifas-Shiman SL, Mora AM, et al.	Early-life exposure to perfluoroalkyl substances and childhood metabolic function.	Environ Health Perspect 125(3):481-487.	Cohort	Massachusetts, US	CA	n=665	Diabetes	HOMA-IR	PFOA	-
											HOMA-IR	PFOS	-
											HOMA-IR	PFDeA	-
187	Diabetes	2018	He X, Liu Y, Xu B, et al.	PFOA is associated with diabetes and metabolic alteration in US men: National Health and Nutrition Examination Survey 2003-2012.	Sci Total Environ 625:566-574.	Cross-sectional	US	Adults	n=7,904	Diabetes	Diabetes	PFOA	+
188	Cancer	2020	Tsai, M.-S., S.-H. Chang, W.-H. Kuo, et al.	A case-control study of perfluoroalkyl substances and the risk of breast cancer in Taiwanese women.	Environment International 142:105850.	Case Control study	Taiwan	Adults	N=239	Cancer	Risk of estrogen receptor + tumors	PFOS	+
											Risk of estrogen receptor + tumors	PFHxS	+
											Risk of estrogen receptor - tumors	PFNA	-
											Risk of estrogen receptor - tumors	PFDA	-
189	Diabetes	2018	Sun Q, Zong G, Valvi D, et al.	Plasma concentrations of perfluoroalkyl substances and risk of type 2 diabetes: A prospective investigation among U.S. women.	Environ Health Perspect 126(3):037001.	Case-Control	US	Adults	General population (n=793 female cases and 793 female controls	Diabetes	Type 2 diabetes	PFOA	+
											Type 2 diabetes	PFOS	+
190	Diabetes	2015a	Zhang C, Sundaram R, Maisog J, et al.	A prospective study of prepregnancy serum concentrations of perfluorochemicals and the risk of gestational diabetes.	Fertil Steril 103(1):184-189	Cohort	Michigan and Texas, US	Adults	General population (n=258	Diabetes	Gestational diabetes	PFOA	+
191	Diabetes	2009	Lin CY, Chen PC, Lin YC, et al.	Association among serum perfluoroalkyl chemicals, glucose homeostasis, and metabolic syndrome in adolescents and adults	Diabetes Care 32(4):702-707.	Cross-sectional	US	Both	Adults n=969 Adolecents n=474	Diabetes	Insulin	PFOS	+
											HOMA-IR	PFOS	+
											β-cell function	PFOS	+
											Insulin	PFNA	+
											β-cell function	PFNA	+
192	Diabetes	2018	Jensen RC, Glintborg D, Gade	Perfluoroalkyl substances and glycemic status in pregnant Danish women: The Odense Child Cohort	Environ Int 116:101-107	Cross-sectional	Municipality of Odense, Region of	Adults	General population (n=158 pregnant women with high risk	Diabetes	Fasting Glucose	PFHxS	+
											Fasting Insulin	PFHxS	+
											HOMA-IR	PFHxS	+
											Fasting Insulin	PFNA	+

			Timmermann CA	Cohort.	107.		Southern Denmark		of gestational diabetes mellitus)		HOMA-β	PFNA	+
193	Diabetes	2010	Nelson JW, Hatch EE, Webster TF.	Exposure to polyfluoroalkyl chemicals and cholesterol, body weight, and insulin resistance in the general U.S. population.	Environ Health Perspect 118(2):197-202.	Cross-sectional	US	Both	General population (NHANES) (n=306 adolescent and 524 adults)	Diabetes	HOMA (adolescent)	PFHxS	-
194	Cancer	1993	Gilliland and Mandel	Mortality among employees of a perfluorooctanoic acid production plant.	J Occup Med 35(9):950-954.	Retrospective cohort moratality	Minnesota, United States	Adults	Occupational (n=389 deaths) Reference population: Minnesota general population	Cancer	Prostate Cancer	PFOA	+
195	Cancer	2017	Wielsoe M, Kern P, Bonefeld-Jorgensen EC.	Serum levels of environmental pollutants is a risk factor for breast cancer in Inuit: A case control study.	Environ Health 16(1):56	Case-Control	Greenland	Adult	General population (n=77 cases and 84 controls)	Cancer	Breast Cancer	PFOA	+
												PFOS	+
												PFNA	+
												PFDeA	+
												PFUA	+
196	Birth Outcomes; Development; Immune	2020	Ait Bamai, Y., H. Goudarzi, A. Arak et al.	Effect of prenatal exposure to per- and polyfluoroalkyl substances on childhood allergies and common infectious diseases in children up to age 7 years: The Hokkaido study on environment and children's health	Environment International 143:105979	Longitudinal birth cohort	Japan	CA	n=2689 (mother-child pairs)	Birth Outcomes; Development; Immune	Wheezing	PFOS	-
											Wheezing	PFNA	-
											Wheezing	PFUA	-
											Wheezing	PFDoA	-
											Pnemonia and RSV infection	PFOS	+
											Rhino-conjunctivitis	PFNA	-
											Rhino-conjunctivitis	PFDeA	-
											Chicken Pox	PFDoA	+
											Pneumonia	PFOA	+
											Eczema	PFDoA	-
											Eczema	PFUA	-
											Eczema	PFOA	-
197	Reproductive	2020	Arbuckle, T. E., S. MacPherson, W. G. Foster, et al.	Prenatal perfluoroalkyl substances and newborn anogenital distance in a Canadian cohort	Reproductive Toxicology (Elmsford, NY) 94:31–39	Cohort	Canada	CA	n=401 (205 male, 196 female newborn)	Reproductive	Anogenital Distance	PFOA	+
198	Reproductive	2018	Zhang, S., R. Tan, R. Pan, et al.	Association of perfluoroalkyl and polyfluoroalkyl substances with premature ovarian insufficiency in Chinese Women.	The Journal of Clinical Endocrinology and Metabolism 103(7):2543–2551.a	case control	Nanjing , China	Adults	N=240	Reproductive	Primary ovarian insufficiency	PFOA	+
											Primary ovarian insufficiency	PFOS	+
											Primary ovarian insufficiency	PFHxS	+
199	Immune; Developmental	2019	Beck, I. H., C. A. G. Timmermann, F. Nielsen, et al.	Association between prenatal exposure to perfluoroalkyl substances and asthma in 5-year-old children in the Odense Child Cohort	Environmental Health: A Global Access Science Source 18(1):97	Cohort	Denmark	CA	n=981 mother-child pairs	Immune; Developmental	Asthma	PFNA	+
200	Endocrine; Renal	2018	Blake, B. E., S. M. Pinney, E. P. Hines, et al.	Associations between longitudinal serum perfluoroalkyl substance (PFAS) levels and measures of thyroid hormone, kidney function, and body mass index in the Fernald Community Cohort	Environmental Pollution (Barking, Essex 1987) 242(P):894–904	Longitudinal cohort	Ohio, USA	Adult	n=210 general population	Endocrine	TSH	PFOS	+
										Renal	eGFR	PFNA	-
											eGFR	PFHxS	-
											eGFR	PFDeA	-
											eGFR	PFOSA	+
201	Pregnancy; Cardiovascular	2020	Borghese, M. M., M. Walker, M. E. Helewa, et al.	Association of perfluoroalkyl substances with gestational hypertension and preeclampsia in the MIREC study	Environment International 141:105789	Cohort	Canada	Adults	n=1739 pregnant women	Pregnancy	Preeclampsia	PFHxS	+
										Cardiovascular	Gestational Hypertension (carrying male fetus only)	PFOS	+
											Gestational Hypertension (carrying male fetus only)	PFHxS	+
											Systolic Blood Pressure	PFOA	+
											Diastolic Blood Pressure	PFOA	+
											Diastolic Blood Pressure	PFOSA	+
											Systolic Blood Pressure	PFHxS	+
											Diastolic Blood Pressure	PFHxS	+
											Diastolic Blood Pressure (carrying male fetus only)	PFOA	+

											Diastolic Blood Pressure (carrying male fetus only)	PFOS	+
											Systolic Blood Pressure (carrying female fetus only)	PFOA	+
											Systolic Blood Pressure (carrying female fetus only)	PFHxS	+
											Diastolic Blood Pressure (carrying female fetus only)	PFHxS	+
202	Birth Outcomes/Obesity	2021	Braun, J. M., M. Eliot, G. D. Papandonatos, J. P. Buckley, et al.	Gestational perfluoroalkyl substance exposure and body mass index trajectories over the first 12 years of life	Int J Obes (Lond). 2021 Jan;45(1):25-3	Cohort	United States	Both	n=345 mothers with singleton child	Obesity	Lower BMI	PFOS	+
											Lower BMI	PFHxS	+
											Greater Increases in BMI	PFOA	+
											Higher BMI	PFOA	+
203	Birth Outcomes	2018	Buck Louis, G. M., S. Zhai, M. M. Smarr, et al.	Endocrine disruptors and neonatal anthropometry, NICHD Fetal Growth Studies—Singletons	Environment International 119:515–526	Cohort	United States	Both	n=2106 pregnant women and newborns	Birth Outcomes	Birth Length	PFOA	-
											Umbilical Circumference	PFHxS	-
											Upper Arm Length	PFDeA	-
											Birth Length	PFOSA	+
											Umbilical Circumference	PFDoDA	+
											Umbilical Circumference	PFHpA	-
											Upper Thigh Length	PFDeA	-
											Upper Thigh Length	PFDoDA	-
											Upper Thigh Length	PFDS	-
											Upper Thigh Length	PFHpA	-
											Upper Thigh Length	PFHxS	-
											Upper Thigh Length	PFNA	-
											Upper Thigh Length	PFOA	-
											Upper Thigh Length	PFUnDA	-
204	Diabetes; Cardiovascular	2019	Cardenas, A., M.-F. Hivert, D. R. Gold, et al.	Associations of perfluoroalkyl and polyfluoroalkyl substances with incident diabetes and microvascular disease	Diabetes Care 42(9):1824–1832	Prospective Cohort	United States	Adult	n=957 DPP participants	Diabetes	Diabetes Risk	Sb-PFOA	+
											Diabetes Risk (Placebo Group only)	SB-PFOA	+
										Cardiovascular	Prevalent microvascular disease (Lifestyle Group only)	PFOS	+
205	Immune	2022	Zhao, Y., Liu, W., Qu, J., et al.	Per-/polyfluoroalkyl substance concentrations in human serum and their associations with immune markers of rheumatoid arthritis	Chemosphere, 298, art. no. 134338. 2022	Cohort	Hangzhou, China	Adults	N=294	Immune	anti-cyclic citrullinated peptide antibody	PFOA	+
											antibody	PFESA	+
											Immunoglobulin G	PFOA	+
											Immunoglobulin G	PFESA	+
											Immunoglobulin G	PFOA	+
											Rheumatoid factors	PFESA	+
206	Immune	2018	Chen, Q., R. Huang, L. Hua, et al.	Prenatal exposure to perfluoroalkyl and polyfluoroalkyl substances and childhood atopic dermatitis: A prospective birth cohort study	Environ Health. 2018 Jan 17;17(1):8	Prospective Birth Cohort	China	Both	n=687 baby-mother pairs	Immune	Atopic Dermatitis (female children only)	PFOA	+
											Atopic Dermatitis (female children only)	PFDeA	+
											Atopic Dermatitis (female children only)	PFDoA	+
											Atopic Dermatitis (female children only)	PFHxs	+
207	Birth Outcomes/Obesity	2019	Chen, Q., X. Zhang, Y. Zhao, et al.	Prenatal exposure to perfluorobutanesulfonic acid and childhood adiposity: A prospective birth cohort study in Shanghai, China	Chemosphere 226:17–23	Prospective Birth Cohort	China	Both	n=404 mothers and children	Obesity	Waist Circumference (females only)	PFBS	+
											Waist to Height Ratio (females only)	PFBS	+
											Fat Mass (females only)	PFBS	+
											Higher Body Fat Percentage (females only)	PFBS	+
											Waist Circumference (females only)	PFDoA	+
											Lower Body Fat Percentage (females only)	PFDoA	+
											Fat Mass (females only)	PFDoA	+
			[illegible]										

208	Birth Outcomes	2020	Chu, C., Y. Zhou, Q.-Q. Li, M. S. Bloom, S. Lin, et al.	Are perfluorooctane sulfonate alternatives safer? New insights from a birth cohort study	Environment International 135:105365	Birth Cohort	China	Both	n=372 mother-child dyads	Birth Outcomes	Higher Risk for Preterm Birth	PFOS	+
209	Birth Outcomes/Cancer	2020	Cohn, B. A., M. A. La Merrill, N. Y. Krigbaum, M. Wang, J.-S. Park, et al.	In utero exposure to poly- and perfluoroalkyl substances (PFASs) and subsequent breast cancer	Reproductive Toxicology (Elmsford, NY) 92:112–119	Nested Case-control	United States	Both	n=102 cases (daughters of mothers in original cohort) and n=310 controls	Cancer	Risk of Breast Cancer in Daughter	PFOS	-
210	Reproductive	2020	Ding, N., S. D. Harlow, J. F. Randolph, A. M. Calafat, et al.	Associations of perfluoroalkyl substances with incident natural menopause: The Study of women's health across the nation	The Journal of Clinical Endocrinology and Metabolism 105(9):e3169–e3182	Prospective Cohort	United States	Adult	n=1120 women	Reproductive	Natural Menopause Occurrence Earlier	n-PFOS	+
											Natural Menopause Occurrence Earlier	Sm-PFOS	+
											Natural Menopause Occurrence Earlier	n-PFOA	+
211	Immune	2019	Zeng, Bloom, Dharmage, et.al.	Prenatal Exposire to perfluoroalkyl subsatnces is associated with lower hand, foot and mouth disease viruses antibody response in infancy: Findings from the Guangzhou Birth Cohort Study	The Science of the total environment, 663, 60–67. https://doi.org/10.1016/j.scitotenv.2019.01.325	birth cohort	Guangzhou, China (Guangdong Province)	Both	N=201 mother-child pairs	Immune	EV71 Antibody Concentration	PFOA	-
											EV71 Antibody Concentration	PFOS	-
											EV71 Antibody Concentration	PFDA	-
											EV71 Antibody Concentration	PFNA	-
											CA16 Antibody Concentration	PFOA	-
											CA16 Antibody Concentration	PFOS	-
212	Hepatic	2019	Donat-Vargas, C., I. A. Bergdahl, A. Tornevi, M. Wennberg, et al.	Associations between repeated measure of plasma perfluoroalkyl substances and cardiometabolic risk factors	Environment International 124:58–65	Cohort from Nested Case-control	Sweden	Adult	n=187 adults from the control group	Hepatic	Triglycerides	PFOA	-
											Triglycerides	PFOS	-
											Triglycerides	PFNA	-
											Triglycerides	PFHxS	-
											Triglycerides	PFDeA	-
											Triglycerides	PFUA	-
213	Development/Reproductive	2019	Andreas Ernst , Nis Brix , Lea Lykke Braskhøj Lauridsen , et al.	Exposure to Perfluoroalkyl Substances during Fetal Life and Pubertal Development in Boys and Girls from the Danish National Birth Cohort	Environmental Health Perspective 2019 Jan;127(1):17004. doi: 10.1289/EHP3567.	Cohort	Denmark	Both	n=722 and b=445	Development/Reproductive	Earlier Age for Onset of Puberty (girls only)	PFOS	+
											Earlier Age for Onset of Puberty (girls only)	PFHpS	+
											Earlier Age for Onset of Puberty (girls only)	PFNA	+
											Earlier Age for Onset of Puberty (girls only)	PFDeA	+
											Earlier Age for Onset of Puberty (boys only)	PFHpS	+
											Later Age for Onset of Puberty (boys only)	PFDeA	+
											Later Age for Onset of Puberty (boys only)	PFNA	+
214	Birth Outcomes	2019	Ke Gao, Taifeng Zhuang , et al.	Prenatal Exposure to Per- and Polyfluoroalkyl Substances (PFASs) and Association between the Placental Transfer Efficiencies and Dissociation Constant of Serum Proteins-PFAS Complexes	*Environ. Sci. Technol.* 2019, 53, 11, 6529–6538	Cohort	China	Both	n=132 paired mother and children	Birth Outcomes	Maternal Weight	PFOS	+
											Birth Length	PFBA	-
215	Immune	2020	Philippe Grandjean, Clara Amalie Gade Timmermann , Marie Kruse, et al.	Severity of COVID-19 at elevated exposure to perfluorinated alkylates	PLoS One. 2020 Dec 31;15(12):e0244815. doi: 10.1371/journal.pone.0244815	Cohort	Denmark	Adult	n=323 subjects aged 30-70	Immune	COVID-19 Severity	PFBA	+
216	Birth Outcomes/Development	2020	Gross, R. S., A. Ghassabian, S. Vandyousefi,et al.	Persistent organic pollutants exposure in newborn dried blood spots and infant weight status: A case-control study of low-income Hispanic mother-infant pairs.	Environmental Pollution 267:115427	Nested Case-control	United States	Both	n=98 mother-child pairs	Birth Outcomes/Development	Birth Weight	PFOS	-
											Birth Weight	PFHxS	-

217	Developmental	2018	Høyer, B.B., J.P Bonde, S.S. Tøttenborg, et al.	Exposure to perfluoroalkyl substances during pregnancy and child behaviour at 5 to 9 years of age.	Hormones and Behavior 101:105–112. https://doi.org/10.1016/j.yhbeh.2017.11.007	Cohort	Greenland, Ukraine	Both	n=1023 mother-child pairs	Developmental	ADHD	PFNA	+
											ADHD	PFDeA	+
218	Musculoskeletal	2019	Hu, Y., G. Liu, J. Rood, L. Liang, et al.	Perfluoroalkyl substances and changes in bone mineral density: A prospective analysis in the POUNDS-LOST study.	Environmental Research 179(P):108775	Prospective Analysis from Randomized Dietary Intervention Trial	United States	Adult	n=811 aged 30-70 years	Musculoskeletal	Bone Mineral Density in the Spine	PFOS	-
											Bone Mineral Density in the Spine	PFOA	-
											Bone Mineral Density in the Total Hip	PFOA	-
											Bone Mineral Density in the Femoral Head	PFOA	-
											Bone Mineral Density in Total Hip (2 year follow up)	PFOS	-
											Bone Mineral Density in Total Hip (2 year follow up)	PFNA	-
											Bone Mineral Density in Total Hip (2 year follow up)	PFDeA	-
											Bone Mineral Density in Hip Intertrochanteric Area (2 year follow up)	PFOS	-
											Bone Mineral Density in Hip Intertrochanteric Area (2 year follow up)	PFOA	-
											Bone Mineral Density in Hip Intertrochanteric Area (2 year follow up)	PFDeA	-
											Bone Mineral Density in Hip Intertrochanteric Area (2 year follow up)	PFNA	-
219	Pregnancy	2019	Huang, R., Q. Chen, L. Zhang, et al.	Prenatal exposure to perfluoroalkyl and polyfluoroalkyl substances and the risk of hypertensive disorders of pregnancy.	Environmental Health: A Global Access Science Source 18(1):5	Cross-sectional	China	Both	n=674 pregnant women and their child	Pregnancy	Preeclampsia	PFBS	+
											Hypertensive Disorders of Pregnancy	PFBS	+
220	Immune	2019	Impinen, A., M. P. Longnecker, U. C. Nygaard, et al.	Maternal levels of perfluoroalkyl substances (PFASs) during pregnancy and childhood allergy and asthma related outcomes and infections in the Norwegian Mother and Child (MoBa) cohort.	Environment International 124:462–472	Cohort	Norway	Both	n=1943 mother-child pairs	Immune	Atopic Eczema (girls only)	PFUA	-
											Common Cold (age 0-3 years) (girls only)	PFOS	-
											Common Cold (age 0-3 years) (girls only)	PFOA	-
											Bronchitis/pneumonia (age 0-3 years)	PFOS	+
											Bronchitis/pneumonia (age 0-3 years) (girls only)	PFOA	+
											Bronchitis/pneumonia (age 6-7 years) (girls only)	PFNA	-
											Throat Infection with Strep (age 0-3 years)	PFNA	+
											Throat Infection with Strep (age 0-3 years) (boys only)	PFOA	+
											Throat Infection with Strep (age 0-3 years) (boys only)	PFUA	+
											Pseudocroup (age 0-3 years)	PFOA	+
											Pseudocroup (age 0-3 years)	PFUA	-
											Ear Infection (age 0-3 years)	PFOS	-
											Ear Infection (age 0-3 years)	PFUA	-
											Diarrhea/gastric flu (age 0-3 years) (girls only)	PFNA	+
											Diarrhea/gastric flu (age 6-7 years)	PFOA	+
											Urinary Tract Infection (age 0-3 years) (girls only)	PFOS	-
											Urinary Tract Infection (age 0-3 years) (girls only)	PFOA	-
											Free T3 (Thyroid Antibody Positive Mothers only)	PFNA	+
											Thyroid Peroxidase Antibody (all mothers)	PFOA	-
											TSH (male offspring only)	PFOS	+

221	Development / Endocrine	2019	Itoh, S., A. Araki, C. Miyashita, K. Yamazaki, et al.	Association between perfluoroalkyl substance exposure and thyroid hormone/thyroid antibody levels in maternal and cord blood: The Hokkaido Study.	Environment International 133(P):105139.	Cohort	Japan	Both	n=701 mother-neonate pairs	Development/Endocrine	TSH (male offspring only) (Thyroid Antibody Negative Mothers only)	PFOS	+
											TSH (male offspring only) (Thyroid Antibody Positive Mothers only)	PFDeA	-
											TSH (male offspring only) (Thyroid Antibody Negative Mothers only)	PFDeA	-
											Free T3 (male offspring only) (Thyroid Antibody Negative Mothers only)	PFUA	-
											Free T3 (male offspring only) (Thyroid Antibody Negative Mothers only)	PFOA	-
											TSH (female offspring only) (Thyroid Antibody Negative Mothers only)	PFDoA	-
											TSH (female offspring only) (Thyroid Antibody Negative Mothers only)	PFDeA	+
											Free T4 (female offspring only) (Thyroid Antibody Positive Mothers only)	PFDoA	-
											Free T4 (female offspring only) (Thyroid Antibody Positive Mothers only)	PFOA	+
											Free T4 (female offspring only) (Thyroid Antibody Positive Mothers only)	PFNA	+
											Thyroglobulin antibody (female offspring only) (Thyroid Antibody Positive Mothers only)	PFDeA	+
222	Development/Metabolic	2022	Cakmak, S., Lukina, A., Karthikeyan, S., et al.	The association between blood PFAS concentrations and clinical biochemical measures of organ function and metabolism in participants of the Canadian Health Measures Survey (CHMS)	Science of the Total Environment, 827, art. no. 153900.	Cross-sectional survey	Canada	Both (6-79 yrs)	N=6045	Development/Metabolic	Gamma-glutamyl transferase	PFOA	+
											Gamma-glutamyl transferase	PFDeA	+
											Gamma-glutamyl transferase	PFNA	+
											Gamma-glutamyl transferase	PFOS	+
											Lipid metabolism biomarkers	PFOA	+
											Lipid metabolism biomarkers	PFOS	+
											Lipid metabolism biomarkers	PFHxS	+
											Lipid metabolism biomarkers	PFNA	+
											Lipid metabolism biomarkers	PFDeA	+
											Lipid metabolism biomarkers	PFUA	+
											Serum Calcium	PFHxS	+
											Serum Calcium	PFOA	+
											Serum Calcium	PFOS	+
											Serum Calcium	PFNA	+
											Serum Calcium	PFDeA	+
223	Metabolic	2020	Jensen, R. C., M. S. Andersen, P. V. Larsen,et al.	Prenatal exposures to perfluoroalkyl acids and associations with markers of adiposity and plasma lipids in infancy: An Odense Child Cohort Study.	Environmental Health Perspectives 128(7):77001	Prospective Cohort	Denmark	CA	n=84 children and mothers	Metabolic	Body Fat % (offspring@ 3 months of age)	PFNA	+
											Body Fat % (offspring @ 3 months of age)	PFDeA	+
224	Endocrine	2020	Jensen, R. C., D. Glintborg, C. A. Gade Timmermann, et al.	Prenatal exposure to perfluorodecanoic acid is associated with lower circulating concentration of adrenal steroid metabolites during mini puberty in human female infants: The Odense Child Cohort.	Environmental Research 182:109101.	Prospective Cohort	Denmark	CA	n=2874 total, n = 1628 pregnant women, n=526 children	Endocrine	Reduced Female DHEA infant serum in girls (4months of age)	PFDeA	-
225	Immune	2021	Ji, J., L. Song, J. Wang, Z. Yang, et al.	Association between urinary per- and poly-fluoroalkyl substances and COVID-19 susceptibility.	Environment International 153:106524.	Case-control	China	Adults	n=80 COVID patients and n=80 controls	Immune	COVID-19 infection risk	PFOS	+
226	Endocrine Disease	2020	Jin, R., R. McConnell, C. Catherine, S. Xu, et al.	Perfluoroalkyl substances and severity of nonalcoholic fatty liver in children: An untargeted metabolomics approach.	Environment International 134:105220.	Cross-sectional Cohort	United States	CA	n=74 children/adolescents aged 7-19	Endocrine Disease	Non-alcoholic steatohepatitis (NASH)	PFOS	+
											Non-alcoholic steatohepatitis (NASH)	PFHxS	+
											Liver fibrosis	PFHxS	+
											Non-alcoholic fatty liver disease score	PFHxS	+

227	Development/Birth Outcomes	2022	Gao, Y., Luo, J., Zhang, Y., et al.	Prenatal Exposure to Per- and Polyfluoroalkyl Substances and Child Growth Trajectories in the First Two Years	Environmental health perspectives, 130(3), p. 37006.	longitudinal	Shanghai, China	Adults	N=3,426	Development/Birth Outcomes	Weight for age (high-rising vs moderately stable)	PFDoA	-
											Weight for age (high-rising vs moderately stable)	PFHxS	-
											Weight for age (high-rising vs moderately stable)	PFDeA	-
											Weight for age (high-rising vs moderately stable)	PFUA	-
											Weight for age (high-rising vs moderately stable)	PFNA	-
											Weight for age (high-rising vs moderately stable)	PFOA	-
											Weight for age (high-rising vs moderately stable)	PFHpA	-
											Weight for length (high-rising vs moderately stable)	PFHpA	+
											Weight for length (high-rising vs moderately stable)	PFDeA	+
											Weight for length (high-rising vs moderately stable)	PFUA	+
											Weight for length (high-rising vs moderately stable)	PFNA	+
											Weight for length (high-rising vs moderately stable)	PFOA	+
											Weight for length (high-rising vs moderately stable)	PFHxS	+
											Head circumference for age (high-rising vs moderately stable)	PFDeA	-
											Head circumference for age (high-rising vs moderately stable)	PFUA	-
											Head circumference for age (high-rising vs moderately stable)	PFNA	-
											Head circumference for age (high-rising vs moderately stable)	PFHxS	-
											Head circumference for age (high-rising vs moderately stable)	PFOA	-
											Head circumference for age (high-rising vs moderately stable)	PFHpA	-
228	Development/Respiratory	2021	Kung, Y.-P., C.-C. Lin, M.-H. Chen, et al.	Intrauterine exposure to per- and polyfluoroalkyl substances may harm children's lung function development.	Environmental Research 192:110178.	Cohort	Taiwan	Children	n=165	Development/Respiratory	Low FEV-1 values (significant PFOS level in cord blood) amongst LBW individuals	PFOS	-
											Peak expiratory flow (PEF) with significant PFOS level in cord blood amongst children w/ allerguc rhinitis	PFOS	-
229	Respiratory	2020	Kvalem, H. E., U. C. Nygaard, K. C. Lodrup Carlsen, et al.	Perfluoroalkyl substances, airways infections, allergy and asthma related health outcomes—Implications of gender, exposure period and study design.	Environment International 134:105259.	Cross-sectional	Norway	Children	n=378	Respiratory	Lower Respiratory Tract Infections (LRTI)	PFHpA	+
												PFOA	+
												PFHpS	+
												PFOS	+
230	Reproductive/Endocrine	2020	Lebeaux, R. M., B. T. Doherty, L. G., Gallagher, et al.	Maternal serum perfluoroalkyl substance mixtures and thyroid hormone concentrations in maternal and cord sera: The HOME Study.	Environmental Research 185:109395.	Cross-sectional Cohort	United States (Cincinatti, OH)	Adults	n=468	Reproductive/Endocrine	Increase in maternal thyroid stimulating hormone	PFOS	+
231	Reproductive Health/ Endocrine	2020	Liang, H., Z. Wang, M. Miao, et al.	Prenatal exposure to perfluoroalkyl substances and thyroid hormone concentrations in cord plasma in a Chinese birth cohort.	Environmental Health: A Global Access Science Source 19(1):127.	Birth cohort study	Shanghai, China	CA	n=300	Reproductive/Endocrine	FT3 concentration	PFOA	+
											FT3 concentration	PFNA	-
											TSH concentration	PFOA	+
											TSH concentration	PFNA	-
											Total Cholesterol Levels	PFOA	+

232	Hepatic	2019	Lin, P.-I. D., A. Cardenas, R. Hauser, et al.	Per- and polyfluoroalkyl substances and blood lipid levels in pre-diabetic adults-longitudinal analysis of the diabetes prevention program outcomes study	Environment International 129:343–353.	Long term prospective study	United States	Adults	n=888 prediabetic adults	Hepatic	Total Cholesterol Levels	PFHxS	+
											Total Cholesterol Levels	PFNA	+
											Risk for Hypercholesterolemia	PFOA	+
											RIsk for Hypertriglyceridemia	PFOS	+
											RIsk for Hypertriglyceridemia	PFOA	+
233	Cardiovascular	2022	Schillemans, T., Donat-Vargas, C., Lindh, C.H., et al.	Per- and Polyfluoroalkyl Substances and Risk of Myocardial Infarction and Stroke: A Nested Case-Control Study in Sweden	Environmental health perspectives, 130(3), p. 37007. 2022	Case Control	Sweden	Adults	N=1528	Cardiovascular disease	First incident of myocardiali infraction and ischemic stroke	PFOS	+
											First incident of myocardiali infraction and ischemic stroke	PFHpA	-
											First incident of myocardiali infraction and ischemic stroke	PFOA	-
											First incident of myocardiali infraction and ischemic stroke	PFNA	-
											First incident of myocardiali infraction and ischemic stroke	PFDeA	+
											First incident of myocardiali infraction and ischemic stroke	PFUA	-
											First incident of myocardiali infraction and ischemic stroke	PFDoA	-
234	Reproductive/Endocrine	2020	Lin, H.-W., H.-X. Feng, L. Chen, et al.	Maternal exposure to environmental endocrine disruptors during pregnancy is associated with pediatric germ cell tumors.	Nagoya Journal of Medical Science 82(2):323–333.	Case-control	China	CA	n=45 children, n=42 adults	Reproductive/Endocrine	Pediatric Germ Cell tumor (GCT)	PFHxS	+
235	Cardiovascular	2020	Lin, P.-I. D., A. Cardenas, R. Hauser, D. R. Gold, et al.	Per- and polyfluoroalkyl substances and blood pressure in pre-diabetic adults-cross-sectional and longitudinal analyses of the diabetes prevention program outcomes study.	Environment International 137:105573.	Cross-sectional & Longitudinal	United States	Adults	n=957	Cardiovascular	Systolic BP	PFOA	+
236	Renal/Diabetes	2021	Lin, P.-I. D., A. Cardenas, R. Hauser, D. R. Gold, et al.	Per- and polyfluoroalkyl substances and kidney function: Follow-up results from the Diabetes Prevention Program trial.	Environment International 148:106375.	Longitudinal cohort	United States	Adults	n-857, prediabetic adults	Renal/Diabetes	Adverse Kidney Function	PFAS	+
											Baseline eGFR	PFAS	-
237	Reproductive/Metabolic	2020	Liu, Y., N. Li, G. D. Papandonatos, A. M. Calafat, et al.	Exposure to per- and polyfluoroalkyl substances and adiposity at age 12 years: Evaluating periods of susceptibility.	Environmental Science & Technology 54(2):16039–16049.	Cross-sectional Cohort	United States	CA	n=468 pregnant women, n=389 children with atleast 1 PFAS serum measure	Reproductive/Metabolic	Central adiposity	PFOA	+
											Risk of overweight/obesity	PFOA	+
											Central adiposity	PFHxS	+
											Risk of overweight/obesity	PFHxS	+
238	Developmental	2019	Long, M., M. Ghisari, L. Kjeldsen, M. Wielsoe, et al.	Autism spectrum disorders, endocrine disrupting compounds, and heavy metals in amniotic fluid: A case-control study.	Molecular Autism 10:1.	Case-control	Denmark	CA	n=175 ASD cases, n=135 controls	Neurodevelopment	ASD Risk	PFOS	-
239	Reproductive	2021	Ma, X., L. Cui, L. Chen,et al.	Parental plasma concentrations of perfluoroalkyl substances and in vitro fertilization outcomes.	Environmental Pollution (Barking, Essex 1987) 269:116159.	Cohort study	China	Adults	n-96 couples	In vitro fertilization outcomes (maternal)	2 PN zygotes	PFOA	-
											Embryo Quality	PFOA	-
										In vitro fertilization outcomes (paternal)	2 PN zygotes	PFOA	-
240	Cancer	2020	Mancini, F. R., G. Cano-Sancho, J. Gambaretti, P. Marchand, M.-C., et al.	Perfluorinated alkylated substances serum concentration and breast cancer risk: Evidence from a nested case-control study in the French E3N cohort.	International Journal of Cancer 146(4):917–928.	Case-control	France	Adults	n=194	Breast Cancer	ER+ Tumor	PFOS	+
											PR+ Tumor	PFOS	+
											ER- Tumor	PFOA	+
											PR- Tumor	PFOA	+
241	Metabolic	2020	Mitro, S. D., S. K. Sagiv, A. F.	Pregnancy per- and polyfluoroalkyl substance concentrations and postpartum health in	The Journal of Clinical Endocrinology and	Prospective	United States	Adults	n=812	Metabolic	Greater mid-upper arm circumference	PFOA	+
											BMI	PFOA	+

241	Metabolic	2020	Fleisch, L. M. Jaacks, et al.	Project Viva: A prospective cohort.	Metabolism 105(9):e3415–e3426.	Cohort	United States	Adults	n=812	Metabolic	skinfold thickness postpartum	PFOA	+
											skinfold thickness postpartum	PFOS	+
242	Reproductive	2020	Mitro, S. D., S. K. Sagiv, S. L. Rifas-Shiman, A. M. Calafat, et al.	Per- and polyfluoroalkyl substance exposure, gestational weight gain, and postpartum weight changes in Project Viva	Obesity (Silver Spring, MD) 28(1):1984–1992.	Prospective Cohort	United States	Adults	n=1614	Reproductive	Gestational weight gain in women w/ normal pre-pregnancy BMI	PFOA	+
											1-year postpartum weight retention	PFOA	+
											3-year postpartum weight retention	PFOA	+
243	Hepatic	2018	Mora, A. M., A. F. Fleisch, S. L. Rifas-Shiman, et al.	Early life exposure to per- and polyfluoroalkyl substances and mid-childhood lipid and alanine aminotransferase levels	Environment International 111:1–13. https://doi.org/10.1016/j.envint.2017.11.008.	Cohort study	United States (Boston, MA)	CA	n=682 mother-child pairs	Hepatic	Total Cholesterol	PFDeA	+
											LDL Cholesterol	PFDeA	+
											HDL Cholesterol	PFOA	+
											HDL Cholesterol	PFOS	+
											HDL Cholesterol	PFDeA	+
											Triglycerides	PFOS	-
244	Developmental	2022	Liu, Y., Eliot, M.N., Papandonatos, G.D., et al.	Gestational Perfluoroalkyl Substance Exposure and DNA Methylation at Birth and 12 Years of Age: A Longitudinal Epigenome-Wide Association Study Environmental health perspectives,	Association Study Environmental health perspectives, 130(3), p. 37005.	Logitudinal	Cincinnati, Ohio, metropolitan area	Adults	N=266 (core blood) N=160 (12yrs)	Developmental	cytosine-guanine dinucleotide (CpG) sites	PFOS	+
												PFOA	+
												PFHxS	+
												PFNA	+
245	Reproductive	2020	Nian, M., K. Luo, F. Luo, et al.	Association between prenatal exposure to PFAS and fetal sex hormones: Are the short-chain PFAS safer?	Environmental Science and Technology 54(1):8291–8299.	Cohort study	China	CA	n=752 mother infant pairs	Reproductive	Fetal Gonadotropins	PFBS	-
											Fetal Gonadotropins	PFHpA	-
246	Immune	2021	Nielsen, C., and A. Jöud.	Susceptibility to COVID-19 after high exposure to perfluoroalkyl substances from contaminated drinking water: An ecological study from Ronneby, Sweden.	International Journal of Environmental Research and Public Health 18(20):10702.	Ecological Study	Sweden	Adults	n=3507	Immune	COVID-19 Susceptability	PFHxS	+
											COVID-19 Susceptability	PFOS	+
247	Neurodevelopment	2019	Niu, J., H. Liang, Y. Tian, et al.	Prenatal plasma concentrations of perfluoroalkyl and polyfluoroalkyl substances and neuropsychological development in children at four years of age.	Environmental Health 18(1):53.	Birth Cohort	Shanghai, China	CA	n=533	Neuropsychological development	Negative impact on personal social skills in girls	PFHxS	-
											Negative impact on personal social skills in girls	PFOS	-
											Negative impact on personal social skills in girls	PFOA	-
											Negative impact on personal social skills in girls	PFNA	-
											Negative impact on personal social skills in girls	PFDeA	-
											Negative impact on personal social skills in girls	PFUA	-
248	Neurodevelopment	2021	Oh, J., D. H. Bennett, A. M. Calafat, et al.	Prenatal exposure to per- and polyfluoroalkyl substances in association with autism spectrum disorder in the MARBLES study.	Environment International 147:106328.	Cohort study	United States	CA	n=173 mother-infant pairs	Neurodevelopment/ Autism	Increased risk of ASD	PFOA	+
											Increased risk of ASD	PFNA	+
249	Diabetes/Metabolic	2020	Preston, E. V., S. L. Rifas-Shiman, M.-F. Hivert, et al.	Associations of per- and polyfluoroalkyl substances (PFAS) with glucose tolerance during pregnancy in Project Viva.	The Journal of Clinical Endocrinology and Metabolism 105(8):e2864–e287	Prospective Cohort study	United States	Adults	n=1450	Diabetes/Metabolic	High Glucose Levels (1 hr post G CT glucose levels)	PFOS	+
250	Endocrine	2020	Preston, E. V., T. F. Webster, B. Claus Henn, et al.	Prenatal exposure to per- and polyfluoroalkyl substances and maternal and neonatal thyroid function in the Project Viva Cohort: A mixtures approach.	Environment International 139:105728.	longitudinal pre-birth cohort study	Boston, Massachusetts	Both	N=725 (mothers) N=465 neonates	Endocrine	T4 levels	PFHxS	-
											Maternal Free T4 Index (FT4I)	PFHxS	-
											Maternal Free T4 Index (FT4I)	PFOA	-
											Gestational diabetes with history of T2D	PFDoA	+

251	Diabetes	2019	Rahman, M. L., C. Zhang, M. M. Smarr, et al.	Persistent organic pollutants and gestational diabetes: A multi-center prospective cohort study of healthy US women.	Environment International 124:249–258.	prospective cohort study	United States	Adults	N=2334	Diabetes	Gestational diabetes with history of T2D	PFHpA	+
											Gestational diabetes with history of T2D	PFOA	+
											Gestational diabetes with history of T2D	PFNA	+
252	Endocrine	2019	Reardon, A. J. F., E. Khodayari Moez, I. Dinu, S. Goruk, C. J. Field, et al.	Longitudinal analysis reveals early-pregnancy associations between perfluoroalkyl sulfonates and thyroid hormone status in a Canadian prospective birth cohort.	Environment International 129:389–399.	Prospective birth cohort	Canada	Adults	N=494	Endocrine	free thyroxine (FT4)	PFUA	_
253	Birth Outcomes	2021	Romano, M. E., L. G. Gallagher, M. N. Eliot, A. M. Calafat, et al.	Per- and polyfluoroalkyl substance mixtures and gestational weight gain among mothers in the Health Outcomes and Measures of the Environment study.	International Journal of Hygiene and Environmental Health 231:113660.	Prospective birth and pregnancy cohort	Cincinnati, Ohio	Adults	N=277	Birth Outcomes	Gestational Weight Gain	PFNA	+
											Gestational Weight Gain	PFOS	+
											Gestational Weight Gain	PFOA	+
254	Birth Outcomes	2018	Rosen, E. M., A. L. Brantsæter, R. Carroll, et al.	Maternal plasma concentrations of per- and polyfluoroalkyl substances and breastfeeding duration in the Norwegian mother and child cohort.	Environmental Epidemiology 2(3):e027. https://doi.org/10.1097/EE9.0000000000000027.	Cohort study	Norway	Both	N=1716	Birth Outcomes	Breast feeding cessation	PFUA	-
											Breast feeding cessation	PFDeA	-
											Breast feeding cessation	PFNA	-
255	Hepatic	2018	Salihovic, S., J. Stubleski, A. Karrman, et al.	Changes in markers of liver function in relation to changes in perfluoroalkyl substances—A longitudinal study.	Environment International 117:196–203.	Logitudinal study	Swden	Adults	N=1002	Hepatic	alkaline phosphatase (ALP)	PFUA	+
											alkaline phosphatase (ALP)	PFDeA	+
											alkaline phosphatase (ALP)	PFNA	+
											alkaline phosphatase (ALP)	PFOA	+
											alkaline phosphatase (ALP)	PFHpA	+
											gamma--glutamyltransferase (GGT)	PFUA	+
											alanine aminotransferase (ALT)	PFNA	+
											alanine aminotransferase (ALT)	PFOA	+
											alanine aminotransferase (ALT)	PFOS	+
											alanine aminotransferase (ALT)	PFHpA	+
256	Cancer	2021	Shearer, J. J., C. L. Callahan, A. M. Calafat, W.-Y. Huang, et al.	Serum concentrations of per- and polyfluoroalkyl substances and risk of renal cell carcinoma.	Journal of the National Cancer Institute 113(5):580–587.	nested case control study	United States	Adults	N=324	Renal Cancer	Renal cell carcinoma risk	PFOA	+
257	Neurodevelopment	2020	Shin, H.-M., D. H. Bennett, A. M. Calafat, D. Tancredi, and I.	Modeled prenatal exposure to per- and polyfluoroalkyl substances in association with child autism spectrum disorder: A case-control study.	Environmental Research 186:109514.	Population based case control study	California	Both	N=453 child mother pairs	Neurodevelopment/ Autism	Risk of ASD diagonosis	PFHxS	+
											Risk of ASD diagonosis	PFOS	+
258	Birth Outcomes	2018	Shoaff, J., G. D. Papandonatos, A. M. Calafat, et al.	Prenatal exposure to perfluoroalkyl substances: Infant Birth weight and early life growth.	Environmental Epidemiology (Philadelphia, PA) 2(2):e101.	Prospective Cohort	Cincinnati, OH	Both	N=345	Birth Outcomes	Birth weight Z-Score	PFOA	-
											BMI Z-score	PFOA	-
259	Cardivascular	2022	Zeng, G., Zhang, Q., Wang, X., Wu, K.-H.	The relationship between multiple perfluoroalkyl substances and cardiorespiratory fitness in male adolescents	Environmental Science and Pollution Research. 2022	Crossectional-NHANES	United States	Adolecents (13-19)	N=491	Cardiovascular	Maximal oxygen consumption	PFNA	-
											Methylation of genes in the HLA-DRB group	PFNA	+

260	Developmental; Immune	2020	Starling, A. P., C. Liu, G. Shen, I. V. Yang, et al.	Prenatal exposure to per- and polyfluoroalkyl substances, umbilical cord blood DNA methylation, and cardiometabolic indicators in newborns: The Healthy Start Study.	Environmental Health Perspectives 128(1):127014.	Prospective Cohort	Colorado	Both	N=583	Developmental	Methylation of genes in the HLA-DRB group	PFOA	+
										Immune	Major histocompatibility complex class 1	PFHxS	+
											PF4	PFDA	+
261	Gastrointestinal	2018	Steenland, K., S. Kugathasan, and D. B. Barr.	PFOA and ulcerative colitis.	Environmental Research 165:317–321	Cohort study	Ohio valley	both	N=249	Gastrointestinal	Ulcerative colitis	PFOA	+
262	Hepatic	2020	Stratakis, N., V. C. D, R. Jin, K. Margetaki, D. Valvi, A. P. Siskos, et al.	Prenatal exposure to perfluoroalkyl substances associated with increased susceptibility to liver injury in children	Hepatology 72(5):1758–1770.	European Human Early-Life Exposome cohort (HELIX)	France, Greece, Lithuania, Norway, Spain, and the United Kingdom	both	N=1105	Hepatic	Amino acid perturbation	PFAS (total)	+
											Glycerophospholipid metabolism		
											High liver enzyme levels		
263	Diabetes	2018	Sun, Q., G. Zong, D. Valvi, et al.	Plasma concentrations of perfluoroalkyl substances and risk of type 2 diabetes: A prospective investigation among U.S. women.	Environmental Health Perspectives 126(3):037001. https://doi.org/10.1289/EHP2619.	Prospective Nested Case Control Study	United States	Adults	N=793	Diabetes	Risk of Type 2 Diabetes	PFOA	+
											Risk of Type 2 Diabetes	PFOS	+
264	Developmental	2019	Tian, Y., H. Liang, M. Miao, F. Yang, H. Ji, et al.	Maternal plasma concentrations of perfluoroalkyl and polyfluoroalkyl substances during pregnancy and anogenital distance in male infants.	Human Reproduction (Oxford, England) 34(7):1356–1368.	Prospective Cohort	Shanghai, China	CA	N=500	Developmental	Anoscrotal Distance	PFOS	-
											Anoscrotal Distance	PFDeA	-
											Anoscrotal Distance	PFUA	-
											Anopenile Distance	PFDeA	-
											Anopenile Distance	PFUA	-
265	Birth Outcomes/Hepatic	2021	Tian, Y., M. Miao, H. Ji, et al.	Prenatal exposure to perfluoroalkyl substances and cord plasma lipid concentrations.	Environmental Pollution 268(P):115426. https://doi.org/10.1016/j.envpol.2020.115426.	Cohort study	Beijing, China	both	N=306 mother-infant pairs	Birth Outcomes/Hepatic	Total Cholesterol	PFNA	-
											Total Cholesterol	PFOS	-
											Total Cholesterol	PFDeA	-
											Total Cholesterol	PFUA	-
											Triglycerides	PFDA	-
											Triglycerides	PFUA	-
											High Density Lipoprotein Cholesterol	PFOS	-
											High Density Lipoprotein Cholesterol	PFNA	-
											High Density Lipoprotein Cholesterol	PFDeA	-
											High Density Lipoprotein Cholesterol	PFUA	-
											Low Density Lipoprotein Cholesterol	PFUA	-
266	Immune	2020	Timmermann, C. A. G., K. J. Jensen, F. Nielsen, E. Budtz-Jorgensen, et al.	Serum perfluoroalkyl substances, vaccine responses, and morbidity in a cohort of Guinea-Bissau children.	Environmental Health Perspectives 128(8):87002.	Randomized control trial	Guinea-Bissau, West Africa	CA	N=237	Immune	Measles Antibody Concentration Post Vaccination	PFOS	-
											Measles Antibody Concentration Post Vaccination	PFDeA	-
											Risk of Any Morbidity	PFHxS	+
											Risk of Any Morbidity	PFOA	+