Vol 5 | Issue 7

# PFAS UPDATES

*Recent Developments in Science, Technology, and Regulation*

## The Interstate Technology and Regulatory Council (ITRC)

ITRC published the updated PFAS-1 Technical and Regulatory Guidance Document. This update includes a brand-new section on Surface Water Quality and significant revisions for Ecological Risk Assessment. Other sections of the document have also been selected for additional content, including information in Chemistry and Terminology, Best Management Practices for Firefighting Foams, Phase Partitioning, PFAS Uptake into Plants, Ecological Toxicology, and Site Characterization.

## Contents



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## Special Highlights

- OECD has published a new report titled *Reconciling Terminology of the Universe of PFAS: Recommendations and Practical Guidance*. The report highlights a revised PFAS definition, practical guidance on how to use the PFAS terminology, a systematic approach to characterization of PFAS based on molecular structural traits, and OECD identified areas in relation to the PFAS terminology that warrant further development.
- The Environmental Working Group published a new analysis of government data on PFAS. A map allows users to identify locations of 41,828 industrial and municipal sites that they say produce or use, are suspected of using, or are a suspected source of PFAS.
- The Environmental Defense Fund published a blog post on fluorinated containers. They conclude that USEPA's findings on PFAS-contaminated pesticides has much broader, concerning implications for food, cosmetics, shampoos, household cleaning products, and other consumer products, as well as recycling.
- The nonprofit Physicians for Social Responsibility published a report on *Fracking with "Forever Chemicals"*, indicating PFAS use in fracking in more than 1,200 wells in Arkansas, Louisiana, Oklahoma, New Mexico, Texas, and Wyoming between 2012 and 2020.
- A recent study found that PFAS levels in urine were significantly correlated with breast cancer in Filipinas. Long-chain PFAS levels were also found to be positively associated with age and were higher in women from an industrialized region, compared to the National Capital Region.

## Policy and Regulation— Federal and International

USEPA announced a public comment period and external peer review for the IRIS Assessment of PFBA and related compound ammonium PFBA, as well as a request for public nominations to the IRIS PFAS external peer review panel. The Federal Register Notice indicates that the comment period ends October 22, 2021 and comments should be submitted to EPA-HQ-ORD-2020-0675 via Regulations.gov. Nominations for expert reviewers of the draft IRIS Toxicological Reviews of PFDA, PFNA, PFHxA, PFHxS and PFBA should be submitted September 22, 2021.

USEPA announced Draft Contaminant Candidate List 5 (CCL 5), which provides the latest list of drinking water contaminants that are known or anticipated to occur in public water systems and are not currently subject to USEPA drinking water regulations. The draft CCL 5 includes PFAS. PFAS are proposed as a group, with the exception of PFOA and PFOS because the agency is moving forward with national primary drinking water standards for these two contaminants.

USEPA opened a Request for Applications regarding Collection of Concordant Multimedia Measurements to Evaluate PFAS Human Exposure Pathways. With this RFA, USEPA seeks to advance common exposure measurement protocols that can be implemented across PFAS cohort studies to generate important exposure data for priority pathways. The agency is soliciting research that proposes and evaluates innovative protocols for measuring human exposure to PFAS chemicals in cohorts where biomonitoring is being conducted. Closing date is August 23, 2021.

The European Chemicals Agency (ECHA) is soliciting comments on the draft opinion of the Committee for Socio-Economic Analysis concerning the restriction proposal from

Germany on PFHxA, its salts, and related substances. The deadline for comments is September 7, 2021.

Denmark, Germany, the Netherlands, Norway, and Sweden have submitted an intention to restrict the manufacture, placing on the market, and use of PFAS. ECHA expects to receive approval of their restriction proposal by July 15, 2022. The five countries have launched a survey on PFAS and their alternatives and are looking for more information for the intended restriction. The deadline for comments is September 19, 2021.

## *Policy and Regulation— State Level*

California's Department of Toxic Substances Control adopted carpets and rugs containing PFAS as a Priority Product under its Safer Consumer Products Regulations, effective July 1, 2021.

California's Office of Environmental Health Hazard Assessment published draft public health goals for PFOA (0.007 ppt based on kidney cancer in humans) and PFOS (1 ppt based on liver and pancreatic cancer in rats).

Maine's Gov. Janet Mills signed into law the country's first ban on products made with "intentionally added" PFAS, setting a 2030 deadline to eliminate most uses of the chemicals.

Connecticut's Gov. Ned Lamont signed Public Act No. 21-191, which phases in a ban of specialized firefighting foams containing certain PFAS.

## *Fate and Transport*

**Ideal versus Nonideal Transport of PFAS in Unsaturated Porous Media.**
M.L. Brusseau, B. Guo, D. Huang…; *Water Res.* 2021

The influence of surfactant-induced flow and nonlinear air-water interfacial adsorption (AWIA) on PFAS transport was investigated through a series of transport experiments. PFOS, PFOA, and GenX were used as model PFAS. The authors demonstrated that AWIA was linear when the input concentration was sufficiently below the critical reference concentration. Independently-predicted simulations provided good predictions of the measured transport. The authors concluded that PFAS retention associated with AWIA can be considered to be ideal when the input concentration was sufficiently below the critical reference concentration, supporting the use of simplified mathematical models.

**A New Framework for Modeling the Effect of Salt on Interfacial Adsorption of PFAS in Environmental Systems.**
S.T. Le, Y. Gao, T.C.G Kibbey …; *Sci. Tot. Environ.* 2021

This work describes a new model for predicting the interfacial behavior of surfactants as a function of salt concentration. The model is fit to interfacial tension data over a range of salt concentrations and is able to predict adsorption isotherms for the entire range, from no added salt to 0.5 M added salt. The model was consistent with experimental data. The model predicts the existence of sigmoidal adsorption isotherms at low salt concentrations (a deviation from isotherms calculated using the Szyszkowski equation) that is supported by a maximum in

measured interfacial adsorption coefficient calculated from low-concentration surface tension measurements.

**Uptake of PFAAs by Crops: Results from a Field Study.**
S. Felizeter, H. Jürling, M. Kotthoff …; *Environ. Sci.* 2021

Four crops were grown on soil spiked with 13 PFAAs at 4 different levels. Edible part/soil concentration factors ranged widely and decreased with increasing PFAA chain length. Three processes responsible for most of the variability include 1) sorption to soil; 2) transport via the transpiration stream to the leaves, which was hindered by retention in the roots driven by sorption; and 3) transfer from the leaves to the fruit via the phloem flow, which was also likely hindered by sorption. A model based on these findings closely described the measured concentrations in roots, leaves, fruits, and radish bulbs in most cases.

## *Monitoring—Environment*

**A Machine Learning Approach for Prioritizing Groundwater Testing for PFAS.**
S. George, A. Dixit; *J. Environ. Manage.* 2021

A series of machine learning models was developed to predict PFAS presence based on a groundwater data set from California. These models were developed to help identify potential drinking water exposure to PFAS because regional sampling data for groundwater wells can have many data gaps. The models were used to predict co-contaminant fingerprints, hydrological properties, soil parameters, proximity of airports/military bases, and geospatial data. The machine learning model was able to predict maximum PFAS concentrations with a Spearman correlation of 0.64 and discern wells with high concentrations of PFAS with an accuracy of 91%.

**Model-Based Assessment of Groundwater Contamination with PFOS due to Fire-Training Activities.**
H. Laine-Kaulio, H. Koivusalo; *J. Environ. Engineer.* 2021

A modeling framework to estimate groundwater pollution from PFOS at fire-training sites with known use was created and applied to an existing contaminated site. Model results indicated that 27% of PFOS released from the fire-training area reached the aquifer. However, levels in the groundwater intake area were still predicted to exceed drinking water standards. Two techniques, adsorption to unburnt fuels and removal by oil separation wells, are also indicated as strategies to decrease PFOS contamination.

**Legacy and Emerging PFAS in the Bohai Sea and its Inflow Rivers.**
L. Meng, B. Song, H. Zhong...; *Environ. Int.* 2021

PFAS concentrations in river sediment, soil near river inflow, sea sediment, and seawater collected from the Bohai Sea were evaluated. Of 29 PFAS analyzed, those with 8 carbons comprised over 60% of all samples by mass, with PFOA dominating by mass and frequency of detection. The primary sources of PFAS in this area were predicted to be AFFF, metal plating, food packages, fluorine chemical industry, fluoropolymer manufacture, and domestic pollution. The environmental risk of PFAS was below levels of concern.

**Distribution of Chlorinated Volatile Organic Compounds (VOCs) and PFAS in Monitoring Wells at the Former Naval Air Warfare Center (NAWC), West Trenton, New Jersey 2014-17.**
T.E. Imbrigiotta, A.R. Fiore; *U.S. Geological Survey Open-file Report 2020-1105.* 2021

Groundwater samples collected from NAWC were analyzed for VOCs and PFAS in 2014-2017 and 2015-2017, respectively. Analysis of the areal and vertical extent of PFAS contamination revealed that the highest PFAS concentrations were found in shallow wells near the firehouse and along railroad tracks, where prior AFFF discharge was noted. Furthermore, PFAS were present in offsite groundwater wells, indicating migration of contaminated groundwater.

**High Concentrations of PFAAs in Arctic Seawater Driven by Early Thawing Sea Ice.**
J. Garnett, C. Halsall, A. Vader...; *Environ. Sci. Technol.* 2021

Late-season ice pack was investigated to determine patterns of PFAA in the Arctic aquatic ecosystem. Samples of under-ice sea water (0.5 m depth) had some of the highest PFAA concentrations among the different samples collected (sea ice, snow, melt ponds, and near-surface seawater). Relatively high concentrations were also observed in sea ice samples, particularly those collected at the surface with snow-ice. Analysis further implicated atmospheric sources of PFAA and transfer to the sea ice column. Overall, meltwater from early in the melt season likely drives high PFAA concentrations in under-ice seawater, and may affect the timing in which organisms are exposed to PFAA.

**PFAS in Sediment Collected from the Pensacola Bay System (PBS) Watershed.**
Ahmadireskety, B.F. Da Silva, J.A. Awkerman...; *Environ. Adv.* 2021

In sediment samples collected from 25 locations in the PBS watershed, 28 of 51 PFAS targeted were detected. PFAS were present at all locations, with PFBA observed in every sample. PFOS dominated samples by concentration. Locations that were near a paper manufacturing company and an airport had the highest total PFAS concentrations. PFAS concentrations were lower than those measured in July 2020 after Hurricane Sally.

## *Monitoring—Biomonitoring*

**First Report on the Bioaccumulation and Trophic Transfer of PFECAs in the Xiaoqing River Estuarine Food Web Based on Water, Sediment, and Aquatic Organism Samples.**
Y. Li, J. Yao, J. Zhang…; *Environ. Sci. Technol.* 2021

PFECAs are novel alternatives to legacy PFAS and have been widely detected in the environment. This study evaluated the bioaccumulation and trophic transfer of PFECAs in a source-impacted estuary. Elevated PFECA concentrations were observed in organisms (e.g., conch, with perfluoro-2-methoxyacetic acid (PFMOAA) concentration up to 16,700 ng/g dry weight), indicating exposure risks to consumers. PFMOAA, hexafluoropropylene oxide trimer acid (HFPO-TrA) and PFOA were predominantly detected in organisms. Based on trophic magnification factors (TMFs), PFECAs with ≥6 perfluorinated carbons could be biomagnified along the food chain (TMF>1), while PFMOAA with the

least perfluorinated carbons undergoes biodilution (TMF<1).

## *Remediation and Treatment*

**Excavated vs. Novel *In Situ* Soil Washing as a Remediation Strategy for Sandy Soils Impacted with PFAS from AFFFs.**
A. Hoisaeter, H.P.H. Arp, G. Slinde …; *Sci. Tot. Environ.* 2021

An *in situ* field test was performed at an AFFF-impacted facility in Oslo, Sweden, to examine the feasibility of soil washing as a remediation method to reduce PFOS concentrations in the vadose zone. Soils were continuously infiltrated with water using a perforated hose at the surface to wash the PFOS into the groundwater (3-4 m below surface), which was then recovered and treated through the site's existing GAC pump and treat system. Results were compared against *ex situ* excavation and washing of soils on a containment liner. The research concluded that the *in situ* washing method was more efficient than ex situ excavation and washing at removing PFOS from the soil. Further, the method was found to be significantly less costly, particularly if the site in question has an existing pump and treat system for groundwater.

**Investigation of an Immobilization Process for PFAS Contaminated Soils.**
E. Barth, J. McKernan, D. Bless …; *J. Environ. Manage.* 2021

This bench-scale study evaluated various sorbents for use in an *in situ* solidifi-cation/stabilization treatment process for PFAS contaminated soils. The first phase involved sorption experiments for six PFAS diluted in water, using GAC, activated carbon-clay blend, modified clay, biochar, iron (Fe)-amended biochar, and Ottawa sand as a control. The second phase involved chemical stabilization treatment using the most effective sorbent identified in the first phase, followed by solidification of two PFAS-contaminated soils. For the majority of the PFAS, the addition of GAC substantially reduced the leachability of PFAS, and the addition of cement as a physical binding agent further decreased leachability for a few of the PFAS. Overall immobilization of PFAS that were detectable in the leachate ranged from 87.1% to 99.9%.

**PFAS Adsorption in Drinking Water by GAC: Influence of Activated Carbon and PFAS Characteristics.**
B. Cantoni, A. Turolla, J. Wellmitz…; *Sci. Tot. Environ.* 2021

Adsorption isotherms and breakthrough curves using rapid small-scale column tests were studied using four different GACs and eight PFAS. The results found the most important factor for GAC adsorption was surface charge, with positively charged GACs performing better than neutral surface GAC. Researchers further observed that the microporous GAC performed better for hydrophilic and marginally hydrophobic PFAS, while mesoporous GAC performed better for hydrophobic PFAS. Results were later confirmed at full-scale with a 1-year monitoring campaign of 17 drinking water treatment plants where all 4 GACs were used.

**Rapid Removal of PFAS from Investigation-Derived Waste (IDW) in a Pilot-Scale Plasma Reactor.**
R.K. Singh, N. Multari, C. Nau-Hix…; *Forever Chemicals.* 2021

A pilot-scale plasma reactor installed in an 8- by 20-ft mobile trailer was used to treat IDW impacted with PFAS at 13 different U.S. Air Force installations. Total PFAS concentrations ranged from 2.7 to 1,440 µg/L with combined PFOA/PFOS concentrations ranging from 365 to 73,700 ng/L. Nine of the 13 samples tested were found to degrade PFAS concentrations below USEPA's health advisory concentration level in less than 1 minute. The remaining 4 samples achieved similar results after up to 50 minutes due to higher solution electrical conductivity or total PFAA/precursor concentrations. No effects to non-PFAS co-contaminants' degradation were observed during the pilot testing.

**Interpretation of Reductive PFAS Defluorination with Quantum Chemical Parameters.**
Z. Cheng, Q. Chen, Z. Liu…; *Environ. Sci. Technol. Lett.* 2021

This study examined and characterized the intrinsic factors that influence PFAS defluorination for advanced reduction using hydrated electrons. The relationships between quantum chemical parameters and the reported overall defluorination ratio were statistically quantified and a model was developed to provide a rapid approach for estimating the overall defluorination ratio of these reductive processes.

**Degradation of PFOS and PFOA in Soil and Groundwater Samples by High Dose Electron Beam Technology.**
J. Lassalle, R. Gao, R. Rodi…; *Rad. Phys. Chem.* 2021

Electron beam technology was applied to PFAS contaminated groundwater and soils to degrade various PFAS at a bench scale. Concentrations of PFOS and PFOA were successfully reduced in groundwater by 87.9% and 53.7%, respectively. In soils with 10% moisture content, concentrations were better reduced by 99.9% and 86.5%. Further, concentratons of 10 additional PFAS compounds were reduced below detection limits, while the remaining 7 tested for were reduced in a range from 49% to 99.9%.

**Adsorption of PFOA and PFOS by Aluminum-Based Drinking Water Treatment Residuals.**
Z. Zhang, D. Sarkar, R. Datta…; *J. Hazard. Mater. Lett.* 2021

Researchers examined the adsorption potential to remove PFOA and PFOS from water systems using aluminum-based water treatment residuals (Al-WTR), which are generated during standard drinking water treatment by alum salts. At low pH, PFOA and PFOS were removed with 97.4% and 99.5% efficiency, respectively. Desorption tests indicated that the adsorption process with Al-WTR is irreversible.

**Detection and Removal of PFAS for Sustainable Environment.**
S. Pilli, A.K. Pandey, V.Pandey…; *J. Environ. Manage.* 2021

Authors provide a general literature review outlining the various sources of PFAS as well as the toxicities imposed on the environment and humans. A further review

of the present-day remediation methods for drinking water treatment is provided, including GAC, filtration, reverse osmosis, nano filtration, and oxidation processes.

**Structure-Specific Aerobic Defluorination of Short-Chain Fluorinated Carboxylic Acids (FCAs) by Activated Sludge Communities.**
S. Che, B. Jin, Z. Liu…; *Environ. Sci. Technol. Lett.* 2021

Defluorination of short-chain FCAs was examined using activated sludge communities as a method of addressing the ever-growing presence of FCAs from PFAS replacement compounds and PFAS remediation using advanced oxidation methods. Four structures exhibited greater than 20% defluorination, with 3,3,3-trifluoropropionic acid being almost completely defluorinated. The findings further quantify the fundamental understanding of aerobic microbial defluorination as a general means of PFAS treatment.

**Efficient Adsorptive Removal of Short-Chain PFAAs Using Reed Straw-Derived Biochar (RESCA).**
N. Liu, C. Wu, G. Lyu…; *Sci. Tot. Environ.* 2021

The use of synthesized RESCA for the adsorption of short-chain PFAAs was examined as an alternative to more traditional GAC treatment, which is relatively inefficient at removal when compared to long-chain performance. RESCA exhibited promising removal efficiencies greater than 92% towards short-chain PFAs at environmentally relevant concentrations, and for specific compounds, performed greater than 6 times better than GAC. Additionally, the efficacy of RESCA packed filters at a full scale was investigated using breakthrough simulations.

**Thermal Decomposition of Anionic, Zwitterionic, and Cationic PFAS in AFFFs.**
F. Xiao, P.C. Sasi, A. Alinezhad…; *Environ. Sci. Technol.* 2021

The goal of this study was to understand and quantify the specific chemical breakdown processes associated with various PFAS compounds during thermal decomposition. Results indicated that PFAS compounds tested begin to decompose at 200–300°C and exhibit near completed decomposition at >400°C. Further, the research demonstrated that low level thermal treatments of AFFFs led to the generation of anionic fluoroalkyl substances, including perfluoroheptanesulfonamide, 8:2 FTSA, N-methyl perfluorooctane sulfonamide (MeFOSA), and a previously unreported compound, N-2-propenyl-perfluorohexylsulfonamide.

**Biochar Sorption of PFAS in AFFF-Impacted Groundwater: Effects of PFAS Properties and Groundwater Chemistry.**
H.N.P. Vo, T.M.H. Nguyen, H.H. Ngo…; *Chemosphere.* 2021

The effects of groundwater chemistry on PFAS sorption to biochar columns was examined to better treat for PFAS in groundwater scenarios. The study treated water spiked with 19 PFAS compounds and AFFF-impacted groundwater. Results indicated that PFSA sorption was 1.3 times higher than PFCA sorption. Additionally, dissolved organic matter (DOM) influenced PFAS sorption to a greater extent than did pH, salinity, and specific ultraviolet adsorbance. The DOM contained hydrophobic compounds and metal ions, which

can form DOM-PFAS complexes and provide more sorption sites for PFAS.

## *Analytical Chemistry*

**LC-HRMS Screening of PFAS in Impregnated Paper Samples and Contaminated Soils.**
B. Bugsel, R. Bauer, F. Herrmann …; *Anal. Bioanal. Chem*.

High PFAS concentrations have been detected in agricultural soils in Southwest Germany. Major contaminants were polyfluorinated dialkylated phosphate esters (diPAPs) and I-ethyl perfluorooctane sulfonamide ethanol-based phosphate diester (diSAmPAP). In this study, HRMS screening for PFAS was applied to 14 soil samples from the contaminated area and 14 impregnated paper samples. The paper samples were characterized by diPAPs (from 4:2/6:2 to 12:2/12:2), fluorotelomer mercapto alkyl phosphates (FTMAPs; 6:2/6:2 to 10:2/10:2), and diSAmPAP. In soil samples, diPAPs and their transformation products were the major contaminants, but also FTMAPs, diSAmPAP, and their transformation products occurred. The presence of major degradation products like PFCAs, FTSAs, or PFOS and their distribution of carbon chain lengths indicate the activity of biotic or abiotic degradation processes and selective leaching processes from the upper soil horizons.

**A Novel Analytical Strategy for the Determination of PFAAs in Various Food Matrices Using a Home-Made Functionalized Fluorine Interaction Solid-Phase Microextraction (SPME) in Combination with Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS).**
J. Li, Y. Gao, Y. Wan…; *Fd. Chem.* 2021

This study describes a fluorine-fluorine interaction approach through fluoridating boron nitride nanosheets (BNNs) for sensing PFAA in multiple food matrices. Through a facile hydrothermal fluorination modification, the BNNs were transferred into homogeneous fluorinated boron nitride nanoparticles (F-BNNs) with robust networks and specific surface area. After morphological modification, the particles displayed strong adsorption and sensing capabilities on PFAAs in both solid and liquid food matrix. Under the evaluation of mass spectrometry, F-BNNs-based microextraction approach exhibited low method detection limits (MDLs) in the ranges of 0.9–3.9 pg/mL and 3.6–15.8 pg/g for milk and meat matrices, respectively, with satisfactory repeatability (RSD% <13.5%) and recoveries (77.7–110.5%).

**Simultaneous Targeted and Non-targeted Analysis of PFAS in Environmental Samples by Liquid Chromatography-Ion Mobility-Quadrupole Time of Flight-Mass Spectrometry (IMS-QTOF-MS) and Mass Defect Analysis.**
R.G. de Vega, A. Cameron, D. Clases...; *J. Chromatogr. A*. 2021

This work details the development of a method that provided simultaneous targeted and non-targeted PFAS analysis. Ultra-high performance liquid chromatography (UHPLC) was coupled to IMS-QTOF-MS and used to quantify known and to screen unknown PFAS in environmental samples collected from the greater Sydney basin (Australia). The method was validated for the quantification of 14 sulfonate-based PFAS, and a non-targeted data analysis

workflow was developed using a combination of mass defect analysis with common fragment and neutral loss filtering to identify fluorine-containing species. This simultaneous analysis reduces the complexity of multiple analyses, and enables a broad determination of PFAS in environmental samples.

**Simultaneous Determination of Nine PFCAs in Chinese Wolfberry and Soybean by Gas Chromatography-Mass Spectrometry (GC-MS) with a Novel Derivatization Method.**
Y. Ji, Y. Cao, X. Huang...; *Fd. Anal. Meth.* 2021

This paper describes a new method to detect PFCAs in Chinese wolfberry and soybean using three derivatization reagents. After extraction, cleaning, and derivatization with the reagents, analysis by GC-MS revealed that PFCAs could be detected in these matrices with low method quantification limits and minimal matrix effects. This method may serve as a rapid and sensitive way to determine PFCAs in Chinese wolfberry and soybean.

## *Ecotoxicology*

**Linking Field and Laboratory Studies: Reproductive Effects of PFAS on Avian Populations.**
C.M. Custer; *Integr. Environ. Assess. Manage.* 2021

This paper analyzes field studies on PFAS reproductive effects on bird populations, noting the differences in outcomes between field studies and laboratory studies. The causes of these differences are posited to include mixture issues, misattribution of the mode of action, and specific impairments caused by PFAS. Possible improvements to link laboratory and field studies are also suggested.

**The Impact of Precursors on Aquatic Exposure Assessment for PFAS: Insights from Bioaccumulation Modeling.**
D. Glaser, E. Lamoureux, D. Opdyke...; *Integr. Environ. Assess. Manage.* 2021

Though exposure to PFOS may occur, the presence of PFOS precursors and their transformation complicates exposure assessment; true exposure to PFOS may also include multiple sources and forms of PFOS. A bioaccumulation model was developed to investigate these intricacies by incorporating toxicokinetic and bioenergetic factors in a larger food web calculation. This model highlights how chemical properties can influence exposure and guide remedial actions.

**Relative Acute Toxicity of Three PFAS on Nine Species of Larval Amphibians.**
B.J. Tornabene, M.F. Chislock, M.E. Gannon…; *Integr. Environ. Assess. Manage.* 2021

Amphibians may be especially vulnerable species to PFAS exposure due to their inhabiting freshwater areas and having permeable skin. To begin filling data gaps, 96-hour lethal concentration toxicity tests for PFOS and PFOA were conducted on nine amphibian species native to eastern and central North America; tests for PFHxS were also conducted for two species. Though toxicity varied according to chemical, species, and developmental stages, PFOS was at least 8 times more toxic than PFOA in all species. The results of these tests may be used to create benchmarks of toxicity,

which may guide conservation and remediation efforts, chronic toxicity studies, and ecological risk assessments.

**Thyroid Function and Immune Status in Perch (*Perca fluviatilis*) from Lakes Contaminated with PFAS or Polychlorinated Biphenyls (PCBs).**
L Birgersson, J. Jouve, E. Jönsson…; *Ecotoxicol. Environ. Safe.* 2021

Thyroid disruption and immunotoxic effects in wild perch from Sweden were examined in one site contaminated with PFAS, two sites contaminated with PCBs, and two reference sites. Results showed lower levels of thyroid hormone T3 and lower lymphocytes and granulocytes in perch collected from the PFAS site compared to reference sites. In addition, mRNA coding for thyroid hormone metabolizing enzymes and thyroid receptor α were significantly different in these fish compared to their reference site. For perch from the PCB sites, there were no significant differences in T3 levels or in expression levels of the thyroid-related genes, compared to the reference fish. The authors suggest that PFAS exposure could affect thyroid hormone status and immune defense of wild perch.

**A Roadmap to the Structure-Related Metabolism Pathways of PFAS in the Early Life Stages of Zebrafish (*Danio rerio*).**
J. Han, W. Gu, H. Barrett...; *Environ. Health Perspect.* 2021

Using the USEPA's PFAS screening library, the metabolism pathways of 74 PFAS in zebrafish were evaluated. Metabolic pathways were determined to be related to chemical structure, and five structural categories of PFAS susceptible to metabolism were identified. These results can serve as a springboard for future research on health risks of other PFAS chemicals.

**New Compounds, Old Problems. The Case of C6O4—a Substitute of PFOA—and Its Effects to the Clam *Ruditapes philippinarum.***
J. Fabrello, M. Ciscato, L. Masiero…; *J. Hazard. Mater.* 2021

C6O4 (difluoro{[2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl]oxy} acetic acid) is used as a substitute of PFOA. In this study, the effects of C6O4 and PFOA to *Ruditapes philippinarum* were evaluated. Short- and long-term exposures to the compounds were carried out and numerous biomarkers were measured in hemolymph, gills and digestive glands. There were statistically significant effects of treatment, time, and treatment-time interaction on the biomarker responses, and the two compounds affected most of the parameters measured. The authors suggested that C6O4—similarly to PFOA—can affect both cellular and biochemical parameters of clams.

**Behavioral Effects of Early-life Exposure to PFOA Might Synthetically Link to Multiple Aspects of Dopaminergic Neuron Development and Dopamine Functions in Zebrafish Larvae.**
T. Yu, G. Zhou, Z. Cai...; *Aquat. Toxicol.* 2021

To investigate the mechanism by which PFOA may affect the dopaminergic nervous system, zebrafish were exposed in this early-life toxicity study. Seven days of exposure led to changes in mRNA levels and decreased locomotor activity. These results suggest that early-life PFOA exposure may

affect dopaminergic neuron development, and may result in neurobehavior changes and dopamine functions.

**Effects of PFOA and PFOS on Soil Microbial Community.**
R. Xu, W. Tao, H. Lin...; *Environ. Microbiol.* 2021

This study examined the effects of PFOA and PFOS exposure on soil microorganisms. After 90 days of exposure, changes in soil microbial communities were observed that ultimately led to larger populations of PFAS-tolerant bacteria. Specific bacteria, such as Proteobacteria, *Burkholderiales*, and *Rhodocyclales* were noted, as well as specific genuses and biomarkers. Also, exposure may further affect soil ecosystems by altering microbial metabolisms.

## *Toxicology*

**Varied Thyroid Disrupting Effects of PFOA and Its Novel Alternatives GenX and Ammonium 4,8-dioxa-3H-perfluorononanoate (ADONA) *In Vitro*.**
S. Zhang, K. Chen, W. Li...; *Environ. Int.* 2021

The thyroid-disrupting effects of PFOA and two of its alternatives, GenX and ADONA, were compared in rat thyroid cell and normal human thyroid cell models. While both PFOA and GenX decreased cell viability and proliferation rate, GenX was more toxic. ADONA did not show adverse effects on either viability or proliferation rate in either of the test models. However, all three changed gene expression, with changes appearing to be dependent on chemical and cell type. Authors concluded that GenX had the greatest effects on the thyroid cells, followed by PFOA and ADONA.

**Characterization of PFOS Toxicity on *In-Vivo* and *Ex-Vivo* Mouse Pancreatic Islets.**
H.T. Wan, L.Y. Cheung, T.F. Chan…; *Environ. Pollut.* 2021

The impacts of PFOS on pancreatic β-cell functions were studied using multiple approaches. Mice showed an increase in liver triglycerides, a reduction of triglycerides in blood sera, and glycogen in livers and muscles. There was a reduction of insulin and the transcriptional factors in islets of pancreatic sections from PFOS-treated groups. There was also a significant reduction in the expression levels of multiple receptors and pathways. PFOS-treatment inhibited Akt-pathway and reduced cellular insulin contents. The authors concluded that their data support the perturbing effects of PFOS on animal metabolism and demonstrate the underlying molecular targets to impair β-cell functions.

**Developmental PFOS Exposure as a Potential Risk Factor for Late-Onset Alzheimer's Disease (LOAD) in CD-1 Mice and SH-SY5Y Cells.**
V. Basaly, J. Hill, S.W. Bihaqi…; *NeuroToxicol.* 2021

Apolipoprotein allele 4 (ApoE4), the only genetic risk factor for LOAD, may accelerate Alzheimer's Disease development by increasing tau hyperphosphorylation. Using *in vivo* and *in vitro* models, this study investigated PFOS as a potential risk factor for LOAD by assessing its impact on amyloidogenesis, tau pathology, and rodent behavior. Exposed mice exhibited a trend of increased rearing and increased distance traveled. GSK3β and total ApoE were also increased following *in vivo* exposure. Low concentrations of PFOS elevated protein

levels of APP, tau, and its site-specific phosphorylation. The authors suggest that total ApoE is inducible by PFOS exposure.

**Patterns in Serum Toxicokinetics in *Peromyscus* Exposed to PFAS.**
A.M. Narizzano, M.E. Bohannon, A.G. East…; *Environ. Toxicol. Chem.* 2021

Five PFAAs and one PFAS were administered to white-footed mice (*Peromyscus leucopus*) to evaluate kinetics over 28 days of exposure. PFOA, PFHxS, and PFBS were administered to male and female mice via drinking water. PFOS, PFNA, 6:2 FTS, and PFHxS were administered to male and female mice via oral gavage. In general, a plateau in serum concentration depended on interactions between 1) the type of PFAS, 2) continuous vs. bolus dosing, and 3) to a lesser extent, sex. Specifically, PFCAs were detected at higher concentration in females than males; whereas, PFSAs were generally detected at similar levels across sex. PFAS had the largest impact on serum concentrations while sex had the lowest.

**PFOS Interferes with Non-genomic Estrogen Receptor Signaling Pathway, Inhibits ERK1/2 Activation and Induces Apoptosis in Mouse Spermatocyte-Derived Cells.**
J. Qu, Y. Han, Z. Zhao...; *Toxicology.* 2021

This study builds upon the authors' previous work by investigating PFOS effects and mechanism of action in GC-2 cells (mouse spermatocyte-derived cell line). Cell viability was inhibited in a dose-dependent manner, as well as induced G0/G1 cell cycle arrest and apoptosis. Though estrogen receptor (ER) protein levels were changed, PFOS exposure did not directly impact gene reporter assays. Pretreating cells with different ER agonists could mitigate or accelerate effects. Therefore, ERs may be important mediators of PFOS-induced toxicity in spermatocytes.

## *Epidemiology*

**Internal Exposure to PFAS in Vegans and Omnivores.**
J. Menzel, K. Abraham, S. Dietrich…; *Int. J. Hyg. Environ. Health.* 2021

This study examined the relationship of PFAS levels and the levels of cholesterol in vegans and omnivores using the cross-sectional "Risks and Benefits of a Vegan Diet" study involving 36 vegans and 36 omnivores. Lower median plasma concentrations were found in vegans compared to omnivores for PFOS (2.31 vs. 3.57 ng/mL, respectively) and for PFNA (<0.25 vs. 0.41 ng/mL, respectively). No significant differences were observed for PFOA and PFHxS. Levels of low density lipoprotein (LDL) cholesterol were confirmed to be considerably lower in vegans compared to omnivores but no associations between the four main PFAS and LDL cholesterol were observed. Results indicate a vegan diet may be related to lower PFAS plasma levels.

**Do PFAS Aggravate the Occurrence of Obesity-Associated Glucolipid Metabolic Disease (GLMD)?**
H. Liu, W. Hu, X. Li…; *Environ. Res.* 2021

This paper summarizes the epidemiological and experimental studies on PFAS and obesity-related GLMD. Both obesity and PFAS exposure can cause disorders of glucose and lipid metabolism. Research indicates obesity is a key factor in the high incidence of PFAS-induced GLMD. PFAS are

aggravating the occurrence of diabetes, cardiovascular disease, and liver disease. Low-dose but sustained PFAS exposure may be more harmful than high-dose acute exposure.

**Prenatal Exposure to PFAS and Associations with Attention-Deficit/Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD) in Children.**
T.S. Skogheim, K.V.F. Weyde, H. Aase…; *Environ. Res.* 2021

The authors investigated whether prenatal exposure to PFAS was associated with childhood diagnosis of ADHD or ASD. This study was based on the Norwegian Mother, Father and Child Cohort Study and measured seven PFAS in maternal plasma sampled mid-pregnancy. Prenatal exposure to PFOA was associated with increased risk of ASD and ADHD in children. Observed inverse associations for some PFAS, and their mixtures with ASD and/or ADHD may be due to unresolved confounding factors. The epidemiologic literature linking PFAS exposures with neurodevelopmental outcomes is still inconclusive, suggesting more research is needed.

**PFAS Exposure and Kidney Damage: Causal Interpretation Using the US 2003–2018 National Health and Nutrition Examination Survey (NHANES) Datasets.**
J. Moon; *Environ. Pollut.* 2021

Using a causal interpretative study based on the U.S. 2003–2018 NHANES data sets, this study validates the hypothesis that increased serum concentrations of PFAS cause kidney damage. Three statistical models evaluated the relationship between the four PFAS and estimated glomerular filtration rate (eGFR). For each 1 ng/mL increase of PFOA, PFOS, PFHxS, or PFNA, eGFR decreased by 4.63, 3.42, 2.37, 2.87 mL/min-1.73 $m^2$, respectively.

**Prenatal and Childhood Exposure to PFAS and Child Executive Function and Behavioral Problems.**
M.H. Harris, E. Oken, S.L. Rifas-Shiman…; *Environ. Res.* 2021

This study examined associations of prenatal and childhood PFAS plasma concentrations with assessments of children's behavior problems and executive function abilities. PFAS concentrations in pregnant mothers and children were similar to concentrations in women and children in the U.S. NHANES. There were no consistent patterns of sexual dimorphism in associations. Results indicated cross-sectional associations of childhood PFAS concentrations with greater behavioral and executive function problems, but no consistent associations with prenatal PFAS.

**PFAS Exposure during Pregnancy and Adverse Pregnancy and Birth Outcomes: A Systematic Review and Meta-analysis.**
X. Gao, W. Ni, S. Zhu…; *Environ. Res.* 2021

The authors conducted a systematic review and meta-analysis to assess PFAS exposure during pregnancy on adverse pregnancy and birth outcomes. A total of 29 studies (32,905 participants) were included. Results indicated that PFOS, PFOA, and PFNA exposure during pregnancy might be associated with increased preterm birth risk and that PFAS exposure might be associated with the risk of miscarriage and pre-eclampsia. Due to the limited evidence obtained for most associations, additional

studies are required to confirm these findings.

**Associations between Exposure to PFAS and Body Fat Evaluated by Dual-Energy X-ray Absorptiometry (DXA) and Magnetic Resonance Imaging (MRI) in 109 Adolescent Boys.**
M.L. Thomsen, L.S. Henriksen, J. Tinggaard…; *Environ. Health*. 2021

This study investigated associations between PFAS exposure and body fat in a cross-sectional study of healthy boys. MRI and DXA were performed to evaluate various body fat levels. Serum was analyzed for five PFAS compounds. The authors found no consistent associations between PFAS exposure and body fat, which may be due to the cross-sectional study design.

**PFAS and Hormone Levels during the Menopausal Transition.**
S.D. Harlow, M.M. Hood, N. Ding…; *J. Clin. Endocrinol. Metab.* 2021

This study examined associations between serum PFAS concentrations at baseline and longitudinal serum concentrations of follicle-stimulating hormone (FSH), estradiol, testosterone, and sex hormone-binding globulin in midlife women 45 to 56 years of age. Results indicated positive associations of PFOA and PFOS with FSH and inverse associations of PFNA and PFOA with estradiol in midlife women during the menopausal transition, consistent with findings that PFAS affect reproductive aging.

**Exposure to PFCs and Cardiovascular Disease: Experimental and Epidemiological Evidence.**
A. Meneguzzi, C. Fava, M. Castelli…; *Front. Endocrinol.* 2021

This review compiled studies exploring the relationship between PFAS exposure and cardiovascular disease. An increase in PFAS-related cardiovascular disease or death has been reported in relation to early vascular lesions and atherosclerosis. Several studies indicate an alteration in lipid and glucose metabolism disorders and increased blood pressure as a possible link. PFAS may be incorporated into platelet cell membranes leading to increased risk of cardiovascular events by promoting thrombus formation. PFAS exposure has also been related to altered plasma membrane fluidity, altered calcium signal, and increased platelet response to agonists.

**Elevated Levels of PFAS in Breast Cancer Patients within the Greater Manila Area.**
M.C. Velarde, A.F.O Chan, M.E.J.V. Sajo…; *Chemosphere.* 2021

This study measured levels of 41 endocrine disrupting chemicals (EDCs) in women residing in the Greater Manila Area. Urine samples from women with and without breast cancer were analyzed for phthalate metabolites, environmental phenols, and bisphenols, while serum samples were analyzed for 12 PFAS. PFAS, specifically PFDoA, PFDA, and PFHxA, were significantly associated with breast cancer. The other EDC groups did not have significant correlations. Additionally, long-chain PFAS were positively correlated with age and were significantly higher in a heavily industrialized region than from the National Capital Region. Not only do these results provide a baseline for EDC levels in Filipinas, but also highlight how different they can be according to location.

**Placental Transfer and Composition of PFAS: A Korean Birth Panel of Parent-Infant Triads.**
H. Kang, H.S. Kim, Y.S. Yoon…; *Toxics.* 2021

This study measured PFAS in maternal, paternal, and umbilical cord serum collected from pregnant women and biological fathers of the fetuses, as well as placental transfer rates of PFAS. PFOS and PFOA showed the highest concentration in maternal and paternal serum, and cord serum, respectively. There was a higher proportion of 9–12 carbon PFCAs than those with 13–14 carbon chains in maternal and paternal serum, but this proportion was in the opposite direction in cord serum. PFOA and PFHxS had higher placental transfer rates than PFOS. Gestational age and birth weight were positively associated with placental transfer rate of PFOA, PFHxS, and PFOS, while pre-pregnant body mass index and weight were inversely associated with PFOS.

**Associations of Single and Multiple PFAS Exposure with Vitamin D Biomarkers in African American Women during Pregnancy.**
C.J. Chang, D.B. Barr, Q. Zhang…; *Environ. Res.* 2021

This study aims to evaluate the associations of serum PFAS with serum 25-hydroxyvitamin D (25(OH)D) during early and late pregnancy. Generally positive associations of total 25(OH)D with PFHxS, PFOS, PFDA, and N-methyl perfluorooctane sulfonamido acetic acid (NMeFOSAA) were found, and negative associations with PFPeA. For free 25(OH)D, positive associations were observed with PFHxS, PFOS, PFOA, and PFDA, and a negative association with PFPeA among the women with male fetuses in late pregnancy. In mixture models, NMeFOSAA, PFDA, and PFOS contributed the most to the overall effects among the PFAS. The authors suggest that PFAS may affect vitamin D biomarker concentrations in pregnant African American women, possibly modified by fetal sex.

**Maternal PFAS, Thyroid Hormones, and *DIO* Genes: A Spanish Cross-sectional Study.**
B. Sarzo, V. Ballesteros, C. Iñiguez…; *Environ. Sci. Technol.* 2021

To characterize the underlying mechanism of action of PFAS on THs, this study examined the relationship between maternal PFAS and thyroid hormone levels and the role played by polymorphisms in the iodothyronine deiodinase 1 (*DIO*1) and 2 (*DIO*2) genes. The sample included 919 pregnant Spanish women. Multivariate regression analyses between PFAS and thyroid hormones indicated PFHxS was associated with an increase in thyroid-stimulating hormones and PFOA and PFNA were associated with a decrease in total triiodothyronine (TT3). No clear modification by *DIO* enzyme genes was observed.

**Effect of PFCs on the Occurrence of Urge Urinary Incontinence: A Population-Based Study.**
S. Cui, X. Zhao, X. Chu…; *Therapeut. Adv. Urol.* 2021

Because PFCs are excreted mainly through passing urine, studies have suggested that PFCs are associated with nephrotoxicity, which may affect urodynamics. This study investigated the relationship between PFCs and the occurrence of urge urinary incontinence (UUI) in females from the U.S.

Using data from the NHANES survey, a logistic regression model examined the relationship between UUI and eight PFCs. The models found total PFCs, PFHxS, N-MeFOSAA, and PFNA were positively correlated with the risk of UUI. Results could apply to developing individualized treatment for female patients suffering UUI.

## *Miscellaneous*

**Hair Determination of PFAS in the Italian Population.**
E. Piva, A. Giorgetti, P. Ioime...; *Toxicology.* 2021

Because PFAS are persistent organic pollutants, there was interest in determining PFAS concentration in hair and how they may differ between populations from five different regions in Italy. Of the 86 total subjects, 66.4% had detectable concentratons of PFAS. PFOA and PFOS were the most commonly detected, whereas PFUnDA and PFHxS were not detected. Though no significant differences were found between genders or ages, differences in presence and prevalence of PFAS were noted, thereby, supporting the use of hair as a matrix for diagnostic assessments.

**Lactic Acid Bacteria Alleviate Liver Damage Caused by PFOA Exposure via Antioxidant Capacity, Biosorption Capacity and Gut Microbiota Regulation.**
L. Shi, R. Pan, G. Lin...; *Ecotoxicol. Environ. Safe.* 2021

The potential of lactic acid bacteria (LAB) as a dietary supplement to alleviate effects of PFOA exposure was investigated. Multiple strains of LAB that differ in adsorption or antioxidant capacities were tested for their ability to reduce PFOA-induced liver damage. Not only were results suggestive of mitigation, but also certain strains were able to recover gut microbiota dysbiosis and adjust short-chain fatty acid content. Therefore, LAB may serve as a safe dietary supplement to reduce liver damage caused by PFOA exposure.

*Notes: PFAS Alerts is based on reviews of literature identified from Google Scholar and PubMed searches, and the following publications: Inside EPA, LAW360, Bloomberg BNA, CCNJ, and ChemInfo. This issue includes a subset of articles selected by Integral. Abbreviated abstracts are based on information presented by the authors. More detailed reviews in the Special Highlights are prepared by Integral based on the information available online. Integral has not verified the accuracy of information posted online.*

## Acronyms and Abbreviations

AFFF = aqueous film-forming foam
Cl-PFAES = chlorinated polyfluoroalkyl ether sulfonate
DWQI = Drinking Water Quality Institute (NJ)
F-53B = 6:2 Cl-PFAES
FT = fluorotelomer
FTAA = fluorotelomer sulfonamide alkylamine
FTAB = fluorotelomer sulfonamide alkylbetaine
FTAC = fluorotelemer acrylate
FTCA = fluorotelomer carboxylic acid
FTI = fluorotelemer iodide
FTMAC = fluorotelemer methacrylate
FTO = fluorotelemer olefin
FTOH = fluorotelomer alcohol
FTS = fluorotelomer sulfonate
FTSA = fluorotelemer sulfonamide
FTUCA = fluorotelomer unsaturated carboxylic acid
GAC = granular activated carbon
GenX = 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propionic acid
PFAA = perfluoroalkyl acid
PFAI = perfluoroalkyl iodide
PFAS = per- and poly-fluorinated alkyl substance
PFBA = perfluorobutanoic acid (C4)
PFBS = perfluorobutane sulfonate (C4)
PFC = perfluorinated compound
PFCA = perfluoroalkyl carboxylate
PFDA and PFDeA = perfluorodecanoic acid (C10)
PFDoDA = perfluorododecanoic acid (C12)
PFECA = perfluoroalkyl ether carboxylic acid
PFHpA = perfluoroheptanoic acid (C7)
PFHxA = perfluorohexanoic acid (C6)
PFHxS = perfluorohexane sulfonate (C6)
PFNA = perfluorononanoic acid (C9)
PFOA = perfluorooctanoic acid (C8)
PFOS = perfluorooctane sulfonate (C8)
PFPeA = pefluroopentanoic acid (C5)
PFSA = perfluorinated sulfonate
PFTeDA = perfluorotetradecanoic acid
PFTrDA = perfluorotridecanoic acid (C13)
PFUA and PFUnDA = perfluoroundecanoic acid (C11)
ppb = parts per billion = µg/l or ng/g
ppm = parts per million = mg/l or µg/g
ppt = parts per trillion = ng/l or pg/g
USEPA = U.S. Environmental Protection Agency
WWTP = wastewater treatment plant

## Questions?
## Don't hesitate to reach out to our Experts


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