**What’s in the Water Lesson 2: Emerging Contaminants**

# **Background Information and References for Instructions**

## **Introduction to Emerging Contaminants**

### **Overview**

Chemicals previously undetected or found in miniscule concentrations are classified as “contaminants of emerging concern” or “**emerging contaminants**”. The environmental and health effects of these contaminants are not fully understood. The primary sources of emerging contaminants are (1) personal care products, such as soaps and fragrances, (2) pharmaceuticals, such as oral drugs like ibuprofen, and (3) natural and man-made **endocrine disruptors**, such as Bisphenol A (BSP), **Perfluoroalkyl and Polyfluoroalkyl substances (PFAS)**, and Polychlorinated biphenyls (PCB) ([Water Quality Association](https://wqa.org/whats-in-your-water/emerging-contaminants)). Endocrine disruptors, also known as endocrine disrupting compounds (EDCs) fall under multiple source categories, including industrial, agricultural, pharmaceuticals, and personal care products ([National Institute of Environmental Health Sciences](https://www.niehs.nih.gov/health/topics/agents/endocrine/index.cfm)). Research on emerging contaminants is fairly new. Prior to 1990, most did not recognize the potential harmful effects of such chemicals, adhering to the old mantra “dilution is the solution to pollution’. Recently, environmental and human health researchers have documented numerous, sometime serious, impacts of these chemicals ([USGS](https://www.usgs.gov/mission-areas/water-resources/science/emerging-contaminants?qt-science_center_objects=0#qt-science_center_objects)). The figures below may be helpful for summarizing the source and pathways of these chemicals for students.

For a helpful images, refer to Figure 1.1 from [Day et al (2019)](https://www.sciencedirect.com/science/article/pii/B9780128161890000019) and Figure 1 from [Gogoi et al (2018).](https://www.sciencedirect.com/science/article/pii/S2352801X17302217#preview-section-figures)

### **Emerging contaminants enter the environment through various pathways**

Pharmaceutical products enter the environment via a few key pathways: unintentionally through human excretion, intentionally through flushing unwanted/expired medications, and in the design and production of medications into wastewater. Broadly, personal care products enter the natural environment through showering, handwashing, cleaning, laundry, etc. ([Stefanikis 2015](https://www.researchgate.net/publication/316889371_Pharmaceuticals_and_Personal_Care_Products_as_Emerging_Water_Contaminants)). Due to the diversity of endocrine disrupting compounds, there are a multitude to pathways that are largely determined based on their intended use. For example, compounds like DDT and other pesticides enter waterways through agriculture runoff. Perfluoroalkyl and Polyfluoroalkyl substances (e.g. PFAS) are commonly used in various industries (e.g. firefighting foams, nonstick pans, and textile coatings) ([NIEHS](https://www.niehs.nih.gov/health/topics/agents/endocrine/index.cfm)).

### **Sample of human health effects from emerging contaminants**

***Personal Care Products and Pharmaceuticals:*** While the research in this area is new and ongoing, current studies suggest that the levels of exposure in drinking water is not likely to have an adverse health effect in humans. Of great concern, however, is the impact that low-level exposure over time and the potential mixture of pharmaceutical and/or personal care products on our health is unknown. There is also the potential for vulnerable populations (e.g. pregnant women, people with disabilities) to experience exasperated or other adverse effects that do not negatively impact the general population.

***Endocrine-Disrupting Compounds (EDCs):*** The human endocrine system regulates the secretion of hormones throughout the body. Hormones control a wide variety of functions, including growth and development, reproduction, balance and maintenance of fluids, and the use and storage of energy. Health effects due to exposure to EDCs vary significantly based on the specific chemical(s) in question, their potential for toxicity, and the concentrations in the drinking water supply Some general health concerns linked to EDCs include:

* Reproductive issues (including fertility concerns)
* Cancers
* Thyroid disfunctions
* Obesity and other metabolic issues
* Neurological/Neurodevelopment issues

### **Transport of emerging contaminants in the environment**

Once products containing emerging contaminants leave the manufacturing plant, they may take complex routes into the environment (e.g. through human excrement, drainage systems, dumping, etc.). Once in the aquatic environment, they can attach (“sorption)” to microplastics, sediment, and other particular materials, and **bioaccumulate** in living organisms. ([Wilkinson et al 2017](https://reader.elsevier.com/reader/sd/pii/S0269749116327257?token=6F4388CDA3A82098CFB6DA018647295A95B6D60129F954F5062F44AFA82E9A164EA5B731E844DC56C08F9433FEE7B7E1)). The figure below from USGS shows the various transport pathways and fates of contaminants. The specific biological, chemical, and hydrological processes utilized during chemical transport play a significant role in the level of **toxicity** of a given contaminant.

For a helpful image, refer to the figure found at [USGS: Environmental Health – Toxic Substances](https://toxics.usgs.gov/regional/emc/transport_fate.html)

### **Sample of environmental effects:**

The table from [Gogoi et al (2018)](https://www.sciencedirect.com/science/article/pii/S2352801X17302217#preview-section-figures) shows a sample of emerging contaminants and their adverse effects.

**Background Information on PFAS**

### **What is PFAS?**

**Perfluoroalkyl and Polyfluoroalkyl substances (PFAS**) are a large and complex group of man-made chemicals. The acronym “PFAS” actually represents a family of over 4500 different chemicals. They are found in hundreds of industrial and household products. PFAS chemicals are extremely robust. It is unknown how long they can remain in the environment, and they can take years to leave the human body. This problem is exacerbated by bioaccumulation, which means the concentration of these chemicals can build over time as the person or environment’s exposure continues at a rate higher than that of excretion. In other words, once it gets into a system, it can be very difficult to eliminate it.

Chemically speaking, PFAS chemicals are negatively charged, water soluble compounds composed of a **hydrophobic** tail made of carbon and fluorine and a **hydrophilic** functional group which can vary in structure, but will include oxygen and hydrogen (see figure at [NIEH](https://www.niehs.nih.gov/health/topics/agents/pfc/index.cfm) for details). The number of carbons and the length of the chain directly correlates with the level of **sorption**, or how well the it attaches to other molecules. PFAS chemicals can bind to organic carbon and ionic soils. The degree to which the PFAS chemical and move within and between system, as well as how long those chemicals remain intact before degrading, is largely dependent on the chemical makeup of the specific PFAS chemical. Research investigations on PFAS chemicals is limited due to the sheer number of PFAS chemicals that exist, plus complex variables related to transport, the ways in which these chemicals can interact with other chemicals in the environment, the rate at which these chemicals biodegrade over time (if at all), and many other complex factors. Research on the health impacts of PFAS exposure is ongoing, but complicated. Information from the Agency for Toxic Substances and Disease Registry, a branch of the CDC, provides an [overview](https://www.atsdr.cdc.gov/pfas/index.html). Many research labs around the world have also contributed, included several local research labs ([NC State](https://chhe.research.ncsu.edu/coec/projects/genx/), [Duke](https://sites.nicholas.duke.edu/stapletonlab/research/pfas-research/pfas-exposure-nc/), the [NC PFAS Network](https://ncpfastnetwork.com/)).

### **Where does it come from?**

PFAS chemicals are excellent **surfactants**, which can be used as detergents, wetting agents, emulsifiers, foaming agents, or dispersants. Primary sources of PFAS include:

* Household products: nonstick pans, popcorn bags and other food packages, waterproofing/stain resistant solutions for furniture, clothing, etc.
* Manufacturing sources: textile industry, fire-fighting products (e.g. Aqueous Film Forming Foam (AFFF), medical, aerospace, automotive applications, etc.
* Landfill **leachate**
* **Wastewater Treatment Facilities/Plants (WWTFs or WWTPs)**, including inputs from humans, industries, and surface water

Once produced, PFAS chemicals are found in the air, surface soils and sediment, surface and ground waters, and living organisms. The figure from page 8 of the American Water Works Association [publication](https://www.awwa.org/Portals/0/AWWA/ETS/Resources/15683PFAS_web.pdf) illustrates the general “life cycle” of PFAS through the environment.

### **Federal Regulation of Emerging Contaminants**

Copied verbatim from the [EPA](https://www.epa.gov/pfas/pfas-laws-and-regulations): “There are currently no MCLs established for PFAS chemicals. EPA initiated the steps to evaluate the need for an MCL for PFOA and PFOS under the [regulatory determination process](https://www.epa.gov/ccl/basic-information-ccl-and-regulatory-determination). However, EPA has issued a [health advisory for PFOA and PFOS](https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos). Health advisories describe non-regulatory concentrations of drinking water contaminants at or below which adverse health effects are not anticipated to occur over specific exposure durations. They serve as informal technical guidance to assist federal, state and local officials, and water system managers by providing information on the health effects of and methods to sample and treat PFOA and PFOS in drinking water. In addition, EPA is developing and updating toxicity values for two additional PFAS, GenX and PFBS. EPA anticipates providing these toxicity assessments for public comment Summer 2018.”

NOTE: The health advisory level for PFOA and PFOS, referenced above, is 70 parts per trillion: <https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos>.

Relevant news from EPA (full list [here](https://www.epa.gov/pfas/epa-actions-address-pfas)):

* Fall 2020: EPA released interim guidance on techniques that can be used to destroy/dispose of PFAS and PFAS-containing materials from non-consumer products.

### **Sample state-level regulation and recent news**

(Source + MANY more examples: [ncsl.org](https://www.ncsl.org/research/environment-and-natural-resources/per-and-polyfluoroalkyl-substances-pfas-state-laws.aspx#:~:text=States%20that%20have%20adopted%20or,in%20public%20drinking%20water%20systems.))

* California: Key PFAS Regulatory Standards Set in California, June 16, 2020. <https://www.fbm.com/publications/key-pfas-regulatory-standards-set-in-california/>
  + San Francisco Bay Regional Water Quality Control Board released final Environmental Screening Levels (ESLs) for PFOS and PFOA
* Michigan: Michigan adopts strict PFAS in drinking water standards, July 22, 2020. <https://www.michigan.gov/som/0,4669,7-192-47796-534660--,00.html>
  + Michigan’s Department of Environment, Great Lakes, and Energy adopted rules to create comprehensive regulations to limit PFAS contamination in drinking water. 7 specific PFAS chemicals have limits set. For example, limits for PFOS is 16 ppt, limits for PFHxA is 400,000 ppt, and limits for PFOA is 8 ppt
* New York: NYS adopts drinking water standards for thee emerging contaminants. July 31, 2020. <https://news.wbfo.org/post/nys-adopts-drinking-water-standards-three-emerging-contaminants>
  + New York State’s Public Health and Health Planning Council’s Committee on Codes, Regulations and Legislation adopted a maximum containment level (MCL) of 12 parts per trillion (ppt) each for PFOA and PFOS

## **General Information on Urban Water Treatment**

The **Urban Water Cycle (UWC)** is comprised of several components that obtain, clean, filter, distribute, and dispose of water. They include one or more natural water bodies, water treatment facilities, water supply system, drinking water delivery and distribution systems, drainage system, wastewater collection and treatment systems. See Figure 1 from [Sun et al (2020)](https://www.researchgate.net/publication/339000263_Real-Time_Control_of_Urban_Water_Cycle_under_Cyber-_Physical_Systems_Framework) below, and the graphical abstract from [Pal et al (2014)](https://www.sciencedirect.com/science/article/pii/S0160412014001767), for graphical illustrations. For a fun visual for students refer to the image at [https://www.neorsd.org](https://www.neorsd.org/wordpress/wp-content/themes/domag/pdf/urban-water-cycle.jpg)

## **Glossary of Important Terms and Acronyms**

(NOTE: definitions are paraphrased from open-source reference material (Oxford Languages, Wikipedia, etc.))

**Bioaccumulation - the gradual accumulation of substances, such as pesticides or other chemicals, in an organism**

**Endocrine disruptor or endocrine disrupting compound (EDCs)** - chemicals that can interfere with endocrine (or hormonal) systems

**Emerging contaminant** - pollutants that have been detected in water bodies, that may cause ecological or human health impacts, and typically are not regulated under current environmental laws

**Hydrophilic** - tending to mix with, dissolve in, or be wetted by water

**Hydrophobic** - tending to repel or fail to mix with water

**Leachate** – water that has percolated through matter and leached out some of the constituent of that matter

**Maximum containment level (MCL)** - standards that are set by the United States Environmental Protection Agency (EPA) for drinking water quality. An MCL is the legal threshold limit on the amount of a substance that is allowed in public water systems under the Safe Drinking Water Act (SDWA).

**Polyfluoroalkyl substances (PFAS)** - a family of human-made chemicals that are found in a wide range of products used by consumers and industry.

**Sorption** - the degree to which a substance attaches to and/or enters another material

**Surfactant** - a substance which tends to reduce the surface tension of a liquid in which it is dissolved

**Toxicity** - the degree to which a chemical substance or a particular mixture of substances can damage an organism

**Urban Water Cycle (UWC)** - 'man made' systems created to provide drinking water to homes and businesses, to remove wastewater and sewage, and redirect stormwater away from homes and businesses and into our waterways.

**Wastewater treatment plant (WWTP)** - a facility in which a combination of various processes (e.g., physical, chemical and biological) are used to treat industrial wastewater and remove pollutants

## References

USGS, Emerging Contaminants. <https://www.usgs.gov/mission-areas/water-resources/science/emerging-contaminants?qt-science_center_objects=0#qt-science_center_objects>

[Becker, Julie & Stefanakis, Alexandros. (2015). Pharmaceuticals and Personal Care Products as Emerging Water Contaminants. 10.4018/978-1-5225-1762-7.ch055.](https://www.researchgate.net/publication/316889371_Pharmaceuticals_and_Personal_Care_Products_as_Emerging_Water_Contaminants)

[Saptarshi Dey, Farhat Bano, Anushree Malik, 1- Pharmaceuticals and personal care product (PPCP) contamination—a global discharge inventory. Editor(s): Majeti Narasimha Vara Prasad, Meththika Vithanage, Atya Kapley, Pharmaceuticals and Personal Care Products: Waste Management and Treatment Technology, Butterworth-Heinemann, 2019, Pages 1-26.](https://www.sciencedirect.com/science/article/pii/B9780128161890000019)

Water Quality Association: <https://wqa.org/whats-in-your-water/emerging-contaminants>

Center for Disease Control (CDC):

* <https://www.cdc.gov/biomonitoring/PFAS_FactSheet.html>
* <https://www.atsdr.cdc.gov/pfas/index.html>

Environmental Protection Agency:

* PFAS Laws and Regulations: <https://www.epa.gov/pfas/pfas-laws-and-regulations>
* PFAS Action Plan: <https://www.epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf#page=61>
* Health Advisory Limits: <https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos>

National Institute of Environmental Health Sciences:

* <https://www.niehs.nih.gov/health/topics/agents/pfc/index.cfm>
* <https://www.niehs.nih.gov/health/materials/endocrine_disruptors_508.pdf>
* <https://www.niehs.nih.gov/health/topics/agents/endocrine/index.cfm> (this link has great podcasts, readings, and other resources that are accessible to students)

[Anindita Gogoi, Payal Mazumder, Vinay Kumar Tyagi, G.G. Tushara Chaminda, Alicia Kyoungjin An, Manish Kumar. 2018. Occurrence and fate of emerging contaminants in water environment: A review. Groundwater for Sustainable Development. 6, 169-180](https://www.sciencedirect.com/science/article/pii/S2352801X17302217#preview-section-figures)

[Amrita Pal, Yiliang He, Martin Jekel, Martin Reinhard, Karina Yew-Hoong Gin. 2014. Emerging contaminants of public health significance as water quality indicator compounds in the urban water cycle. Environment International. 71, 46-62.](https://www.sciencedirect.com/science/article/pii/S0160412014001767)

[Congcong, Sun & Puig, Vicenç & Cembrano, Gabriela. (2020). Real-Time Control of Urban Water Cycle under Cyber- Physical Systems Framework. Water. 12. 406. 10.3390/w12020406.](https://www.researchgate.net/publication/339000263_Real-Time_Control_of_Urban_Water_Cycle_under_Cyber-_Physical_Systems_Framework)

[John Wilkinson, Peter S. Hooda, James Barker, Stephen Barton, Julian Swinden, Occurrence, fate and transformation of emerging contaminants in water: An overarching review of the field, Environmental Pollution. 231(1), 954-970.](https://www.sciencedirect.com/science/article/pii/S0269749116327257)

Dune, Allison. “NYS adopts drinking water standards for thee emerging contaminants”. July 31, 2020. <https://news.wbfo.org/post/nys-adopts-drinking-water-standards-three-emerging-contaminants>

PFAS Research at NC State: <https://chhe.research.ncsu.edu/coec/projects/genx/>

PFAS Research at Duke: <https://sites.nicholas.duke.edu/stapletonlab/research/pfas-research/>

North Carolina PFAS Network: <https://ncpfastnetwork.com/>

Northeast Ohio Regional Sewer District. Urban water cycle. <https://www.neorsd.org/wordpress/wp-content/themes/domag/pdf/urban-water-cycle.jpg>

National Conference of State Legislatures: <https://www.ncsl.org/research/environment-and-natural-resources/per-and-polyfluoroalkyl-substances-pfas-state-laws.aspx#:~:text=States%20that%20have%20adopted%20or,in%20public%20drinking%20water%20systems>.