

Are the Herbicides That We Use in Aquatic Systems Considered PFAS?¹

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Introduction

In the environmental science community, there has been increasing concern and emphasis on a relatively new designation of molecules called per- and polyfluoroalkyl substances, also known as PFAS. These compounds are colloquially referred to as “forever chemicals” due to their potential persistence in the environment. PFAS constitutes a group of synthetic compounds characterized by the presence of specific fluorinated groups (Buck et al. 2011; Panieri et al. 2022). These molecules are widely used in various consumer products and industrial applications because of their unique properties, which include oil, water, heat, and friction resistance. Because of their widespread use, PFAS are nearly ubiquitous in our environment, posing questions about their potential persistence, environmental toxicity, bioaccumulation, and health effects (Abunada et al. 2020). Unfortunately, some of these molecules can persist in the environment for decades, and their collective impact on our ecosystems is generally unknown (World Health Organization 2022). Not all PFAS are the same, and they differ in their persistence and toxicity; as a result, we are still trying to understand how many of these molecules impact our environment. Recent concerns have arisen regarding aquatic herbicides and whether they are classified as PFAS. Given that some aquatic herbicides contain fluorine in their chemical structure and are used in Florida’s river and lake ecosystems, it is important to understand how aquatic herbicides fit the varying definitions of PFAS. The purpose of this publication is to provide information on aquatic herbicides and their classification as PFAS, enabling all stakeholders involved with aquatic environments to gain a

deeper understanding of the herbicides used in their water bodies.

What Molecules Are Considered PFAS?

While PFAS all contain fluorine atoms, there are several currently accepted definitions for what constitutes a PFAS, ranging from very broad to quite specific (Buck et al. 2011). For example, the Environmental Protection Agency (EPA) definition is very strict and states that a PFAS is a chemical substance that must contain at least one of three specific structures (Butler 2024) (Figure 1). However, organizations such as the Organisation for Economic Co-operation and Development (OECD) have a broader definition, stating that PFAS includes any molecule that contains one or more fully fluorinated carbon atoms (Schymanski et al. 2023) (Figure 2). Likewise, the Interstate Technology & Regulatory Council (ITRC) has its own definitions, which include separate definitions for polymer and non-polymer PFAS. They also separate perfluoroalkyl substances, which are molecules with a fully fluorinated carbon chain, and polyfluoroalkyl substances, which are molecules that do not have a fully fluorinated carbon chain (ITRC 2023). While these distinctions in definition may seem minor, the difference results in 4,700 molecules classified as PFAS versus over 7,000,000 molecules (Panieri et al. 2022; Schymanski et al. 2023). To state it simply, there is currently no agreement on how to define PFAS or how to classify over 7,000,000 molecules, because there is no general consensus on the definition.

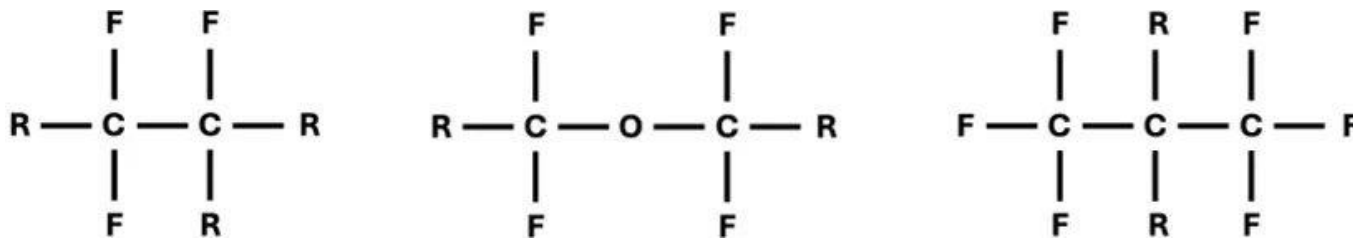


Figure 1. The chemical structures required for a molecule to be a PFAS according to the EPA definition. Depending on the structure, “R” can either be a fluorine, oxygen, or a saturated carbon.

Credit: Eli Russell, UF/IFAS.

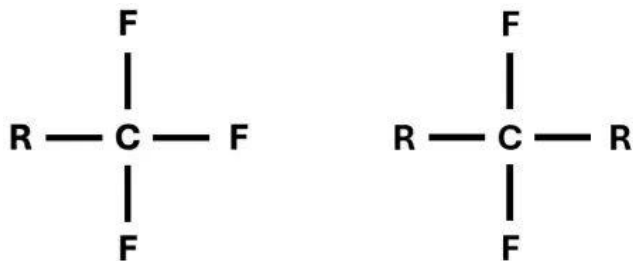


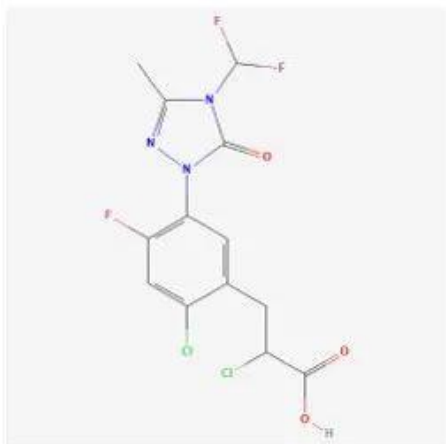
Figure 2. The chemical structures required for a molecule to be considered a PFAS according to the OECD definition.

Credit: Eli Russell, UF/IFAS.

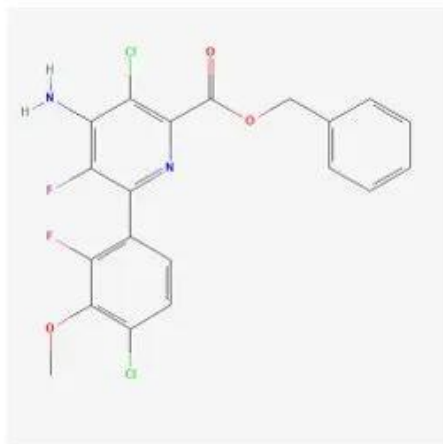
Are Aquatic Herbicides PFAS?

There are currently 15 herbicidal active ingredients that are labeled for use in Florida’s aquatic environments (Table 1). Of those 15 molecules, only five contain fluorine, with those being carfentrazone, florpyrauxifen-benzyl, flumioxazin, fluridone, and penoxsulam (Figure 3) (Shaner 2014). While they all contain fluorine atom(s), they do not meet the EPA definition of a PFAS. However, under the expanded and revised definition used by OECD, two of these herbicides (i.e., fluridone and penoxsulam) meet that definition of a PFAS (Figure 3).

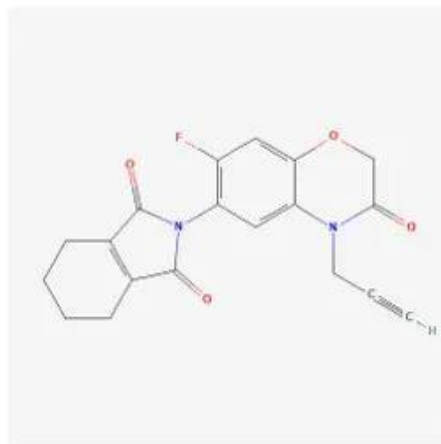
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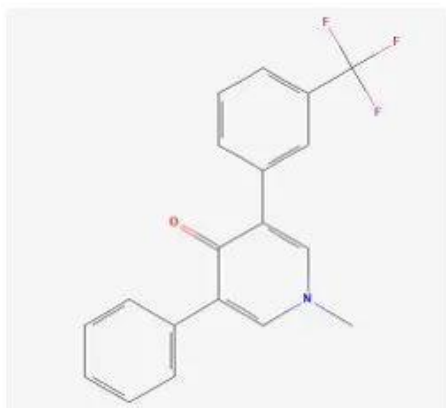
B.



C.



D.



E.

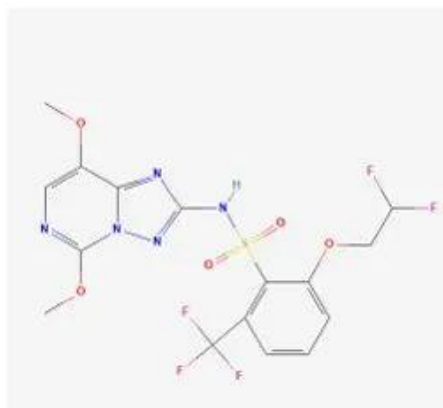


Figure 3. Herbicides containing fluorine: (A) carfentrazone, (B) florypyrauxifen-benzyl, (C) flumioxazin, (D) fluridone, and (E) penoxsulam. Only fluridone and penoxsulam meet the OECD definition of PFAS.

Credit: (A) 2D structure image of CID 443229 (carfentrazone): PubChem Identifier: CID 443229. URL:

<https://pubchem.ncbi.nlm.nih.gov/compound/443229#section=2D-Structure>. (B) 2D structure image of CID 70495450 (florpyrauxifen-benzyl):

PubChem Identifier: CID 70495450. URL: <https://pubchem.ncbi.nlm.nih.gov/compound/70495450#section=2D-Structure>. (C) 2D structure image of

CID 92425 (flumioxazin): PubChem Identifier: CID 92425. URL: <https://pubchem.ncbi.nlm.nih.gov/compound/92425#section=2D-Structure>. (D) 2D

structure image of CID 43079 (fluridone): PubChem Identifier: CID 43079. URL: <https://pubchem.ncbi.nlm.nih.gov/compound/43079#section=2D-Structure>. (E) 2D structure image of CID 11784975 (penoxsulam): PubChem Identifier: CID 11784975. URL:

<https://pubchem.ncbi.nlm.nih.gov/compound/11784975#section=2D-Structure>.

What Do We Know about Our Herbicides?

While it is important to have consistency in definitions and know if these herbicides should be considered PFAS, we also need to provide context for these molecules. While many PFAS molecules can persist in the environment for decades, and their impact on the environment is largely unknown, this is not the case for herbicides. Herbicides

undergo a stringent review with the EPA to be registered for use, and they must undergo reregistration every 15 years to ensure that no new information on their toxicity has emerged. The EPA evaluates numerous factors, including general toxicity, environmental persistence, and potential human exposure and risk. Herbicides are also evaluated for their direct and indirect effects on endangered species, toxicity to bees, animals, and fish, as well as their potential for people to be exposed to

residues (Table 2). As a result, we have very detailed information on how long each herbicide persists in the environment, and we understand the potential for herbicide exposure to humans and impacts on wildlife. In general, the longer the fluorinated carbon chain, the more persistent and toxic the PFAS compound (Evich et al. 2022). For example, both PFOA (perfluorooctanoic acid) and PFOS (perfluorooctane sulfonate), which are well-documented and regulated PFAS, have eight carbon chains and have a half-life ranging from 1.48 to 5.7 years (Table 3). However, all of our herbicides have a single fluorinated carbon, which means that they break down in the environment more easily (Table 3).

Conclusion

Molecules are called PFAS because they have fluorine/carbon bonds. While some have shown to persist for long periods in the environment, this is not a universal trait of all fluorine/carbon molecules. Thus, although some PFAS molecules are called “forever chemicals,” not all have those characteristics. Meanwhile, decades of data have been collected regarding the potential toxicity and environmental persistence for the herbicides (PFAS or not) that are used in aquatic systems. Even though some aquatic herbicides meet the OECD definition of a PFAS, current data indicate that they rapidly break down and have low toxicity to animals.

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Table 1. Herbicides labeled for aquatic environments in Florida and if they contain fluorine in their chemical structure.

Herbicide	Number of Fluorine Atoms	Herbicide	Number of Fluorine Atoms
Bispyribac	0	Imazamox	0
Carfentrazone	3	Imazapyr	0
Diquat	0	Penoxsulam	5
Endothall	0	Sethoxydim	0
Florpyrauxifen-benzyl	2	Topramezone	0
Flumioxazin	1	Triclopyr	0
Fluridone	3	2,4-D	0
Glyphosate	0		

Table 2. Application rate in parts per billion and milligrams per liter of water for fluridone and penoxsulam compared to the herbicide concentration necessary to kill 50% of the population (EC₅₀ and LC₅₀) for select invertebrates and fish.

Herbicide	Max Application Rate	Max Application Rate as Milligrams per Liter (mg/L)	Toxicity EC ₅₀ 48-Hour Exposure: Daphnia (mg/L)	Toxicity LC ₅₀ 96-Hour Exposure: Bluegill (mg/L)	Toxicity LC ₅₀ 96-Hour Exposure: Trout (mg/L)
Fluridone	90 ppb ponds 150 ppb lakes	0.09 in ponds 0.15 in lakes	6.3	14.3	11.7
Penoxsulam	150 ppb	0.15	>98.30	>103	>102

Table 3. Half-life and LD₅₀ for herbicides that are considered PFAS by OECD (fluridone and penoxsulam) and two PFAS molecules that are currently regulated by the EPA (perfluorooctanoic acid [PFOA] and perfluorooctane sulfonate [PFOS]).

Herbicide	Half-Life	Oral LD ₅₀ : Rat
Fluridone	~20 days in aerobic pond water ~90 days in hydrosol	>10,000 mg/kg
Penoxsulam	5–16 days	>5,000 mg/kg
Regulated PFAS	Half-Life	Oral LD ₅₀ : Rat
Perfluorooctanoic acid (PFOA)	92 years in water* 1.48–5.1 years in humans**	>500 mg/kg***
Perfluorooctane sulfonate (PFOS)	41 years in water* 3.4–5.7 years in humans	233 mg/kg***
*World Health Organization (2022). **Rosato et al. (2024). ***Chengelis et al. (2009).		

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All chemicals should be used in accordance with directions on the manufacturer's label.

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