Biosolids and Per- and Polyfluoroalkyl Substances (PFAS)

1 Introduction

This fact sheet summarizes the emerging technical information about risk and management of biosolids (https://www.epa.gov/biosolids) impacted by PFAS. The information in this fact sheet is based on the content of the Guidance Document (section numbers are included in the text of this fact sheet) and includes a discussion of significant topics where the management and use of PFAS-containing biosolids may distribute PFAS into the environment.

PFAS from a host of sources may be conveyed through and aggregated in wastewater treatment plant (WWTP) sludges, creating secondary release sources in areas where biosolids are produced, applied, and disposed. The relative significance of these releases varies based on the PFAS composition, release mechanism(s) (for example, application rates, frequency, and duration for land-applied biosolids), and environmental controls employed throughout this life cycle. See Sections 2.1 and 2.6.4 for further information.

The composition of PFAS in biosolids is a function of the different sources to the WWTP influent and the WWTP processes (Chen, Lo, and Lee 2012; Oliaei, Kriens, and Kessler 2006; Frömel et al. 2016; Schultz et al. 2006). More significant impacts are associated with industrial wastewater discharges. PFAS are not known to be added to biosolids during processing or application.

ITRC has developed a series of fact sheets that summarizes recent science and emerging technologies regarding PFAS. The information in this and other PFAS fact sheets is more fully described in the ***ITRC PFAS Technical and Regulatory Guidance Document (Guidance Document)*** (*https://pfas-1.itrcweb.org/*).

This fact sheet describes issues associated with PFAS-containing biosolids, including:

- Releases to the environment from management approaches
- Mobility, leaching, and transport
- Occurrence
- Sampling and analysis
- Treatment
- Regulations and guidance

Exposure to PFAS-containing biosolids may occur during the (1) biosolids production process, (2) management of PFAS-containing biosolids, (3) use of, or contact with, commercial and consumer products containing PFAS-containing biosolids, or (4) exposure (human or ecological) to environmental media that have been impacted by PFAS-containing biosolids, such as soil, groundwater, and plants and biota. The relative significance of these exposures will also vary widely.

2 Releases to the Environment from Management Approaches

PFAS releases to the environment have been associated with management of biosolids through land application or through use or disposal at landfills. Some PFAS-contaminated solids are or have been managed through incineration, although as further described in Section 12.4, incineration is a topic of current study to better understand the fate of PFAS due to possible incomplete combustion and byproduct generation (USEPA 2020 Ref#1919).

LAND APPLICATION

PFAS, such as perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkane sulfonic acids (PFSAs) (see Section 2.2.3.1), have been found in domestic sewage sludge (Higgins et al. 2005; Yoo et al. 2009) (see below and Section 6), and about 43% of the sewage sludge produced in the United States is applied to agricultural land as biosolids (USEPA 2023 Ref#2347). Therefore, the use of biosolids as a soil amendment might introduce PFAS to the environment through the land application, potentially allowing PFAS to enter surface water through runoff or to infiltrate to groundwater (Lindstrom et al. 2011 Ref#306). The effects on surface water or groundwater depend on the amount and composition of PFAS present in biosolids, soil properties, infiltration rate, land application practices, land use, precipitation, climate, and land slope. PFAS concentrations can be elevated in surface water and groundwater in the vicinity of agricultural fields that received PFAS-contaminated biosolids from industrial discharges over an extended period of time (Washington et al. 2010). Other studies indicate that the potential PFAS releases from municipal biosolids generated from WWTPs that do not receive PFAS-related industrial discharges may present a much lower risk to groundwater quality depending upon site history and hydrogeologic settng (Gottschall et al. 2017; Pepper et al. 2021).

LANDFILLS

Biosolids may be disposed at landfills or, depending on regulatory requirements, landfills may use cover materials such as WWTP sludge and sludge-derived products (such as biosolids) (Pohland and Graven 1993) that are possible sources of PFAS at landfills. Other sources of PFAS to landfills are described in Section 2.6.3.

Biosolids managed at landfills may be a source of PFAS to the landfill leachate, and leachate from some landfills has been shown to be a source of PFAS release to the environment (Busch et al. 2010; Eggen, Moeder, and Arukwe 2010), although the fate and transport processes for PFAS through landfills into leachate are not well understood at this time. The processes for managing leachate have implications on the ultimate fate and transport of PFAS. If landifll liners or leachate collection systems fail, PFAS may directly enter the environment. Leachate collected from landfills is typically treated on site or transported to either a WWTP or evaporation ponds. Leachate treatment by WWTPs is common prior to discharge to surface water or distribution for agricultural or commercial use (Lang 2016 Ref#667). However, standard WWTP technologies are generally ineffective at reducing or eliminating PFAS (Hamid and Li 2016; Ahrens et al. 2016 Ref#182; CRC CARE 2017 Ref#449). As a result, the discharge of landfill leachate, even if treated at WWTPs, can be a significant source of release of some PFAS to the environment (Ahrens et al. 2016 Ref#182; CRC Care 2017 Ref#449). See Section 2.6.3 for more information.

A conceptual site model (CSM) for the dispersion of PFAS in biosolids applied to land, used as landfill cover, or disposed in landfills can be seen in Figure 1. CSM components are discussed in Section 10.2.1.

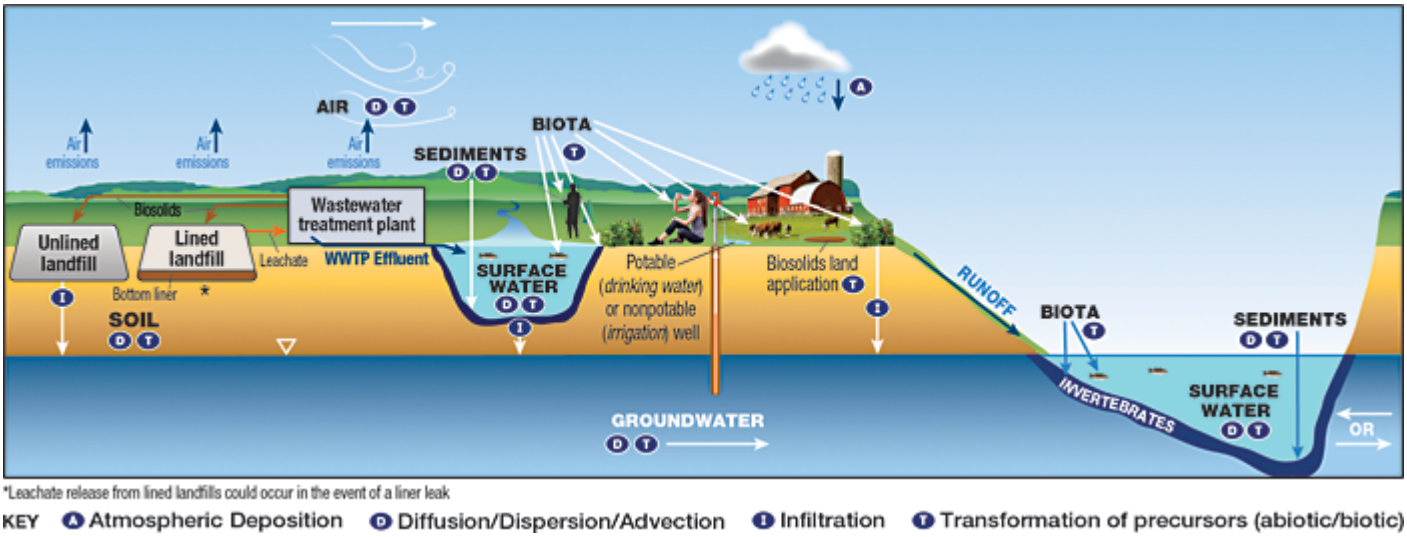


Figure 1. CSM for landfills and WWTPs.

Source: Adapted from figure by L. Trozzolo, TRC, used with permission. PFAS-1, Figure 2-22.

3 Mobility, Leaching and Transport

PFAS-impacted biosolids that are land applied or managed at landfills are subject to transport processes. The fate and transport processes and distribution of PFAS in the environment are discussed in Section 5.3.3. PFAS present in unsaturated soils are subject to downward leaching during precipitation, flooding, or irrigation events that promote dissolution and migration of contaminant mass (Sepulvado et al. 2011; Ahrens and Bundshuh 2014; Sharifan et al. 2021). This process can result in PFAS transport from surface soils to groundwater and surface water because PFAS releases often involve surface applications (Gellrich, Stahl, and Knepper 2012; Anderson, Adamson, and Stroo 2019; Galloway et al. 2020; Borthakur et al. 2022). Leaching is also potentially relevant for plant uptake, as is transport of PFAS contained in landfill waste without adequate leachate control (Benskin et al. 2012 Ref#10; Yan et al. 2015 Ref#278; Lang et al. 2017).

PFAS migration from shallow soils to groundwater is influenced by several interacting processes, which may enhance or limit PFAS leaching rates. The leaching potential will be enhanced in areas with high water infiltration rates, which may include natural water sources such as precipitation or human-made sources such as irrigation. The thickness of the unsaturated zone (depth to water table) will also affect leaching potential. These factors are consistent with other (non-PFAS) contaminants in shallow soils. Conversely, as described in Section 5.2, several PFAS-specific processes (such as partitioning of PFAS to solid phases and adsorption at the air-water interface) potentially limit the extent of PFAS leaching from shallow soil to groundwater. (Brusseau and Guo 2022 Ref#2276; Brusseau 2020 Ref#1837).

4 Uptake into Plants and Biota

Application of municipal or industrial biosolids as a soil amendment can result in a transfer of PFAS to soil (Sepulvado et al. 2011). These PFAS can then be available for uptake by some plants and soil organisms (Yoo et al. 2011). There are indications that perfluoroalkyl acids (PFAAs) can enter the food chain through the use of biosolids-amended soil

(Lindstrom et al. 2011 Ref#306; Blaine et al. 2013 Ref#259; Blaine et al. 2014 Ref#1334; Navarro et al. 2017). Animals can have elevated concentrations of PFAS in their tissues if the animals were fed silage from fields where PFAS-containing biosolids were land applied (Lindstrom et al. 2011 Ref#306; Skutlarek, Exner, and Farber 2006). Refer to Sections 5.6 and 9.

The uptake of PFAS has been well documented in different native and planted species. The majority of these studies have focused on perfluorooctanoic acid (PFOA), and perfluorooctane sulfonic acid (PFOS) uptake by agricultural crops, although there are many other PFAS that have been shown to be subject to plant uptake. Plant uptake is both PFAS- and soil-specific. Wang et al. (2020 Ref#1890) identified at least 16 field studies typically focused on uptake associated with point sources of PFAS. Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) for certain PFAS in select plants are provided in Table 5-2 (see the External Data Tables on https://pfas-1.itrcweb.org).

When using environmental fate and transport models for estimating exposure point concentrations (EPCs) in biota, modeling should be focused on the part of the organism that may be consumed either by humans or by ecological receptors. PFAS generally bind to proteins and accumulate in protein-rich tissues, including the blood, liver, and kidneys (ATSDR 2020 Ref#1942). Currently, models for plant uptake are limited, but several studies have documented uptake of PFAS from soil amended with PFAS-contaminated biosolids (Blaine et al. 2013 Ref#259; Blaine et al. 2014 Ref#1334; Wen et al. 2016).

5 Sampling and Analysis

Biosolids sampling methods will vary based upon the state and homogeneity of the materials to be collected. Additionally, as the materials are often gathered and stored over days to weeks, varying PFAS concentrations in feedstock can cause varying concentrations within the biosolids matrix unless sufficient mixing is performed. Nonhomogeniety can be reduced through thorough materials mixing and/or use of a high number of grab samples to form a composite for analyses.

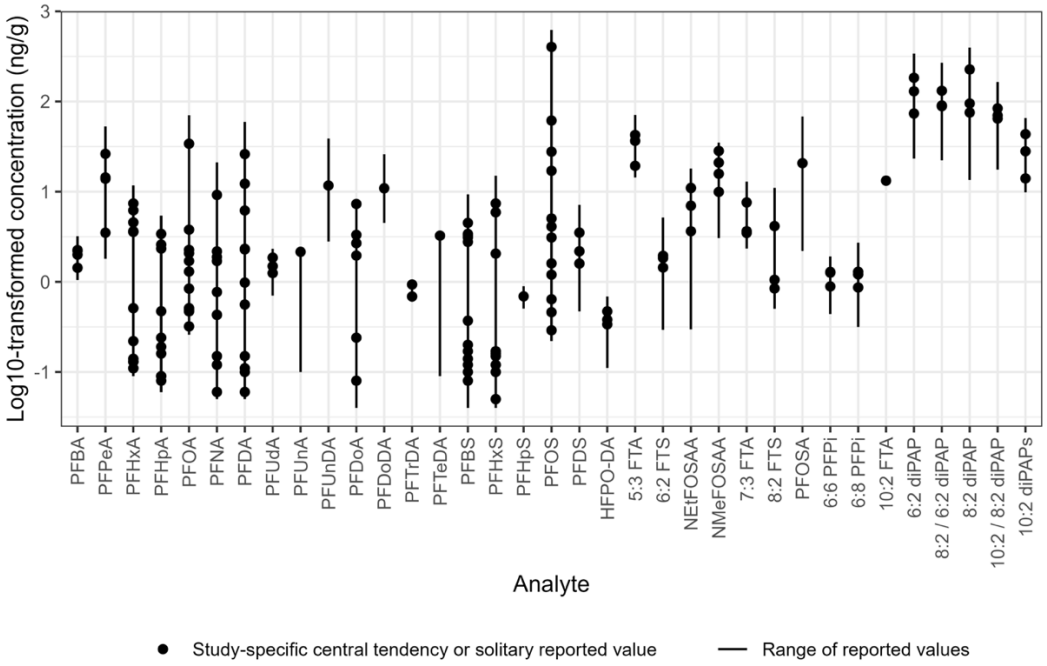
USEPA Draft Method 1633 (USEPA 2023 Ref#2762) is applicable to biosolids, as well as other matrices. However, the analytes that are quantified through use of the 1633 method for biosolids may not include some PFAS that are important to biosolid characterization (for example, diPAPs) (Dickman and Aga 2022). Refer to Section 11 for further information.

6 Occurrence

PFAS occurrence in biosolids is reported to be prevalent nationwide (Venkatesan and Halden 2013). Early studies reported that the most abundant PFAAs (see Section 2.2.3.1) found in biosolids (PFOS and PFOA) are similar to those found in WWTP effluent, although biosolids may also contain other PFAS, including long-chain PFAS (Hamid and Li 2016; Washington et al. 2010). Although multiple studies have reported statistically significant data showing transformation of polyfluorinated substances to PFAAs in land-applied biosolids (Yoo et al. 2010; Sepulvado et al. 2011; Washington et al. 2010), other evidence indicates that some polyfluorinated substances remain in biosolids-amended soils for many years to decades (Yoo et al. 2010; Rich et al. 2015; Washington et al. 2018). See Section 2.6.4.2 for further information.

As described in Sections 6 and 17 of the Guidance Document, PFAS have been detected in various media associated with areas of biosolids production and application, including ambient air (Barton et al. 2006; Ahrens et al. 2011 Ref#144; Liu et al. 2015 Ref#340; Borthakur et al. 2022), groundwater, surface water, soil, sediment, plants, and biota. A 2021 review of reported values for biosolids, compost, and related biowastes highlighted the wide concentration range of reported PFAS (primarily PFAAs) and the relationship of biowaste source to resulting concentrations (Bolan et al. 2021 Ref#2270).

This suggests that limiting PFAS analysis of biosolids to the standard suite of analytes may not account for a substantial fraction of the overall fluorine mass (Schaefer et al. 2023; Thompson et al. 2023).Figure 1 illustrates the PFAS concentrations from several studies.



Sources: Pepper et al. (2021), Schaefer et al. (2022), Venkatsesan and Halden (2013), Venkatsesan and Halden (2014)

Figure 1. Observed PFAS concentrations in biosolids and land-applied soil.
Source: PFAS-1, Figure 6-2C.

7 Treatment

Treatment technologies for PFAS in environmental media are still evolving. Field implemented, limited application and developing treatment technologies for solids, which may be applicable to biosolids, are described in Section 12.3, and Setcion 12. 7, respectively, and Table 12-1 (see the External Data Tables on https://pfas-1.itrcweb.org). Methods include incineration, which is discussed in Section 12.4.

8 Regulations and Guidance

The 2023 ECOS review of state activities found only one state had banned land application of biosolids, and only 6 require testing of biosolids for PFAS. A dozen states reported testing soil, groundwater or surface water downgradient of land application sites, and 21 have or will have publicly available data on PFAS in biosolids (ECOS 2023 Ref#2608). Current regulations and guidance are discussed in Section 8 and the PFAS Regulatory Programs Summary Table (see the External Data Tables on https://pfas-1.itrcweb.org/).

9 References and Acronyms

The references cited in this fact sheet and further references can be found at https://pfas-1.itrcweb.org/references/. Reference numbers are included in this fact sheet for non-unique citations in the Guidance Document reference list.

The acronyms used in this fact sheet and in the Guidance Document can be found at https://pfas-1.itrcweb.org/acronyms/.

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