Summary of Existing Information – Biosolids Communications Materials

Background

This document summarizes existing available information (as of January 2025) to support the development of communications materials related to per- and polyfluoroalkyl substances (PFAS) in biosolids. This summary also incorporates a high-level review of the state of the science on investigation of PFAS in biosolids [including the Water Research Foundation (WRF) Projects 5031, 5042, and 5214], and consideration of relative risk from other exposure sources.

This document provides a summary of:

- The benefits of land-application of biosolids,
- The sources of PFAS to wastewater resource recovery facilities (WRRFs) and the significant efforts being taken to minimize PFAS in biosolids,
- The current state of the science on fate and transport of PFAS in biosolids and the current regulatory environment,
- A relative comparison of potential exposure to PFAS from food and other common sources (such as cosmetics) and an overview of the decreasing blood levels of select PFAS over time in the general population, and
- The importance of source control and the risks associated with over-using PFAS products.

Summary of Existing Information

Biosolids are nutrient-rich organic materials generated from the treatment of domestic sewage in a wastewater treatment facility (i.e., treated sewage sludge). Biosolids serve an important function in a sustainable and circular economy. Land applied biosolids offer moisture retention, slow-release nutrients,[1] carbon sequestration, and provide a cost-effective alternative to commercially manufactured synthetic fertilizers. Alternatively, farmers can opt for manufactured or synthetic fertilizers, which can often be prohibitively expensive and come with intensive energy footprints to manufacture and can have adverse water quality impacts due to their quick release of nutrients.

As of 2022, the United States Environmental Protection Agency (U.S. EPA) identified that approximately 56% of biosolids were land applied, 27% of biosolids were landfilled, and 16% of biosolids were incinerated (Figure 1). Approximately 31% of biosolids are used in agricultural applications. Beneficial application of biosolids is regulated under the Clean Water Act and can be used for crop production, feed crop production, and surface disposal/reclamation of mining sites or burned forests.

[1] Nitrogen and phosphorus are required nutrients for food production. However, continued extraction of phosphorus for fertilizers is contributing to a global shortage of phosphorus, which is exacerbated by soil erosion (Alewell et al. 2020). A phosphorus shortage could have socioeconomic and political consequences. The global increase in demand resulted in an order of magnitude increase in cost for phosphorus fertilizers from 1961 to 2015 ($700 dollars a ton in 2015, Alewell et al. 2020).

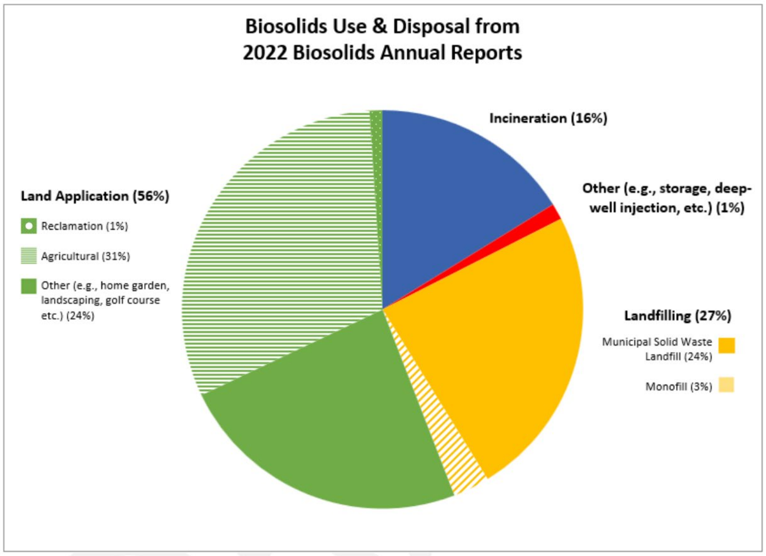

Figure 1. Distribution of biosolids use and disposal. Reproduced from Figure 1 of EPA draft sewage sludge risk assessment for PFOS and PFOA (EPA 2025).

PFAS are a very large group of man-made chemicals that have been used in a variety of consumer and industrial products and processes for decades because of their engineered ability to resist heat, water, and oil.

PFAS are commonly found in everyday consumer goods including non-stick cookware, food paper packaging, cosmetics, fabrics and textiles, and cleaning products. PFAS are also used in lithium-ion batteries, solar panels, fire-fighting foams, and medical devices. PFAS by their very design are intended to be durable and resistant to degradation and treatment. Consequentially, PFAS are found in our bodies and in our environment.

Publicly-owned treatment works (POTWs) tasked with treating billions of gallons of domestic, commercial and industrial wastewater and stormwater daily do not use PFAS in their operations. However, they can receive PFAS in their influent from each of these waste streams. A POTW was not designed or constructed with PFAS treatment or destruction technology in mind, and therefore, conventional treatment processes generally do not remove PFAS. As such, a wastewater utility's effluent and biosolids can contain PFAS. PFAS concentrations in biosolids may be moderately influenced by sources of wastewater to the POTW. For example, Gewurtz et al. (2024) found that POTWs that received landfill leachate containing PFAS tended to have higher PFAS concentrations in their effluent and biosolids than POTWs that did not. Similarly, industrial sources that use PFAS in their processes have effluents containing higher concentrations of PFAS than everyday households sending their waste to POTWs (O'Connor et al. 2022). Despite these slight differences, quantifiable concentrations of one of the most well studied PFAS in biosolids (perfluorooctane sulfonate [PFOS]) were generally within an order of magnitude despite different geographical locations of facilities and upstream sources (Schaefer et al. 2023). Additional technical information can be found as an attachment to this document.

Relative Risk

Because PFAS are ubiquitous in consumer and industrial products and applications, everyone assumes some risk of exposure. Nearly everyone in the United States and other developed countries have measurable amounts of PFAS in their blood. The National Health and Nutrition Examination Survey (NHANES) has been monitoring certain PFAS chemicals in the blood of people living in the United States since 1999, and as phase-outs of these chemicals occur and everyday exposure is reduced, PFAS blood serum levels for some of the most well studied analytes are dropping too (Figure 2).

A key challenge with risk communication is contextualizing PFAS concentrations. The national primary drinking water standard of 4 ppt of PFOS and PFOA is equivalent to four seconds in 31,500 years, or $0.04 out of $10,000,000,000. Similarly, communicating concentrations in biosolids can be challenging because there are no direct comparisons that can be made to other products or materials.

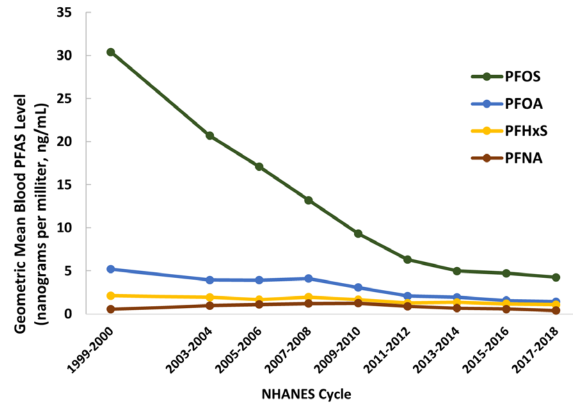

Figure 2. Decline of select PFAS in the blood of people in the United States. Source: ATSDR 2024

When comparing risks, it is tempting to compare concentrations in one product to another. For example, a given PFAS chemical concentration in a given food paper packaging material may be X part per trillion (ppt) while that same chemical may have Y ppt concentration in a given cosmetic product. Such comparisons are commonly made as a means to communicate risks to PFAS. This often results in confusion and misinformation of what is one's real risk to PFAS to one's relative risk to PFAS because it does not provide enough context on potential exposure (Figure 3) since you are often comparing different exposure pathways and assuming the results of different analytical testing methods. For example, exposure to PFAS through fast food paper packaging products coated in PFAS materials will depend on how much and how often you may eat, touch, or breathe in PFAS associated with these products.

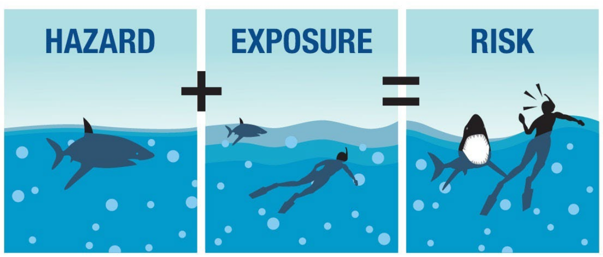

Figure 3. Illustration of hazard, exposure, and risk. Image credit: J.S. Held.

Existing research indicates that the main pathways of human exposure to PFAS for the general population are through consumption of impacted food[2] and drinking water, followed by indoor air and dust (Sunderland et al. 2019). While some PFAS analytes may accumulate in certain plant tissues, like lettuce, Ghisi et al. (2019) estimated that an average adult person (70 kg) would need to eat approximately 1 kg and 3 kg (between 2 – 6 pounds) of lettuce specifically grown in a hydroponic[3] PFAS solution containing 1 ppb per day before exceeding the U.S. reference dose at the time, for PFOA and PFOS, respectively.[4] The serving size of raw lettuce (2 cups) is approximately 85 grams (0.18 pounds).

While PFAS can be found in biosolids due to industrial sources sending untreated effluent to a wastewater utility and commercial and domestic sources contributing concentrations from everyday

[2] Numerous studies have assessed potential dietary sources of PFAS exposure. Fish and seafood, meat, and packaged food consumption tended to be more strongly correlated with PFAS exposure (Domingo and Nadal 2017; Susmann et al. 2019; Seshasayee et al. 2021).

[3] Research is ongoing to better understand uptake to plants from biosolids, however, hydroponic studies are likely conservative because PFAS like PFOS won't be bound to the organic rich soil (Felizeter et al. 2012).

[4] Note that the EPA has since revised down their noncancer reference doses (a reference dose is the amount of chemical an individual can be exposed to every day, over the course of a lifetime, without appreciable health risk). Based on current toxicity and exposure assumptions, an adult would need to eat nearly 230 grams (0.5 pounds) of lettuce per day grown in a 70 ppt solution, or 4,000 grams (8.8 pounds) of lettuce per day grown in a 4 ppt solution (the drinking water maximum contaminant level) to exceed the current reference dose for PFOS.

products, it is important to understand one's potential for exposure to PFAS in biosolids. It is unlikely that the general public will come into direct contact with biosolids containing PFAS at levels that may warrant any more risk than one's direct contact to PFAS in everyday products.

While the U.S. EPA, the U.S. Department of Agriculture, and the U.S. Food and Drug Administration (FDA) are working to understand the potential risk of pollutants in biosolids that are land applied, the uptake rate of PFAS in agricultural produce grown on land supplemented with biosolids, and the concentrations of PFAS in our food supply,[5] the federal government continues to support the land application of biosolids. FDA testing of fresh and processed foods in the general food supply since 2019 did not detect PFAS in over 97% of samples. The few samples where PFAS were detected were primarily seafood samples.

PFAS are also present in cosmetics and other dermally applied-consumer products. Research on the contribution of dermal absorption of PFAS to total exposures is ongoing, but a recent study found that up to 50-60% of certain PFAS could be absorbed through the skin (Ragnarsdottir et al. 2024). This is an important and likely more common potential PFAS exposure pathway to the general population than one's direct exposure to land applied biosolids. A recent study estimated that in California alone, up to 520 milligrams of PFAS per person could be entering wastewater treatment plants from the use of cosmetics containing PFAS (Bălan et al. 2024).

It is also important to note that PFAS may be deposited on agricultural fields from sources other than municipal biosolids. For example, recent research detected PFOS in 60% of insecticide formulations at concentrations ranging from 4 to 19 mg/kg (Lasee et al. 2022).[6] PFAS have also been detected in some commercially available synthetic fertilizers (Lazcano et al. 2019).[7] Phytosanitary product formulations[8] may also contribute to the presence of PFAS on edible portions of produce (Ghisi et al. 2019). PFAS are also aerially deposited to surface soils through pathways such as rainfall (Cousins et al. 2022). As such, PFAS are often detected in soils that have never had biosolids or fertilizers applied to them (Brusseau et al. 2020).

In summary, while PFAS in biosolids should continue to be monitored closely, the significant benefits of land application (circular economy, sustainability, economic considerations, benefits to plant production, and agricultural implications), and one's relative risk of potential exposure to PFAS concentrations in biosolids cannot be overlooked.

[5] The FDA has also tested foods grown, raised, or produced in areas contaminated with PFAS; specifically, two dairy farms using groundwater impacted by aqueous film forming foams (AFFF) from 2018-2021, produce near a PFAS production plant in 2018, and cranberries grown in a bog influenced by AFFF in 2016. When PFAS are detected, the FDA assesses the potential health concern for levels found in food due to environmental contamination. If the agency finds that levels of PFAS may result in a health concern, the FDA will work with the manufacturer to resolve this issue and prevent the product from entering or remaining in the US market.

[6] 1 mg/kg is equal to 1,000 parts per billion (ppb) or 1,000,000 ppt.

[7] Notably, this study also reported a temporal decrease in the total perfluoroalkyl acids (PFAAs) in one biosolids product line analyzed in 2014, 2016, and 2018. Reductions in long chain PFAAs contributed most significantly to the decrease in total PFAAs, with a 67% reduction in PFOS concentrations during that period.

[8] Also referred to as plant protection products or pesticides. https://www.ams.usda.gov/services/fgis/pesticides-residues

Biosolids Regulatory Context

The Part 503 Rule

In 1993, U.S. EPA published, *The Standards for the Use or Disposal of Sewage Sludge*[9] which has become known as the Part 503 Rule. The Part 503 rule is a comprehensive risk-based regulation "to protect public health and the environment from any reasonably anticipated adverse effects of certain pollutants that might be present in sewage sludge biosolids" (EPA 1994). The Part 503 rule was the result of a scientifically conducted risk assessment that followed National Academy of Sciences procedures and was intended to identify what, if any, risks were present with the use or disposal of biosolids across land application, surface disposal, and incineration.

The U.S. EPA started with 200 pollutants that were then narrowed down to 50 common pollutants based on their toxicity, occurrence, and fate/transport in biosolids (EPA 1995). EPA assessed these pollutants using 14 different exposure pathways. Exposure pathways are a means to better understand whether an organism will actually be exposed to the pollutant (e.g., inhalation, eating or drinking it, absorbing it on the skin etc.). Even if an organism comes into contact with a given pollutant, there are various factors at play (e.g., how long it was exposed, the organism's nutritional status etc.) that can impact the response to exposure.

Following EPA's risk assessment, the Agency found it necessary to regulate 10 pollutants (arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc) in biosolids and set numerical limits or standards for their final uses under the Clean Water Act.[10] The rule also includes monitoring, recordkeeping, and reporting requirements. In addition, there are specific requirements for the land application of biosolids to help reduce pathogens and vectors as well as minimize nutrient enhancement in surface waters.

The U.S. EPA recently updated its risk assessment framework to better understand pollutants in biosolids. While the updated risk assessment is similar to the approach for the risk assessment used to derive the 1993 Part 503 rules, EPA has expanded the number of exposure pathways and created a hypothetical "farm family" that would have the greatest potential exposure with land applied biosolids. Based on biennial reviews and sewage sludge surveys, as well as a revised priority chemical screening process and risk assessment, EPA will decide whether a given pollutant rises to the level of requiring a comprehensive risk assessment, whether regulations are necessary, and whether management practices to reduce the likelihood of harm to human health or the environment are needed.

There are also land application requirements in addition to the pathogen and vector attractant reduction defined in Part 503 for Class A and B biosolids.[11]

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[9] (Title 40 of the Code of Federal Regulations [CFR], Part 503).
[10] *See* 33 U.S.C. Section 1251.
[11] The four categories of biosolids are as follows: Exceptional Quality (EQ) biosolids – low pollutant and Class-A pathogen reduction; reduced level of degradable compounds that attract vectors. Virtually unregulated for use upon meeting the Part 503 rule requirements and can be applied in bulk or sold or given away in bags or other containers; Pollutant Concentration (PC) biosolids – same low pollutant concentration limits as EQ biosolids but meet Class-B pathogen reduction and/or are subject to site management practices rather than treatment options to reduce vector attraction properties. May only be applied in bulk, subject to general requirements and management practices; Cumulative Pollutant Loading Rate (CPLR) biosolids – typically exceed at least one of the pollutant concentration limits for EQ and PC biosolids but meet the ceiling concentration limits. Cumulative levels of biosolids pollutants must be tracked and cannot exceed the CPLR. Must be applied in bulk; Annual Pollutant Loading Rate (APLR) biosolids – sold or given away for land application that exceed the pollutant limits for EQ biosolids but meet the ceiling concentration limits.

Most biosolids generated in the U.S. are Class A or B, EQ or PC biosolids. Cumulative levels of pollutants do not need be tracked because the risk assessment indicated that the life of a site would be at least 100-300 years under the conservative risk assessment assumptions (EPA 1994).

Bulk biosolids may not be applied within 10 meters (33 feet) of any waters of the United States (e.g., intermittent flowing streams, creeks, rivers, wetlands, or lakes) unless approved by the permitting authority. To prevent nitrate contamination in groundwater, the rate of land application of biosolids cannot exceed the agronomic rate.[12]

PFAS-Specific Biosolids Activity

On January 14, 2025, the U.S. EPA released the draft risk assessment for PFOS and PFOA in biosolids (EPA 2025). The draft risk assessment focused on potential human health risks to those living on or near sites where PFAS-containing biosolids have been applied. The draft risk assessment does not assess potential risk to the general public, and notes that the general population typically have greater diversity of food sources.

The draft risk assessment indicates that, in some modeled scenarios, there could be human health risks exceeding the EPA's acceptable thresholds to those living on or near impacted farms or primarily relying on their products. These risks are associated with multiple individual exposure pathways if the impacted person consumes the modeled amounts of food or water from the biosolids-amended farms (e.g., drinking 32 ounces of milk per day, drinking 1 liter of water per day, eating 1 egg per day, or eating 1-2 servings of fish from the impacted waterbody per week). The biosolids concentration modeled in this draft risk assessment (1 ppb) is near the limit of detection for many laboratories using EPA Method 1633 and at the low end of concentrations in biosolids reported in currently available state data.

The draft risk assessment is not a regulation and does not compel action. The EPA acknowledges that eliminating risk is likely not possible at this time, and recommends, in addition to pretreatment to reduce PFAS at the source, that wastewater treatment plants (WWTPs) consider management options or practices that can mitigate or lessen risks. WWTPs may choose to evaluate whether additional risk mitigation actions are appropriate to reduce risk posed by certain sewage sludge use and disposal activities. To reduce potential risk associated with land application, considerations may include: land-applying in areas that may be less sensitive to PFOA and PFOS pollution, like areas far from fishable waters or with deep protected drinking water aquifers; avoiding land application in fields used to graze livestock or grow feed, especially for dairy cows; land-applying to fields used to grow fruits and grain as an alternative to those growing hay or leafy greens like spinach or kale. To reduce potential risk associated with surface disposal (landfilling) of sewage sludge the EPA recommends consideration of using disposal sites with composite liners and leachate collection and treatment systems (understanding how that leachate will be disposed or treated).

The EPA recognizes that WWTPs may have constrained options for sewage sludge management and changes may not be possible, particularly in the near term.

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[12] The agronomic rate is a rate that is designed to provide the amount of nitrogen needed by a crop or vegetation to attain a desired yield while minimizing the amount of nitrogen that will pass below the root zone of the crop to the groundwater. Application of biosolids may occur above the agronomic rate in select situations, such as at a reclamation site, with express approval from the permitting authority.

Absent federal regulation, individual states have enacted legislation or developed regulations or interim guidance on the land application of biosolids in response to PFAS.

Some of the impetus for the risk assessment is based upon activities that occurred in Maine, where over-application of industrial pulp and paper mill sludge (in combination with municipal WWTP biosolids) to farms resulted in elevated PFAS levels in the blood of farmers, drinking water, milk, and produce. These elevated levels forced closure of the impacted farms. In response, Maine's governor signed a moratorium banning land application and distribution of biosolids based products on April 20, 2022. This moratorium was opposed by the Maine Water Environment Association, the Maine Work Boots Alliance that includes the Maine Farmers Bureau, New England Water Environment Association, NACWA, and others.

On January 1 2024, Michigan issued an interim strategy on land application of biosolids containing PFAS. The interim strategy provides concentration-based thresholds on land application of biosolids, as follows:

- Industrially impacted biosolids (e.g., biosolids with concentrations of PFOS or PFOA of 100 ppb or higher) cannot be land applied
- PFOS or PFOA concentrations at or above 20 ppb are considered "elevated" and land application rates must be reduced or another risk mitigation strategy must be approved by the state
- PFOS and PFOA concentrations below 20 ppb may be land applied with no additional requirements after results have been provided to the state and communicated with the landowner/farmer

Other states, including California, Colorado, Minnesota, New Hampshire, Connecticut, Massachusetts, and Vermont have initiated programs to monitor PFAS in biosolids.

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Technical Summary – State of the Science

Significant research is ongoing to characterize PFAS in all manner of environmental media, including biosolids. Of particular relevance is the work completed and underway in WRF Projects 5031, 5042, and 5214.

WRF Project 5031 assessed the occurrence of PFAS in WWTPs and their solid and aqueous partitioning through wastewater treatment. The study identified greater quantifiable PFAS mass in aqueous effluent than in biosolids; however, many PFAS that cannot be quantified by current target analytical methods were identified in biosolids using non-target methods. The study identified a limited number of correlations, primarily for influent PFAS, based upon the influence of industrial point sources (e.g., landfill, AFFF, the textile industry, and other significant industrial dischargers). Notably, both PFOS influent and PFOA effluent concentrations were statistically significantly correlated with the textile industry. Only PFBA in biosolids was statistically significantly correlated with significant industrial dischargers.

Despite the differences in upstream PFAS sources, concentrations of one of the most well studied PFAS, PFOS, reported across the 38 US WWTPs assessed in WRF 5031 were generally consistent with observations in Canada (Gewurtz et al. 2024), and quantifiable concentrations in biosolids were within an order of magnitude despite different geographical locations of facilities and upstream sources (Schaefer et al. 2023).

The majority of PFAS that exited the WWTP was in the aqueous effluent as compared to biosolids (Schaefer et al. 2023). However, importantly, precursor PFAS compounds (including polyfluoroalkyl phosphoric acid diesters [di-PAPs]) accounted for approximately 65% of the average quantified PFAS mass in biosolids.[13]

WRF Project 5042 assessed the potential for releases of PFAS from finished biosolids in a 6-month field mesocosm. Similar to the studies described above, concentrations in finished biosolids were generally consistent across the seven facilities assessed. An inverse relationship was observed between desorption partitioning and perfluoroalkyl chain length (e.g., short chain PFAS were more likely than long chain PFAS to leach) and organic carbon content.

An important finding from WRF Project 5042 was that transformation of precursor PFAS compounds accounted for the majority of leached PFAS from the biosolids. In particular, simulated biosolids land application showed sustained PFAS leaching of PFAAs transformed from di-PAPs over the 6-month study period (Schaefer et al. 2022). This observation, and longer term *in situ* leaching potential, is being further studied in the ongoing WRF Project 5214.

Additional work is ongoing to assess the potential for PFAS uptake into crops. Bioavailability of PFAS to plants can vary by soil organic matter content (Li et al. 2024), as well as soil pH and salinity (Adu et al. 2023). Chemical properties of individual PFAS may also affect the potential for uptake into plant tissue; thus, predicting plant uptake under conventional methods for neutral organic compounds may not be appropriate for PFAS (Adu et al. 2023).

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[13] A recent study found 6:2 di-PAP in toilet paper, and the authors estimated that toilet paper usage could result in 6.4 to 80 micrograms (µg) of 6:2 di-PAP per person per year to wastewater systems (Thompson et al. 2023).

Translocation factors (e.g., the ratio of PFAS concentrations in plant shoots vs. plant roots) indicates that short chain PFAS are more likely to translocate into plant shoots than long chain PFAS, however long chain PFAS may accumulate in the edible parts of tubers and root crops (Adu et al. 2023). Notably, PFAS bioconcentration factors (e.g., the ratio of PFAS in plant tissue as compared to soil) were higher for plants grown in soil amended with industrially impacted biosolids as compared to soil amended with municipal biosolids for most PFAS (Ghisi et al. 2019).