Addressing PFAS Leaching Concern Related to Recycled Biosolids & Other Residuals

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- Town of Merrimack, NH
## Topics to Be Covered

- Why biosolids are recycled
- Why the interest in PFAS related to biosolids / residual
- Look to the literature: concerns are raised
- Northeast states evaluate locally
- Perspectives & research needs
- Supplementary material
Why biosolids are recycled
Options for Organic Waste Management

- Organic Waste
- Onsite Composting
- Garbage Disposal
- Wastewater Treatment
- Anaerobic Digestion
- Biogas
- Biosolids
- Materials Recycling Facility
- Solids Separation
- Composting Facility
- Compost
- Electricity
- Waste to Energy
- Landfill
Numerous studies demonstrate the benefits derived from adding organic matter, such as biosolids, to soils: higher carbon content (carbon sequestration), increased microbial activity, increased water-holding capacity, and lower bulk density (which means easier tillage & handling).

– Dr. Sally Brown, Univ. of WA, 2011
Farms benefit

260 lb N/ac

Net Profit Increase = $250 – $500 per acre

Biosolids

Fertilizer

260 lb N/ac
Research going back decades shows benefits: Early growth of corn on control (left) and compost amended (right) plots on Woodstown silt loam soil (Epstein and Chaney, 1974).
Biosolids use: Forestry

Photos courtesy of King County, WA
http://dnr.metrokc.gov/WTD/biosolids/

➡️ Speeds up harvest cycle in actively managed stands.
Reclamation of disturbed sites
perhaps the most environmentally important use – biosolids as a tool solving problems

Pennsylvania mine before
Same Pennsylvania mine after

Photos courtesy Bill Toffey, MABA
Evaluating GHG emissions from different use / disposal of biosolids:
Lower GHG emissions from use on soils

“Methane avoidance”

- Landfill
- Incineration 1: Energy recovery, Cold wet climate
  - 800°C, 25% solids, No recovery
- Incineration 2: 900°C, 30% solids, Energy recovery
- Class A Alkaline Land Ap
- Anaerobic dig. Land Ap

Transport: Using virgin lime *if recycled lime → total to -211*
- 65% heat, 30% elect., 1% fugitive
And biosolids manage many CECs / microconstituents.

• Myriad synthetic (and natural) organics in our daily lives – it’s inevitable
• Focus on removing the most concerning POPs with source control.
• Where should the rest end up? → solids better than effluent and…
  …→ healthy soils better than air or water for managing most CECs*
• In soils, over time, most either…
  • degrade or
  • become less bioavailable and/or mobile
• How PFAS behave needs further research.

* “These terrestrial systems have orders of magnitude greater microbial capability and residence time to achieve decomposition and assimilation compared with aquatic systems.”

– Overcash, Sims, Sims, and Neiman, 2005
Why the interest in PFAS related to biosolids / residuals
Caution: Data quality concerns for non-drinking water tests

- There’s only 1 approved, consistent analytical method - for drinking water only (Method 537…)

- Thus…
  - Consistency & comparability of current data are somewhat suspect
  - Consider data on non-drinking water matrices – including those presented here – to be for screening and understanding only.
Current state concerns around PFAS were triggered by…

Water well testing around known industrial & landfill sites

Red = elevated
Green / Blue = low

PFAS sources: Leaching from landfills or deposition from fabric coaters emitting PFAS to air → soils → groundwater.

Merrimack, NH
St. Gobain Performance Plastics, 2015 - 2016

Coakley Landfill, NH

Red = > 70 ng/L (ppt)

Red = > 1000 ng/L (ppt)
Eastern NY
NY DEC data
2016

Legend
- Surface Water
- Landfill Monitoring Well

Hoosic River sample near landfill.

Landfill seep/leachate sample.

Sample from pond.

Eastern NY
NY DEC data
2016

MW-2
21000 ppt

MW-3A
1900 ppt

MW-4
1300 ppt

MW-4B
1200 ppt

SW-2
9.8 ppt

SW-4
9.2 ppt

MW-1B
150 ppt

Hoosic River sample located downstream of treatment plant.
Farm site:
UCMR public drinking water test identified impacted well: ~60+ ppt near farm. Further testing found soil, water, manure, & milk impacts.

Farmer & water company think elevated PFOS is related to ~1980s land application of residuals from paper mill that coated papers with PFOS?

#TheECSummit
Look to the literature: concerns are raised
PFAS move some in soil

Sepulvado et al; *Environ. Sci. Technol.* 2011, 45, 8106-8112

Concentrations of PFOA and PFOS with depth in the long-term plots at various loading rates.
Control = 0 Mg/ha, LR 1 = 553 Mg/ha, LR 2 = 1109 Mg/ha, LR 3 and LR 3 dup = 2218 Mg/ha (dry weight basis).
Ratios of surface concentration ($C_{surf}$) to concentration in the bottom soil core depth interval (60–120 cm, $C_{depth}$).

Ratios represent an average of the ratios calculated for the long-term plots for each biosolids loading rate.

Mobility varies with chemical structure (C chain length)

Sepulvado et al; *Environ. Sci. Technol.* 2011, 45, 8106-8112
Movement of PFAS to tile drains & shallow groundwater

Study site in ON:
• Humid continental climate
• Corn, wheat, soy rotations
• Very light tillage
• Systematic tiling, 15m spacing, about 1m depth
• Ottawa biosolids (mixed residential, industrial, commercial)
• 1.6 $\mu$g/kg PFOA, 7.2 $\mu$g/kg PFOS
• Treated by anaerobic digestion & centrifugation
• 22 Mg dw/ha (9.8 tons dw/ac)
• Moldboard plow to ~ 20cm
• Planted to winter wheat

ON study conclusions:

• Perfluorinated chemicals detected in both groundwater and tile discharge after a single large biosolids application.
• Chemicals detected for months after the application.
• The contributions of leaching through the soil matrix and preferential flow through macropores are unknown.
  --Ed Topp, AAF Canada
Northeast states evaluate locally
Northeast states evaluate locally...

**PFAS in wastewater**  
(presence further confirmed, 2017 NH DES data)

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<th>PFHPA</th>
<th>PFHXS</th>
<th>PFHXA</th>
<th>PFNA</th>
<th>PFOA</th>
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PFAS in wastewater residuals 2017 (presence further confirmed)

2017 PFAS screening data compiled by NHDES & NEBRA:
22 facilities from NH and Northeast (n = 27, none same as previous slides)

<table>
<thead>
<tr>
<th>Chemical</th>
<th>% detection</th>
<th>Conc. Range (ug/kg)</th>
<th>Ave. Conc. (ug/kg)</th>
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<td>34.6</td>
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<td>PFPeA</td>
<td>8</td>
<td>18 – 27</td>
<td>22.5</td>
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<td>PFHeA</td>
<td>84</td>
<td>0.21 – 75</td>
<td>11.0</td>
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<td>PFHpA</td>
<td>26</td>
<td>0.077 – 2.8</td>
<td>1.1</td>
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<td>PFOA</td>
<td>32</td>
<td>1.1 – 15</td>
<td>6.7</td>
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<td>PFNA</td>
<td>30</td>
<td>1 – 3.6</td>
<td>2.6</td>
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<td>PFBS</td>
<td>7</td>
<td>5.2 – 6.2</td>
<td>5.7</td>
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<tr>
<td>PFHxS</td>
<td>22</td>
<td>0.24 – 73</td>
<td>13.3</td>
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<tr>
<td>PFOS</td>
<td>62</td>
<td>0.59 – 390</td>
<td>34</td>
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Regulatory response in March 2017 drove recycle paper mill residuals to landfill and composting business to laying off workers, due to non-drinking, surface water levels up to combined 240 ng/L (ppt). (Not drinking water. Do we need to have all surface water meet drinking water screening?)
Monitoring well testing at biosolids monofill

- Monofill used in 1980s. Since ~1996, all biosolids from WWTP (11.5 MGD) have been land applied, some on farm field shown.
- Likely a worst-case scenario? No drinking water impacts found.
Monitoring well testing at reclamation site

- Likely a worst-case scenario. No drinking water impacts found.
Attempts defining safe PFAS levels: soils & biosolids/residuals leaching to GW

- Alaska, 2016
  - Proposed migration-to-groundwater soil cleanup level: PFOA: 1.7 ug/kg (ppb)  
    PFOS: 3 ug/kg

- New York, 2017
  - DEC; interim preliminary screening level for specific permits: PFOA + PFOS: 72 ug/kg

- Maine, 2017-18
  - Initial (rote modeling - SEVIEW (SESOIL & AT123D)): PFOA: 0.438 ug/kg  
    PFOS: 0.908 ug/kg
  - Current provisional (adapted from EPA RSLs 2017): PFOA: 2.5 ug/kg  
    PFOS: 5.2 ug/kg
  - NEBRA is encouraging ME DEP to remove any residuals screening levels at this time and wait for the science to catch up.

- VT, 2017 – added PFOA & PFOS to Haz. Waste list for liquids: PFOA + PFOS >20 ppt

- U. S. EPA, 2017 RSLs – anticipated? temporary?  
  Someone reported this at a recent conference. Really?  
  PFOA: 0.00017 ug/kg (!)  
  PFOS: 0.00038 ug/kg (!)
Data on key parameters is variable (e.g. re $K_{oc}$)

<table>
<thead>
<tr>
<th></th>
<th>$K_{oc}$ PFOA (L/kg)</th>
<th>$K_{oc}$ PFOS (L/kg)</th>
<th>Notes</th>
<th>Reference</th>
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<tr>
<td>U. S. EPA</td>
<td>114.8</td>
<td>371.5</td>
<td>Used by ME DEP</td>
<td>Data inputs to RSLs</td>
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<td>Lab sorption</td>
<td>631</td>
<td>1000</td>
<td>Higher values found in field experiments*</td>
<td>Zareitabalad et al. (2013), Chemosphere</td>
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<td>experiments, average</td>
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<tr>
<td>Desorption experiments</td>
<td>204</td>
<td>2188</td>
<td>Sepulvado et al., 2011</td>
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<td>Summary data</td>
<td>83 – 389</td>
<td>250 - 50,100</td>
<td>U. S. National Library of Medicine, 2017,</td>
<td>Hazardous substances data bank</td>
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<td></td>
<td></td>
<td></td>
<td>Hazardous substances data bank</td>
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</table>

- “Applying lab-based log $K(oc)$ distribution coefficients can therefore result in a serious overestimation of PFC concentrations in water and in turn to an underestimation of the residence time of PFOA and PFOS in contaminated soils” – Zareitabalad et al., 2013

- Understanding $K_{oc}$ for PFAS in biosolids & residuals depends on:
  - C chain length: longer-chain PFAS (e.g. PFOA, PFOS) have higher sorption (an estimated 0.5 log $K_{oc}$ increase for each CF$_2$ group (Higgins and Luthy, 2006, Env. Sci. & Tech)),
  - sludge has a higher $K_{oc}$ than sediments (Chen et al., 2012),
  - “organic rich soils retard movement of PFAS” (E. Houtz, 2017, Arcadis to NEWMOA, May 8-10, 2017),
  - site-specific conditions.
States are seeking consistency & collaboration.

January 12, 2018

Mr. Scott Pruitt, Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., NW
Washington, DC 20460

Dr. Brenda Fitzgerald, Director
Centers for Disease Control and Prevention
and Administrator, ATSDR
1600 Clifton Road Atlanta, GA 30329-4027

Subject: State Drinking Water Program Recommendations to EPA and CDC on PFAS

Dear Administrator Pruitt and Director Fitzgerald:

The Association of State Drinking Water Administrators (ASDWA), which represents the 50 states, five territories, the Navajo Nation and the District of Columbia has serious concerns with the growing public health issues associated with Per- and Polyfluoroalkyl Substances (PFAS) in drinking water. ASDWA’s members regulate and provide technical assistance and funding for the nation’s 160,000 public water systems (PWS), and coordinate with multiple partners to ensure safe drinking water for our nation’s 324 million residents.

ASDWA urges EPA and CDC to work in partnership with ASDWA and state drinking water programs, and with the Department of Defense (DoD) to address these growing public health concerns. Our primary recommendation is that a working committee be formed with ASDWA, EPA, CDC, and DoD leadership to work on the list of specific recommendations attached. Given the potential adverse public health implications from PFAS, ASDWA recommends that this group be established as soon as possible.
Perspectives & research needs
Perspective: Wastewater & biosolids mirror modern life.

- Wastewater solids management is not optional.
- Wastewater solids can be landfilled; incinerated; or treated, tested, & applied to soil as biosolids. The latter usually is best environmentally, overall.
Perspective

- PFAS are clearly mobile – found throughout the world
- PFAS are in wastewater & residuals because they have been widely used for decades and are persistent in the environment
- Presence in wastewater & residuals is not necessarily evidence of risk or even significant exposure in excess of current everyday exposure
- Uncertainty continues regarding PFAS public health risk; health studies vary.
- PFOA & PFOS are phased out in No. America. Human blood serum levels down 50%+ over ~15 years.
- Is this is a legacy issue, at least for PFOA & PFOS? Modern biosolids / residuals are likely less of a concern than historic ones.
What about potential environmental impacts?

Perspective: Bioassays get at whole system impacts.

- 1980s & ‘90s: Sopper (Penn State Univ.): testing of plant and rabbit health on sites reclaimed with biosolids (with focus on heavy metals)
- 2000s: Brown (Univ. of WA), USDA, and others: testing of plant and rabbit health on sites reclaimed with biosolids
- 2010: University of Guelph – fate of endocrine disruption during biosolids treatment processes
- 2010: College of William and Mary: bioavailability of PDBEs using earthworms and crickets in laboratory
- 2013: Park, et al. (Tom Young team, UC Davis): Triclosan has “little relative impact on overall community composition…” and “TCS slightly increased biomarkers of microbial stress, but stress biomarkers were lower in all biosolid treated soils, presumably due to increased availability of nutrients mitigating potential TCS toxicity.”
- 2013: Puddephat thesis (Lynda McCarthy team, Ryerson Univ.): lab bioassays in Ontario using earthworms, springtails, brassica rapa, beans, corn, & aquatic organisms
Figure 17: Avoidance chamber setup for *Folsomia candida*

Figure 30: Feeding of Earthworms in Ryerson Long-Term Bioassay Chambers. Image shows the mating chambers atop the Evan’s Boxes.
Conclusions of Puddephat / McCarthy:

Puddephat, 2013:
“...biosolids had little negative impact on the terrestrial biota examined and as a general rule, there was no impact observed. Where effects were observed, the majority of instances were positive. In the few instances where there was negative impact observed, for example in the initial growth stages of the plant bioassays, with further development of the organism, there was no longer a significant difference between the reference and treatment plants.”

And PFAS were most likely in those biosolids at levels higher than today’s biosolids.
Summary

• The core concern for biosolids & residuals management is potential leaching of PFAS impacting drinking water or surface water. Period.

• Initial leaching modeling has instigated concern, but most of that modeling includes:
  • worst-case-scenario assumptions
  • output of concentrations in soil pore water / top of groundwater table
  • no dispersion or dilution factors

• Regulatory agencies that adopt low (<70 ppt) PFAS standards for drinking water or groundwater are finding it hard to enforce and mitigate all locations, because there are many.
  • EPA stresses that the 70 ppt is a public health advisory level for lifetime drinking water; some call it overly conservative, some call for a drinking water level as low as 1 ppt (impractical).
  • With PFOA & PFOS levels already declining dramatically in humans, states need to assess what public health benefit is gained for considerable cost in chasing groundwater protection at lower levels.

• Biosolids managers should apply the same best management practices as for all biosolids and their CECs / microconstituents, including source control (e.g. landfill leachate), setbacks, and agronomic rate applications. And monitor this topic.
The question: Where do normal, modern biosolids applications lie on the continuum of potential PFAS impacts to ground / surface waters?

- Historic residuals impacted by PFAS manufacturer (e.g. 3M, Decatur, AL; NE farm with high PFOS likely from 1980s papermill residuals use)
- Historic / modern residuals heavily applied repeatedly (Sepulvado et al. 2011)
- Modern residuals applied semi-annually with setbacks, etc. (Gotschall et al. 2017)
- EQ biosolids used for several years - home settings (e.g. 3 sites in NH)

Where drinking water & ground water standards are set will determine our level of concern.

Higher concern

Minimal to no concern
State actions can impact residuals / biosolids recycling

It seems premature...

• ...to set lower drinking water numbers (MCLs, etc.); EPA PHA is being applied and provides high level of protection; and
• ...to set soil or wastewater or residuals concentration screening or enforcement levels. The science is not there yet.

Meanwhile...

NH Legislation – a dozen bills in 2017 & 2018
Pushing lower drinking, groundwater, and surface water standards
NJ proposed: 14 ppt for PFOA in drinking water
PA proposed: 6 ppt for PFOA in drinking water
Grandjean et al: 1 ppt for PFOA/PFOS in drinking water!
NEBRA Response to PFAS Concerns

- NEBRA pursuing answers via facilitation of relevant research and guidance (with very limited resources):
  - PFAS Advisory Group
  - Fact Sheets & Perspective
  - PFAS & Residuals Sampling & Analysis Guidance
  - Literature Review
  - PFAS Research with UNH & NH DES
  - Webinars on PFAS issues
- Working with state agencies and legislatures to deal with PFAS risk in a measured and thoughtful manner (need to avoid regulatory over-reaction)
- Nationwide PFAS conference call – last Tuesday of every odd month, 1:30 Eastern (e.g. March 27, 2018) – all welcome.
- Some resources (e.g. recording of analysis webinar) are here: https://www.nebiosolids.org/nebra-publications
- More resources for members & upon request.

Core research question:
“Does land application of wastewater residuals (paper mill solids, municipal biosolids, etc.) at fertilizer rates with current common regulatory requirements and proper industrial source controls represent a risk to public health from PFAS contamination of groundwater via leaching and/or surface water via runoff?”
Research needs

- **Field research** – Evaluate extent of issue re biosolids/residuals with thoughtful, planned testing of current & historic biosolids use sites, including groundwater, surface water, soils at various depths, plant tissues, & considering other potential sources of contamination, age of biosolids used, number of applications, etc. NEBRA/NHDES/UNH research will develop protocol for consistent data.

- **Field research looking forward** - Leaching column studies and full-scale field work at actual land application sites with no legacy biosolids or other PFAS concerns.

- **Basic data on key PFAS parameters**: determine appropriate data inputs to models (e.g. Koc).

- **What about other PFAS besides PFOA & PFOS?** – much data still to be developed.

- **Modeling**: Adapt models for PFAS and **field verify** them to provide screening and guidance.

- **Analysis** – Approved methods for non-drinking waters and solids are needed….  
  - They may be approved under Solid Waste program this year. Years still before they are approved under Clean Water Act.

**Ultimate goal of states**: What is an acceptable concentration of PFAS in biosolids/residuals that is protective of groundwater & surface water when biosolids/residuals land applied at fertilizer rates on an annual basis?
Thank you.

Ned Beecher, Executive Director
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603-323-7654

Biosolids compost for my raspberries.
Selected References


Supplementary Material
Why the interest in PFAS related to biosolids / residuals
Why are PFAS a hot topic for biosolids/residuals now?
(the “elevator talk” history of PFAS & wastewater / residuals)

• 2000s → present: Increasing focus on PFOA & PFOS in the environment worldwide. PFOA & PFOS voluntary phase-out by 2015.

• May 2016 → EPA drinking water public health advisory (PHA) - - 70 ng/L (ppt) for PFOA & PFOS combined. Rare ppt PHA.

• State agencies look for sources → literature points to wastewater & residuals as some.

• Because they reflect modern life, wastewater, biosolids, & other residuals (e.g. from recycle paper mills) contain low microgram/L (ppb) concentrations of PFAS.

• PFOA & PFOS chemistry and persistence → Scant literature shows some leaching to groundwater possible at levels approaching the EPA PHA concentration → Regulators concerned. States’ cursory screening sampling & analysis supports some concern. State reactions follow.

• 2017 – 2018: Public & legislative pressure drives efforts to lower the benchmark below EPA’s PHA of 70 ppt, which could impact biosolids & residuals management.
PFOA/S drinking water standards / screening levels: diverse values drive differences in concern re residuals/biosolids.

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<th>Jurisdiction</th>
<th>PFOA (ppt)</th>
<th>PFOS (ppt)</th>
<th>Notes</th>
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<td>for combined</td>
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<td>Standard</td>
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<td>for combined</td>
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<td>Australia, January 2017 interim drinking water guidance</td>
<td>Advisory</td>
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<td>500 (including PFHxS)</td>
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<td>Australia, April 2017 final drinking water guidance</td>
<td>Advisory</td>
<td>70</td>
<td>560 (including PFHxS)</td>
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<td>Michigan, non-cancer values, 2014</td>
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<td>(as of 2017)</td>
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<td>Maine residential groundwater RAG</td>
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<td>California – Office of Environmental Health Hazard Assessment, Nov. 2017</td>
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Look to the literature: concerns are raised
Look to the literature: PFAS in Wastewater

Look to the literature: PFAS in septic systems → groundwater (Schaider et al., 2014)

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<thead>
<tr>
<th>Chemical name</th>
<th>CAS number</th>
<th>Method reporting limit (ng/L)</th>
<th>Number of times detected (% of wells)</th>
<th>Maximum concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFOA</td>
<td>335-67-1</td>
<td>10</td>
<td>2 (10%)</td>
<td>22</td>
</tr>
<tr>
<td>PFOS</td>
<td>1763-23-1</td>
<td>1</td>
<td>8 (40%)</td>
<td>97</td>
</tr>
</tbody>
</table>

Compare to EPA PHA of 70 ng/L (ppt)
Look to the literature: PFAS in biosolids

Clark and Smith, 2010

Total PFAS are ~ ≤ 100 ng/g (ppb) in biosolids

Fig. 1. Typical concentrations of selected ‘emerging’ organic contaminants in sewage sludge (mg kg⁻¹ dw).
For comparison: Biosolids concentrations vs. other media

<table>
<thead>
<tr>
<th>Biosolids &amp; Residuals</th>
<th>PFOA (ppb)</th>
<th>PFOS (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory standards</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Sampling of U.S. biosolids, 2001 (Venkatasen and Halden, 2013)</td>
<td>34</td>
<td>403</td>
</tr>
<tr>
<td>A northern New England biosolids compost, 2017</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>NH land applied solids, 2017, n=20, non-detects included at detection limit</td>
<td>2.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Northeast paper mill residuals</td>
<td>1.6</td>
<td>25</td>
</tr>
<tr>
<td><strong>Other media</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household organic waste compost</td>
<td>6 (median)</td>
<td></td>
</tr>
<tr>
<td>Dust in U.S. daycare centers, median values (Strynar and Lindstrom, 2008)</td>
<td>142</td>
<td>201</td>
</tr>
<tr>
<td>Human blood, U.S. population 1999 average (CDC NHANES)</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Human blood, U.S. population 2012 average (CDC NHANES)</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>
## Look to the literature: PFAS in soil land application, other sites

<table>
<thead>
<tr>
<th>Source</th>
<th>Type of loading</th>
<th>PFOA (ug/kg)</th>
<th>PFOS (ug/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington et al., 2009, Decatur, AL biosolids</td>
<td>High PFAS in biosolids</td>
<td>50 – 320</td>
<td>30 – 410</td>
</tr>
<tr>
<td>Sepulvado et al., 2011 Chicago, IL biosolids</td>
<td>Short-term Long-term Control plots (cross contaminated?)</td>
<td>no data</td>
<td>2 – 11</td>
</tr>
<tr>
<td>Gottschall et al., 2017, Ottawa, ON biosolids</td>
<td>One-time</td>
<td>0.1 – 0.8</td>
<td>0.2 – 0.4</td>
</tr>
<tr>
<td>Garden control soils, MN (=6)</td>
<td>No significant PFAS source</td>
<td>0.29 – 0.54</td>
<td>0.93 – 2.1</td>
</tr>
<tr>
<td>VT Dept. Health testing (n=100), for comparison</td>
<td>Aerial deposition from nearby industry use</td>
<td>ND – 45</td>
<td>ND – 33</td>
</tr>
<tr>
<td>NH DES soil testing 2016 (n=160)</td>
<td>Aerial deposition from nearby industry use</td>
<td>ND – 45</td>
<td>ND – 33</td>
</tr>
</tbody>
</table>
For comparison: PFOA/S soil screening levels
No significant risk likely from dermal, ingestion, etc. direct exposure from biosolids & soils.

<table>
<thead>
<tr>
<th>Soil</th>
<th>PFOA (ppb)</th>
<th>PFOS (ppb)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia, 2017 – soil screening level for 99% species protection</td>
<td>650</td>
<td>6,600</td>
<td></td>
</tr>
<tr>
<td>Minnesota soil reference value, in effect in 2012</td>
<td>2100</td>
<td>2100</td>
<td></td>
</tr>
<tr>
<td>NH DES Soil Screening Level</td>
<td>500</td>
<td>none</td>
<td>Based on risk from dermal exposure and ingestion</td>
</tr>
<tr>
<td>VT DEC Soil Screening Level</td>
<td>300</td>
<td></td>
<td>Based on risk from dermal exposure and ingestion</td>
</tr>
</tbody>
</table>
PFAS risk & land applied biosolids/residuals (Mobility/Leaching)

Correlations from the literature:

- Biosolids/PFAS loading → PFAS soil concentrations. Correlation is especially strong for longer chain (>C8) PFCA.
- Biosolids/PFAS loading → groundwater and surface water concentrations
- For short-chain PFCAs, soil concentration may correlate better with time from last application.
- For short-chain PFAS, loading rate → PFAS concentrations in well water and surface water
- Soil PFAS concentrations at depth may increase over time (slow leaching? degradation of precursors?)
- Presence in groundwater may follow release to surface soils by years if not decades, especially for longer chain PFAS (C8 and higher)
PFAS risk & land applied biosolids/residuals (Mobility/Leaching)

- Sorption in the soil does occur and may best be described as a sorption equilibrium reaction.
- PFAS sorption equilibria are influenced by:
  - PFAS carbon chain length
  - Organic carbon content
  - pH
  - [Ca$^{+2}$]
  - Clay content
  - Specific surface area
- More research needed.
PFAS risk and land applied biosolids/residuals (public health)

- Little evidence to date that residuals without obvious industrial PFAS contributions are a risk to public health via groundwater contamination following typical land application
- A determination of public health risk is influenced by several factors:
  - Type and quality of wastewater residuals,
  - PFAS compounds to be considered,
  - Field conditions (climate, soil type, depth to groundwater, etc.), and
  - Regulatory requirements (loading limits, land application restriction, drinking water standards, required setback, application rates).
- Differences in these factors from state to state can lead to different conclusions regarding public health risk.
- One potential set of conservative soil screening levels for protection of groundwater were calculated for PFOS (3 ug/kg) and PFOA (3 ug/kg) (Xiao et al. 2015). Other modeling suggests ~140 ug/kg may be appropriate. NY State is now using 72 ug/kg PFOA + PFOS for screening in particular permit conditions. These are the numbers state regulators want ASAP, but data is lacking for precision.
Northeast states evaluate locally
**PFAS in wastewater residuals: ≤2016 (presence)**

<table>
<thead>
<tr>
<th>Biosolids / Residual</th>
<th>PFOA (ug/kg)</th>
<th>PFOS (ug/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decatur, AL, PFAS manufacturer discharges (Lindstrom et al. 2011)</td>
<td>244</td>
<td>3000</td>
</tr>
<tr>
<td>Venkatesan &amp; Halden, 2013 (2001 TNSSS)</td>
<td>34</td>
<td>403</td>
</tr>
<tr>
<td>VT WRFF, town with industrial use (DEC, 2016) - wastewater solids compost</td>
<td>7.5 (mean)</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>ND (with SPLP = .061)</td>
<td>ND (with SPLP = .011)</td>
</tr>
<tr>
<td>VT septage, industrial impacted area</td>
<td>69</td>
<td>ND</td>
</tr>
</tbody>
</table>