Emerging Contaminants in U.S. Water Resources: Challenges and Potential Solutions

Rolf Halden, PhD, PE
Johns Hopkins University
Center for Water and Health

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Looking for a Simple Answer...

...to a Complex Problem
Overview

• Behavior & characteristics of environmental pollutants
  – Opportunities for learning from past mistakes

• Wastewater treatment - benefits and limitations

• Pollutant transfer from wastewater to agricultural land
The Chemosphere

- Actual number of chemicals is unknown (=> ∞)
- 26 million organic and inorganic compounds have been documented
- 9 million were commercially available in 2005
- 240,000 are inventoried or regulated by governments worldwide
- >4,800 are produced at quantities of >1 million lbs per year
- 2,800 earmarked for toxicity testing
- Which ones are emerging contaminants, EDCs, carcinogens?
What's Regulated?

List of Drinking Water Contaminants & MCLs

National Primary Drinking Water Regulations

National Primary Drinking Water Regulations (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems by limiting the levels of contaminants in drinking water. Visit the list of regulated contaminants with links for more details.

- List of Contaminants & their Maximum Contaminant Level (MCLs)
- Setting Standards for Safe Drinking Water to learn about EPA's standard-setting process
- EPA's Regulated Contaminant Timeline (88.7 KB PDF FILE, 1 pg) (ALL ABOUT PDF FILES)
- National Primary Drinking Water Regulations - The complete regulations regarding these contaminants available from the

National Secondary Drinking Water Regulations

National Secondary Drinking Water Regulations (NSDWRs or secondary standards) are non-enforceable guidelines regulating contaminants that affect public health or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems to comply. However, states may choose to adopt them as enforceable standards.

- List of National Secondary Drinking Water Regulations
- National Secondary Drinking Water Regulations - The complete regulations regarding these contaminants available from the

Unregulated Contaminants

This list of contaminants, at the time of publication, are not subject to any proposed or promulgated national primary drinking water regulations under SDWA. For more information check out the list, or visit the Drinking Water Contaminant Candidate List (CCL) website.

- List of Unregulated Contaminants
- Drinking Water Contaminant Candidate List (CCL) Web Site
- Unregulated Contaminant Monitoring Program (UCM)
Primary Chemical Contaminants

- Chemicals (~80 total)
  - Inorganic compounds (16)
    - Radionuclides (4 types/groups)
    - Elements (14)
  - Organic compounds (~53)
    - Non-halogenated compounds (12)
    - Halogenated compounds (~41)
    - Chlorinated compounds (40)

=> 75% of regulated organic DW contaminants are chlorinated organics
Global Transport of Pollutants
Origin of Surface Water & Drinking Water

Surface water

Drinking water

Wastewater

Metals, persistent biocides, etc.
Lessons (To Be) Learned

- **Produce and use** chemicals that:
  - have natural counterpart or origin
  - degrade rapidly
  - have a good safety record

- **Avoid** chemicals that are:
  - halogenated (Cl, Br, F substituents)
  - rare in nature / have random structure / mixtures
  - structurally related to chemicals of concern

- “Wastewater” is not waste, it is a source of drinking water
Overview

- Behavior (Individual & Societal)

- Wastewater Treatment

- Agriculture
## Triclosan (TCS) vs. Triclocarban (TCC)

<table>
<thead>
<tr>
<th>Name</th>
<th>Triclosan</th>
<th>Triclocarban</th>
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</thead>
<tbody>
<tr>
<td>Year Introduced</td>
<td>1964</td>
<td>1957</td>
</tr>
<tr>
<td>$\log K_{OW}$ (at 25°C, pH 7)</td>
<td>4.8</td>
<td>4.9</td>
</tr>
</tbody>
</table>

For each molecule in water, there are $\sim10^5$ in octanol (fat)

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1500 New Antimicrobial Products Since the Year 2000

- Production is increasing
- Benefits have been called into question (FDA panel, 2005)
- New risks are emerging
Cell assay: concentrations of as low as 30 ng/L alter thyroid hormone receptor mRNA expression (Remaining question: does this occur in vivo?)
Effects of Triclosan on *Mytilus galloprovincialis* hemocyte function and digestive gland enzyme activities: Possible modes of action on non target organisms

Laura Canesi a,*, Caterina Ciacci b, Lucia Cecilia Lorusso b, Michele Betti b, Gabriella Gallo a, Giulio Pojana c, Antonio Marcomini c

a Dipartimento di Biologia, Università di Genova, Corso Europa 26, 16132, Italy  
b Istituto di Scienze Fisiologiche, Università “Carlo Bo” di Urbino, Italy  
c Università Ca’ Foscari di Venezia, Italy

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Antimicrobials Can Act as Endocrine Disruptors

Short-Term *in Vivo* Exposure to the Water Contaminant Triclosan:
Evidence for Disruption of Thyroxine

Kevin M. Crofton¹, Katie B. Paul², Michael J. DeVito³ and Joan M. Hedge¹

¹ Neurotoxicology Division and ³ Experimental Toxicology Division, National Health and Environmental Effects Research Laboratory, Office of Research and Development, U.S. EPA, Research Triangle Park, NC; ² Curriculum in Toxicology, University of North Carolina, Chapel Hill, NC.
Co-Occurrence of TCC and TCS in MD Streams

Calculate TCC

Measure TCS

R² = 0.988

TCC [ng/L]

TCS [ng/L]

Predictions for 85 Streams Across the U.S.


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Predicted Nationwide Contamination Was Confirmed Experimentally

<table>
<thead>
<tr>
<th></th>
<th>Model</th>
<th>Experimental</th>
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<tbody>
<tr>
<td>Number of samples</td>
<td>85</td>
<td>18</td>
</tr>
<tr>
<td>Detection Frequency</td>
<td>60%</td>
<td>56% 100%</td>
</tr>
<tr>
<td>Mean [ng/L]</td>
<td>213</td>
<td>12±15 84±109</td>
</tr>
</tbody>
</table>

(Sapkota et al., Environmental Research 2007)
Partitioning, Persistence, and Accumulation in Digested Sludge of the Topical Antiseptic Triclocarban during Wastewater Treatment

JOCHEN HEIDLER, AMIR SAPKOTA, AND ROLF U. HALDEN*

Department of Environmental Health Sciences, Bloomberg School of Public Health, Johns Hopkins University Center for Water and Health, Johns Hopkins University, 615 North Wolfe Street, Room E6618, Baltimore, Maryland 21205-2103

attention has been focused on PPCPs passing through conventional wastewater treatment plants (WWTPs) and becoming detectable in effluent-receiving streams (3), few studies have explored the partitioning of compounds into municipal wastewater residuals and their subsequent fate during sludge treatment (1, 4, 5). This lack of information is due in part to the difficulty of accurately detecting and quantifying PPCPs in the challenging analytical matrix of municipal sludge. Previously, our laboratory employed isotope dilution gradient liquid chromatography with electrospray ionization mass spectrometry (6) to perform a preliminary analysis of the behavior of PPCPs in a large activated sludge WWTP (5). Following development of a more selective method using triple quadrupole tandem mass spectrometry (7), this novel tool was applied to conduct a mass balance for a specific PPCP whose environmental fate has long been neglected (4).

• Activated sludge WWTP
• 600 ML/D (180 MGD)
• Population served: 1.3 M
Triclocarban Is Removed From Wastewater

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...Only to Accumulate in Sludge
Mass Balance Calculation

\[ M_{\text{trans}} = (Q_{\text{inf}} \times C_{\text{inf}}) - (Q_{\text{eff}} \times C_{\text{eff}}) - (TS_{\text{dig}} \times Q_{\text{dig}} \times C_{\text{dig}}) - M_{\text{vol}} \]

- **M** = Mass loading (kg/d)
- **Q** = Flow rate (L/d)
- **C** = Concentration (g/L)
- **TS** = Total solids (%)  

\[ M_{\text{vol}} = \text{negligible} \]
TCC Mass Balance for a Mid-Atlantic Plant

- Mass in effluent: 795 g/d
- Mass in sludge: 2815 g/d
- Mass transformed/lost: 127 g/d

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Triclosan Mass Balance for a Mid-Atlantic Plant

- Mass in effluent: 2 ± 1%, 55 g/d
- Mass in sludge: 48 ± 19%, 1540 g/d
- Mass transformed/lost: 50 ± 19%, 1640 g/d

Lessons (To Be) Learned

• Control chemical inputs into wastewater more tightly

• “Treat” wastewater as a resource!

• Pollution prevention is the fastest, most economical and most effective way of reducing EDC & pollutant releases
  – Biocides, pharmaceuticals, personal care products, etc.

• Have reasonable expectation; cleaning water generates sequestered pollutants as byproducts (e.g., metals in sludge)
Treatment Solutions

• Don’t allow unnecessary EDCs into commerce and into wastewater

• Polishing technologies can help to reduce EDCs in secondary effluent
  – Activated carbon: $$$, waste transfer, secondary pollution
  – Chlorination, ozonation, UV treatment: $-$$$, unknown byproducts
  – Design & cost: WWTP => DWTP

• However, pollution prevention is cheaper & more practical
Overview

- Behavior (Individual & Societal)
- Wastewater Treatment
- Agriculture
Fate of Sludge Produced at the WWT Plant

- Beneficial Reuse: 95%
- To Landfill: 4%
- Incineration: 1%

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Unexpected Consequences of Consumer Behavior

Antibacterial bar soap used by consumers

“Active” ingredient (Triclocarban) applied onto soils

4 Soap bars

3 Soap bars

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12.5 Billion dry lb/yr (125,000 railroad cars) of sludge

- Land Application: 63%
- Landfills: 17%
- Incineration: 19%
- Other: 1%

*Estimated Mass & Use of Biosolids in U.S.*

*Biosolids Applied to Land, National Research Council of the National Academies, 2002*
Map of States Examined
Biocide Inputs to Agricultural Soils

Triclocarban

- ~74% to Ag

Triclosan

- ~10^5 Kg/year to Ag


Chemosphere 2007
Sludge: a Repository of Recalcitrant Chemistry

The JHU National Biosolids Repository

2005 JHSPH Faculty Research Initiative

R. Halden, N. Kanarek and E. Platz

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Lessons (To Be) Learned

- Sludge composition is presently unknown
- Sludge is a concentrate of “hard-to-deal-with” compounds
- Sludge quality depends on wastewater quality
- Sludge is a resource of nutrients (N, P, C) and potentially valuable (but we have to protect its quality)
Conclusions: We Can...

- Reduce EDCs at the source
  - Individual household
  - Community
  - Society
- Save $$$ and time by doing the above
- Increase the safety profile of biosolids in the process
- (We can) But may NOT have to turn every WWTP into a DWTP

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Control Pollutant Release at the Source by Changing Individual Behavior and Chemicals Used

Influent → Mechanical Screens → Primary Clarifiers → Activated Sludge Treatment → Secondary Clarifiers → Chlorine → Sand Filters → Effluent

- Primary Clarifiers
- Activated Sludge Treatment
- Secondary Clarifiers
- Chlorine
- Sand Filters
- Effluent

- Primary Sludge
- Secondary Sludge
- Sludge Thickeners
- Anaerobic Digesters
- Dewatered digested sludge

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