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

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Johns Hopkins University
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Invited Presentation to the Interstate Commission on the Potomac River Basin, Rockville, MD

May 7, 2007

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?

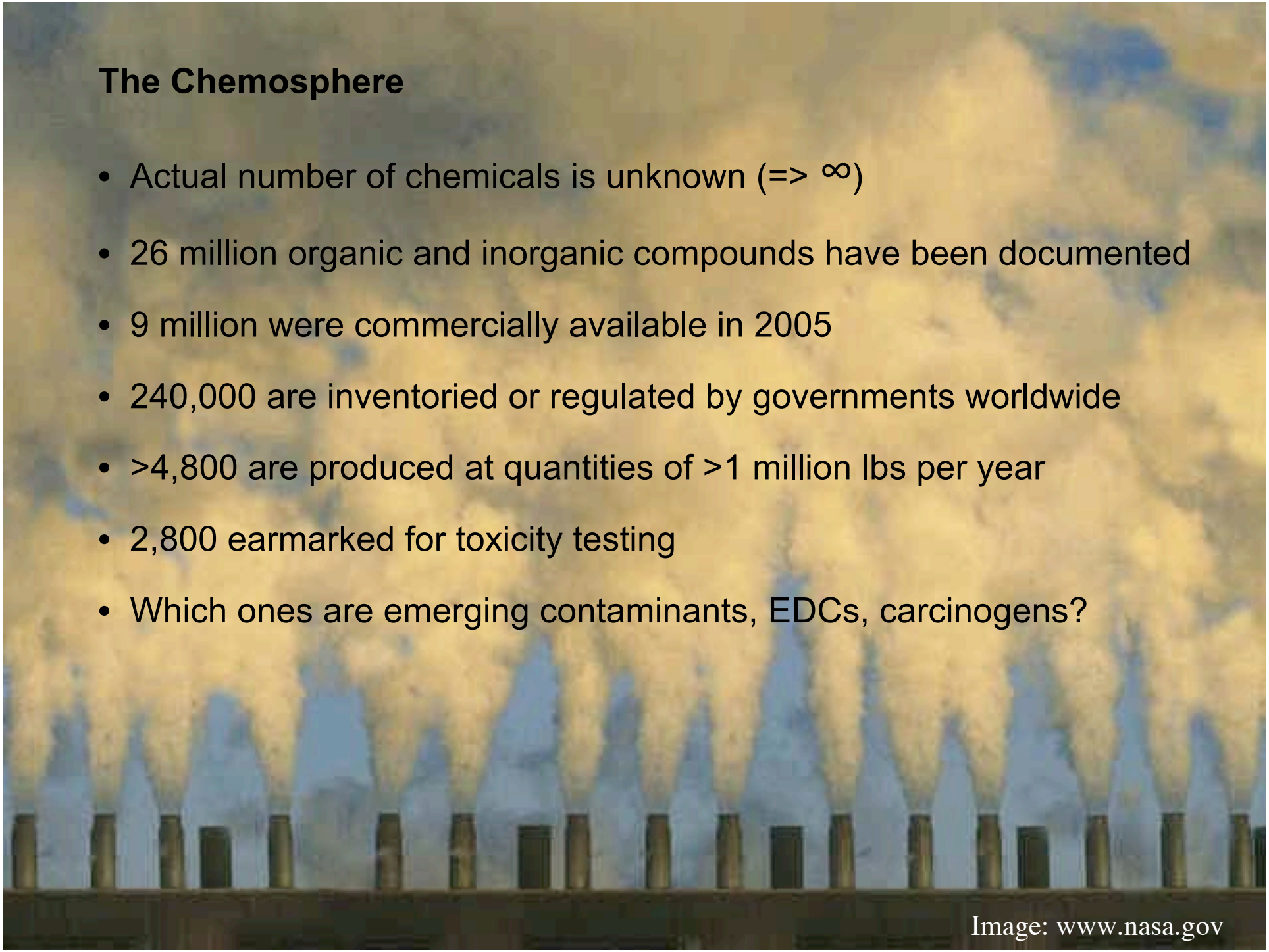
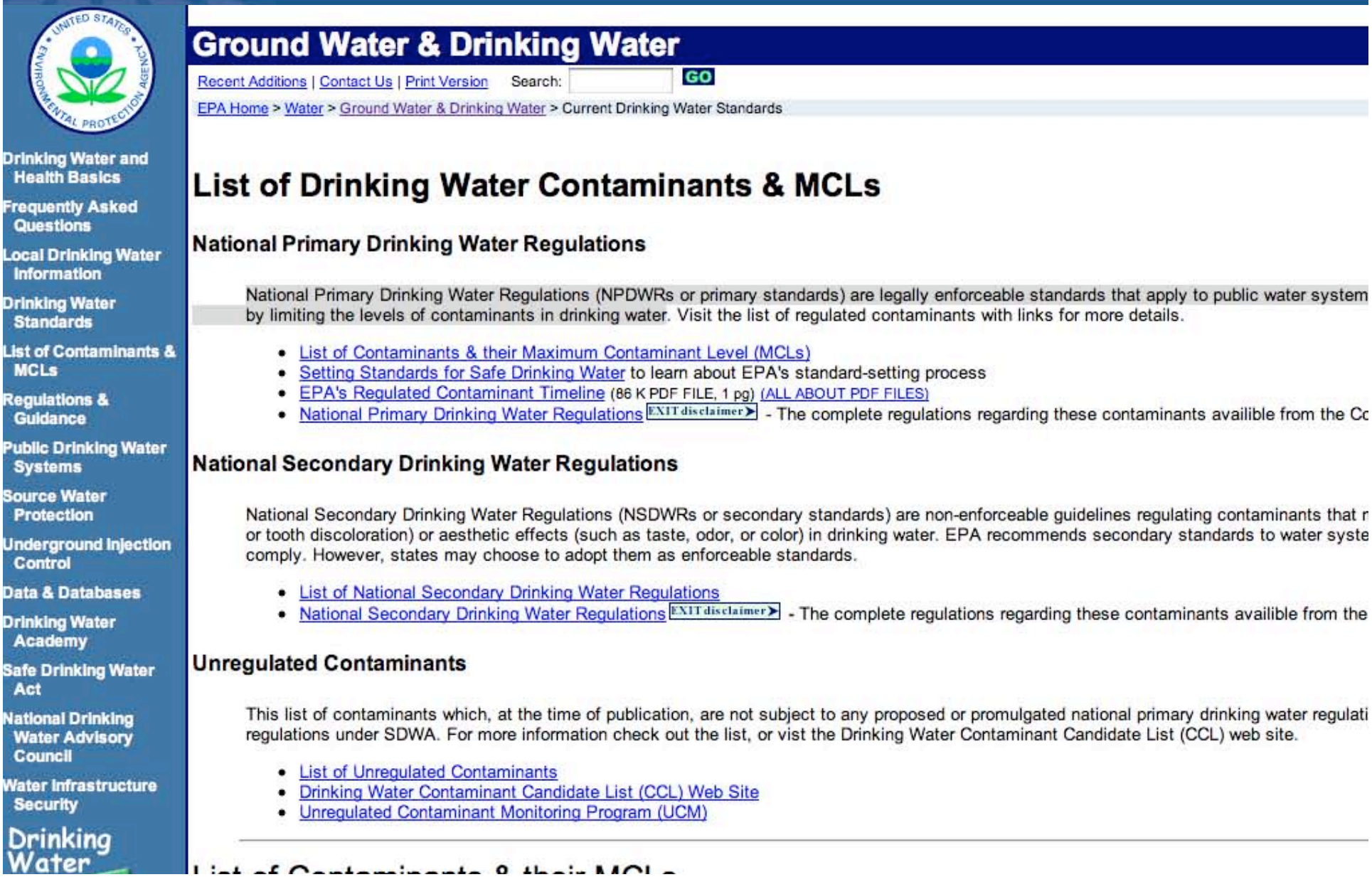


Image: www.nasa.gov

What's Regulated?



Ground Water & Drinking Water

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EPA Home > Water > Ground Water & Drinking Water > Current Drinking Water Standards

- Drinking Water and Health Basics
- Frequently Asked Questions
- Local Drinking Water Information
- Drinking Water Standards
- List of Contaminants & MCLs
- Regulations & Guidance
- Public Drinking Water Systems
- Source Water Protection
- Underground Injection Control
- Data & Databases
- Drinking Water Academy
- Safe Drinking Water Act
- National Drinking Water Advisory Council
- Water Infrastructure Security

Drinking Water

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 system 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 (86 K PDF FILE, 1 pg) (ALL ABOUT PDF FILES)
- National Primary Drinking Water Regulations EXIT disclaimer - The complete regulations regarding these contaminants availible from the Cc

National Secondary Drinking Water Regulations

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

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

Unregulated Contaminants

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

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

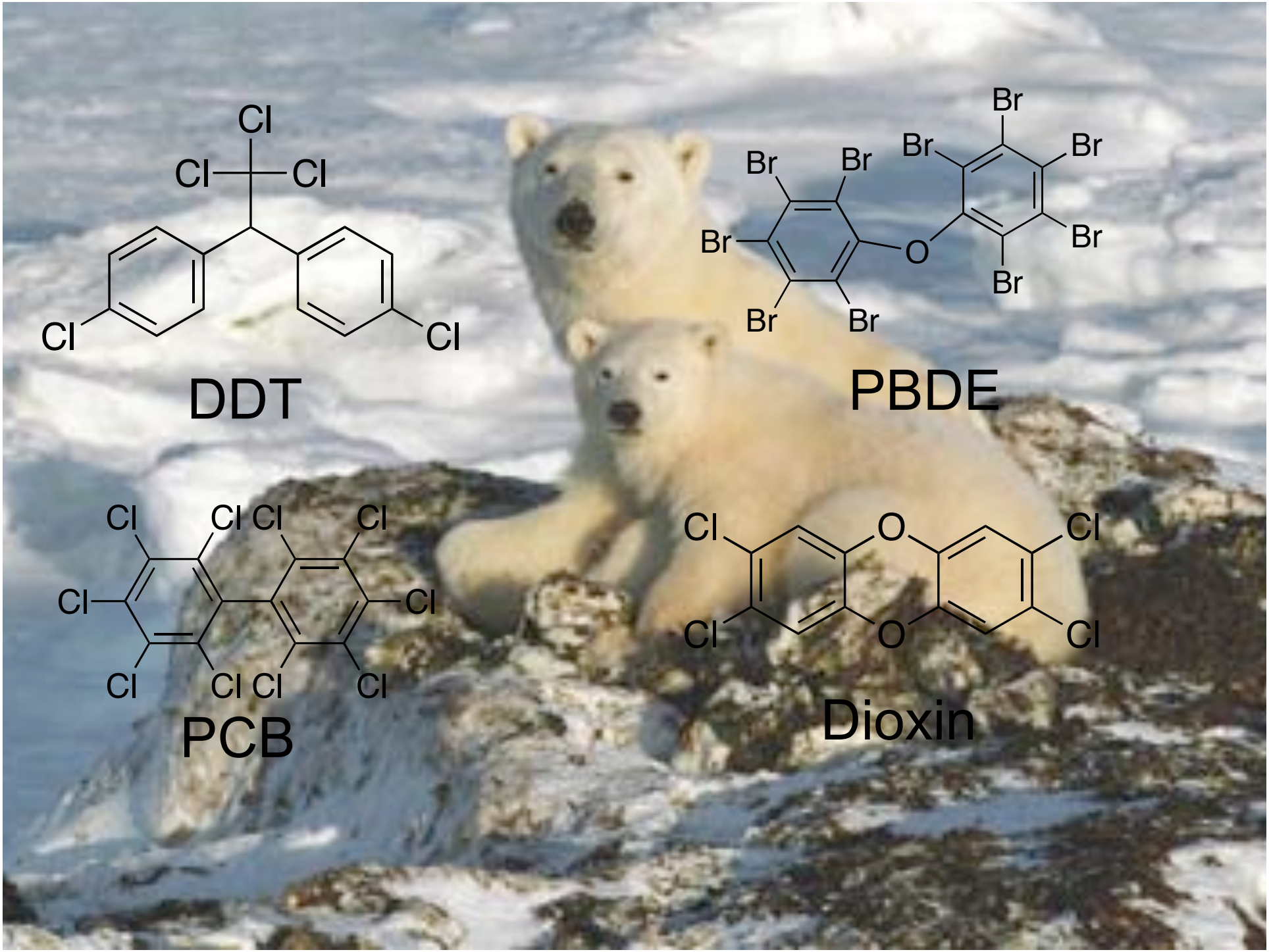
List of Contaminants & their MCLs

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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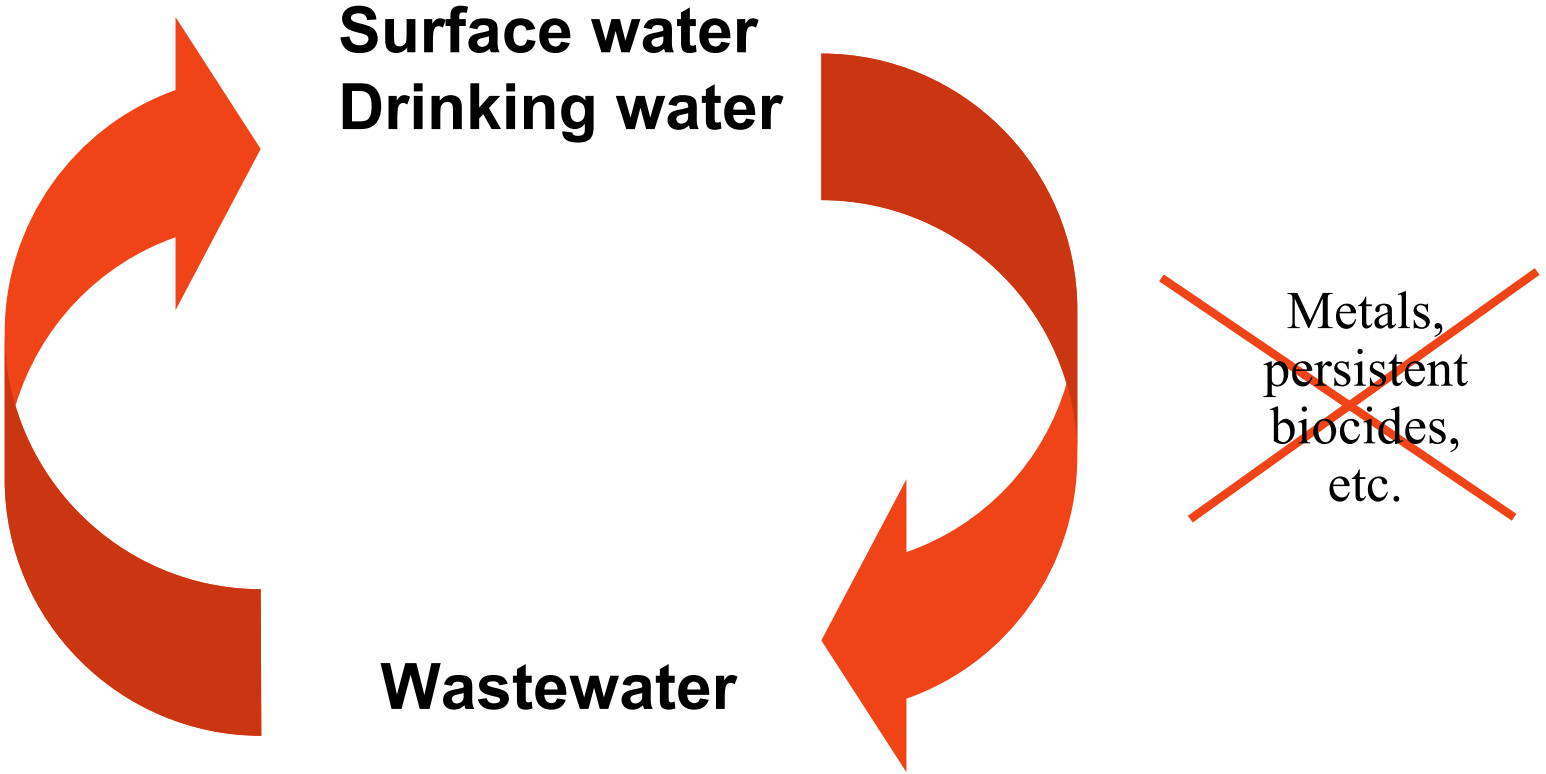
Dioxin

Origin of Surface Water & Drinking Water



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

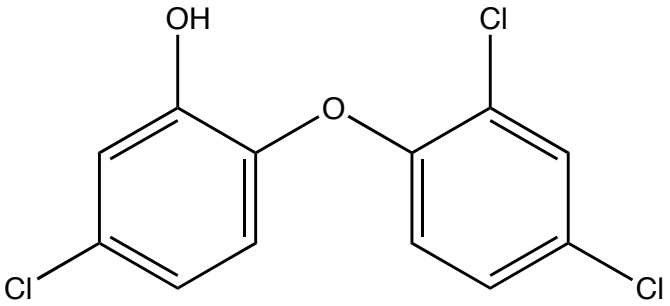
- “Wastewater” is not waste, it is a source of drinking water

Overview

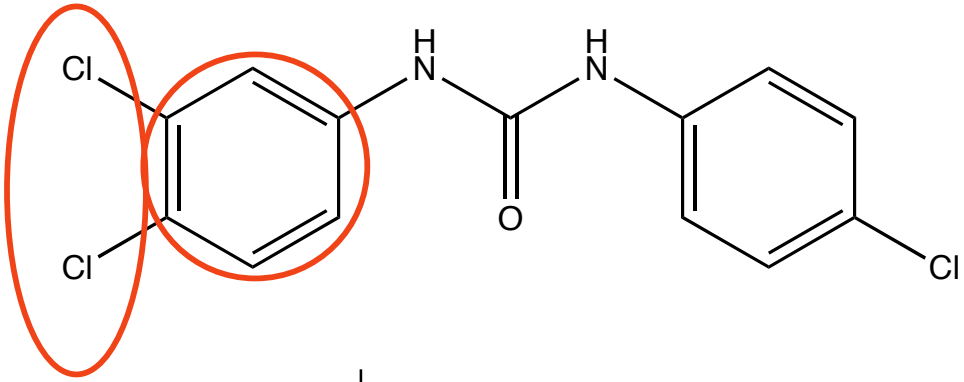
- Behavior (Individual & Societal)
- **Wastewater Treatment**
- Agriculture

Walking 2 Pollutants Through a Sewage Treatment Plant

Triclosan (TCS)



Triclocarban (TCC)



Name	Triclosan	Triclocarban
Year Introduced	1964	1957
Log K_{OW} (at 25ºC, pH 7)	4.8	4.9

For each molecule in water, there are ~10^5 in octanol (fat)

1500 New Antimicrobial Products Since the Year 2000

- Production is increasing
- Benefits have been called into question (FDA panel, 2005)
- New risks are emerging

Antimicrobials Can Act as Endocrine Disruptors

ELSEVIER

Aquatic Toxicology 80 (2006) 217–227

AQUATIC TOXICOLOGY

www.elsevier.com/locate/aquatox

The bactericidal agent triclosan modulates thyroid hormone-associated gene expression and disrupts postembryonic anuran development

Nik Veldhoen [a], Rachel C. Skirrow [b], Heather Osachoff [b], Heidi Wigmore [b], David J. Clapson [a], Mark P. Gunderson [a], Graham Van Aggelen [b], Caren C. Helbing [a,*]

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[b] *Pacific Environmental Science Centre, 2645 Dollarton Highway, North Vancouver, British Columbia V7H 1V2, Canada*

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Cell assay: concentrations of as low as 30 ng/L alter thyroid hormone receptor mRNA expression (Remaining question: does this occur in vivo?)

Antimicrobials Can Act as Endocrine Disruptors

Available online at www.sciencedirect.com
ScienceDirect
Comparative Biochemistry and Physiology, Part C 145 (2007) 464–472
CBP
www.elsevier.com/locate/cbpc

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]

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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

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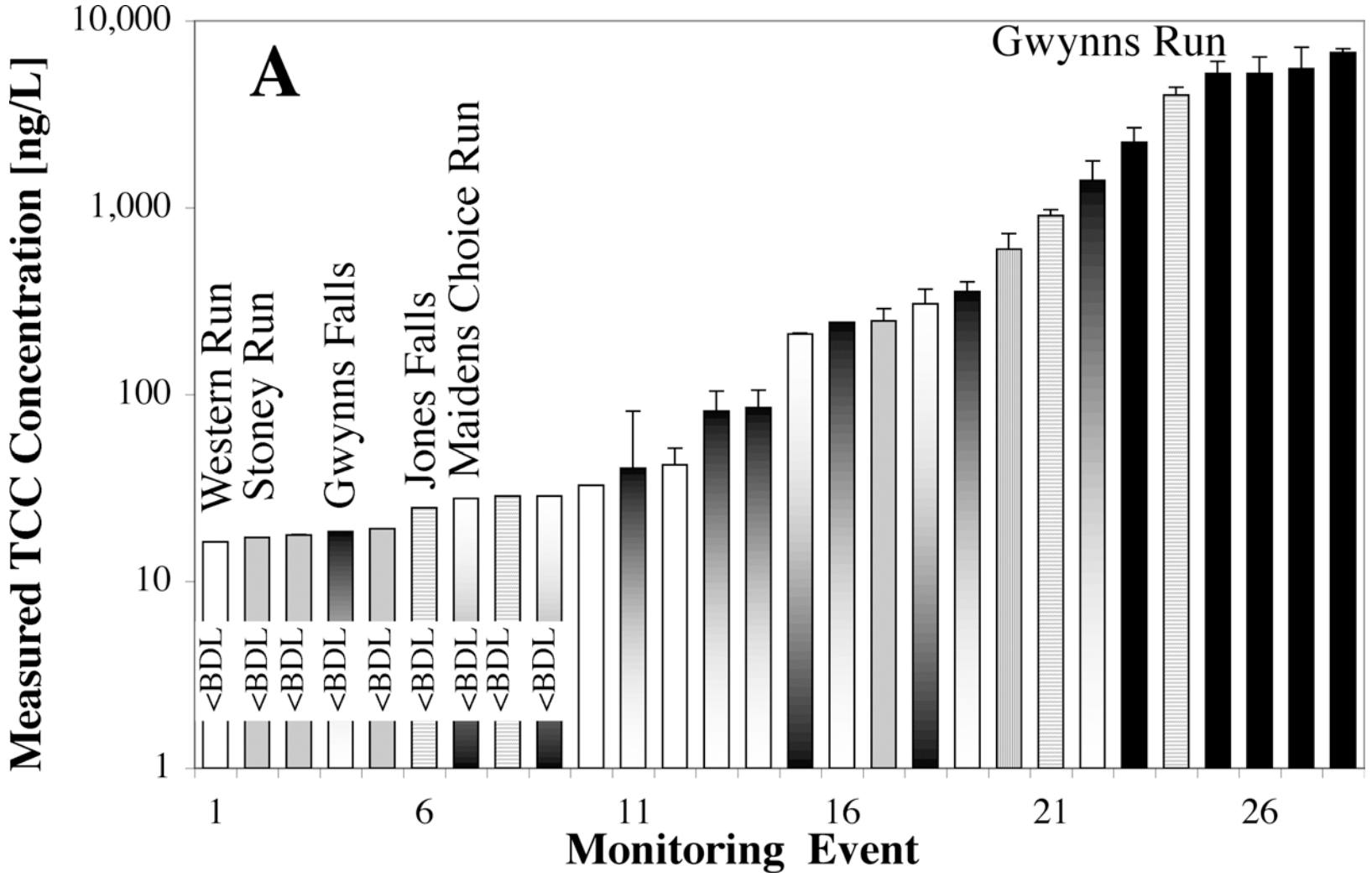
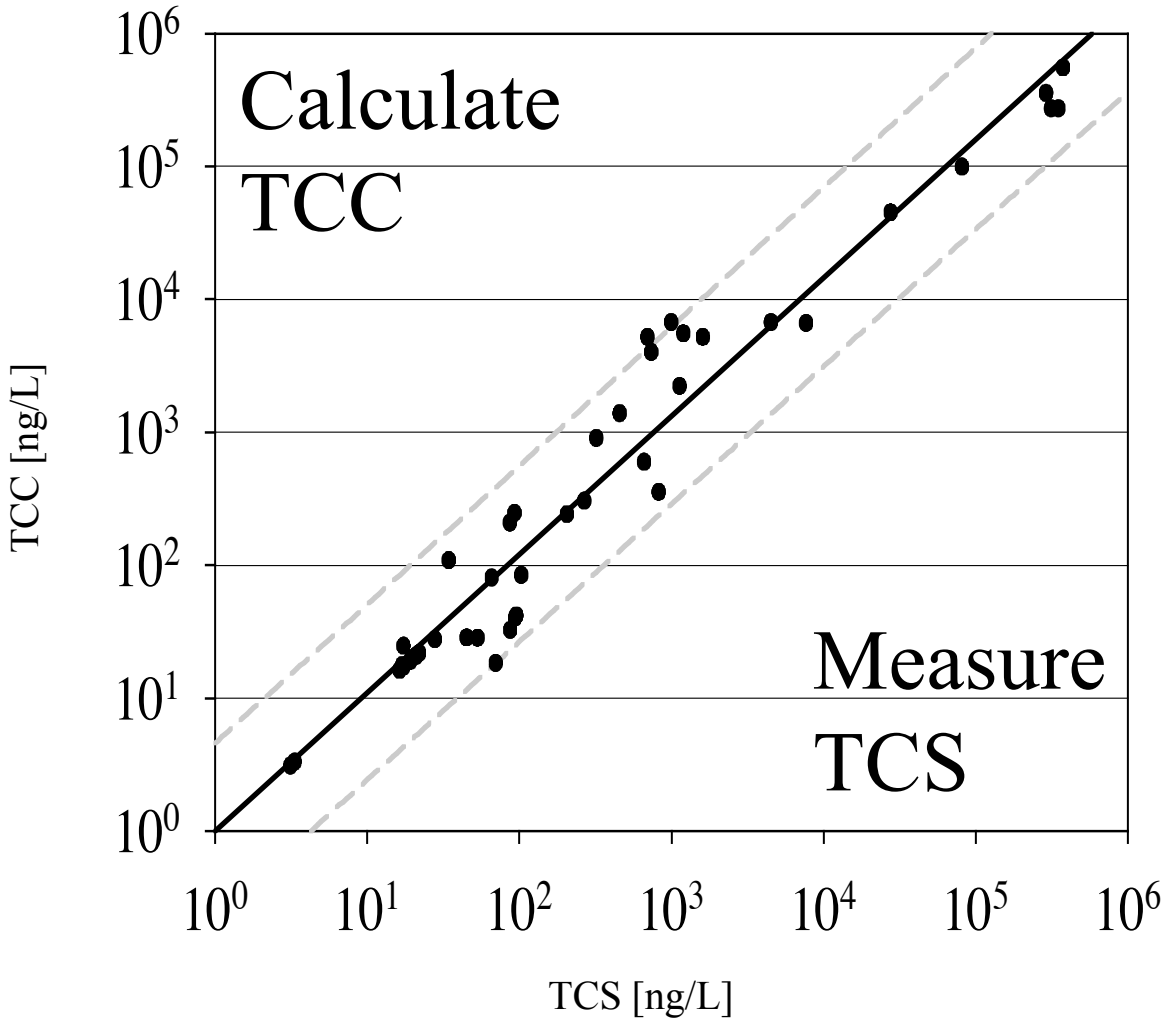
[1] Neurotoxicology Division and [3]Experimental Toxicology Division,
National Health and Environmental Effects Research Laboratory,
Office of Research and Development, U.S. EPA, Research Triangle Park, NC;
[2]Curriculum in Toxicology, University of North Carolina, Chapel Hill, NC.

Triclocarban Contamination in Baltimore Streams



Halden & Paull, ES&T 38(18):4849-4855 (2004)

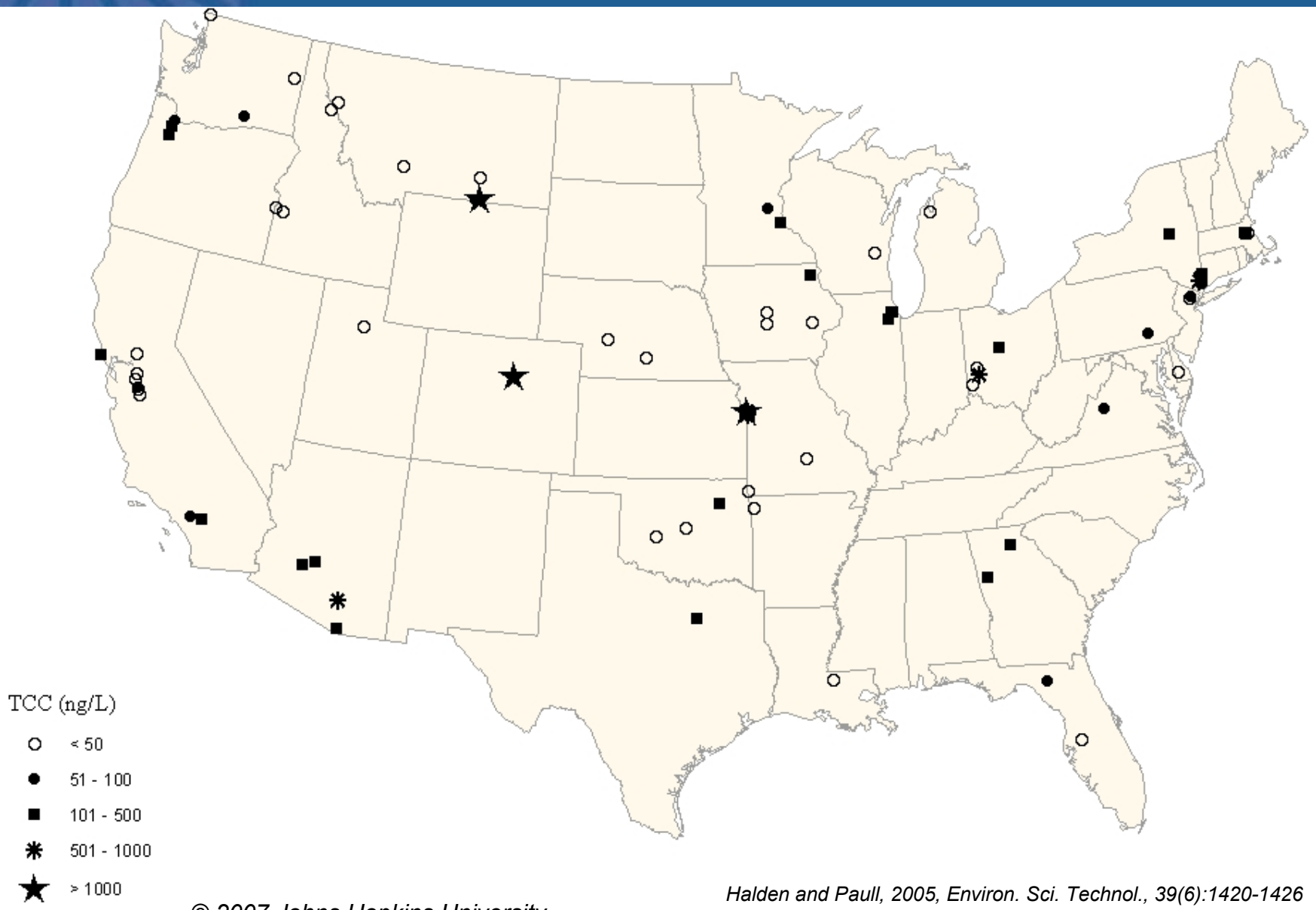
Co-Occurrence of TCC and TCS in MD Streams



$R^2 = 0.988$

Halden and Paull, 2005, Environ. Sci. Technol., 39(6):1420-1426

Predictions for 85 Streams Across the U.S.



Halden and Paull, 2005, Environ. Sci. Technol., 39(6):1420-1426

Predicted Nationwide Contamination Was Confirmed Experimentally

	Model	Experimental	
		Upstream	Downstream
Number of samples	85	18	18
Detection Frequency	60%	56%	100%
Mean [ng/L]	213	12±15	84 ±109

(Sapkota et al., Environmental Research 2007)

Antimicrobials Defy Wastewater Treatment

Environ. Sci. Technol. **2006**, *40*, 3634−3639

Partitioning, Persistence, and Accumulation in Digested Sludge of the Topical Antiseptic Triclocarban during Wastewater Treatment

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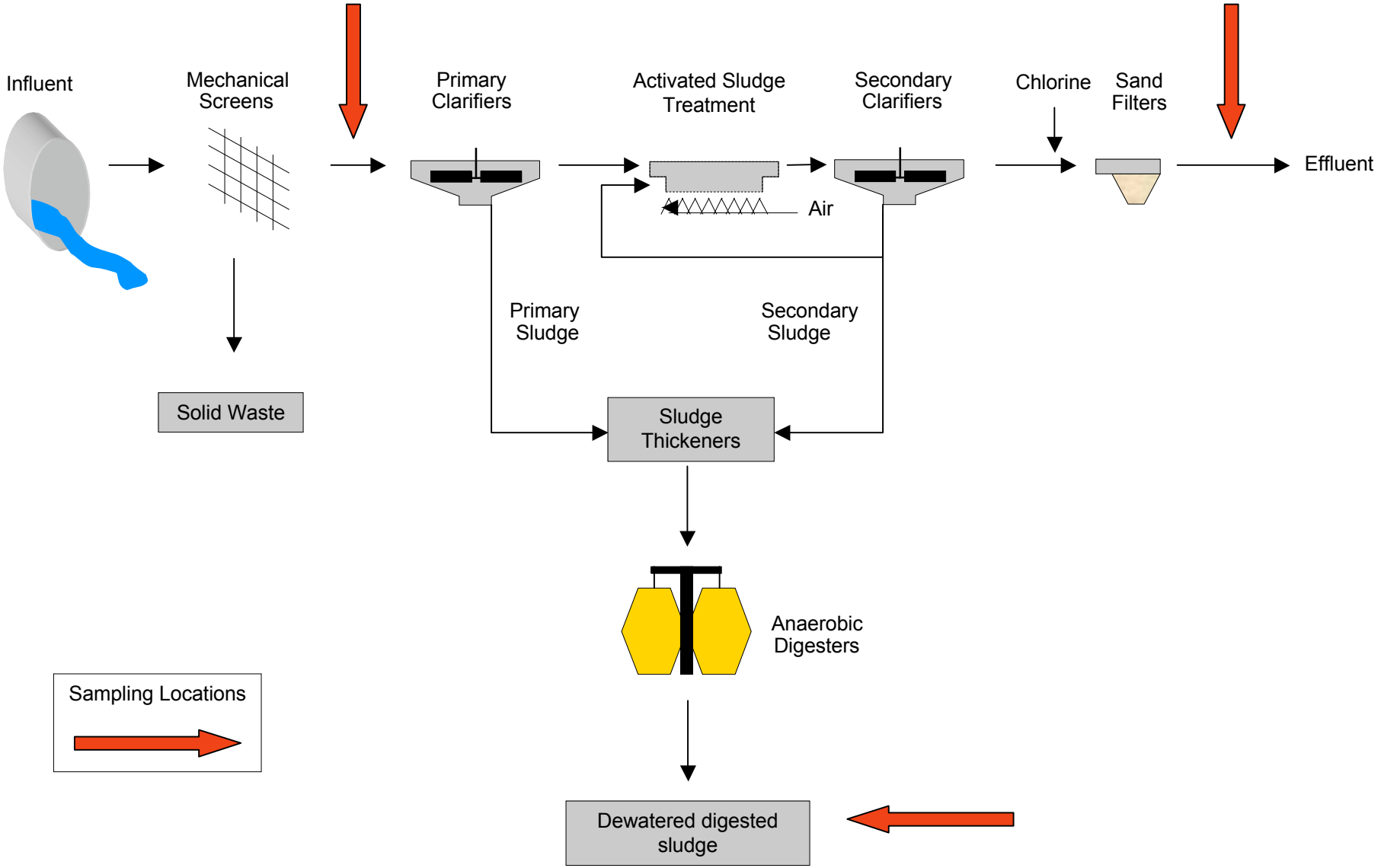
attention has been focused on PPCPs passing through conventional wastewater treatment plants (WWTPs) and becoming detectable in effluent-receiving streams (*3*), few studies have explored the partitioning of compounds into municipal wastewater residuals and their subsequent fate during sludge treatment (*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*).

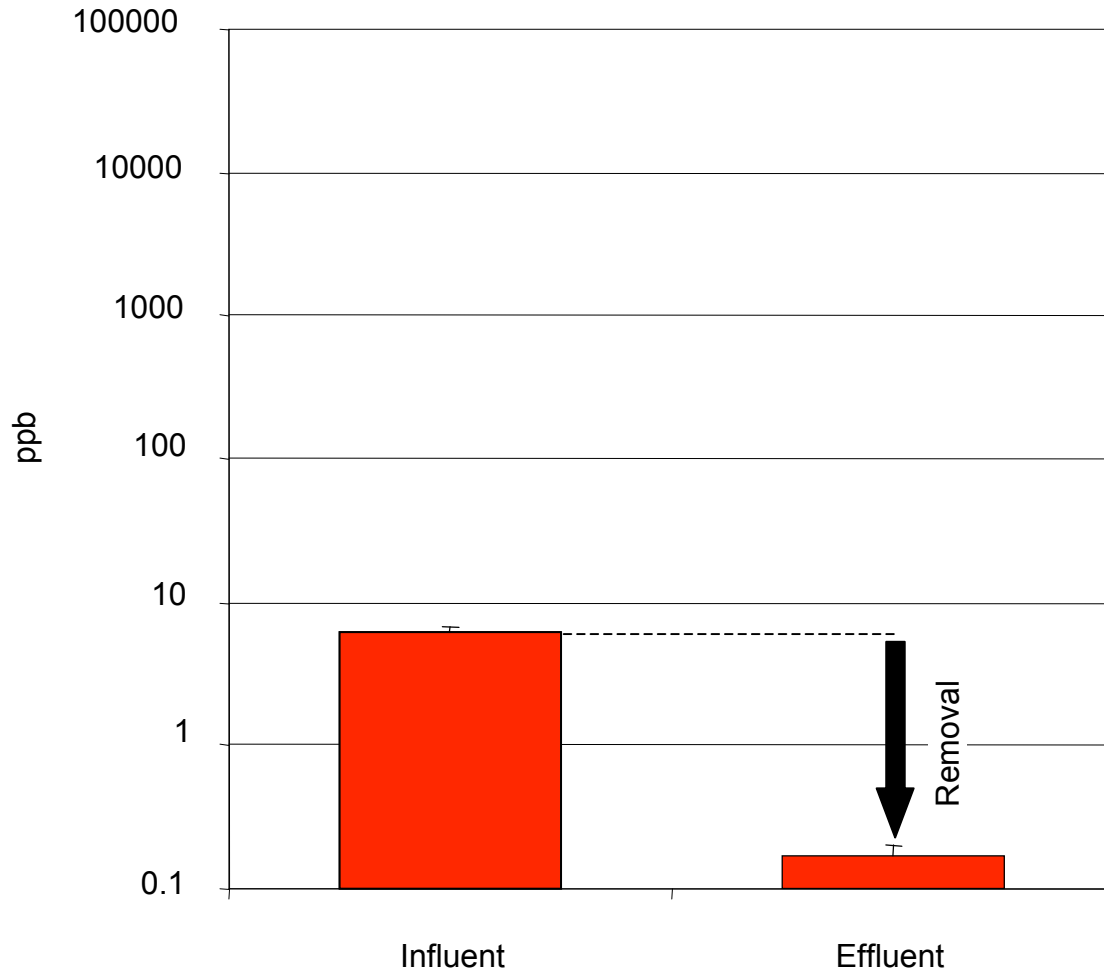
- Activated sludge WWTP
- 600 ML/D (180 MGD)
- Population served: 1.3 M

Process Diagram of Activated Sludge Wastewater Treatment Plant

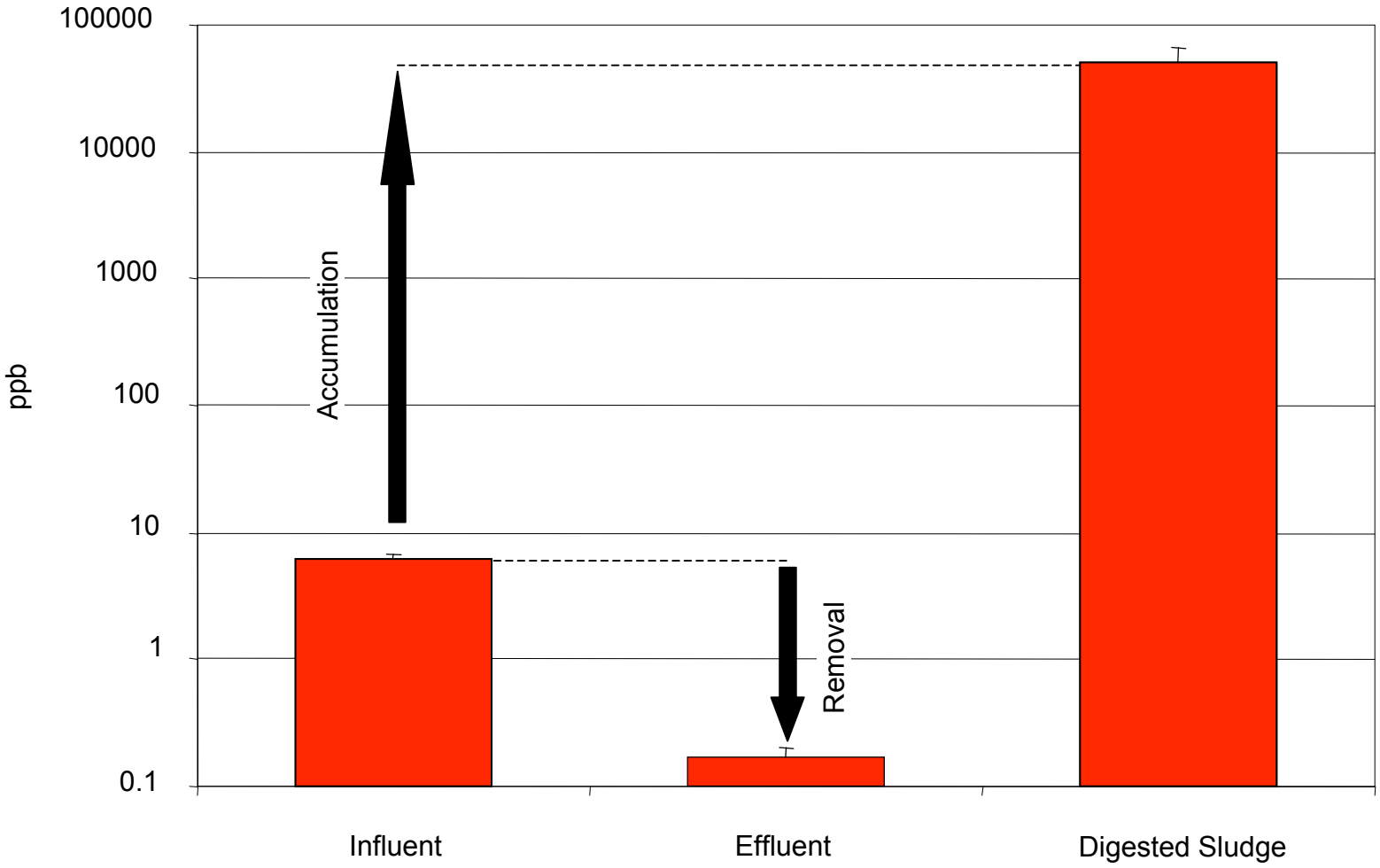


ES&T 40(11) 3634-39, (2006)

Triclocarban Is Removed From Wastewater

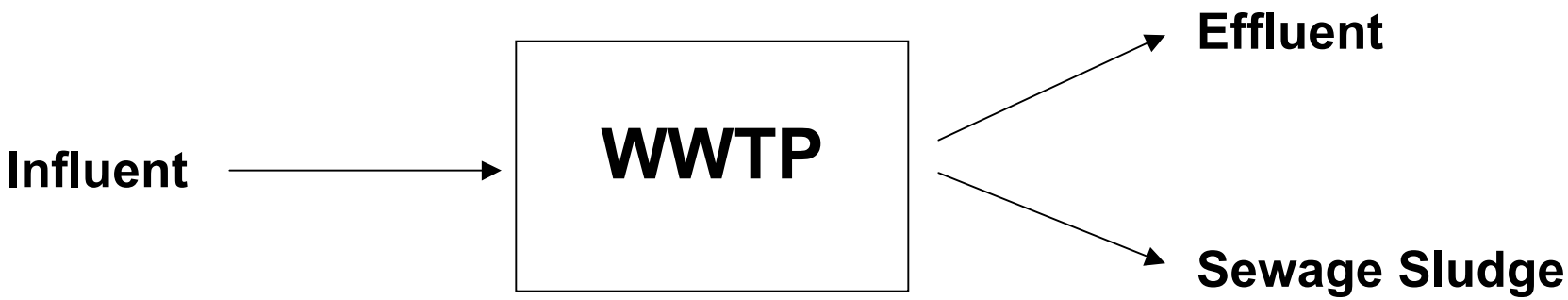


...Only to Accumulate in Sludge



ES&T 40(11) 3634-39, (2006)

Mass Balance Calculation



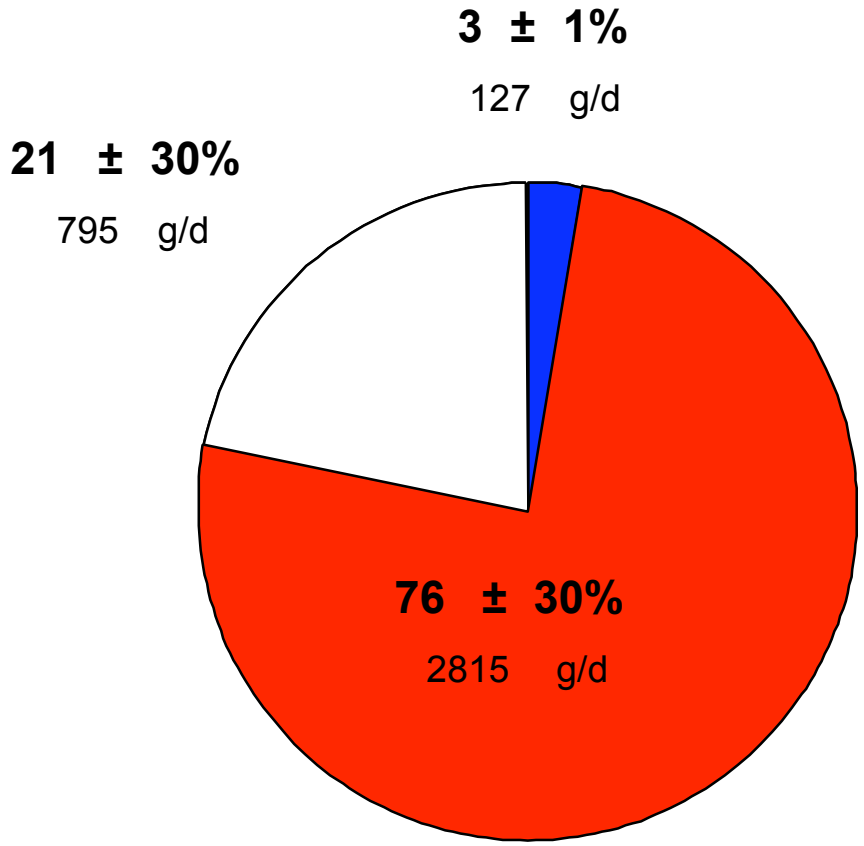
$$M_{trans} = \left(Q_{\inf} \times C_{\inf}\right) - \left(Q_{eff} \times C_{eff}\right) - \left(TS_{dig} \times Q_{dig} \times C_{dig}\right) - M_{vol}$$

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

M_{vol} = negligible

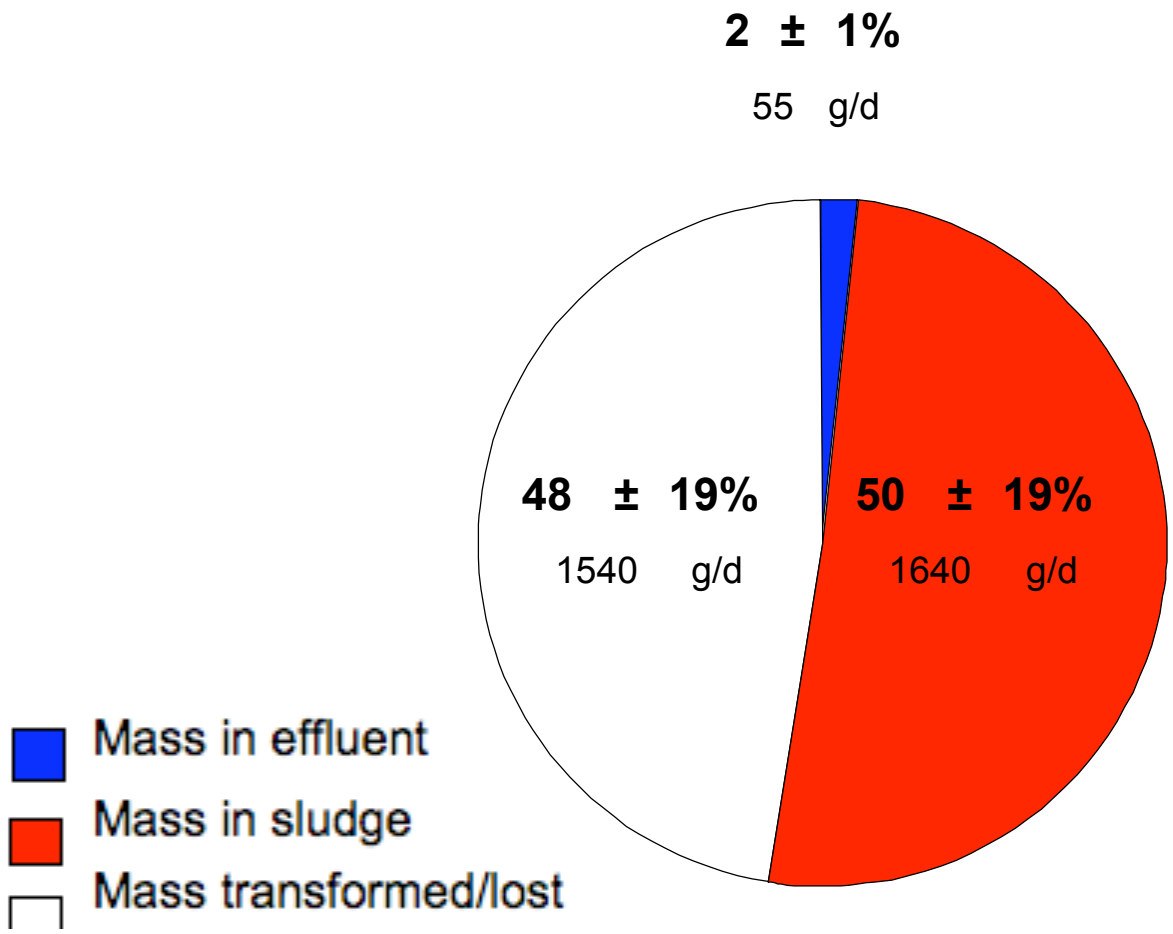
ES&T 40(11) 3634-39, (2006)

TCC Mass Balance for a Mid-Atlantic Plant



ES&T 40(11) 3634-39, (2006)

Triclosan Mass Balance for a Mid-Atlantic Plant



Heidler & Halden, 2007. Chemosphere, 66(2):362-369.

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

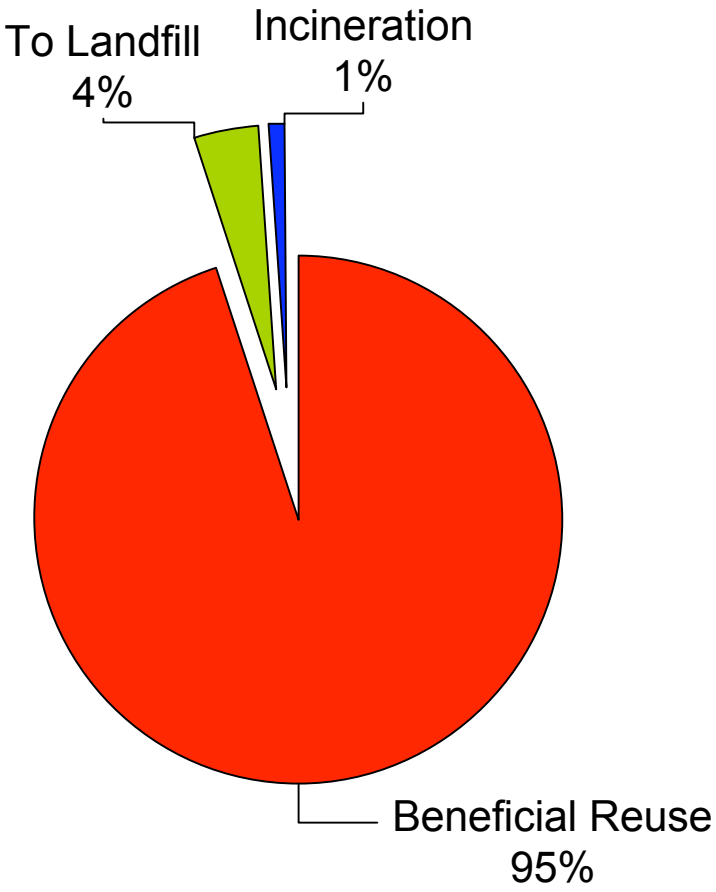
- Polishing technologies can help to reduce EDCs in secondary effluent
  - Activated carbon: $$$, waste transfer, secondary pollution
  - Chlorination, ozonation, UV treatment: $-$$$, unknown byproducts
  - Design & cost: WWTP => DWTP

- However, pollution prevention is cheaper & more practical

Overview

- Behavior (Individual & Societal)
- Wastewater Treatment
- **Agriculture**

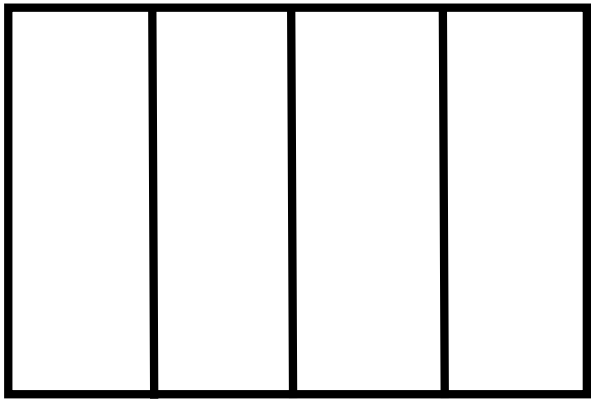
Fate of Sludge Produced at the WWT Plant



ES&T 40(11) 3634-39, (2006)

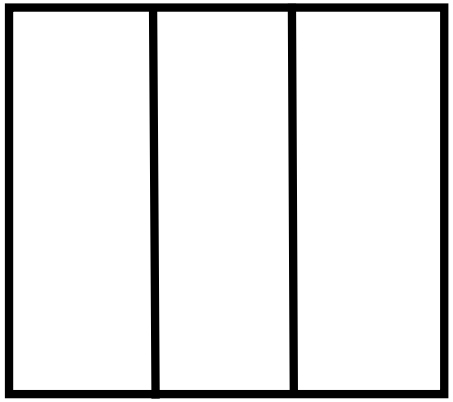
Unexpected Consequences of Consumer Behavior

Antibacterial bar soap used by consumers



4 Soap bars

"Active" ingredient (Triclocarban) applied onto soils

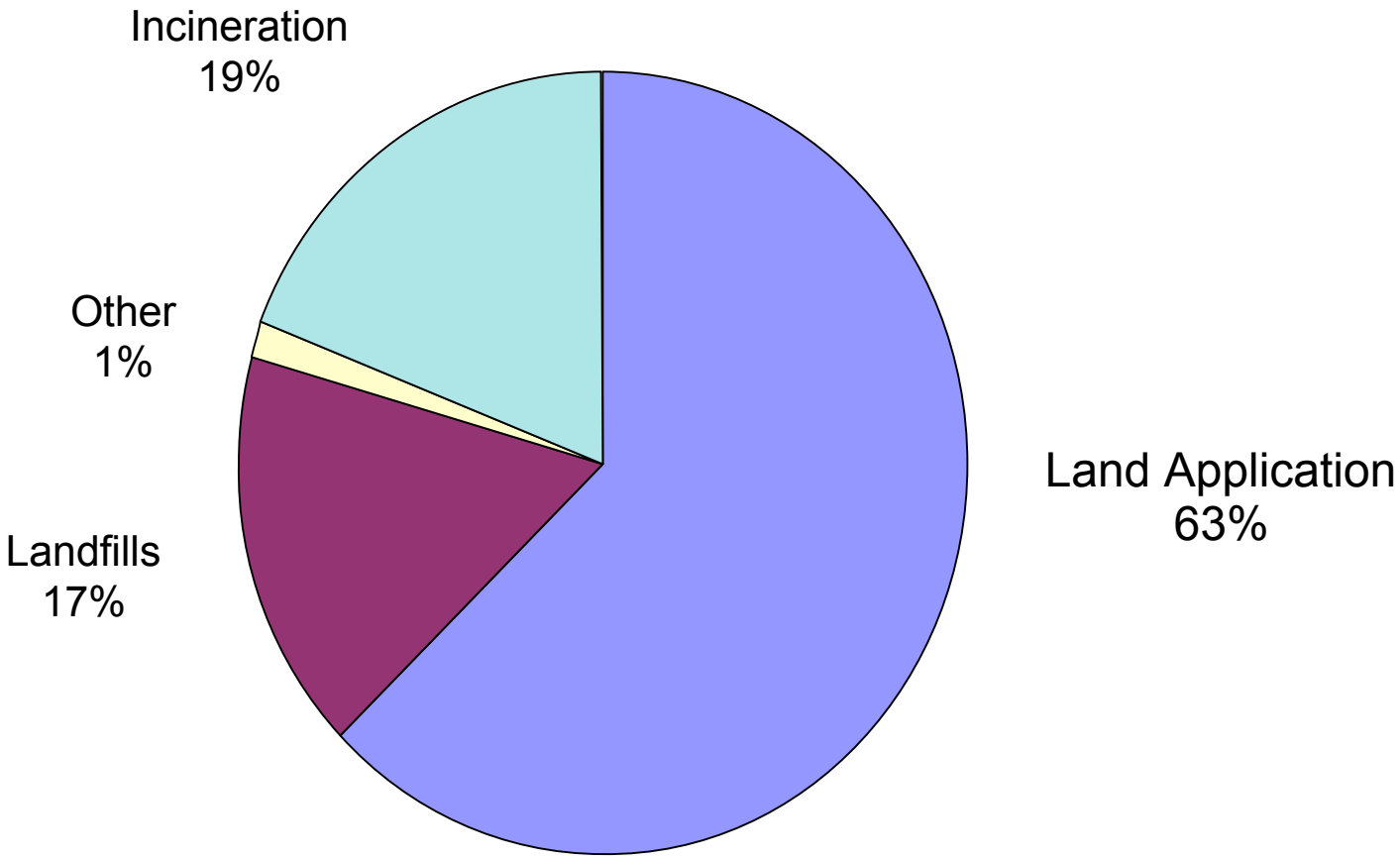


3 Soap bars

Environ. Sci. & Technol. 40(11) 3634-39, (2006)

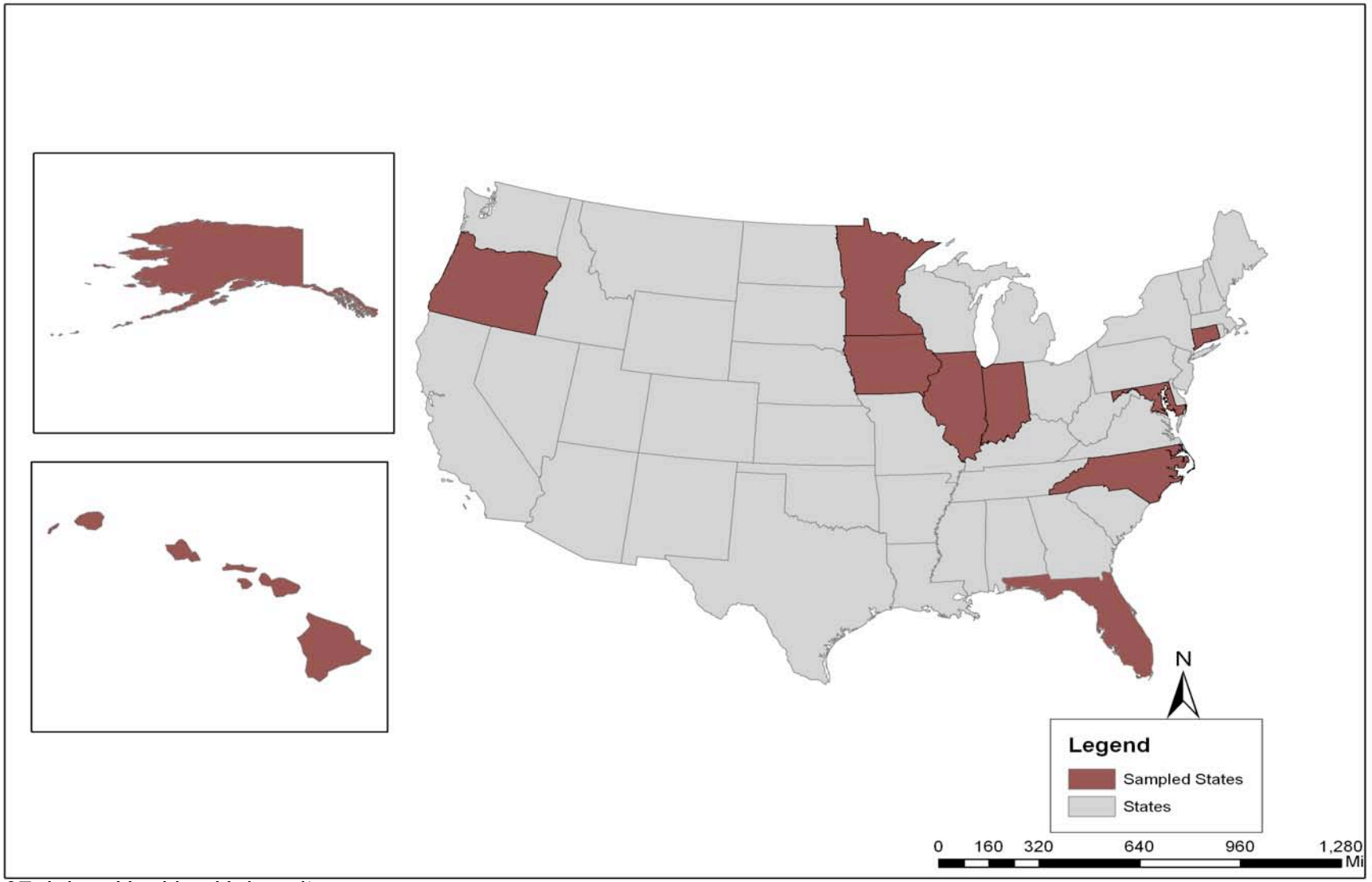
Estimated Mass & Use of Biosolids in U.S.

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



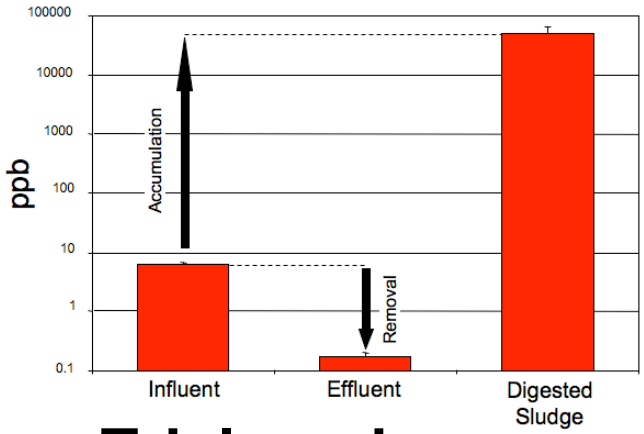
Biosolids Applied to Land, National Research Council of the National Academies, 2002

Map of States Examined

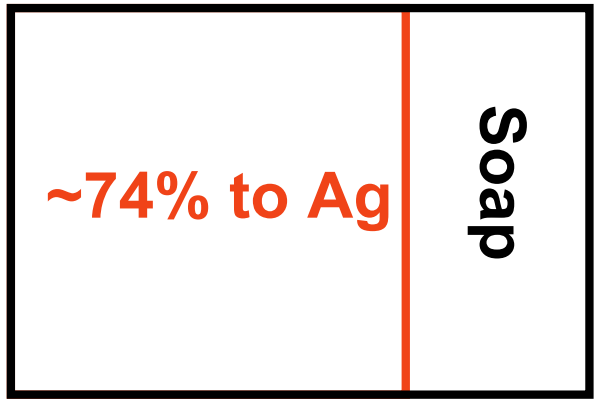


Unpublished data; Heidler et al.

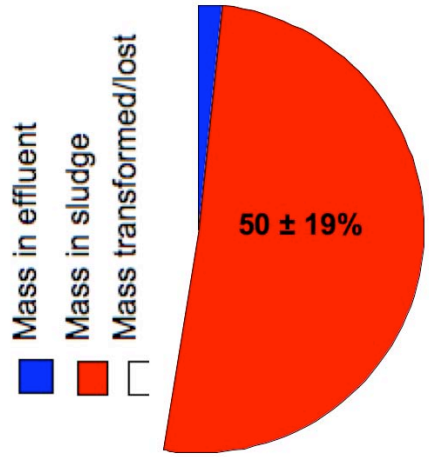
Biocide Inputs to Agricultural Soils



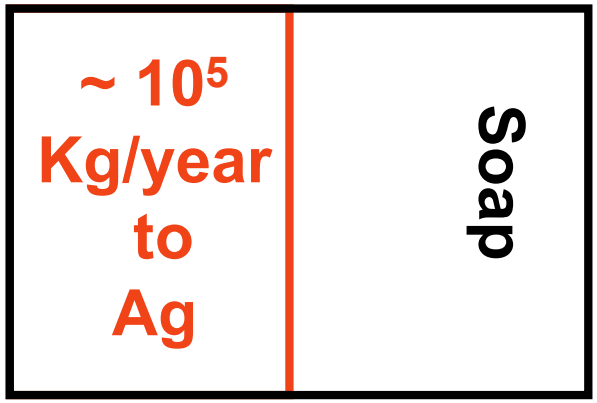
Triclocarban



ES&T 40(11) 3634-39, (2006)

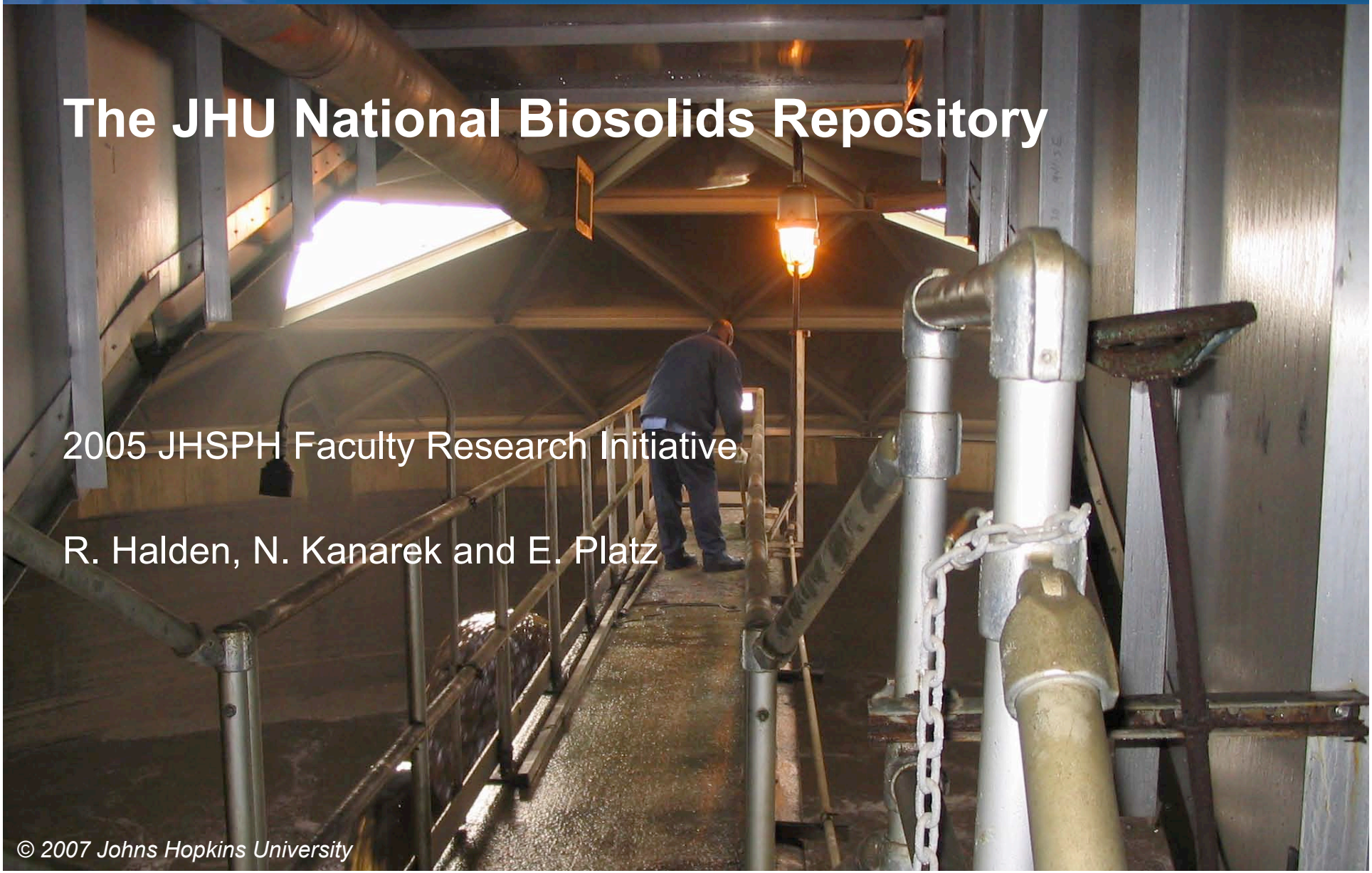


Triclosan



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

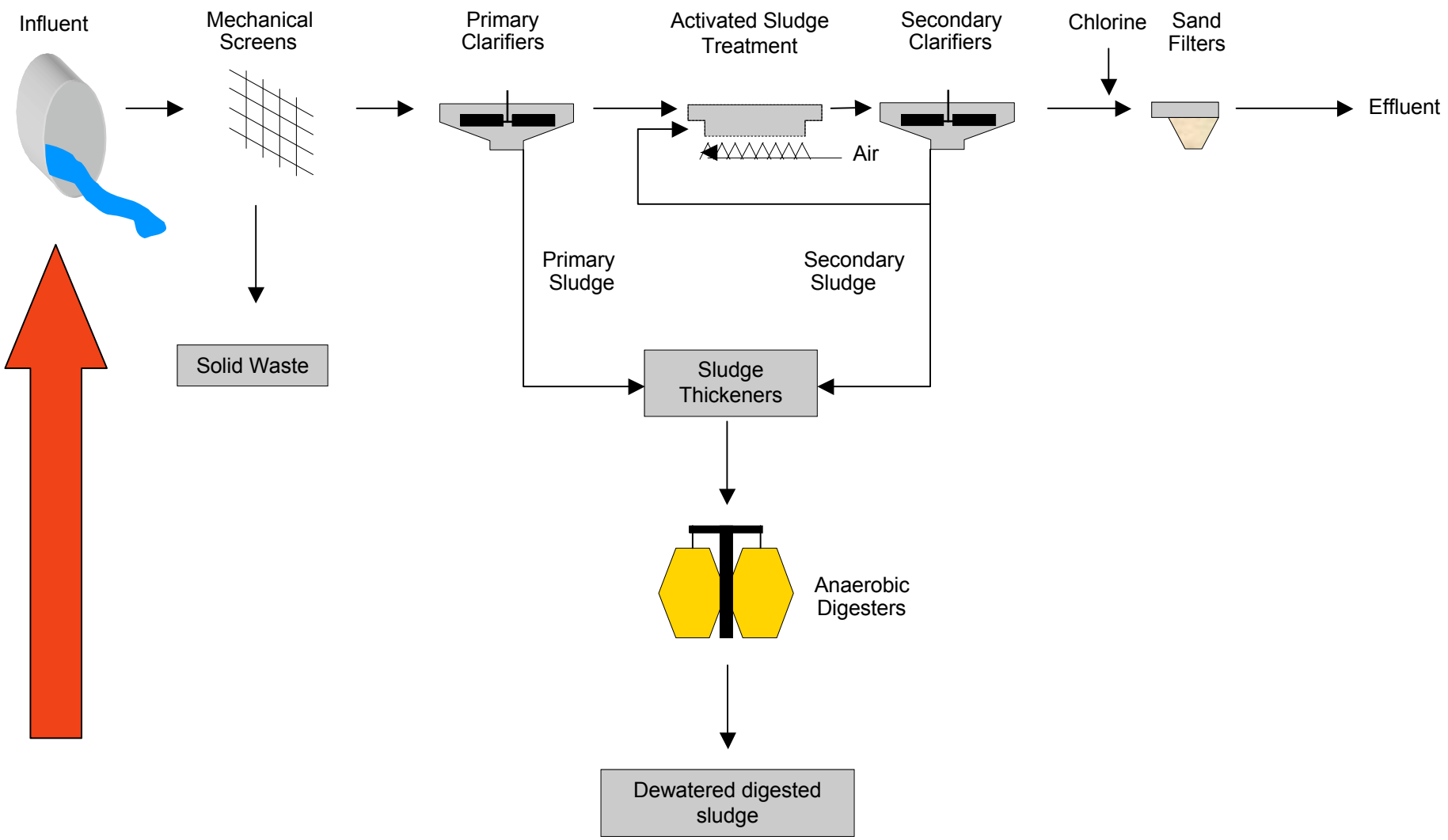
Lessons (To Be) Learned

- 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)

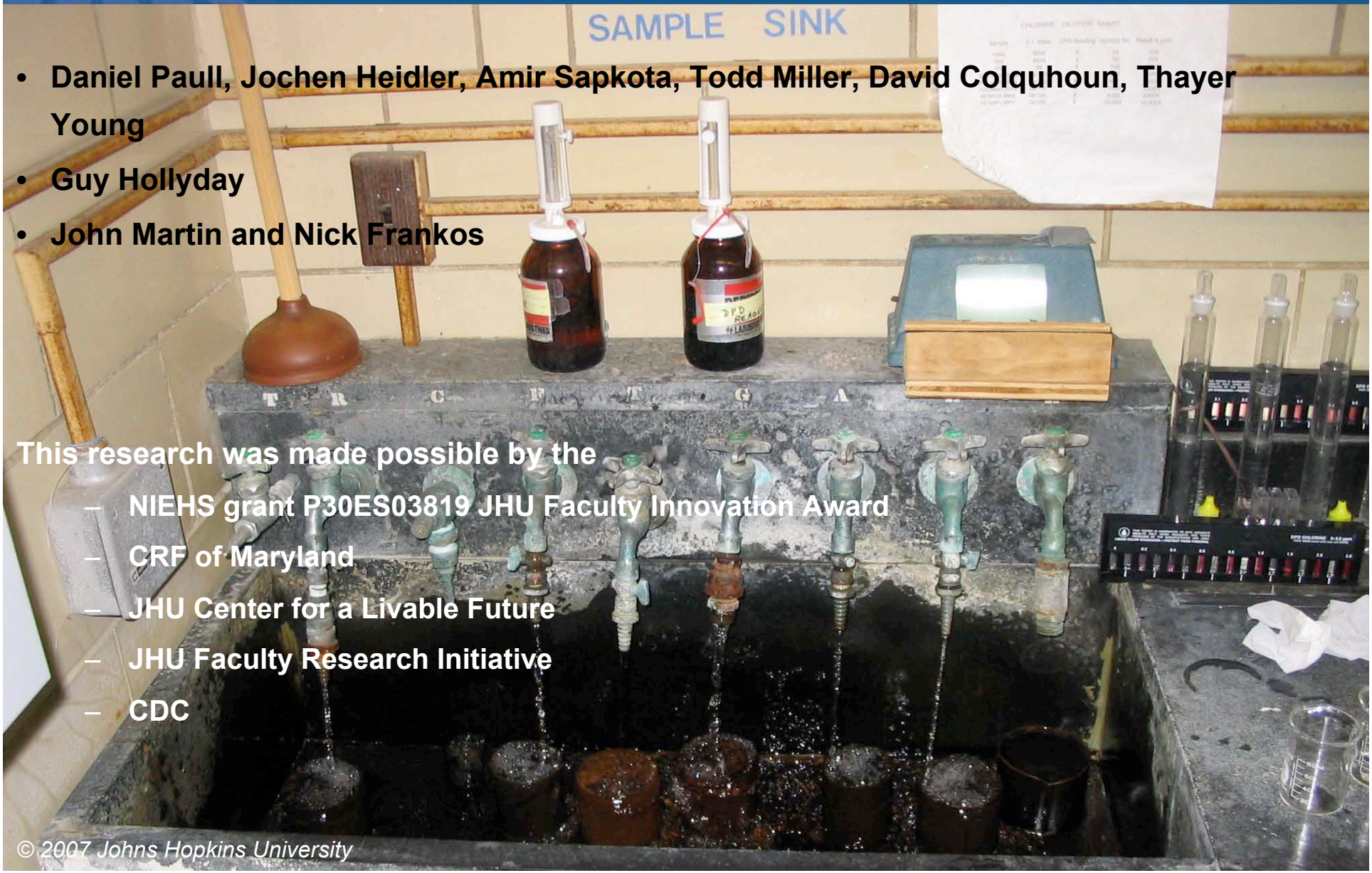
Conclusions: We Can…

- 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

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



Acknowledgements



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- John Martin and Nick Frankos

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- JHU Faculty Research Initiative
- CDC