Contaminant Accumulation and Release from Plastic Piping in Buildings

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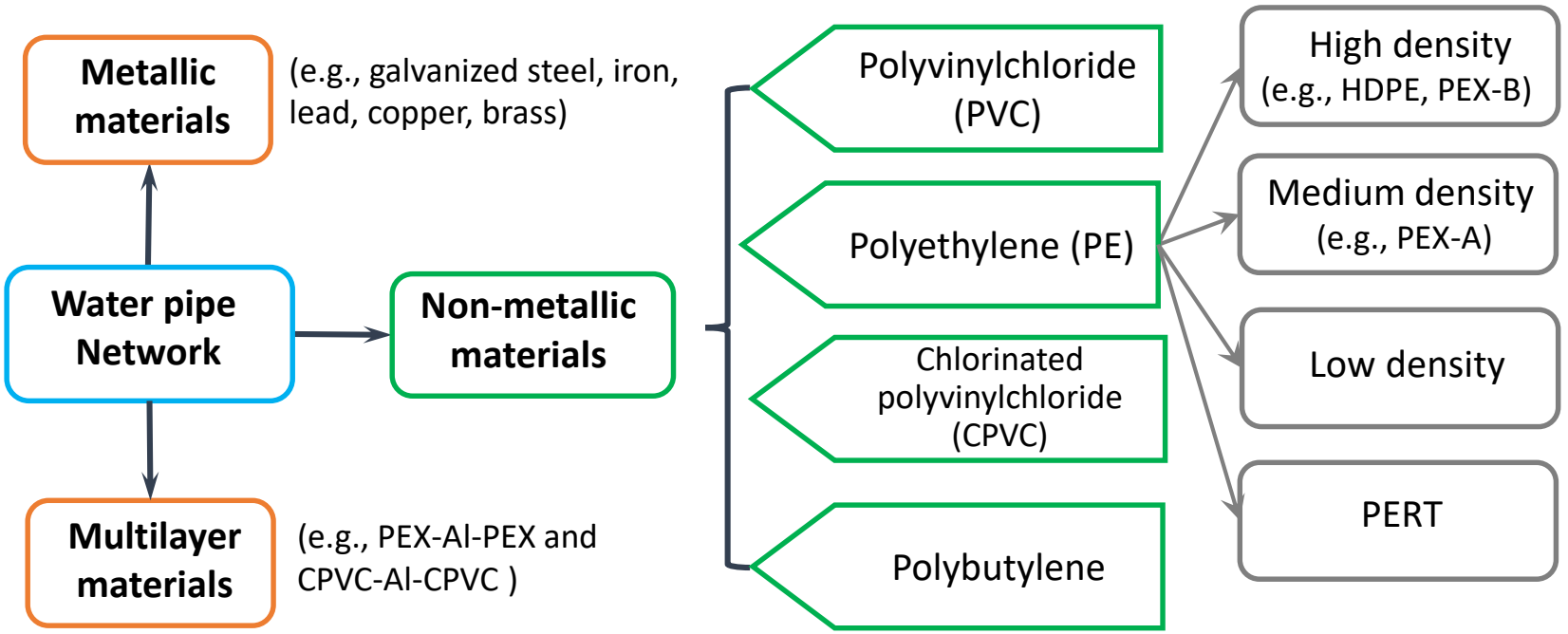
14th Annual EPA Drinking Water Workshop
August 22, 2017, Cincinnati, OH

Materials being used in drinking water systems

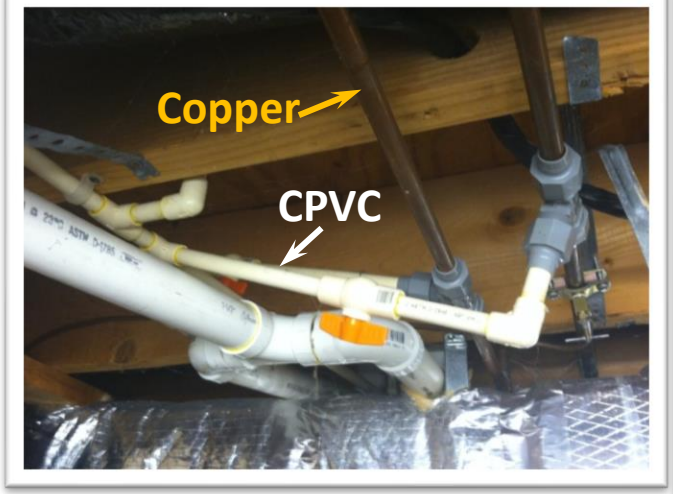


Advantages of plastic pipes:

Less expensive *and* ***more flexible*** and can be ***used for both cold and hot water supply***.

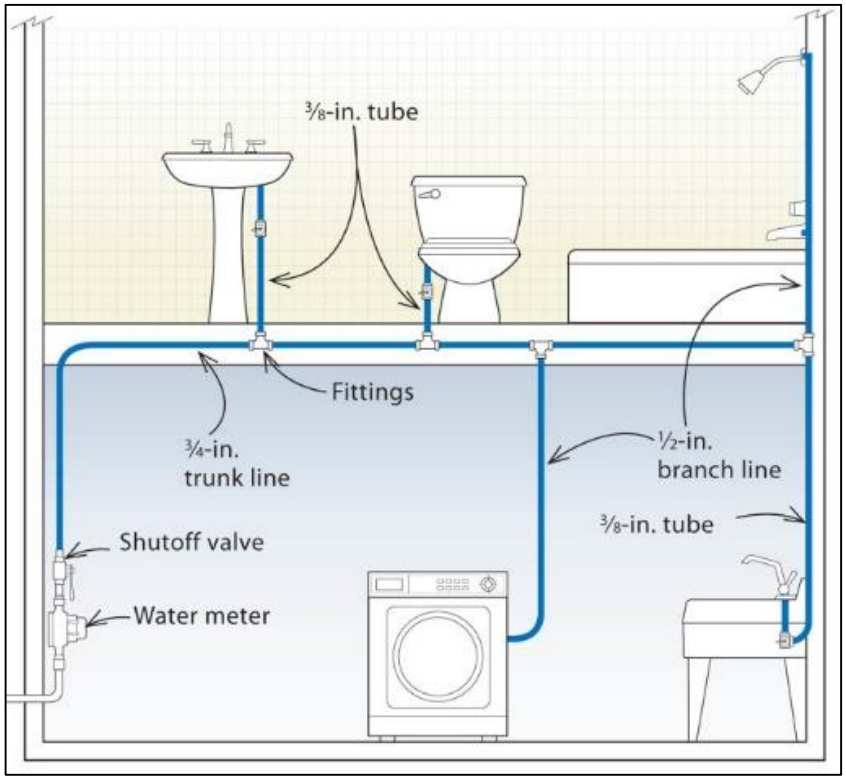
However the fate of organic and inorganic compounds within plastic piping systems has received little study…

Building plumbing systems are complex



Growing trend: Low-flow fixtures, different water flow designs, and plastics

Legacy Technology:
Trunk-and-Branch Design



New **Technology:**
Manifold Design

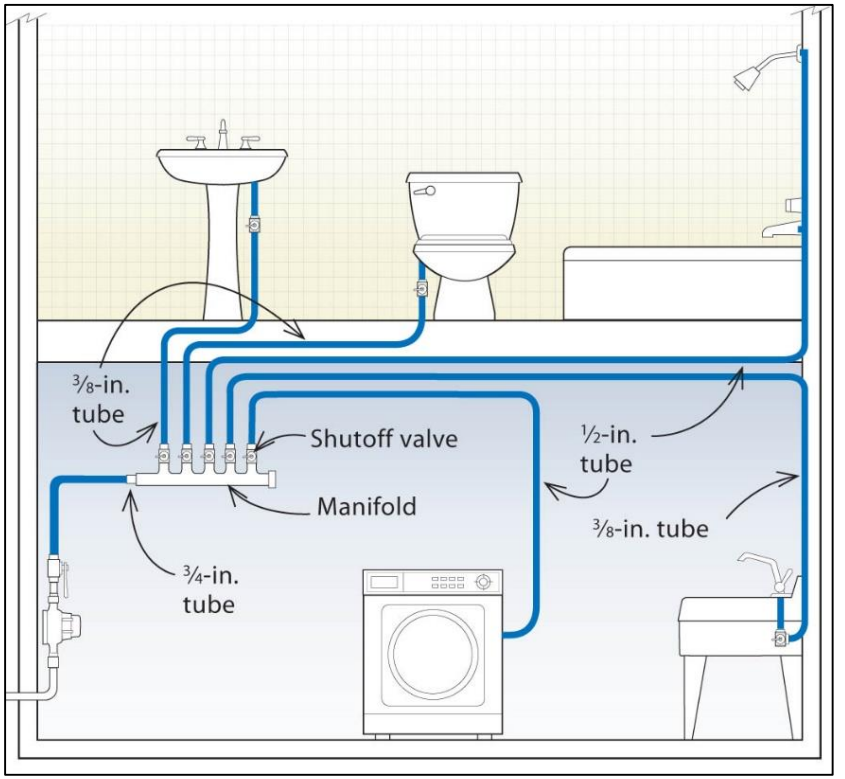


Image Source: Fine Home Building Magazine

Outline

- Interaction of ***organic contaminants*** with plastic piping materials
  - Crude oil contamination with various piping materials
  - Decon of crude oil residuals through leaching only
  - Decon of crude oil residuals by other strategies
- Interaction of ***inorganic contaminants*** with plastic piping materials
  - Metal deposition onto plastic materials
  - Use biomass derived ligand to remove metals on plastics
- Update about the ***plumbing research project*** (funded by EPA)

Crude oil constituents sometimes come into contact with drinking water plumbing pipes

Location	Pop.	Spill Details			Water System Details	
		Cause	Product	Est. Vol., gal	Alert?	Assets
Nibley, UT	5,000	Truck	Diesel	nr	No	WTP, **DS**, **PS**
Mt Carbon, WV	2,000	Rail	Crude: Light	378,000	Yes	nc
Greenbrier Co., WV	12,000	Truck	Diesel	4,000	Yes	WTP
Longueuil, CAN	300,000	AST	Diesel	7,500	No	WTP, **DS**, **PS**
Glendive, MT	5,500	Pipe	Crude: Light	30,000	No	WTP, **DS**, **PS**

All incidents occurred in 2015
AST = Above ground storage tank; WTP = water treatment plant; DS = Distribution system;
PS = Building plumbing systems; nr = not reported; nc = not contaminated

Decontamination needed after short term contamination events (i.e., 2-5 days).

Crude oils contain a variety of compounds that do and do not have regulated drinking water standards

- Crude oils and their related products are complex mixtures that contain **organic**, **inorganic**, and **radionuclide** compounds.
- Monoaromatic (**MAHs**) and polycyclic aromatic hydrocarbons (**PAHs**) are two classes of organic contaminants in oil products.

Contaminant Detected in Oil	Drinking Water Limit, ppm	Concentration in Oil, ppm	Max Con. in Oil/ DWL Ratio	Property VP @ 25°C, mmHg	Property Sw @25°C, ppm	Property Log K_{ow} @ 23°C
Monoaromatic Hydrocarbons (MAHs)						
Benzene	0.005	0-2866	573,200	94.8	1,790	2.13
Toluene	1	136-5,928	5,928	28.4	526	2.73
Ethylbenzene	0.7	58-1,319	1,884	9.6	169	3.15
Total Xylenes	10	396-6,187	618	6.61	178	3.12
C_3-Benzenes	-	**940-13,780**	-	-	-	-
Polynuclear Aromatic Hydrocarbons (PAHs)						
Naphthalene	0.02	3,939-20,852	1,042,600	8.50×10^{-2}	31	3.30
Phenanthrene	-	**1,296-22,779**	-	1.21×10^{-4}	1.15	4.46
Dibenzothiophene	-	**609-2,033**	-	2.05×10^{-4}	1.47	4.38
Fluorene	0.04	513-4,986	124,650	6.00×10^{-4}	1.69	4.18
Chrysene	-	**167-11,887**		6.23×10^{-9}	2.00×10^{-3}	5.81

Short-term crude oil-piping material interaction

Pipe materials examined (*cut into 5 ft. length*):
PEX-A (medium density); *PEX-B* (high density); HDPE (high density); *cPVC* and Copper.

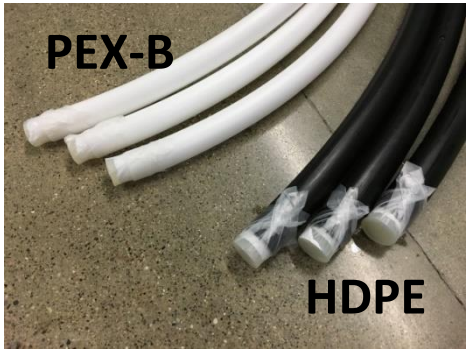
Pipe disinfection protocol:
200 mg/L free chorine (*diluted from 6% wt% of NaOCl, Fisher Chemical*)

→

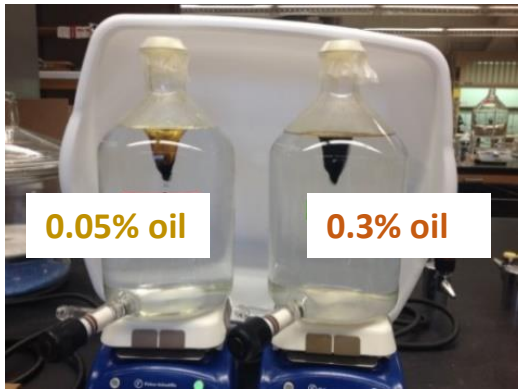
Contamination:
Louisiana light sweet crude (LLSC) solutions
Duration:
3 days

→

Decontamination:
Rinse, flushing and surfactant addition



"Fill and drain method"



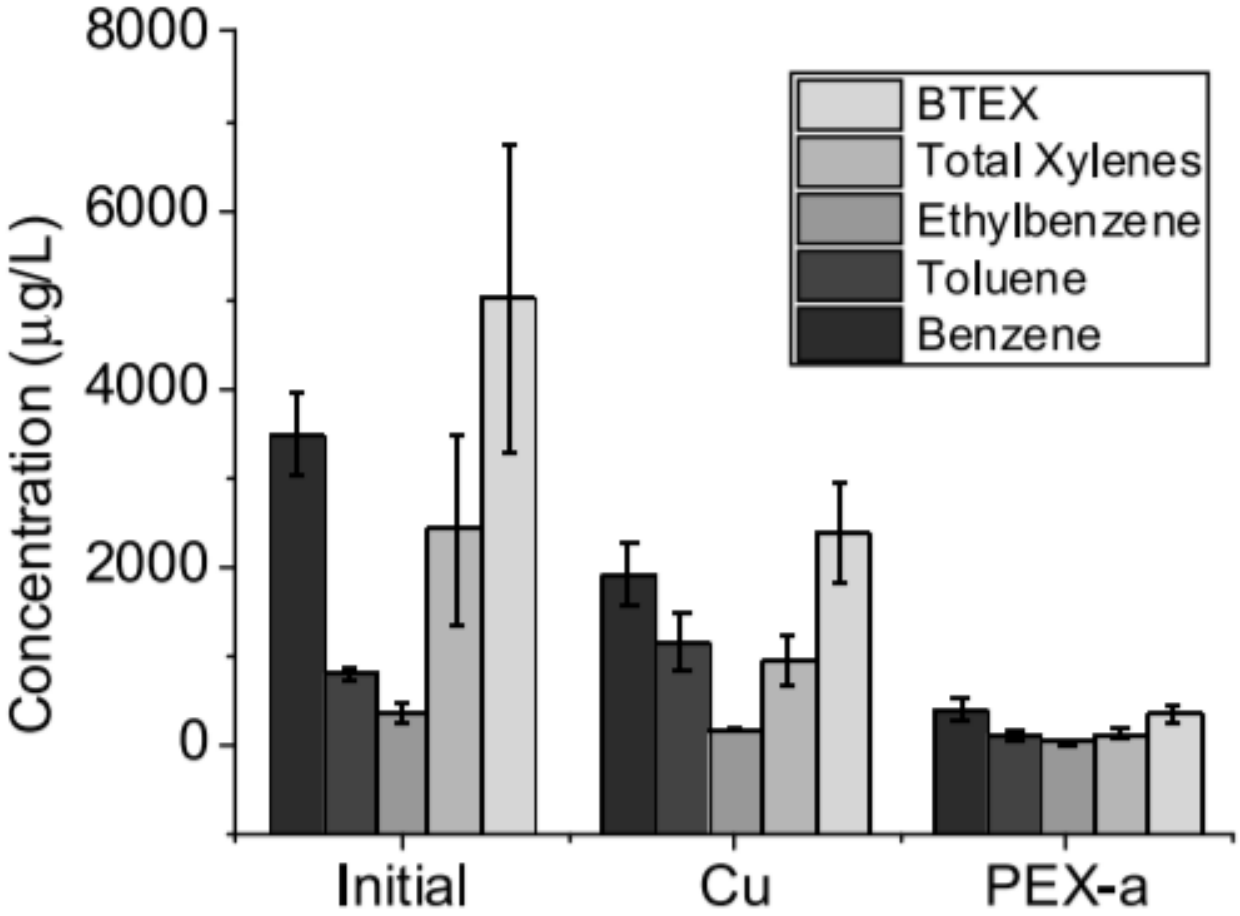
Oil mixing with synthetic water

Measurement Techniques

HS-SPME-GC/MS
Liquid Injection-GC/MS
TOC analyzer
Statistical analysis

0.3% oil/water ratio was used by EPA to contaminate ductile iron and cement pipes

Crude oil contaminated water interacted with both copper and plastic piping materials



Comparison of BTEX in initial crude oil mixture and those contacted with Cu and PEX-a piping materials after 3 days exposure period.

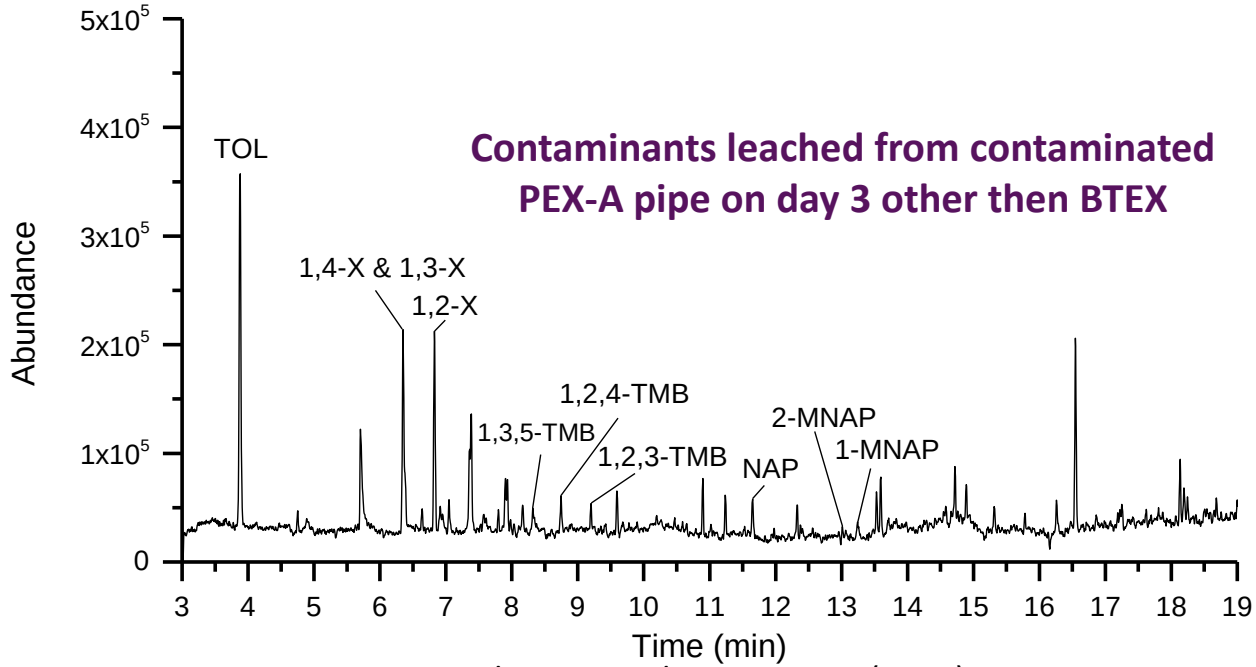
K.S. Casteloes et al., *J. Hazard. Mater.,* 325 (2017): 8-16.

Rinsing only required a long time to bring the water back in order

BTEX leaching data

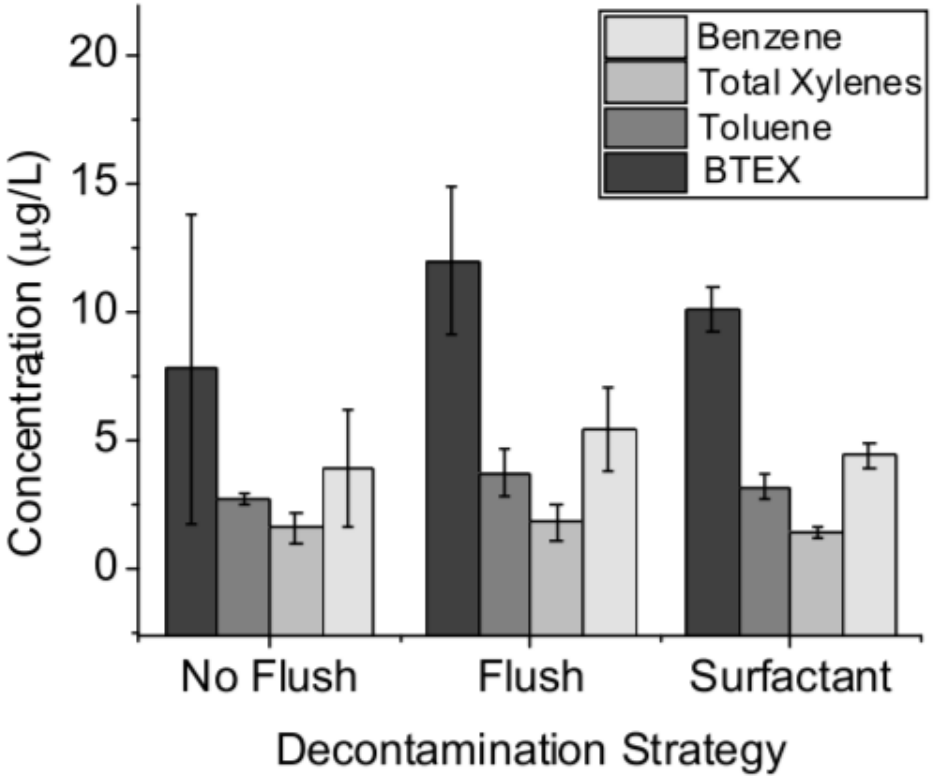
Material	Mean Desorbed Concentration (µg/L)							
	B	T	E	X[a]	B	T	E	X
		0.3% oil mixture Day 3				*0.05% oil mixture Day 3*		
PEX-A	**1,434.4**	140.2 O*	2.43 O	73.00 O	**77.0**	12.6	-	-
PEX-B	**1,167.9**	116.8 O*	1.68	66.80 O	**36.0**	3.53	-	-
HDPE	**1,274.1**	129.0 O*	2.07 O	58.50 O	**39.6**	1.61	-	-
CPVC	**81.03**	38.88 O	2.42 O	10.36	**9.22**	0.76	-	
Copper	**5.45**	7.90	2.18 O	22.60 O	0.46	0.85	-	-
		0.3% oil mixture Day 15				*0.05% oil mixture Day 15*		
PEX-A	**21.0**	9.46	-	-	**6.14**	-	-	-
PEX-B	**16.5**	5.33	-	-	3.01	-	-	-
HDPE	**18.5**	7.63	-	-	2.10	-	-	-
CPVC	1.74	0.28	-	-	0.70	0.37	-	-

Contaminants leached from contaminated PEX-A pipe on day 3 other then BTEX

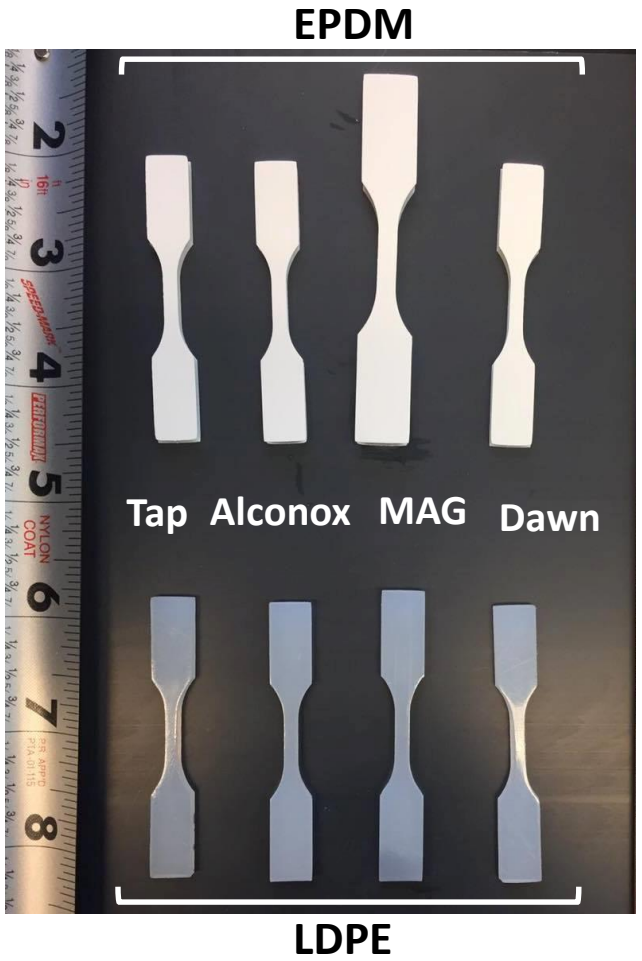


X. Huang et al., *J. Hazard. Mater.*, 339 (2017): 385-394.

Short-term water flushing and addition of surfactant were not effective in removing crude oil residuals from plastics



Flush refers to 10 min flush at 2.5 gpm after the full removal of contaminated water. Alconox® solution (10%) was adopted as the decon surfactant.



Dimension changes of EPDM (top) and LDPE (bottom) samples exposed to various surfactants after 3 days

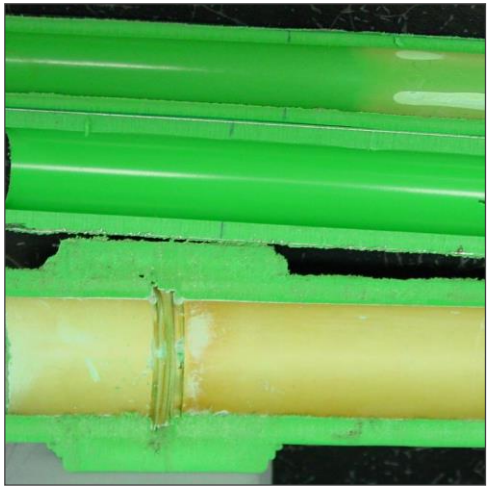
K.S. Casteloes et al., *J. Hazard. Mater.*, 325 (2017): 8-16.

As more plastic pipes are being installed, metal deposits are being found on their surface

Utility HDPE Water Service Connection in Florida

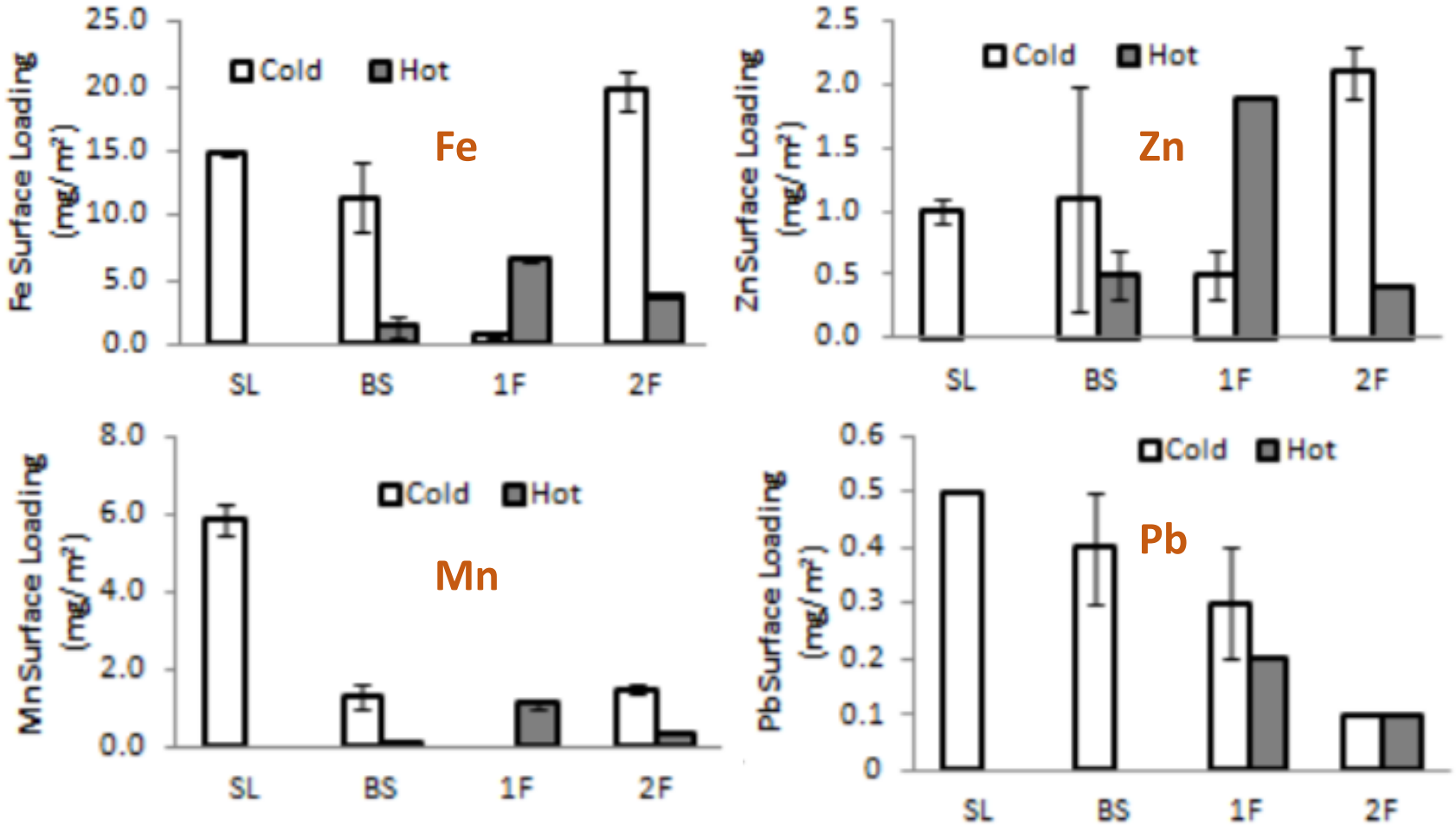
One year old PEX pipe pulled from the ReNEWW House

Utility PVC Water Main in Honduras



Premise Plumbing, Australia Polypropylene Pipe

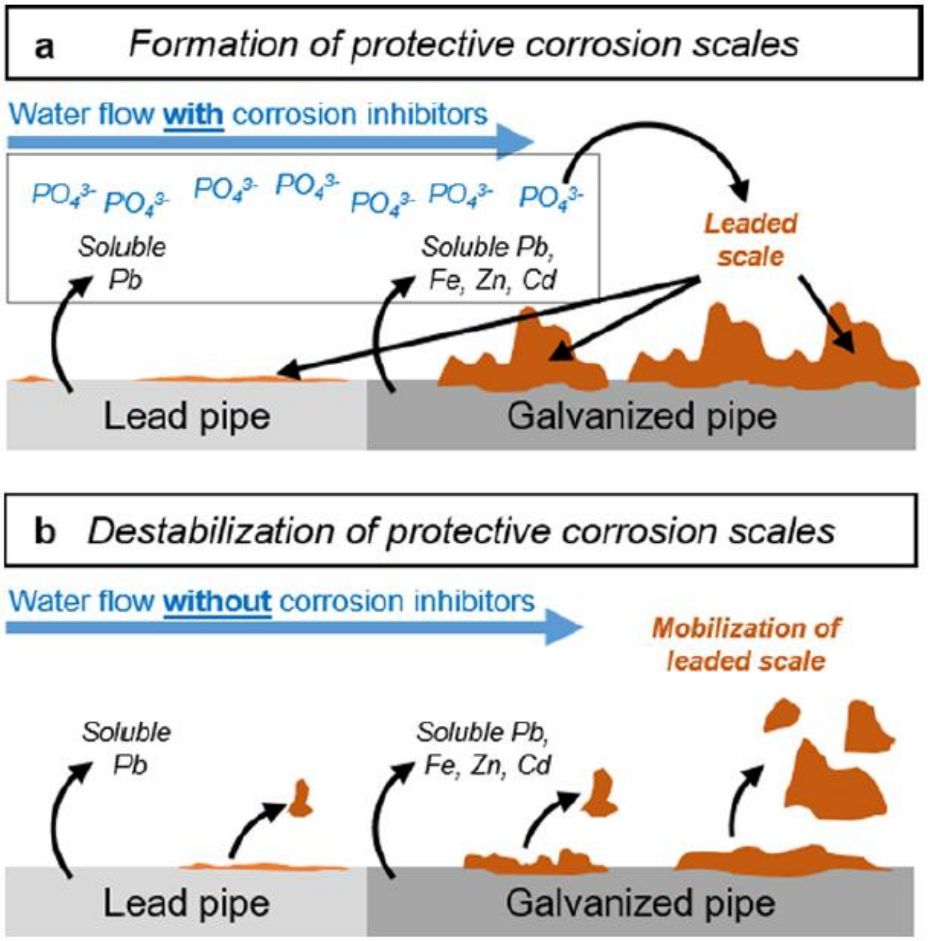
Metal accumulation was found on the exhumed plastic pipes; unequal loads across the building were observed

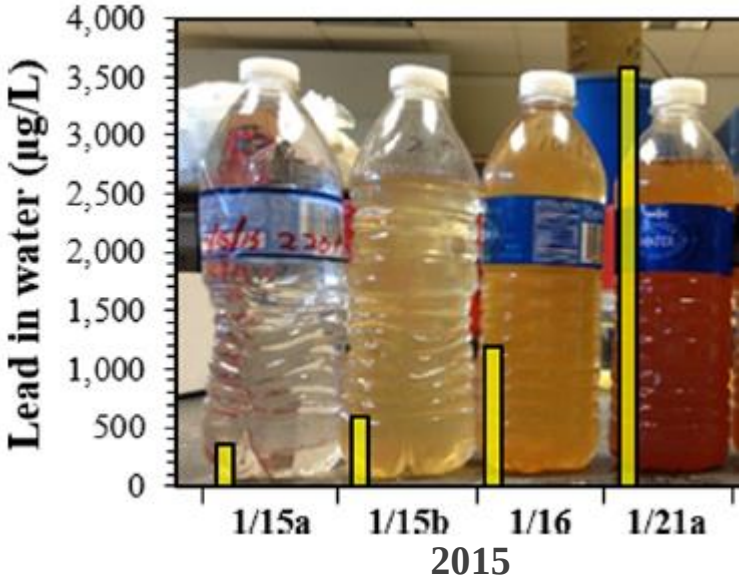


Selected metal loadings on PEX-a pipe surfaces (SL: Service Line, BS: Basement, 1F: 1st Floor, 2F: 2nd Floor).

M. Salehi et al., *J. Am. Water Works Ass.,* 109.11 (2017).

Elevated Pb was found from the past study





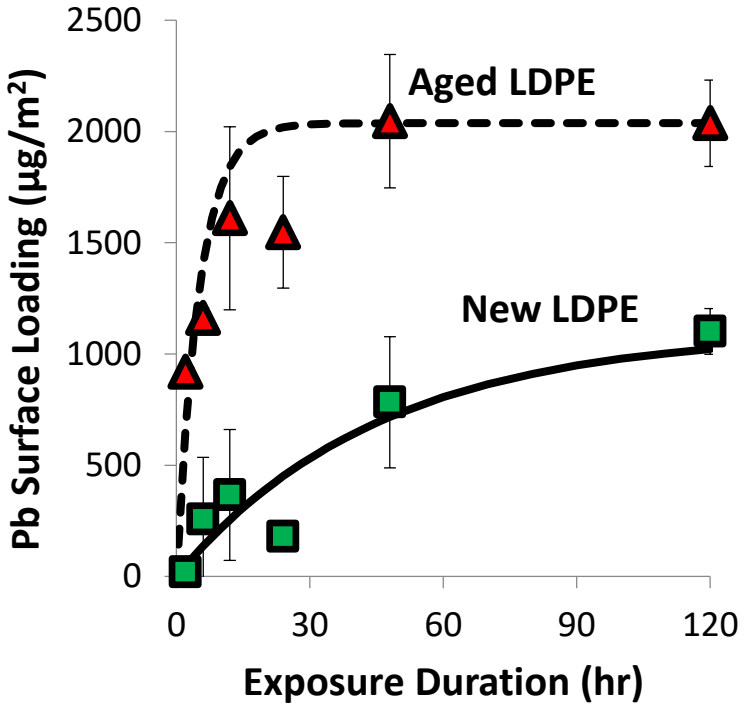
Lead drinking water action level is 15 µg/L

Change water conditions or **flow patterns** can **affect metals released** from metal piping scales into drinking water

Pieper et al., *Environ. Sci. Technol.,* 51.4(2017): 2007-2014.

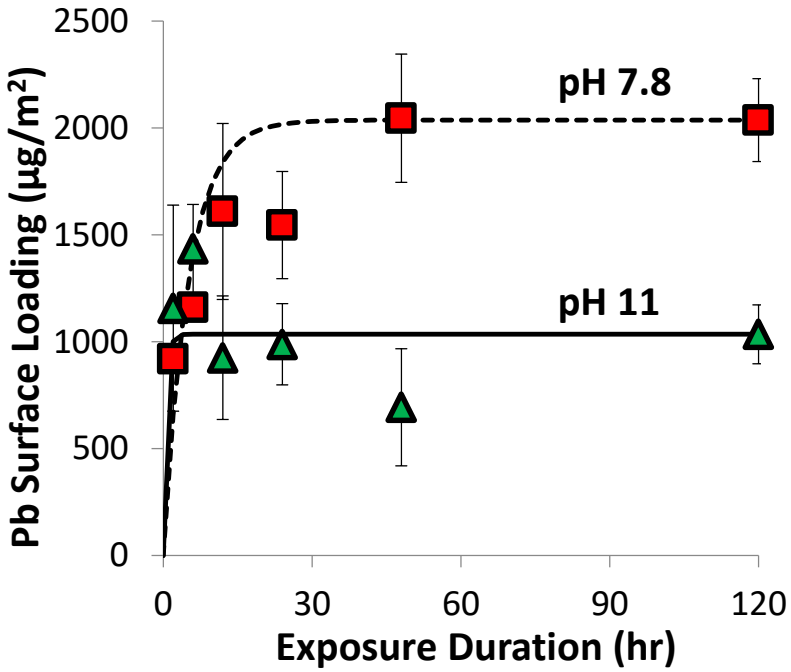
Bench-scale testing on Pb adsorbed onto polyethylene (LDPE) plastics and affected by different conditions

Aged plastics adsorbed more Pb than new plastics



Experimental condition:
PH was 7.8 with initial Pb concentration as 300 µg/L, at room temperature

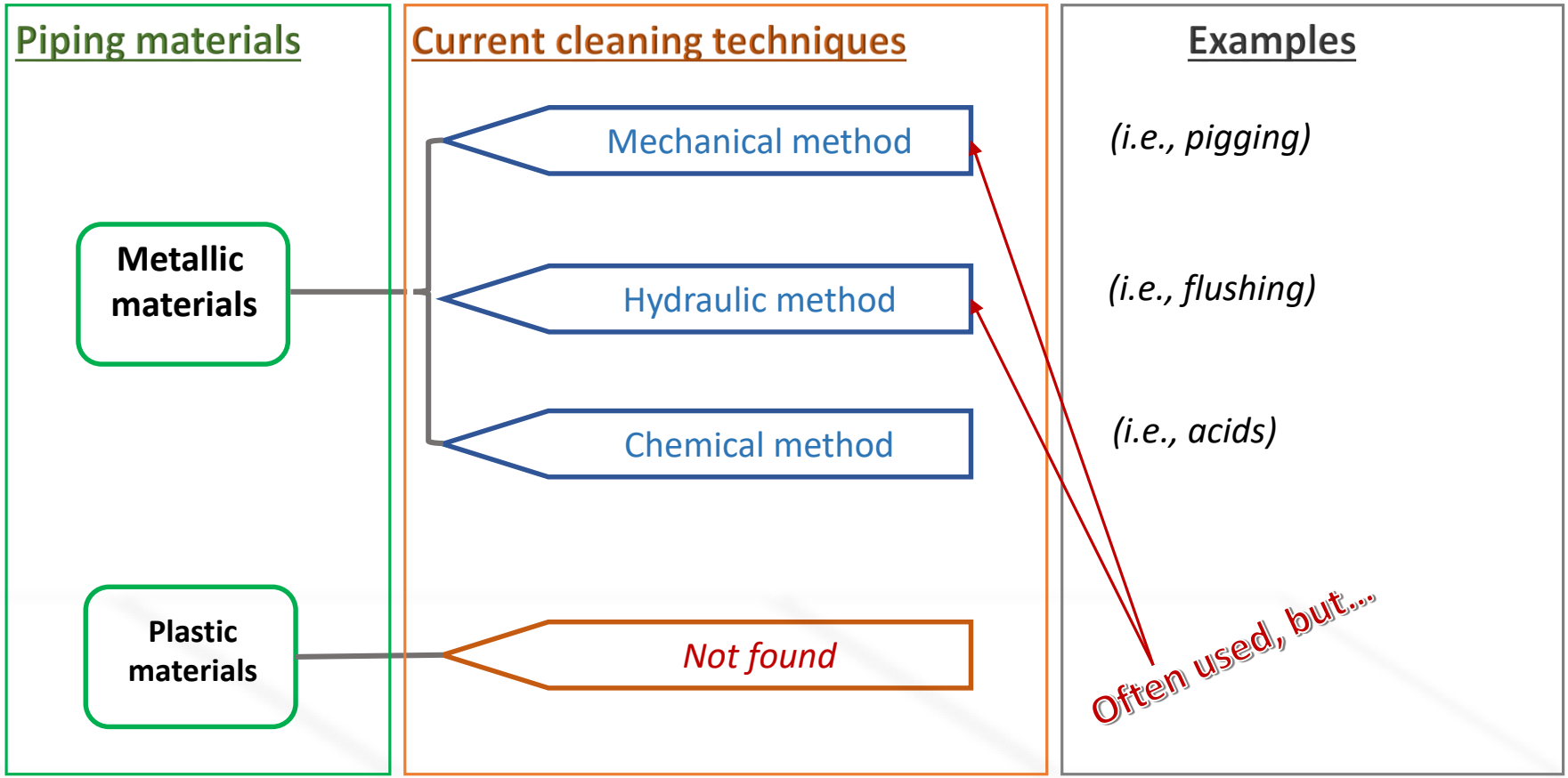
Water pH could alter the metal adsorption amount



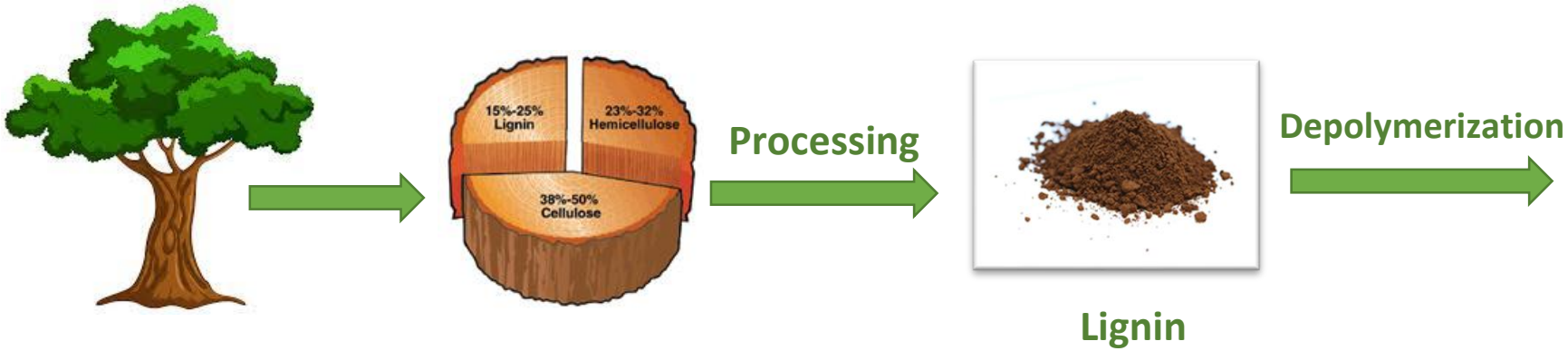
Experimental condition:
NEW LDPE pellets were used with initial Pb concentration as 300 µg/L, at room temperature

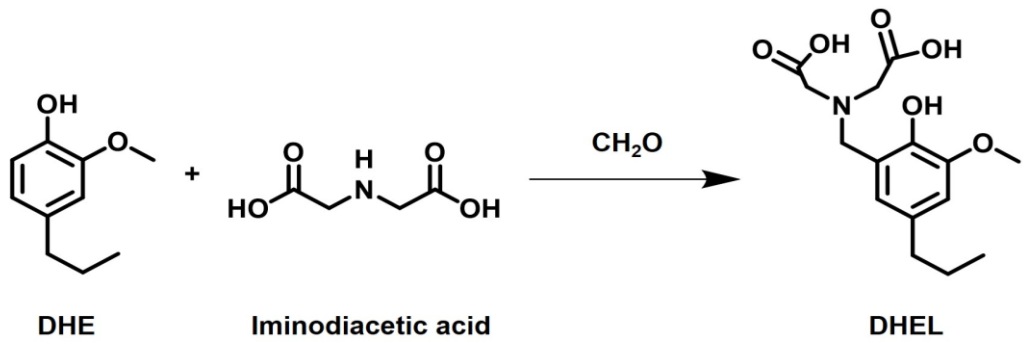
M. Salehi et al., PhD Dissertation, Purdue University (2017).

Overview of the current plumbing cleaning techniques, but no plastic pipe cleaning methods were found



Synthesis of lignin derived DHEL

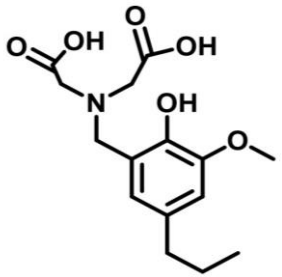




Name: 2,2'-((2-hydroxy-3-methoxy-5-propylbenzyl)azanediyl)diacetic acid

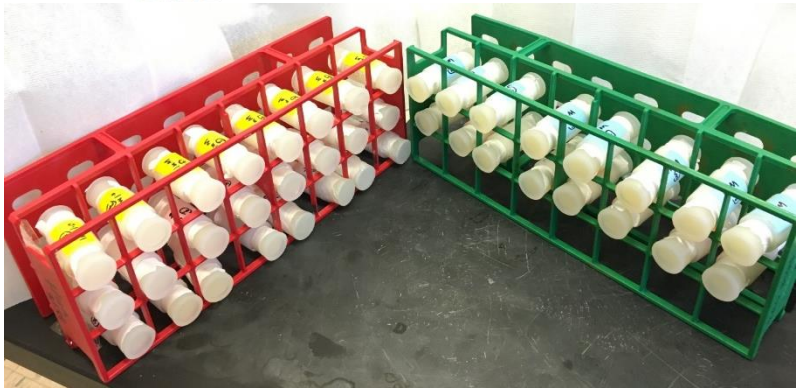
Abbreviation: DHEL

Use DHEL to remove heavy metals from exhumed plastic pipes



DHEL

Biomass derived ligand



Exhumed pipes were *harvested from ReNEWW house.*

Use simple ***fill and drain*** *method*.

DHEL concentration: 0-10 mM.

Experimental condition and duration:

At room temperature, **pH = 7** for up to **7 days**.

Pipe digestion: 2.5% HNO_3 for min. 48 hrs.

Measurement techniques: **ICP-MS**.

Before treatment

After treatment

pH is unadjusted, the immersion duration was 7 days

Conditions

Control group

0.1 mM DHEL

1.0 mM DHEL

5.0 mM DHEL

Control group

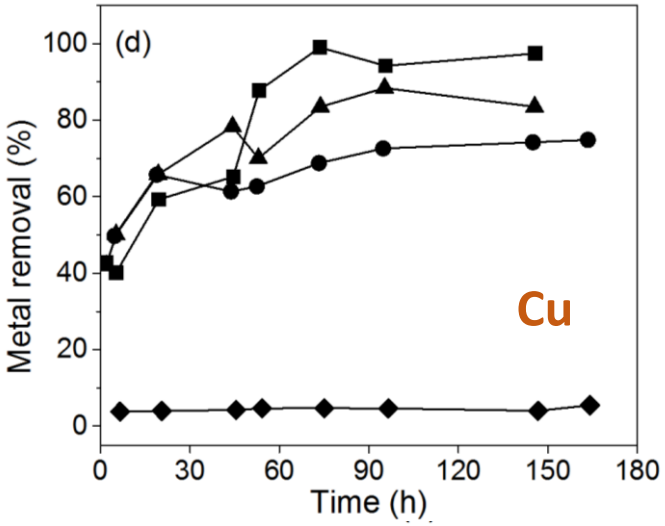
0.1 mM DHEL

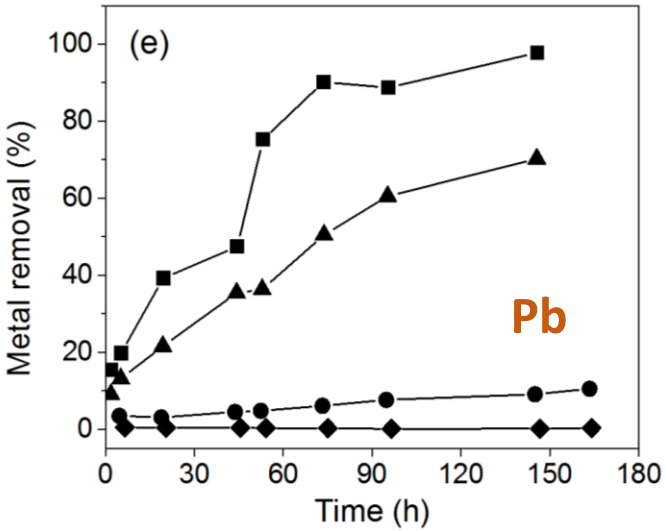
1.0 mM DHEL

5.0 mM DHEL

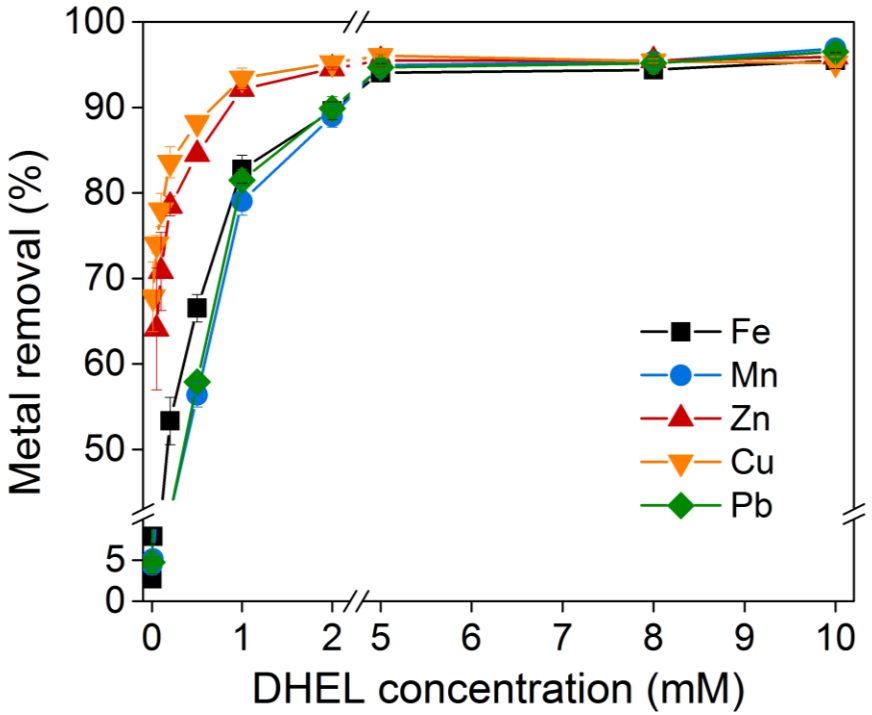
DHEL could achieve desired metal removal efficiency and showed preference to certain metals

(◆) blank, (●) 0.1 mM, (▲), 1 mM, (■) 5mM





Initial pH was at 7, room temperature



7 day exposure period: at room temperature; initial pH 7; error bars represent standard deviation for triplicates

Huang et al., *J. Environ. Chem. Eng.*, 5 (2017): 3622-3631.

The EPA Plumbing Project Core Team

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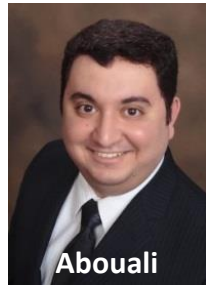
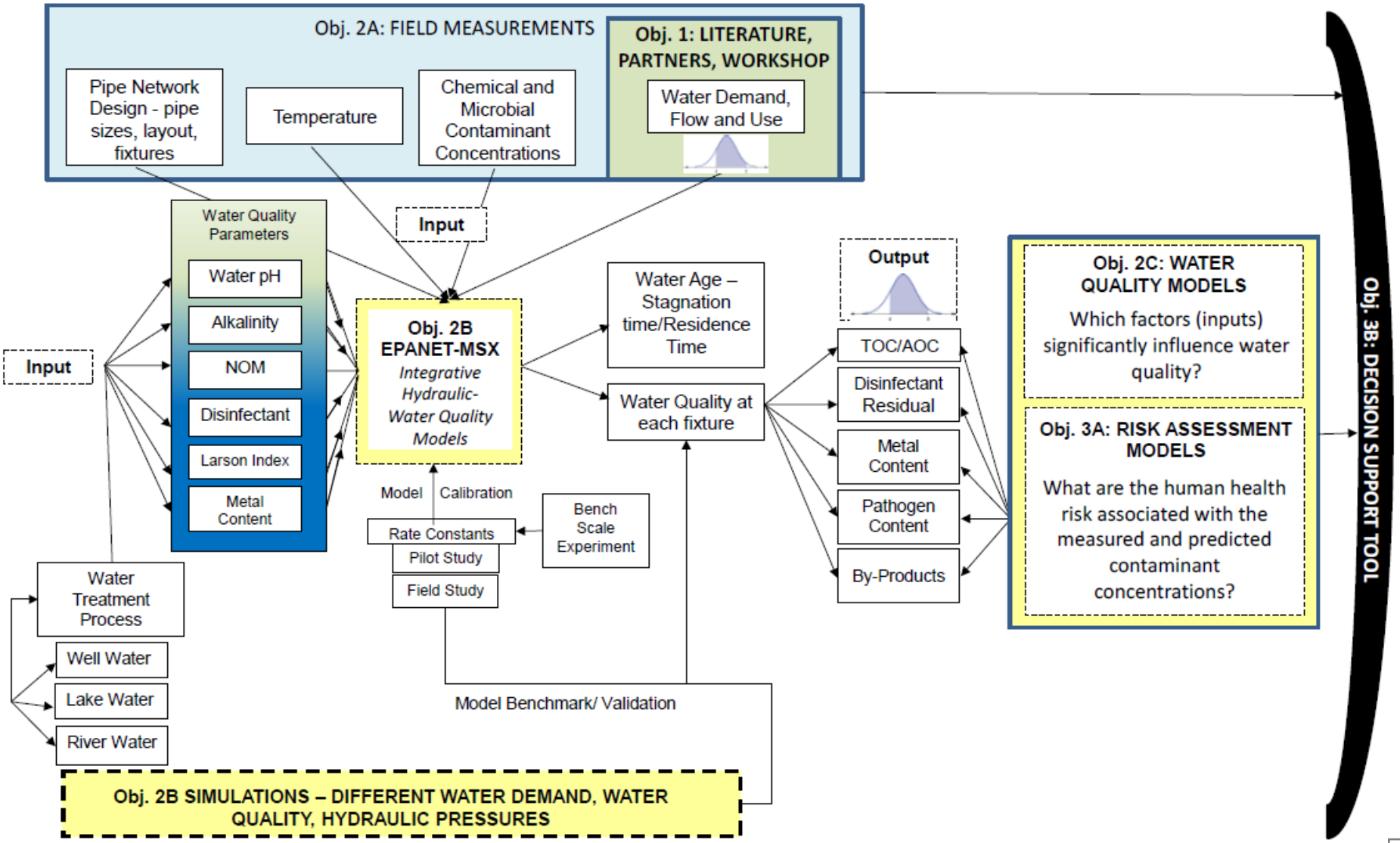
Tulane University



MICHIGAN STATE UNIVERSITY

Please visit the website for more details:
https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/10736/report/0

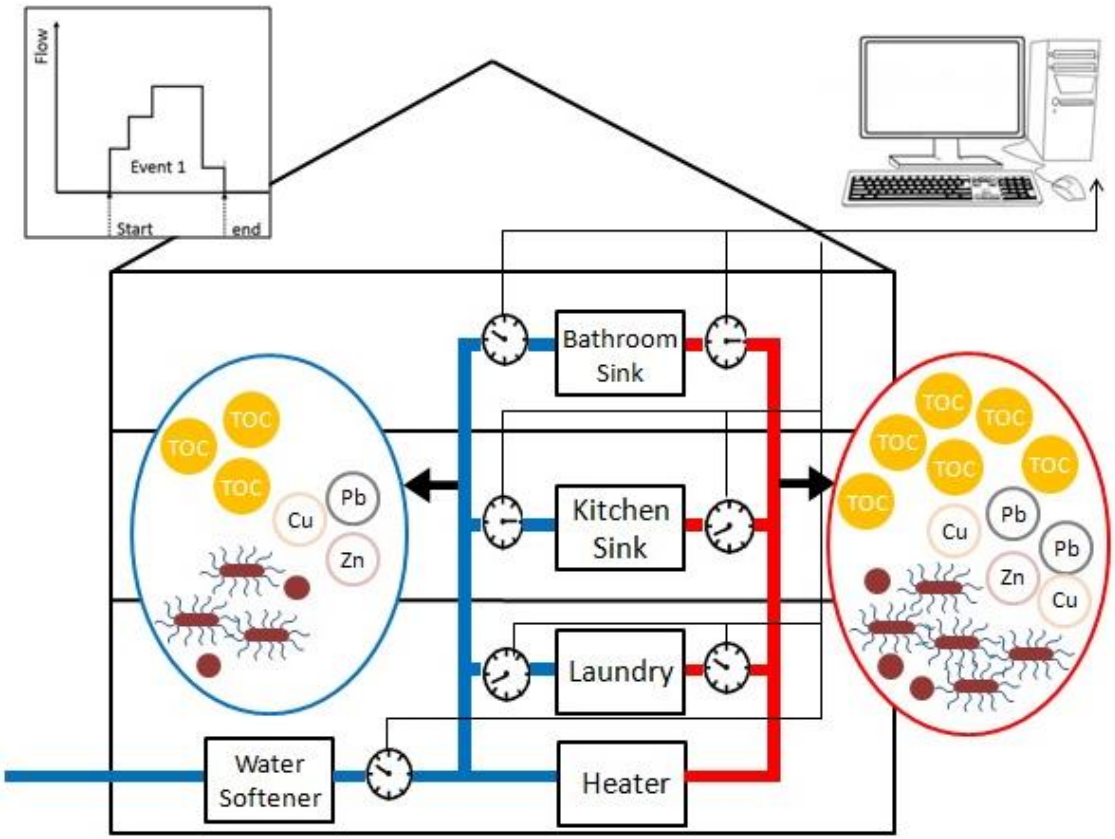
Develop integrative hydraulic-water quality and health risk models, and *evaluate how indoor water quality* would be affected by changing the water distribution system, plumbing design, operation, and fixture use conditions.



Several full-scale buildings are being studied

Characteristics	ReNEWW Net-Zero Energy Home, IN	LEED Platinum Office Bldg, IN	LEED Silver Lab/Office Bldg, MI	LEED Middle School, IN	Legacy Renovated Office Bldg, MI
Area, square feet	3,000	22,500	30,000	220,000	156,752
Number of Floors	2	3	5	1	16
Potable water pipe type	PEX-a plastic	Cu	Cu & Galv. Steel	Cu	Brass (hot) & galvanized Fe (cold)
Water heaters, gal	Two: 300 & 50	On-demand	Continuous recirculation	Five: 300 each	Two: 75 & 115
Sample points	SL; 1Flr Kitchen sink; 1Flr Island sink; 1Flr, 2Flr Bath sink	SL; 1Flr, 2Flr, 3Flr Kitchen sink	SL; 1Flr to 5Flr Bath sink	SL; 1Flr Kitchen sink; 1Flr Class Rm	Basement, 2, 6, 14, 16 Flr Bath sink
Sampling approach	For 1 wk period every day, 1x/season; then 1x/mo. for 6 mo.	For 1 wk period every day, 1x/season; then 1x/mo. for 6 mo.	School start; Aug-Dec 1x/mo.	School start; Aug-Dec 1x/mo.	Apr-Sept 1x/mo.
Other building characteristics*	SW, SL, FF, IBT, HWS, LOW	SL, FF, PT, HWS, LOW	SL, FF, LOW, HWS	HWS, VP, LOW	HWS

Preliminary water sampling results from the ReNEWW House



- ✓ The *elevated metal concentrations* (i.e., Zn Fe and Pb) inside of the building were due to plumbing system materials, valves and fixtures.
- ✓ *Bacteria* and *organic carbon levels were increased* within the building plumbing system.
- ✓ Compared to the cold water, *more bacteria* was detected *in hot water* samples.
- ✓ The *maximum water stagnation time* was found to be *3 days*.

HAPPENING NOW: Plumbing Safety Workshop, August 23-24, 2017

Stewart Center, Purdue University, 128 Memorial Mall, West Lafayette, IN

Goals:

1. Identify community research questions regarding water conservation and its water quality impact;
2. Solicit input on unpublished water use trends and conservation drivers; and
3. Gain feedback regarding available data to inform the project team's analysis and modeling efforts.

Date	Time	Activity
August 22	3:00	Optional pre-workshop site visit to the state-of-the-art ReNEWW house (www.ReNEWW.com), ride the Boilermaker; notify peters54@purdue.edu by July 31
August 23	8:00-8:30	Sign-in, food, and networking
	8:30-9:15	Welcome and opening remarks Overview of the group and introductions
	9:15-10:00	Project Overview
	9:45-10:45	Identifying challenges: Group Discussion Session 1 • What are the problems and challenges of greatest interest and concern to you regarding premise plumbing and water safety?
	10:45-11:00	Break
	11:00-12:00	Identifying challenges: Group Discussion Session 2 • Given these problems and challenges identified by the group, which could make the greatest difference to the future of plumbing safety?
	12:00-1:00	Lunch
	1:00-2:15	Prioritizing challenges: Group Discussion • Given these problems and challenges identified by the group, which are the highest priority for action? • What information/knowledge is needed to address these challenges?
	2:15-2:30	Break

Selected Whelton's group recent publication

- K.S. Casteloes et al., *J. Hazard. Mater.*, 325 (**2017**): *8-16*.
- J.K. Hawes et al., *J. Am. Water Works Ass.*, 109.8 (**2017**).
- X. Huang et al., *J. Hazard. Mater.*, 339 (**2017**): *385-394*.
- M. Salehi et al., *J. Am. Water Works Ass.*, 109.11 (**2017**).
- S. M. Teimouri Sendesi et al., *Environ. Sci. Tech. Let.*, (**2017**).
- A.J. Whelton et al., *Environ. Sci. Wat. Res. Technol.*, 3.2 (**2017**): *312-332*.

Acknowledgements

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Jian Zhang, John Hall, Kevin Morley and Say Kee Ong, *WaterRF*

Amir Pouyan Nejadhashemi, Jade Mitchell and Mohammad Abouali, *Michigan State University*

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Thank you!

Questions & Discussions

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