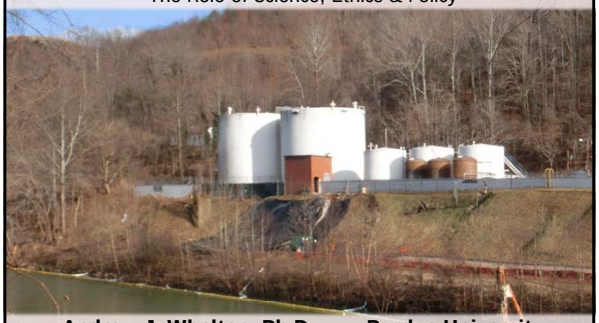
Chemical Spills, Drinking Water Contamination, & Recovery:

The Role of Science, Ethics & Policy



Andrew J. Whelton, Ph.D. **Purdue University**

October 20, 2015

Acknowledgements

Karen Casteloes, Jake Hawes, Randi Brazeau, Xiangning Xuang, LaKia McMillan, Matt Connell, Keven Kelley, Jeff Gill, Kevin White, Mahmoud Alklahout, Fredrick Avera, Caroline Novy, Alex Beebe

Special thanks to …

West Va. homeowners
Rob Goodwin, WV Clean Water Hub
Maya Nye, PCACS
Drs. Bill Cooper, NSF
WVTAP colleagues
Laura Linn, Dauphin Island Sea Lab
Dr. Randi Brazeau, Metro State Univ.
Dr. Omur-Ozbek, Colorado State Univ.
Eastman Chemical Company
West Virginia American Water

Funded by:

CBET # 1424627

Questions?

Andrew Whelton, Ph.D.
T: (540) 230-6069
awhelton@purdue.edu

2

Re·sil·ience

\ri-’zil-yen(t)s\

The ability to recover from or adjust easily to misfortune or change

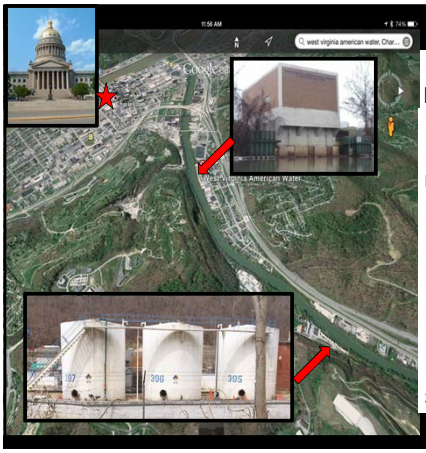
West Virginia

The "Mountain State"
Seceded from Virginia in 1863
Population 1,850,000

State capital: Charleston
Legislature meets once a year
Industries: tourism, chemicals and coal mining

January 9, 2014, 8:16am
Resident tells West Va. DEP and stated "something in the air at the 77-79 split each morning when he comes into work. He said it is coating his wife's throat."

11:15am – West Va. DEP finds spill
12:05pm – Freedom Industries reports spill to WV DEP hotline
12:00-12:30pm – Water utility notified, PAC feeding begins
4:00pm – Water plant overwhelmed, water enters distribution system
5:36pm – Do Not Use order issued



Freedom Industries Spill
January 9, 2014

No plant shutdown:
Public safety concerns

300,000 people
9 counties
15% of West Va. pop.

2,200 mi. water mains
107 water tanks
>90,000 buildings

8 days after the spill:
366 miles downstream

The Liquid Spilled was a Complex *Mixture*

Crude MCHM & **Stripped PPH**

2,500 gal initial estimate, then ***>10,000 gal***

17+ ingredients, most lacked toxicity data

Most ingredients **lacked water sampling and analysis methods**

Utility, State, Federal agencies keyed in on **4-methylcyclohexane methanol (MCHM)** isomers, but other chemicals were present

Officials Did Not Fully Characterize the Spilled Liquid or Fully Understand what was in the Water

Chemicals in Tank 396 Liquid	MSDS		Est.	Chemical Analysis by Others			
	EastM 1/98	FDM 1/12	CDC 1/14	REIC 3/14	WVTAP 3/14	USGS 12/14	ATTY 4/15
4-MCHM (a.k.a. MCHM)	68 to 89%			79.6%	Detect	77-89%	940 g/kg
4-MMCHM	4 to 22%						
Water	4 to 10%						
MMCHC	5%		88.5%	1.6%		Detect	
DM14CHDC	1%						
Methanol	1%						
1,4–CHDM	1 to 2%			5.6%	Detect		
Polyglycolethers (9d after spill)		100%	7.3%				
PPH							
DiPPH				11.3%			
Formaldehyde							86 ppm
Methylene chloride							13,621 ppm
Water			4.2%				
2-Methoxyethoxybenzene					Detect		
Cyclohexanemethanol				1.8%	Detect		
1,4-CHDADME					Detect		
4-MMECHCA					Detect		
Other unidentified compounds				< 5%			

McMillan et al. 2015

Jan. 9: West Va. Asked the CDC to Determine the Safe Drinking Water Level for 4-MCHM

Concerns from the Public:
Infants, expectant mothers, immunocompromised persons, toddlers, healthy adults, pets, livestock, fish

Ames assay for mutagenic activity on cells (Crude MCHM)
Rat, 14 day acute oral studies (*pure MCHM*)
Guinea pig, 48 hr acute dermal study (*pure MCHM*)
Rabbit, acute dermal irritation (eye) study (*pure MCHM*)
Rat, 14 day acute dermal study (*pure MCHM*)
Rat, 28 day acute oral study (*pure MCHM*)

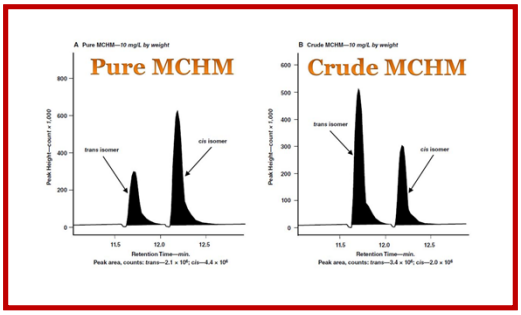
Animal

Environmental

Minnow, 48 hr acute toxicity (Crude MCHM)
Daphnia, 48 hr acute toxicity (Crude MCHM)
Environmental biodegradation (Crude MCHM)
COD, BOD (Crude MCHM)

Adams et al. 2014.

Chemically… Pure MCHM and Crude MCHM were NOT the same



10

Noezeyn and Suffett (2014)

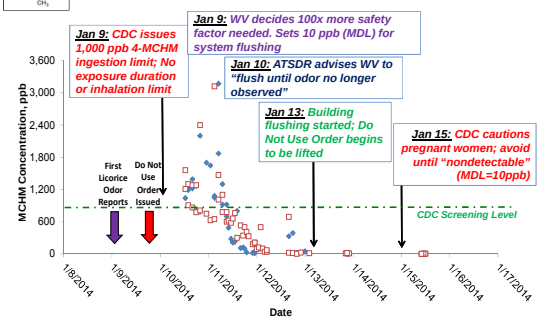
"…I would appreciate it if we could wrap this thing up…"

January 10, 2014, 5:30 pm

"…Occasionally we have had reports of an odor previously…."

MCHM Levels were Monitored at the Affected Water Treatment Plant

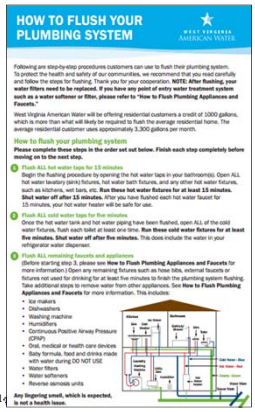
The Whelton Group



Whelton et al. 2014. Environ. Sci. Technol.

Anna Belcher, Born: January 9, 2014

"One hour before I was to bathe they announced the water was not safe, they had bathed my new born baby …."


HOW TO FLUSH YOUR PLUMBING SYSTEM

Following are step-by-step procedures customers can use to flush their plumbing system. To protect the health and safety of our communities, we recommend that you read carefully and follow the steps for flushing. Thank you for your cooperation. **NOTE: After flushing, your water filters need to be replaced. If you have any point of entry water treatment system such as a water softener or filter, please refer to "How to Flush Plumbing Appliances and Faucets."**

West Virginia American Water will be offering residential customers a credit of 1000 gallons, which is more than what will likely be required to flush the average residential home. The average residential customer uses approximately 3,300 gallons per month.

How to flush your plumbing system

Please complete these steps in the order set out below. Finish each step completely before moving on to the next step.

1. Flush ALL hot water taps for 15 minutes
   Begin the flushing procedure by opening the hot water taps in your bathroom(s). Open ALL hot water lavatory (sink) fixtures, hot water bath fixtures, and any other hot water fixtures, such as kitchens, wet bars, etc. **Run these hot water fixtures for at least 15 minutes. Shut water off after 15 minutes.** After you have flushed each hot water faucet for 15 minutes, your hot water heater will be safe for use.
2. Flush ALL cold water taps for five minutes
   Once the hot water tank and hot water piping have been flushed, open ALL of the cold water fixtures, flush each toilet at least one time. **Run these cold water fixtures for at least five minutes. Shut water off after five minutes.** This does include the water in your refrigerator water dispenser.
3. Flush ALL remaining faucets and appliances
   (Before starting step 3, please see **How to Flush Plumbing Appliances and Faucets** for more information.) Open any remaining fixtures such as hose bibs, external faucets or fixtures not used for drinking for at least five minutes to finish the plumbing system flushing. Take additional steps to remove water from other appliances. See **How to Flush Plumbing Appliances and Faucets** for more information. This includes:
   - Ice makers
   - Dishwashers
   - Washing machine
   - Humidifiers
   - Continuous Positive Airway Pressure (CPAP)
   - Oral, medical or health care devices
   - Baby formula, food and drinks made with water during DO NOT USE
   - Water filters
   - Water softeners
   - Reverse osmosis units

Any lingering smell, which is expected, is not a health issue.

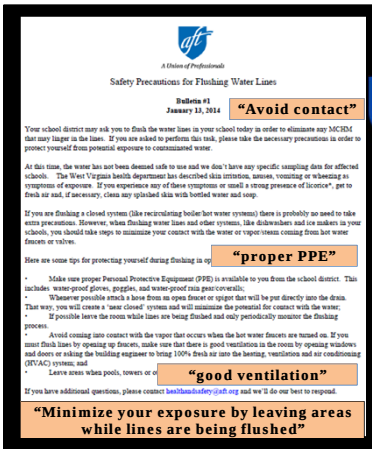
4 Days After the Spill: Utility Recommends the Population Flush their Plumbing Systems

1. Flush ALL hot water taps for 15 minutes
2. Flush ALL cold water taps for five minutes
3. Flush ALL remaining faucets and appliances

Water supplies for pets
Pets need clean water too. Be sure to empty all water bowls, bottles, or other water supplies for your pet. After flushing your water system, wash the pet bowl, bottle or other water supply. Then refill with tap water.

Any lingering smell, which is expected, is not a health issue.

WVAW. 2014.


A Union of Professionals

Safety Precautions for Flushing Water Lines

Bulletin #1
January 13, 2014

"Avoid contact"

Your school district may ask you to flush the water lines in your school today in order to eliminate any MCHM that may linger in the lines. If you are asked to perform this task, please take the necessary precautions in order to protect yourself from potential exposure to contaminated water.

At this time, the water has not been deemed safe to use and we don't have any specific sampling data for affected schools. The West Virginia health department has described skin irritation, nausea, vomiting or wheezing as symptoms of exposure. If you experience any of these symptoms or smell a strong presence of licorice*, get to fresh air and, if necessary, clean any splashed skin with bottled water and soap.

If you are flushing a closed system (like recirculating boiler/hot water systems) there is probably no need to take extra precautions. However, when flushing water lines and other systems, like dishwashers and ice makers in your schools, you should take steps to minimize your contact with the water or vapor/steam coming from hot water faucets or valves.

Here are some tips for protecting yourself during flushing in op

"proper PPE"

- Make sure proper Personal Protective Equipment (PPE) is available to you from the school district. This includes water-proof gloves, goggles, and water-proof rain gear/coveralls;
- Whenever possible attach a hose from an open faucet or spigot that will be put directly into the drain. That way, you will create a 'near closed' system and will minimize the potential for contact with the water;
- If possible leave the room while lines are being flushed and only periodically monitor the flushing process.
- Avoid coming into contact with the vapor that occurs when the hot water faucets are turned on. If you must flush lines by opening up faucets, make sure that there is good ventilation in the room by opening windows and doors or asking the building engineer to bring 100% fresh air into the heating, ventilation and air conditioning (HVAC) system; and
- Leave areas when pools, towers or o

"good ventilation"

If you have additional questions, please contact healthandsafety@aft.org and we'll do our best to respond.

"Minimize your exposure by leaving areas while lines are being flushed"

A Union of Professionals
Washington, D.C.

Safety Precautions for Flushing Water Lines

January 13, 2014

Guidance issued to school staff only

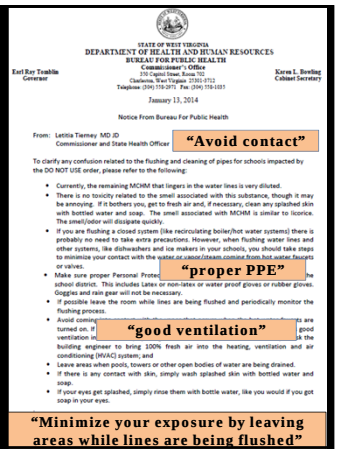
WEST VIRGINIA Department of Health & Human Resources BUREAU FOR PUBLIC HEALTH

To clarify confusion related to flushing and cleaning of pipes impacted…

January 13, 2014

Guidance issued to school staff

NOT the public



STATE OF WEST VIRGINIA
DEPARTMENT OF HEALTH AND HUMAN RESOURCES
BUREAU FOR PUBLIC HEALTH
Commissioner's Office
350 Capitol Street, Room 702
Charleston, West Virginia 25301-0712
Telephone (304) 558-2971 Fax (304) 558-1035

Earl Ray Tomblin, Governor — Karen L. Bowling, Cabinet Secretary

January 13, 2014

Notice From Bureau For Public Health

From: Letitia Tierney MD JD
Commissioner and State Health Officer

"Avoid contact"

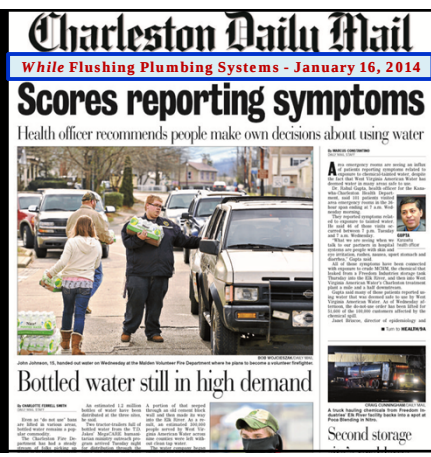
To clarify any confusion related to the flushing and cleaning of pipes for schools impacted by the DO NOT USE order, please refer to the following:

- Currently, the remaining MCHM that lingers in the water lines is very diluted.
- There is no toxicity related to the smell associated with this substance, though it may be annoying. If it bothers you, get to fresh air and, if necessary, clean any splashed skin with bottled water and soap. The smell associated with MCHM is similar to licorice. The smell/odor will dissipate quickly.
- If you are flushing a closed system (like recirculating boiler/hot water systems) there is probably no need to take extra precautions. However, when flushing water lines and other systems, like dishwashers and ice makers in your schools, you should take steps to minimize your contact with the water or vapor/steam coming from hot water faucets or valves.
- Make sure proper Personal Protec… the school district. This includes Latex or non-latex or water proof gloves or rubber gloves. Goggles and rain gear will not be necessary.
- If possible leave the room while lines are being flushed and periodically monitor the flushing process.
- Avoid coming… ts are turned on. If … good ventilation in… sk the building engineer to bring 100% fresh air into the heating, ventilation and air conditioning (HVAC) system; and
- Leave areas when pools, towers or other open bodies of water are being drained.
- If there is any contact with skin, simply wash splashed skin with bottled water and soap.
- If your eyes get splashed, simply rinse them with bottle water, like you would if you got soap in your eyes.

"proper PPE"

"good ventilation"

"Minimize your exposure by leaving areas while lines are being flushed"



Charleston Daily Mail

While Flushing Plumbing Systems - January 16, 2014

Scores reporting symptoms

Health officer recommends people make own decisions about using water

John Johnson, 15, handed out water on Wednesday at the Malden Volunteer Fire Department where he plans to become a volunteer firefighter.

Bottled water still in high demand

A truck hauling chemicals from Freedom Industries' Elk River facility backs into a spot at Pace Standing in Nitro.

Second storage

Local

WATER CONTAMINATION

How do they know it's safe at 1 ppm?

Officials still silent on how they arrived at figure for chemical limit

the Charleston Gazette

THE STATE NEWSPAPER — OUR 140TH YEAR

CDC: 'A dynamic and evolving event'

Federal agency defends stated threshold for drinking tainted water in Kanawha Valley

Is the Water "Safe?"

7 Days After the Spill (Jan 17): We drove to West Va. and Teamed with NGOs

Rob Goodwin
WV Clean Water Hub

Maya Nye
PCACS

On the Ground…
in Affected Homes

Resident interviews
In-home water testing
Home flushing

Charleston Daily Mail

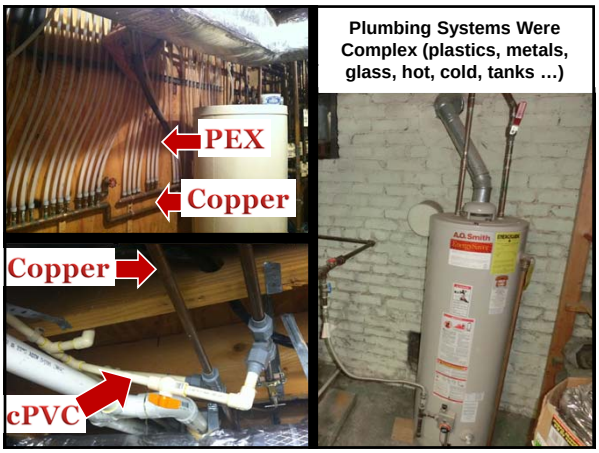
Friday, January 17, 2014 Charleston, West Virginia, dailymailwv.com

The day we arrived

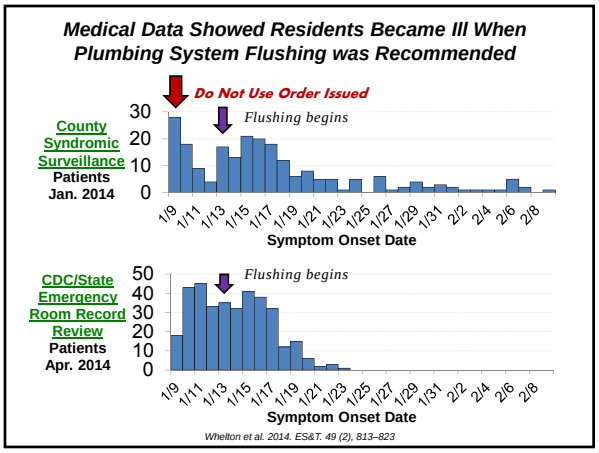
Bulk water containers pulled

Company gets more violations

Handouts halt after complaints


Plumbing Systems Were Complex (plastics, metals, glass, hot, cold, tanks …)
PEX
Copper
Copper
cPVC

OUR MODIFIED FLUSHING RECOMMENDATIONS
Shutoff hot water heater and allow to cool before flushing
Flush 1 room at a time
Use fans and open all windows (and doors) to expel contaminated air
Flush, not once, but multiple times
WEST VIRGINIA WATER CRISIS
Krista Bryson
WEST VIRGINIA WATER CRISIS: EXCLUSIVE "CRUCIAL" INFORMATION ABOUT FLUSHING
YOUR QUESTIONS ANSWERED: FLUSHING RECOMMENDATIONS, WATER AND WATER SYSTEMS SAFETY, AND HEALTH CONCERNS

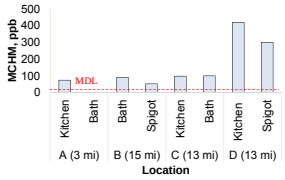

Medical Data Showed Residents Became Ill When Plumbing System Flushing was Recommended
Do Not Use Order Issued
Flushing begins
County Syndromic Surveillance Patients Jan. 2014
30
20
10
0
1/9 1/11 1/13 1/15 1/17 1/19 1/21 1/23 1/25 1/27 1/29 1/31 2/2 2/4 2/6 2/8
Symptom Onset Date
CDC/State Emergency Room Record Review Patients Apr. 2014
Flushing begins
50
40
30
20
10
0
1/9 1/11 1/13 1/15 1/17 1/19 1/21 1/23 1/25 1/27 1/29 1/31 2/2 2/4 2/6 2/8
Symptom Onset Date
Whelton et al. 2014. ES&T. 49 (2), 813–823

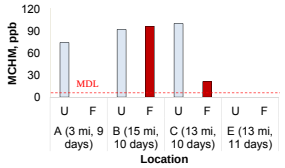
Former Resident Charleston, West Va.

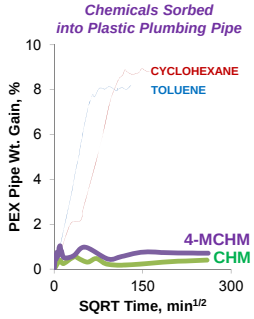
Flushed her premise plumbing 3x per guidance

Diagnosed with adult onset asthma after flushing her house

By Conducting Rapid In-Home Tests We Were Able to Understand Resident Experiences and Exposures

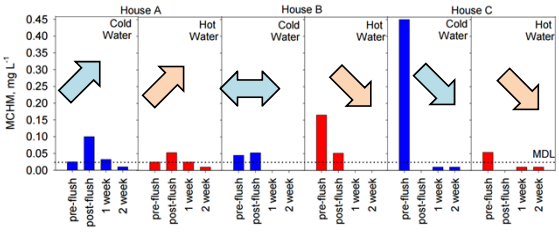






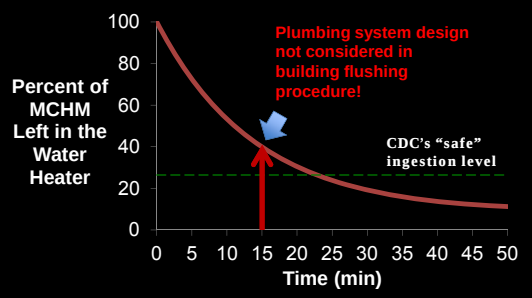
Whelton et al. 2014. ES&T. 49 (2), 813–823

Others Found Residential Flushing Had Mixed Effectiveness



Weidhass et al. 2015. Presented at the WV Taskforce Symposium. Morgantown, WV.

"…after you have flushed each hot water faucet for 15 minutes, your water heater will be safe for use."
- West Virginia American Water, 2014

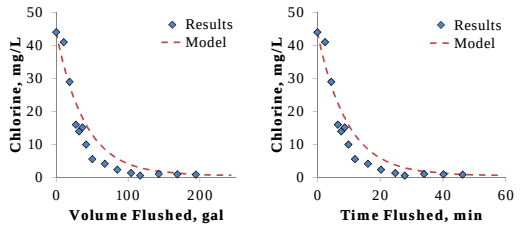


28 *Casteloes et al. 2015. ES: Wat. Res. Technol.*

NEW RESULTS:
Our 2015 Field Testing Demonstrated that Our New Water Heater Flushing Model Works

40 Gallon Water Heater in a Two Story Home
[Q_{in} = 4.2 GPM; Chlorine C_{in} = 0.6-0.9 mg/L]

$$C = C_{in} - (C_{in} - C_0)e^{-\frac{Q}{V}t}$$



Field data: KS Casteloes, X Huang, J Hawes, RH Brazeau, AJ Whelton (9/2015)

NEW RESULTS:
Our Indoor Air Exposure Modeling Results Show EPA's 4-MCHM Air Health Limits were Exceeded

Kitchen, Bathroom, Half-bath, Dishwasher Scenarios

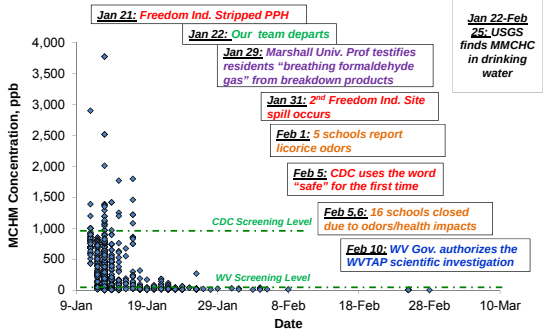
4-MCHM indoor air health limit exceeded for bathrooms

Only opening 1 or multiple windows insufficient to prevent indoor air levels from exceeding the 4-MCHM health limit

Countermeasures should have been implemented: Mechanical ventilation, Protective wear, Building evacuation

30 *Lead Investigation: Dr. Pinar Omur-Ozbek, Colorado State Univ; Akalp, Whelton, Omur-Ozbek. 2015. In Prep.*

The Water Company Flushed its Distribution System and the National Guard Flushed Government Buildings



31

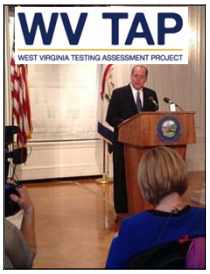
Whelton et al. 2014. Environ. Sci. Technol. 49 (2), 813–823

"Dr. Tierney, Is the Water Safe to Drink?"

February 10, 42 days after the spill

"That's, in a way, is a difficult thing to say…"

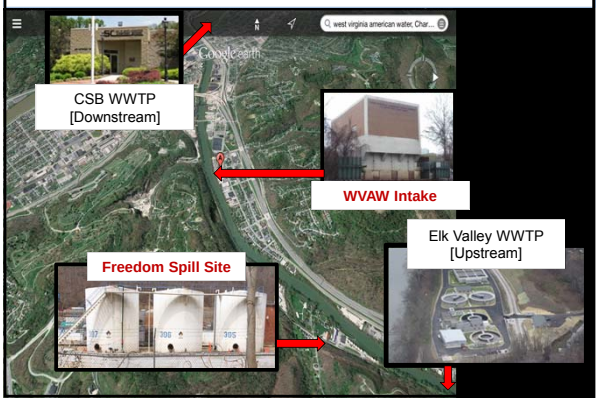
WVTAP was Authorized because of Unexplained Illnesses, Chemical Levels, and Odors



Team:
Jeffrey Rosen, CEC
Andrew Whelton, Ph.D.
Michael McGuire, Ph.D., McGuire, Inc.
Jennifer Clancy, Ph.D., CEC
Tim Clancy, CEC
Tim Bartrand, Ph.D., CEC
Andy Eaton, Ph.D., Eurofins
Craig Adams, Ph.D., Utah State University
Jacqueline Patterson, TERA
Michael Dourson, Ph.D., TERA
Patricia Nance, TERA
And the Expert Health Effects Panel

34 *Rosen et al. 2014. JAWWA.*

Environmental Impacts Remain Poorly Understood

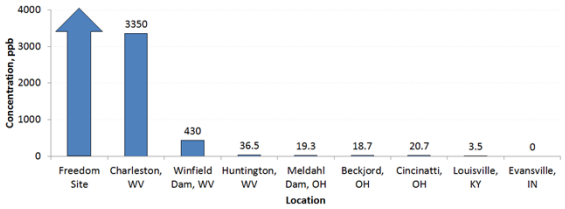


Citizens and businesses organized to protect water supplies
Maya Nye, People Concerned About Chemical Safety

Senate Bill 373, The Water Resources Protection Act
March 2014

Multiple tanks leaking before January 9, 2014
Chemical Safety Board, 2014

Communities in 4 States, 700 Miles Downstream were Impacted by the Spill



- ❑ Huntington WV: 4-MCHM finished water level = 9 ppb
- ❑ Numerous communities downstream
  - Shut their intakes
  - Conducted odor monitoring of their raw and drinking waters

Novy, Beebe, Whelton. 2015. In Prep.

NEW RESULTS:

Initial Toxicological Information on Crude MCHM, and Pure 4-MCHM Limited, No Data for Tank Liquid

Officials relied on crude MCHM SDS, Eastman Chemical Company toxicity data, and data for Stripped PPH to make decisions

Officials assumed: Toxicity of these 3 liquids was equal

Crude MCHM

1:2 cis:trans

Mixture

=

4-MCHM

2:1 cis:trans

Pure standard

=

Tank Liquid

1:2 cis:trans

Mixture + Stripped PPH

?

Novy, Beebe, Whelton. 2015. In Prep.

NEW RESULTS:

Our Toxicity Testing: *D. magna*

a.k.a. "water flea"

D. Magna cultures growing in a dark room

Indicator species, model organism

Acute toxicity tests commonly used to assess potential harm

Experimental Design
3 tests per liquid
48-hr,18-22°C, 16 h light
EC_{50},NOEC calculated

USEPA toxicity protocol
Eastman toxicity protocol

Novy, Beebe, Whelton. 2015. In Prep.

NEW RESULTS:

Crude MCHM spilled in 2014 was much *More Toxic* compared to Crude MCHM in 1998

Tox. End Point (mg/L)	Crude MCHM			Analytical Grade 4-MCHM (2014)	Freedom Industries Tank Liquid (2014)
	1998 Eastman Study	2014 Eastman Method	2014 USEPA Method		
EC_{50}	98.1*	56.8 ± 5.3	50.8 ± 11.7	84.3 ± 7.9	94.0 ± 9.5
NOEC	50*	6.25 ± 0	16.7 ±7.2	33.3 ± 14.4	41.4 ± 14.4

Highest 4-MCHM level in stormwater: 76 – 190 mg/L

Novy, Beebe, Whelton. 2015. In Prep.

NEW RESULTS:

Several Important Discoveries

2014 Crude MCHM was more toxic than…	Possible Reason(s)	Implication
1998 Crude MCHM	Mixture composition	MSDS used by responders did not representatively describe toxicity of crude MCHM in Freedom tank
2014 Analytical MCHM standard	Pure vs. mixture; Isomeric ratios and properties	Assumption by responders and gov't that liquids were equally toxic invalid
2014 Freedom Industries tank liquid	Crude MCHM diluted with stripped PPH	Toxicity of complex mixture is not simple

Additional testing ongoing to examine sublethal effects to daphnids

Does existing toxicological data available today represent that of products in commerce today?

Novy, Beebe, Whelton. 2015. In Prep.

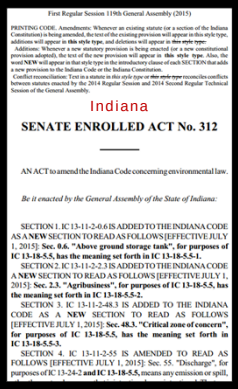
Reporters influenced information disclosure, and notified the public of our results

Charleston Gazette: Ken Ward, Jr. David Guttman
Charleston Daily Mail: David Boucher
Associated Press: Jonathan Mattise
NPR All Things Considered: Melissa Block
West Va. Public Radio: Ashton Marra, Dave Mistich
CBS Evening News: Jeff Pegues
WOWK: Alanna Autler
WCHS: Kallie Cart
And many more…

The Elk River Spill Catalyzed Action Across the US including in Washington, D.C. …and Indiana

S. 1961 - Chemical Safety and Drinking Water Protection Act of 2014, 113th Congress (2013-2014), Introduced January 27, 2014

H.R. 4024 - Ensuring Access to Clean Water Act of 2014, 113th Congress (2013-2014), Introduced February 10, 2014



First Regular Session 118th General Assembly (2015)

PRINTING CODE. Amendments: Whenever an existing statute (or a section of the Indiana Constitution) is being amended, the text of the existing provision will appear in this style type, additions will appear in **this style type**, and deletions will appear in ~~this style type~~.

Additions: Whenever a new statutory provision is being enacted (or a new constitutional provision adopted), the text of the new provision will appear in **this style type**. Also, the word **NEW** will appear in that style type in the introductory clause of each SECTION that adds a new provision to the Indiana Code or the Indiana Constitution.

Conflict reconciliation: Text in a statute in *this style type* or ~~*this style type*~~ reconciles conflicts between statutes enacted by the 2014 Regular Session and 2014 Second Regular Technical Session of the General Assembly.

Indiana

SENATE ENROLLED ACT No. 312

AN ACT to amend the Indiana Code concerning environmental law.

Be it enacted by the General Assembly of the State of Indiana:

SECTION 1. IC 13-11-2-0.6 IS ADDED TO THE INDIANA CODE AS A **NEW** SECTION TO READ AS FOLLOWS [EFFECTIVE JULY 1, 2015]: **Sec. 0.6. "Above ground storage tank", for purposes of IC 13-18-5.5, has the meaning set forth in IC 13-18-5.5-1.**

SECTION 2. IC 13-11-2-2.3 IS ADDED TO THE INDIANA CODE A **NEW** SECTION TO READ AS FOLLOWS [EFFECTIVE JULY 1, 2015]: **Sec. 2.3. "Agribusiness", for purposes of IC 13-18-5.5, has the meaning set forth in IC 13-18-5.5-2.**

SECTION 3. IC 13-11-2-48.3 IS ADDED TO THE INDIANA CODE AS A **NEW** SECTION TO READ AS FOLLOWS [EFFECTIVE JULY 1, 2015]: **Sec. 48.3. "Critical zone of concern", for purposes of IC 13-18-5.5, has the meaning set forth in IC 13-18-5.5-3.**

SECTION 4. IC 13-11-2-55 IS AMENDED TO READ AS FOLLOWS [EFFECTIVE JULY 1, 2015]: Sec. 55. "Discharge", for purposes of IC 13-24-2 **and IC 13-18-5.5,** means any emission or spill,

INDIANA

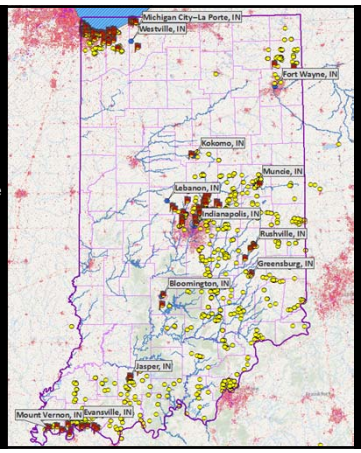
Approximately 10,000 known chemical tanks

Thousands very close to drinking water intakes

More than 2 million people served by surface water

Economy relies on these sources

10 LARGEST SYSTEMS
Indianapolis, Fort Wayne
Gary-Merrillville
Evansville, Hammond
Muncie, Bloomington
Kokomo, Richmond
Michigan City



Looking Forward: Research for Improved Chemical Spill Resilience

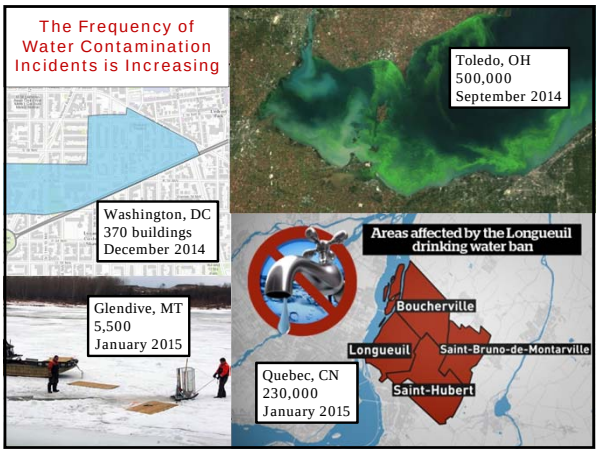
…chemical fate in premise plumbing
… premise plumbing decon
… indoor air chemical exposure
… chemical properties
… environmental fate
… transformation products
… toxicity
… social media
… risk communication
… T&D for large volumes of contaminated water
… rational decision process for incident responses
… legal responsibility for disaster response actions
… and more

47

PURDUE
UNIVERSITY

Water Infrastructure Testing & Evaluation (T&E) Facility

Recreate field conditions, Evaluate system design and contamination scenarios, Explore material-contaminant interactions, Challenge decontamination aide effectiveness



Re·sil·ience

\ri-'zil-yen(t)s\

The ability to recover from or adjust easily to misfortune or change

National Society of Professional Engineer's CREED:

Hold paramount the safety, health, and welfare of the public.

Thank you

Visit www.WheltonGroup.org

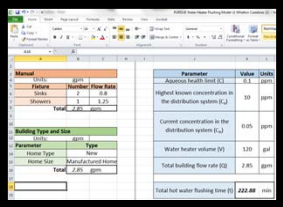
PURDUE UNIVERSITY

awhelton@purdue.edu

EXTRA SLIDES

53

What Next?



Manual

Units:	gpm	
Fixture	Number	Flow Rate
Sinks	2	0.8
Showers	1	1.25
Total	2.85	gpm

Building Type and Size

Units:	gpm
Parameter	Type
Home Type	New
Home Size	Manufactured Home
Total	2.85 gpm

Parameter	Value	Units
Aqueous health limit (L_i)	0.1	ppm
Highest known concentration in the distribution system (C_o)	10	ppm
Current concentration in the distribution system (C_{ss})	0.05	ppm
Water heater volume (V)	120	gal
Total building flow rate (Q)	2.85	gpm
Total hot water flushing time (t)	222.88	min

Download and use our *free* premise plumbing flushing model. Copy of associated study also free online.

Adopt a step-wise process for rapid investigation, response, and recovery … how-to outline coming 2016

Identify safe plumbing system cleaning agents … coming 2016

Develop and adopt indoor air chemical exposure model for premise plumbing flushing … coming 2016

Practice stepwise investigation for incident response and recovery

A Variety of Aquatic Toxicity Tests Have Been Completed and are Ongoing

Tests in Isolation
Tank 396 Liquid
2014 Crude MCHM
2014 Stripped PPH
Pure 4-MCHM
Pure DMCHC
Pure 1,4-CHDM
Pure PPH
Pure DiPPH
And others…

Tank 396 liquid

2014 Crude MCHM → Tank 396 liquid ← 2014 Stripped PPH

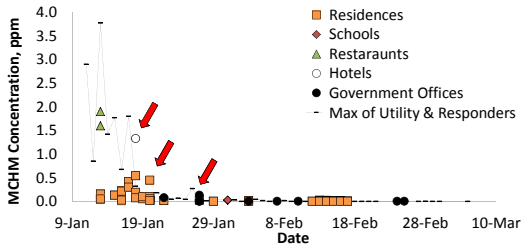
Animal Toxicity Responses Detected [Rat, Rabbit, Guinea pig, Mouse]

Acutely toxic
Dermal, oral, eye exposures
kidney and liver responses

Aquatic Organism Toxicity Responses Detected
[*E. coli*, *Salmonella*, Yeast, Daphnid, Fathead minnow, Zebrafish, Frog]

Acutely toxic
DNA damage; Metabolites more toxic
CNS defects, growth cessation
Neurotoxic, Embryonic malformations

Responder Water Distribution Data Sometimes Did Not Match In-Home Concentrations



>2,500 responder water distribution water samples vs. much fewer samples from 38 buildings
Neither distribution sampling or building sampling was statistically designed

McMillan & Whelton. In Prep.

Symptom	Our Home Survey *1/14*	KCHD Phys. Records *1/14*	WVTAP Home Survey *2/14*	CDC & WV ER Records *3/14*	WV Phys. Records *3/14*	KCHD Tel. Survey *4/14*	CDC Home Survey *6/14*
Dermatologic							
Skin irritation	-	40	-	-	-	60§	53
Rash	12	47	40	28	21	§	43
Itching	-	-	10	19	60	-	-
Eye irritation	12	25	10	14	13	24	5
Gastrointestinal							
Nausea	31	21	30	37	-	24Δ	12
Vomiting	0	13	10	28	8	Δ	5
Abdominal Pain	6	-	-	24	8	25Φ	5
Diarrhea	6	16	0	24	5	Φ	12
Respiratory							
Unspecified	-	-	-	-	-	15	-
Sore Throat	-	9	-	14	8	-	10
Cough	-	6	-	12	15	-	15
Orientation							
Dizziness	18	-	40	-	-	22ε	7
Headache	12	13	30	21	11	ε	10
Other	12	-	80	-	-	14	23

Higher Water Temperature, More Chemicals Volatilized into the Air! *(EPA SPARC Modeling Software)*

Constituent	Log K_{ow}			Water Solubility, mg/L			Vapor Press., mmHg		
	5	21	60	5	21	60	5	21	60
CRUDE MCHM									
4-MCHM	2.77	2.43	1.71	1,340	2,900	14,900	0.01	0.07	1.50
4-MMCHM	NF	NF	NF	NF	NF	NF	NF	NF	NF
M4-MCHC	2.81	2.54	2.51	508	924	964	0.11	0.44	4.46
D1,4-CHD	1.65	1.58	2.02	8,210	9,550	3,330	0.002	0.014	0.220
Methanol	-0.58	-0.58	-0.59	10,000	10,000	10,000	48.7	118.9	633.5
1,4-CHDM	0.78	0.62	0.17	15,200	28,100	176,000	<0.0001	<0.0001	0.0017
CHM	2.27	1.98	1.38	3,630	7,040	27,600	0.027	0.140	2.580
2-MEB	2.70	2.44	2.39	1,370	2,510	2,790	0.021	0.110	1.290
STRIPPED PPH									
PPH	2.49	2.19	1.88	2,020	4,620	11,300	0.0009	0.0059	0.2000
DiPPH	NF	NF	NF	NF	NF	NF	NF	NF	NF

58

Whelton et al. 2014. Environ. Sci. Technol.

New Results! Methods for Decontaminating Residential Premise Plumbing

- 39 organic chemical plumbing contamination incidents
- Disparate decon approaches applied without justification and nearly all lacked water quality monitoring to verify effectiveness
- Flushing most popular, but sometimes ineffective and caused illness
- Surfactant use and component replacement less popular, but sometimes carried-out
- 2014 West Va. incident: Model and field data show several types of premise plumbing were not decontaminated

Casteloes et al.

Oxygen	58%
Aluminum	18%
Carbon	17%
Zinc	1.4%
Phosphorous	1.4%
Fluorine	1.0%
Chromium $^{+6}$	**0.8%**
Calcium	0.2%
Copper	0.1%

Exited faucets during flushing: ***Not Sediment***

Whelton et al. EST. 2014. Downey et al. 2014

State of the Science Report Published 2015
Decontamination Methods for Premise Plumbing

Environmental Science: Water Research & Technology

PAPER

Decontaminating Chemically Contaminated Residential Premise Plumbing Systems by Flushing†

Received 00th January 20xx,
Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

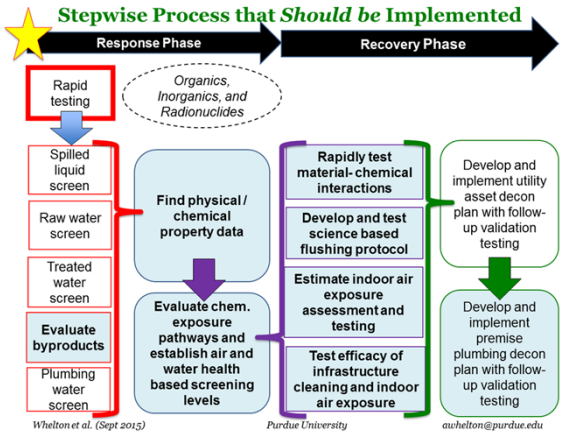
www.rsc.org/

K. S. Casteloes,[a] R. H. Brazeau[b] and A. J. Whelton[b,*]

Recent large-scale drinking water chemical contamination incidents in Canada and the U.S. have affected more than 1,000,000 people and involved disparate premise plumbing decontamination approaches. In this study, past premise plumbing decontamination approaches were reviewed and a mass balance water heater model was developed and tested. Organic contaminants were the sole focus of this work. Thirty-nine contamination incidents were identified and contaminants had a wide range of physiochemical properties [i.e., Log K_{ow}, water solubility, vapor pressure]. Minimal data was available pertaining to flushing protocol design and effectiveness. Results showed that premise plumbing design, operational conditions, contaminants present and their properties, as well as building inhabitant safety have not been fully considered in flushing protocol design. Results indicated that flushing could decontaminate some, but not all plumbing systems. Several modeling scenarios showed contaminant levels exceeded drinking water health limits after flushing following recent large-scale water contamination incidents. Water saving fixtures and devices, water heater size, and flow rate affected contaminant removal efficiency. Modeling did not consider service lines or piping. This study provides a first step in the development of science based premise plumbing flushing protocols for organic contaminants.

Link to Royal Society of Chemistry
http://pubs.rsc.org/en/content/articlelanding/2015/ew/c5ew00118h#!divAbstract

Stepwise Process that *Should be* Implemented



Whelton et al. (Sept 2015) *Purdue University* *awhelton@purdue.edu*

Use the Purdue University Water Heater Flushing Model

This allows you to estimate the time required to flush...

$$C = C_{in} - \left(C_{in} - C_0\right)e^{-\frac{Q}{V}t}$$

C_{in} = Chemical concentration entering the water heater
C_0 = Chemical concentration in the water heater at time zero
C = Chemical concentration in the water heater at time *t*
Q = Water flow rate entering and exiting the water heater
V = Water storage volume of the water heater
➔ *OUTPUT …… t* = time needed to flush water heater

Use the MS Excel file provided to you enter in what you know and the model tells you how long you need to flush the water heater.

63

Casteloes et al. 2015. ES: WR&T.

PURDUE Water Heater Flushing Model

Spreadsheet 1 of 3

version 1.0

Created by
K. Casteloes and A.J. Whelton August 2015

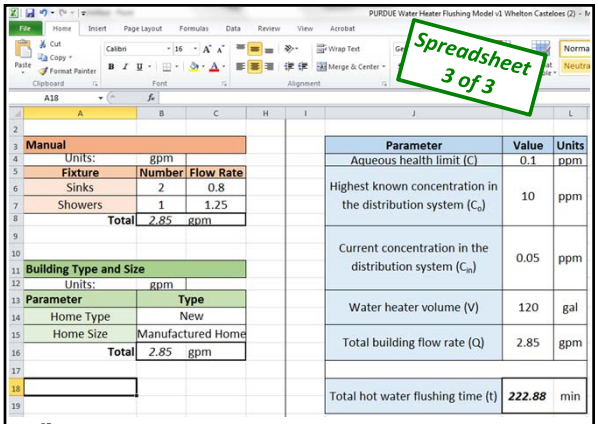
Source Document

Decontaminating chemically contaminated residential premise plumbing systems by flushing. 2015.
K. S. Casteloes, R. H. Brazeau, A. J. Whelton. Environ. Sci.: Water Res. Technol. DOI: 10.1039/C5EW00118H
Open Access, Free Download
http://pubs.rsc.org/en/content/articlelanding/2015/ew/c5ew00118h#!divAbstract

Contact
Purdue University
Lyles School of Civil Engineering and Division of Environmental and Ecological Engineering
West Lafayette, IN USA 47906
T: (540) 230-6069
E: awhelton@purdue.edu
W: http://www.wheltongroup.org

Link to Published Water Heater Model: Royal Society of Chemistry
http://pubs.rsc.org/en/content/articlelanding/2015/ew/c5ew00118h#!divAbstract

64



Manual		
Units:	gpm	
Fixture	Number	Flow Rate
Sinks	2	0.8
Showers	1	1.25
Total	2.85	gpm

Building Type and Size	
Units:	gpm
Parameter	Type
Home Type	New
Home Size	Manufactured Home
Total	2.85 gpm

Parameter	Value	Units
Aqueous health limit (C)	0.1	ppm
Highest known concentration in the distribution system (C_o)	10	ppm
Current concentration in the distribution system (C_n)	0.05	ppm
Water heater volume (V)	120	gal
Total building flow rate (Q)	2.85	gpm
Total hot water flushing time (t)	***222.88***	min

65

Spreadsheet 2 of 3

The model's assumptions are listed

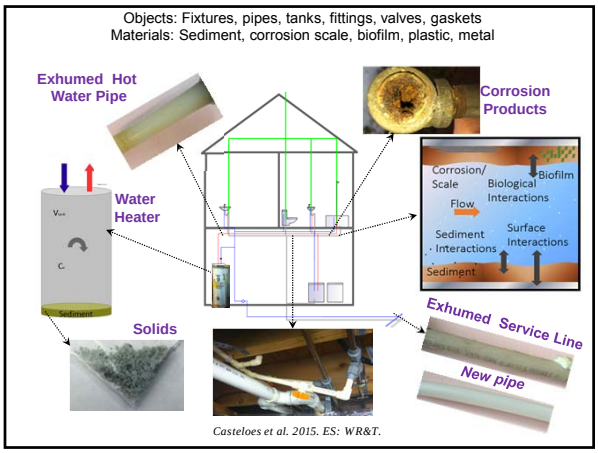
This file was created to assist persons to estimate the time needed to reduce the chemical concentration of water stored in a stand water heater.

Users should recognize the numerous limitations of this mathematical model.
No chemical interactions with plumbing materials, scale or sediment are considered.
The tank performs like a continuous flow/stirring tank reactor where the chemical concentration at any point of the tank is the concentration exiting the tank.
The flowrate entering the tank equals the flowrate exiting the tank. No headloss is encountered.
Chemical does not degrade into other chemical(s)
Temperature is not considered in mixing, - No temperature dependence
Chemical concentration in the tank and water that will be used to flush are known.

The following designs are considered for three types of residential homes:
"Legacy" home: 2-4 (2 for safety) gpm faucet, 5 gpm shower head (A = 4 gpm faucet, B = 2 gpm faucet)
"Renovated": 1.5 gpm faucet, 2 gpm shower head
"New" Home: 0.8 gpm faucet, 1.25 gpm shower head

Because of the numerous limitations of this model, persons are urged to add a safety factor.

We recommend adding safety factors


Objects: Fixtures, pipes, tanks, fittings, valves, gaskets
Materials: Sediment, corrosion scale, biofilm, plastic, metal
Exhumed Hot Water Pipe
Corrosion Products
Water Heater
Corrosion/ Scale
Biofilm
Biological Interactions
Flow
Sediment Interactions
Surface Interactions
Sediment
Solids
Exhumed Service Line
New pipe
Casteloes et al. 2015. ES: WR&T.