In 2021, wildfires occurred in all 50 states...

Large fires didn’t just occur out West.
Public water systems and private drinking water wells are vulnerable to fire.

2017-2021, fires chemically contaminated at least 11 California and Oregon water distribution systems

Proctor et al. 2020
https://doi.org/10.1002/aws2.1183

Odimayomi et al. 2021
https://doi.org/10.1007/s11069-021-04714-9

USGS 2009

CA Utility 2021

San Francisco Chronicle 9/3/20, Sara Gobets
Possible Primary VOC & SVOC Sources

1. *In-situ* plastic thermal decomposition (PVC pipes, HDPE pipes, PB pipes, gaskets, meter components, etc.)

2. Contaminated air/materials drawn into depressurized system

3. Contaminated water from building plumbing drawn into compromised distribution system

Confirmed Secondary Sources

Partitioning/Adsorption/Absorption:

Water ↔ Material

See video at www.PlumbingSafety.org
15% of the U.S. population receives water from a private well.
Welcome to Boulder County

U.S. pop
Boulder Co., CO
Butte Co., CA

331,893,745
330,758
208,309

$62,843
$127,292
$51,566

$217,500
$592,000
$49,000

32.1%
62.1%
26.0%
Fires historically occurred to the West of Boulder, CO.
December 30, 2021

11:06 am, Fire in Boulder Co.
12:10 pm, Fire in Superior
12:50 pm, Fire in Louisville
1:00 pm, 1,000 acres

40,000+ evacuation ordered

The 3 largest communities
Lafayette: 30,411
Louisville: 21,266
Superior: 13,094

Grass fire: 70 mph sustained, 90 to 102 mph wind gusts

Source: Fischer & Wham et al. GEER. The 2021 Marshall Fire, Boulder County, CO.
100,000+ residents

715,000+ residents

6 public water systems were in the burn area
The 6 public water systems impacted served about 60,000 people

<table>
<thead>
<tr>
<th>Public Water System (population)</th>
<th>Damaged/ Destroyed Properties</th>
<th>Water Mains, miles</th>
<th>Hydrants</th>
<th>Finished Water Storage, MG</th>
<th>Raw Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louisville (20,319)</td>
<td>593</td>
<td>120</td>
<td>1,200</td>
<td>7.5</td>
<td>Surface water</td>
</tr>
<tr>
<td>Superior (17,170)</td>
<td>436</td>
<td>50</td>
<td>430</td>
<td>3.4</td>
<td>Surface water</td>
</tr>
<tr>
<td>Lafayette (28,700)</td>
<td>~50</td>
<td>177</td>
<td>900</td>
<td>14</td>
<td>Surface water</td>
</tr>
<tr>
<td>EBCWD (300)</td>
<td>72 of 137</td>
<td>8</td>
<td>40</td>
<td>0.1</td>
<td>Lafayette</td>
</tr>
<tr>
<td>Eldorado Artesian Spring (259)</td>
<td>0</td>
<td>&lt;1</td>
<td>0</td>
<td>None</td>
<td>2 Wells, 1 Spring</td>
</tr>
<tr>
<td>S.S. Mobile Home Park (150)</td>
<td>3, wind</td>
<td>&lt;1</td>
<td>0</td>
<td>None</td>
<td>1 Well</td>
</tr>
</tbody>
</table>
The first 24 hours
After 24 hours

Snowfall helped extinguish the fire and hotspots.
WE ARE TEMPORARILY CLOSED DUE TO NO ACCESS TO CLEAN WATER. SEE YOU SOON!
Internal leadership, exceptional staff, and requests for aide helped utilities stabilize.

Helpful neighbors: Boulder, Ft. Collins, Erie, Westminster, South Adams County, Broomfield, Longmont, more…
Technology was critical to Louisville and Superior in finding valves, isolating systems, flushing, and identifying sampling locations to restore pressure.

Each utility moved at a different pace with different challenges.

1st focus: Bacteria and chlorine

Next: Fire caused VOCs

And then: Fire caused SVOCs

Red = water mains shutoff
Is **benzene** THE indicator of contamination?
   --No

Is **BTEX** THE indicator of contamination?
   --No

Is **VOC** THE indicator of SVOC contamination?
   --Probably not, untested theory

**Oregon 2021:** MEK (138 ppm) exceeded the USEPA 1-day health advisory in the absence of benzene

*No shortcuts to chemical contamination decisions*
To expedite contamination testing, we reviewed all literature and compiled a “fire package” list of chemicals

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Chlorinated Compound</th>
<th>Alcohol</th>
<th>Other Common Name</th>
<th>Molecular Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetonitrile</td>
<td>Chlorodibromomethane</td>
<td>Ethyl-tert-butyl ether (ETBE)</td>
<td>1,2,4-Trichlorobenzene</td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td>Chloromethane</td>
<td>Iodomethane</td>
<td>1,1,1-Trichloroethane</td>
<td></td>
</tr>
<tr>
<td>Acrolein</td>
<td>4-Chlorotoluene</td>
<td>Isopropylbenzene</td>
<td>1,1,2-Trichloroethane</td>
<td></td>
</tr>
<tr>
<td>Acrylonitrile</td>
<td>Dibromochloromethane</td>
<td>Methylene chloride</td>
<td>Trichloroethylene</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>1,2-Dichlorobenzene</td>
<td>Methyl ethyl ketone (MEK)</td>
<td>Trichloromethane</td>
<td></td>
</tr>
<tr>
<td>Bromochloromethane</td>
<td>1,4-Dichlorobenzene</td>
<td>Methyl iso butyl ketone (MIBK)</td>
<td>1,2,4-Trimethylbenzene</td>
<td></td>
</tr>
<tr>
<td>Bromodichloromethane</td>
<td>1,1-Dichloroethane</td>
<td>Methyl-tert-butyl ether (MTBE)</td>
<td>1,3,5-Trimethylbenzene</td>
<td></td>
</tr>
<tr>
<td>Bromoform</td>
<td>1,2-Dichloroethane</td>
<td>Naphthalene</td>
<td>Vinyl chloride</td>
<td></td>
</tr>
<tr>
<td>n-Butylbenzene</td>
<td>1,1-Dichloroethene</td>
<td>Styrene</td>
<td>ortho-Xylene</td>
<td></td>
</tr>
<tr>
<td>sec-Butylbenzene</td>
<td>cis-1,2-Dichloroethylene</td>
<td>tert-Butyl alcohol (TBA)</td>
<td>meta-Xylene</td>
<td></td>
</tr>
<tr>
<td>tert-Butylbenzene</td>
<td>trans-1,2-Dichloroethylene</td>
<td>Tetrachloroethylene</td>
<td>para-Xylene</td>
<td></td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>1,2-Dichloropropane</td>
<td>Tetrahydrofuran (THF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon tetrachloride</td>
<td>Ethanol</td>
<td>Toluene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorobenzene</td>
<td>Ethylbenzene</td>
<td>1,2,3-Trichlorobenzene</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Look for SVOCs too.
10,000 ft view of the Marshall Fire water distribution system contamination

Zero systems found bacteria during their return to service

No fire damage: S.S. Mobile Home Park and Eldorado Artesian Springs

The Mobile Home Park lost power for 4 days: no generator, no storage tank

Lafayette, Louisville, and Superior flushed to bring chlorine residual back

Lafayette shutdown the small area (22 homes) affected and did not find VOC contamination

Louisville had isolated depressurized areas; Found VOC and SVOC contamination

Superior found a different type of VOC contamination

Paint thinner odor was reported at the East Boulder County Water District so they flushed and sampled (no stagnation), but did not find contamination; 3 weeks later (with stagnation) they found 5.1 ppb benzene
In Louisville, CO, chemical contamination was found above short-term drinking water exposure limits in isolated, shutoff sections. Locations with VOC exceedances were not returned to service until results were below health limits. Majority of samples had no detections. SVOCs were present too.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Max</th>
<th>&gt;Limit?</th>
<th>Odor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>221</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>511</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>160</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Xylenes</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Styrene</td>
<td>1,900</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>11</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Acrolein</td>
<td>24</td>
<td></td>
<td>Y</td>
</tr>
</tbody>
</table>

Others: 1,1-DCP, 1,2,4-TMB, 1,2-Dichloroethane, 4-Chlorotoluene, Acetone, Acetonitrile, Acrylonitrile, DEHP, Carbon disulfide, Chlorobenzene, Chloromethane, IPB, MEK, MTBE, N-Butylbenzene, N-Propylbenzene

3 EPA Methods (524.2, 524.4, and 8260C) and >4 laboratories used.
Smoky, Ash Tray, Camp Fire Flavored Water

Superior received 300+ complaints in a day

Community concerns:
- Present at 1 household and not the neighbors
- Present in hot water only, not cold water
- Water heaters were contaminated
- The depressurized system sucked in chemicals
- Contamination was trapped in parts of the system

Smoke flavor after ‘03, ‘13, ‘16 wildfires assumed to be caused by drinking water source ash contamination.

Food science literature: Caused by phenols, o-cresol, p-cresol, m-cresol, guaiacol

CSU Dr. Omur-Ozbek confirmed the flavor was originating from the source water (lake) —and— in the treatment plant —and— in the water distribution system

CU Boulder Dr. Thurman, Dr. Ferrer, and Corona identified and attributed a tricarboxylic benzoic acid and a dicarboxylic benzoic acid as the “smoky flavor” agents at ppb (Ferrer et al. 2021).

They stated chemicals identified were not known to be a health risk at levels found.
Private drinking water wells and the buildings they supply can be damaged by fire

**BCHD:** Bacteria, Al, As, Cd, Pb, Sb, Se, PAH's

**CDC:** Bacteria, NO$_3^-$; BTEX; local contaminants

**WaDOH:** Coliform bacteria

**SCCHD:** Coliform bacteria, turbidity, pH, conductivity, color, NO$_3^-$; VOCs, SVOCs

**OHA:** Coliform bacteria, As, Pb, NO$_3^-$; BTEX
We reached out to help those served by private wells.
Other wells had structures that were destroyed, debris was blown into them for more than 12 hr
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>W7 (surface)</th>
<th>W7 (3-4 ft)</th>
<th>W13</th>
<th>W5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azobenzene</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td>2-Nitrophenol</td>
<td>0.15</td>
<td>0.11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1,2,3-Trichlorobenzene</td>
<td>0.14</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>0.15</td>
<td>0.19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2-Methylnaphthalene</td>
<td>0.10</td>
<td>0.08</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1-Methylnaphthalene</td>
<td>0.16</td>
<td>0.18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2-Nitroaniline</td>
<td>-</td>
<td>0.10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Acenaphthylene</td>
<td>0.19</td>
<td>0.23</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1,2-Dinitrobenzene</td>
<td>0.14</td>
<td>0.11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluorene</td>
<td>0.10</td>
<td>0.13</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4-Nitroaniline</td>
<td>0.10</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phenanthrene</td>
<td>0.14</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Di-n-butylphthalate</td>
<td>5.9</td>
<td>0.48</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluoranthene</td>
<td>0.13</td>
<td>1.0</td>
<td>0.19</td>
<td>-</td>
</tr>
<tr>
<td>Pyrene</td>
<td>0.14</td>
<td>0.19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bis(2-ethylhexyl)adipate</td>
<td>9.3</td>
<td>4.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chrysene</td>
<td>0.12</td>
<td>0.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bis(2-ethylhexyl)phthalate</td>
<td>3.6</td>
<td>3.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Anthracene</td>
<td>-</td>
<td>-</td>
<td>0.11</td>
<td>-</td>
</tr>
</tbody>
</table>

W7 was a hand-dug well with debris
### Lithium Source Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Mean ± Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells &amp; Cisterns – Marshall Fire (14)</td>
<td>12.4</td>
<td>105</td>
<td>42 ± 26</td>
</tr>
<tr>
<td>Faucet – Marshall Fire (8)</td>
<td>4.2</td>
<td>89.3</td>
<td>34.8 ± 25.1</td>
</tr>
<tr>
<td>PWS UCMR3 – Colorado (108)</td>
<td>0.9</td>
<td>1,700</td>
<td>20.3 ± 54.1</td>
</tr>
<tr>
<td>PWS UCMR3 – Marshall Fire area (108)</td>
<td>1.6</td>
<td>131</td>
<td>25.8 ± 23.7</td>
</tr>
</tbody>
</table>

**USEPA Health Based Screening Level: 10 ppb**

### Vanadium Source Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Mean ± Stdev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells &amp; Cisterns – Marshall Fire (14)</td>
<td>9.3</td>
<td>243</td>
<td>69.4 ± 73</td>
</tr>
<tr>
<td>Faucet – Marshall Fire (8)</td>
<td>15.5</td>
<td>86.5</td>
<td>59.3 ± 30.4</td>
</tr>
<tr>
<td>PWS UCMR5 – ongoing</td>
<td>tbd</td>
<td>tbd</td>
<td>tbd</td>
</tr>
</tbody>
</table>

**USEPA Health Based Regional Screening Level: 86 ppb**
1. Assessing well damage
2. Permit requirements for well repair
3. Water testing
4. CDPHE Factsheets: Lithium and vanadium
5. Testing laboratories for VOCs, SVOC, and heavy metals
6. Home water filtration systems
7. Resources for well owners
8. Resources for onsite wastewater treatment system owners
8 customers, not an HOA
1 well, 1 chlorinator, flow, pressure monitoring
2 concrete cisterns
780 ft HDPE (3") water main
No hydrants
No water meters, no curb stops
1" HDPE service lines
160 ft max length
11 days after the fire... before debris removal began
National Lessons

• Assume chemical contamination has occurred, then work to find and remove it.
• Keeping water flowing can prevent contamination of the distribution system.

Source: Ellen Harris, Boulder Co Open Space
1. For initial response, success can be achieved with trained staff, practice, nearby friends, interconnections, maintaining power, water storage, pressure, and knowing where and how to monitor and operate facilities without technology.

2. Decision making processes for water contamination response and recovery continue to be made on-the-fly. Qualified expert input can expedite and hone decision making. A guiding CONOPS plan is needed...and is being developed by Purdue with partners.

3. Boulder County-CDPHE-USEPA demonstrated admirable community support.

4. Very small systems and well owners need explicit help post-fire. Remains unclear what specific contaminants are most likely after fire.

5. After fires, are we focused on the right contaminants? VOC and SVOC drinking water contamination after fires is real. Bacteria contamination of public water systems not found yet for any wildfire I’ve been involved in. Are health officials focused on the right contaminants?
Angela Raff, Melissa Westendorf, Carmen Turner, Caroline Jankowski, Kris Isaacson, Myles Cook, Madeline Larsen, Deepika Solamuthu, Alan Holtman, Brad Caffery

Christian Ley, Brad Wham, Amy Javernick-Will, Karl Linden

Kurt Kowar, Justin Ferron, Cory Peterson, Greg Vinette, Jill Fischer, and more

Alex Arinello, David Lewis, Jim Widener, Wayne Ramey, and more

Scott Pavlik, Callie Hayden

Tyson Engles, Chelsea Cotton, Kelsey Barton, Shannon Barbare, Kristy Richardson

Erin Dodge, Celeste Gleason, Nickie Mercke, and more

Mark Johns, Marsh Lavenue

Erica Fischer

Chad Seidel and more
Thank you. More results coming...

Andrew Whelton, Ph.D.  awhelton@purdue.edu

Learn more at: