Assessing exposures from drinking water at the point of use: USGS collaborative tapwater research.

Michael J. Focazio, U.S. Geological Survey, Reston, Virginia
Paul M. Bradley, U.S. Geological Survey, Columbia, South Carolina
Dana W. Kolpin, U.S. Geological Survey, Iowa City, Iowa
Kristin M. Romanok, U.S. Geological Survey, Lawrenceville, New Jersey
Is tap water safe?

Death Rate for Typhoid Fever
United States, 1900-1960

Chlorination Begun

Rates per 100,000 Population

1900 1910 1920 1930 1940 1950 1960

Is tap water safe?

• USEPA: Stage 2 DBPR improves on public health protection by limiting exposure to DBPs, specifically:
  • Total trihalomethanes (TTHM) & 5 haloacetic acids (HAA5)

In 2016 Alzheimer’s Disease and other dementias will cost the U.S. $236 Billion

-Alzheimer’s Association

Studies published (8,102 papers) on 5 categories of environmental contaminants associated with AD or AD-like progression

Someone in the U.S. develops Alzheimer’s Disease every 66 seconds.

NHANES Biomonitoring

GM urinary concentration (µg/L)

- TCPy (chlorpyrifos)
- 3-PBA (pyrethroids)

<table>
<thead>
<tr>
<th>Year</th>
<th>TCPy Mean (µg/L)</th>
<th>3-PBA Mean (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999-2000</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>2001-2002</td>
<td>1.8</td>
<td>0.5</td>
</tr>
<tr>
<td>2007-2008</td>
<td>1.6</td>
<td>0.5</td>
</tr>
<tr>
<td>2009-2010</td>
<td>1.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>
CDC Confirms Lead Levels Shot Up in Flint Kids After Water Switch

- NBC News

Mayor says water crisis is similar to 9/11

- The Toledo Blade

WV water crisis settlements provide community up to $151M

- The Charleston Gazette-Mail

Is tap water safe?
Currently over 143 million different organic and inorganic substances in CAS registry; 15,000 new substances daily;
Monitor untreated sources of drinking water (SW & GW):

- Nationally consistent sampling & analysis methods
- Develop methods with low detection levels
- Nationally distributed & trained field & lab personnel
- Assess unmonitored resources like private wells

Develop models and decision support tools to:

- Predict source-water quality in unmonitored areas
- Forecast short- & long-term changes in water quality
A Retrospective Analysis on the Occurrence of Arsenic in Ground-Water Resources of the United States and Limitations in Drinking-Water-Supply Characterizations

Water-Resources Investigations Report 99–4279

...percent exceedance...
Figure 4. Detections and MCL exceedances for all analyses of VOCs, pesticides, uranium, and arsenic.

Note: Detection levels before mid 2000’s were ~ 1ug/L

Focazio et al., 2006. The Chemical Quality of Self-Supplied Domestic Well Water in the United States. Ground Water Monitoring and Remediation, 26; 92-104
What have we learned about drinking water contaminants over the past two decades from USGS science?

Inorganic contaminants occur more frequently and above drinking water standards in sources of drinking water than organic contaminants

Advanced detection and quantitation technologies lead to low-level detections of organic contaminants in sources of drinking water. You will find it if you look hard enough.

Mixtures of contaminants are the rule not the exception. Monitoring all contaminants everywhere is not possible.

Exposure data are inadequately addressed due to sampling locations and times.

Potential linkages between drinking water exposures and human-health outcomes are rarely investigated.
Ayotte, personal comm
Models predict benchmark exceedance probabilities in streams & rivers: pesticides

Stone et al: Watershed Regressions for Pesticides (WARP) models
https://cida.usgs.gov/warp/home/
Contaminants of “Emerging Concern”

Note: Detection levels were ~ 1μg/L
So What?

Davis, M. 1959
**Human-health benchmark tool**

Norman, Toccalino, and Morman (expected 2018)
http://water.usgs.gov/nawqa/HBSL

*Toccalino et al., 2007, USGS SIR 2007-5106*
Do natural and infrastructure related factors lead to significant changes in arsenic exposure?


**NEW ENGLAND**

**A** Arsenic concentrations by quarter

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Arsenic Concentration, µg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>January to March</td>
<td>5.00 (3959)</td>
</tr>
<tr>
<td>April to June</td>
<td>10.00 (3950)</td>
</tr>
<tr>
<td>July to September</td>
<td>15.00 (4264)</td>
</tr>
<tr>
<td>October to December</td>
<td>20.00 (3789)</td>
</tr>
</tbody>
</table>

Kruskal-Wallis p < 0.001

**B** Water levels by quarter

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Water Level, feet below land surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>January to March</td>
<td>0.00 (3959)</td>
</tr>
<tr>
<td>April to June</td>
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</table>

**FIELD-READY ELECTROCHEMICAL DETECTOR®**

**ARSENIC ANALYSIS SYSTEM**
Can USGS science add value to the public health community of researchers and practitioners?
Linking human health outcomes to exposure estimates with modeled arsenic concentrations in groundwater

Principal Investigator(s):
Maria Argos (*University of Illinois at Chicago*)
Joseph D Ayotte (*New Hampshire/Vermont Water Science Center*)
Matthew Gribble (*Emory University*)
Bernard T Nolan (*National Water-Quality Assessment Program*)

Award Date: 2018

Everyone needs clean drinking water in order to thrive. The US EPA and public water purveyors in the US have adhered to the Safe Drinking Water Act to make water safe for public consumption. The recent media attention on public drinking water supplies in Flint, Michigan, and schools in many cities with aging infrastructure has raised public awareness of drinking water as a potential pathway of exposure to toxic chemicals. Epidemiological researchers have conclusively shown that high arsenic levels in drinking water in Bangladesh, Taiwan, and adverse human health outcomes. However, research in study populations with levels of arsenic exposure in communities in the US is needed to understand the health risks, if any, contributed by drinking water exposur...
Collaborative Tapwater Research: Ongoing & Opportunities
Drinking Water concerns:

• Increased water-reuse (intentional and de facto)
• Contaminant mixtures in SW/GW sources & finished DW
• Disconnect between regulation/treatment & environmental-contaminant complexity
• Aging drinking-water infrastructure and legacy plumbing materials
• New research linking public health outcomes to low-level contaminant exposures
• Water treatment public-health tradeoffs (e.g., disinfection vs DBP)
• High-visibility water-quality failures
USGS Drinking-Water Quality Science ...

DW Information Imbalance:

- Public supply (EPA):
  - Routine compliance monitoring:
    - Regulated contaminants
    - Primarily pre-distribution
    - Limited POU monitoring

- Private supply (owner):
  - <15 person/<25 hookups (EPA not authorized)
  - Monitoring rare:
    - Over reliance on organoleptic quality
    - Cost prohibitive
    - Disclosure disincentive (property sales)
USGS Drinking-Water Quality Science ...

Regulation/Guidance Considerations:

- **Maximum Contaminant Level (MCL):**
  - Enforceable (triggers action)
  - Based on:
    - Public Health concern
    - Technical/Economic Feasibility

- **MCL Goal (MCLG):**
  - "level of a contaminant in drinking water below which there is no known or expected risk to health"
  - Non-enforceable
  - Based on:
    - Public Health
    - Specific emphasis on vulnerable populations
Great Chemical Unknown:

- TSCA inventory:
  - ~83,000 chemicals
  - voluntary HPV assessment (~300)
- CAS:
  - 2014: ~99 million organic/inorganic
  - 2004: ~23 million organic/inorganic
- Regulated/Assessed chemicals:
  - Priority Pollutant List:
    - 1980: 129
    - 2015: 126
USGS Drinking-Water Quality Science ...

2012-2014: CMEE National Pilot SW Study

Targeted Chemicals
Unique Organics: 719
Designed-bioactive: 55%
USGS Drinking-Water Quality Science ...

2012-2014: CMEE National Pilot SW Study

Detected Chemicals
Unique Organics: 406
Designed-bioactive: 57%
Top10: 100% bioactive
Top30: 70% bioactive
USGS Drinking-Water Quality Science …

DW Resource ➔ Treated DW?

Furlong, Glassmeyer, Kolpin, Mills, …
STOTEN 2016-2018

Phase II
25 DWTP
Raw/finished (time adjusted)
247 Compounds & Elements:
• Intake: 148 at least once
• Treated: 121 at least once

Intake
Treated

Explaination
50th percentile
75th percentile
Mean (blue square)
95th percentile
99th percentile
USGS Drinking-Water Quality Science ...

Furlong, Glassmeyer, Kolpin, Mills, ...

Organic Detections (Qualitative + Quantitative)

Organic Concentration

Sampling Location
Grab sample for chemical, microbial, and bioactivity measurements
Integrative passive sampler deployment
USGS Drinking-Water Quality Science …

DW Resource ➔ Treated DW ➔ DW Exposure?

2016 Reconnaissance of Chemical & Biological Contaminant Exposures from Residential and Workplace Tapwaters at Selected Sites in the United States
2016 National Tapwater Exposure Pilot
2016 National Tapwater Exposure Pilot

Pilot research to establish roles, ask questions, engage stakeholders, etc.
Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

- 11 states
- 26 sites/samples (+2 Blanks)

**Home tapwater (13)**
- Private wells (GW)
- Municipal (GW, SW)

**Office tapwater (12+1)**
- Municipal (GW, SW)
- Bottled water
Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

**Sampling Approach**

- **Human Exposure** vs DW source/supply characterization
- “Realistic” Tap Exposures:
  - Screen/aerator not removed
  - Sink area not cleaned/disinfected
  - Any existing “point of use” treatment left in place
  - Immediate collection (no flush)
  - Stagnant sampling not required (not worst-case for distribution/plumbing derived contaminants, like Pb, Cu)
2016 National Tapwater Exposure Pilot

Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

**Analytical Methods**

- **Inorganics (19)**
- **Unique Organics (482)**
  - PESTS designed-bioactive
  - PHARMS designed bioactive
  - DBPs intrinsic to treatment
  - PFAS (10)
  - VOCs
  - Hormones
- **Microorganisms:**
  - Selective plate (viability)
  - Sequencing (ID confirmation)
- **Biological Effects Potential:**
  - In Vitro Bioassays (ER/AR/GR)
  - Predictive Toxicology
2016 National Tapwater Exposure Pilot

Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

Results Overview

- TW Inorganics:
  - Detected: 18/19
  - Guidance (MCL, AL, MCLG): 10/18
    - MCL Exceedance:
      - U (MCL = 30 µg L\(^{-1}\)); 1/25 (self-supply)
      - Pb (AL = 15 µg L\(^{-1}\)); 0/25
    - MCLG Exceedance:
      - U (zero); 18/25 (self & public)
      - Pb (zero); 23/25 (self & public); max: 1.53 µg L\(^{-1}\)
Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

2016 National Tapwater Exposure Pilot

Risk Communication Challenge

- **Analytical sensitivity:**
  - Pb:
    - USGS Pb method: 0.08 µg L\(^{-1}\)
    - Pb Monitoring: MDL 1 µg L\(^{-1}\)
  - **Zero:**
    - theoretical target
    - “non-detect” (only 2/23 detects exceeded 1 µg L\(^{-1}\))
2016 National Tapwater Exposure Pilot

Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

Results Overview

- TW Organics:
  - Detected: 75/482
    - Max Detects: 12 self; 29 public
    - Med Detects: 4.5 self; 17 public (significant)
  - DBP: 21% of detected; public (excluding DBP → self & public not different)
  - Designed-Bioactives: 48% of detected; >90% of samples
    - Pesticides: 35%
    - Pharmaceuticals: 13%
  - PFAS: 9% of detected; 84% of samples (med: 2 ng L⁻¹)
2016 National Tapwater Exposure Pilot

Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

Results Overview

- **TW Organics:**
  - Detected: 75/482
  - Guidance (MCL, MCLG):
    - MCL:
      - 10(+1)/75; no exceedances
    - MCLG:
      - 14/75
    - Exceedances: 5
      - Bromodichloromethane (zero): 95% public-supply TW samples
      - Tribromomethane (zero): 68% public-supply TW samples
2016 National Tapwater Exposure Pilot

Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

21st Century Toxicology

ToxCast

> 600 assays,
> 2000 chemicals
~$20k per chemical
(< single early life stage fish study)

Rapidly, cost-effectively screen chemicals for:
1. Potential to perturb biological pathways
2. Relative perturbation concentration

*HTS = high throughput screening
Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

**Computational Toxicology**

**Exposure-Activity Ratios (EAR):**

- **EAR mix (unitless)** = \[ \sum \frac{\text{Exposure} \ (\text{dose uM})}{\text{Activity} \ (\text{ACC uM})} \]

- EAR calculated using toxEval (Corsi, DeCicco)
  - Tool developed in R
  - GUI, user friendly
Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.
2016 National Tapwater Exposure Pilot

Systematic assessment of the contribution to the human exposome from a range of chemical and microbial contaminants in home/work drinking water.

EAR (endpoint)
USGS Drinking-Water Quality Science ...

2017 Greater Chicago Tapwater Exposure Pilot
2017 Chicago Tapwater Exposure Pilot

Lake Source Water

WFP Raw Intake

Water Filtration Plant

WFP Treated

Water Main (Utility)

Tap

No POU Filter

Tap

POU Filter

Curb to Tap (Owner)

Main to Curb (Utility)
2017 Chicago Tapwater Exposure Pilot

Systematic assessment of human exposome from a range of chemical and microbial contaminants in domestic tapwater in a large urban center.

Sampling Approach

• Human Exposure vs DW source/supply characterization
• “Realistic” Tap Exposures:
  • Screen/aerator not removed
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  - DBPs intrinsic to treatment
  - PFAS
  - VOCs
  - Hormones

- **Inorganics (27)**

- **Microorganisms**:
  - Selective plate (viability)
  - Sequencing (ID confirmation)

- **Biological Effects Potential**:
  - In Vitro Bioassays (ER/AR/GR)
  - **NTP High Throughput Bioassays**
  - Predictive Toxicology
Systematic assessment of human exposome from a range of chemical and microbial contaminants in domestic tapwater in a large urban center.

- **Chicago, IL:**
  - Jardine DWP (~1.5 bgd)
    - DWP Raw (Lake Michigan)
    - DWP Finished DW
    - 15 residential TW
  - Sawyer DWP (~750 mgd)
    - DWP Raw (Lake Michigan)
    - DWP Finished
    - 15 residential TW

- **East Chicago, IN:**
  - Old & New DWP
    - DWP Raw (Lake Michigan)
    - DWP Finished DW
    - 15 residential TW
2018 Tapwater Exposure Pilots

Systematic assessment of human exposome from a range of chemical and microbial contaminants in domestic tapwater in a large urban center.

- **Cape Cod:**
  - Coastal Plain
  - Private/public, septic/sewer
- **Puerto Rico:**
  - Includes Karst
  - Private, public
- **Northeast Iowa Well Study:**
  - Private, septic
  - Agriculture
2019 Tapwater Exposure Studies

Systematic assessment of human exposome from a range of chemical and microbial contaminants in domestic tapwater in a large urban center.

- **Cape Cod:**
  - Spatial, temporal
- **Puerto Rico:**
  - Spatial, temporal
- **Northeast Iowa Well Study:**
  - ??
Assessing exposures from drinking water at the point of use: USGS collaborative tapwater research.

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