Drinking Water from Source to Tap: Ordering our Priorities

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Challenges to Providing Safe Drinking Water
Drake University
Des Moines, Iowa

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How we use the land affects water quality (a lot)

90% of Iowa land in agriculture

Inputs: Tillage, fertilizers, pesticides + sun + precipitation + air, $N_2$, $CO_2$

Precipitation runs through the soil/land. It is collected, treated, & distributed to us. WATER = $H_2O$ + other constituents
Traditional Surface Water Treatment in Midwest from Source to Tap

1. Raw water (surface water) intake
2. Alum or iron salts (+coagulant) added for:
   - Coagulation
   - Flocculation
   - Sedimentation
3. Lime softening (if necessary)
4. Rapid Sand (or mixed media) Filtration
5. Chlorination or alternative disinfection
6. Storage and Distribution
How is drinking water regulated?

EPA Drinking Water Standards

Primary Standards
- Also called Maximum Contaminant Level (MCL)
- Cause health problems
- Enforced for public systems
- 80+ contaminants, including
  - Nitrate
  - Lead
  - Coliform bacteria
  - Most organic chemicals and pesticides

Secondary Standards
- Also called SMCL or RMCL
- Cause aesthetic problems:
  - Staining
  - Taste
  - Odor
- Can naturally occur in ground water
- States can choose to enforce
- About 15, including:
  - Iron
  - pH

http://www.epa.gov/safewater/contaminants/index.html
Regulated Contaminant [Nitrate] seems to have leveled off but it’s concentration is too high in Iowa

- Nitrate concentrations and loadings have clearly increased from 1930s to today, however, concentrations are rather steady now but at too high of levels for health concerns
- Nitrate is mobile anion that leaves the soil profile in leaky crop systems like corn, especially when tiled
- We apply billions of pounds N per year on 10+ million acres of Iowa land, and an equivalent 10-20% runs off the land into waterways
Lead (Pb) in Flint Michigan drinking water came from service lines, solder & faucets in presence of corrosive water

A regulated contaminant, Lead, but in service lines, not regularly checked or known.

Ron Fonger, October 23, 2015, rfonger1@mlive.com
Pb in water mains, service lines, and premise plumbing dissolves (Pb$^{2+}$) and forms particles in drinking water.
Water Main Pipe cross-section (15 cm) with iron-scale terbicles

Investment in infrastructure is needed to address Pb in service line pipes.
What about unregulated and emerging chemicals?
Contaminant Candidate List (CCL) List 4 (2016)

- EPA’s Contaminant Candidate List originated with the Safe Drinking Water Act Amendments of 1986
- It’s purpose is to identify possible chemical and microbial contaminants that are not currently regulated as primary drinking water standards, but may need to be in the future.
- 100 chemicals + 12 microbiological agents listed in 2016. New list every five years.
- List includes pesticides, disinfection byproducts, chemicals used in commerce, waterborne pathogens, pharmaceuticals, and biological toxins.

Emerging Chemicals should be on this CCL list, but there remain other chemicals in common use that are also unregulated.
<table>
<thead>
<tr>
<th>Microbial Contaminant Name</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adenovirus</td>
<td>Virus most commonly causing respiratory illness, and occasionally gastrointestinal illness</td>
</tr>
<tr>
<td>Caliciviruses</td>
<td>Virus (includes Norovirus) causing mild self-limiting gastrointestinal illness</td>
</tr>
<tr>
<td>Campylobacter jejuni</td>
<td>Bacterium causing mild self-limiting gastrointestinal illness</td>
</tr>
<tr>
<td>Enterovirus</td>
<td>Group of viruses including polioviruses, coxsackieviruses and echoviruses that can cause mild respiratory illness</td>
</tr>
<tr>
<td>Escherichia coli (0157)</td>
<td>Toxin-producing bacterium causing gastrointestinal illness and kidney failure</td>
</tr>
<tr>
<td>Helicobacter pylori</td>
<td>Bacterium sometimes found in the environment capable of colonizing human gut that can cause ulcers and cancer</td>
</tr>
<tr>
<td>Hepatitis A virus</td>
<td>Virus that causes a liver disease and jaundice</td>
</tr>
<tr>
<td>Legionella pneumophila</td>
<td>Bacterium found in the environment including hot water systems causing lung diseases when inhaled</td>
</tr>
<tr>
<td>Mycobacterium avium</td>
<td>Bacterium causing lung infection in those with underlying lung disease, and disseminated infection in the severely immunocompromised</td>
</tr>
<tr>
<td>Naegleria fowleri</td>
<td>Protozoan parasite found in shallow, warm surface and ground water causing primary amebic meningoencephalitis</td>
</tr>
<tr>
<td>Salmonella enterica</td>
<td>Bacterium causing mild self-limiting gastrointestinal illness</td>
</tr>
<tr>
<td>Shigella sonnei</td>
<td>Bacterium causing mild self-limiting gastrointestinal illness and bloody diarrhea</td>
</tr>
</tbody>
</table>
### Selected Chemical Contaminants on CCL4 List (out of 100)

<table>
<thead>
<tr>
<th>Substance Name</th>
<th>CASRN</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,1,1,2-Tetrachloroethane</td>
<td>630-20-6</td>
<td>It is an industrial chemical used in the production of other substances.</td>
</tr>
<tr>
<td>1,1-Dichloroethane</td>
<td>75-34-3</td>
<td>It is an industrial chemical used as a solvent.</td>
</tr>
<tr>
<td>1,2,3-Trichloropropane</td>
<td>96-18-4</td>
<td>It is an industrial chemical used in paint manufacture.</td>
</tr>
<tr>
<td>1,3-Butadiene</td>
<td>106-99-0</td>
<td>It is an industrial chemical used in rubber production.</td>
</tr>
<tr>
<td>1,3-Dinitrobenzene</td>
<td>99-65-0</td>
<td>It is an industrial chemical and is used in the production of other substances.</td>
</tr>
<tr>
<td>1,4-Dioxane</td>
<td>123-91-1</td>
<td>It is used as a solvent or solvent stabilizer in the manufacture and processing of paper, cotton, textile products, automotive coolant, cosmetics and shampoos.</td>
</tr>
</tbody>
</table>
EPA risk assessments indicate that the drinking water concentration representing a $1 \times 10^{-6}$ cancer risk level for 1,4-dioxane is 0.35 μg/L (EPA IRIS 2013).
The EPA has set an interim health advisory level of 15 ppb for drinking water, the highest level that the most sensitive populations, (pregnant women for example), should ingest.

However, some CDC studies suggest the thyroid can become reactive to very low levels, between 1 and 20 parts per billion, of perchlorates.
How many unregulated chemicals are there? Can EPA keep up?

- 129 million organic and inorganic substances and 67 million protein and DNA sequences (CAS registry)
- 80,000 chemicals in commercial and industrial use
- About 2000 high production chemicals over 1 million lbs/yr
- 15,000 additional new substances daily!
- Lautenberg Chemical Safety Act, TSCA reform “The EPA will review a minimum of 20 chemicals at a time, and each has a seven-year deadline. Industry may then have five years to comply after a new rule”
Chemicals in the Environment – What’s the Risk?
Chemicals in the Environment – What’s the Risk?

Bisphenol A - endocrine disruption at 0.025 ug/kg/day permanent changes in fetal genital tract and breast tissue; EPA max safe dose 50 ug/kg/day (low acute)

Perfluorooctanoic acid (PFOA) - in 100% of 300 umbilical cord blood in Baltimore, 2004-05; “suggestive carcinogen”

Ethinyl estradiol (EE) – some endocrine effects on fish at ng/L levels

Polybrominated diphenyl ethers (PBDEs) - in U.S. breast milk and children’s blood ~62 ppb
Cape Fear River and drinking water contaminated with PFC chemicals

- Wilmington, North Carolina: PFOA replaced by “GenX” in 2009 after class action lawsuit
- GenX has many of the same health effects
- Now the GenX concs (631 ng/L) are even higher than the legacy PFOA and PFCs
- EPA set health advisory of 70 ng/L last year on PFCs
- GenX is not regulated!

Sun et al. (2017) *ES&T Letters*
DOI: 10.1021/acs.estlett.6b00398

Legacy and Emerging Perfluoroalkyl Substances Are Important Drinking Water Contaminants in the Cape Fear River Watershed of North Carolina

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$ Supporting Information
Kolpin et al. (2002) first article to measure unregulated chemicals in Midwest streams

- The most frequently detected compounds were coprostanol (fecal steroid), cholesterol (plant and animal steroid), N,N-diethyltoluamide (insect repellant), caffeine (stimulant), triclosan (antimicrobial disinfectant), tri(2-chloroethyl)phosphate (fire retardant), and 4-nonylphenol (nonionic detergent metabolite).

Triclosan is still controversial

- EPA re-registered triclosan for uses in 2008; it is known EDC chemical
- Environmental risk quotients (RQs) were compared to levels of concern (LOCs) for triclosan. LOCs were not exceeded for fish but were exceeded for aquatic plants.
- Now, most industries have begun to remove it from products
- FDA Finally Bans Toxic Triclosan from Antibacterial Hand Soaps. WASHINGTON – The federal Food and Drug Administration announced today that triclosan, a toxic chemical ingredient associated with hormone disruption in people, will no longer be allowed in antibacterial hand soaps.
- Sep 2, 2016
Mixtures Matter (Sumpter et al, ES&T 2006)

- Mixtures matter
- Metabolites matter
- EDCs introduce new problems
  - Intergenerational toxicity
  - J-shaped response curves with effects at very low levels
Neonicotinoid pesticides are emerging chemicals, but around for a long time

Story on neonicotinoid pesticides and their damage to the brains of bees was widely covered and downloaded
Chlorpyrifos – Pruitt refuses to ban it despite studies of harm to children

In 2015, EPA decided to ban chlorpyrifos on all food crops. Decision was made in response to NRDC lawsuit and studies showing an association with neurodevelopment problems in children. (At age 3 they found increased odds of mental delay, psychomotor delay, attention disorders and pervasive developmental disorders among the high-exposure children. At age 11, tremors.)

Chlorpyrifos, a cholinesterase inhibitor.
Another unregulated chemical: MCHM Spill into Elk River, West Virginia on January 9, 2014

- 4-Methylcyclohexanemethanol used as a chemical in coking coal washing
- 7500 gallons spilled
- Not regulated, no NPDES permit, no TSCA, no SDWA 1st drinking water standard; only one toxicity study at CDI 100 mg/kg/day
- 300,000 people without potable water
Unregulated Contaminant Monitoring Rule 2 (metabolites, DBPs, and others)

- Acetochlor Acetochlor, Acetochlor ESA and OA
- Alachlor Alachlor, Alachlor ESA and OA
- Metolachlor Metolachlor, Metolachlor ESA and OA
- Nitrosamines
  - NDMA, NDBA, NDEA, NDPA, NMEA, NPyr
- Dimethoate
- Terbufos sulfone
- BDE BDE-47, BDE BDE-99, BDE BDE-100, BDE BDE-153
- 245 245-HBB
- 1,3 1,3-dinitrobenzene, TNT, RDX

Nitrosamines in drinking water
What seems to be emerging now?

- Pharmaceutically-active compounds
- Prescription drugs
- Over the counter medications
- Veterinary antibiotics and hormones
- Personal care products
- Endocrine disrupting chemicals
- Estrogens and androgens
- Pesticides

Trenbolone acetate

Adapted from: Bruce Macler, EPA Region 9
Some Other Emerging Chemicals

Human-derived, environmentally-persistent contaminants of possible health concern (HDEPCPHC)*

• Disinfection byproducts
  – N-nitrosamines, halo-nitro compounds, iodoacetate
• Algal toxins, microcystin
Cyanobacteria and algal toxins like microcystin (Lake Erie and Toledo, Ohio)

- HABs and algal toxins are major concern today!
More emerging issues

• Hormone-influenced health effects
  – Obesogens
  – Diabetes
  – Early puberty
• Reproductive and developmental effects
• Antiobiotic resistance genes (ARGs)
Legionella causes the most water-borne disease in the U.S.

- 19 out of 33 (58%) waterborne disease outbreaks in the U.S. are caused by Legionella
- Second most disease outbreaks are use of intermittent water supplies without chlorination or disinfection
Waterborne Disease Outbreaks

- Legionella is #1 (inhaled from water aerosols) especially associated with showers, hospitals and cooling water
- If you are admitted to a hospital, you have a 5% chance of contracting a Healthcare Associated Infection (HAI)
  - 1.7 million infected/yr and ~100,000 die (Direct Medical Costs of HAIs in US Hospitals, CDC, 2009.)
- The 2\textsuperscript{nd} major cause of drinking water-borne disease is untreated, intermittent groundwater use from small systems

Waterborne Disease and Outbreak Surveillance System, Morbidity and Mortality Weekly Reports (2015), CDC
https://www.cdc.gov/healthywater/surveillance/drinking-surveillance-reports.html
Legionella are part of pipe biofilms. Amoeba protozoa may play a role in grazing and liberating.

Legionella like hot water (25-55 °C). They are resistant to chlorine disinfection because of biofilms. Only a few cells can cause pathogenesis, especially in hospitals.

The role of biofilms and protozoa in Legionella pathogenesis (PDF Download Available).
Our distribution system is like an aquarium, a whole ecosystem of little known processes

- The biofilms vary according to the chemistry and disinfectant residual used in the water treatment plant
  - Chlorine
  - Chloramines
  - Chlorine Dioxide
  - Ozone
Millions of people without drinking water for weeks due to extreme storms

- Hurricane Harvey hits Corpus Christi and Houston August 25
- Hurricane Irma decimates Caribbean and Florida Sept. 11
- Hurricane Maria hits Puerto Rico September 20, 2017
How do we order our priorities?

- Topics discussed here:
  - Nitrates in drinking water
  - DBPs
  - Emerging, unregulated chemicals (PFCs, dioxane)
  - Pesticides, neonicotinoids
  - Harmful algal bloom toxins
  - Pb, As in drinking water
  - Threats to drinking water from storms and floods
    - Hurricanes Harvey, Irma, Maria
Solutions: Emphasize cost-effective infrastructure in context of risk

- We should consider:
  - Risk-based approach
  - Cost-Effectiveness
  - The “Big Picture” innovation: Integrated Water Resources Management
- Multiple Barriers of Protection
- Continuous Improvement
- Alternate approaches
  - Advanced treatment to minimize assimilable organic carbon (AOCs) and prevent DBPs
  - Decentralized, point-of-use treatment where applicable
  - Water reuse and recharge of depleted aquifers

Our rules and regulations will never catch-up with the plethora of chemicals emerging and unknown, so we must use “common sense” and innovative approaches to protect the health and welfare of the public.
Continuous Improvement

• John L. (Jack) Cleasby
  – Anson Marston Distinguished Professor in Engineering Emeritus
  – National Academy of Engineering member since 1983
  – The expert in filtration
  – “It’s our duty as engineers to help society continuously improve”
Multiple Barriers for Production of Safe Drinking Water

How do you like your tap water?

Safe drinking water may not need to contain a residual disinfectant

By Fernando Rosario-Ortiz,1,2 Joan Rose,3 Vanessa Speight,4 Urs von Gunten,2,5 Jerald Schnoor2,6

The expectation that tap water is safe has been sorely tested by the recent events in Flint, Michigan, where lead contamination has caused a public health emergency (1). Apart from contamination with heavy metals and other harmful substances, a key concern is the control of microbial contamination. To prevent microbial growth and protect consumers from pathogens from other sources, some countries, such as the United States, require the presence of residual disinfectant in drinking water. However, the presence of a disinfectant can lead to the formation of potentially carcinogenic disinfection by-products, issues with corrosion, and complaints based on the fact that people dislike the taste of disinfectants in their water (2). The experience of several European countries shows that such residual disinfectants are not necessary as long as other appropriate safeguards are in place.

From the early 1900s, the control of microbial waterborne pathogens, including Salmonella typhi and Vibrio cholera, led to a major reduction of waterborne diseases in the industrialized world. Filtration and chlorine disinfection reduced mortality in the United States substantially. But in 1974, chloroform, a probable human carcinogen formed by the reaction of chlorine with naturally occurring organic matter, was discovered in chlorinated drinking water. This discovery led to a debate about microbiological safety versus exposure to harm-
Conclusions

- Multiple Barriers for Protection of Human Health in Drinking Water
- Infrastructure investment for continuous improvement and reducing risk (Pb, Legionella, extreme events)
- Risk Based, common sense approach (integrated water resource management)
- Pollution Prevention (regulate chemicals at the source)
- Continuously improve treatment standards (move towards RO and BAC)
“We call on water professionals and scientists to bring their expertise and skills—whether through synthesis, research to fill pressing gaps or technology development—to fulfill the “great potential to complement sustainable development projects...with robust knowledge, tools and scientific methods”.

Water Reuse: recover energy, nutrients and **water** from wastewater but w/o emerging chemicals