Safe and Sustainable Wastewater Treatment and Reuse: In Theory and Reality

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University of Florida
Subject matter for the day...

Brief introduction of my history with water

- What is ‘wastewater’ (WW)?, and is it safe to reuse??

- Who is reusing WW in the United States, and for what?

- Who is re-using WW around the world, and for what?

- The future of reusing WW: Challenges and opportunities
B.S. Environmental Biology
Ohio University (2000-2005)

Ohio EPA (2004-2005)
Division of Surface Water

- Assessment of state water conditions/trends
- Information used for TMDL modeling

- Physical (turbidity, flow, sediments)
- Chemical (pH, conductivity, nutrients)
M.S. Environmental Science
Univ. of Cincinnati (2005-2007)
- Water Quality Specialization

- Studied physical, chemical, and biological methods for the remediation for heavily contaminated sediments

Thesis: Steam extraction of polycyclic aromatic hydrocarbons and lead from contaminated sediment using surfactant, salt and alkaline conditions

Indiana Harbor Canal Superfund Site

- Contaminated sediments polluting Lake Michigan
- Containing PAHs, PCBs, heavy metals (Pb, Cd)
U.S. EPA Contractor (Cincinnati, OH) (2007-2011)

Formation, fate, and transport of contaminants in aquatic and terrestrial systems:

- Drinking water distribution systems and source waters
  - Precipitation and dissolution of metals
  - Disinfection byproduct (DBP) formation
Wastewater: Liquids and Solids

Method development and analysis of:
• Pharmaceuticals, industrial byproducts
• Microbial contaminants
Surface Water ↔ Groundwater

Green Infrastructure

• Rain barrels, rain gardens, bioswales
• Influence on sediment and nutrients loads
Watershed Restoration

Wetland and Stream Restoration Institute (KY)
- Ecological restoration
- Stormwater management

Eastern Coal Regional Roundtable (WV)
- Addressing mining impacted waters
Ph.D. Environmental Engineering Sciences
Univ. of Florida (2011-2015)

Interdisciplinary program applying ecological, hydrological, and sociological principles to solve complex water quality/quantity issues

- Soil and Water Science
- Ag and Bio Engineering
- Forestry/Eco-hydrology
- Hydro-geology
- Law/Policy

Courses Taught:
- ✓ Issues in Water Resources
- ✓ Green Engineering Design
- ✓ Environmental Analysis
Univ. of Arizona – Water Resources Research Center
“wastewater”

- **Greywater** - the relatively clean wastewater from baths, sinks, washing machines, and other kitchen appliances.

- **Wastewater** - Spent or used water with dissolved or suspended solids, discharged from homes, commercial establishments, farms, and industries.

- **Reclaimed water** – or recycled water, is defined as “municipal wastewater that has been treated to meet specific water quality criteria with the intent of being used for a range of purposes”.
Some of the (biological & chemical) factors in wastewater that could degrade a receiving waterbody?

• Physical materials
  • sediment, organic matter, food scraps
• Chemicals
  • (dissolved) and (solid)-bound phases
  • pH, metals, nutrients (N and P)
• Pathogens
  • bacteria = not all are pathogenic
  • viruses
  • protozoa
    • Giardia, *Naegleria fowleri*, cryptosporidium
• helminths

**EPA 2° Effluent Standards**

- $< 200 \text{ FC} / 100 \text{ mL}$
- $6 < \text{pH} < 9$
- $\text{BOD}_5 < 20 \text{ mg/L}$
- $\text{TSS} < 20 \text{ mg/L}$
Common Wastewater Treatment Process

The diagram illustrates the common wastewater treatment process, which includes:

1. **Grid Solid Removal**
2. **Pre-treatment**
3. **Aeration Zone**
4. **Settler**
5. **Sand Filtration**
6. **Disinfection**

The process begins with wastewater entering the grid for solid removal, followed by pre-treatment, aeration, settling, filtration, and disinfection to produce clean effluent.
Primary (Physical) Treatment: Coagulation and Precipitation of Denser Material
Secondary (Biological) Treatment: Activated Sludge Process

- The liquid portion of the settled sewage then flows to an \textit{aerobic} biological treatment stage for several hours where it comes into contact with micro-organisms which remove and oxidize most of the remaining organic pollutants.
Settling of aeration zone microbes
Tertiary (Advanced) Treatment

• Not required by law for most facilities, except when the receiving water body is in need of pollutant reduction
  • Nitrogen removal
    • Convert the dissolved nitrogen to a gas
      \( \text{NH}_4 \Rightarrow \text{NO}_3 \Rightarrow \text{N}_2 \)
  • Phosphorus reduction
    • Biological or chemical removal
  • Additional contaminant reduction
    • Pharmaceuticals, endocrine disruptors, nanoparticles...
Disinfection

To meet the EPA standard for domestic water discharges:

• in FL < 200 fecal coliforms (FC) per 100 mL of water
• in AZ < 23 FC (max) per 100 mL for reuse purposes

99.99% reduction of pathogens can be achieved with:

• Chlorine/chloramine
• Ozone (O$_3$), Peroxides (H$_2$O$_2$)
• Ultraviolet (UV) radiation
Additional compounds in treated wastewaters

• Disinfection By-Products (DBPs)
  • Tri-halo-methanes (THMs)
  • Halo-acetic acids (HAAs)
  • Nitrosamines

• Contaminants of emerging concern
  • Endocrine disrupting compounds (EDCs)
  • Nanoparticles
  • Pharmaceuticals and personal care products
    • Some contaminants can negatively impact aquatic organisms at:
      $< 1 \text{ ng/L} = 1 \text{ part per trillion} = 1 \times 10^{-9} \text{ g/L}$
Dealing with the Sludge turned “Biosolids”

These “digestion” systems are *anaerobic*.

What potentially *beneficial gas is produced*?

**Methane** produced by digestion is fed to a generator, *producing electricity*.

The **sludge** can be dried and *processed into fertilizer pellets*. 
Effluent Disposal/Usage Methods

Surface water discharge

i. Land application
ii. Ground water recharge
iii. Wetland augmentation
iv. Industrial
v. other uses?
vi. Potable reuse
Reuse rates are increasing in the United States

But < 10% of total WW flows

Some cities & countries around the world reusing > 90%

# Reuse Flow Per Capita for the Nine States that Reported Having Reuse in 2006

<table>
<thead>
<tr>
<th>State</th>
<th>Population (2006 est)</th>
<th>Reported Reuse(^1) in Millions of Gallons per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>18,019,093</td>
<td>663.0</td>
</tr>
<tr>
<td>California</td>
<td>36,121,296</td>
<td>580.02</td>
</tr>
<tr>
<td>Virginia</td>
<td>7,628,347</td>
<td>11.2</td>
</tr>
<tr>
<td>Texas</td>
<td>23,367,534</td>
<td>31.4</td>
</tr>
<tr>
<td>Arizona</td>
<td>6,178,251</td>
<td>8.2</td>
</tr>
<tr>
<td>Colorado</td>
<td>4,751,474</td>
<td>5.2</td>
</tr>
<tr>
<td>Nevada</td>
<td>2,484,196</td>
<td>2.6</td>
</tr>
<tr>
<td>Idaho</td>
<td>1,461,183</td>
<td>0.7</td>
</tr>
<tr>
<td>Washington(^3)</td>
<td>6,360,529</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^1\) Reuse excluding reclaimed water, effluent reuse, and treated mine water re-use.

AZ Active Management Area Water Sources

- **Groundwater**: 43%
- **Surface Water**: 21%
- **CAP**: 32%
- **Effluent**: 4%
### California Water Use by Type (FDEP, 2012)

<table>
<thead>
<tr>
<th>Use</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>48%</td>
</tr>
<tr>
<td>Landscape irrigation</td>
<td>20%</td>
</tr>
<tr>
<td>Groundwater recharge</td>
<td>15%</td>
</tr>
<tr>
<td>Industry</td>
<td>5%</td>
</tr>
<tr>
<td>Environment &amp; other</td>
<td>12%</td>
</tr>
<tr>
<td>Industrial Uses</td>
<td>16%</td>
</tr>
<tr>
<td>Groundwater Recharge</td>
<td>11%</td>
</tr>
<tr>
<td>Public Access Areas</td>
<td>58%</td>
</tr>
<tr>
<td>Wetlands and Other</td>
<td>5%</td>
</tr>
</tbody>
</table>

Figure 5-12
Water reuse in Florida by type (FDEP, 2012)
i. Land Application
i. Land Application
ii. Ground water recharge

- Aquifer storage and recovery (ASR)
- Maintaining ‘Minimum Flows and Levels’ of surface waters
- Salt water intrusion barriers
iii. Wetland / Riparian Zone Augmentation
iii. Wetland / Riparian Zone Augmentation

- Ecological engineering alternative to typical tertiary treatment methods

- Benefit to natural and economic systems
iii. Wetland / Riparian Zone Augmentation
Functional and Educational Wetland Systems

Stormwater Ecological Enhancement Project (SEEP)
iv. Industrial Uses
v. Other uses??
vi. Potable Reuse – (Indirect and Direct)
Indirect Potable Reuse (IPR) of WW

Has always been occurring... since downstream of every WW effluent outfall is (nearly) always a drinking water intake
## “Direct” Potable Reuse (DPR) of WW

<table>
<thead>
<tr>
<th>Country</th>
<th>City</th>
<th>Project Capacity (mgd)</th>
<th>Description of Advanced System for Potable Reuse</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Wulpen</td>
<td>1.9</td>
<td>Reclaimed water is returned to the aquifer before being reused as a potable water source</td>
<td>[Belgium-Recharge]</td>
</tr>
<tr>
<td>India</td>
<td>Bangalore (planned)</td>
<td>36</td>
<td>Reclaimed water will be blended in the reservoir, which is a major drinking water source</td>
<td>[India-Bangalore]</td>
</tr>
<tr>
<td>Namibia</td>
<td>Windhoek</td>
<td>5.5</td>
<td>Reclaimed water is blended with conventionally-treated surface water for potable reuse</td>
<td>(NAS, 2012)</td>
</tr>
<tr>
<td>United States</td>
<td>Big Spring, Texas</td>
<td>3</td>
<td>Reclaimed water is blended with raw surface water for potable reuse</td>
<td>[US-TX-Big Spring]</td>
</tr>
<tr>
<td>United States</td>
<td>Upper Occoquan, Virginia</td>
<td>54</td>
<td>Reclaimed water is blended in the reservoir, which is a major drinking water source</td>
<td>[US-VA-Occoquan]</td>
</tr>
<tr>
<td>United States</td>
<td>Orange County, California</td>
<td>40</td>
<td>Reclaimed water is returned to the aquifer before being reused as a potable water source</td>
<td>[US-CA-Orange County]</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Langford</td>
<td>10.5</td>
<td>Reclaimed water is returned upstream to a river, which is the potable water source</td>
<td>[United Kingdom-Langford]</td>
</tr>
<tr>
<td>Singapore</td>
<td><strong>Singapore</strong></td>
<td><strong>122</strong></td>
<td>Reclaimed water is blended in the reservoir, which is a major drinking water source</td>
<td>[Singapore-NEWater]</td>
</tr>
<tr>
<td>South Africa</td>
<td>Malahleni</td>
<td>4.2</td>
<td>Reclaimed water from a mine is supplied as drinking water to the municipality</td>
<td>[South Africa-eMalahleni Mine]</td>
</tr>
</tbody>
</table>

Source: Adapted from Von Sperling and Chernicharo (2002)
Human pathogens, real issues...

• Poor water quality and sanitation account for 1.7 million deaths a year, mainly through infections and diarrhea.
  • 9 out 10 are children
  • Virtually all from developing countries

• Disease outbreaks attributed to:
  • Use of untreated water
  • Inadequate or faulty treatment
  • Contamination after treatment

- **Mexico City** – The Atotonilco project will hygienise 60% of wastewater from the metropolitan areas (compared to 8% before)
- **India** – 73% of urban WW untreated
- **China** - 27% of surface waters > 10,000 FC / 100 mL
- **Pakistan** – “much value attributed to the elevated nutrient loads associated with irrigating with wastewater”

$940/ha if access to WW vs. $170/ha with only fresh water

...but, 5x greater risk for hookworm infection!
Africa

• **Nairobi** – 34% of irrigators diverted untreated sewage from trunk sewers directly onto land

• **Ghana** – 25% no toilet facilities in household
  • 4% use bucket latrines, and dump directly into waterways
  • $10^6$ – $10^8$ fecal coliforms (FC) / 100 mL
    
    \[= 1,000,000 – 100,000,000 \text{ FC} / 100 \text{ mL}\]

- WHO goal < 1000 FC / 100 mL
- USEPA goal < 100 FC / 100 mL
Issues Related to Untreated WW Usage

“If I could have a permanent supply of raw WW for irrigation... without being bothered by the health authorities, I could feed (support) more than 30 people” – farmer in Senegal
Ecological Sanitation

Tree planted on used pit

Arborloo in use

Pit filling up

New pit dug within ring beam

EcoSanRes
Closing the Loop on Sanitation

Image showing an Arborloo in use.
1. Water Conservation

**Global Water Consumption 1900 - 2025**
(by region, in billion m³ per year)
2. Reduced Nutrient Loading to Surface Waters
Reducing soil erosion and recycling phosphorus from farm and human waste could help make food production sustainable and prevent algal blooms.

– Scientific American; Vacarri 2009
Bottoms up!

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