Pharmaceuticals in the Environment.

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Municipal Wastewater Effluent

- Largest point source of pollution.
- Released to a wide variety of receiving environments: lakes, ponds, streams, rivers, estuaries, and oceans.

Photo credit: Ings, 2007
Municipal Wastewater Effluent

- Grit, debris, and suspended solids.
- Disease-causing pathogens.
- Decaying organic wastes.
- Nutrients.
- ~200 different identified chemicals:
  - PCBs, PAHs, dioxins.
  - Industrial chemicals
  - Pharmaceuticals and personal care products.
Pharmaceuticals and Personal Care Products (PPCPs)
PPCPs

• Parent drug
  – Un-metabolized excretion
  – Improper disposal
  – Post-excretion modifications during wastewater treatment processes

• Metabolites

May be as bioactive or more bioactive as the parent compounds!

Image credit: http://www.thebody.com/content/art875.html
Origins and Fate of PPCPs† in the Environment
Pharmaceuticals and Personal Care Products

Legend

1. Usage by individuals (1a) and pets (1b):
   - Metabolic excretion (unmetabolized parent drug, parent-drug conjugates, and biotransformations); sweat and vomitus.
   - Excretion exacerbated by disease and slow-dissolving medications
   - Disposal of unused/outrated medication to sewage systems
   - Underground leakage from sewage system infrastructure
   - Disposal of euthanized/meatated animal carcasses serving as food for scavengers (1c)

2. Release of treated/untreated hospital wastes to domestic sewage systems
   - Weighted toward acutely toxic drugs and diagnostic agents, as opposed to long-term medications
   - Also disposal by pharmacies, physicians, humanitarian drug surplus

3. Release to private septic/leach fields (3a):
   - Treated effluent from domestic sewage treatment plants discharged to surface waters, re-injected into aquifers (recharge), recycled/reused (irrigation or domestic uses) (3b)
   - Overflow of untreated sewage from storm events and system failures directly to surface waters (3b)

4. Transfer of sewage solids ("biosolids") to land (e.g., soil amendment/fertilization)
   - "Straight-piping" from homes (untreated sewage discharged directly to surface waters)
   - Release from agriculture: spray drift from tree crops (e.g., antibiotics)
   - Dung from medicated domestic animals (e.g., feed) - CAFOs (confined animal feeding operations)

5. Direct release to open waters via washing/bathing/swimming

6. Discharge of regulated/controlled industrial manufacturing waste streams
   - Disposal/release from clandestine drug labs and illicit drug usage

7. Disposal to landfills via domestic refuse, medical wastes, and other hazardous wastes
   - Leaching from defective (poorly engineered) landfills and cemeteries

8. Release to open waters from aquaculture (medicated feed and resulting excreta)
   - Future potential for release from molecular pharming (production of therapeutics in crops)

9. Release of drugs that serve double duty as pest control agents:
   - Examples: 4-aminopyridine, experimental multiple sclerosis drug used as avicide; warfarin, anticoagulant; rodenticide inhibitors; certain antibiotics used for orchard pathogens; acetaminophen, analgesics; brown tree snake control; caffeine, stimulant; *coqui* frog control

10. Ultimate environmental transport/fate:
    - Most PPCPs eventually transported from terrestrial domain to aqueous domain
    - Phototransformation (both direct and indirect reactions via UV light)
    - Physicochemical alteration, degradation, and ultimate mineralization
    - Volatilization (mainly certain anesthetics, fragrances)
    - Some uptake by plants
    - Respirable particulates containing sorbed drugs (e.g., medicated-feed dusts)

March 2006
Christian G. Daughton, U.S. EPA/Las Vegas

from: http://epa.gov/merl/1/chemistry/pharma/
COUNTERTHINK

Is it a boy or a girl?

Both, actually, thanks to all the chemicals in the water these days.

FACT: Pharmaceuticals destroy aquatic ecosystems.
<table>
<thead>
<tr>
<th>Pharmaceutical</th>
<th>Class</th>
<th>Observed effect(s) in fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>17α-ethinylestradiol</td>
<td>Hormone</td>
<td>Reproduction</td>
</tr>
<tr>
<td>Fluoxetine (Prozac®)</td>
<td>SSRI</td>
<td>Neuroendocrine, metabolic</td>
</tr>
<tr>
<td>Venlafaxine (Effexor®)</td>
<td>SSNRI</td>
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</tr>
<tr>
<td>Ibuprofen (Advil®)</td>
<td>NSAID</td>
<td>Neuroendocrine</td>
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<tr>
<td>Naproxen (Aleve®)</td>
<td>NSAID</td>
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<tr>
<td>Salicylate (Aspirin®)</td>
<td>Analgesic</td>
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<tr>
<td>Gemfibrozil</td>
<td>Lipid regulator</td>
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<tr>
<td>Carbamazepine</td>
<td>Anti-epileptic</td>
<td>Reproduction</td>
</tr>
<tr>
<td>Sulfonamide</td>
<td>Antibiotic</td>
<td>Growth</td>
</tr>
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</table>
PPCPs in the Maritimes


- Brun et al. 2006. Pharmaceutically active compounds in Atlantic Canadian sewage treatment plant effluents and receiving waters, and potential for environmental effects as measured by acute and chronic aquatic toxicity. Environmental Toxicology Chemistry 25:2163–2176.
PPCPs in the Maritimes
Effects of 17α-ethynylestradiol on early-life development, sex differentiation and vitellogenin induction in mummichog (*Fundulus heteroclitus*)

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effects on reproductive potential and endocrine status in the mummichog (*Fundulus heteroclitus*) after exposure to 17α-ethynylestradiol in a short-term reproductive bioassay

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Modulation of steroidogenesis and estrogen signalling in the estuarine killifish (*Fundulus heteroclitus*) exposed to ethynylestradiol

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Photo credit: http://crawford.rsmas.miami.edu/_Media/twofh_blck.jpg
Environmental Estrogens

• Effects of EE2:
  – Decreased egg production in spawning females
  – Altered hormone levels
    • Important for regulating reproduction
  – Decreased secondary sex characteristics in males
  – Presence of eggs in male testes, called intersex (Jobling et al. 2006)

This may impact reproductive success in the wild, which could potentially impact population levels over time.
What about the other drugs?

- Increased number of studies looking at the effects of these drugs, but there are still many unknowns.
  - Precautionary Principle

Photo credit: http://ngm.nationalgeographic.com/2010/04/pollution/fish-pharm
Removal of PPCPs

- Standard sewage treatment plants not designed to remove chemicals, even with advanced treatment processes

Influent – residential, commercial, and industrial

Primary treatment
- Screening, Settling

Secondary treatment
- Activated sludge, Clarification

Tertiary treatment
- Variety of physical, chemical and biological processes

Sludge/biosolids

Effluent still contains chemicals!
What can we do?

- **New Brunswick**: No official program for pharmaceutical disposal, but most pharmacies voluntarily take back unwanted drugs (and cover the cost themselves).

- **Nova Scotia**: **Nova Scotia Medication Disposal Program (NSMDP)**
  - Formal, funded program to dispose of pharmaceutical waste.
What can we do?

- Awareness!

- What we put down the drain does not just disappear, so we can do our part to minimize the impacts.