**Origins and Fate of PPCPs in the Environment**

Pharmaceuticals and Personal Care Products

**Sources of PPCPs**

1. **Usage by individuals (1a) and pets (1b):** Metabolic excretion (unmetabolized parent drug, parent-drug conjugates, and bioactive metabolites); sweat and vomitus. Excretion exacerbated by disease and slow-dissolving medications
   - Disposal of unused/outdated medication to sewage systems
   - Underground leakage from sewage system infrastructure
   - Disposal of euthanized/medicated 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
   - 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)

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)
   - Overflow of untreated sewage from storm events and system failures directly to surface waters

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

8. **Release of drugs that serve double duty as pest control agents:**
   - Examples: 4-aminopyridine, experimental multiple sclerosis drug used as avicide; warfarin, anticoagulant → rat poison; azacholesterol, antilipidemias → avian/rat reproductive inhibitors; certain antibiotics → used for orchard pathogens; acetaminophen, analgesic → brown tree snake control; caffeine, stimulant → *coqui* frog control

9. **Ultimate environmental transport/fate:**
   - Most PPCPs eventually transported from terrestrial domain to aqueous domain
   - 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)

**Legend**

- **1** • Usage by individuals (1a) and pets (1b):
  - Metabolic excretion (unmetabolized parent drug, parent-drug conjugates, and bioactive metabolites); sweat and vomitus. Excretion exacerbated by disease and slow-dissolving medications
  - Disposal of unused/outdated medication to sewage systems
  - Underground leakage from sewage system infrastructure
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- **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
  - Release to private septic/leach fields
  - Treated effluent from domestic sewage treatment plants discharged to surface waters, re-injected into aquifers (recharge), recycled/reused (irrigation or domestic uses)
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- **3** • Transfer of sewage solids ("biosolids") to land
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  - Release from agriculture: spray drift from tree crops (e.g., antibiotics)
  - Dung from medicated domestic animals (e.g., feed) - CAFOs (confined animal feeding operations)

- **4** • Direct release to open waters via washing/bathing/swimming

- **5** • Discharge of regulated/controlled industrial manufacturing waste streams
  - Disposal/release from clandestine drug labs and illicit drug usage

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