



Pharmaceuticals and Personal Care Products (PPCPs) as Pollutants: Origins, Fate, and Control in the Environment

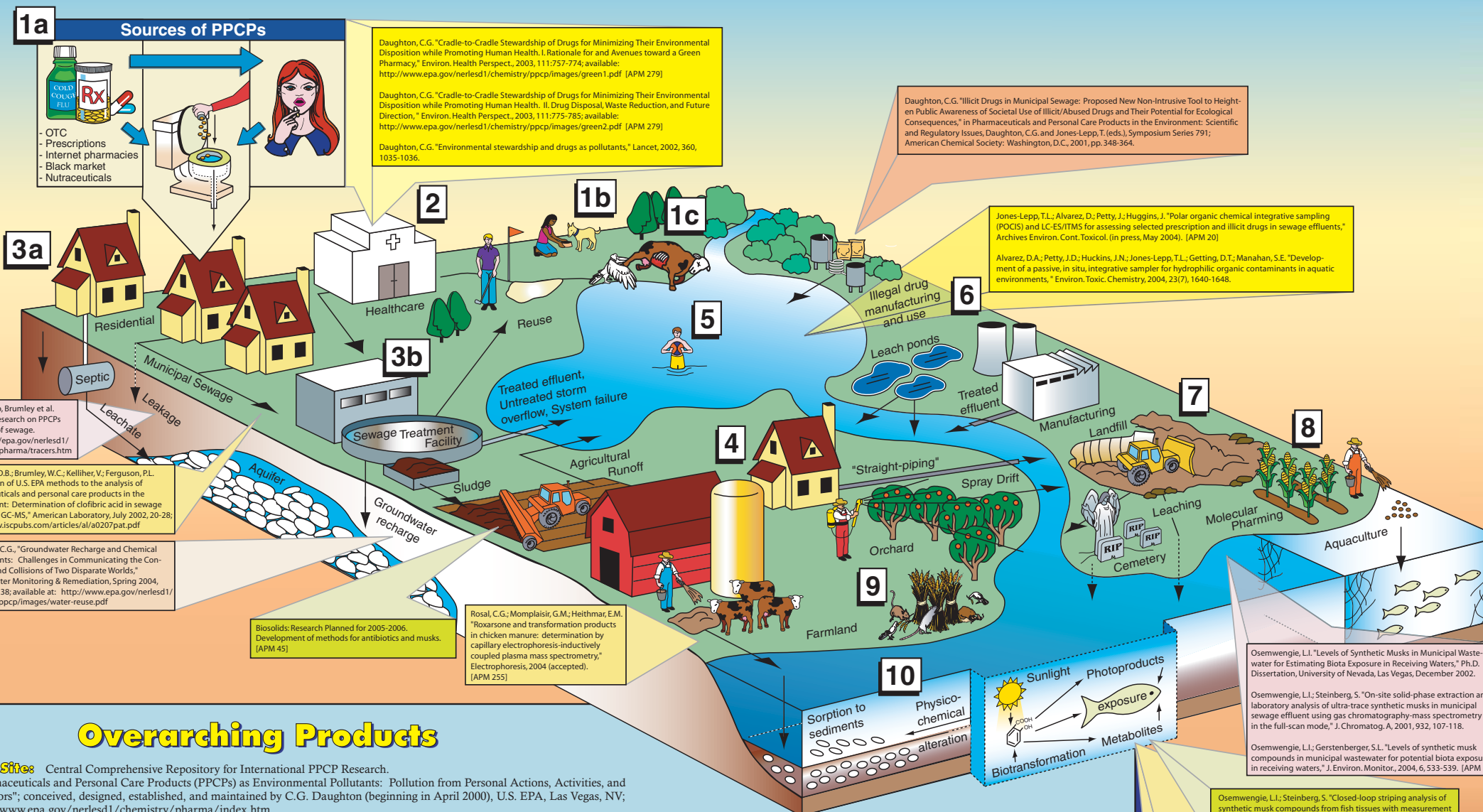
Major Products Under Task 6980 (PPCPs)

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Legend

- 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 - Disposal of unused/outdated medication to sewage systems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)
- 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 or re-injected into aquifers (recharge)
 - Overflow of untreated sewage from storm events and system failures directly to surface waters
- 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)
- Direct release to open waters via washing/bathing/swimming
- Discharge of regulated/controlled industrial manufacturing waste streams
 - Disposal/release from clandestine drug labs and illicit drug usage
- Disposal to landfills via domestic refuse, medical wastes, and other hazardous wastes
 - Leaching from defective (poorly engineered) landfills and cemeteries
- Release to open waters from aquaculture (medicated feed and resulting excreta)
 - Future potential for release from molecular pharming (production of therapeutics in crops)
- 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, antilipidemics → avian/rodent reproductive inhibitors; certain antibiotics → used for orchard pathogens; acetaminophen, analgesic → brown tree snake control; caffeine, stimulant → coqui frog control
- 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)

<http://epa.gov/nerlesd1/chemistry/pharma/images/drawing.pdf>
from: <http://epa.gov/nerlesd1/chemistry/pharma/>



1a Sources of PPCPs

Daughton, C.G. "Cradle-to-Cradle Stewardship of Drugs for Minimizing Their Environmental Disposition while Promoting Human Health. I. Rationale for and Avenues toward a Green Pharmacy." *Environ. Health Perspect.*, 2003, 111:757-774; available: <http://www.epa.gov/nerlesd1/chemistry/ppcp/images/green1.pdf> [APM 279]

Daughton, C.G. "Cradle-to-Cradle Stewardship of Drugs for Minimizing Their Environmental Disposition while Promoting Human Health. II. Drug Disposal, Waste Reduction, and Future Direction." *Environ. Health Perspect.*, 2003, 111:775-785; available: <http://www.epa.gov/nerlesd1/chemistry/ppcp/images/green2.pdf> [APM 279]

Daughton, C.G. "Environmental stewardship and drugs as pollutants," *Lancet*, 2002, 360, 1035-1036.

Daughton, C.G. "Illicit Drugs in Municipal Sewage: Proposed New Non-Intrusive Tool to Heighten Public Awareness of Societal Use of Illicit/Abused Drugs and Their Potential for Ecological Consequences," in *Pharmaceuticals and Personal Care Products in the Environment: Scientific and Regulatory Issues*, Daughton, C.G. and Jones-Lepp, T. (eds.), Symposium Series 791; American Chemical Society: Washington, D.C., 2001, pp. 348-364.

Jones-Lepp, T.L.; Alvarez, D.; Petty, J.; Huggins, J. "Polar organic chemical integrative sampling (POCIS) and LC-ES/TMS for assessing selected prescription and illicit drugs in sewage effluents," *Archives Environ. Cont. Toxicol.* (in press, May 2004). [APM 20]

Alvarez, D.A.; Petty, J.D.; Huggins, J.N.; Jones-Lepp, T.L.; Getting, D.T.; Manahan, S.E. "Development of a passive, in situ, integrative sampler for hydrophilic organic contaminants in aquatic environments," *Environ. Toxic. Chemistry*, 2004, 23(7), 1640-1648.

Jones-Lepp, T.L.; Brumley, W.C.; Kelliker, V.; Ferguson, P.L. "Ongoing research on PPCPs as tracers of sewage." See: <http://epa.gov/nerlesd1/chemistry/pharma/tracers.htm>

Patterson, D.B.; Brumley, W.C.; Kelliker, V.; Ferguson, P.L. "Application of U.S. EPA methods to the analysis of pharmaceuticals and personal care products in the environment: Determination of clofibric acid in sewage effluent by GC-MS," *American Laboratory*, July 2002, 20:28; <http://www.iscpubs.com/articles/al/a0207pat.pdf>

Daughton, C.G. "Groundwater Recharge and Chemical Contaminants: Challenges in Communicating the Connections and Collisions of Two Disparate Worlds," *Ground Water Monitoring & Remediation*, Spring 2004, 24(2):127-138; available at: <http://www.epa.gov/nerlesd1/chemistry/ppcp/images/water-reuse.pdf>

Biosolids Research Planned for 2005-2006. Development of methods for antibiotics and musks. [APM 45]

Rosal, C.G.; Mompalao, G.M.; Heithmar, E.M. "Roxarsone and transformation products in chicken manure: determination by capillary electrophoresis-inductively coupled plasma mass spectrometry," *Electrophoresis*, 2004 (accepted). [APM 255]

Overarching Products

Web Sites Central Comprehensive Repository for International PPCP Research. "Pharmaceuticals and Personal Care Products (PPCPs) as Environmental Pollutants: Pollution from Personal Actions, Activities, and Behaviors"; conceived, designed, established, and maintained by C.G. Daughton (beginning in April 2000), U.S. EPA, Las Vegas, NV; <http://www.epa.gov/nerlesd1/chemistry/pharma/index.htm>

Seminal Book

Daughton, C.G.; Jones-Lepp, T. (eds.) *Pharmaceuticals and Personal Care Products in the Environment: Scientific and Regulatory Issues*, Symposium Series 791; American Chemical Society: Washington, D.C., 2001, 416 pp; available at <http://www.oup-usa.org/isbn/0841237395.html> (0-8412-3739-5)

Research Needs and Gaps

Daughton, C.G. "PPCPs in the Environment: Future Research - Beginning with the End Always in Mind," in *Pharmaceuticals in the Environment*, Krummerer, K. (Ed.), 2nd edition, Springer, 2004, Chapter 33, pp. 463-495; available: <http://epa.gov/nerlesd1/chemistry/pharma/needs.htm>

High Resolution Mass Spectrometry in Environmental Forensics

<http://epa.gov/nerlesd1/chemistry/ice/default.htm>

Grange, A.H.; Sovocool, G.W. "Identification of Unanticipated Compounds by High Resolution Mass Spectrometry," *Spectroscopy*, 2003, 18, 12-24.

Outreach

Daughton, C.G. "Chemicals from Pharmaceutical and Personal Care Products," in *Water: Science and Issues*, E. Julius Dasch (ed.), New York: Macmillan Reference USA, 2003, vol. 1, p. 158-164.

Over 50 invited presentations at scientific meetings; numerous interviews for newspapers, magazines, radio and TV.

Seminal Critical Review Articles

Daughton, C.G.; Ternes, T.A. "Pharmaceuticals and Personal Care Products in the Environment: Agents of Subtle Change?" *Environ. Health Perspect.* 1999, 107(suppl 6), 907-938.

Daughton, C.G. "Pharmaceuticals in the environment: Overarching issues and overview," in *Pharmaceuticals and Personal Care Products in the Environment: Scientific and Regulatory Issues*, Daughton, C.G. and Jones-Lepp, T. (eds.), Symposium Series 791; American Chemical Society: Washington, D.C., 2001, pp. 2-38.

Seminal Symposia

Daughton, C.G.; Jones-Lepp, T. (co-organizers/chairs) "Environmental Chemistry of Pharmaceuticals and Personal Care Products (PPCPs)" (virtual symposium sponsored by the American Chemical Society [ACS] Division of Environmental Chemistry and the U.S. EPA) at the ACS 228th National Meeting in Philadelphia, PA, 25-26 August 2004 (first international virtual symposium for the ACS). [APM 23]

Daughton, C.G.; Ternes, T. (organizers/chairs) Special Symposium on "Pharmaceuticals in the Environment," held at the 219th National Meeting of the American Chemical Society, San Francisco, CA, 27 March 2000 (first international symposium on PPCPs in North America).

Osemwengie, L.L. "Levels of Synthetic Musks in Municipal Wastewater for Estimating Biota Exposure in Receiving Waters," Ph.D. Dissertation, University of Nevada, Las Vegas, December 2002.

Osemwengie, L.L.; Steinberg, S. "On-site solid-phase extraction and laboratory analysis of ultra-trace synthetic musks in municipal sewage effluent using gas chromatography-mass spectrometry in the full-scan mode," *J. Chromatog. A*, 2001, 932, 107-118.

Osemwengie, L.L.; Gerstenberger, S.L. "Levels of synthetic musk compounds in municipal wastewater for potential biota exposure in receiving waters," *J. Environ. Monitor.*, 2004, 6, 533-539. [APM 21]

Osemwengie, L.L.; Steinberg, S. "Closed-loop stripping analysis of synthetic musk compounds from fish tissues with measurement by gas chromatography-mass spectrometry with selected-ion monitoring," *J. Chromatog. A*, 2003, 993(1-2):1-15. [APM 283]

Mottaleb, M.A.; Brumley, W.C.; Pyle, S.M.; Sovocool, G.W. "Determination of a Boud Musk Xylene Metabolite in Carp Hemoglobin as a Biomarker of Exposure by Gas Chromatography Mass Spectrometry Using Selected Ion Monitoring," *J. Anal. Toxicol.*, 2004 (in press).

Mottaleb, M.A.; Brumley, W.C.; Curtis, L.R.; Sovocool, G.W. "Nitro musk adducts of rainbow trout hemoglobin: Dose-response and toxicokinetics determination by GC-NICI-MS for a sentinel species," *American Laboratory*, 2004 (in press).

Mottaleb, M.A.; Zhao, X.; Curtis, L.R.; Sovocool, G.W. "Formation of nitro musk adducts of rainbow trout hemoglobin for potential use as biomarkers of exposure," *Aquatic Toxicol.*, 2004, 67, 315-324.

Publications on musks available: <http://www.epa.gov/nerlesd1/chemistry/pharma/musks.htm>

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