Using Pharmaceuticals and Protective Care Products (PPCP) as Forensic Indicators

By William E. Motzer, Ph.D., PG
Senior Geochemist, Todd Engineers

Introduction

Pharmaceuticals and Protective Care Products (PPCP), a large class of organic chemicals, have been designated as emerging contaminants because they are disposed or discharged to the environment on a continual basis from domestic and industrial sewage including septic sewage, landfills, and wet weather runoff. PPCP include pharmaceutical drugs, cosmetics, household and industrial chemicals, organic and wastewater contaminants, and nutritional supplements. Some of these compounds are very persistent in the environment and therefore could be potential forensic tracers.

Classification

There are three classes of PPCP chemicals:
Pharmaceuticals are chemicals formulated into drugs for treatment of diseases (cure/mitigation), as chemopreventatives (chemicals that reduce chances of disease or slow its onset; e.g., tamoxifen for breast cancer), or those that enhance health or structural functioning of the human body (e.g., by use of steroids and hormones). They also include diagnostic agents (e.g., X-ray contrast media), illicit (recreational), and veterinary drugs.
Protective Care Products include cosmetics (e.g., hairsprays), fragrances (e.g., musks), soaps, detergents, insect repellants, sun-screen agents, skin anti-aging preparations, and disinfectants.
Nutriceuticals are bioactive chemicals contained in nutritional supplements.

Excluding antimicrobials and steroids, over 50 individual PPCPs exist with more than 10 classes of therapeutic agents. These range from simple low molecular mass compounds to large, complex molecules, and from inert to extremely bioactive compounds. Production is worldwide in quantities ranging from kilograms to thousands of metric tons per year for some individual PPCPs.

Environmental Sources

PPCPs may enter the environment through several different routes, including:

(1) Sewage and domestic wastes such as septic fields, leaking underground sewage lines, and surface water runoff either directly contaminated by bathing, washing, and swimming (via discharge of externally applied PPCPs such as fragrances or sun-screen agents, or those excreted in perspiration) or indirectly excreted as feces or urine of unmetabolized parent compounds.

(2) Disposal via municipal refuse in landfills that leach to groundwater.

(3) Storm water overflow from residential sources, “straight piping” disposal, and disposition of massive quantities of drugs contributed for humanitarian purposes largely to third world countries.

(4) Recharge of groundwater from tertiary (and higher) treated waste water.

Environmental Transport/Fate in Soil and Groundwater
PPCP environmental transport and fate is quite variable depending on the individual chemical. Some PPCPs are produced in small quantities, are highly soluble, are readily degradable, are difficult to analyze, and have very small detection limits (occurring in nanogram per liter or part per trillion quantities). These PPCPs would not make good groundwater tracers. Other PPCPs are manufactured in large quantities (resulting in continual environmental replacement), can be more easily analyzed because they occur in microgram per liter or part per billion quantities, do not readily degrade or produce known and detectable metabolites, and are environmentally persistent. These PPCPs may be useful as groundwater tracers.

Environmentally Persistent PPCPs
U.S. Geological Survey (USGS) research and other studies have found the most frequently detected PPCPs in surface and wastewater (Table 1). Because PPCP usage varies with type and amounts used or consumed, groundwater concentrations are not reliable indicators of contamination intensity.

PPCP Analyses and Analytical Laboratories
Many PPCP compounds do not have analytical standards, and analytical methods vary depending on compound type. However, most PPCPs are analyzed by either:

(1) Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS);
(2) Gas Chromatography/Mass Spectrometry (GC/MS); or
(3) High Performance Liquid Chromatography/Tandem Mass Spectrometry (HPLC/MS/MS).

The USGS conducts analytical testing for PPCPs but only for non-commercial entities such as regulatory agencies, water districts, and municipal utilities. Currently they can analyze for at least 158 emerging contaminants, including PPCPs, in aqueous samples. Few commercial laboratories exist that can analyze PPCPs in groundwater; those that do, primarily analyze drugs.

Environmental Forensics
The more persistent PPCPs may be useful source indicators, particularly for contaminants emanating from treated municipal waste water effluent and septic systems. Based on first manufactured and use dates, individual PPCP chemicals may be used to determine time of introduction to groundwater (Table 2). As in other forensic investigations, PPCPs as source indicators should be used with other environmental forensic techniques such as stable isotopes (i.e., oxygen-deuterium isotopes of water, nitrogen-oxygen isotopes in dissolved nitrate) and tritium/helium-3 ratios to age date groundwater recharge.

In summary, additional studies on the transport and fate of individual PPCPs will lead to specific chemicals being found useful in particular environments for specific purposes. This technology is in its early stages, so stay tuned!

William Motzer is Senior Geochemist with Todd Engineers in Emeryville, CA. He may be contacted at bmotzer@toddengineers.com

TABLE 1
Some Frequently Detected PPCP Chemicals in Surface and Wastewater

Chemical Name	CAS* No.	General Classification
benzophenone:	119-61-9	household and industrial chemical
caffeine:	58-08-2	stimulant
carbamazapine	298-46-4	prescription drug
carbaryl	100-46-9	household and industrial chemical
cholesterol	57-88-5	plant and animal steroid and OWC
cotinine	486-56-6	non prescription drug
2,6-dimethylnapthalene	581-42-0	household and industrial chemical
isophorone	78-59-1	household and industrial chemical
5-methyl-1H-benzotriazole	136-85-6	household and industrial chemical
N-*N*-diethyltoluamide (DEET)	134-62-3	insect repellant
4-nonylphenol	104-40-5	nonionic detergent metabolite
ticlosan	3380-34-5	an antimicrobial disinfectant
tributylphosphate	126-73-8	household and industrial chemical
tri(2-chloroethyl) phosphate	115-96-8	fire retardant
sulfamethoxazole	723-46-6	veterinary and human antibiotic

Notes:
* CAS = Chemical Abstract Service Registry Number
OWC = Organic Wastewater Compounds

TABLE 2
Representative Classes and Members of PPCPs Reported in Sewage Treatment Work (STW) Systems and Environmental Samples

Therapeutic Class	Example Generic Name	Example Brand Name	OTC Date* Introduced
Analgesics/non-steroidal anti-inflamatories (NSAIDS)	acetaminophen (analgesic)	Tylenol	1955
	diclofenac	Voltaren	1974
	ibuprofen	Advil	1984
	ketoprofen	Oruvail	1994 (OTC)
	naproxen	Naprosyn	1995 (OTC)
Antimicrobials	e.g., sulfonamide, fluoroquinolones	many	1930s
Antiepileptics	carbamazepine	Tegretol	1974
Antihypertensives (betablockers, beta-adrenergic receptor inhibitors)	bisoprolol	Concor	~1995
	metoprolol	Lopressor	mid 1990s
Antieoplastics	cyclophosphamide	Cycloblastin	1973
	ifosfamide	Holoxan	1981
Antiseptics	triclosan	Igrasan DP 300	1972
Contraceptives	–estradiol	Diogyn	1960
	17-ethinyl estradiol	Oradiol	1960s**
2-sympathomimetics (bronchodilators)	albuterol	Ventolin	1996
Lipid regulators (anti-lipidemics; cholesterol-reducing agents and their bioactive metabolites)	clofibrate (active metabolite: clofibric acid)	Atromid-S	1967
	gemfibrozil	Lopoid	1982
Musks (synthetic)	nitromusks	Musk xylene	1990s
	polycyclic musks	Celestolide	1951
	avobenzene	Parsol A	mid 1960s
	octyl methoxycinnamate	Passol MOX	mid 1970s
X-ray contrast agents	diatrizoate	Hypaque	1980s

Reference: Daughton, 2004, *Pollution From the Combined Activities, Actions, and Behaviors of the Public Pharmaceuticals and Personal Care Products*: NorCal SETAC News, v. 14, n. 1, pp. 5-15, http://www.norcalsetac.org/news.htm.

Notes :
* OTC = date introduced over the counter
** Naturally produced and excreted by humans and animals

Selected References and Bibliography

Barnes, K.K., Christenson, S.C., Kolpin, D.W., Focazio, M.J., Furlong, E.T., Zaugg, S.D., Meyer, M.T., and Barber, L.B., 2004, *Pharmaceuticals and Other Organic Waste Water Contaminants Within a Leachate Plume Downgradient of a Municipal Landfill*: Ground Water Monitoring & Remediation, v. 24, n. 2, pp. 119-126.

Brun, G.L., Bernier, M., Losier, R., Doe, K., Jackman, P., and Hing-Biu Lee, 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 and Chemistry, v. 25, no. 8, pp. 2163-2176.

Carballa, M., Omil, F., Lema, J.M., Llompart, M., García-Jares, Rodríguez, Gómez, M., Ternes, T., 2004, *Behavior of Pharmaceuticals, Cosmetics and Hormones in a Sewage Treatment Plant*: Water Research, v. 24, pp. 2918-2926.

Campbell, C.G., Borglin, S.E., Green, F.B., Grayson, A., Wozei, E., and Stringfellow, 2006, *Biologically Directed Environmental Monitoring, Fate, and Transport of Estrogenic Endocrine Disrupting Compounds in Water: A Review*: Chemosphere, v. 65, pp. 1265-1280.

Cordy, G.E., Duran, N.L., Bouwer, H./, Rice, R.C., Furlong, E.T., Zaugg, S.D., Meyer, M.T., Barber, L.B., and Kolpin, D.W., 2004, *Do Pharmaceuticals, Pathogens, and Other Organic Waste Water Compounds Persist When Waste Water is Used for Recharge?*: Ground Water Monitoring & Remediation, v. 24, n. 2, pp. 58-69.

Daughton, C.G., 2003, *Pollution from the Combined Activities, Actions, and Behaviors of the Public Pharmaceuticals and Personal Care Products*: NorCal SETAC News, v. 14, n. 1, pp. 5-15, http://www.norcalsetac.org/news.htm.

Daughton, C.G., 2004a, *Origins and Fate of PPCPs in the Environment*: U.S. Environmental Protection Agency (USEPA), 1 p., http://epa.gov/nerlesdl/chemistry/pharma/images/drawing.pdf.

Daughton, C.G., 2004b, *PPCPs as Environmental Pollutants: Pharmaceutical and Personal Care Products in the Environment: Overarching Issues and Overview*: U.S. Environmental Protection Agency (USEPA), http://www.epa.gov/nerlesd1/chemistry/pharma/book-summary.htm, 29 p. (accessed 10/27/05).

Daughton, C.G. and Ternes, T.A., 1999, *Pharmaceuticals and Personal Care Products in the Environment: Agents of Subtle Change?*: Environmental Health Perspectives, v. 107, supplement 6, pp. 906-942.

Erickson, B.E., 2002, *Analyzing the Ignored Environmental Contaminants*: Environmental Science & Technology, v. 36, n. 7, pp. 141A-145A.

Kolpin, D.W., Furlong, E.T., Meyer, M.T., Thurman, E.M., Zaugg, S.D., Barber, L.B., Buxton, H.T., 2002, *Pharmaceutical, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999 – 2000*: A National Reconnaissance: Environmental Science & Technology, v. 36, n.6, pp. 1202-1211.

Skadsen, J.M., Rice, B.L., and Meyering, D.J., 2004, *The Occurrence and Fate of Pharmaceuticals, Personal Care Products and Endocrine Disrupting Compounds in a Municipal Water Use Cycle: A Case Study in the City of Ann Arbor*: City of Ann Arbor, Water Utilities and Fleis & VandenBrink Engineering, Inc., Ann Arbor, MI, 22 p., http://www.ci.ann-arbor.mi.us/PublicServices/water/WTP/EndocrineDisruptors.pdf.

Verstraeten, I.M., Fetterman, G.S., Meyer, M.T., Bullen, T., and Sebree, S.K., 2005, *Use of Tracers and Isotopes to Evaluate Vulnerability of Water in Domestic Wells to Septic Waste*: Ground Water Monitoring & Remediation, v. 25, n. 2, pp. 107-117.

U.S. Environmental Protection Agency (USEPA), 2002, *PPCPs as Environmental Pollutants*: http://www.epa.gov/esd/chemistry/pharma/tracers.htm, 4 p. (accessed 10/24/05).

U.S. Environmental Protection Agency (USEPA), 2004, *Some Historical Perspectives & Significance Regarding the Environmental Health Perspectives Critical Review Article – Pharmaceuticals and Personal Care Products in the Environment: Agents of Subtle Change?*: http://www.epa.gov.esd/chemistry/pharma/history.htm., 4 p. (accessed 10/27/05)

U.S. Geological Survey (USGS), 2005a, *Current Analytical Capabilities to Measure Emerging Contaminants in Water*: http://toxics.usgs.gov/regiona/emc_water.html, 3 p. (accessed 10/24/05).

U.S. Geological Survey (USGS), 2005b, *Landfill Leachate*: http://toxics.usgs.gov/regional/emc/landfills.html, 2 p., (accessed 10/24/05)