

Emerging Contaminants: A Proactive Approach to Enhance Drinking Water Quality

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Natural rivers, streams, and groundwater, which serve as drinking water sources, contain trace amounts of chemical contaminants that are currently unregulated and are not completely removed by most drinking water treatment systems. Some of these emerging contaminants are generated from pharmaceuticals, hormones, detergent residues, pesticides, flame retardants, plasticizers, and their metabolites. Awareness of emerging contaminants has increased in correlation with improvements to sensitive analytical methods, which can identify low concentrations of chemicals that were previously undetectable.

The long-term health effects of exposure to low concentrations of emerging contaminants in drinking water are not well understood. Nonetheless, potential health risks from the numerous emerging contaminants are creating growing concern among regulatory agencies' and drinking water providers.

Raw water sources near urban centers and agricultural activities

frequently contain emerging contaminants. The US Geological Survey (USGS) analyzed water samples from 139 streams in 30 states located downstream from urban areas and livestock production areas. Low concentrations of natural and synthetic organic contaminants were found in 80% of the streams sampled during 1999 and 2000. Unregulated organic compounds, such as detergents, steroids, plasticizers, and non-prescription drugs, were measured in the surface and ground waters, and were found at low concentrations – generally less than 1 ug/L.

In 2007, the USGS analyzed 100 analytes in 25 groundwater and 49 surface water sources of drinking water in the United States. The most frequently detected chemicals are summarized in **Table 1**. The sample sites contained a median of four targeted chemicals, often near detection limits. Most of the chemicals detected in the survey are currently unregulated but some may have long-term health effects at low concentrations.

USGS measured organic wastewater compounds at eight sites, which are drinking water sources in the Triangle Area of North Carolina, from 2002 through mid-2005 (M.J. Giorgino, R.B. Rasmussen, and C.A. Pfeifle, June 2007, Occurrence of Organic Wastewater Compounds in Selected Surface-Water Supplies, Triangle Area of North Carolina, 2002–2005). A total of 24 target compounds were detected at low concentrations (< 1 ug/L) in at least one sample. The most frequently detected compounds included:

- acetaminophen (nonprescription analgesic);
- caffeine (nonprescription stimulant)
- cotinine (nicotine metabolite)
- metolachlor (herbicide)
- 3 fire retardants - tri(2-chloroethyl) phosphate, tri(dichloroisopropyl) phosphate, and tributyl phosphate
- 2 synthetic musk fragrances (known endocrine disruptors) - acetyl-hexamethyl tetrahydronaphthalene and hexahydro-hexamethyl cyclopentabenzopyran

Table 1: Emerging Contaminants in Groundwater and Surface Water Sources of Drinking Water

Contaminant	Detection Frequency, percent		Description
	Surface water	Groundwater	
Bisphenol-A		20	plasticizer
β-sitosterol	37		natural plant sterol
Carbamazepine		20	Pharmaceutical, anti-epilepsy drug
Cholesterol	59		plant and animal sterol
Cotinine	51		nicotine metabolite
1,7-dimethylxanthine	27	16	caffeine metabolite
Metolachlor	53		herbicide
Tetrachloroethylene		24	solvent
Tri(2-chloroethyl) phosphate		12	fire retardant

Source: Michael J. Focazio, Dana W. Kolpin, Kimberlee K. Barnes, Edward T. Furlong, Michael T. Meyer, Steven D. Zaugg, Larry B. Barber, and Michael E. Thurman. (September 2008). A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States – II) Untreated drinking water sources, Science of The Total Environment, 402, 2–3.



Rueter-Hess Water Treatment Plant under construction.



Ceramic membrane filter 2 being installed at Rueter-Hess Water Treatment Plant

• sulfamethoxazole (prescription antibiotic)
At least one organic wastewater compound was detected at every location. Up to 12 compounds were observed in individual samples and the median number was 3.5 for all of the sample locations. Concentrations of individual compounds generally were less than 0.5 ug/L and were less than Federal drinking-water standards, health advisories, and North Carolina water-quality criteria. However, such criteria only exist for a few of the compounds studied.

Acetaminophen, cotinine, tri(2-

chloroethyl) phosphate, and metolachlor, were detected at numerous sites and in numerous samples, indicating that they are widely distributed in the environment. Synthetic musk fragrances were detected in numerous samples but at only one location. In general, concentrations of organic wastewater compounds detected in the Triangle Area were within ranges of concentrations reported for other areas. Municipal wastewater and storm water runoff from agricultural, urban, and residential areas were probable sources of these organic compounds.

Endocrine Disrupting Compounds (EDCs)

The physiological functions of living organisms are regulated by natural hormones produced by the endocrine system. Hormones are normally present in the body at very low concentrations and regulate many critical metabolic functions. Many emerging contaminants can interfere with or disrupt normal hormonal functions. Trace amounts of endocrine disrupting compounds (EDCs) can have significant ecological and biological effects.

Estrogens are hormones that regulate the female reproductive system. Estrogens are steroid compounds that have chemical structures similar to synthetic steroid medications. Due to their essential biological function, natural estrogens and synthetic compounds that mimic estrogens can have endocrine-disrupting effects that adversely impact aquatic wildlife and other exposed organisms at very low concentrations.

Widely used medications such as ibuprofen, acetaminophen, phenazone, and carbamazepine (anti-epilepsy drug) exhibit estrogenic activity. Nonylphenols (NP) formed from detergents exhibit well known endocrine-disrupting effects. Other common EDCs include 4-tert-octylphenol (OP), 4-nonylphenol (NP), bisphenol-A (BPA), and several phthalates (plasticizers).

Both natural estrogens and synthetic organic compounds, which mimic estrogen, are present in all domestic wastewaters. Aqueous-phase estrogenic activity in raw domestic wastewater is reduced significantly during secondary wastewater treatment. However, conventional wastewater treatment processes only partially remove many pharmaceuticals and their derivatives and these biologically active chemicals are discharged into receiving surface waters. Steroid hormones are the most significant endocrine disrupting chemicals in wastewater effluent. Reproductive hormones have been identified in 40% of surface waters and estrogenic alkylphenols in 70% of surface waters in the United States by the US Geological Survey. Concentrations of the

Endocrine-Disrupting Compounds

Endocrine-disrupting chemicals (EDCs) mimic or block the action of natural hormones that regulate metabolism, growth, development, and reproduction in animals. Most EDCs affect the action of estrogen, androgen, or thyroid hormones. EDCs include natural and synthetic hormones excreted from the human body, many prescription drugs, and non-prescription medicines. Some detergent degradation products are estrogenic.

hormone ethinyl estradiol are typically less than 2 ug/l in wastewater effluent (US EPA, 2004). EDCs discharged into surface waters eventually reach groundwater and intakes to drinking water systems.

Pesticides and Herbicides

Pesticides and herbicides are frequently found in surface streams and ground water. The National Water-Quality Assessment (NAWQA, USGS, 1998) found that more than 50% of all stream samples contained five or more pesticides and about 25% of ground water samples had two or more pesticides. Although pesticides and herbicides are present in most surface waters, the concentrations are generally below 1 ug/L and are substantially below US Environmental Protection Agency (EPA) drinking water standards.

The United States Department of Agriculture (USDA) Pesticide Data Program (PDP) surveyed drinking water systems in several states for pesticide and herbicide residues. In 2005, PDP analyzed 750 drinking water samples for more than 200 pesticides and metabolites. Treatment plants participating in the 2005 survey draw from surface water as their primary source waters. Drinking water sampling sites were located in watersheds where pesticides were heavily applied. A total of 48 residues were detected in the untreated intake water and 43 in the treated drinking water. Treated drinking water exhibited little or no reduction in most pesticides compared with the raw water. None of the pesticides detected

in the finished water samples exceeded EPA Maximum Contaminant Levels (MCL) or Health Advisory (HA) levels.

Future Regulated Compounds

US EPA periodically publishes the Contaminant Candidate List (CCL) to identify chemicals that are known or anticipated to occur in public water systems and may be regulated in the future. US EPA published the third Contaminant Candidate List (CCL3) in February 2008. The CCL3 lists 104 chemicals or chemical groups, many of which are synthetic organic compounds. The final CCL3 list includes pharmaceutical products, synthetic hormones, pesticides, endocrine-disrupting chemicals (EDCs), nitrosamines, three cyanotoxins and several microorganisms. In addition, several chemicals, which are currently regulated under the national primary drinking water standards (NPDWRs), are being reviewed or revised for more stringent MCLs by recent or ongoing regulatory actions.

When new contaminants become regulated or when currently regulated contaminants receive more stringent MCLs, existing drinking water treatment systems may need to be upgraded. Existing drinking water treatment systems, which plan to expand, and new water treatment systems should anticipate low MCLs for emerging contaminants and be designed to remove emerging contaminants or be planned for future upgrades to remove emerging contaminants that may be in their raw water sources.

Treatment Alternatives to Remove Emerging Contaminants

Most of the emerging contaminants are natural or synthetic dissolved organic compounds (DOC), which are not removed or are partially removed by conventional water treatment processes. US EPA published an extensive database of capabilities for wastewater and drinking water treatment processes to remove emerging contaminants (US EPA, August 2010, *Treating Contaminants of Emerging Concern, A Literature Review Database*). The removal percentages for specific emerging contaminants vary over a wide range. The most effective treatment process depends on the specific emerging contaminants that are present in the source water.

Treatment technologies, which have the capability to remove high percentages of a broad range of DOC from the raw water, would eliminate most of the emerging contaminants, endocrine-disrupting chemicals (EDCs), and provide the ability to meet future regulatory limits for synthetic organic compounds. Removal of high percentages of DOC from the raw water would also reduce disinfection by-product (DBP) formation potential. Treatment technologies that can reduce DOC to low concentrations are summarized in **Table 2**.

Rueter-Hess Water Treatment Plant

The Parker Water and Sanitation District (PWSD) located in Parker, Colorado constructed the Rueter-Hess Reservoir and is currently constructing the Rueter-Hess Water Treatment Plant (RHWTP) to maximize reuse of groundwater and alternative renewable surface water sources. The RHWTP will treat surface water from local

Table 2: Treatment Processes to Remove Emerging Contaminants

Treatment Process	Description
Activated carbon	Adsorption of organic compounds onto activated carbon surface
Biological filtration	Ozonation followed by biological oxidation in granular activated carbon filters
Ion exchange	Adsorption of specific ions onto exchange media surface
Advanced oxidation	Ultraviolet (UV) light combined with hydrogen peroxide or ozone to generate hydroxyl radicals, which oxidize DOC
Nanofiltration	Excludes molecules > 0.001 microns in size (multivalent ion range); removes many heavy metals and most EDCs
Reverse osmosis	Membrane separation removes dissolved solids < 0.001 microns in size including pharmaceuticals and endocrine disrupters



Rueter Hess Reservoir partially filled, water treatment plant construction site in lower right corner (photo by Jackie Schumaker)

streams and reclaimed tertiary wastewater effluent, which will be stored in the 72,000-acre-foot Rueter-Hess Reservoir. All of the water flowing into the reservoir is retained for water supply except for evaporation and seepage losses. Rueter-Hess Reservoir has no downstream release of water (except for emergency overflows).

The RHWTP will treat reclaimed effluent for indirect potable reuse for drinking water supply. The local surface water sources and the reclaimed water have high organic content. Average dissolved organic carbon (DOC) levels in the raw water within the reservoir are expected to be 10 to 12 mg/L, especially during the summer. The raw water sources are expected to contain a mixture of emerging contaminants. Significant amounts of many of the dissolved natural and synthetic organic chemicals would not be removed by conventional water treatment processes.

The RHWTP was designed to eliminate most of the natural organic matter and synthetic organic chemicals in the finished drinking water by removing a high percentage of DOC. Removing most of the DOC from the raw water will achieve compliance with drinking water standards for DBPs and will proactively remove most of the organic emerging contaminants and EDCs, which might be regulated in the future.

The treatment process selected for the Rueter-Hess WTP consists of enhanced coagulation using ferric chloride in a ballasted sedimentation system, adsorption of DOC with powdered activated carbon

(PAC), ceramic membrane filtration, and sodium hypochlorite disinfection. Enhanced coagulation will remove approximately half of the DOC in the raw water. Adsorption on recirculating PAC will remove most of the DOC remaining in the water after enhanced coagulation. Pilot tests conducted by Dewberry Engineers showed that recirculating PAC at an equivalent PAC dose of 25 mg/L achieved 70% DOC removal and pre-filter DOC less than 2 mg/L using 100% reclaimed wastewater effluent as the source water. In addition, the PAC dose can be increased to achieve up to 90% DOC removal if necessary. The recirculating PAC system, originally developed in France to comply with European Union standards for pesticide removal, will be one of the first US applications.

The RHWTP will be the first application of ceramic membranes for drinking water treatment in the United States. Ceramic membrane microfilters will remove particulates larger than 0.1 micron while achieving high flux rates without progressive membrane fouling. The ceramic membrane filter pilot system at Parker maintained flux rates of 90 to 100 gallons per square foot per day (gfd) during enhanced coagulation using coagulant doses greater than 100 mg/L without sedimentation upstream of the ceramic membrane filter. Ceramic membrane filters are an approved filtration technology in California and Colorado for flux rates up to 175 gfd. These ceramic membrane flux rates are much higher than those achieved by conventional polymeric microfilters.

Although ceramic membrane microfilters for drinking water are new to the US, the technology is well established with over 15 years of full scale operating experience. There are more than 100 ceramic membrane drinking water facilities in Japan with over 140 mgd of total installed ceramic membrane capacity. Ceramic membrane microfilters were selected for the RHWTP because they have several advantages over conventional polymeric membranes, including:

- 20+ year membrane life
- 0.1 micron pores are absolute barrier to bacteria, Giardia and Cryptosporidium
- Low trans-membrane pressure
- No irreversible fouling or progressive flux decline
- No membrane damage from exposure to strong chemical oxidants and extreme pH
- Ceramic membranes have never failed a membrane integrity test
- Ceramic membranes have never needed to be replaced over 15 years of operation

Construction of the RHWTP started in the fall of 2012. The ceramic membrane microfilters have been fabricated, delivered to the site, and will be installed this summer. When completed in 2014, the RHWTP will produce drinking water from reclaimed effluent and native surface water. The innovative PAC adsorption process will remove most of the DOC and organic emerging contaminants, which will achieve compliance with drinking water standards for DBPs and proactively address potential future regulations for many organic emerging contaminants. [↗](#)

Authors

Mike Lutz is an Associate Vice President with Dewberry Engineers. He participated in pilot testing, planning, and design of the 10-mgd Rueter-Hess water treatment plant. The unique treatment process features the first ceramic membrane filters and one of the first recirculating PAC adsorption systems in the US.

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