



Cartwright Consulting Co., LLC

WWW.CARTWRIGHT-CONSULTING.COM

peterscartwright@gmail.com

United States Office

8324 16th Avenue South
Minneapolis, MN 55425-1742
Phone: (952) 854-4911
Fax: (952) 854-6964

European Office

President Kennedylaan 94
2343 GT Oegstgeest
The Netherlands
Phone: 31-71-5154417

The Next Drinking Water Contamination Issue?

By Peter S. Cartwright, PE

Abstract

Every time water goes down the drain, whether to a sewer, a septic system, a storm drain, or wherever, it carries contaminants with it, which usually end up in someone's drinking water. Included are unmetabolized pharmaceuticals, chemicals and particles from hand and face washing, bathing, laundry, the toilet - from virtually any and all human activity. The contaminants are in tiny concentrations, but come from many thousands of sources, and as our use of pharmaceutical and personal care products (PPCPs) increases, our drinking water is becoming more contaminated.

No scientific connection between this contaminated drinking water and human health has yet been made, but, in this writer's opinion, it will surely come, and there is lots of anecdotal evidence supporting this belief.

This document addresses the sources of water contaminants, their possible health effects, and offers some guidance on what we, as responsible caretakers of this planet and concerned consumers, can do now and in the future.

Introduction

Virtually every water source, whether wells, rivers, lakes, oceans or rainwater, requires some treatment to make the water potable. The 1974 US EPA Safe Drinking Water Act is one of our fundamental environmental laws to ensure this. At this time, the Act addresses about 100 contaminants and lists the maximum acceptable concentrations for each, above which the water is not considered safe to consume for drinking or cooking. These particular contaminants have undergone thorough scientific screening and risk assessment protocols, but they represent only a tiny fraction of the trace chemicals that are actually in our water supplies. Additional chemicals are being assessed and some will ultimately be added, but it is a necessarily slow process.

The Next Drinking Water Contamination Issue?

By Peter S. Cartwright, PE

What is the issue?

Globally, we now produce more than 85,000 different chemicals,¹ many of which end up in our drinking water. Chemicals are used to manufacture 96% of consumer products; the average adult uses nine products per day containing 126 different chemicals.² Fertilizers, pesticides, herbicides and antibiotics are all also used in agriculture and animal husbandry operations.

Whether from hand washing, bathing, showering, laundry, dishwashing, toilet use - no matter for what purpose we use water, it carries contaminants down the drain. If this water enters a municipal wastewater treatment system, it ultimately ends up in a body of water (lake, river, etc.) which often becomes a source of drinking water. If the wastewater is directed into a septic system, the treated water percolates into the earth where it usually enters an aquifer or other water supply. Weather events generating runoff from lawn and agricultural surfaces also contribute to this contamination.

It's a fact of life: virtually every time water goes down the drain, it is carrying some contaminants which end up in someone's drinking water.

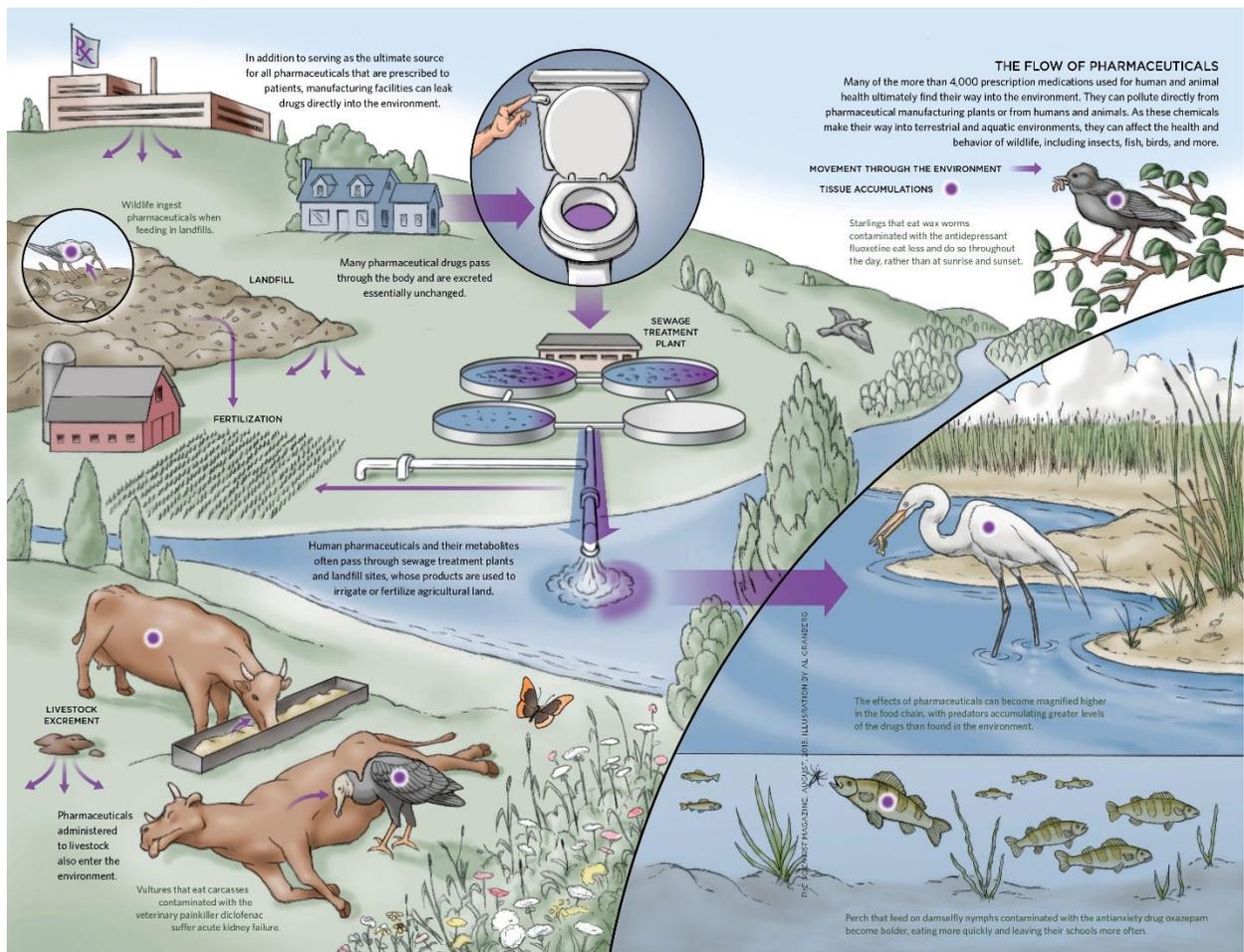


Illustration by Al Granberg

The Next Drinking Water Contamination Issue?

By Peter S. Cartwright, PE

Many of the pharmaceutical products we ingest are not completely metabolized, pass through the body and contribute to this contamination, as illustrated above. America is the largest “pill popping” nation in the world, with 70% of us taking one prescription a day, 50% taking two, and 25% five or more per day.³ Additionally, because people are living longer, more pharmaceuticals are consumed and more end up in the water. Opiate addiction has become a crisis. In the U.S. alone, in 2016, almost 4½ billion medical prescriptions were issued.⁴

Other sources of contaminants include food, toothpaste, artificial sweeteners, caffeine, vitamins, as well as makeup products, lotion, sunscreen, perfume, deodorant; the list goes on and on.

The primary contaminants in toilet discharges are organic materials with high concentrations of what is known as BOD (biochemical oxygen demand). BOD is readily broken down into generally benign components during the traditional sewage treatment process. On the other hand, this water, and virtually all other waters leaving any facility of human or animal activity, will contain tiny concentrations of other contaminants as described above. These are mainly in two forms: dissolved organic compounds and tiny particles, fibers or other insoluble materials.

Contaminants in the first form are known by many acronyms:

PPCPs (pharmaceutical and personal care products)

CECs (contaminants of emerging concern)

EPOCs (emerging pollutants of concern)

EPPPs (environmental persistent pharmaceutical pollutants)

APIs (active pharmaceutical ingredients)

EDCs (endocrine disrupting chemicals [compounds])

The acronym EDC describes specific chemicals that interfere with human hormone function, and ongoing investigations conclude that even very low concentrations may disrupt the hormones related to obesity, diabetes, human reproduction processes, and various cancers. More on EDCs later.

The illicit “drug of choice” in a particular city can be identified by analyzing the water leaving its sewage treatment plant.

In my home state of Minnesota, a 2013 study of 50 lakes found PPCPs in 47 of them. They included DEET (used in mosquito and tick repellents), cocaine, caffeine, and triclosan (an “antibacterial” agent in hand soap). None of the lakes were located near a municipal wastewater plant.⁵

The above examples are just from residential activity, and don’t account for the huge number of other contaminants from our agricultural and industrial activities.

The second form, particles, can range from tiny fibers to bits of plastic. Known by such terms as nanofibers, nanoparticles, microplastics, nanomaterials, and others, they add to the myriad of manufactured contaminants which do not readily degrade in nature.

Examples include exfoliant cosmetic beads, lint, particles washed out of the air, laundry and carpet cleaning wastewater and many more.

The Next Drinking Water Contamination Issue?

By Peter S. Cartwright, PE

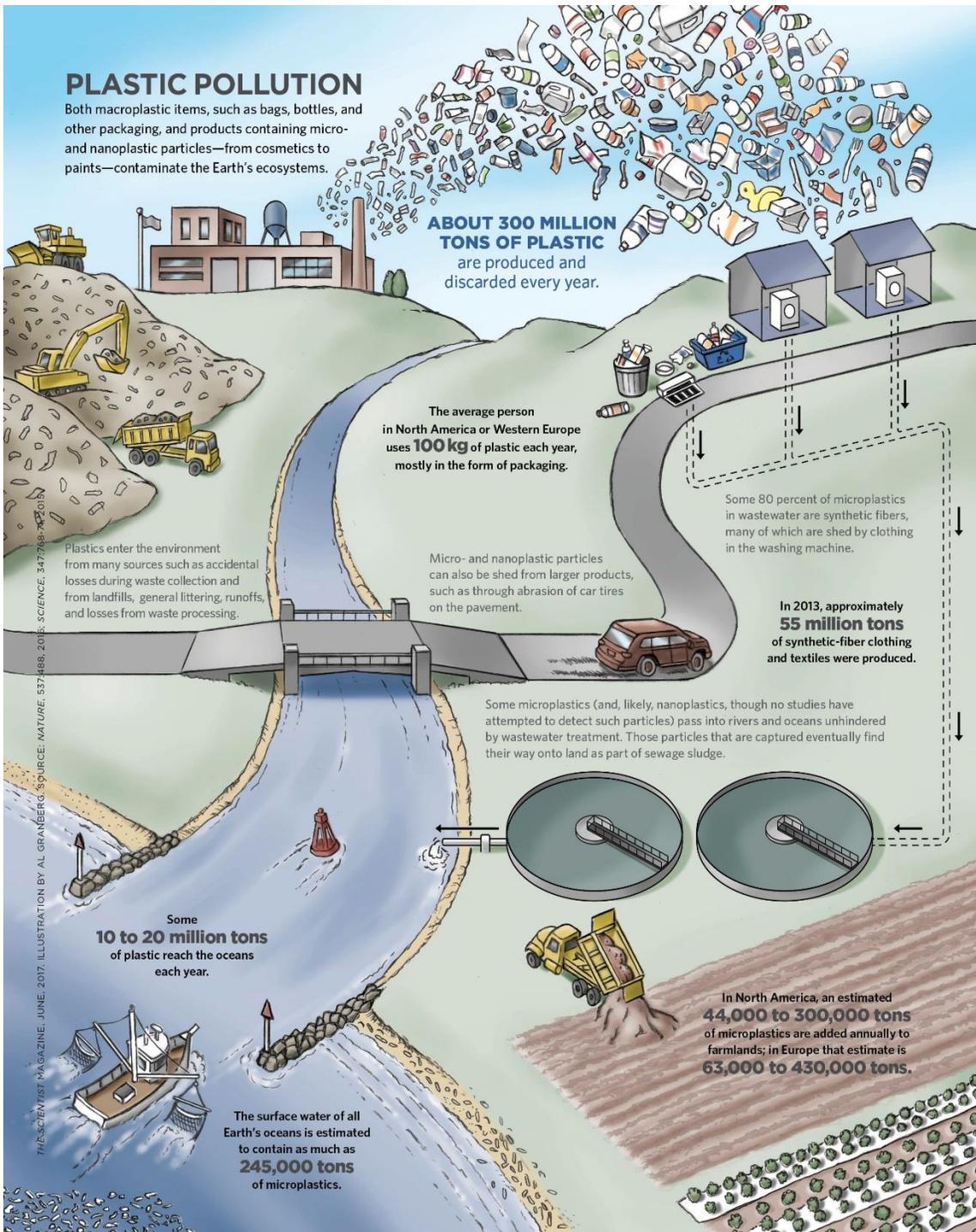


Illustration by Al Granberg

The Next Drinking Water Contamination Issue?
By Peter S. Cartwright, PE

The contribution by plastic alone is illustrated above.

Because of their benefits as catalysts and as additives, industry is starting to use many more nanoparticles in manufacturing processes in such areas as medicine, energy and electronics.

It is estimated that there are more than 1000 “nano-enabled” products produced in the industrialized countries today, and this number is increasing rapidly.

A 2016 study at Loyola University of Chicago indicates that up to 4½ million pieces of plastics per day are released into rivers by municipal wastewater treatment plants.

Interestingly, this is the quantity released after the plants have removed 90% of the incoming microplastics.⁶ The USGS (U.S. Geological Survey) participated in an extensive study, “Microplastics in the Great Lakes,” in 2016. One outcome was the document, “Microplastics in our Nation’s Waterways.”⁷

The categories of microplastics identified in this document included beads, films, foams, fragments and fibers, with the latter comprising over 70% of all the microplastics.

Our oceans contain huge masses of plastic debris known as gyres or “garbage patches.”

There are five major gyres, with the largest, the Great Pacific, estimated to be at least the size of Texas in area.⁸ Most of these plastics are susceptible to degradation by ultraviolet radiation from the sun and break down into relatively inert microplastic particles.

They are often coated with dissolved organic PPCPs, which can then be released into water supplies.⁷ Surprisingly, they are found even in such remote locations as the Antarctic.

So, how many of these chemicals and nanoparticles are in our drinking water?

Obviously, the concentrations vary from place to place and from time to time; however, the concentrations are very, very small, measured in parts per trillion.

What is a part per trillion? It’s about one second in 32,000 years, a pinch of salt in 10,000 tons of potato chips, or a 6” leap in a journey to the sun.

Is there a health risk?

Does this tiny concentration of the huge number of these various contaminants pose a health problem? So far, there is no scientifically-proven link, but lots of anecdotal evidence.

A Canadian study in 2008 provides some of this evidence:⁹

- 1) In 20 industrialized nations, the birthrate for boys has declined every year for the past 30 years.
- 2) There has been a 200% increase in male sex organ abnormalities over the last 20 years.
- 3) The average sperm count of North American college students has dropped by over 50% in the last 50 years.
- 4) Up to 85% of the sperm in healthy males contains damaged DNA.
- 5) Over the last 50 years, there has been a 300% increase in testicular cancer.

For many years, there have been reports of “feminization” in fish and amphibians, as well as documented genitalia deformities in such diverse animal populations as bears, panthers, sea lions, whales, birds, alligators and others.

Between 1999 and 2003, in a population of Chippewa aboriginal peoples in southwestern Ontario, Canada, the birth ratio of boys to girls declined from roughly 50/50 to 33/67.¹⁰

Significant research is underway on EDCs. A citation in the journal, “Endocrine Reviews,” contains the statement: “Whether low doses of EDCs influence certain human disorders is no longer conjecture, because epidemiological studies show that environmental exposures to EDCs are associated with human diseases and disabilities.”¹¹ A follow-up review in 2015 contains the statement: “It simply is not reasonable to assume a chemical is safe until proven otherwise. Clearly, not all chemicals are EDCs, but substantial information needs to be provided before inclusion of a new compound in a food storage product, a water bottle, health and beauty products, or a household product. The BPA substitute, BPS, is now shown to have endocrine-disrupting activity on par with BPA in experimental studies discussed in EDC-2. A further need for precaution is based on evidence that individuals exposed to EDCs may carry that body burden for their entire lives in the case of long-lived chemicals; that even short-lived chemicals may induce changes that are permanent and that some actions of EDCs are observed in an individual’s offspring. Transgenerational effects of EDCs mean that even if a chemical is removed from use, its imprints on the exposed individual’s DNA may persist for generations and possibly forever.”¹²

Chlorine, the common water disinfectant used in municipal drinking water treatment plants can chemically react with some PPCPs and produce disinfection byproducts (DBPs), a class of which, trihalomethanes (THMs), contains chemicals known to cause cancer. In recognition of this, the EPA has established a maximum limit for THM compounds, listed in the Safe Drinking Water Act. Many municipalities are adding ammonia to chlorine to produce chloramines which do not generate dangerous DBPs.

The Next Drinking Water Contamination Issue?
By Peter S. Cartwright, PE

The formation of these compounds is an example of the complex chemistry associated with PPCP contamination.

In addition, there is the issue of the fluorine-based chemical contamination of aquifers that has become a major issue in many areas. Under the general acronym, PFAS (poly- and perfluoroalkyl substances), they are major components of firefighting foam, Teflon® and Scotchgard® products, coatings on carpeting, clothing, fast-food wrappers, and many other consumer products. PFAS exposure has been linked to cancer, obesity, immune system suppression, and endocrine system disruption.¹³ The USEPA has suggested “advisory” levels, but, has not established specific limits for any of the many fluorine-containing chemicals in the environment.

The National Groundwater Association has recently published a document, “Groundwater and PFAS: State of Knowledge and Practice.” “It is intended to provide technically defensible guidance useful in defining an appropriate path forward for a client, a water resource, or a regulatory action.”¹⁴

The U.S. Department of Health and Human Services Centers for Disease Control and Prevention (CDC) publishes a report every two years, “The National Report on Human Exposure to Environmental Chemicals,” which is “...a series of ongoing assessments of the U.S. population’s exposure to environmental chemicals by measuring chemicals in people’s blood and urine, also called biomonitoring.”¹⁵ This report provides exposure information with regard to chemicals in the environment that enter the human body. The Fourth Report (2017) includes data for 308 chemicals.

Today, there is a continuous stream of news releases on credible scientific studies that address links between common household chemicals and various health effects. Here are some examples:

In a 2014 study at Columbia University, two chemicals found in such products as lipstick, hairspray, nail polish, dryer sheets and vinyl fabrics (phthalates - suspected EDCs) lowered the IQ of children born to mothers exposed to them.¹⁶

A recent Virginia Tech study has found a connection between quaternary ammonium compounds (“quats”) found in cleaners, laundry detergent, fabric softener, shampoo, conditioner and eye drops, and birth defects in laboratory rodents.¹⁷

Again, common household products are implicated in a Washington University in St. Louis study that linked them with ovarian function resulting in women experiencing menopause two to four years earlier than normal.¹⁸

It is very important to underscore the fact that, so far, there is no proven link between these trace contaminants and human health. Although many scientific studies are underway, there is lack of conclusive proof that PPCPs are harmful. On the other hand, with so many different chemicals in our drinking water, in this writer’s opinion, it is only a matter of time before a health risk is identified.

Here are some unanswered questions:

The Next Drinking Water Contamination Issue?
By Peter S. Cartwright, PE

What is the specific risk: cancer, autism, ADHD, Parkinson's disease, diabetes, allergies, something else?

What is the most vulnerable population: babies? the elderly? pregnant women? adults with compromised immune systems?

Which chemicals are more dangerous than others? ones that bioaccumulate in the body? those that break down in the body?

Are there mixtures of them that present even greater risk?

Do they react with each other to produce other dangerous compounds?

The evidence is certainly persuasive, but not yet conclusive.

What can we do about this issue?

Individual Practices

Obviously, we can (and should) all become personal stewards of our own environment. This includes more diligence about what we throw down the drain as well as our overall water usage. There is evidence that people are becoming more knowledgeable about waste in general, and more careful about how they dispose of unused pharmaceutical products, for example. Many pharmacies are accepting them at no charge, and, at the very least, more consumers are disposing them in the trash rather than the toilet.

We must individually monitor our personal practices regarding purchases and disposal of personal care products. Fortunately, this attitude seems to be taking hold, albeit very slowly.

There is an exciting paradigm shift slowly taking hold in the manufacturing and agricultural industries: the trend is towards water conservation, as well as wastewater recovery and reuse.

Legislative Activities

There is significant federal activity addressing PPCP issues. One bill introduced in the Senate in 2015, Personal Care Products Safety Act, amends the Federal Food, Drug and Cosmetic Act to require cosmetics companies to submit to the FDA (Food and Drug Administration) a list of the chemicals in their products and to report any serious adverse health events associated with their products.¹⁹ It has not yet been enacted into law.

A new EPA Rule requires companies that manufacture chemical substances known as "Nanoscale Materials" to submit a report containing manufacturing data and "existing information concerning environmental and health effects." These materials are defined as particles of sizes of 1-100 nanometers (a nanometer is 0.001 μ).²⁰

Individual states can enact their own contaminant concentration limits for drinking water, providing they are more stringent than existing EPA standards, and many states have chosen to do so for specific contaminants.

Treatment Technologies

Although the huge number of chemicals with their innumerable structures and properties presents a significant challenge for drinking water treatment, the good news is that the concentrations of almost all of these contaminants can be reduced with existing water treatment technologies. On the other hand, the most complete removal will probably involve not one, but several technologies, probably used in combination.

Although the current biodegradation technologies employed by municipal wastewater treatment plants have little or no effect on overall PPCP removal,^{21,22} much scientific activity is underway on new microorganism approaches, and improvements in remediation of these contaminants through this route may be possible. It appears that “In-Situ Bioremediation” offers promise by using customized bacteria designed to treat localized aquifers in certain cases. Unfortunately, most municipal water and wastewater treatment plants are significantly underfunded and the monies for new technologies are generally not available.

Activated carbon, long employed for removal of chlorine, certain gases, and many dissolved organics, is an effective technology for many of the lower molecular weight organic contaminants in PPCPs. Utilizing surface adsorption, activated carbon filters capture these chemicals and can be very effective. They ultimately require replacement; however, the “exhausted” resins can usually be safely landfilled.^{22,23,24,25}

The family of membrane technologies: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO), are very effective for the reduction of a wide range of contaminants. MF and UF will target higher molecular weight PPCP organic compounds, while NF and RO are most effective on the more ionic (polar) and lower molecular weight organic compounds. These membrane technologies are designed to reject the contaminants in a separate “concentrate” stream which is usually discharged to drain. They are most effective when used to treat water specifically for drinking and culinary purposes. Of course, these technologies don’t destroy PPCPs, they just redirect them into the drain. Such notorious contaminants as lead and nitrate are also readily removed by reverse osmosis.^{22,24,25,26,27}

Distillation is also an effective technology for reduction of water-borne contaminants. This process involves boiling the water and then condensing the water vapor to produce purified water. A potential problem is that those organics with boiling points close to that of water may also evaporate and end up in the distillate. Activated carbon can be utilized to help mitigate this problem. A downside of distillation is the energy required to boil water and to cool the distillate.

The technologies known as AOPs (advanced oxidation processes), utilize destructive technologies such as ultraviolet irradiation (UV), ozone and hydrogen peroxide in various combinations and concentrations to break organic bonds, and generally produce more benign chemicals. Depending on the characteristics of the chemicals resulting from these oxidation processes, they may or may not be less dangerous; however, the resulting chemicals may be more easily removed by the other processes. In the wastewater

The Next Drinking Water Contamination Issue?

By Peter S. Cartwright, PE

treatment industry, AOPs are currently primarily used to inactivate (kill) microorganisms.^{21,22,24,25}

It may be that harnessing the (elusive) hydroxyl radical (●OH) will be required to more completely break down some compounds. The technologies to produce this very powerful oxidant have escaped widespread practical application so far, but it should become reality in the not too distant future.

The POU (point of use) “undersink” reverse osmosis units (designed to treat drinking water for a single tap) so readily available from water conditioning dealers and DIY stores have been shown to be capable of removing an estimated 60 to 80% of all PCPPs. Because they virtually all incorporate both activated carbon and RO membrane technology, they should all work equally well. This is the best possible solution to the PCPP issue at this time.

Although less commonly available, POU distillers are also available.

Regardless of the treatment technology selected, they all require maintenance, primarily dictated by the characteristics of the water to be treated. Usually, the issue is suspended solids (dirt) in the water supply, or certain chemicals that may become insoluble during the purification process. For example, with POU reverse osmosis units and distillers, they should be fed with softened water.

Because the water conditioning industry includes some “con-artists” selling “foo-foo dust” or unproven technologies, it is imperative that only units that have been validated by third-party credible organizations be selected. Fortunately, excellent manufacturing and performance standards for each technology have been developed. For POU RO units, NSF/ANSI 58 Standard establishes manufacturing and performance protocol, and several ANSI-accredited organizations are capable of certifying a unit to meet this standard. They include CSA (Canada Standards Association), IAPMO Research and Testing, NSF International, WQA (Water Quality Association), and UL (Underwriters Laboratories). These organizations provide certification that treatment units meet the appropriate manufacturing and performance standards associated with their specific technology.

It is important that the product label include a statement that the unit complies with the requirements established by the appropriate standard.

Other Observations

Philosophically, I have always had an issue with the requirement to deliver the high purity water we require for drinking and cooking when we actually only consume about 1% of what comes into the house. Without dual piping systems in the home, our choices are limited, however.

If bottled water manufacturers’ labels confirm that the product is treated by reverse osmosis or distillation, this product should be acceptable. On the other hand, the plastic,

The Next Drinking Water Contamination Issue?
By Peter S. Cartwright, PE

BPA, is now being discontinued, and its replacement, BPS, is under suspicion for causing endocrine system problems, And then there is the solid waste issue.

My suggestion is that if you want to take your drinking water with you, get a stainless steel water bottle and fill it up from your own RO unit or distiller when you leave your residence.

Conclusions

So, what does the future hold?

First, remember that a human health link to PPCPs in drinking water has NOT YET been established.

My personal predictions are:

- 1) The concentrations of PPCPs will increase in our water supplies.
- 2) A risk to human health from these will eventually be identified.
- 3) The immediate (?) solution will be to put a drinking water treatment system in each home, initially consisting of a POU RO or distillation unit, as described above.
- 4) A fundamental change to the way we use our water supplies may be required: accessing only this treated water for our individual drinking and culinary requirements.
- 5) More effective and less expensive wastewater treatment technologies will be developed to facilitate reuse.
- 6) People will become better water stewards: installing dual piping systems, collecting and using rainwater and graywater for non-potable applications.
- 7) There will be greater use of wetlands and innovative processes for treating and reusing wastewater from virtually all sources.

Summary

In this writer's opinion, the vast (and still growing) array of contaminants in our drinking water will inevitably result in the identification of new health risks. In the meantime, the concerned consumer can reduce self exposure with a simple, economical water purification unit feeding a single tap dedicated to drinking and culinary purposes.

Additionally, we must all recognize the limits of our finite water supply and conserve, collect and reuse.

As a disclaimer, I have no monetary interest in the sales of any water treatment components, systems or processes. The preparation of this article has been motivated solely by my concern for the health of those of us now on this planet and those who will follow.

Just as the knowledge of water contamination has resulted in the elimination of virtually all water-borne pathogens and mitigated the exposure to heavy metals, arsenic, etc., we need to develop a science and risk-based understanding of the PPCP issue in order to determine how to most effectively minimize its effect.

The Next Drinking Water Contamination Issue?

By Peter S. Cartwright, PE

Creativity and innovation are human characteristics, and once we know the chemistry of the problem, I am confident that new products, processes and improvements will come on the scene.

These are exciting times for the water/wastewater treatment industry. We have only begun to scratch the surface and the best is yet to come!

References

- 1) ANH-USA. June 4, 2013
- 2) <http://www.ewg.org/skindeep/2004/06/15/exposures-add-up-survery-results/>
- 3) <http://newsnetwork.mayoclinic.org/discussion/nearly-7-in-10-americans-take-perscription-drugs-mayo-clinic-olmsted-medical-center-find/>
- 4) <http://www.statista.com/statistics/238702/us-total-medical-prescriptions-issued/>
- 5) www.wisconsinwatch.org/2013/05/13/studies-endocrine-disruptors-in-common-in-mn-waters/
- 6) Hoellein, Timothy. 24 February 2016. "Wastewater Treatment Plants Significant Source of Microplastics in Rivers, New Research Finds." American Geophysical Union.
- 7) <https://owi.usgs.gov/vizlab/microplastics/>
- 8) http://en.wikipedia.org/wiki/Great_Pacific_garbage_patch. 7 June 2017.
- 9) <https://topdocumentaryfilms.com/the-disappearing-male/>
- 10) Environ Health Perspect. 2005 Oct;113(10):1295-8.
- 11) Vandenberg LN., Colborn T, Hayes TB, Heindel JJ, Jacobs DR, Lee DH, Shioda T, Soto AN, vom Saal FS, Welshons WV, Zoeller RT, Myers JP. June 2012. Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses. Endocrine Reviews. 33(3):378-455.
- 12) Gore AC, Chappell VA, Fenton SE, Flaws JA, Nadal A, Prins GS, Toppari J, Zoeller RT. December 2015. Executive Summary to EDC-2: The Endocrine Society's Second Scientific Statement on Endocrine-Disrupting Chemicals. Endocrine Reviews. 36(6):593-602.
- 13) Hu XC, Andrews DQ, Lindstrom AB, Bruton TA, Schaidler LA, Grandjean P, Lohmann R, Carignan CC, Blum A, Balan SA, Higgins CP, Sunderland EM. Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants. Environmental Science & Technology Letters. August 9, 2016.
- 14) <http://comments.ngwa.org>.
- 15) <http://www.cdc.gov/exposurereport>.
- 16) Columbia University's Mailman School of Public Health. "Prenatal exposure to common household chemicals linked with substantial drop in child IQ." ScienceDaily. ScienceDaily, 10 December 2014. www.sciencedaily.com/releases/2014/12/141210140823.htm.
- 17) Virginia Tech. "Common household chemicals lead to birth defects in mice, research finds." ScienceDaily. ScienceDaily, 17 June 2017. www.sciencedaily.com/releases/2017/06/170617073635.htm.

- 18) Washington University in St. Louis. "Earlier menopause linked to everyday chemical exposures." ScienceDaily. ScienceDaily, 28 January 2015
www.sciencedaily.com/releases/2015/01/150128141417.htm.
- 19) www.congress.gov/bill/114th-congress/senate-bill/1014
- 20) www.regulations.gov/document?D=EPA-HQ-OPPT-2010-0572-0137
- 21) Mohammad Feisal Rahman, et al. Advanced Oxidation Treatment of Drinking Water: Part 1. Occurrence and Removal of Pharmaceuticals and Endocrine-Disrupting Compounds from Lake Huron Water. *Ozone: Science & Engineering*, 32; 217-229
- 22) M. F. Rahman, et al. Endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs) in the aquatic environment: implications for the drinking water industry and global environmental health. *Journal of Water and Health*. 07.2 2009
- 23) Gregory H. LeFevre et al. Occurrence of Neonicotinoid Insecticides in Finished Drinking Water and Fate During Drinking Water Treatment. *Environmental Science & Technology Letters*, April 2017 DOI: 10.1021/acs.eslett.7b00081
- 24) Shane Snyder, et al. Pharmaceuticals in the Water Environment. NACWA (pp. 22, 23)
- 25) World Health Organization 2012. Pharmaceuticals in drinking-water. ISBN 978 92 4 150208 5 (p. 28)
- 26) T. U. Kim, G. Amy, J. E. Drewes. Rejection of trace organic compounds by high-pressure membranes. *Water Sci Technology* 2005; 51:335-44 16003994
- 27) Rosa Boleda, et al. Winning the Wastewater Drug War. *Pollution Engineering*, May 2010

BIOGRAPHY

Peter Cartwright entered the water and wastewater treatment field in 1974 and has had his own consulting engineering company since 1980.

He is a graduate of the University of Minnesota in Chemical Engineering, and is a registered Professional Engineer in that state. He has authored over 300 articles, written several book chapters, presented more than 300 lectures around the world and holds several patents.

Peter is a recipient of both the Award of Merit and Lifetime Member Award from the Water Quality Association, and is the Technical Consultant to the Canadian Water Quality Association. He was the 2016 McEllhiney Distinguished Lecturer for the National Ground Water Research and Educational Foundation.

He lives in Bloomington, MN, and can be reached at peterscartwright@gmail.com.

His website is www.cartwright-consulting.com.