Executive Summary

Chemicals of Concern

Iowa's First Field Research Area for Emerging Contaminants

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Emerging Contaminants: Chemicals of Concern

As Americans, we use a wide variety of chemicals in our homes and our jobs, whether we work at factories, on farms, or in offices. Recent research has shown compounds not previously considered contaminants are present in the environment.[1] These include human and veterinary prescription drugs, diagnostic agents, hormones, cosmetics, dyes, preservatives, detergents, and numerous other organic compounds. There are increasing concerns about the potential environmental effects that may occur from such "emerging contaminants" (ECs). ECs are defined as:

> Any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment, but has the potential to enter the environment and can cause suspected adverse ecological and/or human health effects. In some cases, release of emerging chemical or microbial contaminates to the environment has likely occurred for a long time, but may not have been recognized until new detection methods were developed. In other cases, synthesis of new chemicals or changes in use and disposal of existing chemicals can create new sources of emerging contaminates.[2]

Most ECs are not routinely monitored. Indeed, water-quality monitoring in the United States is largely driven by regulations of the Clean Water Act and Safe Drinking Water Act. Over the last three decades, much of the water-quality monitoring work has focused almost exclusively on the conventional "priority pollutants," however this is only one piece of the larger environmental puzzle.[3] Recently ECs have begun to be examined in limited studies using newly developed laboratory analytical methods and techniques allowing detection at much lower levels. Furthermore, the possibility that environmental contaminants may be complex mixtures that can interact synergistically or antagonistically has increased the need to understand ECs.

In order to minimize ecologic effects from ECs, it is essential to understand how a contaminant moves and is altered in the environment. Investigations of processes influencing transport (e.g. sorption, dispersion, degradation, etc.) require a systematic evaluation of a variety of hydrologic, landscape and anthropogenic factors. The purpose of this paper is to provide a short synopsis of ECs as potential contaminants of concern and to highlight an 8-km reach of Fourmile Creek in central Iowa as an ideal research site to investigate the transport, fate and effects from an urban source of ECs.

Possible Effects of ECs: Endocrine Disruption and Antibiotic Resistance

The potential toxicological behavior from the environmental occurrence of ECs and mixtures of ECs are largely unknown. In particular, the effects of ECs on aquatic organisms are difficult to measure because concentrations of these compounds are generally low (nanogram per liter range) and, over the life of the organism produce no acutely toxic effects. However, detrimental effects to organisms from ECs may be subtle and go unnoticed until some cumulative threshold is reached. In recent years, the presence and effects of endocrine disrupting compounds (EDCs) in the environment has become an important issue.[4] The endocrine system is the “key control system” of most organisms.

The presence of low concentrations of some chemicals in the environment (e.g. natural and synthetic hormones, alklyphenols, pesticides, solvents and pharmaceuticals) could affect or damage the function of the endocrine system.[5] For example, nonylphenol (a detergent degradation product found in laundry and dish detergents), and AHTN (a polycyclic musk found in perfumes, laundry products, air fresheners and cosmetics) have been shown to disrupt reproduction and growth in fish by affecting endocrine systems.[6] A variety of ECs have been shown to bioaccumulate in fish tissue.[7] Data from laboratory experiments suggest that EDCs in the aquatic environment may impact the reproductive health of fish populations.[8] Linking EDCs to observed changes in fish populations, however, remains an open challenge.[9] As the ecological risk assessment of EDCs is in its infancy stage, less is known about potential effects to other aquatic species, yet early research suggests effects to aquatic organisms are possible.[10]

Antibiotics are an important class of pharmaceuticals and their prevalence in the last 60 years has brought dramatic and often even “miraculous” progress in fighting bacterial infections in humans and animals. In livestock farming, sub-therapeutic doses of antibiotics are often used to promote more rapid animal growth.[11] Despite their widespread use, antibiotics have only recently received attention as environmental contaminants. However, the increase of resistant bacterial strains and the spread of bacterial resistance have become a worldwide concern.[12] Concerns also exist for antibiotic use and increasing antibiotic resistance in livestock confined feeding operations.[13] Many antibiotics are only partially metabolized after administration to humans or animals.[14] Concentrations of select antibiotics in animal manure have been reported at milligrams per liter levels (they are typically reported at parts per billion levels).[15]

Antibiotics can reach streams and ground water via a variety of mechanisms and the potential for the aquatic environment to promote or maintain antibiotic resistance is largely unknown. Some chemicals, such as triclosan (an antimicrobial disinfectant found in many liquid soaps, dishwasher powders and plastics), are suspected of increasing the antibiotic resistance of bacteria in the environment,[16] reducing algae diversity in streams,[17] and affecting natural ecosystem functions such as soil microbial activity.[18] In addition, research has shown effects of mixtures of antibiotics to aquatic organisms.[19]

Evolution of Fourmile Creek as a Research Site for ECs

Following a national stream reconnaissance study,[20] water samples were collected in 2001, upstream and downstream of select towns and cities in Iowa during low-, normal- and high-flow conditions to determine the contribution of urban centers to concentrations of ECs in streams under varying flow conditions.[21] This study found the number of ECs detected decreased as streamflow increased from low- (51 ECs detected) to normal- (28) to high-flow (24) conditions. Fourmile Creek near Ankeny, Iowa, was initially sampled for ECs during this study and results showed a strong gradient in EC detections during low-flow conditions between samples collected upstream of Ankeny (three ECs detected) compared to samples collected downstream (31 EC detected).

The initial EC results from Fourmile Creek,[22] led to including this stream as part of collaborative research between the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency to better understand the fate of ECs following their discharge from wastewater treatment plants (WWTPs).[23] This research involved collecting four samples at each of 10 WWTPs across the nation: upstream of the WWTP, at the WWTP where effluent was being discharged into the stream, at a location in close proximity downstream of the WWTP, and at a location farther downstream from the WWTP. All samples were measured for 110 different ECs. Between 28 and 50 ECs were found in treated wastewater effluent being discharged to streams.[24] The similarity in chemical concentrations between WWTP effluent and proximal downstream sampling points clearly shows the contribution of WWTPs to EC concentrations in streams. Additional knowledge gained from Fourmile Creek during this study included:

1. the ECs detected in Fourmile Creek during the previous study[25] were primarily derived from the Ankeny WWTP (see Figure 1),
2. there are significant reductions of the number of ECs detected and total EC concentrations through the 8.4 km study reach (Figure 1),
3. ECs vary in their type of transport (conservative versus nonconservative) through the study reach (see Table 1),
4. at low-flow conditions, greater than 90 percent of the streamflow is derived from WWTP discharge.[26]

Figure 1. Compounds and Concentrations of Emerging Contaminants at Various Locations of Fourmile Creek

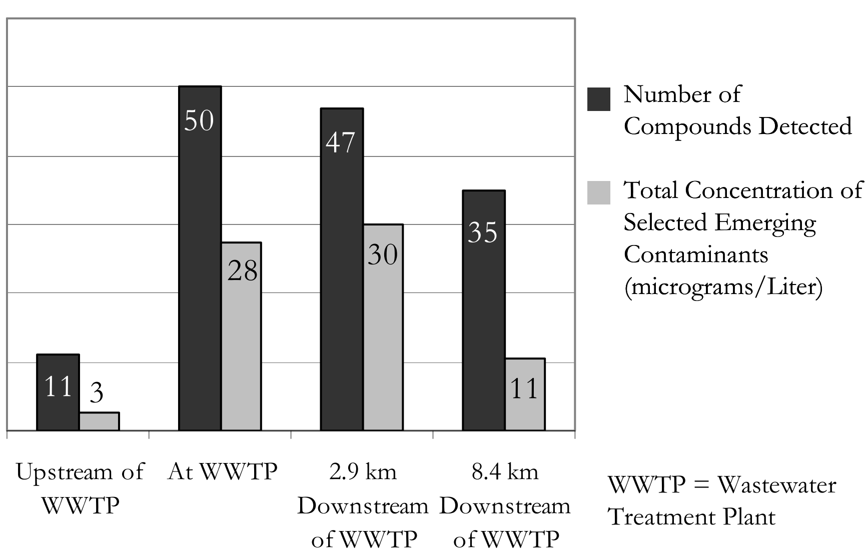

Table 1. Selected Compounds Detected, Primary Use, Reporting Level, and Concentration from Samples Collected at Various Locations of Fourmile Creek

Compound	Primary Use	Reporting Level (μg/L)	Upstream of WWTP	WWTP Effluent	8.4 km Downstream of WWTP
			(concentration in (μg/L)		
Cimetidine	Antacid	0.012	undetected	0.123	0.107
Dehydronifedipine	Antianginal	0.015	undetected	0.202	0.018
Diltiazem	Antihypertensive	0.016	undetected	0.053	0.029
Diphenhydramine	Antihistamine	0.015	undetected	0.218	undetected
Sulfamethozole	Antibiotic	0.064	undetected	0.589	0.321
Tonalide (AHTN)	Fragrance, musk	0.500	undetected	2.300	0.700
Trimethoprim	Antibiotic	0.013	undetected	0.353	0.093

In 2003, the USGS EC Project[27] was searching for a real-world setting to investigate the complex in-stream processes (e.g. dilution, sorption, degradation, dispersion, etc.) that can affect ECs following their discharge from a WWTP and determining if such input is having an effect on the aquatic ecosystem. Such research requires the integration of multi-disciplinary efforts at a carefully selected field site. Knowledge gained from previous research[28] and other unique aspects of Fourmile Creek led to its selection as a field setting to help answer these important research questions. Critical aspects of Fourmile Creek include the following:

1. A single source WWTP effluent-dominated stream. This allows for the examination of EC concentrations as water moves downstream without complications from additional inputs.

2. Data documented the input of a wide variety of ECs from WWTP discharge. Previous research found between 3 and 10 ECs present upstream of the WWTP and between 30 and 50 downstream.[30]

3. Small basin size (less than 160 km^2 size). This facilitates an increased understanding of the transport and fate of environmental contaminants.

4. Relatively simple flow system. Little to no ground-water or surface-water inputs to streamflow exist in Fourmile Creek during normal flow conditions. Thus, any changes in EC concentrations observed downstream can be attributed to in-stream processes.

5. Data documented that ECs vary in their type of transport. Undefined processes are taking place within the stream that affect EC concentrations.

6. The WWTP uses a treatment technology (conventional activated-sludge) typical of many towns and cities across the United States. Thus, the source is representative of many similar sources in the United States.

7. The hydrogeologic setting (low-gradient stream, glaciated deposits, rowcrop agriculture) is typical of the Midwest.

8. A low-head dam exists approximately 2 km upstream of the WWTP outfall. The dam provides a physical barrier to fish migration. Thus, comparisons in fish community structure and fish health assessment can be made to more accurately determine potential effects from the input of ECs by the WWTP. Research has found a range of abnormalities in fish populations (vitellogenin induction in males and juvenile females, development of oocytes in testes, etc.) downstream of WWTPs.[31]

9. A major change is anticipated to the primary source of ECs in the system. Around 2010, the WWTP is scheduled to close. This closure provides a unique opportunity to examine how a stream and aquatic biota react to the removal of the primary source of ECs and allows a novel "before" and "after" assessment not been previously available in EC research.

Future Work

Future work on ECs will involve not only the occurrence of these compounds, but also their fate, transport and possible effects in the environment. Several large-scale studies in the United States by the USGS Toxic Substances Hydrology Program have already documented the occurrence of ECs in the environment.[32] These studies have shown that a wide variety of ECs are commonly detected in streams, streambed sediment, and ground water as complex mixtures of compounds. Other studies have documented the occurrence of ECs globally.[33] Many of these same EC compounds have been detected in a study of Iowa's streams.[34] Indeed, the data on ECs collected at Fourmile Creek are consistent with similar national studies. However, the effects of long-term, low-level exposure to these mixtures of emerging contaminants on aquatic life and humans are currently unknown. Research on the effects of ECs in the environment is only in the beginning stages.

The field research site established at Fourmile Creek will continue to build a framework for better understanding of the transport, fate, and effects of ECs in the environment. One goal of the field research site at Fourmile Creek is to move beyond documenting the occurrence of these compounds to examine what happens to these compounds once they enter the environment and their potential effects to aquatic ecosystems.

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