



Scope of Contaminants of Emerging Concern in National Parks

Natural Resource Report NPS/NRPC/NRR—2008/032



ON THE COVER

Rainbow over Upper Falls of the Yellowstone River, Yellowstone National Park, WY
Photograph by: Rebecca A. Landewe (2007)

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Contents

	Page
Figures	iv
List of Acronyms	v
Executive Summary	vii
Acknowledgements	viii
Introduction	1
Effects of Contaminants of Emerging Concern in the Environment	3
Sources of Contaminants of Emerging Concern	3
Preventing EC Contamination	7
Extent of ECs in National Parks	8
Pacific West Region	9
Intermountain Region	10
Southeast Region	10
Midwest Region	11
Northeast Region	11
Alaska Region	11
Regional and National Studies	11
Future Research Needs	15
Literature Cited	17

Figures

	Page
Figure 1. Map of National Park Service regions and locations where research has been conducted in National Park Service units.....	8
Figure 2. Parks labeled are in the vicinity of a USGS monitoring site included in Kolpin et al. (2002) study on organic wastewater contaminants.....	12
Figure 3. Map of largest National Park units identified by Rattner et al. (2005) as lacking ecotoxicological data.	13
Figure 4. Map of largest National Park units identified by Rattner et al. (2005) as being located in watersheds with “more serious water quality problems,” with a “high vulnerability to pollution,” and lacking data.....	14

List of Acronyms

EC	emerging contaminants
EDC	endocrine disrupting compounds
EPA	Environmental Protection Agency
NPS	National Park Service
NB	National Battlefield
NHP	National Historical Park
NHS	National Historic Site
NL	National Lakeshore
NM	National Monument
NP	National Park
NRA	National Recreation Area
NRRA	National River and Recreation Area
NS	National Seashore
OWC	organic wastewater contaminants
PPCP	pharmaceuticals and personal care products
USGS	U.S. Geological Survey
WWTF	wastewater treatment facility

Executive Summary

One of the fundamental purposes of the National Park Service is to conserve the natural state of National Parks such that they remain unimpaired for future generations. In recent years, a number of studies have reported that a group of compounds broadly categorized as contaminants of emerging concern can be found in many National Parks across the country. The presence of these emerging compounds of concern in urban and remote areas of National Parks raises several questions regarding the extent of contamination, the potential environmental impact, and how they might influence the ability of the National Park Service to fulfill its mission. There is a growing national interest among the scientific community to ascertain the sources, transport, fate, and environmental effects of contaminants of emerging concern, such as pharmaceuticals, personal care products, and endocrine disruptors. There are numerous studies documenting emerging contaminants below wastewater treatment facilities, a few articles that suggest human, natural, or aerial transport into remote and mountainous regions, and a growing body of research identifying some of the impacts of these compounds on aquatic communities. Additional research is also being conducted on identifying methods to reduce or remove emerging contaminants in municipal wastewater treatment plants. While the existing literature on emerging contaminants provides a significant amount of insight, overall, there is still a need for a deeper understanding on the transport, fate, and metabolic impacts of contaminants of emerging concern in the environment. Studies and research in National Parks have been primarily limited to areas that receive treated domestic sewage; however, there is evidence that remote environments in parks contain emerging contaminants of concern. This review summarizes the state of the current knowledge on emerging contaminants, identifies specific studies that have occurred in or near National Parks, and highlights areas identified by researchers as needing additional investigation. The current body of research leaves several unanswered questions regarding emerging contaminants and National Parks, which are suitable for a focused and well-designed servicewide research project to address the source and transport of these compounds into relatively pristine and sensitive aquatic ecosystems. After gaining a better understanding of the presence and effect of emerging contaminants on National Park resources, managers can begin to develop management plans that consider these compounds. The result of a servicewide research project could help in assessing threats to vulnerable areas and inform the development of measures to reduce or remove sources of contamination.

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Introduction

Purpose and Objectives

The National Park Service (NPS) manages units across the country that are exposed to a myriad of potential sources of contaminants of emerging concern (ECs). To date, some effort has been focused on detecting, quantifying, and assessing the threat of ECs in NPS units. The goals of this review are to summarize what is currently known about ECs in National Parks, with specific focus on endocrine disrupting compounds (EDCs), and to identify areas where additional attention may be needed.

Defining Contaminants of Emerging Concern

In the May 2007 issue of *Water Resources Impact* magazine, Battaglin et al. define contaminants of emerging concern as “any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has been recently detected in the environment” (Battaglin et al. 2007). These compounds may not themselves be emerging, but the concern about the environmental impact of these compounds, some of which have been in existence for quite some time, is emerging. As noted in a paper by Daughton (2003), the term “emerging” refers to old pollutants with new concerns and new pollutants with unknown issues.

Other researchers use several different terms and acronyms to identify the numerous compounds that can be broadly described as contaminants of emerging concern. While there may be nuances in how each author defines the terms emerging contaminants, emerging contaminants of concern, and contaminants of emerging concern, they are often used synonymously and interchangeably. For the purposes of this review, the acronym EC will be used to generally represent *new or existing compounds with emerging concerns*.

There are two other categories also used to refer to many of the same compounds captured under the broader EC definition:

Pharmaceuticals and Personal Care Products (PPCPs)

Pharmaceuticals and personal care products are often lumped together in a subcategory of ECs. Because pharmaceuticals are designed to be biologically available and physiologically active in small doses, very low concentrations could potentially have significant effects on the aquatic environment. The Environmental Protection Agency (EPA) is focusing research efforts on PPCPs and has a website devoted to summarizing the issues (www.epa.gov/ppcp).

Endocrine Disrupting Compounds (EDCs)

Some ECs and PPCPs are suspected of having effects on the endocrine system. These endocrine disrupting compounds have come under intense scrutiny because extremely small doses that may be undetectable by common sampling methods could have significant effects on the reproduction, growth, and development of organisms. However, not all ECs and PPCPs are endocrine disruptors. There are many unanswered questions

about EDCs, including what concentrations are biologically relevant and the effects of complex mixtures.

The widespread use of ECs for personal, agricultural, and industrial purposes has resulted in a ubiquitous presence of these compounds in the environment. Researchers have documented the ability of many ECs, notably including many PPCPs and EDCs, to pass through wastewater treatment facilities (WWTFs) and enter the aquatic environment (Kolpin et al. 2002). The literature also documents the presence of ECs in rural watersheds—where pesticides, hormones, and antibiotics are used in plant and animal agriculture—and in remote watersheds where some ECs migrate via atmospheric transport and deposition (Daly and Wania 2005; Daly et al. 2007). As scientists better understand how ECs disperse in the environment, others are identifying additional compounds of concern. The growing list of ECs makes the problem of linking cause and effect more difficult in field studies where, unlike the controlled laboratory environment, there may be complex mixtures of ECs and numerous confounding factors. Despite these difficulties and complexities, the scientific community along with government agencies is working hard to better understand the transport, fate, and effects of these compounds in the environment.

Effects of Contaminants of Emerging Concern in the Environment

The fate of ECs in the environment and how they impact aquatic biota is not well-understood, though recent research findings are continually adding to the cumulative body of knowledge. Some scientists have focused on compound-specific research on the distribution and impact of ECs. For example, several studies have attested to the ubiquity of perfluorinated compounds in the environment, documented their accumulation in tissues and organs, and identified impacts on hormonal function as an area for additional research (Giesy and Kannan 2002; Oakes et al. 2005). EPA's ECOTOX database (www.epa.gov/ecotox/) is one tool scientists can use to search for publications on chemical-specific toxicological effects on terrestrial and aquatic life. Building upon the research focused on specific compounds, others have evaluated the endocrine disrupting properties of the chemical mixtures found in the environment. In effluent from a WWTF, one would expect to find not just one but many ECs that could have additive or synergistic effects. Scientists recently presented data documenting the significant changes that the mixture of endocrine disruptors present in WWTF effluent can have on the sex ratios of fish (Vajda et al. 2007) and bullfrog populations (Propper et al. 2007).

In addition to direct impacts on sexual development, there is evidence that EDCs can have indirect or behavioral impacts on aquatic life. Propper et al. (2007) found that the pesticide endosulfan impacts the ability of amphibians to produce and detect pheromones. The ability of fathead minnows exposed to environmentally relevant concentrations of estrogenic compounds were not as successful in competing with unexposed males for females and spawning sites (Schoenfuss et al. 2007). While not a direct impact on the gonadal differentiation, these research findings suggest that such changes could result in negative impacts on reproductive fitness.

Sources of Contaminants of Emerging Concern

ECs can come from point sources, such as in a municipal wastewater discharge, or nonpoint sources, like leaking septic systems and runoff from agricultural land or urban areas. Each source is most likely discharging multiple types of ECs, and for each EC there may be numerous potential sources. Additionally, each compound may breakdown into a suite of degradates or metabolites, most of which have unknown fates or effects in the environment.

Wastewater Treatment Facilities and Septic Systems

Wastewater treatment facilities are a frequent source of ECs, PPCPs, and EDCs. Kolpin et al. (2002) conducted a landmark study of organic wastewater contaminants (OWCs) that included pesticides, PPCPs, and industrial chemicals. In this national study, the U.S. Geological Survey (USGS) evaluated streams from 139 monitoring locations in 30 states for OWCs and found that 80% contained one or more OWCs. Of all the classes of compounds that were analyzed, steroids, detergent metabolites, and plasticizers made up about 80% of the total concentration. Nonprescription drugs were more frequently detected than antibiotics, hormones, and other prescription drugs. Approximately 35% of the compounds are suspected of being endocrine disruptors. While the individual concentrations of the OWCs may have been small, the combined

effect of these endocrine disruptors is potentially significant. The authors cited research showing that exposure to low levels (<0.001 ug/L) of some hormones can have significant effects on aquatic life. Given this data and other research on the presence of ECs in WWTF effluent, it is reasonable to assume that most, if not all, National Parks that have a WWTF discharge or are downstream of a domestic WWTF have ECs in their waterways, to which aquatic biota are being exposed and potentially affected. Septic systems, although more dispersed in a watershed, can also contribute PPCPs to the environment through nonpoint source runoff from the drain field.

Biosolids

Biosolids, a byproduct of the wastewater treatment process, are another potentially significant pathway for transport of ECs into the environment. According to one national survey (NEBRA 2007), approximately half of the biosolids produced in the United States are land applied and thus have the potential to enter waterways via surface runoff. Kinney et al. (2006) analyzed biosolids from municipal wastewater treatment plants and found a total of 55 OWCs in the nine samples taken from seven states, with a minimum of 30 found in each sample. The authors concluded “that biosolids are highly enriched in OWCs (as mass-normalized concentrations) when compared to effluent or effluent-impacted water.” There are two known National Parks that may be impacted by the use of biosolids. Spectacle Island, part of Boston Harbor Islands National Recreation Area, was capped with 65,000 cubic yards of biosolids as part of the effort to convert the landfill to a recreation area. Additional research may be warranted to determine whether the biosolids cap could be a potential source of ECs to the underlying groundwater or into Boston Harbor. Grant-Kohrs Ranch National Historic Site accepts biosolids and, as such, may be introducing a source of ECs into the park.

Agricultural Land Uses

Research indicates that several common pesticides used in row crop agriculture have endocrine disrupting properties and are introduced into the local aquatic environment through stormwater runoff or to more remote watersheds through air transport and deposition. One report from the USGS National Water Quality Assessment Program, which assessed ten years of sampling data from sites across the U.S., provides clear documentation that agricultural pesticides run off into local waterways (Gilliom 2006). Other research, which will be discussed in greater detail below, indicates that atmospheric transport has resulted in the wide distribution of pesticides in remote watersheds (Blais 2005, Daly et al. 2007, Hageman et al. 2006, WACAP 2004). Parks that have agricultural uses within their watershed or airshed, or that use pesticides in their resource management, may be at risk of finding ECs in their waterways.

Pharmaceuticals (e.g., hormones and antibiotics) used in livestock operations and confined animal feeding operations can travel to local waterways through nonpoint source runoff. Meyer et al. (2004) found frequent detections of antibiotics, including chlortetracycline, sulfamethazine, and lincomycin, in wastewater lagoons at swine feeding operations, which indicates that these compounds can either resist degradation or revert back to the parent compound after being excreted. Natural steroid hormones and hormones used for veterinary purposes (e.g., growth hormone, birth control) have also been found in agricultural watersheds and they may impact aquatic life. Hutchins et al. (2003) found significant concentrations of natural estrogens in

wastewater lagoons at swine feeding operations. In a separate study, Hutchins et al. (2007) found evidence to suggest the concentration of these estrogens significantly decreases with subsequent treatment stages, indicating that the level of treatment undergone by the land applied manure could significantly affect the concentrations of estrogens that could run off into local waterways. This information is important for park managers to consider if their resource management plans include the land application of manure from animal feeding operations.

Industry

Industrial manufacturing may also be a source of ECs and, as such, may be of concern to those parks downstream of industrial WWTF discharges. Examples of ECs that are suspected endocrine disruptors include perfluorinated compounds, phthalates found in plasticizers, and surfactants such as nonylphenol. Perchlorate, a component of rocket fuel, is one industrial compound utilized by the U.S. Department of Defense (DoD) that is suspected of having endocrine disrupting effects on the thyroid system. The DoD has used perchlorate as a solid propellant since the 1940s and currently uses it in 14% of munitions (DoD 2007). Although the DoD currently has strict procedures to prevent releases, historical handling practices of the compounds resulted in releases to the environment, like at Lake Mead National Recreational Area, Nevada. The DoD Materials of Evolving Regulatory Interest Team (MERIT) placed perchlorate on their Action List to develop risk management options (DoD 2007).

Natural Sources

In addition to anthropogenically created ECs and potential EDCs, there are natural sources of these compounds in the environment. Pulp mill effluents release significant quantities of natural phytoestrogens from plant material, including β -siterosterol (which has been shown to be estrogenic in fish) (Tremblay and Van der Kraak 1998). In addition to the production of perchlorate for use in rocket fuel and munitions as noted above, scientists have documented perchlorate as naturally occurring in the arid western regions of the United States (Rajagopalan et al. 2006). Plants, wildlife, and livestock (Kolodziej and Sedlak 2007) contribute natural steroid hormones to waterways, which could potentially have endocrine-disrupting effects on aquatic life. The waterways in parks with grazing wildlife, cattle, horseback riding, or unmanaged populations of feral pigs, goats, or horses may be at risk of EC contamination through nonpoint source runoff or direct deposition into water bodies. Unfortunately, the background concentrations of ECs from natural sources are not well-known and have been identified as an area where additional study is needed (Geschwind et al. 1999).

Transport of ECs to Remote Areas

In remote areas, determining the source of EC contamination is more difficult. ECs can be deposited directly in remote areas by humans or wildlife, or transported great distances atmospherically from sources far from the point of detection. Activities like swimming or angling, when users are likely to have personal care products (e.g., sunscreen, fragrances, DEET) on their skin, can introduce contaminants into the aquatic environment via direct human contact. The use of boats, all-terrain vehicles, and snowmobiles can result in the deposition of harmful byproducts from the combustion of fossil fuels (Ingersoll 1999). Backcountry campers and the

wastes they leave behind might also serve as a source. Human urine and defecation products are scattered about the landscape and, sometimes, inadequately treated in pit toilets. Outdoor recreators have also been known to use soaps and/or detergents in remote water bodies for bathing or cleaning dishes. These soaps may contain the antimicrobial agent triclosan, which is suspected of having effects on the thyroid system. Although the introduction of these compounds into remote streams or lakes may be infrequent, some of them may be very persistent in the environment, and if they are introduced during a vulnerable time period (e.g., developmental time period after eggs hatch), even very small concentrations could result in endocrine disrupting effects.

For this type of nonpoint source, especially the impact of individual visitors in remote areas, there is a paucity of available research, but a few studies have evaluated the potential risk. In Kakadu National Park, Australia, there was a growing concern about the potential impact on park resources of EDCs introduced by swimmers at waterfall plunge pools and from a small wastewater treatment plant. Researchers conducted “tier 1” screening tests (Yeast Estrogen Screen, YES) to measure estrogenicity of park waters. Although they found some degree of estrogenic activity in their samples, they compared these values to current literature values and concluded that the levels observed during this preliminary research did not warrant immediate concern about the threat to aquatic life in the park (Hogan et al. 2005). This study suggests that ECs may not be of significant concern in all locations. The number of swimmers, the available dilution and the flow of the receiving waters are factors that influence the potential impact of swimmers on EC concentrations in remote areas. Results from this research indicate that screening tests like the YES can be a helpful tool in determining risk and the need for additional investigations, which could be useful in establishing an EC monitoring program to evaluate the potential risks within the National Park system.

Sometimes ECs are found far from the sources, particularly in the case of pesticides that are transported atmospherically. There are several environmental and chemical factors that affect the distance a compound can travel and that determine where the compound is eventually deposited. Blais (2005) describes that the weight, volatility, vapor pressure, and condensation temperature of the contaminant all factor into whether or not it is likely to travel atmospherically. Environmental factors that affect the deposition of contaminants include air currents, quantity and type of precipitation, snowpack accumulation, altitude, and latitude. In their critical review of research from around the globe, Daly and Wania (2005) found that factors such as local and regional wind patterns, dominant form of precipitation, temperature inversions, proximity to sources (e.g., local use of pesticides), and weight and volatility of the compound of concern all affect the air transport and deposition patterns. They found that concentrations of some compounds decreased with elevation, others increased, and still others showed no clear correlation.

Site specific examples of the principles discussed by Blais (2005), Daly and Wania (2005) include a study from the montane region of Costa Rica, where researchers found concentrations of several pesticides at high altitudes downwind of an active banana plantation. They modeled the fate of contaminants and found that the field results supported the model’s prediction that pesticides accumulate in the tropical mountains because of “enhanced precipitation scavenging at high elevations” (Daly et al. 2007). Similarly, the Canadian Northern Contaminants Program

(Blais 2005) and the National Park Service's Western Airborne Contaminants Assessment Project (WACAP), discussed in detail below, further document the effect that cold temperatures, northern latitudes, high altitudes, and snowpack accumulation can have in determining the distribution of ECs (Hageman et al. 2006). The phenomenon where certain compounds have shown a tendency to accumulate in colder parts of the globe is referred to as "cold fractionation" (WACAP 2004). The research suggests that the potential for air transport and deposition will vary from site to site, but, considering the climatic patterns and surrounding land use, is important for determining the potential threat of ECs in montane parks.

For other vectors of transport, such as wildlife, the ability of the compound to bioaccumulate is important in considering the global distribution of certain persistent toxics, such as dichloro-diphenyl-trichloroethane (DDT), polychlorinated biphenyls (PCBs), and chlordane. Migrating wildlife can carry significant concentration of ECs to remote areas of the globe. Blais (2005) cites several examples where migrating salmon and seabirds have served as vectors in transporting PCBs, DDT, other organochlorine compounds, and/or mercury to remote lakes in Alaska and Canada.

Preventing EC Contamination

With the increasing concerns about EC contamination has come an interest in finding ways to prevent contamination at the source. In February 2007, the Office of National Drug Control Policy issued new drug disposal guidelines to educate consumers on the proper method of disposing unwanted, unused, or expired prescription medications (ONDCP 2007). Communities, universities, and other organizations have sponsored one-day disposal events to collect unwanted prescription drugs, and some pharmacies have begun to place disposal bins in their stores to encourage proper disposal by customers. These efforts reduce the source of pharmaceuticals, thus preventing some quantifiable amount from entering the wastewater.

At the other end of the pipe, researchers investigating the ability of a WWTF to remove ECs from wastewater have found that the removal effectiveness varies with the type of technology used in the treatment process. One USGS study found that effluent from trickling-filter WWTFs, one type of conventional treatment system, contained greater concentrations of OWCs than the effluent from other types of WWTFs in the study area (Lee et al. 2005). Research on engineered treatment wetlands also indicates that these systems provide little benefit in reducing concentrations of pharmaceuticals in effluent (Sedlak et al. 2004). Advanced treatment systems can significantly reduce the concentrations of ECs, but several factors can influence the effectiveness. Research by Snyder et al. (2006a) shows that membrane filtration is effective in removing many types of ECs; however, results depend on the type of membrane and the target compounds of concern. They also found that activated carbon systems can be up to 90% effective in removing ECs, but the presence of natural organic matter can negatively impact the results. Reverse osmosis and nanofiltration were highly successful in removing target compounds, but the compounds were then found at concentrated levels in the brine, thus raising the question of how to safely dispose of this waste stream. Ozone is also an extremely effective oxidant for decreasing the concentrations of ECs in treated wastewater. Certain compounds may require a higher dose to oxidize, which may be cost prohibitive for many treatment facilities. Hydrogen peroxide, although it can increase the rate of oxidation when added to the ozone

treatment process, did not show an overwhelmingly positive benefit to the process of removing ECs (Snyder et al. 2006b).

Extent of ECs in National Parks

To date, the majority of EC research has focused on downstream impacts of treated wastewater effluent, and as such, the studies are centered in more urban areas. Therefore, the majority of what is known about ECs in National Parks is confined to those that are influenced by WWTF effluent. However, there are also several studies documenting the ability of ECs to accumulate at high elevations due to atmospheric transport and deposition, including WACAP (mentioned above), which was initiated by NPS in 2002 to determine the extent of contamination in parks in the western U.S. The research on the variety of potential sources and contaminants suggests that the risk of contamination is likely to be park-specific based on the proximity to population centers and the surrounding land uses within both the watershed and airshed. The following sections contain summaries of existing research on ECs that were conducted in or near National Park Service units (Figure 1).

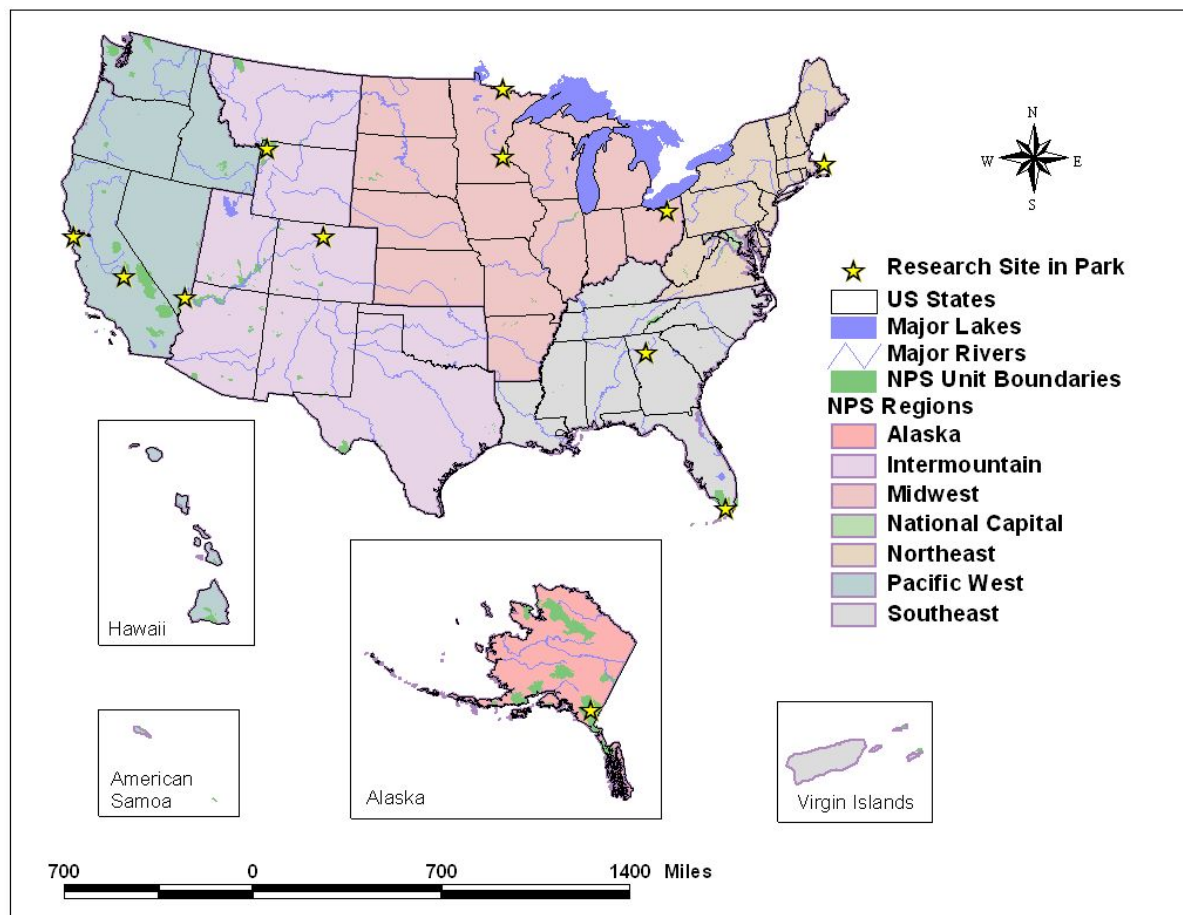


Figure 1. Map of National Park Service regions and locations where research has been conducted in National Park Service units.

Pacific West Region

Research conducted by the USGS and the U.S. Fish and Wildlife Service documented the presence of environmental contaminants, including EDCs and PPCPs, in parts of Lake Mead National Recreation Area (Bevans et al. 1996, Covay and Leiker 1998, Covay and Beck 2001, Boyd and Furlong 2002, Goodbred et al. 2007). These studies detected contaminants in water, sediments, and fish tissue, with the largest number of compounds and highest concentrations occurring in areas impacted by the discharge of municipal wastewater, groundwater, and stormwater, such as Las Vegas Bay. A study of Las Vegas Bay (Snyder et al. 1999) found five compounds with estrogenic activity, of which estradiol (a naturally occurring sex steroid hormone) and ethinyl estradiol (a synthetic estrogen used in birth control) had the highest estrogenicity. The studies not only found a variety of well known legacy chemical compounds that have not been used for decades, such as DDT and PCBs, but also a number of ECs, including commonly prescribed pharmaceuticals and consumer products like caffeine, 1,7-dimethylxanthine (metabolite of caffeine), acetaminophen (pain reliever), carbamazepine (anticonvulsant), cotinine (metabolite of nicotine), sulfamethoxazole (antibiotic), and the microbial agent triclosan (Boyd and Furlong 2002; Rosen et al. 2006). Studies detected many ECs in Las Vegas Bay but not in other areas of the lake, indicating that the discharge of sewage effluent has a direct and localized impact on water quality in the lake (Rosen et al. 2006).

Evidence collected from Lake Mead studies indicate that contaminants in effluents may adversely affect the health and reproduction of fish in receiving waters (Patino et al. 2003). These results are supported by the findings of similar studies throughout the world (Sumpter and Johnson 2005). Fish in receiving waters may be exposed to hundreds of chemical contaminants simultaneously, which makes it difficult to determine which individual compounds are altering endocrine and reproductive functions. Studies are ongoing in Lake Mead to determine which chemicals are the most active in causing endocrine and reproductive effects in fish, including common carp, largemouth bass, and the endangered razorback sucker. In addition, there is a collaborative research project underway to examine the efficacy of enhanced treatment for removal of emerging contaminants from effluents.

In Golden Gate National Recreation Area, managers considered using treated wastewater as a source of irrigation water for Crissy Field. Concerns about the potential impact of ECs from the treated wastewater getting into and affecting the recently restored Crissy Marsh prompted a baseline study before irrigation began. USGS researchers used passive samplers at several locations within the marsh and one in San Francisco Bay to determine if there were EDCs present, and used the YES assay to establish if any estrogenic compounds were present. The results of the research (Alvarez and Perkins 2006) confirmed the presence of compounds “capable of producing an estrogenic response” before the irrigation had started, but not enough information was available to ascertain the ecological effect of these compounds.

A review by Daly and Wania (2005) noted that the insecticides chlorpyrifos, diazinon, and parathion were detected in Sequoia National Park. Unlike the studies identified above, this review focused on the mechanisms for atmospheric transport and deposition from areas of heavy pesticide use in California’s Central Valley to remote montane parks in the Sierra Nevada, such as Sequoia National Park. Although many of the compounds reviewed by Daly and Wania

(2005) are currently regulated, their transport and fate into remote montane areas could be indicative of the potential for atmospheric transport of the newer ECs.

Intermountain Region

One study conducted in Yellowstone National Park evaluated snowmobiles as a source of contamination of the winter snowpack. The researchers found elevated levels of fossil fuel combustion byproducts (e.g., toluene, xylenes, benzene) near snowmobile routes, but in their preliminary analysis, they stated that the concentrations were not suspected to be problematic as they were below the detection limit of 10 ng/L (Ingersoll 1999). However, there is more recent evidence to suggest that toluene may be an endocrine disruptor (Yamaguchi et al. 2002). As such, additional evaluation may be warranted to determine whether the concentrations are environmentally relevant.

In Rocky Mountain National Park, Usenko et al. (2007) sampled sediment cores and winter snowpack from two lakes, which are approximately 10 km apart, but on opposite sides of the Continental Divide. They analyzed samples for semivolatile organic compounds (SOC) that were historically or are currently in use. While the deposition of historic-use SOC, such as nonachlor, dieldrin, DDT, and PCBs, decreased after federal regulations prohibited their use, it has not been completely eliminated, which may be due to local volatilization. As expected, the deposition of current-use SOC increased as their use increased, including endosulfan, dacthal, polycyclic aromatic hydrocarbons (PAHs), and polybrominated diphenyl ethers (PBDEs). There were also significant differences in the concentrations of the target compounds between the two lakes, which the researchers suggest could be attributed to regional summer wind patterns. Their findings suggest that topographic barriers can play a significant role in determining the atmospheric transport and deposition of SOC to high elevations.

Southeast Region

In the Chattahoochee River National Recreation Area, researchers found low concentrations (<1 ug/L) of individual OWCs, but higher concentrations of mixtures (>1 ug/L). Of the contaminants detected, thirteen are suspected endocrine disruptors (Frick and Zaugg 2003). So, while the individual OWCs might not have been detected at environmentally relevant levels, it is possible that the concentration of the mixtures is relevant. The effects of these mixtures on human health and aquatic life are unknown.

The Comprehensive Everglades Restoration Program identified treated wastewater as a possible source of water for restoring the natural hydroperiods to the coastal wetlands of Biscayne Bay. Prior to using the treated effluent, the USGS conducted sampling on the effluent to determine the presence of ECs. While they found that the treatment process was effective in reducing the concentrations for many ECs, they still found detectable levels. The compounds included 11 pharmaceuticals, eight antibiotics, and one hormone with “‘known’ endocrine disrupting potential” (Lietz and Meyer 2006).

Midwest Region

Two studies on major riverways in the Midwest document the impact of effluent from WWTFs. One report cites research indicating that estrogenic compounds from WWTFs are impacting fish in the Mississippi National River and Recreation Area (Lafrancois et al. 2007). Scientists found concentrations of nonionic surfactants in over 74 miles of the Cuyahoga River, which flows through Cuyahoga Valley National Park (Rice et al. 2003). Research by Oliaei (2005) documented perfluorinated compounds, which are manufactured by 3M, in 50% of fish sampled in Voyageurs National Park.

Northeast Region

In Cape Cod, researchers found that residential septic systems were contaminating groundwater with estrogenic compounds (Swartz et al. 2006). This study suggests that septic systems are not completely effective at removing compounds that may act as endocrine disruptors and that these compounds have the potential to move through the groundwater system. Although the exact location of the study is not known, it is likely in the vicinity of Cape Cod National Seashore. The impact of septic systems as a source of wastewater contamination at the Seashore is unknown.

Alaska Region

Some ECs have the potential to bioaccumulate. In an EC source study, Ewald et al. (1998) found that the population of migrating salmon served as a significant transport vector for PCBs and DDT to freshwater inland lakes. As the salmon migrated upstream, their lipids were used as an energy source, which resulted in the redistribution of the pollutants to other tissues of the organisms. For example, in females the pollutants accumulated in the gonads, which may have affected the survival of eggs and fry. After spawning, the Pacific salmon died, leaving their body burden of PCBs and DDT in the environment, contributing to the bioaccumulation in the local freshwater food web. The study took place along the Copper River upstream of Wrangell-St. Elias National Park and Preserve. While PCBs and DDT are no longer used in the U.S., they are used in other parts of the world and are very persistent in the environment, and as such, salmon maturing in various areas of the Pacific Ocean could be exposed. Current research suggests that biotransport could be a significant factor in the movement of bioaccumulative compounds that would not otherwise be found as a result of air deposition or the presence of local source.

Regional and National Studies

The NPS initiated WACAP to evaluate the risk of contamination from long-range transport of compounds to western National Parks. The project analyzed the deposition of semi-volatile organic compounds, which include persistent organic pollutants such as PCBs and DDT, and current-use and historic-use pesticides in the western U.S. WACAP results confirm other research of long-range transport in northern latitude and Arctic environments, such as those documented by the Canadian Northern Contaminants Program (Macdonal et al. 2000). In a study of pesticide deposition in several National Parks located in California, Colorado, Washington, and Alaska, Hageman et al. (2006) found that transport and deposition of pesticides was largely attributed to regional use, as supported by a significant correlation between the cropland intensity

and snowpack concentrations of agricultural pesticides. However, in places where they found detections and no significant regional sources, such as Alaska, transport and deposition was, therefore, attributed to long-range transport across the Pacific Ocean (Hageman et al. 2006). Current use pesticides that are suspected endocrine disruptors, dacthal, chlorpyrifos, and endosulfan, were frequently detected. This research suggests that while parks near agricultural land are probably at a greater risk of exposure to contamination by regional use of pesticides, more remote parks may still be at risk as well.

As noted above, research by Kolpin et al. (2002) has documented the presence of OWCs in waters receiving effluent from WWTFs throughout the U.S. The streams were selected in areas that were likely to be at risk of contamination by municipal, industrial, or agricultural wastewater. As such, this study does not represent the probability of OWC being present in all streams throughout the U.S. Nevertheless, it shows that if sources of wastewater are present near a National Park it is probable that ECs will be in the streams receiving the discharge. Several of the study sites were in or near National Park Service lands (Figure 2).

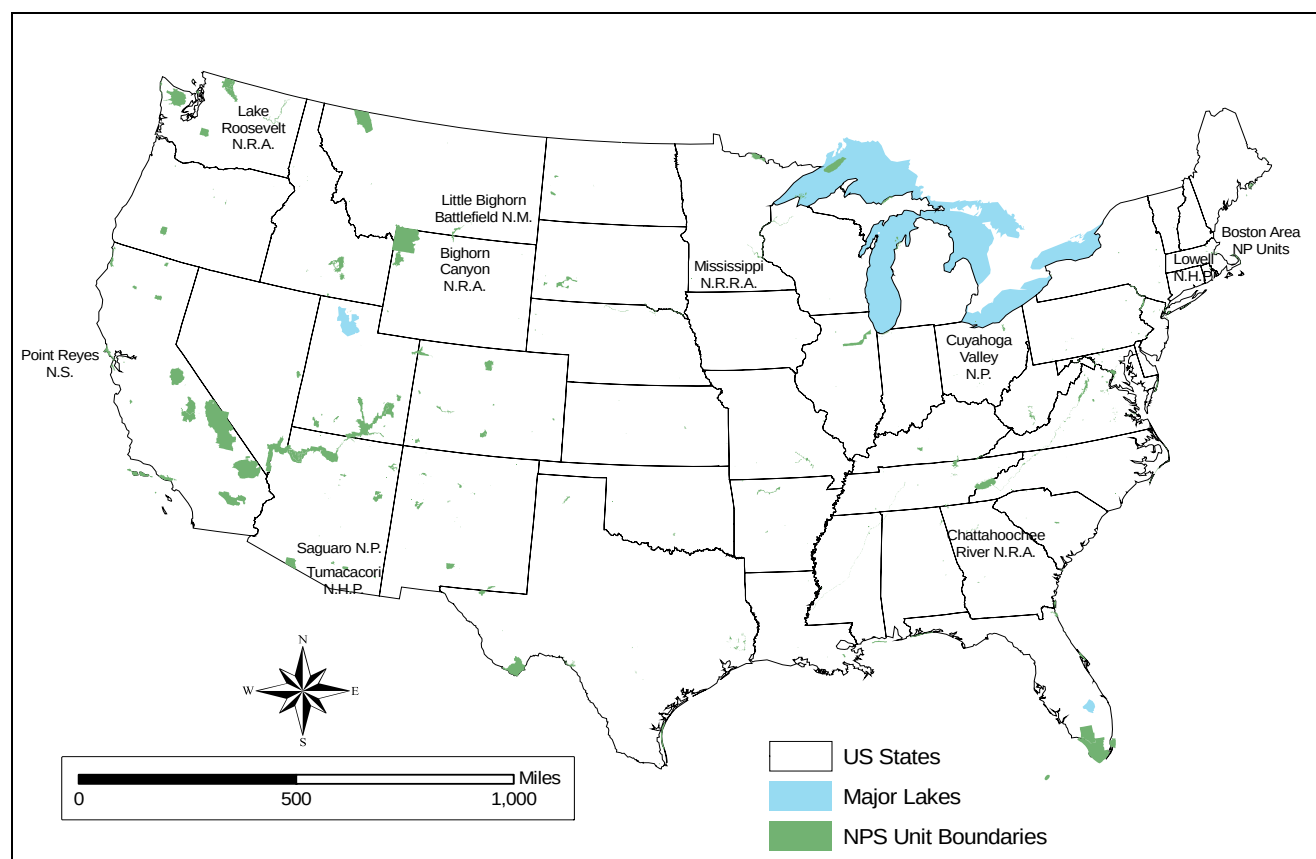


Figure 2. Parks labeled are in the vicinity of a USGS monitoring site included in Kolpin et al. (2002) study on organic wastewater contaminants. Captain John Smith Chesapeake National Historic Trail not shown.

In a study by Rattner et al. (2005), many National Parks were identified as having little or no ecotoxicological data. The focus of the research was to determine data gaps to help guide future

monitoring efforts, and although they did not focus specifically on ECs, the parks identified by the researchers as vulnerable to pollution might also be at greater risk of being impacted by ECs. What they found is that there was no recent data for approximately half of the National Parks in the geographic area of the toxicology database, which targeted coastal habitats. There were 59 parks in watersheds “exhibiting serious water quality problems and/or high vulnerability to pollution” that did not have recent data. Overall, there was very little herpetological data available, especially for the Pacific Coast and Hawaii. The figures below highlight the largest park units identified in the report as lacking ecotoxicological data (Figure 3) and as being located in problematic watersheds that may make the parks vulnerable to pollution (Figure 4).

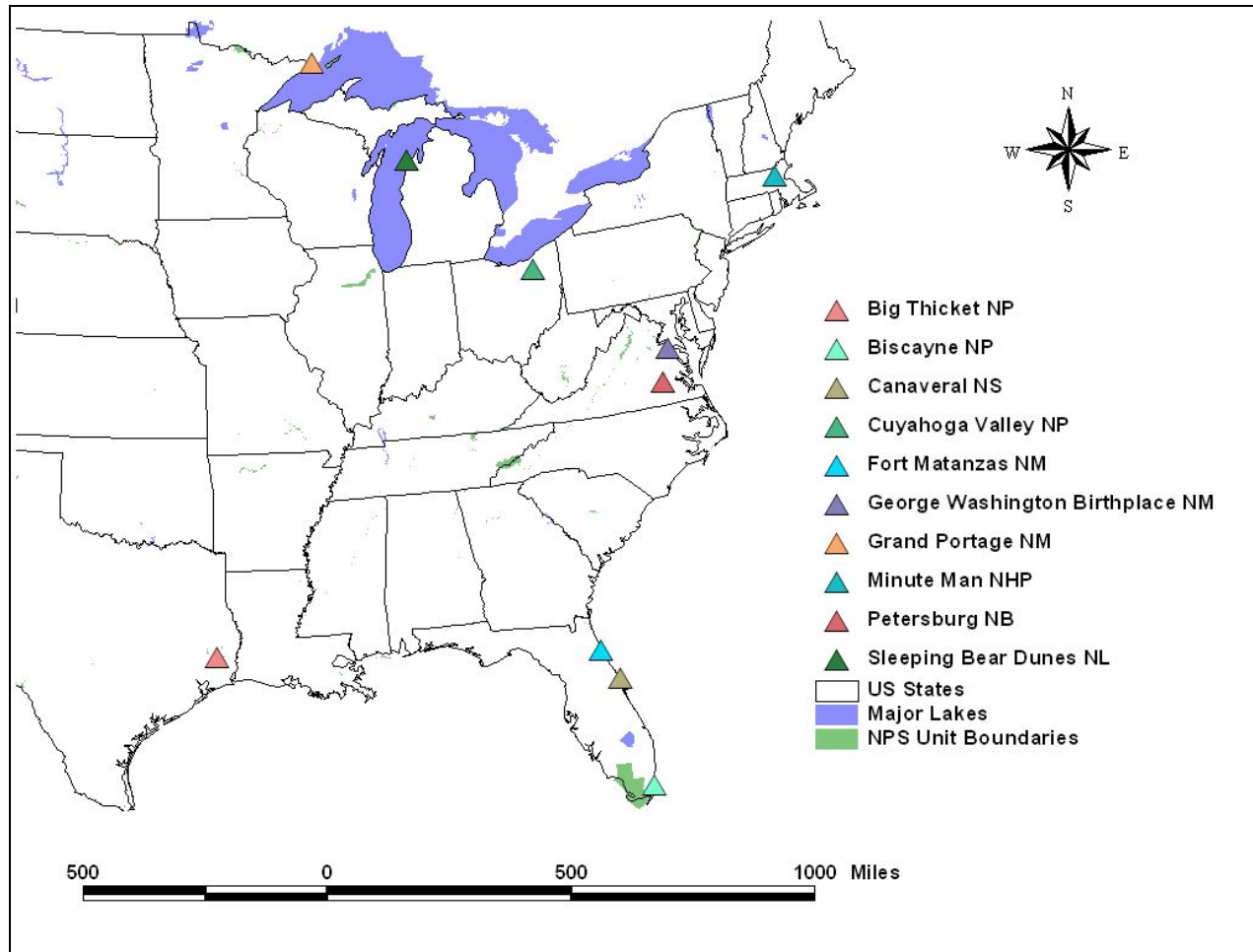


Figure 3. Map of largest National Park units identified by Rattner et al. (2005) as lacking ecotoxicological data.

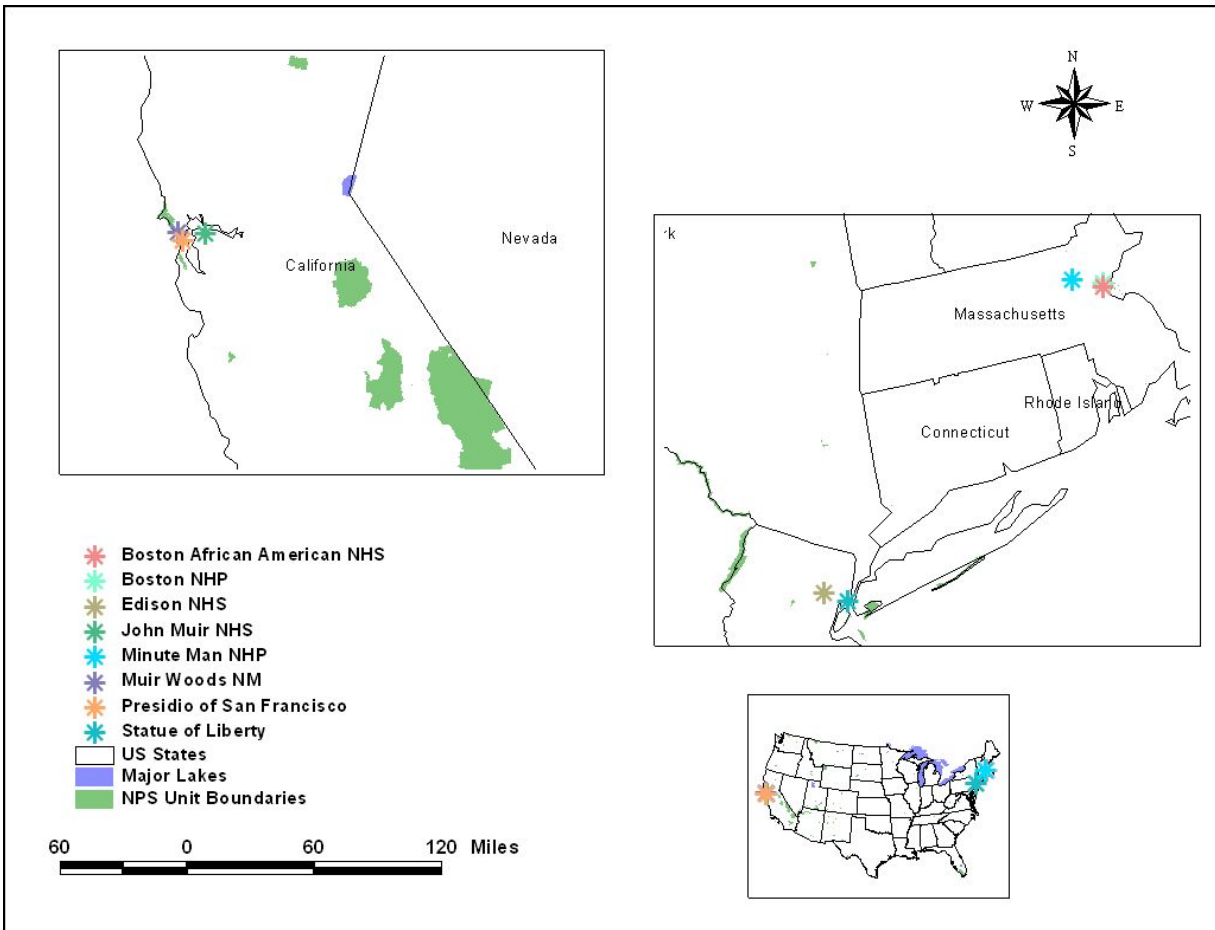


Figure 4. Map of largest National Park units identified by Rattner et al. (2005) as being located in watersheds with “more serious water quality problems,” with a “high vulnerability to pollution,” and lacking data.

Future Research Needs

While the existing research on the occurrence and distribution of ECs across the U.S. and the effects on certain aquatic populations has begun to elucidate the possible impacts of ECs in the environment, the literature identifies multiple areas of research to further the mechanisms and understanding of this complex issue.

There is limited research on the presence, transport, fate and extent of ECs in National Parks. While this report identifies parks where studies have shown the presence of ECs and discusses some activities (e.g., swimming and horseback riding) that are potential sources of EC contamination, there are other sources of ECs and environmental factors influencing the risk of contamination that have not been comprehensively studied or analyzed in the literature. One approach for prioritizing further research in National Parks would be to develop a risk assessment procedure using existing information. After developing a priority ranking of parks based on vulnerability to EC contamination, field studies using passive samplers and methods to detect estrogenic compounds (e.g., *in vitro* assays and YES) can direct further analytical tests to identify the specific compounds of concern. This approach, known as the contaminant assessment process (CAP), has been used by the USGS to assess the threat of environmental contamination on other lands managed by the Department of the Interior and could be similarly useful for better understanding the extent of environmental contaminants in the National Park system. The results of such an approach could then be used to inform the development of management plans to minimize any potential negative impacts of contamination.

Further information is needed about the degradation and distribution of ECs in the environment. Laboratory results from Borch et al. (2007) indicate that photolysis might be an important degradation mechanism, but in general, the degradation rates of hormones in the aquatic environment, as introduced by livestock or wildlife, are not well known. As Kolpin (2007) discussed, the compounds detected in high concentrations in water were detected in low concentrations in sediments and vice versa. As such, concentrations in sediments and water need to be evaluated because each compound is transported in different ratios across various media depending on its physical and chemical properties.

There is a lack of baseline data on EDCs in the environment (Geschwind et al. 1999). Methods for determining intersex still need to be developed and standardized among investigators. Presently, it is unclear how many oocytes in a testis have (or what percentage of feminized tissue has) a substantial effect on sperm production or general reproduction of a population of fish. Also, scientists do not know what percentage of male fish of various species might naturally exhibit intersex characteristics, identifying a further need for baseline data. There needs to be a better method for distinguishing between the effects resulting from exposure to natural (e.g., plant derived phytoestrogens) and anthropogenic sources of estrogen.

Researchers are calling for an increased focus to look holistically at the impacts of mixtures of ECs in the environment (Geschwind et al. 1999). In some cases, the metabolites and degradates of ECs are found in higher concentrations in the environment than their parent compounds (David et al. 2003; Osano et al. 2003; Hackett et al. 2005) and may have a more significant

environmental impact. Future research needs to consider the presence, fate, transport, and impacts on aquatic life of these metabolites.

Literature Cited

- Alvarez, D. A. and S. D. Perkins. 2006. Determining the presence and potential estrogenic and androgenic activity of chemical sequestered by POCIS in the Golden Gate National Park. U.S. Geological Survey, Final Report.
- Battaglin, W., J. Drewes, B. Bruce, and M. McHugh. 2007. Introduction: Contaminants of emerging concern in the environment. *Water Resources Impact* **9**(3):3-4.
- Bevans, H. E., S. L. Goodbred, J. F. Miesner, S. A. Watkins, T. S. Gross, N. D. Denslow and T. Schoeb. 1996. Synthetic organic compounds and carp endocrinology and histology in Las Vegas Wash, and Las Vegas and Callville Bays of Lake Mead, Nevada, 1992 and 1995. U.S. Geological Survey Water Resources Investigations Report 96-4266.
- Blais, J. M. 2005. Biogeochemistry of persistent bioaccumulative toxicants: Processes affecting the transport of contaminants to remote areas. *Canadian Journal of Fisheries and Aquatic Sciences* **62**: 236-243.
- Borch, T., J. G. Davis, C. R. Simpson, R. B. Young, J. M. Jones, and H. Lu. 2007. Impact of photolysis and manure-borne bacteria on the fate of steroid hormones. AWRA Summer Specialty Conference on Emerging Contaminants of Concern in the Environment: Issues, Investigations and Solutions. Vail, CO, June 25-27, 2007.
- Boyd, R. A. and E. T. Furlong. 2002. Human-health pharmaceutical compounds in Lake Mead, Nevada and Arizona, and Las Vegas Wash, Nevada, October 2000-August 2001. U.S. Geological Survey Open File Report 02-385. Online. (http://toxics.usgs.gov/regional/emc/mead_vegas.html). Accessed 5 June 2007.
- Covay, K. J. and D. A. Beck. 2001. Sediment-deposition rates and organic compounds in bottom sediment at four sites in Lake Mead, Nevada. U.S. Geological Survey Open-File Report 01-282.
- Covay, K. J. and T. J. Leiker. 1998. Synthetic organic compounds in water and bottom-sediment from streams, detention basins, and sewage-treatment plant outfalls in Las Vegas Valley, Nevada, 1997. U.S. Geological Survey Open-File Report 98-633.
- Daly, G. L. and F. Wania. 2005. Organic contaminants in mountains (critical review). *Environmental Science and Technology* **39**(2):385-398.
- Daly, G. L., Y. D. Lei, C. Teixeira, D. C. G. Muir, L. E. Castillo, and F. Wania. 2007. Accumulation of current-use pesticides in neotropical montane forests. *Environmental Science and Technology* **41**(4):1118-1123.
- Daughton, C. G. 2003. "Non-regulated contaminants: Emerging issues," presentation handout. Roundtable on Environmental Health Sciences, Research, and Medicine (EHSRT), Workshop #5: From Source Water to Drinking water: Emerging Challenges for Public

- Health. Washington, DC, National Academies, Institute of Medicine. 16 October 2003. Online. (www.epa.gov/esd/chemistry/ppcp/images/iom-2003.pdf). Accessed 17 July 2007.
- David, M. B., L. E. Gentry, K. M. Starks, and R. A. Cooke. 2003. Stream transport of herbicides and metabolites in a tile-drained, agricultural watershed. *Journal of Environmental Quality* **32**:1790-1801.
- DoD. 2007. The official DoD source for perchlorate information. United States Department of Defense Materials of Evolving Regulatory Interest Team. Online. (<https://www.denix.osd.mil/denix/Public/Library/MERIT/Perchlorate/index.html>). Accessed 23 July 2007.
- Ewald, G., P. Larsson, H. Linge, L. Okla, and N. Szarzi. 1998. Biotransport of organic pollutants to an inland lake by migrating sockeye salmon (*Oncorhynchus nerka*). *Arctic* **51**(1):40-47.
- Frick, E. A. and S. D. Zaugg. 2003. Organic wastewater contaminants in the Upper Chattahoochee River Basin, Georgia, 1999-2002. Proceedings of the 2003 Georgia Water Resources Conference. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia. Athens, GA, April 23-24, 2003.
- Geschwind, S. A., E. Eiseman, D. Spektor, and A. Hudson. 1999. The impact of endocrine disrupting chemicals on wildlife: A review of literature 1985-1998. Rand Corporation. Science and Technology Policy Institute. Online. (http://www.rand.org/pubs/monograph_reports/MR1050.0/MR1050.0.pdf). Accessed 5 June 2007.
- Giesy, J. P. and K. Kannan. 2002. Perfluorochemical surfactants in the environment. *Environmental Science and Technology* **36**(7):146A-152A.
- Gilliom, R. J. et al. 2006. The quality of our nation's waters—pesticides in the nation's streams and ground water, 1992–2001. U.S. Geological Survey Circular 1291.
- Goodbred, S. L., T. J. Leiker, R. Patino, J. A. Jenkins, N. D. Denslow, E. Orsak, and M. R. Rosen. 2007. Organic chemical concentrations and reproductive biomarkers in common carp (*Cyprinus carpio*) collected from two areas in Lake Mead, Nevada, May 1999-May 2000. U. S. Geological Survey Data Series 286.
- Hackett, A. G., D. I. Gustafson, S. J. Moran, P. Hendley, I. van Wesenbeeck, N. D. Simmons, A. J. Klein, J. M. Kronenberg, J. D. Fuhrman, J. L. Honegger, and others. 2005. The acetochlor registration partnership surface water monitoring program for four corn herbicides. *Journal of Environmental Quality* **34**:877-889.

- Hageman, K. J., S. Simonich, D. H. Campbell, G. R. Wilson, and D. Landers. 2006. Atmospheric deposition of current-use and historic-use pesticides in snow at National Parks in the western United States. *Environmental Science and Technology* **40**(10):3174-3180.
- Hogan, A., M. Peck, R. van Dam, and R. Kennett. 2005. Screening for endocrine disrupting activity in surface waters of Kakadu National Park. *Ecological Management Restoration* **6**(3):219-221.
- Hutchins, S. R., M. V. White, D. D. Fine, and P. G. Breidenbach. 2003. Analysis of swine lagoons and groundwater for environmental estrogens. *Proceedings of the Seventh International In Situ and On-Site Bioremediation Symposium*. Orlando, FL, June 2-5, 2003.
- Hutchins, S. R., M. V. White, F. M. Hudson, and D. D. Fine. 2007. Analysis of lagoon samples from different concentrated animal feeding operations for estrogen and estrogen conjugates. *Environmental Science and Technology* **41**(3): 738-744.
- Ingersoll, G. P. 1999. Effects of snowmobile use on snowpack chemistry in Yellowstone National Park, 1998. U.S. Geological Survey Water-Resources Investigations Report 99-4148.
- Kinney, C. A., E. T. Furlong, S. D. Zaugg, M. R. Burkhard, S. L. Werner, J. D. Cahill, and G. R. Jorgensen. 2006. Survey of organic wastewater contaminants in biosolids destined for land application. *Environmental Science and Technology* **40**(23):7207-7215.
- Kolodziej, E. P. and D. L. Sedlak. 2007. The occurrence and fate of steroidal hormones in surface waters impacted by cattle grazing and animal agriculture. *AWRA Summer Specialty Conference on Emerging Contaminants of Concern in the Environment: Issues, Investigations and Solutions*. Vail, CO, June 25-27, 2007.
- Kolpin, D. 2007. Emerging contaminants: Understanding their occurrence, fate, and effects. Keynote Presentation. *AWRA Summer Specialty Conference on Emerging Contaminants of Concern in the Environment: Issues, Investigations and Solutions*. Vail, CO, June 25-27, 2007.
- Kolpin, D. W., E. T. Furlong, M. T. Meyer, E. M. Thurman, S. D. Zaugg, L. B. Barber, and H. T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. Streams, 1999-2000: A National Reconnaissance. *Environmental Science and Technology* **36**(6):1202-1211.
- Lafrancois, B. M., D. L. Vana-Miller, and S. P. Johnson. 2007. Water resources information and issue overview report: Mississippi River National River and Recreation Area. National Park Service, Water Resources Division. Natural Resource Technical Report NPS/NRWRD/NRTR—2007/364.

- Lee, C. J., D. P. Mau, and T. J. Rasmussen. 2005. Effects of contaminant sources on stream-water quality in Johnson County, northeastern Kansas, October 2002 through June 2004. U.S. Geological Survey Fact Sheet 2005-3080. Online.
(<http://pubs.usgs.gov/fs/2005/3080/>). Accessed 14 October 2007.
- Lietz, A. C. and M. T. Meyer. 2006. Evaluation of emerging contaminants of concern at the South District Wastewater Treatment Plant based on seasonal sampling events, Miami-Dade County, Florida, 2004. U.S. Geological Survey Scientific Investigations Report 2006-5240.
- Macdonald, R. W., L. Barrie, T. Bidleman, M. Diamond, D. Gregor, R. Semkin, W. Strachan, Y. Li, F. Wania, M. Alaee, and others. 2000. Contaminants in the Canadian Arctic: 5 years of progress in understanding sources, occurrence, and pathways. *Science of the Total Environment* **254**(2-3):93-234.
- Meyer, M., G. Ferrell, J.E. Bumgarner, D. Cole, S. Hutchins, I. Krapac, K. Johnson, I. Verstraeten, and D. Kolpin. 2004. Occurrence of antibiotic residues in waste storage facilities at swine animal feeding operations. 227th ACS National Meeting. Anaheim, CA, March 28-April 1, 2004.
- NEBRA - North East Biosolids and Residuals Association. 2007. A national biosolids regulation, quality, end use, and disposal survey: Preliminary report. 14 April 2007. Online.
(<http://www.nebiosolids.org/pdf/BiosolidsInTheU.S.-14Apr07.pdf>). Accessed 17 July 2007.
- Oakes, K. D., P. K. Sibley, J. W. Martin, D. D. Maclean, K. R. Solomon, S. A. Mabury, and G. J., Van Der Kraak. 2005. Short-term exposures of fish to perfluorooctane sulfonate: Acute effects on fatty acyl-coa oxidase activity, oxidative stress, and circulating sex steroids. *Environmental Toxicology and Chemistry* **24**(5):1172-1181.
- Oliaei, F. 2005. Complaint before the United States Department of Labor Occupational Safety and Health Administration. 13 May 2005. Online.
(http://www.peer.org/docs/mn/05_16_5_complaint.pdf). Accessed 23 July 2007.
- ONDCP – Office of National Drug Control Policy. 2007. Proper disposal of prescription drugs. February 2007. Online.
(http://www.whitehousedrugpolicy.gov/publications/pdf/prescrip_disposal.pdf). Accessed 13 December 2007.
- Osano, O., D. Nzyuko, M. Tole, and W. Admiraal. 2003. The fate of chloroacetanilide herbicides and their degradation products in Nzoia Basin, Kenya. *AMBIO: A Journal of the Human Environment* **32**(6):424-427.
- Patino, R, S. L. Goodbred, R. D. Dale, C. E. Barry, J. S. Foott, M. R. Wainscott, T. S. Gross and K. J. Covay. 2003. Morphometric and histopathological parameters of gonadal

- development in adult common carp from contaminated and reference sites in Lake Mead, Nevada. *Journal of Aquatic Animal Health* **15**:55-68.
- Propper, C. R., D. Park, and L. P. Mayer. 2007. From individual compounds to complex mixes: Impacts of contaminant exposure on development and reproductive behavior. AWRA Summer Specialty Conference on Emerging Contaminants of Concern in the Environment: Issues, Investigations and Solutions. Vail, CO, June 25-27, 2007.
- Rajagopalan, S., T. A. Anderson, L. Fahlquist, K. A. Rainwater, M. Ridley, and W. A. Jackson. 2006. Widespread presence of naturally occurring perchlorate in high plains of Texas and New Mexico. *Environmental Science and Technology* **40**(10):3156-3162.
- Rattner, B. A., K. M. Eisenreich, N. H. Golden, M. A. McKernan, R. L. Hothem, and T. W. Custer. 2005. Retrospective ecotoxicological data and current information needs for terrestrial vertebrates residing in coastal habitat of the United States. *Archives of Environmental Contamination and Toxicology* **49**:257-265.
- Rice, C. P., I. Schmitz-Afonso, J. E. Loyo-Rosales, E. Link, R. Thoma, L. Fay, D. Altfater, and M. J. Camp. 2003. Alkylphenol and alkylphenol-ethoxylates in carp, water, and sediment from the Cuyahoga River, Ohio. *Environmental Science and Technology* **37**(17):3747-3754.
- Rosen, M. R., S. L. Goodbred, R. Patino, T. A. Leiker, and E. Orsak. 2006. Investigation of the effects of synthetic chemicals on the endocrine system of common carp in Lake Mead, Nevada and Arizona. U.S. Geological Survey, Fact Sheet 2006-3131.
- Schoenfuss, H., K. J. Grove, S. E. Bartell, and L. B. Barber. 2007. Natural and synthetic estrogens at environmentally relevant concentrations disrupt reproductive competence in male fathead minnows. AWRA Summer Specialty Conference on Emerging Contaminants of Concern in the Environment: Issues, Investigations and Solutions. Vail, CO, June 25-27, 2007.
- Sedlak, D. L., K. Pinkston, and C. H. Huang. 2004. Occurrence survey of pharmaceutically active compounds. American Water Works Association Research Foundation Project #2617. Winter 2004/2005.
- Snyder, S. A., E. C. Wert, D. J. Rexing, R. E. Zegers, and D. D. Drury. 2006b. Ozone oxidation of endocrine disruptors and pharmaceuticals in surface water and wastewater. *Ozone: Science and Engineering* **28**: 445-460.
- Snyder, S. A., S. Adham, A. M. Redding, F. S. Cannon, J. DeCarolis, J. Oppenheimer, E. C. Wert, and Y. Yoon. 2006a. Role of membrane and activated carbon in the removal of endocrine disruptors and pharmaceuticals. *Desalination* **202**: 156-181.

- Snyder, S. A., T. L. Keith, D. A. Verbruge, E. M. Snyder, T. S. Gross, D. Dannan, and J. P. Giesy. 1999. Analytical methods for detection of selected estrogenic compounds in aqueous mixtures. *Environmental Science and Technology* **33**: 2814-2820.
- Sumpter, J. P. and A. C. Johnson. 2005. Lessons from endocrine disruption and their applications to other issues concerning trace organics in the aquatic environment. *Environmental Science and Technology* **39**:4321-4332.
- Swartz, C. H., S. Reddy, M. J. Benotti, H. Yin, L. B. Barber, B. J. Brownawell, and R. A. Rudel. 2006. Steroid estrogens, nonylphenol ethoxylate metabolites, and other wastewater contaminants in groundwater affected by a residential septic system on Cape Cod, MA. *Environmental Science and Technology* **40**(16):4894-4902.
- Tremblay, L. and G. Van der Kraak. 1998. Use of a series of homologous *in vitro* and *in vivo* assays to evaluate the endocrine modulating actions of β -sitosterol in rainbow trout. *Aquatic Toxicology* **43**:149-162.
- Usenko, S., D. H. Landers, P. G. Appleby, and S. L. Simonich. 2007. Current and historical deposition of PDBEs, pesticides, PCBs, and PAHs to Rocky Mountain National Park. *Environmental Science and Technology* **41**:7235-7241.
- Vajda, A., J. L., Gray, L. B. Barber, E. M. Lopez, J. D. Woodling, and D. O. Norris. 2007. Reproductive disruption of fishes by an endocrine-active wastewater effluent. AWRA Summer Specialty Conference on Emerging Contaminants of Concern in the Environment: Issues, Investigations and Solutions. Vail, CO, June 25-27, 2007.
- WACAP – Western Airborne Contaminants Assessment Project. 2004. Western Airborne Contaminants Project fact sheet. February 2004. National Park Service, Air Resources Division. Online.
(http://www2.nature.nps.gov/air/Studies/air_toxics/docs/05_loResLetterCS.pdf). Accessed 10 December 2007.
- Yamaguchi, H., Y. Kidachi, and K. Ryoyama. 2002. Toluene at environmentally relevant low levels disrupts differentiation of astrocyte precursor cells. *Archives of Environmental Health* **May/June 2002**: 232.

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