WERF

Water Environment Research Foundation

Collaboration. Innovation. Results.

Trace Organics

FINAL REPORT

Diagnostic Tools to Evaluate Impacts of Trace Organic Compounds

PRIORITIZATION FRAMEWORK FOR TRACE ORGANIC COMPOUNDS

Co-published by

IWA Publishing

CEC5R08a

DIAGNOSTIC TOOLS TO EVALUATE IMPACTS OF TRACE ORGANIC COMPOUNDS

PRIORITIZATION FRAMEWORK FOR TRACE ORGANIC COMPOUNDS

by:

Jerry Diamond, Ph.D.
Henry Latimer, M.Sc.
Tetra Tech, Inc.

Kelly Munkittrick, Ph.D.
Karen Kidd, Ph.D.
University of New Brunswick

Kent Thornton, Ph.D.
FTN Associates, Inc.

Steve Bartell, Ph.D.
E2 Consultants, Inc.

2010

WERF

The Water Environment Research Foundation, a not-for-profit organization, funds and manages water quality research for its subscribers through a diverse public-private partnership between municipal utilities, corporations, academia, industry, and the federal government. WERF subscribers include municipal and regional water and wastewater utilities, industrial corporations, environmental engineering firms, and others that share a commitment to cost-effective water quality solutions. WERF is dedicated to advancing science and technology addressing water quality issues as they impact water resources, the atmosphere, the lands, and quality of life.

For more information, contact:
Water Environment Research Foundation
635 Slaters Lane, Suite G-110
Alexandria, VA 22314-1177
Tel: (571) 384-2100
Fax: (703) 299-0742
www.werf.org
werf@werf.org

This report was co-published by the following organization.

IWA Publishing
Alliance House, 12 Caxton Street
London SW1H 0QS, United Kingdom
Tel: +44 (0) 20 7654 5500
Fax: +44 (0) 20 7654 5555
www.iwapublishing.com
publications@iwap.co.uk

© Copyright 2010 by the Water Environment Research Foundation. All rights reserved. Permission to copy must be obtained from the Water Environment Research Foundation.
Library of Congress Catalog Card Number: 2010936103
Printed in the United States of America
IWAP ISBN: 978-1-84339-535-5/1-84339-535-5

This report was prepared by the organization(s) named below as an account of work sponsored by the Water Environment Research Foundation (WERF). Neither WERF, members of WERF, the organization(s) named below, nor any person acting on their behalf: (a) makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report or that such use may not infringe on privately owned rights; or (b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

Tetra Tech, Inc.

This document was reviewed by a panel of independent experts selected by WERF. Mention of trade names or commercial products or services does not constitute endorsement or recommendations for use. Similarly, omission of products or trade names indicates nothing concerning WERF's positions regarding product effectiveness or applicability.

ACKNOWLEDGMENTS

The authors wish to thank all of the individuals who helped develop this document. In addition, the authors also wish to thank the Trace Organic Compounds Ecological Steering Committee and the WERF program director for their valuable input, which helped to make this a useful product for WERF subscribers and the water resource community as a whole. Research for this report was conducted under WERF contract CEC5R08 Deliverable 1A.

Report Preparation

Principal Investigator:
Jerry Diamond, Ph.D.
Center for Ecological Sciences, *Tetra Tech, Inc.*

Project Team:
Kent Thornton, Ph.D.
FTN Associates, Inc.

Steve Bartell, Ph.D.
E2 Consulting Engineers, Inc.

Kelly Munkittrick, Ph.D.
Karen Kidd, Ph.D.
University New Brunswick

Katherine Kapo, Ph.D.
Montani Run LLC

Henry Latimer
Jaime Gilliam
Center for Ecological Sciences, *Tetra Tech, Inc.*

Technical Review Committee:

Scott Dyer, Ph.D.
Drew McAvoy, Ph.D.
Procter & Gamble

Erich Emery
Ohio River Sanitation Commission

Steve Bay
Southern California Coastal Water Research Project

Paul DeLeo
American Cleaning Institute (formerly Soap & Detergent Association)

Deb Lester
King County Department of Natural Resources

Jim Pletl
Hampton Roads Sanitation District

Elizabeth Toot-Levy
Northeast Ohio Regional Sewer District

Mary Buzby
Merck & Co.

Mike Focazio
U.S. Geological Survey

Water Environmental Research Foundation Staff:

Director of Research: Daniel M. Woltering, Ph.D.
Program Director: Lola Olabode, M.P.H.

ABSTRACT AND BENEFITS

Abstract:

With the advent of improved analytical detection capabilities, a variety of organic chemicals have been found in trace amounts (Trace Organic Chemicals, TOrCs) in surface waters, sediment, and fish tissue. These TOrCs include pharmaceuticals, personal care products, surfactants, and other currently unregulated chemicals. This WERF sponsored research presents a preliminary screening process and ecological diagnostic approaches that could be used to help prioritize and evaluate treated wastewater-influenced sites that may be most at risk from trace organic chemical (TOrC) exposure. Identifying or predicting ecological effects of TOrCs in typical aquatic systems is challenging, requiring a variety of tools that can diagnose effects at multiple scales of ecological organization. Development of a prioritization process is the goal of Task 1 of this research and the focus of this report. This research developed three approaches to prioritize TOrCs: 1) risk-based, 2) chemical persistence, bioaccumulation potential, and toxicity (PBT), and 3) a hybrid based on risk, persistence, and bioaccumulation potential. Using an occurrence database compiled from over 100 monitoring studies, the three prioritization approaches were applied to over 500 TOrCs that have been detected in water or effluent samples in the U.S. over the past 10 years. Types of TOrCs identified as high priority differed among approaches: steroids/hormones, pharmaceuticals, and surfactants comprised most of the high priority TOrCs based on risk while pesticides, industrial chemicals, and PAHs comprised most of the high priority TOrCs based on a PBT approach. Except for the synthetic hormones and steroids, results of all three prioritization approaches yielded only a few pharmaceuticals of high priority. Using a risk-based prioritization approach, predicted chronic toxicity endpoints were more sensitive than endpoints based on estrogenic activity for most TOrCs. The prioritization list(s) resulting from this work is not necessarily intended to be viewed as a list of compounds to be monitored or for which water quality criteria should be developed. The process of developing the list(s) is as important as the list(s) itself and the appropriate use of any resulting list(s) will depend largely on the goals of the user.

Benefits:

- Identifies potentially useful prioritization approaches for identifying TOrCs that should be monitored or considered.
- Collates useful information regarding fate and effects of TOrCs monitored by numerous water quality agencies.
- Developed an approach to calculate estrogenicity equivalents of various TOrCs for prioritization .

Keywords: Contaminants of emerging concern, trace organic chemical, endocrine disruptors, aquatic ecology.

TABLE OF CONTENTS

Acknowledgments iii
Abstract and Benefits v
List of Tables vii
List of Figures viii
Executive Summary ES-1

1.0 Introduction 1-1

2.0 Existing Prioritization Processes 2-1
2.1 Occurrence Surveys 2-1
2.2 Government Chemical Prioritization Programs 2-2

3.0 Occurrence Database 3-1
3.1 Source of Occurrence Data 3-1
3.2 Fate and Effects Database 3-5
3.3 Calculation of Risk 3-6

4.0 Proposed TOrC Prioritization Approaches 4-1
4.1 Approach #1 4-1
4.2 Approach #2 4-1
4.3 Approach #3 4-2
4.4 Comparisons Between the Three Prioritization Approaches 4-3

Appendix A A-1

References R-1

LIST OF TABLES

2-1 Scoring System Used by the Oregon DEQ to Develop Individual Scores for Persistence, Bioaccumulation, and Toxicity for Use In Prioritizing Compounds 2-3

3-1 Sample of References Used to Derive Occurrence Data as Well as Geographic Area Sampled, Sample Collection Date, Number of Sites, and Potential Sources of Organic Chemicals Identified in the Study. Appendix A Contains the Full Dataset with All Sources Identified 3-2

3-2 The Minimum, Median, Maximum, and Second Highest Value Reported, from a Different Monitoring Study for Select Torcs. All Concentrations Are µG/L..... 3-5

3-3 Databases and Sources Of Information On Trace Organic Compounds Used in Task 1 ... 3-7

4-1 Scoring For Parameters Used in Approach #2 and Approach #3 4-2

4-2 Advantages and Limitations of the Three Different Approaches Proposed for Prioritizing Trace Organic Chemicals (TOrCs) 4-4

4-3 High Priority Torcs Obtained From Each of the Three Prioritization Approaches 4-5

4-4 Summary of Torcs Listed as High Priority Using the Three Prioritization Approaches Indicating for Each if it is an Endocrine Disrupting Compound (EDC), the Most Sensitive Organism Type, the Most Sensitive Endpoint Type, and a Potential Analytical Method Reference (If Available) 4-13

4-5 High Priority Torcs Using Either Prioritization Approach #1 or #2 That Appear to be Monitored Relatively Infrequently Thus Far in Many Monitoring Programs 4-14

LIST OF FIGURES

4-1 Types of High Priority Torcs by Percentage Using Each of the Three Prioritization Approaches 4-9

4-2 Percentage of Persistence and Bioaccumulation Categories for the Three Different Prioritization Approaches 4-11

EXECUTIVE SUMMARY

With the advent of improved analytical detection capabilities, a variety of organic chemicals have been found in trace amounts (Trace Organic Chemicals, TOrCs) in surface waters, sediment, and fish tissue. These TOrCs include pharmaceuticals, personal care products, surfactants, and other currently unregulated chemicals. Identifying or predicting ecological effects of TOrCs in typical aquatic systems is challenging, requiring prioritization of those TOrCs most likely to present a risk to aquatic ecological populations and communities so that monitoring and assessment efforts are properly focused. This research developed three approaches to prioritize TOrCs: 1) risk-based, 2) chemical persistence, bioaccumulation potential, and toxicity (PBT), which is used in many applications worldwide, and 3) a hybrid approach based on risk, persistence, and bioaccumulation potential. Risk was determined by comparing the maximum concentration reported for each TOrC with the most sensitive effect endpoint (chronic toxicity or estrogenic activity). Using an occurrence database compiled from over 100 monitoring studies, the three prioritization approaches were applied to over 450 TOrCs that have been detected in water or effluent samples in the U.S. over the past 10 years. Toxicity information was compiled from EPA's ECOSAR and estrogenic activity of TOrCs was compiled using the Food and Drug Administration's database, which are compiled in a companion database for this project. In addition, fate information was compiled for these TOrCs using EPA's EpiSuite and PBT profiler, which is also available in the companion database.

Types of TOrCs identified as high priority differed among approaches: steroids/hormones, pharmaceuticals, and surfactants comprised most of the high priority TOrCs based on a risk approach, while pesticides, industrial chemicals, and PAHs comprised most of the high priority TOrCs based on a PBT approach. The hybrid approach predictably resulted in a mixture of high risk and high PBT TOrCs. Although it is not definitively known at this time, it appears that many of the high priority TOrCs using the risk-based approach could originate from treated wastewater sources while those TOrCs identified using the other two approaches are more likely to originate from other sources (e.g., nonpoint source runoff, CAFOs, agricultural practices). The risk-based approach resulted in the fewest number of high priority TOrCs (41) while the PBT approach resulted in the greatest number of high priority TOrCs (108). Each approach has advantages and disadvantages. For most utilities and resource agencies beginning the process of examining TOrCs, the risk-based approach may be most appropriate because these TOrCs are known to occur in surface waters in the U.S., they are thought to elicit effects on aquatic biota at relatively low concentrations, and they appear to sometimes occur at concentrations that might result in a risk to aquatic biota.

Results of the prioritization analyses indicated that many pharmaceuticals currently being monitored are unlikely to occur at concentrations that would present a risk to aquatic biota based on predicted toxicological or estrogenic activity endpoints. Exceptions were synthetic hormones and steroids. In addition, the risk-based approach suggested that predicted chronic toxicity endpoints were more sensitive than endpoints based on estrogenic activity for most TOrCs.

Again, the exception was hormones and steroids. However, the estrogenic activity levels for many TOrCs is presently uncertain and other types of endocrine disruption effects of TOrCs could not be addressed based on the current state of knowledge.

The lists of high priority TOrCs generated in this research should not be taken as required monitoring lists or as compound lists for regulation because much is uncertain regarding the occurrence and effects of many TOrCs given our current state of knowledge. High priority TOrCs are expected to vary somewhat with the region of the U.S. and types of TOrCs that may be generated. However, the prioritization approaches presented in this report should prove useful for a utility or locality to help them organize, reduce, and manage the process of screening TOrCs.

CHAPTER 1.0

INTRODUCTION

With the advent of improved analytical and biomarker detection capabilities over the past 10-15 years, trace amounts of a variety of organic chemicals have been detected in surface waters, treated effluents, drinking water supplies, and fish tissue. In addition, the water resource community and the public have become increasingly concerned about these chemicals and the reproductive disorders reported in individual fish, reptiles, and amphibians from waterbodies throughout the U.S. and elsewhere. It has been established that: 1) a number of organic chemicals are capable of disrupting vertebrate endocrine function (and reproductive function in particular) at relatively low concentrations (e.g., Guillette and Gunderson, 2001), and 2) many of these same chemicals have been reported in surface waters and in fish tissues in association with a variety of potential sources and environmental conditions (e.g., Kolpin et al. 2002; Focazio et al. 2008; Ramirez et al, 2009). The documented presence of estrogenic trace organic compounds (TOrCs) in surface waters has been hypothesized to be related to biological responses including the occurrence of intersex fish at a number of locations in the U.S. and elsewhere (e.g., Iwanowicz et al, 2009; Williams et al, 2009). The increasing awareness that a large number of trace organic compounds (TOrCs) occur in surface waters, and with unknown but suspected potential ecological effects, has led to the need for reliable screening tools with which to determine actual or predicted ecological risks of TOrCs.

The focus of this research is on TOrCs that are currently unregulated and are suspected of having caused or have the potential to cause deleterious ecological effects in aquatic systems. Therefore, the primary TOrCs evaluated in this research include pharmaceuticals, personal care products, natural and synthetic hormones, surfactants, current use pesticides, certain flame retardants, and plasticizers. Because of the diversity of potential sources of TOrCs in surface waters (e.g., industrial effluent, waste-water treatment plant effluent, agricultural run-off, etc.) it was determined that this research should not be limited to those compounds found in wastewater effluents only, but should include TOrCs from other potential anthropogenic sources. Therefore, the universe of potential TOrCs under consideration in this research includes those that occur or have a reasonable potential to occur in surface waters and meet the above definition.

TOrC are defined as organic compounds that are known or suspected to be released to the aquatic environment but are not commonly regulated or monitored, and whose potential risk to human or ecological health are relatively unknown.

Anthropogenic organic pollutants that are currently regulated and monitored both in ambient waters and in permitted discharges (e.g., PCBs, PAHs, legacy pesticides) are also considered in this research but to a limited degree because they have been extensively researched elsewhere and are less relevant to the present research goals. Also, for many legacy contaminants (i.e., those banned from production such as DDT and PCBs), water quality criteria and effluent

limits are very low, which already acknowledges that the chemical is environmentally unsafe. Still, some of these regulated chemicals are included in our evaluations because potential toxic modes of action of these compounds (e.g., endocrine disruption) may not have been fully characterized and may not be the basis upon which some of these compounds are currently regulated.

In 2002, approximately 9,000 organic compounds were produced or imported to the U.S. at volumes in excess of 4.5 tons/year, with approximately 2,800 produced in excess of 454 tons/year (Muir and Howard, 2006). The threshold value for high production volume (HPV)chemicals used by U.S. EPA's High Production Volume Challenge under the Toxic Substance and Control Act (TSCA; http://www.epa.gov/hpv/index.htm) is 500 tons/year. An additional 30,000 were produced or imported at volumes below 4.5 tons/year (Muir and Howard, 2006). Thus, the entire universe of TOrCs could potentially approach 40,000 compounds, before considering break-down products. Because the definition of a TOrC is broad, a prioritization process is necessary to screen the universe of potential TOrCs and identify those TOrCs that have the greatest potential to cause ecological effects. Simply creating a comprehensive list of TOrCs that are known or suspected to be released to the aquatic environment would result in a large and unwieldy list. Therefore, some type of prioritization is needed to further monitoring objectives and assessment goals regarding TOrCs (SCCWRP, 2009). Development of a prioritization process is the goal of Task 1 of this research and the focus of this report. The prioritization list(s) resulting from this work is not necessarily intended to be viewed as a list of compounds to be monitored or for which water quality criteria should be developed. The process of developing the list(s) is as important as the list(s) itself and the appropriate use of any resulting list(s) will depend largely on the goals of the user.

An ideal prioritization process would be risk-based, such that those TOrCs known to have the greatest potential of causing ecological effects would be identified as the highest priority for monitoring. Most available field information on TOrCs addresses exposure, such as concentrations in treated effluents, surface waters, fish tissue, as well as various biochemical indicators of organism exposure, such as vitellogenin and steroid concentration. In contrast, relatively little information is available linking these exposure observations to population or community effects in aquatic systems. Furthermore, field exposure data are being collected and reported by many different organizations with different monitoring objectives resulting in inconsistency in the suites of TOrCs analyzed, detection limits and analytical methods used and types of samples analyzed. A truly integrated evaluation of these data is needed to help characterize the current status with respect to occurrence of TOrCs so that a meaningful prioritization process is developed. In addition, laboratory response thresholds for mortality, growth, or reproductive impairment are available for relatively few TOrCs, and there are even fewer TOrCs for which endocrine disrupting effects are linked to population-level effects. A useful prioritization process needs to integrate these various types of biological effects in order to determine conditions under which TOrCs pose the greatest ecological risks, and postulate exposure-response pathways that can then be used to develop useful conceptual frameworks and tools for assessing and predicting effects of TOrCs at a given site.

In some ways, TOrCs are no different from "classic" toxicants such as metals or ammonia, in terms of ecological risk assessment because:

- they often co-occur with other, less subtle stressors (e.g., habitat modification, nutrients) that could mask subtle sublethal effects;

- in open populations, physiological or anatomical effects on individual organisms may or may not be evidenced as population or community level effects;

- low level but continuous exposures from some effluents may result in relatively persistent exposure (pseudo persistent), despite ready degradation of the chemical;

However, TOrCs appear to differ from classic toxicants in that:

- specific modes of action of some TOrCs may result in widely disparate effects on different species and/or life stages;

- some TOrCs do not elicit classic acute and chronic toxicological responses at ambient concentrations but they do elicit strong endocrine disruption effects which may not be evidenced until a future generation; and

- many TOrCs have unknown modes of action and poorly characterized concentration-response relationships, particularly given effects at low levels of exposure.

As a result of the above differences, the traditional risk-based approach for prioritizing chemicals may need some refinements in order to assess TOrCs in an efficient and useful manner. The following section summarizes some of the existing frameworks that are being used by various organizations to prioritize TOrCs or contaminants of emerging concern (CECs) for various environmental monitoring programs.

CHAPTER 2.0

EXISTING PRIORITIZATION PROCESSES

A number of organizations are monitoring the occurrence of various TOrCs or CECs for a variety of reasons (See Appendix A for objectives of various TOrC monitoring programs). In the U.S., the USGS has been the major organization monitoring TOrCs across the U.S. Therefore, it is useful to review why USGS monitored particular TOrCs. Several government agencies are responsible for regulating the use of chemicals and have developed prioritization methods to efficiently identify potentially hazardous chemicals. EPA, Environment Canada, and Oregon Department of Environmental Quality (ODEQ) have particularly relevant approaches and they are described as well.

2.1 Occurrence Surveys

To date, many if not most monitoring studies of TOrCs in surface water or effluent appear to have relied primarily on best professional judgment in determining the list of compounds to evaluate. The USGS national surveys (e.g., Focazio et al., 2008 and Kolpin et al., 2002) appear to have selected compounds for study based on usage, toxicity/hormone activity, potential for persistence, and known occurrence. Similarly, the list of compounds analyzed by EPA (Ramirez et al., 2009) in a recent survey of pharmaceuticals and personal care products (PPCPs) in fish tissue was determined using best professional judgment, but also relied heavily on available analytical methods in developing the targeted analyte list. Thus, the compounds selected in past studies by the USGS and EPA relied heavily on best professional judgment rather than a formal prioritization system in selecting compounds for analysis.

As an example of one study, Benotti et al. (2009) evaluated the concentrations of 51 pharmaceuticals and endocrine disrupting compounds (EDCs) in drinking water throughout the U.S. In selecting these compounds, the authors considered different criteria for each of these two groups. For the pharmaceuticals, the authors focused only on prescription drugs because these compounds tend to have a higher potency and potential for toxicity than over-the-counter medications. From the available prescription drugs, representative drugs from several classes of pharmaceuticals were selected. Further, the authors considered volume of use, measures of human toxicity, documented occurrence, and level of public interest in selecting specific chemicals. Benotti et al. (2009) used a similar screening process for selected EDCs. In selecting EDCs, consideration was given to the reported magnitude of endocrine effect, occurrence, other aspects potentially affecting magnitude of effects (e.g., potency, half-life, and bioaccumulation), mode of action, and public interest. A final consideration for both the pharmaceutical and EDC groups was the availability of analytical methods. Although the screening process used in this

study was fairly well defined, it was still dependent upon best professional judgment of the researchers.

2.2 Government Chemical Prioritization Programs

Environment Canada – Domestic Substances List

Environment Canada (EC) categorizes risks associated with substances currently existing in Canada (the Domestic Substances List or DSL). These compounds are assessed based on the persistence, bioaccumulation, and inherent toxicity (iT) to non-humans (Arnot and Mackay 2008; Environment Canada 2006, Muir and Howard 2006), however, it does not appear that the likelihood of occurrence of the compound in surface waters is a factor in the evaluation. Compounds are considered to be persistent if the half-life in water is at least 182 days. Compounds are considered to be bioaccumulative if the log K_{ow} is at least 5.0 or the BAF or BCF is at least 5,000. Finally, compounds are considered iT if the LC_{50} (acute toxicity) is no greater than 1 mg/L and the no observed effect concentration (NOEC, chronic toxicity) is no greater than 0.1 mg/L. Those compounds which are considered persistent, bioaccumulative, and inherently toxic to non-humans are then prioritized for further screening assessment. It appears that this further screening assessment is a more detailed evaluation of available toxicity and exposure data for the purposes of assessing risk, but may not involve the ranking of the relative risk of all compounds.

U.S. Environmental Protection Agency – TSCA

The U.S. Environmental Protection Agency (EPA) Toxic Substances Control Act (TSCA) requires pre-manufacture evaluation and, potentially, regulation of new chemicals. This evaluation primarily addressed the persistence and bioaccumulation potential of these chemicals. Generation and/or evaluation of toxicity data is required for those chemicals determined to have a half-life of greater than 2 months and bioconcentration or bioaccumulation factors (BCF or BAF) greater than 1,000. Chemicals with a half-life of greater than 6 months and BCF or BAF greater than 5,000 are banned pending generation and evaluation of toxicity data (Federal Register 1999). However, similar to the EC program, compounds are not prioritized by potential ecological harm and actual occurrence of compounds in surface water is not considered.

Most other screening programs have focused on describing the potential for persistence, bioaccumulation, and toxicity ("PBT") of various compounds (e.g., ODEQ, EPA Great Lakes Initiative, Washington State DOE PBT Rule, and the UN's Stockholm Convention on POPs). Typically, these efforts defined thresholds of each measure of PBT (persistence, bioaccumulation, and toxicity) (e.g., ODEQ's thresholds shown in Table 2-1).

Table 2-1. Scoring System Used by the Oregon DEQ to Develop Individual Scores for Persistence, Bioaccumulation, and Toxicity for Use in Prioritizing Compounds.

Parameter	None to Low (0)	Moderate (1)	High (2)
Persistence	Half life in water, soil, or sediment < 60 days	Half-life in water, soil, or sediment ≥60 and < 180 days	Half-life in water, soil, or sediment > 180 days
Bioaccumulation	Bioconcentration Factor (BCF) < 1000	BCF ≥1000 and <5000	BCF > 5000
Toxicity (non-human receptor)	Fish chronic value > 10 mg/L	Fish chronic value ≥0.1 and ≤10 mg/L	Fish chronic value < 0.1 mg/L

Both the Canadian DSL and U.S. TSCA approaches use a PBT framework to prioritize chemicals for screening and regulation. Several concerns have been raised regarding the PBT approach in relation to assessing many of the TOrCs or CECs that are of interest to the water resource community. First, many chemicals such as pharmaceuticals are often not produced in high enough volumes to warrant scrutiny based on high production volume (HPV) chemical assessments. However, these TOrCs may be highly potent and pose high potential risks to certain aquatic biota (Ankley et al. 2007). Second, traditional measures of persistence (e.g., half-life, K_{oc}) may underestimate actual exposures and risks to aquatic biota for TOrCs that have inherently short half-lives but are released almost constantly by wastewater discharges and other sources (i.e., pseudopersistence) . Third, classical toxicity test endpoints (e.g., acute LC_{50}s or 30d chronic EC_{20}s) are not likely to be effective in evaluating the potential effects of EDCs (Caldwell et al. 2008; Ankley et al. 2007; Crane et al. 2006). Thus, a true risk-based prioritization process needs to be sufficiently flexible to address both classical toxicity as well as EDC information in light of actual or projected exposure concentrations.

Oregon Department of Environmental Quality Priority Persistent Pollutant List (P^3L)

In 2007, Oregon passed a law (Senate Bill 737) which required ODEQ to develop a prioritized list of persistent pollutants (the Priority Persistent Pollutant List or P^3L). Following development of this list, assessments will be made regarding sources and potential reductions in discharges of these materials to Oregon waters. This study presents their process in more detail because it is one of the few that have objective criteria that appear relevant to this WERF research, and because the ODEQ approach attempts to address some of the concerns raised previously regarding the PBT approach.

To address some of the concerns raised above regarding the PBT approach, DEQ, defined a persistent pollutant as "…a substance that is toxic and either persists in the environment or accumulates in the tissues of humans, fish, wildlife, or plants." Other PBT or persistent organic pollutant (POP) identification schemes have used a more restrictive definition that requires compounds to be persistent, bioaccumulative, and toxic. The broader definition used by ODEQ allowed for consideration of compounds that may not have been previously considered as PBTs,

including some pesticides, herbicides, suspected endocrine disruptors, industrial chemicals, pharmaceuticals and personal care products, and other "emerging" contaminants."

For the first prioritization step, ODEQ used EPA's online PBT Profiler to develop a compound-specific "total PBT score" that uses various data (including structure/activity relationship models [QSARS]) to estimate the potential persistence, bioaccumulative potential, and toxicity. A score of none to low (0), moderate (1), or high (2) was assigned to each of the three parameters of persistence, bioaccumulation, and toxicity (Table 2-1). Each of these values was summed to give a "total PBT score" (with a minimum value of 0 and a maximum of 6) for each chemical. ODEQ used a total PBT score of "3" as a prioritization cut-off point to focus the P^3L on those chemicals likely to be more persistent, bioaccumulative, or toxic.

Once PBT scores were calculated, ODEQ categorized the chemicals in one of three tiers, where Tier I is persistent chemicals originating primarily from anthropogenic sources, Tier II is for legacy chemicals that are persistent, and Tier III is for pollutants under review, including many pesticides, pharmaceuticals, and perfluorinated surfactants for which fate and effects data are scarce.

ODEQ identified 51 Tier I chemicals, 46 Tier II (legacy) chemicals, and 43 Tier III chemicals for a total of 140 chemicals on the ODEQ list. Tier I chemicals include 22 pesticides/herbicides, 13 pharmaceuticals, 4 perfluorinated surfactants, 2 PAHs, 1 phthalate ester, and 1 fuel antioxidizer. The December 2009 proposed ODEQ regulations set trigger levels for the priority persistent pollutants and requires any municipal wastewater facility with a dry weather design flow capacity of 1 million gallons per day to develop toxics reduction plans if any of those pollutants are found in their effluent above the trigger levels set by the rule.

The foregoing review of some of the existing chemical prioritization schemes raises several important points with respect to developing a useful prioritization framework for water resource managers and waste water utilities. First, the approach of taking high production volume (HPV) chemicals and then prioritizing them on the basis of toxicity and fate information is neither efficient nor likely to be especially helpful regarding ecological effects of TOrCs because: (1) many TOrCs with the greatest potency are not necessarily high production volume chemicals (e.g., EE2) and therefore aren't in the initial HPV list; and (2) the degree to which many HPV chemicals actually have a reasonable probability of entering surface water systems is often unknown. Recent efforts by the European Union have acknowledged that their chemical screening approach needs to expand beyond HPV chemicals and include low production volume chemicals, many of which might be endocrine disrupting chemicals (EDCs) (Petersen et al. 2007).

Second, it may be both more efficient and technically more defensible to base a prioritization framework on occurrence information rather than on modeled exposure concentrations because such a prioritization framework includes TOrCs that are known to occur in surface waters. Thus, there is no controversy as to whether the TOrC can occur in surface waters. For many monitoring programs, and particularly for those programs initiating monitoring of TOrCs, an occurrence-based prioritization process is more likely to yield a useful list of TOrCs.

Third, for many TOrCs, there are critical data gaps in terms of effect thresholds or mode of action. While some tools are available to partially address these gaps (e.g., use of QSARs for predicted toxicity data), information on other modes of action such as estrogenicity, might not be predicted using currently available models. Thus, ecological risk of some TOrCs will necessarily be characterized with high uncertainty.

CHAPTER 3.0

OCCURRENCE DATABASE

Given the above discussion, it appears most useful to base a TOrC prioritization framework on reasonably representative occurrence information. This approach is consistent with recommendations made in 2009 by a panel of experts at the SCCWRP conference on chemicals of emerging concern (SCCWRP, 2009). However, occurrence information alone is not sufficient for prioritizing TOrCs; occurrence concentrations must be placed in the context of relevant ecological effects information as well as fate characteristics (e.g., bioaccumulation potential, persistence), which together can help prioritize TOrCs in terms of potential ecological risk. This section describes the process used to obtain occurrence data for TOrCs as well as fate and effects information for those TOrCs.

3.1 Source of Occurrence Data

More than 100 studies were reviewed in search of monitoring data reporting the concentrations of TOrCs in U.S. waters. Emphasis was placed on TOrC occurrence data from freshwater systems and effluents because monitoring data for these media are most readily available. TOrC data for fish tissue, sediments, and estuarine systems will be compiled as well in the project database. Studies were sought that monitored primarily unregulated organic chemicals. In many cases, these studies also included more commonly monitored and regulated organic chemicals such as certain PCBs, PAHs, and legacy pesticides. The researchers included all organic chemicals monitored in a given study in the occurrence database. However, because they focused on studies of unregulated TOrCs, this occurrence database should not be construed as comprehensive regarding currently regulated chemicals.

Study QA/QC methods were checked prior to incorporating data into the occurrence database. Studies lacking established QA/QC protocols were not included. However, data were not audited nor were QC results obtained or evaluated for any study as this was beyond the resources of this research. Data in the occurrence database were assembled from an in-depth review of 70 peer-reviewed journal articles (three of which were review articles) and reports (including a report by the International Joint Commission on emerging contaminants in the Great Lakes Basin; Klecka et al., 2009) that had established QA/QC protocols. Table 3-1 summarizes general information regarding the studies in the occurrence database. The vast majority of observations presently in the occurrence database are for ambient surface water. Many geographic areas in the U.S. and Canada are represented in this database and both effluent-dominated and non-effluent surface waters are represented.

Table 3-1. Sample of References Used to Derive Occurrence Data as Well as Geographic Area Sampled, Sample Collection Date, Number of Sites, and Potential Sources of Organic Chemicals Identified in the Study.
Appendix A contains the full dataset with all sources identified.

Reference	Geographic area	Date collected	# of sites	Potential Source
Alvarez, D.A. et al. 2009	Potomac River watershed	2005-2006	6	Agriculture, wastewater, industrial, "other human activities"
Batt, A.L. et al. 2008	Surface water - North Shore Channel East Fork River (Chicago, IL), Wastewater - 7 WWTPs throughout NM.	2007	8	Wastewater
Benotti, M.J. et al. 2009	19 drinking water treatment plants across the U.S. (unspecified)	2006 - 2007	19	Various including: municipal wastewater effluent, agriculture, landfill leachates, and urban runoff.
Brun, G. L. et al. 2006	Canadian provinces of New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Laborador.	May and September 2003	8	Wastewater treatment plant effluent.
Campagnolo, E.R. et al. 2002	Iowa and Ohio	Oct. - Dec. 1998	14	Agriculture
Dorabawila, N and Gupta, G. 2005	Chesapeake Bay	Feb. 2004	18	Agriculture.
Drewes, J.E et al. 2009.	3 different states within the western United States	Oct. 2005	7	Wastewater.
Ferguson, P.L et al. 2001	Jamaica Bay, NY	Summer 1998 and September 1999	21	Urban wastewater effluent.
Focazio, M.J. et al. 2008.	U.S. Including Puerto Rico and Hawaii	2001	49	Wastewater
Frick, E.A. and Dalton, M.S. 2005	Apalachicola-Chattahoochee-Flint River Basin, Atlanta, Georgia.	October 2002-December 2003, July 2004-May 2005	6	Treated wastewater and untreated urban runoff.
Gagńe, F. et al. 2006	Canada	Unknown	1	Wastewater

Table 3-1. Sample of References Used to Derive Occurrence Data as Well as Geographic Area Sampled, Sample Collection Date, Number of Sites, and Potential Sources of Organic Chemicals Identified in the Study, Continued.

Reference	Geographic area	Date collected	# of sites	Potential Source
Guo, Y. C. et al. 2009.	California	2008-2009	31	Wastewater
Kolodziej, E.P. et al. 2004	North Eastern San Joaquin Valley, CA	May 2003 and September 2003	25	Agriculture and aquaculture.
Kolpin, D.W. et al. 2002	30 U.S. states.	1999-2000	139	Residential, industrial, and agricultural sources.
Lazorchak, J.M. et al. 2005	Little Miami River, Ohio	Feb. 2002 - Mar. 2003	4	Agriculture.
Metcalfe, C.D. et al. 2003	Canadian cities (national)	Oct. 1998 - Feb. 1999	18	Residential, industrial, and commercial wastewater.
Petty, J.D. et al. 2004	Throughout the city of Columbia, Missouri.	September 1999	5	Wastewater treatment plant effluent.
Ramirez, A.J. et al. 2009	Salt River in Phoenix, AZ, Little Econlockhatchee River in Orlando, FL, North Shore Channel in Chicago, IL, Taylor Run in West Chester, PA, Trinity River in Dallas, Texas, and Gila Wilderness Area, NM.	Aug. - Nov. 2006	6	Wastewater treatment plant effluent.
Seiders, K. et al. 2008	Washington state	2006	14	Surface water.
Sellin, M.K. et al. 2009	Eastern Nebraska	Summer 2006	8	Wastewater treatment plant effluent.
Thomas, P.M., Foster, G.D. 2004	Arlington County Water Pollution Control Plant, VA	Jan. 2004	1	Wastewater treatment plant effluent.

Occurrence data (documented occurrence) were compiled for 469 TOrCs (see Appendix A). Many chemicals were studied by multiple researchers and information on them was presented in several papers. The typical study contained data related to the frequency of detection and/or observed concentrations of TOrCs. If concentrations were reported for multiple sites in a single study the maximum value was recorded in the database. The primary focus of this task, as noted previously, is those TOrCs that are not currently regulated or commonly monitored and could be an ecological concern. Therefore, maximum concentration data presented for regulated TOrCs should be treated with caution. Given that a risk-based screening approach was desired in this research, maximum rather than median or mean observed concentrations were used for each TOrC. In addition, maximum values were commonly reported in the literature whereas median or mean occurrence concentrations were less frequently presented. Additional inspection of several sources of occurrence data indicated that the maximum value reported was typically within an order of magnitude of the median value when sufficient data were available for a given TOrC (Table 3-2).

TOrCs were grouped into one of 10 categories, which included:

- deodorizers/fragrances
- flame retardants
- industrial chemicals
- natural hormones/steroids
- PAHs
- personal care products
- pesticides
- pharmaceuticals
- plasticizers
- surfactant

Additionally, Appendix A includes information about the purpose of the monitoring and, if given, rationale for the choice of chemicals analyzed. The full database also presents the analysis methods used and the reporting or detection limits, geographical location of the sampling sites, and the major agency involved, where available.

Table 3-2. The Minimum, Median, Maximum, and Second Highest Value Reported, from a Different Monitoring Study for Select TOrCs. All Concentrations are μg/L.

Compound	CAS Number	Number of entries	Min	Median	Max	2nd Highest Value from Different Reference
17α-ethynylestradiol	57-63-6	18	ND	0.00195	0.273	0.0089
17β-estradiol	50-28-2	23	ND	0.0043	0.65	0.2
4-Nonylphenol	25154-52-3	12	0.13	0.57	40	15
Acetaminophen	103-90-2	14	0	0.13	10	9
Albuterol	18559-94-9	10	ND	0.014	0.06	0.036
Anthracene	120-12-7	10	0.000011	0.00865	0.5	0.5
Atrazine	1912-24-9	11	0.001	0.5	25	2.1
Bisphenol A	80-05-7	18	0.014	0.24	12	9.14
Caffeine	58-08-2	17	0.016	0.5	22	6
Carbamazepine	298-46-4	15	0.02	0.24	2.3	1.5
Carbaryl	63-25-2	11	ND	0.1	2	1
Chlorpyrifos	2921-88-2	10	0.00048	0.005	0.5	0.5
Cotinine	486-56-6	13	0.042	0.2	1	1
Diazinon	333-41-5	10	ND	0.225	0.6	0.51
Diclofenac	15307-86-5	12	0.0012	0.715	2.5	2.349
Diltiazem	42399-41-7	10	0.0034	0.0205	0.2	0.079
Erythromycin	114-07-8	16	0.009	0.28	5.7	1.842
Estrone	53-16-7	19	ND	0.0041	0.112	0.076
Fluoranthene	206-44-0	10	0.00032	0.1727	1.2	0.5
Fluoxetine	54910-89-3	11	ND	0.012	0.073	0.018
Gemfibrozil	25812-30-0	16	ND	0.054	1.4	1.3
Ibuprofen	15687-27-1	23	0.01	0.277	27.256	24.6
Metolachlor	51218-45-2	10	0.005	0.089	0.67	0.5
N,N-Diethyl-meta toluamide (DEET)	134-62-3	14	0.04	0.345	1.5	1.1
Naproxen	22204-53-1	10	0.023	1.22	33.9	14
Phenanthrene	85-01-8	10	0.00076	0.0525	0.53	0.5
Prometon	1610-18-0	10	0.0042	0.019	0.5	0.5
Pyrene	129-00-0	10	0.00017	0.1197	0.84	0.5
Ranitidine	66357-35-5	10	ND	0.0115	0.55	0.16
Sulfamethoxazole	723-46-6	19	0.064	0.212	2.2	1.9
Trimethoprim	738-70-5	19	0.001	0.14	1.288	0.71
Warfarin	81-81-2	10	ND	0.001	0.05	0.03

3.2 Fate and Effects Database

Data describing the fate, toxicity, and other useful aspects of identified TOrCs were assembled from a variety of sources (Table 3-3). Fate data for TOrCs were compiled from EPA's most recent EpiSuite database and PBT Profiler. Fate data includes: half-life (in water, soil, sediment, and air), octanol-water partition coefficient (K_{OW}), solubility in water, Henry's Constant, soil adsorption coefficient, and bioconcentration factors.

Effects data for TOrCs focused on predicted chronic toxicity thresholds for fish, *Daphnia*, and algae (based on QSAR models) and an estrogenic activity value (based on E2 equivalents) derived from FDA's database (see Table 3-3). Predicted chronic toxicity thresholds were obtained from ECOSAR and PBT profiler. In addition to the toxicity data discussed above, empirical toxicity endpoints were available for a subset of the TOrCs identified in our research. These toxicity endpoints were variable in form (e.g., non-standard test durations, use of sub-organismal measures) and, at this point, not suitable for inclusion in the larger database. However, this information has been updated in an additional database, which might prove useful for future understanding of potential impacts associated with selected TOrCs and predicted toxicity thresholds used in prioritization.

For purposes of prioritizing or screening TOrCs in terms of ecological risk, chronic toxicity and estrogenic activity thresholds were considered more relevant than physiological or other types of effect endpoints. In addition to the TOrCs having occurrence information, fate and effects information were also included for 48 high production volume (HPV) compounds identified as having a relatively high potential for ecological effects (Muir et al, 2009). Inclusion of these 48 chemicals provided a means to evaluate a prioritization approach that is not dependent on occurrence information only. Finally, where available, data on TOrC production volumes were included as well.

3.3 Calculation of Risk

Risk was calculated for each TOrC for which both effects and occurrence data were available. Three different risk quotients were calculated. First a risk value (RV) based on the most sensitive predicted chronic toxicity endpoint (i.e., fish, *Daphnia*, or algae) was calculated (see Equation 1). The calculation of a RV is similar to the calculation of a Risk Assessment Factor used by Arnot and Mackay (2008). An RV greater than 1.0 indicates that the maximum observed concentration of the selected TOrC exceeds the most sensitive predicted toxicity threshold.

Equation 1:

$$Risk\ Value = \frac{Max\ Occurrence Concentration}{Lowest\ Chronic\ Toxicity\ Threshold}$$

Table 3-3. Databases and Sources of Information on Trace Organic Compounds Used in Task 1.

Data Type	Database Name	Database Administration	Database Location
Persistence, bioaccumulation, and toxicity	PBT Profiler	U.S. EPA and Syracuse Research Corporation	www.pbtprofiler.net
	Fate of TOrCs in WWTPs	Grady and Magbanua 1998	WERF 920TFT-2
	Fate of PPCPs in wastewater	Stephenson and Oppenheimer 2007	WERF 03-CTS-22UR
	Fate of household chemicals in POTWs	Drewes et al. 2009	WERF 03-CTS-21UR
K_{OW}, water solubility, Henry's Constant	PhysProp Database	SRC	http://www.syrres.com/what-we-do/databaseforms.aspx?id=386
Toxicity	ECOSAR	U.S. EPA	http://www.epa.gov/oppt/newchems/tools/21ecosar.htm
Bioaccumulation and K_{OC}	EPI Suite	U.S. EPA	http://www.epa.gov/oppt/exposure/pubs/episuitedl.htm
Endocrine Disrupting Compounds	NA	Our Stolen Future	http://www.ourstolenfuture.org/basics/chemlist.htm
Endocrine Disrupting Compounds	NA	European Commission on Endocrine Disruptor Research	http://ec.europa.eu/research/endocrine/background_disruption_en.html
Endocrine Activity	Endocrine Disruptor Knowledge Base (EDKB)	FDA	http://edkb.fda.gov/
Chemical Production Volume	Inventory Update Reporting (IUR)	U.S. EPA	http://cfpub.epa.gov/iursearch/index.cfm?s=chem
Toxicity	P*h*ACT	P*h*RMA	Limited access

Two other risk quotients were calculated based on estrogenic effects. TOrCs in the occurrence database were cross-checked with the EDC database compiled by the EU (Table 3-3) to help determine whether a given TOrC was a known or probable EDC. Using the estrogenic activity for those TOrCs identified by EU as EDCs (based on FDA information normalized to E2), the estrogenic potency of each TOrC was identified. To convert these activity levels to biological effect thresholds, concentrations of EE2 were identified that *are not* likely to have an effect on aquatic life (e.g., a no effect concentration) and those that *are* likely to have an impact on aquatic life. This approach is somewhat analogous to that used in proposing sediment quality

guidelines (e.g., MacDonald et al, 2000). EE2 was selected because there is relatively abundant high quality effects data available for this chemical. The predicted no effect concentration (PNEC) for EE2 used was 0.35 ng/L (Caldwell et al., 2008) and the probable effect concentration (PEC) used was 5 ng/L (Kidd et al., 2007). The estrogenic activity values from FDA were then multiplied by the PNEC and PEC described above for EE2 to derive a PNEC and PEC for each TOrC with known estrogenic activity. Observed maximum occurrence concentrations and PNEC and PEC values were then used to calculate either a No Effect Endocrine Activity Risk Value (No Effect EARV) or a Probable Effect Endocrine Activity Risk Value (Probable Effect EARV) for each TOrC (where applicable) using Equations 2 and 3 below.

Equation 2:

$$No\ Effect\ EARV = \frac{Max\ Occurrence\ Concentration}{Normalized\ PNEC}$$

Equation 3:

$$Probable\ Effect\ EARV = \frac{Max\ Occurrence\ Concentration}{Normalized\ PEC}$$

For those TOrCs with No Effect EARV scores of 1.0 or below, the TOrC is unlikely to occur at sufficiently high enough concentrations to induce endocrine disrupting activity or cause reproductive effects. Therefore, the TOrC should be considered lower priority for risk on this basis. For those TOrCs with Probably Effect EARVs of 1.0 or greater, the TOrC may occur at concentrations sufficiently high to induce reproduction effects and the TOrC should be considered high priority for risk in general. For those TOrCs with No Effect EARV scores greater than 1.0, but Probable Effect EARV scores less than 1.0, there is high uncertainty and the TOrC may or may not occur at concentrations sufficiently high to induce endocrine disrupting effects.

CHAPTER 4.0

PROPOSED TORC PRIORITIZATION APPROACHES

Three different prioritization approaches have been developed in this research, which are designed to address different monitoring objectives or priorities as described below. It should be noted that the lists of high priority TOrCs generated using these approaches should not be taken as required monitoring lists or as compound lists for regulation because much is uncertain regarding the occurrence and effects of many TOrCs given our current state of knowledge.

4.1 Approach #1

The first approach is a simplistic but conservative risk-based prioritization based on 1) predicted chronic toxicity (from ECOSAR and PBT Profiler) or estrogenic activity (FDA database) of a chemical (whichever is more sensitive) and 2) its maximum observed concentration in the occurrence database. A risk quotient of maximum concentration divided by the most sensitive effect threshold is calculated for each chemical. While the occurrence database includes many studies and sites, the researchers recognize that is not complete and may under-represent the potential maximum environmental concentration for some chemicals and sites. To help account for this uncertainty, a risk quotient of 0.1 (as opposed to 1.0) is used as a high priority threshold in this approach. It should be noted that this screening approach has additional conservatism in using the maximum concentration observed thus far in surface waters and effluents. Had a median concentration been used, very few TOrCs would have risk quotients > 0.10.

This prioritization approach may be useful to wastewater utilities and other organizations that are interested in understanding the relative ecological risk of TOrCs based on those that have been monitored in various national and regional studies. Because this approach is based, in part, on observed TOrC measurements at many sites across the U.S., it may also provide a defensible starting point for those organizations initiating TOrC monitoring. In addition, this approach may be useful in a screening diagnostic tool for site-specific assessments involving a particular set of TOrCs.

4.2 Approach #2

The second prioritization approach uses a risk quotient similar to the first approach but converts the quotient to a score (1-3) that equates to low, medium, or high risk potential (see Table 4-1). In addition, this approach includes scores (1-3 or low, medium, or high risk) for two other categories: bioaccumulation potential (based on log K_{ow}) and persistence (based on half-life in water) for each TOrC in the occurrence database (see Table 4-1). Scoring for bioaccumulation and persistence are based on those used by Oregon DEQ and several other organizations (e.g., Environment Canada-DSL, EPA-TSCA). Scores based on predicted chronic toxicity or estrogenic activity, bioaccumulation potential, and half-life are summed for each chemical; the maximum score is 9. A high priority chemical is one that scores high (i.e., a score of 3) for at least one out of the three categories or a total score of at least 7. Approach #2 will provide a more inclusive list of TOrCs than that obtained using Approach #1 because

bioaccumulation potential and persistence are now also included as factors. Those chemicals with a score of 9 should be very high priority because: 1) they are known to occur at concentrations potentially exceeding toxicity or estrogenic thresholds, 2) they are highly bioaccumulative and therefore have the potential to have effects on upper trophic levels, and 3) they are highly persistent, suggesting that they have the potential for long-term exposures. Approach #2 may be useful for organizations needing a more comprehensive estimation of risk of different TOrCs, but are primarily concerned with those TOrCs that are likely to pose a potential ecological risk based on known occurrence information. This approach could also be useful in a site-specific screening diagnostic tool.

Table 4-1. Scoring for Parameters Used in Approach #2 and Approach #3.

Parameter	Used in Approach #	Low Risk (1)	Intermediate Risk (2)	High Risk (3)
Max of Risk Value, NEERAV, or PEERAV	2	< 0.01	< 0.1 to ≥ 0.01	≥ 0.1
log K_{ow}	2 and 3	< 3.0	< 5.0 to ≥ 3.0	≥ 5.0
Half-life in water	2 and 3	< 60 days	< 180 to ≥ 60 days	≥ 180 days
Toxicity	3	> 100 µg/L	> 10 to ≤ 100 µg/L	≤ 10 µg/L
1/No Effect EAV	3	< 0.00001	< 0.01 to ≥ 0.00001	≥ 0.01
1/Probable Effect EAV	3	< 0.00001	< 0.01 to ≥ 0.00001	≥ 0.01

4.3 Approach #3

This approach is similar to the "PBT" approach used by many organizations and includes the evaluation of several HPV chemicals considered high priority in the literature, as well as the TOrCs in the occurrence database. Approach #3 differs from the other two approaches chiefly in the fact that this approach does not rely on or use occurrence concentration information or risk quotients based on occurrence data. Thus, a TOrC could be scored as high priority using Approach #3 but may actually never occur (or cannot occur) in effluents or surface waters; or, if it could occur, it will always be present at concentrations well below predicted chronic toxicity threshold levels because of the way the chemical is used. Scoring of TOrCs using this approach is similar to that used in Approach #2 except that toxicity scores are based on the predicted toxicity values obtained from ECOSAR and PBT profiler or the inverse of the no effect endocrine activity value (EAV) or the probable effect EAV; they are not risk-based quotients (see Table 4-1). A high priority chemical is still one that receives a total score of at least 7. Organizations concerned with potential risk of TOrCs that might occur in waste streams or surface waters (e.g., chemical manufacturing companies) may find Approach #3 useful. Approach #3 may also be useful to those organizations concerned with occurrence and risk of TOrCs that may not be monitored currently but perhaps should be.

Each of the three prioritization approaches summarized above have advantages and limitations (see Table 4-2). For example, while Approach #1 is fairly simple to construct and communicate, and has reasonably high relevance related to ecological assessments, the

prioritized list of TOrCs is dependent on TOrC occurrence data, which is always incomplete. In addition, several researchers have noted that there is significant variability and false positive/negative issues that may confound occurrence data, particularly when low level reporting limits are required for some TOrCs. Thus, the TOrCs considered, and the maximum concentrations recorded may not truly represent TOrCs of highest concern in surface waters. This limitation is true for Approach #2 as well. Therefore, it is important that users understand both the advantages and limitations of each prioritization approach presented.

4.4 Comparisons Between the Three Prioritization Approaches

Table 4-3 presents the high priority TOrCs obtained using each of the three prioritization approaches summarized in the previous section. Both the number and types of high priority TOrCs are clearly different among the three lists, which is a direct reflection of the different approaches used. The fewest high priority TOrCs are obtained using Approach #1 (41 TOrCs) and the most TOrCs are obtained using Approach #3 (108 TOrCs).

Detailed analysis of the biological effect values used in Approaches #1 and 2 indicated that predicted chronic toxicity thresholds (based on QSAR information in ECOSAR and PBT Profiler) to either fish, *Daphnia*, or algae were more sensitive than estrogenic activity-based thresholds for all but 12 high priority TOrCs. The TOrCs for which estrogenic activity thresholds were more sensitive (and therefore

used instead of toxicity thresholds in the risk quotient) included: 17α-estradiol, 17β-estradiol, 17α-ethynylestradiol, Bisphenol A, Estriol, Estrone, Equilenin, Mestranol, Methoxychlor, Norethisterone, Tamoxifen, and Testosterone. These results may not be surprising in light of the fact that most TOrCs have purportedly weak estrogenic activity, if any, but they may be chronically toxic at relatively low concentrations in comparison with maximum occurrence concentrations identified in this research. It is important to recognize, however, that there are other potential endocrine effects besides estrogenic disruption and those that involve the hypothalamus-pituitary-gonad (HPG) axis and these cannot be readily characterized for TOrCs given the current state of knowledge (e.g., thyroid disruption effects). Even the characterization of estrogenic potential for TOrCs is imperfectly known at this time as noted by many researchers (Anderson, 2008). Therefore, it is expected that risk quotients will be refined as new information is collected.

Table 4-2. Advantages and Limitations of the Three Different Approaches Proposed for Prioritizing Trace Organic Chemicals (TOrCs).

Approach	Description	Advantages	Limitations
1	Risk-based: max concentration divided by most sensitive predicted effects threshold (toxicity or estrogenicity). Quotient ≥ 0.10 considered high priority.	Simple to use and communicate; based on actual measurements of TOrCs; considers TOrCs that are known to occur in surface waters; relatively high relevance to ecological risk.	Dependent on maximum concentrations observed and recorded in occurrence database; does not consider high production TOrCs not monitored.
2	Risk-based and fate-based: Sum of effect, bioaccumulation, and persistence scores; effect score based on quotient as in Approach #1; quotient ≥ 0.10 = score of 3 (highest priority); log K_{ow} ≥ 5.0 = score of 3; half-life in water ≥ 180 d = score of 3. Total score ≥ 7 is high priority TOrC.	Uses effects, bioaccumulation and persistence information for each TOrC-addresses fate as well as effects; based on TOrCs known to occur and that have been measured; relatively high relevance to ecological risk.	Dependent on TOrCs and their maximum concentrations in the occurrence database; does not consider HPV TOrCs not monitored.
3	Tox and fate-based: Sum of toxicity, bioaccumulation, and persistence scores; toxicity score based on predicted chronic toxicity; bioaccumulation and persistence scores same as in Approach #2.	Uses widely-accepted "PBT" approach-consistent chemical prioritization approaches used by other agencies; considers high production volume TOrCs as well as other TOrCs; not necessarily dependent on occurrence information; capable of identifying TOrCs that should be evaluated or have methods developed.	May include TOrCs that are unlikely to result in exposure to aquatic biota; based on toxicity effects, not endocrine effects; toxicity thresholds may have high uncertainty for some HPV TOrCs that don't have QSAR models.

Table 4-3. High Priority TOrCs Obtained from Each of the Three Prioritization Approaches.

Approach #1	Approach #2	Approach #3
Coprostanol	Pentachlorophenol	3-methylcholanthrene
17α-ethynylestradiol	PBDE-209	o,p'-DDE
Cholesterol	Tonalide	Mirex
Stigmastanol	Galaxolide	p,p'-DDE
β-sitosterol	Tamoxifen	cis-Nonachlor
Stigmasterol	Hexabromocyclododecane	p,p'-DDT
17β-estradiol	Desmosterol	p,p'-DDD
Bis(2-ethylhexyl)adipate	Cholesterol	o,p'-DDT
PBDE-209	Epicoprostanol	trans-Nonachlor
Bis(2-ethylhexyl)phthalate	Coprostanol	γ-Chlordane
Mestranol	Campesterol	trans-Chlordane
Di-N-octyl phthalate	Stigmasterol	Trifluralin
Desmosterol	β-sitosterol	Ethalfluralin
Cholestanol	Stigmastanol	Benfluralin
4-Nonylphenol	cis-Chlordane	PBDE-209
4-n-nonylphenol	Bis(2-ethylhexyl)adipate	Miconazole
Estrone	4-nonylphenol diethoxycarboxylate	cis-Chlordane
Testosterone	4-nonylphenol monoethoxylate	pentachloro-Benzenethiol
Novobiocin	4-Nonylphenol	3-chloro-2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)-Benzenamine
Campesterol	4-n-nonylphenol	Aldrin
4-nonylphenol diethoxycarboxylate	4-nonylphenol monoethoxycarboxylate	Bicyclo 2.2.1 hept-5-ene-2,3-dicarboxylic acid, 1,4,5,6,7,7-hexachloro-, dibutyl ester
4-nonylphenol monoethoxycarboxylate	Bis(2-ethylhexyl)phthalate	Lofepramine
17α-estradiol	Di-N-octyl phthalate	Octachlorostyrene
Bisphenol A	para-nonylphenol	1,3,6,8-tetrabromo-Pyrene
4-nonylphenol monoethoxylate	17α-ethynylestradiol	2,4,6-trimethyl-2,4,6-tris(3,3,3-trifluoropropyl)-Cyclotrisiloxane
Epicoprostanol	Oryzalin	1,1'- 1,2-ethanediylbis(oxy) bis 2,4,6-tribromo-Benzene
para-nonylphenol	Musk ketone	tetracosafluorotetradecahydro-Phenanthrene
Galaxolide	Mestranol	1H-Isoindole-1,3(2H)-dione, 2,2'-(1,2-ethanediyl)bis 4,5,6,7-tetrabromo-
Norethisterone	Triclosan	1,4:7,10-Dimethanodibenzo a,e cyclooctene, 1,2,3,4,7,8,9,10,13,13,14,14-dodecachloro-1,4,4a,5,6,6a,7,10,10a,11,12,12a-

Approach #1	Approach #2	Approach #3
Tamoxifen	Acetyl cedrene	Dibenz[a,h]anthracene
Tonalide	Fluoranthene	trans-permethrin
Estriol	OTNE	Heptachlor
Propranolol	Celestolide (ADBI)	Endrin
Fenoprofen	Benzo[a]pyrene	o,p'-DDD
Oryzalin	Clotrimazole	Hexachlorobenzene
Equilenin	Traseolide (ATII)	Oxychlordane
Hexabromocyclododecane	Musk xylene	cis-permethrin
Musk ketone	Methoxychlor	Pentachloroanisole (PCA)
3-tert-butyl-4-hydroxy anisole	Ethalfluralin	Methoxychlor
Pentachlorophenol	Benfluralin	Perylene
Triclosan	Trifluralin	Benzo[g,h,i]perylene
	Endrin	Permethrin
	Dieldrin	Indeno[1,2,3-c,d]pyrene
	Pentachloroanisole (PCA)	Pendimethalin
	Heptachlor	Benzo[e]pyrene
	Oxychlordane	Benzo[b]fluoranthene
	Hexachlorobenzene	Benzo[k]fluoranthene
	o,p'-DDD	Epicoprostanol
	o,p'-DDE	Phantolide (AHMI)
	p,p'-DDD	Hexabromocyclododecane
	trans-Nonachlor	Celestolide (ADBI)
	cis-Nonachlor	Campesterol
	trans-Chlordane	Traseolide (ATII)
	Miconazole	Musk xylene
	3-methylcholanthrene	Tamoxifen
	p,p'-DDE	Dieldrin
	o,p'-DDT	Benzo[a]pyrene
	Mirex	Desmosterol
	p,p'-DDT	Stigmasterol
	γ-Chlordane	Pentachlorophenol
		β-sitosterol
		Tonalide
		Stigmastanol
		Galaxolide
		Cholesterol
		Coprostanol
		Acetyl-hexamethyl-tetrahydro-napthalene (AHTM)
		Cyclohexasiloxane, dodecamethyl-Cyclohexasiloxane
		2,4,6-tris(1,1-dimethylethyl)-Phenol
		Perthane
		2-(2H-benzotriazol-2-yl)-4,6-bis(1,1-dimethylpropyl)-Phenol

Approach #1	Approach #2	Approach #3
		Hexadecamethyl heptasiloxane octadecamethyl-Octasiloxane
		Ergosterol
		tetrabromo-, bis(2-ethylhexyl) ester Phthalic acid
		Heptachlor epoxide
		2-Methylfluoranthene
		4-n-octylphenol
		Benzo[b]naphtho[2,1-d]thiophene
		Propargite
		Benzo[a]anthracene
		Chrysene
		Clotrimazole
		Chlorpyrifos
		Mestranol
		4-tert-octylphenol
		Musk ketone
		17α-ethynylestradiol
		Fluoranthene
		Acetyl cedrene
		OTNE
		Di-N-octyl phthalate
		para-nonylphenol
		Bis(2-ethylhexyl)adipate
		Bis(2-ethylhexyl)phthalate
		4-n-nonylphenol
		4-Nonylphenol
		Octylphenol
		β-estradiol-3-benzoate
		Heptamethylphenylcyclotetrasil oxane
		1,1'-ethylidenebis 3,4-dimethyl-Benzene
		2,4,6,8-tetraethenyl-2,4,6,8-tetramethyl-Cyclotetrasiloxane
		1,1,1,5,5,5-Hexamethyl-3,3-bis[(trimethylsilyl) oxy]-trisiloxane
		Dodecylmethylpentasiloxane
		triphenyl ester Phosphorous acid
		1,1'-Biphenyl, bis(1-methylethyl)-
		1,1,1,5,5,5-hexamethyl-3-phenyl-3-[(trimethylsilyl)oxy]-Trisiloxane
		1,3-DiNO2 2-CL 5-CF3 benzene

A summary of the general types of TOrCs represented in the high priority category for each of the three priority lists in Table 4-3 is shown in Figure 4-1. High priority TOrCs based on Approach #1 were primarily natural hormones/steroids, pharmaceuticals, and, surfactants, in descending order of importance. Approach #2 yielded a somewhat different representation, mostly comprised of pesticides. Approach #3 yielded a list very different from the other two lists with some representation of HPV TOrCs that are not in the occurrence database and have very limited information regarding the likelihood of

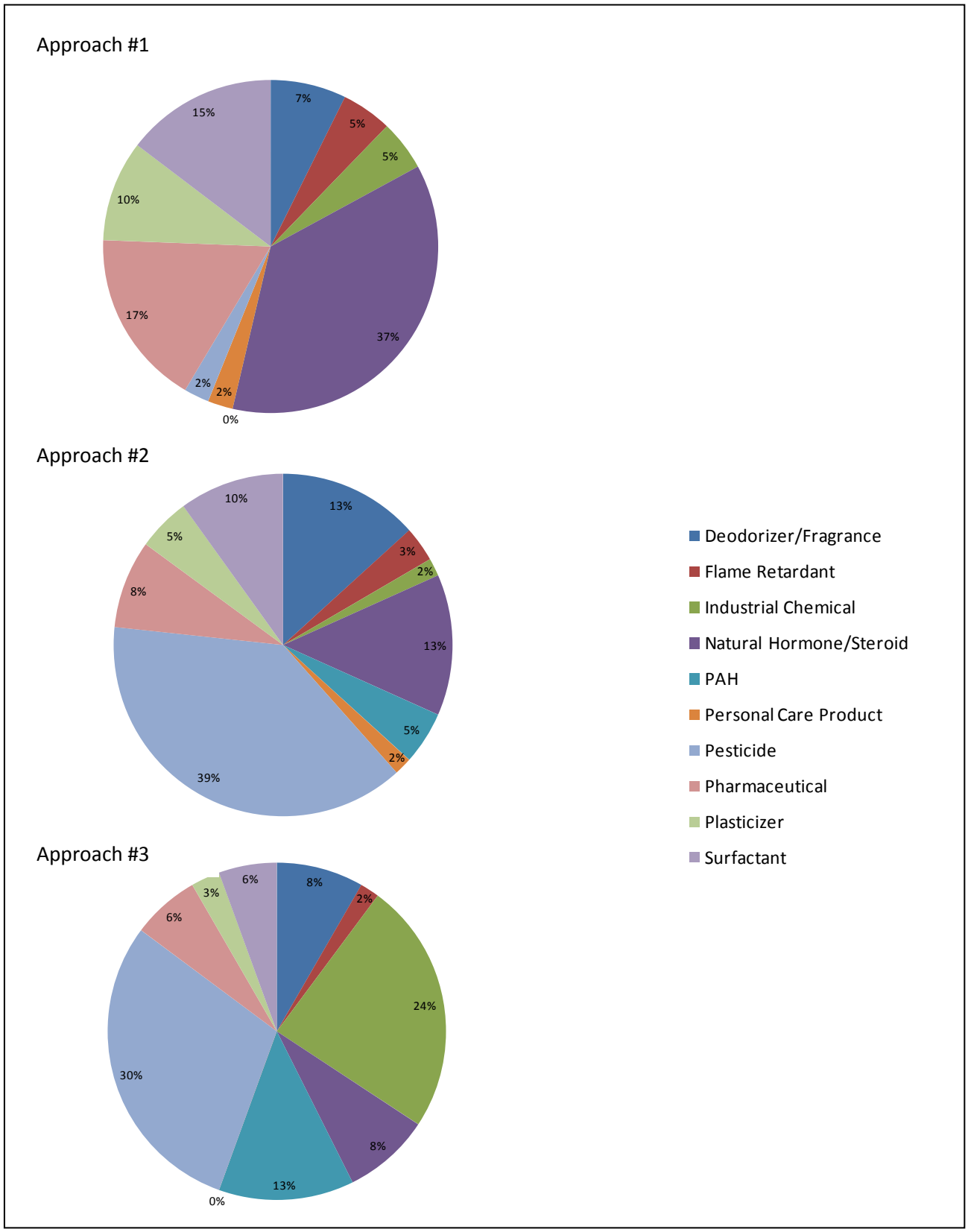

Figure 4-1. Types of High Priority TOrCs by Percentage Using Each of the Three Prioritization Approaches.

occurring in wastewater or in surface waters. 30% of the high priority TOrCs using Approach #3 were pesticides, while 24% and 13% were industrial chemicals and PAHs, respectively.

Figure 4-2 compares the high priority TOrCs from the three approaches based on bioaccumulation and persistence data. When considering bioaccumulation, most high priority TOrCs for all three approaches have half-lives in water from 60 days to greater than 180 days. Fifty-nine percent of the TOrCs identified using Approach #1 have high bioaccumulation potential ($K_{ow} \geq 5$). Approach #2 and #3 have 90% and 94% of the TOrCs identified as having a $K_{ow} \geq 5$, respectively.

Of the 108 high priority TOrCs identified using Approach #3, approximately 25 may not have low level analytical methods capable of detecting surface water concentrations near the effect thresholds identified in this research. More information on the use of these TOrCs should be obtained to determine whether they have a high likelihood of occurring in surface waters and therefore warrant method development.

There are 23 TOrCs common to all three high priority lists generated by each of the three prioritization approaches (Table 4-4). The types of TOrCs represented on this list include natural hormones/steroids (8), deodorizer/fragrances (3), pharmaceuticals (3), plasticizers (3), surfactants (3), flame retardants (2), and one industrial chemical. Also listed in Table 4-4 is whether each compound is an EDC, the species-type (fish, daphnid, or algae) most sensitive to chronic toxicity related to each TOrC, the most sensitive endpoint (either toxicity or endocrine activity), and an appropriate analytical method. For many of these TOrCs, EPA Method 1698 might be an appropriate method, pending more research and refinement. The current lack of robust, commercially available methods to reliably analyze many high priority TOrCs at low levels is a critical gap that needs to be addressed. Modeled toxicity data were available for each compound, but estrogenic activity and analytical method information are not available for some compounds.

Several high priority TOrCs identified using either Approach #1 or #2 appear to be monitored relatively infrequently based on occurrence information compiled in this research (see Table 4.5). In general, these TOrCs were not monitored by many of the larger monitoring studies conducted thus far, even though potential effects may be likely at concentrations that have been measured in surface waters in a few studies. Given the high bioaccumulative potential and/or persistence of many of these same TOrCs, future monitoring studies should consider analyzing these TOrCs.

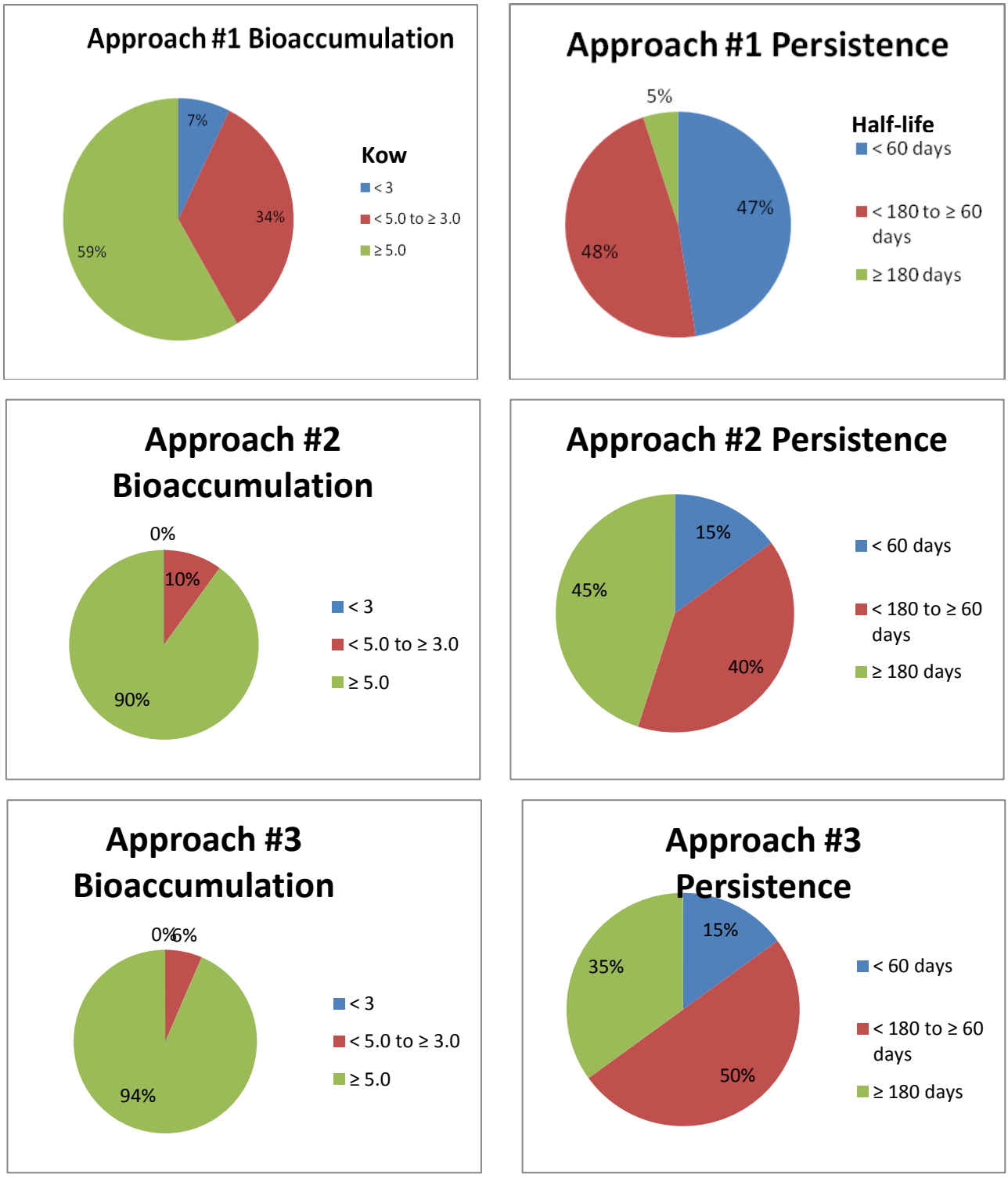

Figure 4-2. Percentage of Persistence and Bioaccumulation Categories for the Three Different Prioritization Approaches.

Table 4-4. Summary of TOrCs Listed as High Priority Using the Three Prioritization Approaches Indicating for Each if it is an Endocrine Disrupting Compound (EDC), the Most Sensitive Organism Type, the Most Sensitive Endpoint Type, and a Potential Analytical Method Reference (if available).

Note: analytical methods for most TOrCs are still being refined and should be used with caution.

Compound	CAS Number	Trace Organic Type	Use and/or Secondary Type	EDC[1]	Most Toxic[2]	Most Sensitive[3] Endpoint Type	Analytical Method Reference
17α-ethynylestradiol	57-63-6	Pharmaceutical	NA	Y	Daphnid	Endocrine Activity	EPA Method 1698
4-n-nonylphenol	104-40-5	Surfactant	NA	N	Fish	Toxicity	EPA Method 1613*
4-Nonylphenol	25154-52-3	Surfactant	nonionic detergent metabolite	N	Fish	Toxicity	EPA Method 1613*
Bis(2-ethylhexyl)adipate	103-23-1	Plasticizer	Cosmetics	N	Fish	Toxicity	EPA Method 8061
Bis(2-ethylhexyl)phthalate	117-81-7	Plasticizer	Cosmetics	N	Fish	Toxicity	EPA Method 8061
Campesterol	474-62-4	Natural Hormone/ Steroid	plant sterol, dietary supplement		Fish	Toxicity[4]	EPA Method 1698
Cholesterol	57-88-5	Natural Hormone/ Steroid	NA	N	Fish	Toxicity	EPA Method 1698
Coprostanol	360-68-9	Natural Hormone/ Steroid	fecal sterol, from the biohydrogenation of cholesterol	N	Fish	Toxicity	EPA Method 1698
Desmosterol	313-04-2	Natural Hormone/ Steroid	cholesterol precursor that accumulates in blood serum when cholesterol synthesis is inhibited	NA[4]	Fish	Toxicity[4]	EPA Method 1698
Di-N-octyl phthalate	117-84-0	Plasticizer	NA	N	Fish	Toxicity	NA
Epicoprostanol	516-92-7	Natural Hormone/ Steroid	a breakdown product of coprastanol	N	Fish	Toxicity	EPA Method 1698
Galaxolide	1222-05-5	Deodorizer/ Fragrance	musk fragrance	NA[4]	Fish	Toxicity[4]	NA
Hexabromocyclododecane	3194-55-6	Flame Retardant	NA	NA[4]	Daphnid	Toxicity[4]	NA

Table 4-4. Continued.

Compound	CAS Number	Trace Organic Type	Use and/or Secondary Type	EDC[1]	Most Toxic[2]	Most Sensitive[3] Endpoint Type	Analytical Method Reference
Mestranol	72-33-3	Pharmaceutical	ovulation inhibitor	Y	Fish	Endocrine Activity	EPA Method 1698
Musk ketone	81-14-1	Deodorizer / Fragrance	fragrance	NA[4]	Fish	Toxicity[4]	NA
para-nonylphenol	84852-15-3	Surfactant	nonionic detergent metabolite	NA[4]	Fish	Toxicity[4]	EPA Method 1613*
PBDE-209	1163-19-5	Flame Retardant	NA	NA[4]	Fish	Toxicity[4]	NA
Pentachlorophenol	87-86-5	Industrial Chemical	herbicide, fungicide, wood preservative	N	Fish	Toxicity[4]	EPA method 8270
Stigmastanol	19466-47-8	Natural Hormone / Steroid	plant steroid	NA[4]	Fish	Toxicity[4]	EPA Method 1698
Stigmasterol	83-48-7	Natural Hormone/ Steroid	plant steroid, dietary supplement, precursor in progesterone manufacture, may be useful in cancer prevention	NA[4]	Fish	Toxicity[4]	EPA Method 1698
Tamoxifen	10540-29-1	Pharmaceutical	anti-cancer	Y	Fish	Endocrine Activity	NA
Tonalide	21145-77-7	Deodorizer/ Fragrance	fragrance: musk	NA[4]	Fish	Toxicity[4]	NA
β-sitosterol	83-46-5	Natural Hormone/ Steroid	plant sterol, reduces cholesterol in blood, used in treating hyper-cholesterolemia	NA[4]	Fish	Toxicity[4]	EPA Method 1698

1 = Yes if EAV normalized to EE2 was greater than 0.001

2 = Based on ECOSAR ChV values

3 = Lesser of Minimum Toxicity Value and Probable Effect Concentration based on estrogenic activity

4 = No estrogenic acitivity data available

NA = Not Available; * =Tentative method pending validation

Table 4-5. High Priority TOrCs Using Either Prioritization Approach #1 or #2 that Appear to be Monitored Relatively Infrequently Thus Far in Many Monitoring Programs.

3-methylcholanthrene
4-nonylphenol diethoxycarboxylate
4-nonylphenol monoethoxycarboxylate
Acetyl cedrene
Benfluralin
Celestolide (ADBI)
Clotrimazole
Di-N-octyl phthalate
Musk xylene
Novobiocin
Oryzalin
OTNE

Of interest is how the TOrCs listed as high priority by this study compared to those listed as high priority (or equivalent) by other processes. To address this, the list of chemicals on Oregon DEQ's P^3L was compared to those TOrCs that were listed as high priority in any of the three approaches taken in this work. Of the 140 chemicals on ODEQ's list, 73 were not represented in the current lists. This is because no occurrence data were available for any of these 73 compounds and/or the compounds listed by ODEQ did not meet the definition of TOrC applied in this research. The Tetra Tech and ODEQ approaches resulted in 67 common compounds.

Of the 67 compounds in common between the ODEQ P^3L and the Tetra Tech list, 47 were also identified as high priority by Approach #3. This is expected because the ODEQ P^3L was constructed using a similar approach as used in Approach #3 (i.e., followed a PBT model). Interestingly, only nine of the 67 compounds in common between these approaches were considered to be high priority using Approach #1. This also makes sense in that observed ambient TOrC concentrations factored heavily in Approach #1 and were not considered at all in the ODEQ approach.

Many of the TOrC monitoring studies evaluated in this research focused entirely or in part on pharmaceuticals. Results of all three prioritization approaches yielded only a few pharmaceuticals of high priority (Table 4-3, Figure 4-1). Based on predicted toxicity or estrogenic activity, many of the other pharmaceuticals commonly monitored do not appear to pose a risk based on current information. This is also the case for many of the pharmaceuticals identified as high priority by Kostich and Lazorchak (2007). Of the top 50 pharmaceuticals they identified based on predicted non-human exposure concentrations and effects on biological systems, 26 were included in the occurrence database compiled in this research. However, only four of these compounds were identified as high priority based on the three prioritization approaches used (17α-ethynylestradiol, 17α-estradiol, 17β-estradiol, and Estriol). Furthermore, based on actual measurements, fate, and predicted toxicity/estrogenicity effects information, five pharmaceuticals were identified as high priority using Approach #1. However, these five compounds were not in the top 50 identified by Kostich and Lazorchak (Norethisterone, Mestranol, Novobiocin, Fenoprofen, and Tamoxifen). These results illustrate the difficulties in prioritizing TOrCs based on predicted occurrence or predicted effects information.

To date, the three prioritization approaches and subsequent lists of TOrCs generated in this research have been applied only to freshwater. Further consideration will be given to estuarine waters, sediments, and fish tissues (estuarine and freshwater) in the future. It is thought that perhaps fish tissue occurrence data could be used as a check on the list of high priority TOrCs because those TOrCs with larger K_{ow}s, should tend to bioaccumulate and thus be priority TOrCs in surface water.

The three approaches for estimating risk of TOrCs are similar in concept to the methodology used by various water resource agencies to assess risk of more commonly monitored chemicals (e.g., metals, legacy pesticides) in that a chemical by chemical approach is used. However, for TOrCs of interest in this research, the environmental protectiveness of this type of approach has been questioned. Many monitoring studies have documented that a number of TOrCs may occur together from a single source or at a site (Kolpin et al., 2002; Daughton and Teine, 1999; Snyder et al., 2003) and several laboratory studies have demonstrated additive effects of certain types of TOrCs (e.g., estrogenic hormones: Kortenkamp and Altenberger, 1999; Brian et al., 2007). As one example, the study by Vajda et al. (2008) reported that observed intersex in field collected white suckers was more accurately predicted based on the sum of estrogenically active hormones and steroid concentrations measured. These results indicate that while a chemical by chemical approach may be acceptable for developing screening risk quotients and prioritizing TOrCs that pose the greatest risk, actual site assessments need to consider the cumulative risk of the mixture of TOrCs present.

As stated at the outset of this prioritization exercise, the lists of high priority TOrCs listed above in this report should not be taken as desired monitoring lists or as criteria lists for regulation. High priority TOrCs are expected to vary somewhat with the region of the U.S. and types of TOrCs that may be generated. For example, in California and perhaps other areas of the U.S., some current use pesticides, such as diazinon and metolachlor, may be high priority TOrCs while in other areas, personal care products such as triclosan and bisphenol-A might be important TOrCs for monitoring. The prioritization approaches presented in this report, however, should prove useful for a utility or locality to help them organize, reduce, and manage the process of screening TOrCs.

APPENDIX A

THE PURPOSE OF STUDY AND RATIONALE FOR CHOOSING ANALYTES WHERE AVAILABLE FOR REFERENCES USED IN THE OCCURRENCE DATABASE

Reference	Reason for study	Reason for analytes
Alvarez, D.A. et al. 2008.	"To identify AOCs (anthropogenic organic compounds) in the river water and assess the estrogenicity of the complex mixtures of chemicals present using an in vitro assay"(1).	Chemicals were selected as representative anthropogenic organic chemicals that may be present from agricultural, industrial, and municipal inputs.
Alvarez, D.A. et al. 2009.	Determine seasonal occurrence of targeted chemicals.	Chemicals were selected as representative anthropogenic organic chemicals that may be present from agricultural, industrial, and municipal inputs.
Ashton, D. et al. 2004.	To provide lacking occurrence data on pharmaceuticals in aquatic environments in the UK.	"The substances selected for the monitoring program were identified by risk ranking procedure to identify those substances with the greatest potential to pose a risk to the aquatic environment" (1).
Baronti, C., et al. 2000.	To ascertain whether activated sludge STPs (ASSTPs) are able to produce significant amounts of free estrogens (1).	"Chemicals having estrogenic activity (denominated as endocrine disrupters) and thus able to interfere with the endocrine/reproductive functions in wild fish has been the object of studies and investigations (1)".
Batt, A.L. et al. 2008.	"Development of rapid and sensitive method for the analysis of 48 human prescription active pharmaceutical compounds"	Analytes were chosen based on "the prioritization of a list of the most prescribed APIs in the United States based on the potential of their wastewater residues to cause biological effects" (5022).
Benotti, M.J. et al. 2009.	"Describes results from a comprehensive survey of 20 pharmaceuticals, 25 known or potential EDC's, and 6 other wastewater contaminants in source water, finished drinking water, and distribution water from 19 U.S. DWTPs". "Results provide an assessment of the actual concentration to which people are exposed from drinking water."	20 pharmaceuticals and pharmaceutical metabolites were selected based on the following criteria: (a) prescription drug status, (b) volume of use, (c) toxicity, (d) occurrence and public interest, (e) pharmaceutical class, and (f) availability of analytical standards (597).

Reference	Reason for study	Reason for analytes
Boyd R.A. and Furlong E.T. 2002.	"To assess the occurrence of selected human-health pharmaceutical compounds in Lake Meade on the Colorado River in Nevada and Arizona and Las Vegas Wash, a waterway used to discharge treated effluent from the Las Vegas Valley to Lake Meade in Nevada" (2).	"Current research indicates many of these compounds can bioaccumulate and may adversely affect aquatic organisms by disrupting physiological processes, impairing reproductive functions, increasing cancer rates, contributing to the development of antibiotic-resistant strains of bacteria, and acting in undesirable ways when mixed with other substances (1)."
Campagnolo, E.R. et al. 2002.	"obtain background data on a broad profile of antimicrobial residues in animal wastes and surface water and groundwater proximal to large-scale swine and poultry operations." p. 89	
Carballa, M., et al. 2004.	"The aim of this study was therefore to investigate the behavior of 13 cosmetic and pharmaceutical compounds belonging to different groups (musks, anti-inflammatories, antiepileptics, tranquillizers, antibiotics, natural and synthetic estrogens and contrast media) along the different units of a municipal STP located in Galicia (NW Spain)" (2919).	The removal of pharmaceuticals and personal care products in municipal STPs is often incomplete; as a consequence significant fractions of PPCPs are discharged with the final effluent of the STP into the aquatic environment. (2919)
Cargouët, M. et al. 2004.	"There is a lack of information in France about the suspected contamination of rivers by EDCs" (56).	Among others, natural and synthetic estrogens have shown to be the most potent in vitro and in vivo studies (56).
Chambers, D.B. and Leiker, T. J. 2006.	"to present results of the analyses of passive-sampler extracts, stream water samples, wastewater effluent samples, and smallmouth bass blood plasma samples from sites in the South Branch Potomac River, Cacapon River, and Williams River Basin of West Virginia" (2).	Analytes were chosen based on the sources of contamination including: "runoff from agricultural activities, municipal and domestic wastewater effluent (both treated and untreated), industrial wastewater, and gypsy moth control programs using dimilin (diflubenzuron)" (4).
Costanzo, S.D. et al. 2007.	DEET "has commonly been detected in aquatic water samples from around the world, indicating that DEET is both mobile and persistent, despite earlier assumptions that DEET was unlikely to enter aquatic ecosystems. DEET's registration category does not require an ecological risk assessment, thus information on the ecological toxicity of DEET is sparse" (214).	DEET has not been subject to ecological risk assessment, but has been found in aquatic water samples worldwide.

Reference	Reason for study	Reason for analytes
Dorabawila, N and Gupta, G. 2005.	"measure the concentration of estradiol in the rivers, STPs on these rivers, ponds and Coastal Bays on the Chesapeake Bay Watershed on the Eastern Shore of MD" (68).	Estradiol (E2) is the most potent of all xenoestrogens (67).
Drewes, J.E et al. 2009.	"To study the occurrence and fate of HPV household chemicals and chemicals in household commodities in wastewater systems" (ES-1).	"The selection of compounds from the comprehensive list of approximately 720 compounds identified for further study and analysis followed a two tiered ranking approach based on production volumes, environmental relevance, and feasibility for analytical quantification" (ES-2).
Focazio, M.J. et al. 2008.	To provide new data and insights about the environmental presence of some of these chemicals in untreated sources of drinking water in the United States.	The relatively small subset of potential OWCs analyzed in these studies typically were targeted because of the large volumes that are manufactured and used, the chemical properties such as water solubility, and(or) the known or suspected toxicity to ecological or human health.
Frick, E. A. and Dalton, M. S. 2005.	"As part of the Source Water-Quality Assessment (SWQA)-one of the several study components within the U.S. Geological Survey's National Water-Quality Assessment Program- the source water and finished water for the city of Atlanta are being analyzed for the presence of more than 270 anthropogenic compounds" (1).	
Gagńe, F. et al. 2006.	"The purpose of this study was to examine the cytotoxic effects of PPCPs in primary cultures of rainbow trout hepatocytes" (329).	These products have the potential to produce a toxic response in aquatic organisms.
Giger, W. et al. 2006.	"The objective of this study was to investigate the environmental occurrence of BT and TT in Swiss rivers and lakes (7186)."	"Due to their low biodegradability and limited sorption tendency, BT and TT are only partly removed in wastewater treatment (7186)."
Guo, Y.C. et al. 2009.	Determine occurrence, fate, and transport of PPCPs in three drinking water sources.	
Heberer, T. 2002.	Give an overview and compile recent data on pharmaceutically active compounds originating from human application.	"The studies show that some PhACs originating from human therapy are not eliminated completely in the municipal STPs and are, thus, discharged as contaminants into the receiving waters (5)."
Kummerer, K., Steger-Hartmann, T., Meyer, M. 1997.	"...the biodegradability of the widely used anti-tumor agent ifosfamide (IF) was assessed with the modified Zahn-Wellens test (OECD 302 B) and a test simulating biological sewage treatment" (2705).	Some pharmaceuticals used as anti-tumor agents (such as IF) are carcinogenic, mutagenic, teratogenic and fetotoxic, and can be found in hospital effluent and municipal sewage.

Reference	Reason for study	Reason for analytes
King County. 2007.	"A pilot monitoring survey of King County surface waters was initiated for a select group of EDCs (endocrine disrupting chemicals) of concern. The primary purpose of this effort was to determine if these compounds are present in different types of waters, and if so, at what levels (1)."	"Although some chemicals classified as EDCs have been monitored in the past (e.g., PCBs, DDT), some of the EDCs of most recent concern (e.g., estrogenic hormones) have not been evaluated (1)."
Kolpin, D.W. et al. 2002.	"To provide the first nationwide reconnaissance of the occurrence of pharmaceuticals, hormones, and other organic wastewater contaminants (OWC) in water resources" (1202).	
Lindqvist, N., Tuhkanen, T., Kronberg, L. 2005.	"The occurrence of five acidic pharmaceuticals, ibuprofen, naproxen, ketoprofen, diclofenac, and bezafibrate, in seven different sewage treatment plants (STP) and three receiving waters were determined."	The removal in wastewater treatment plants has been shown to be incomplete and thus the pharmaceuticals are found as contaminates in surface waters throughout the world.
Loper, C.A. et al. 2007.	"The analyses are part of a study by the U.S. Geological Survey (USGS) in cooperation with the Pennsylvania Department of Environmental Protection (PADEP) to define concentrations of selected emerging contaminants in streams and well water in Pennsylvania (1)."	"Because of the potential for environmental disruption and perhaps human health effects, a better understanding of emerging contaminants and their fate is needed (2)."
Metcalfe, C.D. et al. 2003.	"to evaluate the occurrence and concentrations of prescription and nonprescription drugs in the effluents of sewage of sewage treatment facilities in Canada" (2872).	"Several neutral and acidic drugs were detected in effluents, including analgesic/anti-inflammatory agents, lipid regulators, and an antiepileptic drug, carbamazepine (2872)."
Murphy, S.F. et al, eds. 2003.	"The study was designed to capture a detailed profile of water quality during high-flow and low-flow conditions of Boulder Creek (6)."	
Petty, J.D. et al. 2004.	A proof-of concept field study for a suite of passive integrative samplers for ultra-trace to trace levels of complex mixtures of waterborne contaminants (696).	
Ramirez, A.J. et al. 2009.	"a pilot study to advance the science related to detecting PPCPs in the environment by investigating occurrence of PPCP chemicals in fish tissue" (8).	

Reference	Reason for study	Reason for analytes
Sando, S.K., et al. 2005.	"...to determine the occurrence of organic wastewater compounds (OWCs) in wastewater effluent and the Big Sioux River at or near the cities of Watertown, Volga, and Brookings in the upper Big Sioux River Basin during August 2003 through June 2004 (1)."	"A total of 125 different OWCs were analyzed for and were classified into six compound classes – human pharmaceutical compounds (HPCs), human and veterinary antibiotic compounds (HVACs), major agricultural herbicides (MAHs), household, industrial, and minor agricultural compounds (HIACs), polyaromatic hydrocarbons (PAHs), and sterol compounds (SCs) (1)."
Seiders, K. et al. 2008.	"Conduct exploratory monitoring to characterize toxic contaminants in fresh water fish across Washington where historical data are lacking" (9).	
Sellin, M. K. et al. 2009.	"to determine, if WWTP effluent contributes estrogens to surface waters of Nebraska" and "to determine if these compounds were found in quantities sufficient enough to manifest feminizing effects in fish" (15).	estrogenic compounds discharged by wastewater treatment plants can have feminizing effects on fish
Tertuliani, J.S. et al. 2008.	"...to determine the occurrence and distribution of organic wastewater compounds (OWCs) in the Tinkers Creek watershed in northeastern Ohio (1)."	"Many OWCs are characterized as 'contaminants of emerging concern' because they currently are not included in routine monitoring programs but may be candidates for future regulation once more becomes known about their toxicity and health effects (2)."
Thomas, P.M., Foster, G.D. 2004.	To determine if Gas Chromatography-Mass Spectrometry is suitable for the determination of a variety of pharmaceutical compounds (1976).	
U.S. EPA. 2009.	"to investigate the occurrence of Contaminants of Emerging Concern (CECs) in untreated and fully treated wastewater at publicly owned treatment works" (1).	"Conventional, non-conventional, and toxic pollutants, including many of the pollutants in EPA's 1982 "50-POTW Study" (EPA, 1982)" (1).
Williams, M. et al. 2007.	"To survey a number of Australian riverine systems impacted from a number of different activities to assess the levels of a selected group of estrogenic EDCs," "To assess the potential for endocrine disruption within the Australian riverine environment using available bioassays," and "To gain a better understanding of the risk EDCs present in the Australian environment and to provide the basis from which future assessments of endocrine disruption in Australian riverine systems could be made (iv)."	Selection of EDCs is usually undertaken by ranking EDCs based on a hazard assessment approach.

REFERENCES

Arnot, J.A. and D. Mackay. 2008. Policies for chemical hazard and risk priority setting: Can persistence, bioaccumulation, toxicity, and quantity information be combined? *Environmental Science & Technology* 42(13): 4648-4654.

Benotti, M.J., R.A. Trenholm, B.J .Vanderford, J.C. Holaday, B.D. Stanford, and S.A. Snyder. 2009. Pharmaceuticals and endocrine disrupting compounds in U.S. drinking water. *Environmental Science & Technology* 43(3): 597-603.

Brian, J., C. Harris, M. Cholze, A. Kortenkamp, P. Booy, M. Lamoree, G. Pojana, N. Jonkers, A. Comini, and J. Sumpter. 2007. Evidence of estrogenic mixture effects on the reproductive performance of fish. *Environ. Sci. Technol*. 41, 337-344.

Caldwell, D.J., F. Mastrocco, T.H. Hutchinson, R. Lange, D. Heijerick, C. Janssen, P.D. Anderson, and J.P. Sumpter. 2008. Derivation of an aquatic predicted no-effect concentration for the synthetic hormone, 17 α-Ethynl Estradiol. *Environmental Science and Technology* 42: 7046-7054.

Daughton, C. and T. Ternes. 1999. Pharmaceutical and personal care products in the environment: agents of subtle change? *Environ. Health Persp*. 107: 907-938.

Drewes, J., E. Dickenson, and S. Snyder. 2009. Contributions of Household Chemicals to Sewage and Their Relevance to Municipal Wastewater Systems and the Environment. Project #: 03-CTS-21UR, Water Environment Research Foundation, Alexandria, VA.

Environment Canada. 2006. Existing Substances Evaluation, Priorities for Assessment. Available on Environment Canada website: http://www.ec.gc.ca/substances/ese/eng/dsl/cat_criteria_process.cfm

Federal Register. 1999. Category for persistent, bioaccumulative, and toxic new chemical substances. Federal Register: November 4, 1999. Volume 64, Number 213.

Focazio, M.J., D.W. Kolpin, K.K. Barnes, E.T. Furlong, M.T. Meyer, S.D. Zaugg, L.B. Barber, and M.E. Thurman. 2008. A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States – II) Untreated drinking water sources. *Science of the Total Environment* 402: 201-216.

Grady, C. and B. Magbanua, Jr. 1998. Toxic organic Compounds: Fate and Biodegradation in Aerobic Systems. Project #: 920TFT-2. Water Environment Research Foundation, Alexandria, VA.

Guillette, L.J. and M.P. Gunderson. 2001. Alterations in development of reproductive and endocrine systems of wildlife populations exposed to endocrine-disrupting contaminants. *Reproduction* 122: 857-864.

Iwanowicz, L.R., V.S. Blazer, C.P. Guy, A.E. Pinkney, J.E. Mullican, and D.A. Alvarez. 2009. Reproductive health of bass in the Potomac, USA, drainage: Part 1. Exploring the effects of proximity to wastewater treatment plant discharge. *Environmental Toxicology and Chemistry* 28(5)" 1072-1083.

Kidd, K.A., P.J. Blanchfield, K.H. Mills, V.P. Palace, R.E. Evans, J.E. Lazorchak, R.W. Flick. 2007. Collapse of a fish population after exposure to a synthetic estrogen. Proceedings of the National Academy of Sciences 104: 8897-8901.

Klecka, G, C. Persoon, and R. Currie. 2009. Review of Contaminants of Emerging Concern and Analysis of Environmental Exposures in the Great Lakes Basin. International Joint Commission of the Great Lakes.

Klecka, G.M. and D.C.G. Muir. 2008. Science-based guidance and freamework for the evaluation and identification of PBTs and POPs: Summary of a SETAC Pellston workshop. Summary of the SETAC Pellston Workshop on Science-Based Guidance and Framework for the Evaluation and Identification of PBTs and POPs. January 28 – February 1, 2008; Pensacola Beach, FL; Society of Environmental Toxicology and Chemistry (SETAC).

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, 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.

Kortenkamp A., R. Altenburger. 1999. Approaches to assessing combination effects of oestrogenic environmental pollutants. *Science Total Environment* 233:131–140.

Kostich, M. and J. Lazorchak. 2007. Risks to aquatic organisms posed by human pharmaceutical use. *Science Total Environment* 389:329-339.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Archives of Environmental Contamination and Toxicology* 39(1): 20-31.

Muir, D.C.G. and P.H. Howard. 2006. Are there other persistent organic pollutants? A challenge for environmental chemists. *Environmental Science and Technology* 40(23): 7157-7166.

Muir, D., P.H. Howard, and W. Meylan. 2009. Developing analytical methodology for PB&T substances – a systematic process for identification of important chemicals. An update. Report updated March 11, 2009. Distributed as background material for 2009 SCCWRP workshop:

"Managing Contaminants of Emerging Concern in California: A Workshop to Develop Processes for Prioritizing, Monitoring, and Determining Thresholds of Concern."

Oregon Department of Environmental Quality. 2009. Senate Bill 737: Development of a priority persistent pollutant (P^3) list for Oregon. Oregon Department of Environmental Quality, Portland, OR.

Petersen, G., D. Rasmussen, and K. Gustavson. 2007. Study on enhancing the endocrine disrupter priority list with a focus on low production volume chemicals. ENV.D.4/ETU/2005/0028r. DG Environmental, DHI water & Environment, Europa, European Union, http://ec.europa.eu/environment/endocrine/documents/final_report_2007.pdf

Ramirez, A.J., R.A. Brain, S. Usenko, M.A. Mottaleb, J.G. O'Donnell, L.L. Stahl, J.B. Wathen, B.D. Snyder, J.L. Pitt, P. Perez-Hurtado, L.L. Dobbins, B.W. Brooks, and C.K. Chambliss. 2009. Occurrence of pharmaceuticals and personal care products in fish: Results of a national pilot study in the United States. *Environmental Toxicology and Chemistry*. In press

Snyder, S., P. Westerhoff, Y. Yoon, and D. Sedlak. 2003. Pharmaceuticals, personal care products, and endocrine disruptors in water: implications for the water industry. *Environ. Eng. Sci.* 20:449-456.

Southern California Coastal Water Research Project (SCCWRP). 2009. Managing Contaminants of Emerging Concern in California: A Workshop to Develop Processes for Prioritizing, Monitoring and Determining Thresholds of Concern. Summary Report. Costa Mesa, CA April 28-29, 2009. Costa Mesa, CA.

Stephenson, R. and J. Oppenheimer. 2007. Fate of Pharmaceuticals and Personal Care Products Through Municipal Wastewater Treatment Processes. Project #: 03-CTS-22UR. Water Environment Research Foundation, Alexandria, VA.

U.S. EPA. 2009. Occurrence of Contaminants of Emerging Concern in Wastewater From Nine Publicly Owned Treatment Works. EPA-821-R-09-009. Office of Water, Washington, D.C.

Vajda A., L. Barber, J. Gray, E. Lopez, J. Woodling, and D. Norris. 2008. Reproductive disruption in fish downstream from an estrogenic wastewater effluent. *Environ. Sci. Technol*. 2008, 42, 3407–3414

Williams, R.J., V.D.J. Keller, A.C. Johnson, A.R. Young, M.G.R. Holmes, C. Wells, M. Gross-Sorokin, and R. Benstead. 2009. A national risk assessment for intersex in fish arising from steroid estrogens. *Environmental Toxicology and Chemistry* 28(1): 220-230.

Williams, M., M. Woods, A. Kumar, G. Ying, A. Shareef, M. Karakkainen, and R. Kookana. 2007. Endocrine Disrupting Chemicals in the Australian Riverine Environment: A Pilot Study On Estrogenic Compounds. Land & Water Australia, Canberra, Australia.

WASTEWATER UTILITY

Alabama
Montgomery Water Works & Sanitary Sewer Board

Alaska
Anchorage Water & Wastewater Utility

Arizona
Avondale, City of
Glendale, City of, Utilities Department
Mesa, City of
Peoria, City of
Phoenix Water Services Dept.
Pima County Wastewater Management
Safford, City of
Tempe, City of

Arkansas
Little Rock Wastewater Utility

California
Central Contra Costa Sanitary District
Corona, City of
Crestline Sanitation District
Delta Diablo Sanitation District
Dublin San Ramon Services District
East Bay Dischargers Authority
East Bay Municipal Utility District
El Dorado Irrigation District
Fairfield-Suisun Sewer District
Fresno Department of Public Utilities
Inland Empire Utilities Agency
Irvine Ranch Water District
Las Gallinas Valley Sanitary District
Las Virgenes Municipal Water District
Livermore, City of
Los Angeles, City of
Los Angeles County, Sanitation Districts of
Napa Sanitation District
Novato Sanitary District
Orange County Sanitation District
Palo Alto, City of
Riverside, City of
Sacramento Regional County Sanitation District
San Diego Metropolitan Wastewater Department, City of
San Francisco, City & County of
San Jose, City of
Santa Barbara, City of
Santa Cruz, City of
Santa Rosa, City of
South Bayside System Authority
South Coast Water District
South Orange County Wastewater Authority
South Tahoe Public Utility District
Stege Sanitary District
Sunnyvale, City of
Union Sanitary District
West Valley Sanitation District

Colorado
Aurora, City of
Boulder, City of
Greeley, City of
Littleton/Englewood Water Pollution Control Plant
Metro Wastewater Reclamation District, Denver

Connecticut
Greater New Haven WPCA
Stamford, City of

District of Columbia
District of Columbia Water & Sewer Authority

Florida
Broward, County of
Fort Lauderdale, City of
Jacksonville Electric Authority (JEA)
Miami-Dade Water & Sewer Authority
Orange County Utilities Department
Pinellas, County of
Reedy Creek Improvement District
Seminole County Environmental Services
St. Petersburg, City of
Tallahassee, City of
Toho Water Authority
West Palm Beach, City of

Georgia
Atlanta Department of Watershed Management
Augusta, City of
Clayton County Water Authority
Cobb County Water System
Columbus Water Works
Fulton County
Gwinnett County Department of Public Utilities
Savannah, City of

Hawaii
Honolulu, City & County of

Idaho
Boise, City of

Illinois
Decatur, Sanitary District of
Greater Peoria Sanitary District
Kankakee River Metropolitan Agency
Metropolitan Water Reclamation District of Greater Chicago
Wheaton Sanitary District

Indiana
Jeffersonville, City of

Iowa
Ames, City of
Cedar Rapids Wastewater Facility
Des Moines, City of
Iowa City

Kansas
Johnson County Wastewater
Unified Government of Wyandotte County/ Kansas City, City of

Kentucky
Louisville & Jefferson County Metropolitan Sewer District
Sanitation District No. 1

Louisiana
Sewerage & Water Board of New Orleans

Maine
Bangor, City of
Portland Water District

Maryland
Anne Arundel County Bureau of Utility Operations
Howard County Bureau of Utilities
Washington Suburban Sanitary Commission

Massachusetts
Boston Water & Sewer Commission
Massachusetts Water Resources Authority (MWRA)
Upper Blackstone Water Pollution Abatement District

Michigan
Ann Arbor, City of
Detroit, City of
Holland Board of Public Works
Saginaw, City of
Wayne County Department of Environment
Wyoming, City of

Minnesota
Rochester, City of
Western Lake Superior Sanitary District

Missouri
Independence, City of
Kansas City Missouri Water Services Department
Little Blue Valley Sewer District
Metropolitan St. Louis Sewer District

Nebraska
Lincoln Wastewater & Solid Waste System

Nevada
Henderson, City of
Las Vegas, City of
Reno, City of

New Jersey
Bergen County Utilities Authority
Ocean County Utilities Authority

New York
New York City Department of Environmental Protection

North Carolina
Charlotte/Mecklenburg Utilities
Durham, City of
Metropolitan Sewerage District of Buncombe County
Orange Water & Sewer Authority
University of North Carolina, Chapel Hill

Ohio
Akron, City of
Butler County Department of Environmental Services
Columbus, City of
Metropolitan Sewer District of Greater Cincinnati
Montgomery, County of
Northeast Ohio Regional Sewer District
Summit, County of

Oklahoma
Oklahoma City Water & Wastewater Utility Department
Tulsa, City of

Oregon
Albany, City of
Clean Water Services
Eugene, City of
Gresham, City of
Portland, City of Bureau of Environmental Services
Lake Oswego, City of
Oak Lodge Sanitary District
Water Environment Services

Pennsylvania
Hemlock Municipal Sewer Cooperative (HMSC)
Philadelphia, City of
University Area Joint Authority

South Carolina
Charleston Water System
Mount Pleasant Waterworks & Sewer Commission
Spartanburg Water

Tennessee
Cleveland Utilities
Murfreesboro Water & Sewer Department
Nashville Metro Water Services

Texas
Austin, City of
Dallas Water Utilities
Denton, City of
El Paso Water Utilities

Fort Worth, City of
Houston, City of
San Antonio Water System
Trinity River Authority

Utah

Salt Lake City Corporation

Virginia

Alexandria Sanitation Authority
Arlington, County of
Fairfax, County of
Hampton Roads Sanitation District
Hanover, County of
Henrico, County of
Hopewell Regional Wastewater Treatment Facility
Loudoun Water
Lynchburg Regional Wastewater Treatment Plant
Prince William County Service Authority
Richmond, City of
Rivanna Water & Sewer Authority

Washington

Everett, City of
King County Department of Natural Resources
Seattle Public Utilities
Sunnyside, Port of
Yakima, City of

Wisconsin

Green Bay Metro Sewerage District
Kenosha Water Utility
Madison Metropolitan Sewerage District
Milwaukee Metropolitan Sewerage District
Racine, City of
Sheboygan Regional Wastewater Treatment
Wausau Water Works

Water Services Association of Australia

ACTEW Corporation
Barwon Water
Central Highlands Water
City West Water
Coliban Water Corporation
Cradle Mountain Water
Gippsland Water
Gladstone Area Water Board
Gold Coast Water
Gosford City Council
Hunter Water Corporation
Logan Water
Melbourne Water
Moreton Bay Water
Onstream
Power & Water Corporation
Queensland Urban Utilities
SEQ Water
South Australia Water Corporation
Sunshine Coast Water
Sydney Catchment Authority
Sydney Water
Unity Water
Wannon Regional Water Corporation
Watercare Services Limited (NZ)
Water Corporation
Western Water
Yarra Valley Water

Canada

Edmonton, City of/Edmonton Waste Management Centre of Excellence
Lethbridge, City of
Regina, City of, Saskatchewan
Toronto, City of, Ontario
Winnipeg, City of, Manitoba

STORMWATER UTILITY

California

Fresno Metropolitan Flood Control District
Los Angeles, City of, Department of Public Works
Monterey, City of
San Francisco, City & County of
Santa Rosa, City of
Sunnyvale, City of

Colorado

Aurora, City of
Boulder, City of

Florida

Orlando, City of

Iowa

Cedar Rapids Wastewater Facility
Des Moines, City of

Kansas

Lenexa, City of
Overland Park, City of

Kentucky

Louisville & Jefferson County Metropolitan Sewer District

Maine

Portland Water District

North Carolina

Charlotte, City of, Stormwater Services

Pennsylvania

Philadelphia, City of

Tennessee

Chattanooga Stormwater Management

Texas

Harris County Flood Control District, Texas

Washington

Bellevue Utilities Department
Seattle Public Utilities

STATE

Connecticut Department of Environmental Protection
Kansas Department of Health & Environment
New England Interstate Water Pollution Control Commission (NEIWPCC)
Ohio Environmental Protection Agency
Ohio River Valley Sanitation Commission
Urban Drainage & Flood Control District, CO

CORPORATE

ADS LLC
Advanced Data Mining International
AECOM
Alan Plummer & Associates
Alpine Technology Inc.
Aqua-Aerobic Systems Inc.
Aquateam–Norwegian Water Technology Centre A/S
ARCADIS
Associated Engineering
Bernardin Lochmueller & Associates
Black & Veatch
Blue Water Technologies, Inc.
Brown & Caldwell
Burgess & Niple, Ltd.
Burns & McDonnell
CABE Associates Inc.
The Cadmus Group
Camp Dresser & McKee Inc.
Carollo Engineers Inc.
Carpenter Environmental Associates Inc.
CET Engineering Services
CH2M HILL
CRA Infrastructure & Engineering
CONTECH Stormwater Solutions
D&B/Guarino Engineers, LLC
Damon S. Williams Associates, LLC
Ecovation
EMA Inc.
Environmental Operating Solutions, Inc.
Environ International Corporation
Fay, Spofford, & Thorndike Inc.
Freese & Nichols, Inc.
ftn Associates Inc.
Gannett Fleming Inc.
Garden & Associates, Ltd.
Geosyntec Consultants
GHD Inc.
Global Water Associates
Greeley and Hansen LLC
Hazen & Sawyer, P.C.
HDR Engineering Inc.
HNTB Corporation
Hydromantis Inc.
HydroQual Inc.
Infilco Degremont Inc.
Jason Consultants LLC Inc.
Jordan, Jones, & Goulding Inc.
KCI Technologies Inc.
Kelly & Weaver, P.C.
Kennedy/Jenks Consultants
Larry Walker Associates
LimnoTech Inc.
Lombardo Associates, Inc.
The Low Impact Development Center Inc.
Malcolm Pirnie Inc.
Material Matters, Inc.
McKim & Creed
MWH
NTL Alaska, Inc.
O'Brien & Gere Engineers Inc.
Odor & Corrosion Technology Consultants Inc.
Parametrix Inc.
Parsons
Post, Buckley, Schuh & Jernigan
Praxair, Inc.
RMC Water & Environment
Ross & Associates Ltd.
SAIC
Siemens Water Technologies
The Soap & Detergent Association
Smith & Loveless, Inc.
Southeast Environmental Engineering, LLC
Stone Environmental Inc.
Stratus Consulting Inc.
Synagro Technologies Inc.
Tetra Tech Inc.
Trojan Technologies Inc.
Trussell Technologies, Inc.
URS Corporation
Wallingford Software
Westin Engineering Inc.
Wright Water Engineers
Zoeller Pump Company

INDUSTRY

American Electric Power
American Water
Anglian Water Services, Ltd.
Chevron Energy Technology
The Coca-Cola Company
Dow Chemical Company
DuPont Company
Eastman Chemical Company
Eli Lilly & Company
InsinkErator
Johnson & Johnson
Merck & Company Inc.
Procter & Gamble Company
Suez Environnment
United Utilities North West (UUNW)
United Water Services LLC
Veolia Water North America

Note: List as of 4/20/10

WERF Board of Directors

Chair
Alan H. Vicory, Jr., P.E., BCEE
Ohio River Valley Water Sanitation Co

Vice-Chair
William P. Dee, P.E., BCEE
Malcolm Pirnie, Inc.

Secretary
William J. Bertera
Water Environment Federation

Treasurer
Jeff Taylor
Freese and Nichols, Inc.

Patricia J. Anderson, P.E.
Florida Department of Health

Jeanette A. Brown, P.E., BCEE, D.WRE
Stamford Water Pollution Control Authority

Catherine R. Gerali
Metro Wastewater Reclamation District

Charles N. Haas, Ph.D., BCEEM
Drexel University

Stephen R. Maguin
Sanitation Districts of Los Angeles County

Karen L. Pallansch, P.E., BCEE
Alexandria Sanitation Authority

Robert A. Reich, P.E.
DuPont Company

R. Rhodes Trussell, Ph.D., P.E.
Trussell Technologies Inc.

Rebecca F. West
Spartanburg Water

Brian L. Wheeler
Toho Water Authority

Joseph E. Zuback
Global Water Advisors, Inc.

Executive Director
Glenn Reinhardt

WERF Research Council

Chair
Karen L. Pallansch, P.E., BCEE
Alexandria Sanitation Authority

Vice-Chair
John B. Barber, Ph.D.
Eastman Chemical Company

William J. Cooper, Ph.D.
University of California-Irvine

Ann Farrell, P.E.
Central Contra Costa Sanitary District (CCCSD)

Robbin W. Finch
Boise, City of

Thomas Granato, Ph.D.
Metropolitan Water Reclamation District of Greater Chicago

James A. Hanlon
U.S. Environmental Protection Agency

James A. Hodges, CPEng.
Watercare Services Limited

David Jenkins, Ph.D.
University of California at Berkeley

Lloyd W. Johnson, M.P.D., P.E.
Aqua-Aerobic Systems, Inc.

Terry L. Johnson, Ph.D., P.E., BCEE
Black & Veatch Corporation

Beverley M. Stinson, Ph.D.
AECOM

Susan J. Sullivan
New England Interstate Water Pollution Control Commission (NEIWPCC)

WERF Product Order Form

As a benefit of joining the Water Environment Research Foundation, subscribers are entitled to receive one complimentary copy of all final reports and other products. Additional copies are available at cost (usually $10). To order your complimentary copy of a report, please write "free" in the unit price column. WERF keeps track of all orders. If the charge differs from what is shown here, we will call to confirm the total before processing.

Name _____ Title _____

Organization _____

Address _____

City _____ State _____ Zip Code _____ Country _____

Phone _____ Fax _____ Email _____

Stock #	Product	Quantity	Unit Price	Total

Postage & Handling	
VA Residents Add 5% Sales Tax	
Canadian Residents Add 7% GST	
TOTAL	

Method of Payment:

(All orders must be prepaid.)

- ❑ Check or Money Order Enclosed
- ❑ Visa ❑ Mastercard ❑ American Express

Account No. _____ Exp. Date _____

Signature _____

Shipping & Handling:

Amount of Order	United States	Canada & Mexico	All Others
Up to but not more than:	Add:	Add:	Add:
$20.00	$7.50*	$9.50	50% of amount
30.00	8.00	9.50	40% of amount
40.00	8.50	9.50	
50.00	9.00	18.00	
60.00	10.00	18.00	
80.00	11.00	18.00	
100.00	13.00	24.00	
150.00	15.00	35.00	
200.00	18.00	40.00	
More than $200.00	Add 20% of order	Add 20% of order	

* minimum amount for all orders

Make checks payable to the Water Environment Research Foundation.

To Order (Subscribers Only):

Log on to www. werf.org and click on "Publications."

Phone: 571-384-2100
Fax : 703-299-0742

WERF
Attn: Subscriber Services
635 Slaters Lane
Alexandria, VA 22314-1177

To Order (Non-Subscribers):

Non-subscribers may order WERF publications either through WERF or IWAP (www.iwapublishing.com). Visit WERF's website at www.werf.org for details.

Water Environment Research Foundation
635 Slaters Lane, Suite G-110 ■ Alexandria, VA 22314-1177
Phone: 571-384-2100 ■ Fax: 703-299-0742 ■ Email: werf@werf.org
www.werf.org
WERF Stock No. CEC5R08a

Co-published by

IWA Publishing
Alliance House, 12 Caxton Street
London SW1H 0QS
United Kingdom
Phone: +44 (0)20 7654 5500
Fax: +44 (0)20 7654 5555
Email: publications@iwap.co.uk
Web: www.iwapublishing.co
IWAP ISBN: 978-1-84339-535-5/1-84339-535-5

Sept 2010