

Pharmaceuticals, Personal Care Products & Other Contaminants in Wastewater



Bryan W. Brooks, Ph.D.

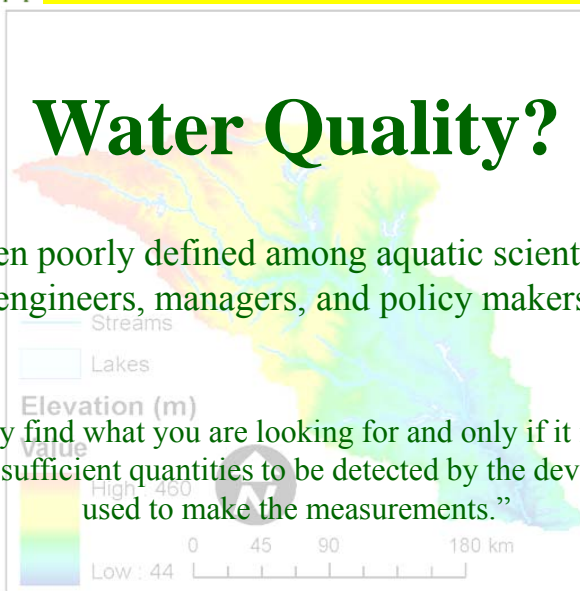
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Water Quality?

Often poorly defined among aquatic scientists, engineers, managers, and policy makers

“You only find what you are looking for and only if it is present in sufficient quantities to be detected by the device used to make the measurements.”



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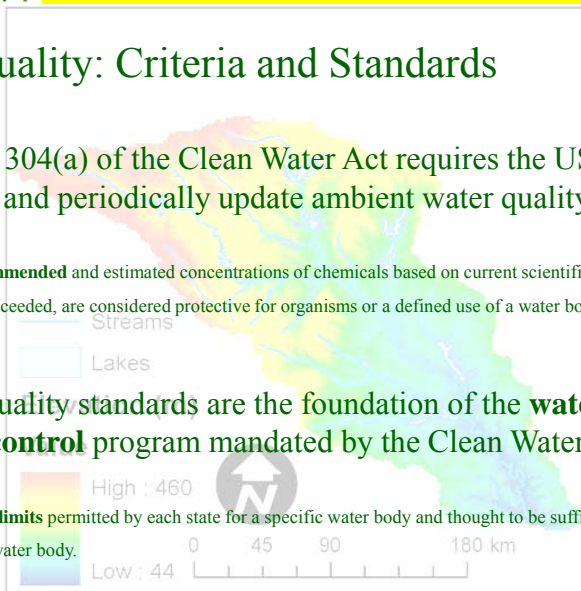
Water Quality: Criteria and Standards

I. Section 304(a) of the Clean Water Act requires the USEPA to publish and periodically update ambient water quality criteria.

Criteria: Recommended and estimated concentrations of chemicals based on current scientific information that, if not exceeded, are considered protective for organisms or a defined use of a water body.

II. Water quality standards are the foundation of the **water quality based control** program mandated by the Clean Water Act (CWA).

Standards: Legal limits permitted by each state for a specific water body and thought to be sufficient to protect that water body.



Centralized Wastewater Quality



- Point source “effluent” water quality evaluated by whole effluent toxicity tests, chemistry, pathogens
- Biological integrity evaluated by “ambient” toxicity tests, biotic surveys, biomarkers



Decentralized Wastewater Quality



- Compared to centralized effluents, onsite effluent quality is often quantified with basic measures of water quality
 - Total Suspended Solids (TSS)
 - Carbonaceous Biochemical Oxygen Demand (CBOD)
- Limited information on potential impacts to aquatic life
- Increasing interest in pathogens, nutrients, emerging pollutants of concern

“Emerging” Contaminants

- Unregulated compounds that have limited environmental chemistry, hazard information
- Harmful algal toxins (e.g., microcystins)
 - Nanomaterials (e.g., fullerenes, nanotubes, TiO₂)
 - Select fluorinated (PFOS), brominated compounds (PBDEs)
 - New generation pesticides (e.g., pyrethroids)

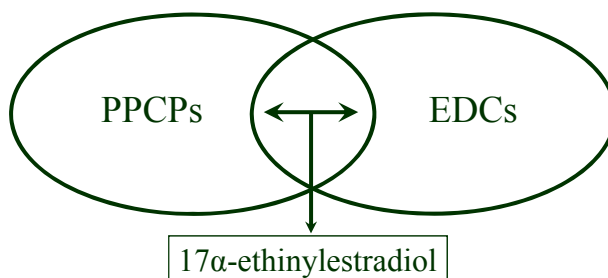
Emerging Contaminants?

- **Pharmaceuticals and Personal Care Products (PPCPs)**

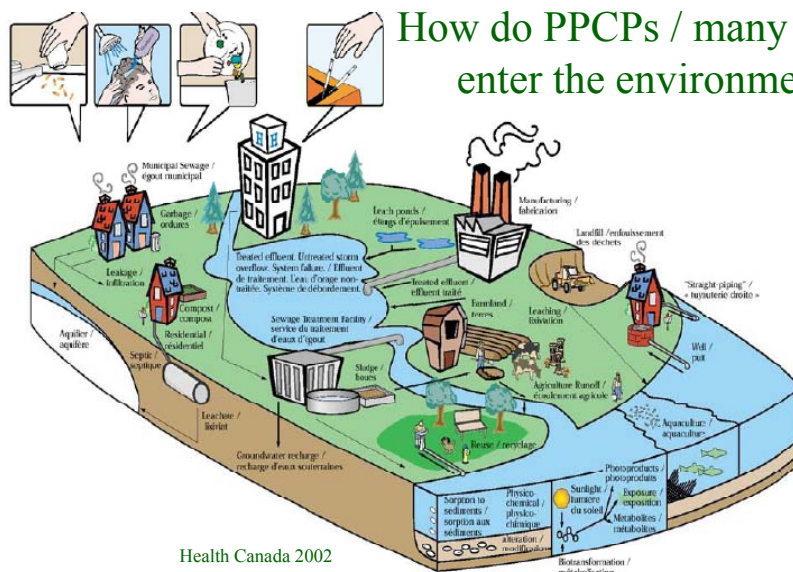
- Heart medications, Antidepressants, Antibiotics, Antimicrobials, Fragrances (e.g., musks), etc

- **Endocrine Disrupting/Modulating Compounds (EDCs)**

- Surfactants, Plasticizers, Pesticides, Steroids, etc



How do PPCPs / many EDCs enter the environment?



Health Canada 2002

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PPCPs and EDCs

Attention in the Popular Press...

CNN SCIENCE & SPACE
Frogs, fish and pharmaceuticals a troubling brew
Prozac, other drugs detected in streams and their inhabitants

Fish on Prozac? How depressing!
Antidepressant ingredient detected in Texas lake water

M5 NBC **REUTERS**

FIELD & STREAM
THE WORLD'S LEADING OUTDOOR MAGAZINE

...muddy,

washingtonpost.com

“Male fish becoming female? Researchers worry about estrogen & pollutants in the water”
NBC Nightly News, November 9, 2004

C&EN
PHARMACEUTICAL POLLUTION

...and many others from the LA Times, Globe, Chicago Tribune, NPR Science USA Today, NY Times, etc.

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Ecological Risk Assessment

Prospective and Retrospective

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graph TD
    A[Problem Formulation] --> B((Exposure & RISK & Effects))
    B --> C[Risk Characterization]
    C --> D[Risk Management]
            
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Assessment Endpoints:
structure, function

Measures of Effect:
survival, growth, reproduction

Deterministic Approach:
 $[Exposure] / [Effect] > 1$

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BAYLOR UNIVERSITY **Weight of Evidence: Lab, Field Studies**

Ceriodaphnia dubia

Pecan Creek: An Effluent-dominated Stream, Denton County, TX, USA

Layout and dimensions of the BEAR Facility, top view.

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BAYLOR UNIVERSITY **Potential Worst Case Scenarios**

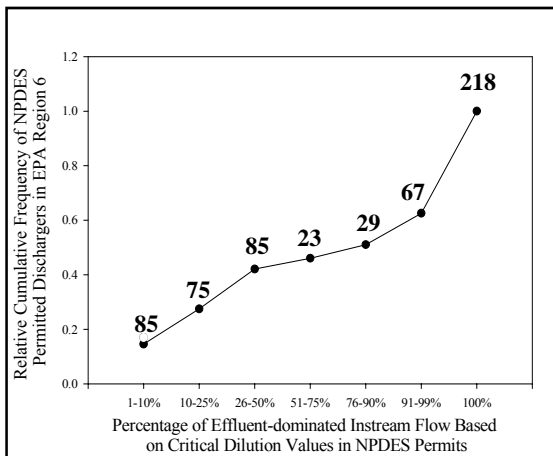
North Bosque River Watershed
Central Texas, USA

Upper Trinity River Watershed
North Central Texas, USA

Texas, USA

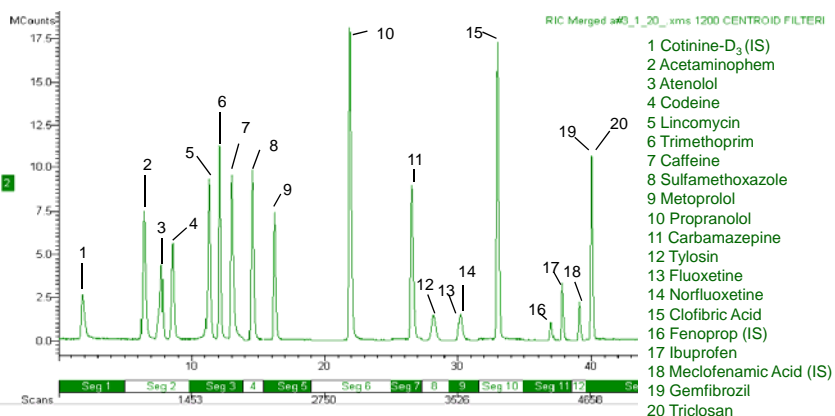
BWRP Brooks et al. In press **CRASR**
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Effluent-dominated Freshwater Systems in Texas, New Mexico, Oklahoma, Louisiana, Arkansas

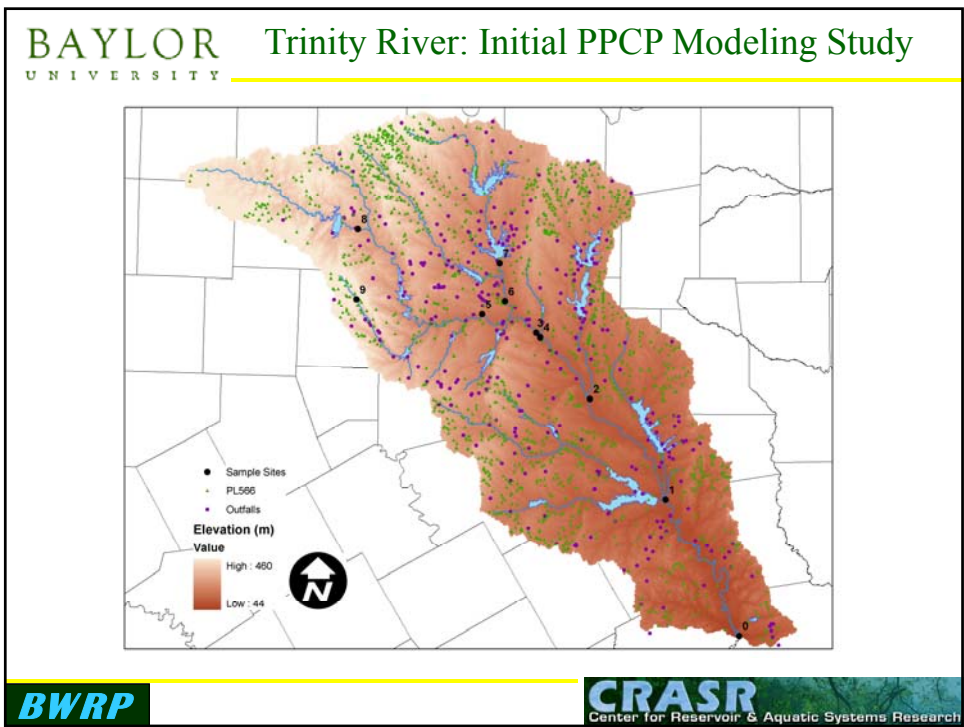
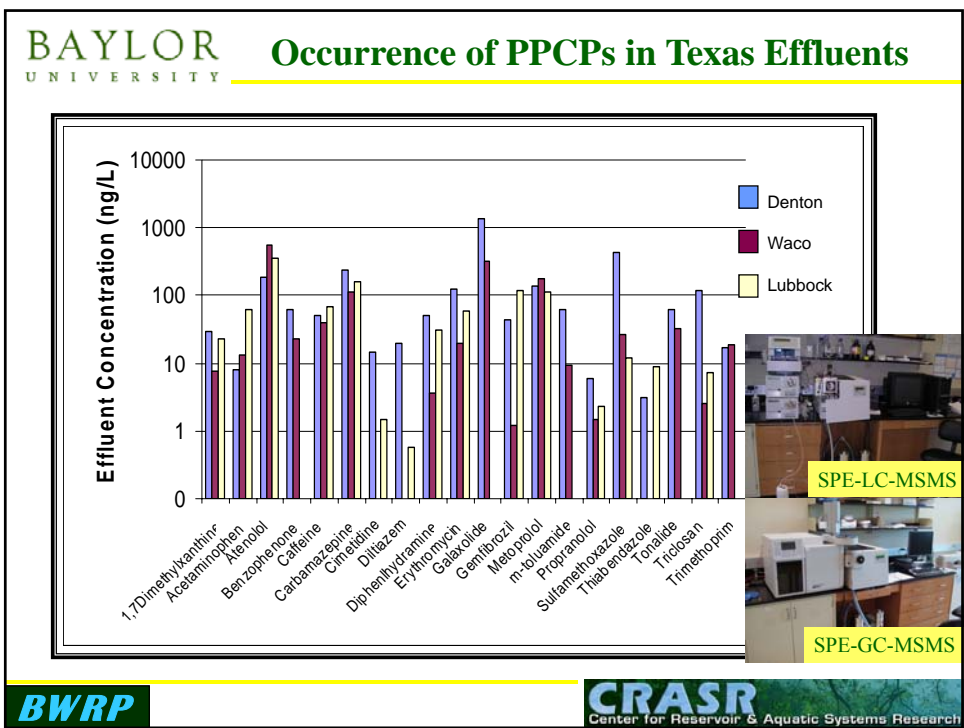


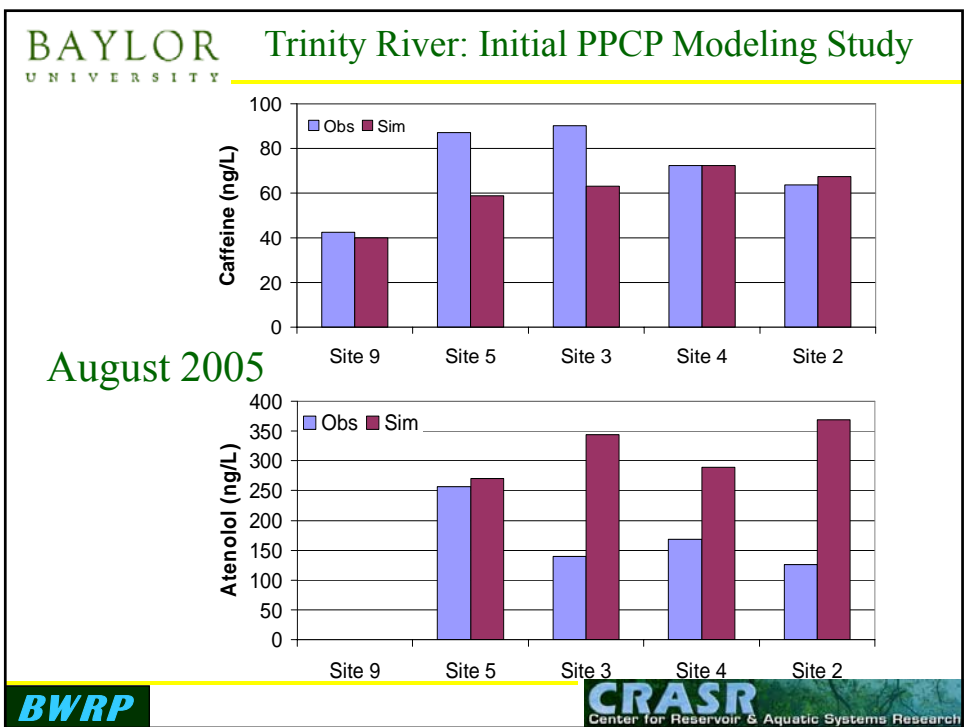
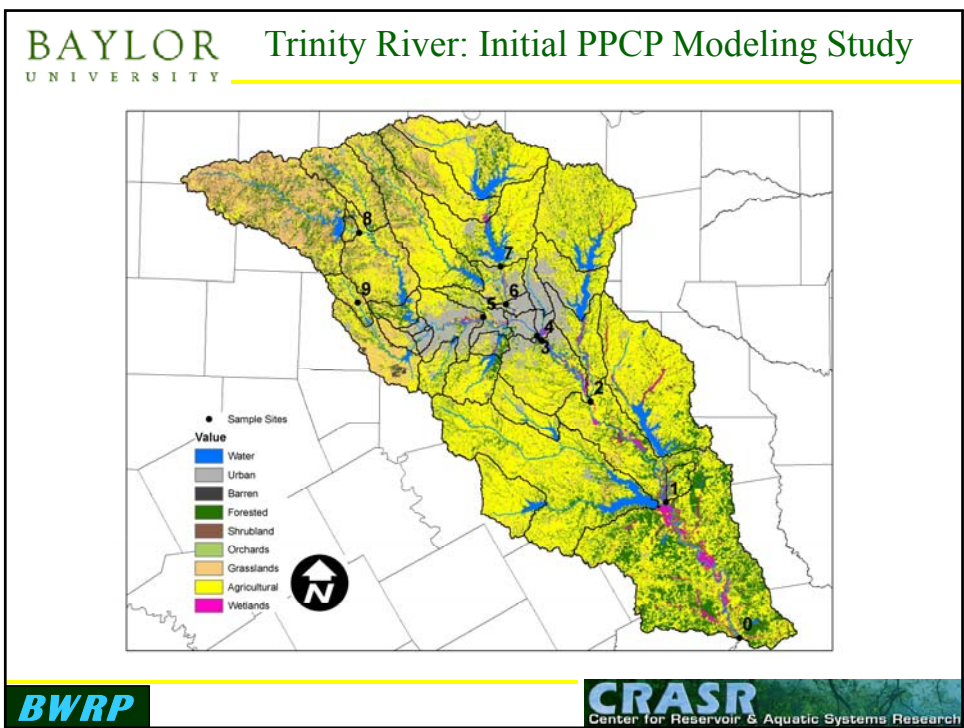
Effluent-dominated Streams are Worse Case Scenarios for PPCPs / some EDCs

Brooks et al. 2006



Understanding Occurrence in Aquatic Systems

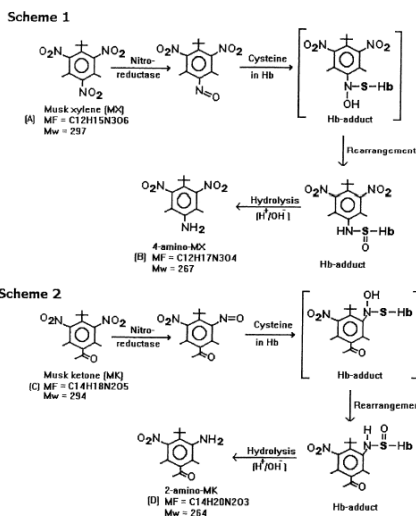




- Less data for fate and effects in aquatic systems

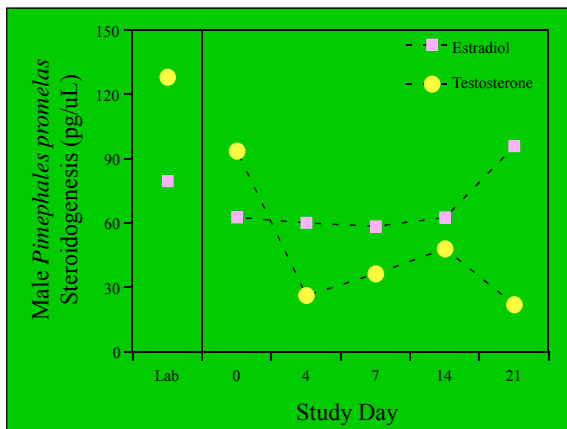
Nitro Musk Fragrances Bioaccumulate, Form Adducts with Human and Fish Hemoglobin

Biomarker of Exposure in Effluent-dominated Ecosystems?



Mottaleb et al. 2004.

Effects of municipal effluent exposure on median steroidogenesis of adult male fathead minnows during a three week study (N=10)



By Day 21:

- ↑ Vtg
- ↑ Vtg mRNA
- ↓ SSCs
- tubercles
- stripe
- fatpad



Pimephales promelas, the fathead minnow

Understanding the Disposition of Contaminants Fish Sampling in Pecan Creek



TCEQ methods for collection of fish tissue samples

Pecan Creek Water Reclamation Plant

- Conventional Activated Sludge Treatment Plant
- Discharge: >14 million gallons day⁻¹
- Effluent discharge contains:

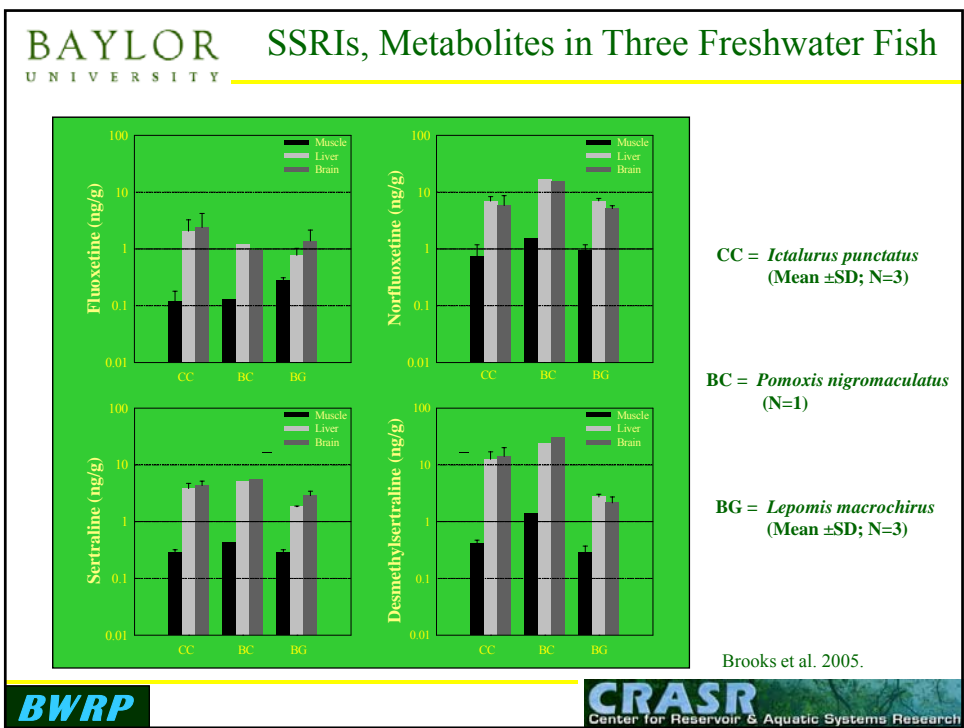
Steroids: Huggett et al. 2003.; Brooks et al. 2003

Exogenous EDCs (e.g., NPs, phthalates): Hemming et al. 2001;
Brooks et al. 2002

β-blockers: Huggett et al. 2003

Antidepressants: Brooks et al. 2005

Many others: USGS



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Fluoxetine 2 0.0019 28 1.84 17 116 6 37.4

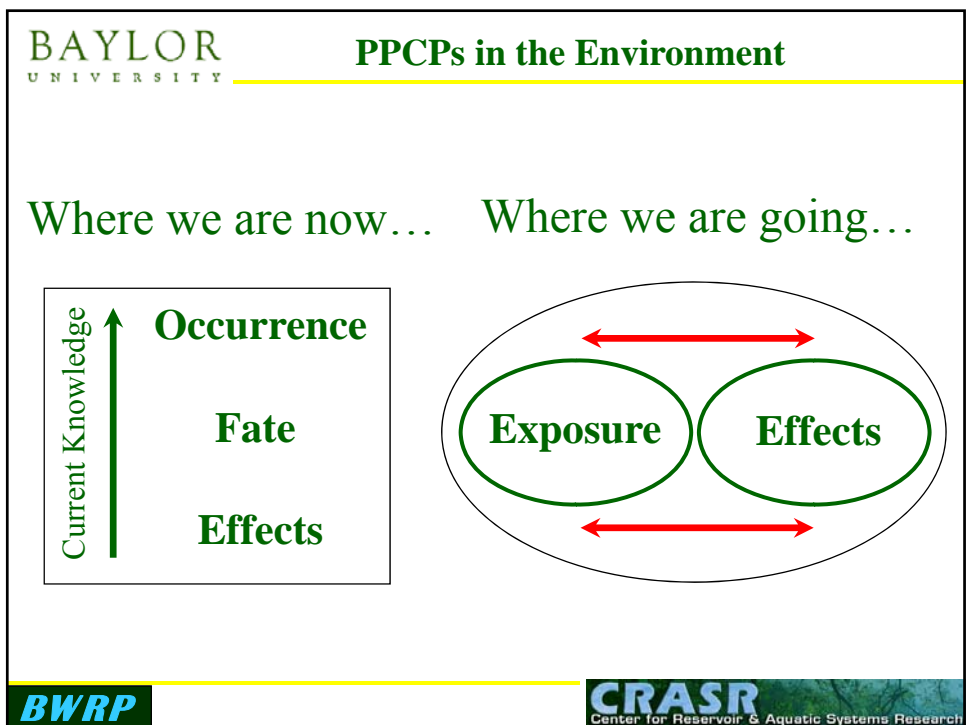
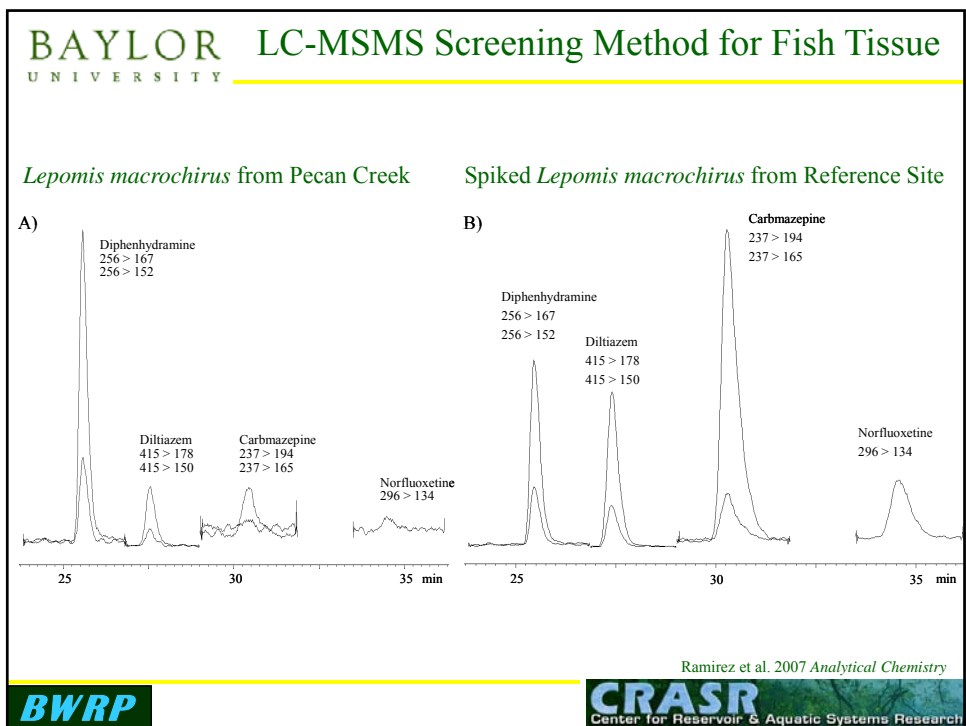
Table 1. Summary of pharmaceutical concentrations in water, sediment, wastewater-irrigated soils and biosolid products.

Compound	Number of detections in water (of 44 samples)	Mean of detections in water, in µg/L	Number of detections in sediment (of 44 samples)	Mean of detections in sediment, in µg/kg	Number of detections in wastewater-irrigated soil (of 18 samples)	Mean of detections in wastewater-irrigated soil, in µg/kg	Number of detections in biosolid products (of 6 samples)	Mean of detections in biosolid products, in µg/kg
Metformin	3	0.112	N/A	N/A			N/A	N/A
Cotinine	36	0.0332	15	0.51	11	49.7	5	21.0
Salbutamol	4	0.0282	0	0.00	6	124	1	29.7
Cimetidine	6	0.112	15	2.45	5	25.0	3	44.98
Acetaminophen	16	0.0630	11	0.27	18	317	6	122
Ranitidine	4	0.1218	N/A	N/A	N/A	N/A	N/A	N/A
1,7-Dimethylxanthine	7	0.7500	1	0.09	5	634	6	1330
Trimethoprim	10	0.1110	12	1.22	15	25.7	2	11.6
Diltiazem	0	0.0065	10	4.66	12	26.2	2	29.0
Fluoxetine	2	0.0019	28	1.84	17	116	6	37.4
Ibuprofen	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gemfibrozil	0	N/A	10	20.4	5	611	6	235
Paroxetine metabolite	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Caffeine	24	0.424	13	10.9	15	127	6	242
Sulfamethoxazole	16	0.161	3	1.08	15	311	1	162
Dehydronifedipine	16	0.0088	28	1.79	16	41.63	3	16.8
Codine	15	0.0700	3	0.70	3	2.67	3	10.1
Thiabendazole	1	0.0072	19	4.96	14	163	5	6.55
Diphenhydramine	12	0.0598	20	15.6	15	38.0	6	165
Erythromycin	0	N/A	16	5.67	17	2660	2	5.00
Carbamazepine	26	0.0576	22	4.16	18	282	6	20.9
Miconazole	0	N/A	10	2.99	16	39.2	6	199
Warfarin	0	N/A	6	0.69	12	338	6	31.9

Furlong et al. 2004.

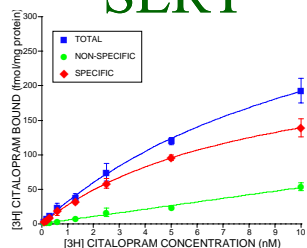
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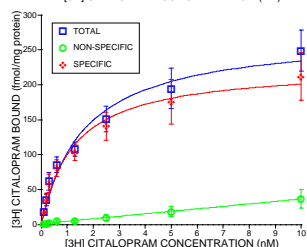


Limitations of current tool box:

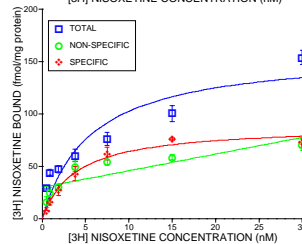
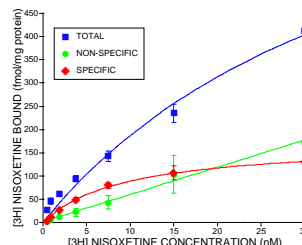
- Chemical properties (e.g., ionization, ion exchange) influence partitioning, exposure modeling estimates
- Some standard methods may not be appropriate
- FDA: default dilution; ↓ data; assessment factors; trigger value of 1 µg/L
- EPA: Water quality criteria?
 - Standard toxicity tests with organisms from 8 families
- Limited field studies; no stream studies

Comparative Pharmacological Profiling**SERT**

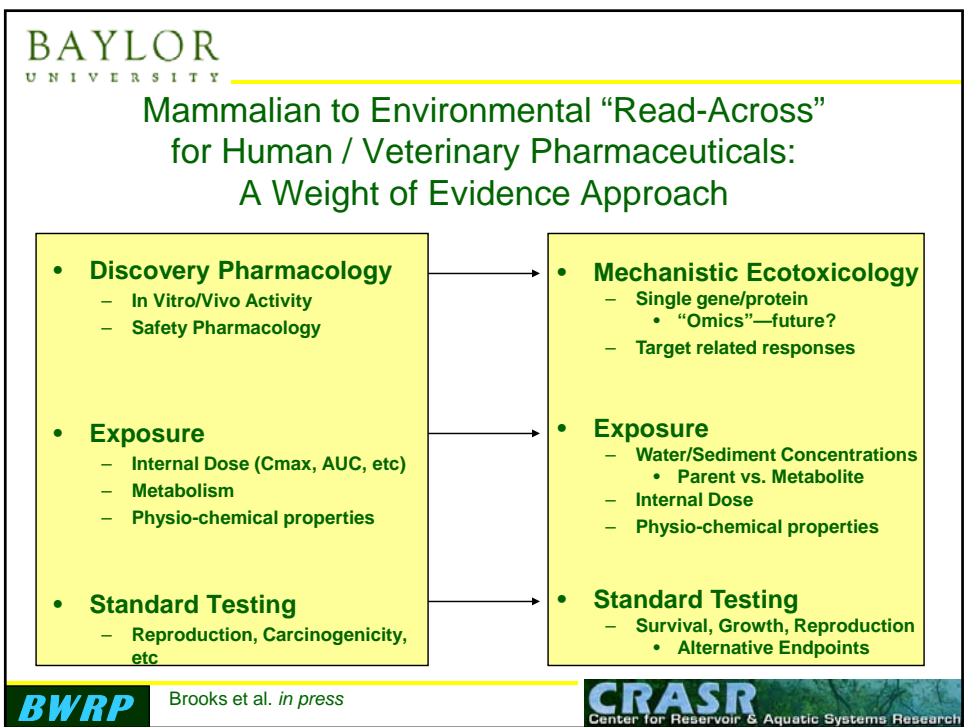
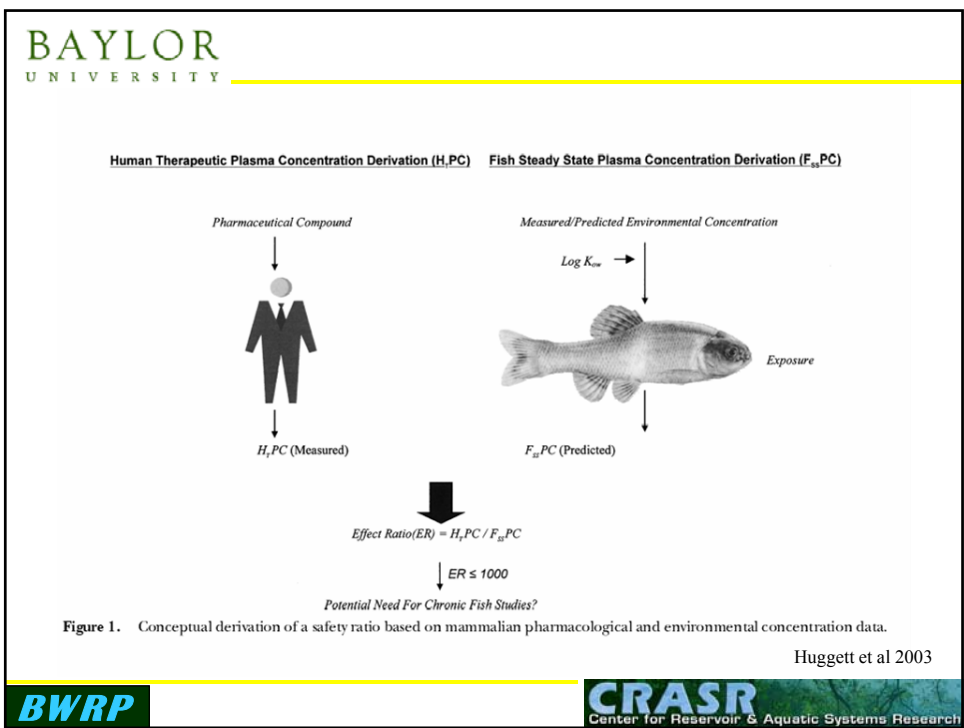
FISH



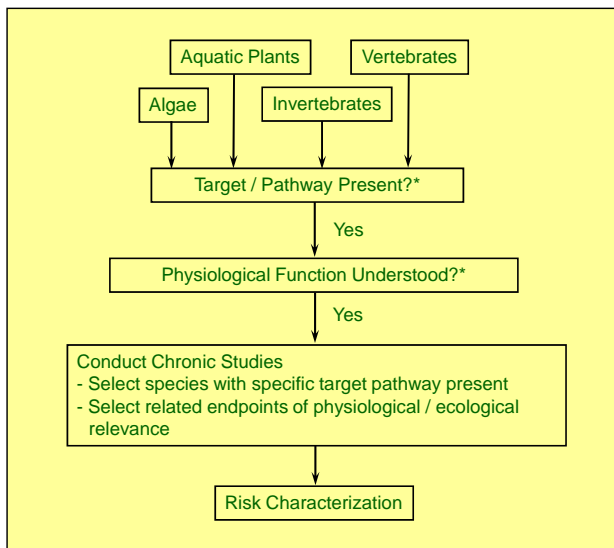
RAT

NET

Gould, Brooks, Fraser 2007 BCPT



BAYLOR UNIVERSITY Pharmaceutical Effects Characterization



*May require baseline *in vitro* and/or *in vivo* studies to ascertain

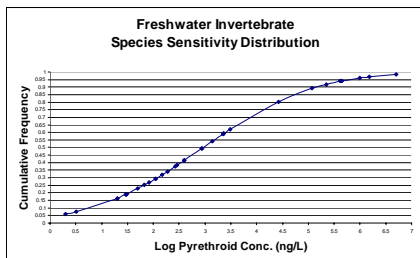
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Ankley et al. 2007, ES&T feature

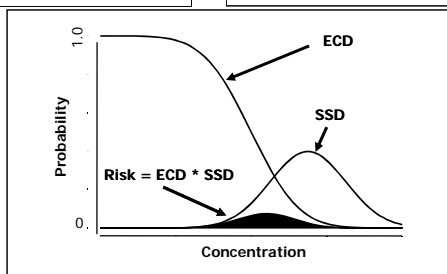
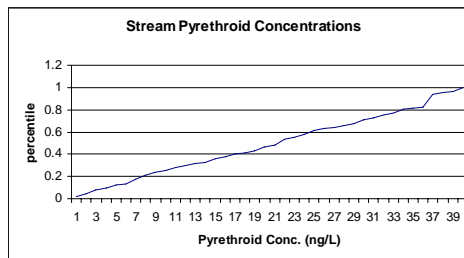
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BAYLOR UNIVERSITY Probabilistic Ecological Risk Assessment

Species Sensitivity Distribution (SSD)

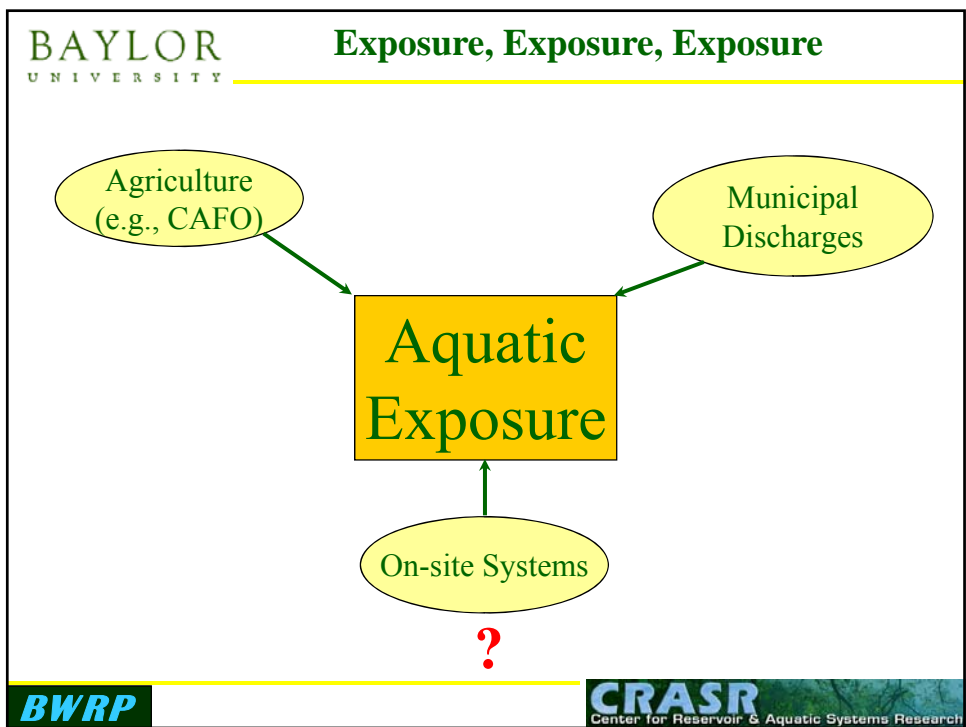
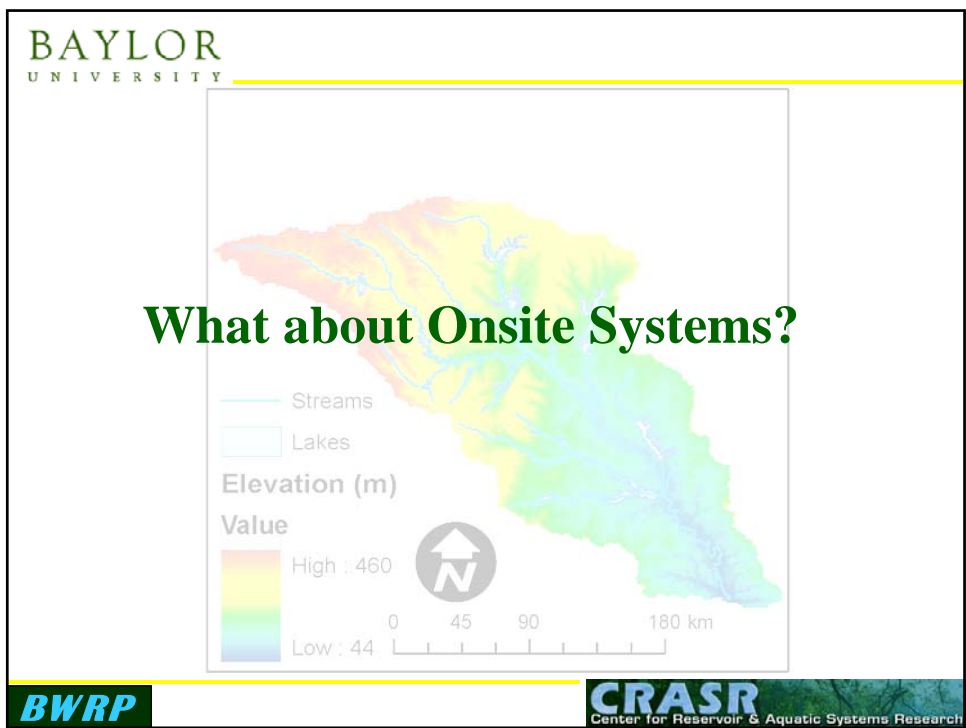


Exposure Concentration Distribution (ECD)



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Baylor Wastewater Research Program (BWRP)

Waco Metropolitan Area Regional Sewerage System (WMARSS)
Waco, Texas, USA



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Comparative Water Quality Study

-Effluents from a Municipal Treatment Plant, and an aerobic and a septic system receiving a common influent

I. WMARSS

- conventional activated sludge treatment plant (~25 MGD)

II. Extended Aeration System

- 1500 gallon multi-chambered system with a pretreatment tank,
an aeration chamber and a final clarifier
- contains an activated sludge process

III. Septic System

- a basic, two-chambered 750-gallon tank



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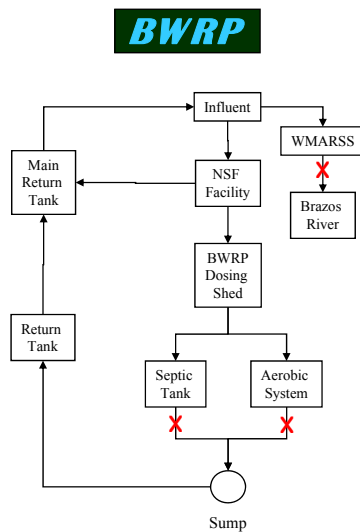
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Comparative Water Quality Study

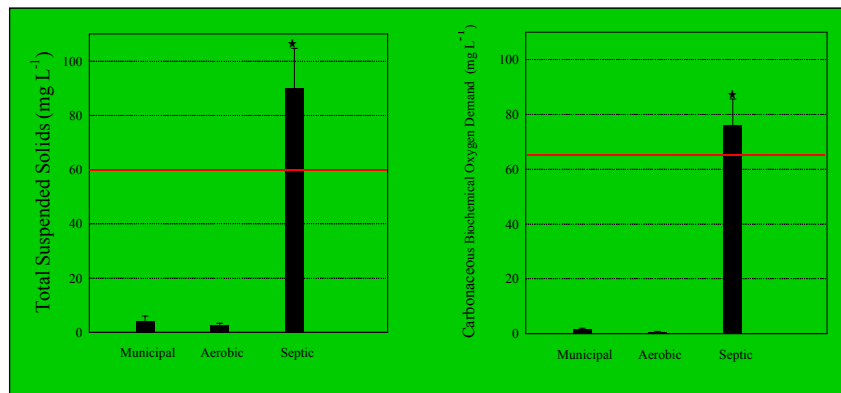
- Sampling over a 3 week period
- Sample collection from each system based on hydrologic retention time

Three Types of Parameters

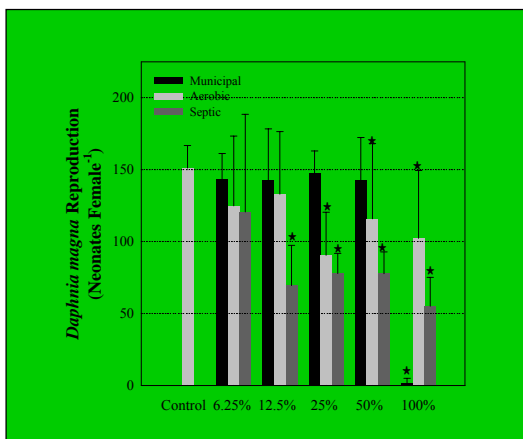
1. General parameters (TSS, CBOD)
2. Whole Effluent Toxicity
3. Hormones



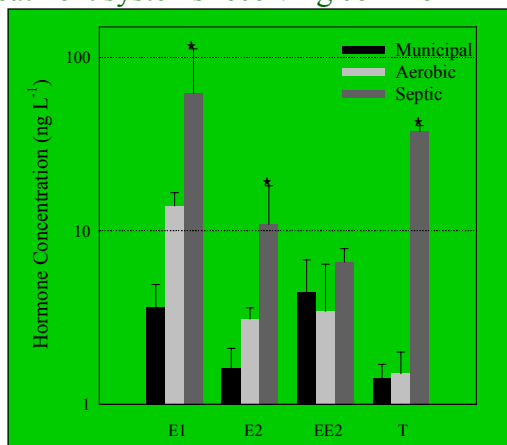
Mean TSS and CBOD (N=7; ±SD) of effluents from a municipal wastewater treatment plant and two on-site wastewater treatment systems receiving common influent wastewater



Mean *Daphnia magna* reproduction (N=10; ±SD) over a 21 d exposure to effluents from a municipal wastewater treatment plant and two onsite wastewater treatment systems receiving common influent wastewater



Mean estrone (E1), 17β-estradiol (E2), 17α-ethinylestradiol and testosterone (T) (N=6; ±SD) in effluents from a municipal wastewater treatment plant and two onsite wastewater treatment systems receiving common influent



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Comparative PPCP Removal Study

- Sampling over a 7 week period
- Sample collection from each system based on hydrologic retention time

Broad Suite of PPCPs

- SPE + LC/MSMS
- SPE + GC/MSMS

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
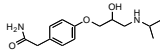
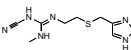


Comparative PPCP Effluent Study

- Sampling over a 7 week period
- Sampling based on HRT on weeks 1, 4, 7
- Broad suite of PPCPs
 - SPE + LC/MSMS
 - SPE + GC/MSMS

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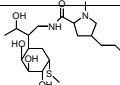
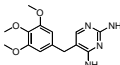


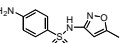
Analyte-Dependant Mass Spectrometry Parameters for Target Compounds.

Compound	Use	Structure	Precursor Ion	Collision energy (eV)	Product ion	pKa
ESI POSITIVE ANALYTES						
Acetaminophen	analgesic		152 [M + H] ⁺	-11.0	110	9.86
Atenolol	anti-hypertension		267 [M + H] ⁺	-21.5	145	13.8
Cimetidine	anti-acid reflux		253	-13.5	159	14.0
Codeine	analgesic		[M + H] ⁺ 300 [M + H] ⁺	-38.0	165	13.4
1,7-dimethylxanthine	antispasmodic		181 [M + H] ⁺	-15.5	124	8.50

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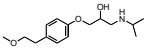
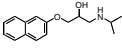
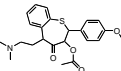

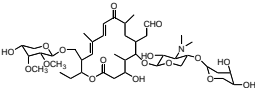
Analyte-Dependant Mass Spectrometry Parameters for Target Compounds (cont.).

Compound	Use	Structure	Precursor Ion	Collision energy (eV)	Product ion	pKa
Lincomycin	antibiotic		407 [M + H] ⁺	-15.5	359	12.9
Trimethoprim	antibiotic		291 [M + H] ⁺	-17.5	261	7.20
Thiabendazole	antibiotic		202 [M + H] ⁺	-23.0	175	10.5
Caffeine	stimulant		195 [M + H] ⁺	-16.0	138	0.73
Sulfamethoxazole	antibiotic		254	-13.0	156	5.81

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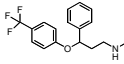
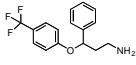
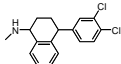
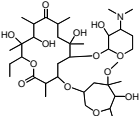
Analyte-Dependant Mass Spectrometry Parameters for Target Compounds (Cont.).

Compound	Use	Structure	Precursor Ion	Collision energy (eV)	Product ion	pKa
Metoprolol	anti-hypertension		268 [M + H] ⁺	-15.5	191	13.9
Propranolol	anti-hypertension		260 [M + H] ⁺	-11.0	116	13.8
Diltiazem	anti-hypertension		415 [M + H] ⁺	-22.0	178	8.94
Carbamazepine	anti-seizure		237 [M + H] ⁺	-13.5	194	13.9
Tylosin	antibiotic		916 [M + H] ⁺	-31.5	174	13.1

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Analyte-Dependant Mass Spectrometry Parameters for Target Compounds (Cont.).

Compound	Use	Structure	Precursor Ion	Collision energy (eV)	Product ion	pKa
Fluoxetine	antidepressant		310 [M + H] ⁺	-6.0	148	10.1
Norfluoxetine	antidepressant		296 [M + H] ⁺	-4.5	134	9.05
Sertraline	antidepressant		306 [M + H] ⁺	-11.0	275	9.47
Erythromycin	antibiotic		716 [M + H - H ₂ O] ⁺	-18.0	558	13.1

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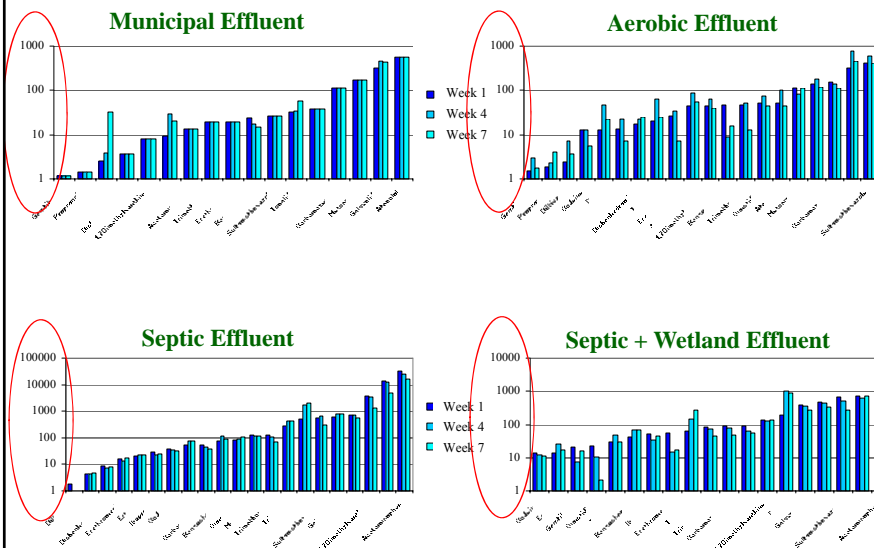
Analyte-Dependant Mass Spectrometry Parameters for Target Compounds (Cont.).

Compound	Use	Structure	Precursor Ion	Collision energy (eV)	Product ion	pKa
Warfarin	anti-coagulant	<chem>O=C1C(=C2C(=C1)OC(=O)C2)c3ccccc3</chem>	309 [M + H] ⁺	-14.0	163	4.50
Miconazole	antibiotic	<chem>Cc1cc(Cl)c(Cl)c(Cl)c1N1C=NC=C1</chem>	417 [M + H] ⁺	-27.5	161	6.67
ESI NEGATIVE ANALYTES						
Clofibric Acid	antilipemic	<chem>CC(C)(O)C(=O)Oc1ccc(Cl)cc1</chem>	213 [M - H] ⁻	15.4	127	3.18
Ibuprofen	analgesic	<chem>CC(C)C(=O)Oc1ccc(cc1)C(C)C</chem>	205 [M - H] ⁻	7.0	161	4.41
Gemfibrozil	antilipemic	<chem>CC(C)(O)C(=O)OCCOc1cc(C)c(C)c1</chem>	249 [M - H] ⁻	13.0		4.75

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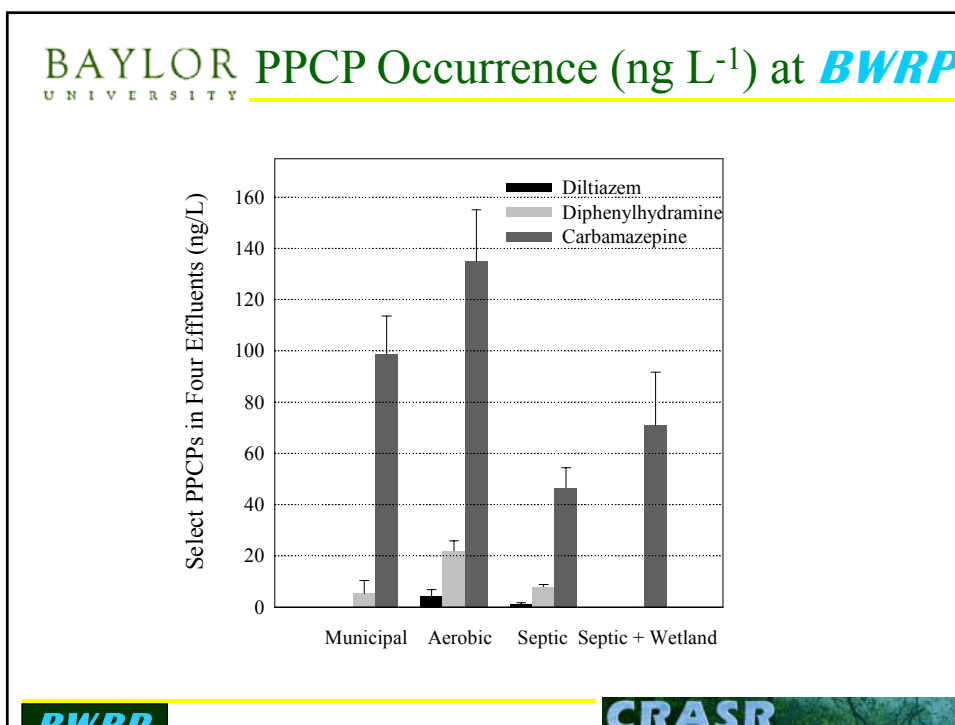
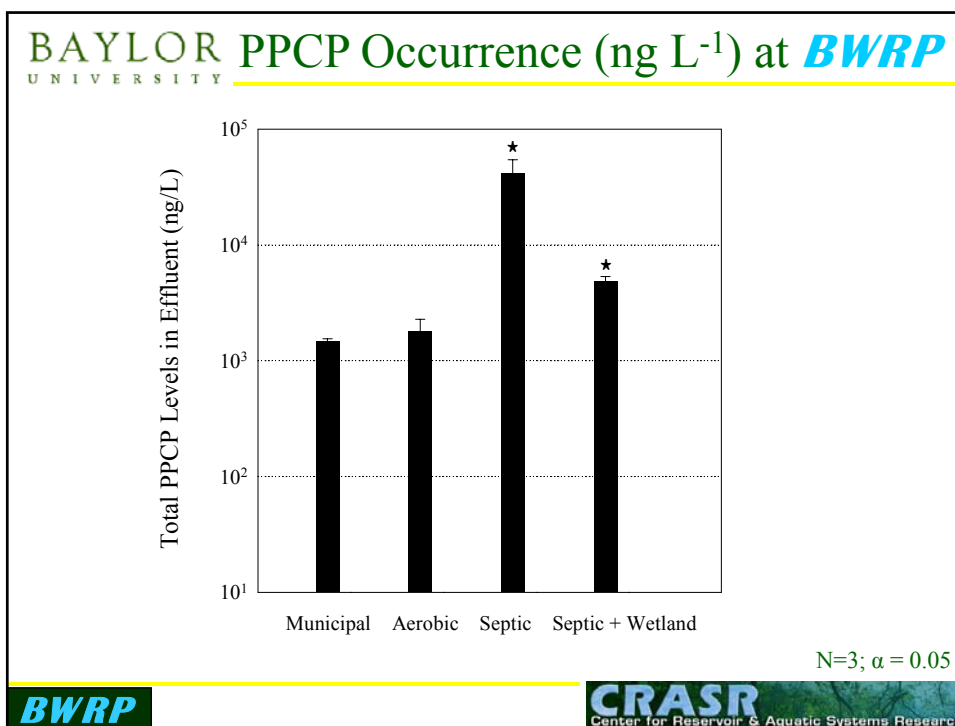
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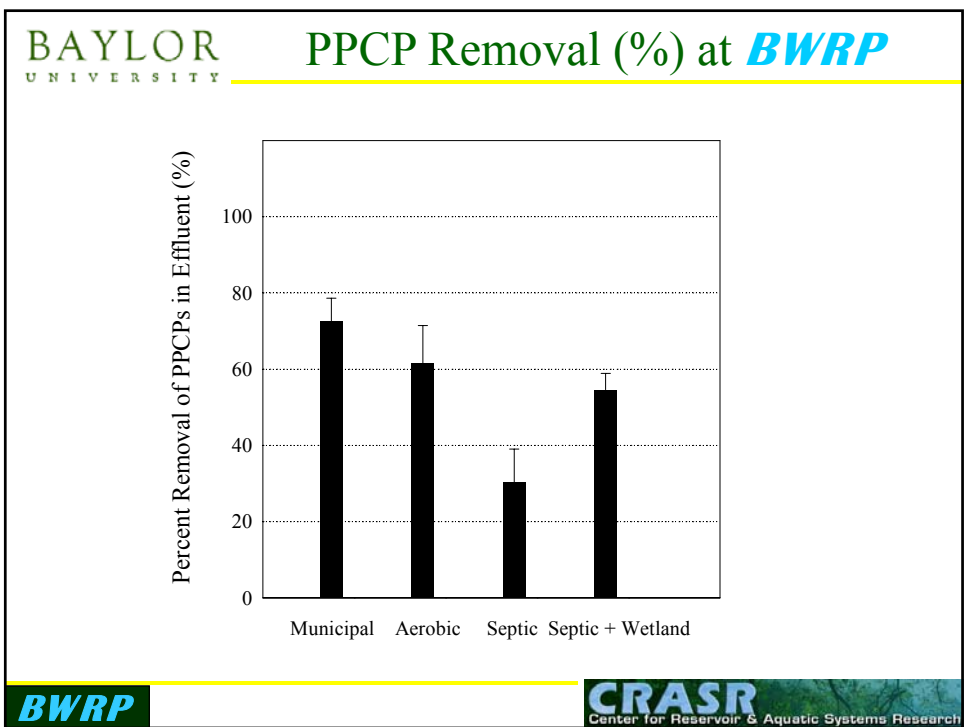
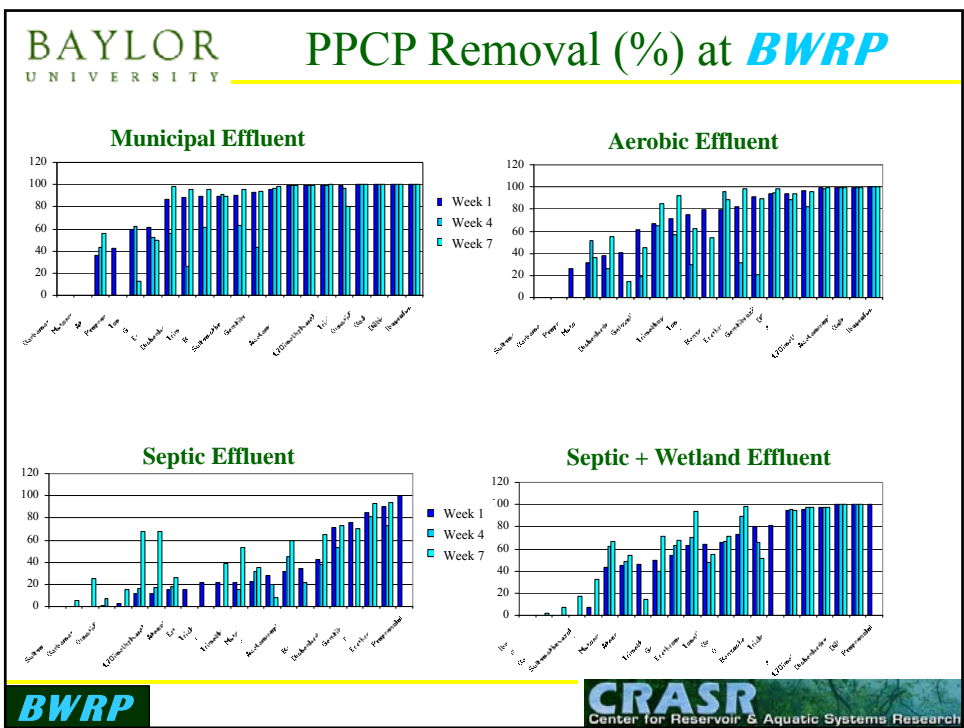
BAYLOR PPCP Occurrence (ng L⁻¹) at **BWRP**
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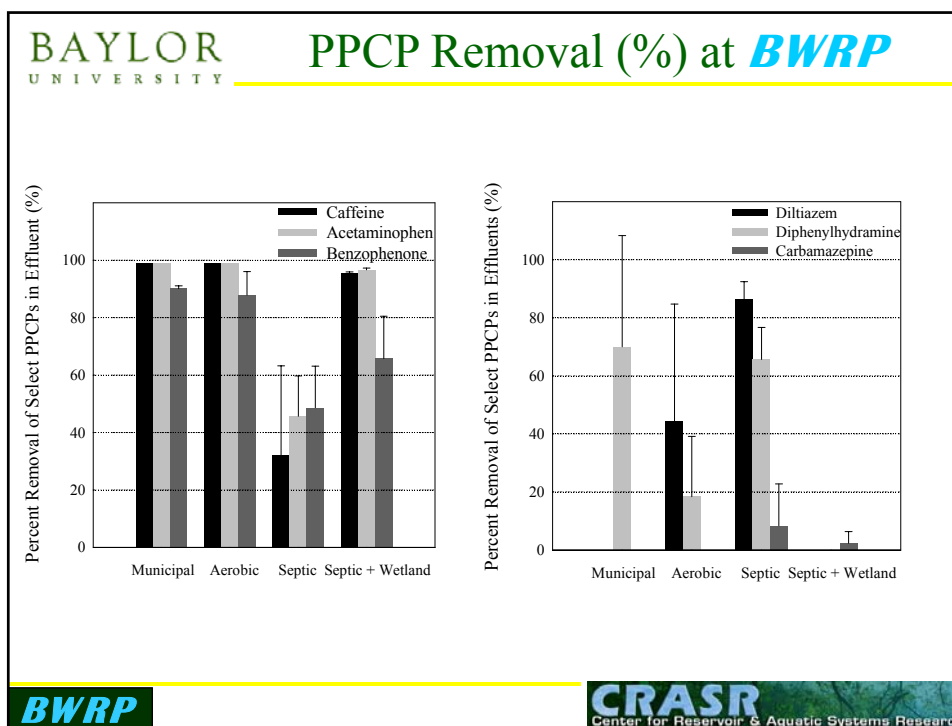


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What next?



- Exposure vs. Effects – which compounds present problems, where?
- Structural and functional impacts on receiving systems?
- Refining risk assessment procedures for pharmaceuticals
- Development of water quality criteria (WQC) for therapeutics?
- Removal Technologies
 - cost/benefit analyses
- Consumer Education

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What next for Onsite Systems?

Integrated Watershed Management

- Lessons learned from centralized systems
- Consider water quality based approach for decentralized systems
- PPCP / EDC loadings from various technologies
- Soil infiltration studies = new funding from TOWTRC w/ TTU



Water Reuse?

All Western States employing reuse

WaterReuse Foundation project to evaluate constructed wetland treatment of PPCPs, EDCs, others

- Baylor (Brooks, Kevin Chambliss, Joe Yelderman)
- UC Berkeley (David Sedlak)
- Alan Plummer and Assoc. (Loretta Mokry)
- Wetland Solutions (Robert Knight)

US EPA PPCP Fish Tissue Pilot Project

So What's Happening Now?

Society of Environmental Toxicology and Chemistry
- Pharmaceuticals Advisory Group



- Balanced, Global Approach: Government, Industry, Academia

Steering Committee

	Geographic Unit	Affiliation
Bryan Brooks	North America	Academic (Baylor Univ.)
Dan Caldwell	North America	Industry (Johnson & Johnson)
Suzy Fitzpatrick	North America	Government (US FDA)
Jim Lazorchak	North America	Government (US EPA)
Hans Sanderson	North America	Industry (S&D Assoc.)
Jane Staveley	North America	Industry (Arcadis)
Rich Williams	North America	Industry (Pfizer)

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More information:

<http://www.baylor.edu/crasr>

<http://www.epa.gov/esd/chemistry/pharma/index.htm>

<http://toxics.usgs.gov/highlights/whatsin.html>

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Dr. Maggie Forbes (Research Scientist)
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Dr. Sascha Usenko (Research Scientist)
Dr. Alejandro Ramirez (Staff Scientist)
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Jason Berninger (PhD Student)
Jeff Bardwell (PhD Student)
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Laura Dobbins (MS Student)
Barry Fulton (MS Student)
Susan James (MS Student)
Mieke Lahousse (Technician)

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