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How Well Can EDC's be Removed in Drinking Water Treatment?

September 19, 2005

Emerging Contaminants Workshop

Presented by Kim Linton
Sr. Account Manager, AwwaRF

AwwaRF

Mission: Advance the science of water to improve the quality of life

- **Centralized research program for drinking water utilities**
  - Sponsor research
  - Develop knowledge
  - Promote collaboration
- **Agenda is planned and guided by drinking water utilities**
- **Research covers a broad range of topics including source water, treatment, infrastructure, and management for drinking water utilities**

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Funding

- **Subscribers**
  - **800+ utility members, 50 consultants, 14 manufacturers**
- **Congressional Earmarks**
- **Partnerships**
  - **17 International**
  - **17 U.S. based or U.S. Govt.**

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Emerging Contaminants

Sunday, October 03, 2004

Mutant fish prompt concern

Study focuses on sewage plants

By Theo Stein and Miles Moffeit, Denver Post Staff Writers

“When Colorado biologist John Woodling and a team of researchers pulled fish from the South Platte River and Boulder Creek two years ago, they found deformities they'd never seen before.

Some had both male and female sex tissue.”

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1993 - Adsorption of Pesticides by Powdered Activated Carbon #715

Project Summary:

- Develops isotherms
- Develops methods to account for site-specific characteristics such as temperature, pH, and competition from natural organic matter
- Provides a protocol to predict the site-specific performance

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Publication # 90664

Research Planning

2598	Endocrine Disruptors and Pharmaceuticals in Drinking Water	1999
2938	International Workshop and Report on Pesticides, their Degradates, and Adjuvants	2003
2972	Research Strategy Workshop on Pharmaceuticals and Personal-Care Products in the Water Cycle	2003
3060	WateReuse Foundation Research Conference	2004
3064	2004 Water Quality (Perchlorate, Pharmaceuticals, DBPs)	2004

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Source Water

#3060	WateReuse Foundation Research Conference	2004
#3123	Reservoir Management Strategies for Control and Degradation of Algal Toxins: Phase 2	2005
#3170	Pesticide Degradates in Water Treatment: and Partitioning Parameter Estimation	2005
#3020	Concentrated Animal Feeding Operations (CAFOs): Water Utility Issues and Regulatory Controls	2003
#2616	Impacts of Major Point and Non-Point Sources on Raw Water Treatability	1999

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Aquifer Storage & Recovery

#713	**Aquifer Storage Recover of Treated Drinking Water**	**1993**
#901	**Soil Treatability Pilot Studies to Design and Model SAR Treatment Systems**	**1993**
#487	**Investigation of Soil Aquifer Treatment for Sustainable Reuse**	**1997**
#2618	**Water Quality Improvements During Aquifer Storage and Recovery**	**1999**
#2974	**Water Quality changes Associated with Aquifer Storage and Recovery**	**2003**

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River Bank Filtration

#3180	**Evaluation of River Bank Filtration Systems to Optimize Removal of Bulk Organize Matter, Emerging Organic Micropollutants and Nutrients**	1995
#3136	**Removal and Fate of EDCs and PhACs in Bank Filtration**	2005

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Membrane Removal

#170	Investigation of Reverse Osmosis and Nanofiltration Processes for Removing Organic Contaminants and the Development of Piloting Procedures for Drinking Water Treatment	1994
#412	Evaluation of Membrane Technologies for Removal of Atrazine and Other SOCs	1997
#2945	Rejection of Trace Organic Contaminants by Reverse Osmosis and Nanofiltration Membranes	2003

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UV Treatment

#2599	Innovative UV Technologies to Oxidize Organic and Organoleptic Chemicals	1999
#2897	Impact of UV and UV - Advanced Oxidation Processes on Toxicity of Endocrine-Disrupting Compounds in Water	2002

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EDC Treatment

2758	Evaluation of Conventional and Advanced Treatment Processes to Remove Endocrine Disruptors and Pharmaceutically Active Compounds	2001
3033	Comprehensive Utility Guide for Endocrine Disruptors and Pharmaceuticals In Drinking Water	2004
3071	Pharmaceuticals, Personal Care Products and Endocrine Disruptors--Occurrence, Fate and Transport in the Great Lakes Water Supplies and the Effect of Advanced Treatment Processes on Their Removal	2004
3170	Pesticide Degradates in Water Treatment: Oxidative Formation and Partitioning Parameter Estimation	2005

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Evaluation of Treatment Technologies

- Researchers: Dr. Shane Snyder, Dr. Paul Westerhoff, Dr. Rengao Song, Bruce Long, Dr. Bruno Levine

- 1) Develop surrogate and characteristic compounds for specific classes of EDCs and PPCPs based on lit. search
- 2) Test treatment processes at bench, pilot, and full-scale facilities using purified and real waters
- 3) Examine Qualitative Structure Activity Relationship (QSAR) properties of test compounds

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Acknowledgements

- Mihaela Stefan – Trojan Technologies
- Fred Cannon & Adam Redding – Penn State University
- Alex Mofidi - MWD
- MWH and B&V for providing samples from various pilot-scale process evaluations
- SNWA Research & Development Team
- AwwaRF - funding

Treatment Processes

- Coagulation and Softening
- Activated Carbon (GAC and PAC)
- Membranes (UF, NF, RO, MBR, e-dialysis)
- Magnetic Ion-Exchange (MIEX)
- Chlorination (ambient and pH 5.5)
- Ozonation (and AOP with peroxide)
- UV (and AOP with peroxide)
- Biological Processes
  - Biologically active filtration (carbon and anthracite)
  - River Bank Filtration
  - MBR
  - ASR/SAT

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Water Quality

Water	Code	pH	DOC (mg/L)	alkalinity (mg/L as CaCO3)
Colorado River	CR	8.2	2.5	140.0
Passaic Valley	PV	6.8	3.4	52.0
Suwannee River NOM	SR	7.5	4.0	N/A
Louisville	LsV	7.9	3.5	79.0

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Target Compounds

- Occurrence - based on literature review
  - usage patterns (likelihood of occurrence)
- Classes/physical properties
  - polarity, molecular size, acid, base, neutral
  - volatility – naphthalene vs. iopromide
  - log K_{ow} from -2.05 – 6.91
  - pKa from 1.6 – 10.5
  - MW from 128 – 791 Daltons
- Analytical Concerns
  - availability of standards (and quantity)
  - instrumental and extraction issues

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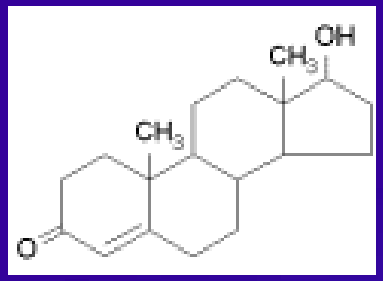
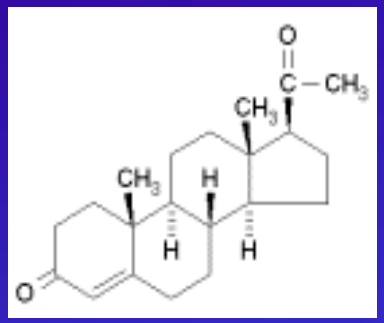
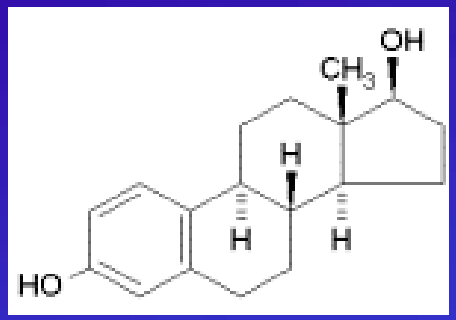
Steroids



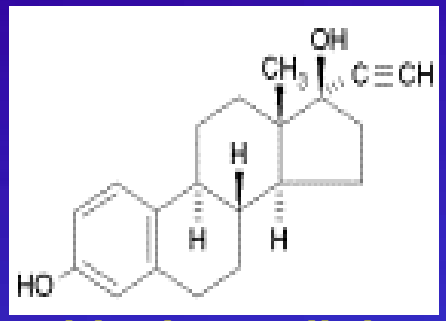
Testosterone
(Androgen)



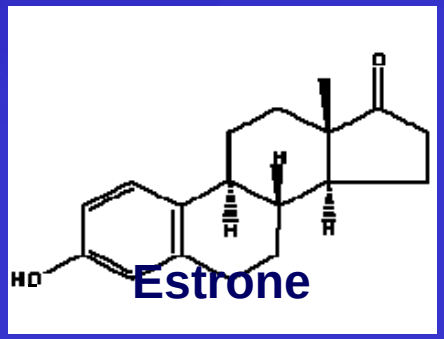
Progesterone
(Estrogen)



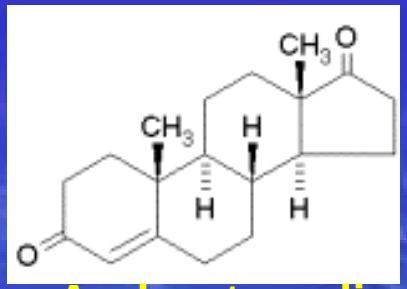
17ß Estradiol
(Estrogen)



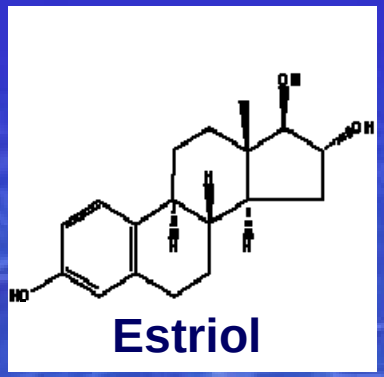
Ethinylestradiol
(Synthetic estrogen)



Estrone



Androstenedione
(Androgen)



Estriol

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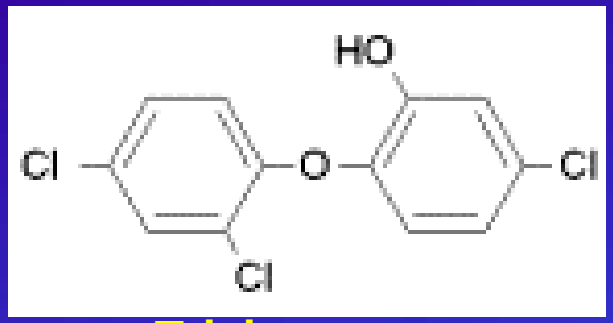
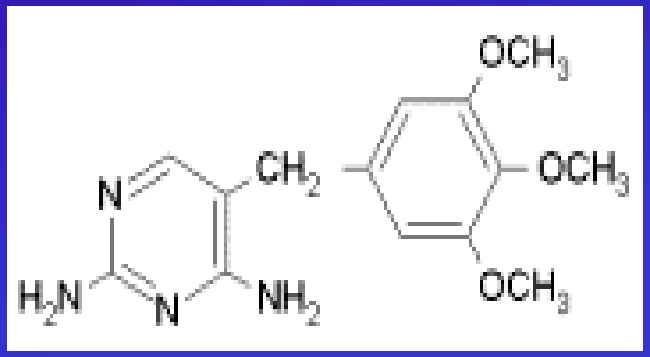
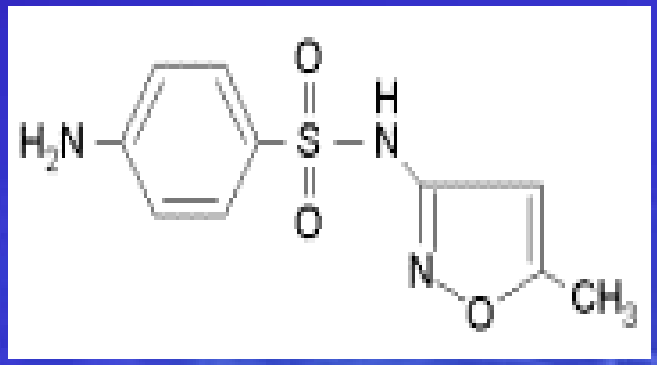
Antimicrobials (antibiotics)



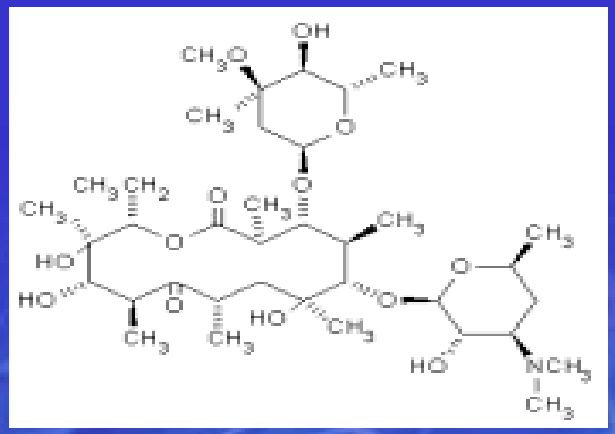
Triclosan



Trimethoprim



Sulfamethoxazole



Erythromycin

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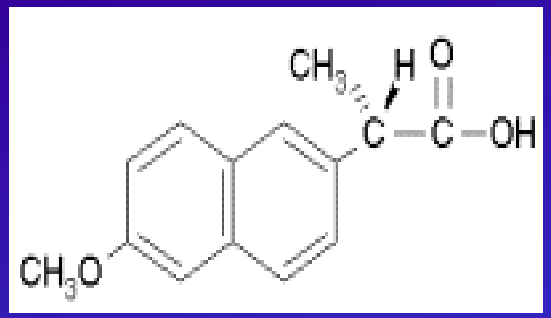
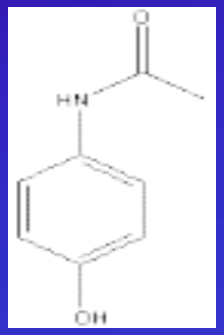
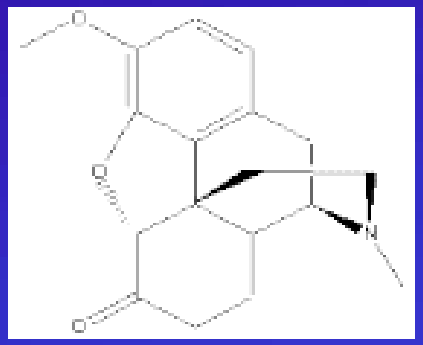
Analgesics



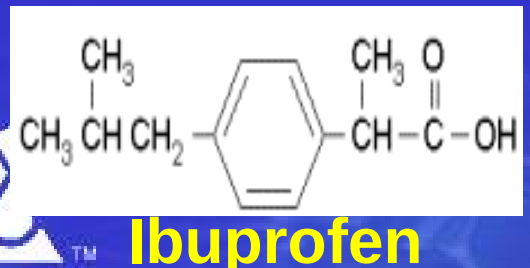
Naproxen



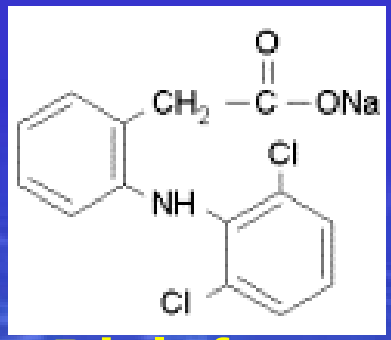
Acetaminophen



Hydrocodone



Ibuprofen



Diclofenac

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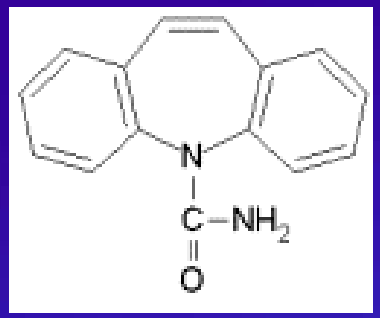
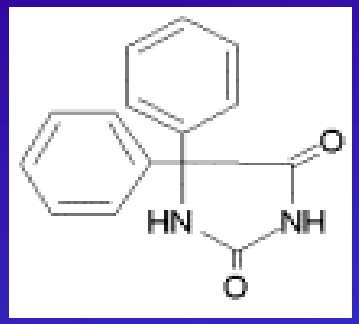
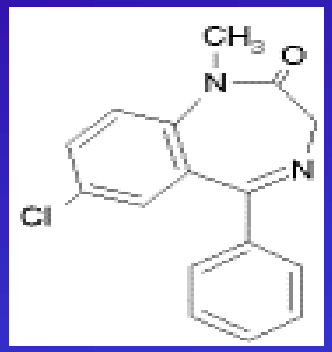
Psychoactive



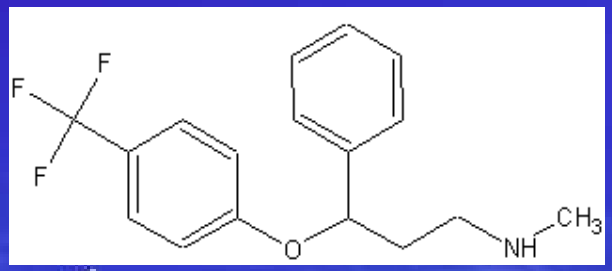
Carbamazepine
(anti-seizure)



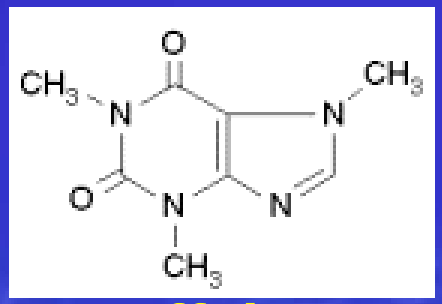
Dilantin
(Anti-convulsant)



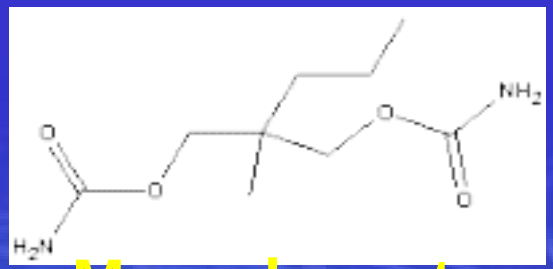
Diazepam
(muscle relaxant)



Fluoxetine
(Anti-depressant)



Caffeine



Meprobamate
(Anti-anxiety)

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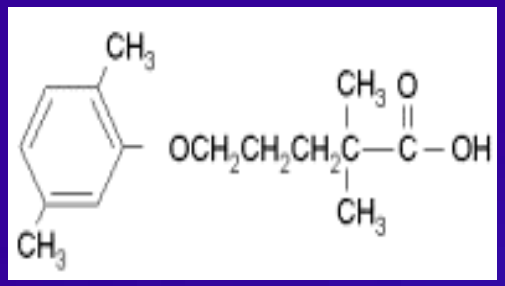
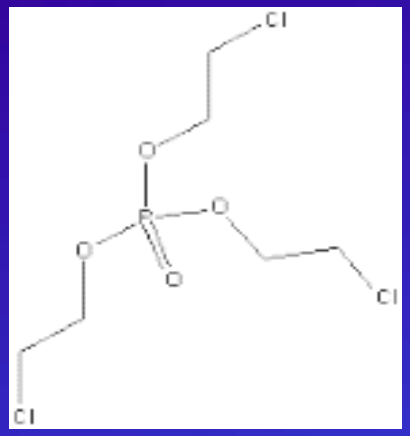
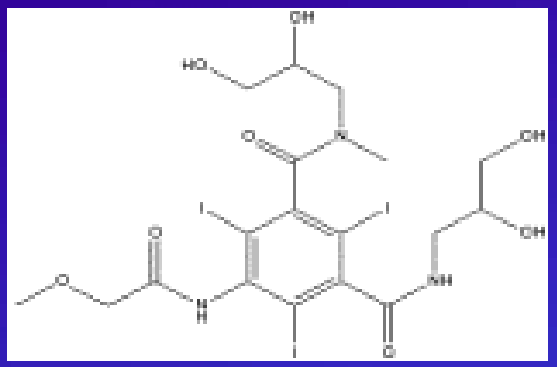
Others



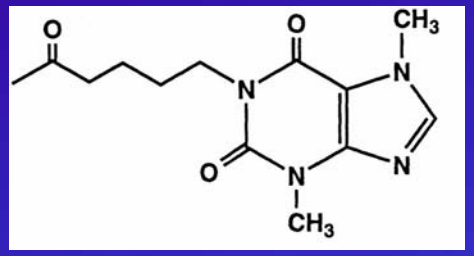
Gemfibrozil
(Anti-cholesterol)



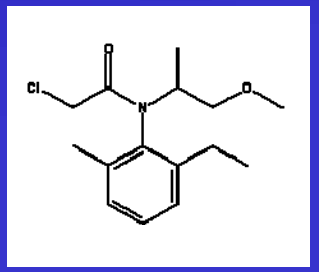
TCEP
(Flame retardandt)



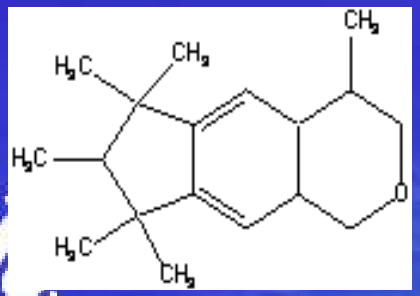
Iopromide
(x-ray contrast agent)



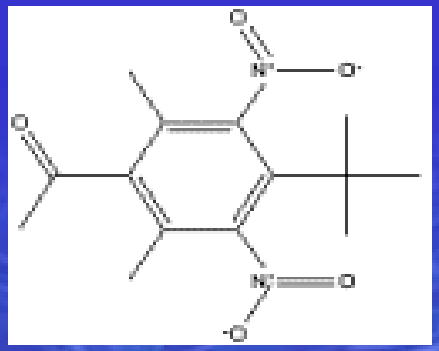
Pentoxifylline
(Blood viscosity
reducing agent)



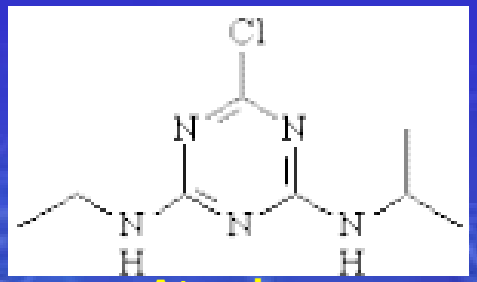
Metolachlor



Galaxolide



Musk Ketone



Atrazine
(Pesticide)

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^{13}C surrogates

Sample Collection
1L silanized bottle

Solid Phase Extraction
500 mg HLB

Micro LLE

^{13}C internals

^{13}C internals

GC / MS / MS

LC / MS / MS

Related Articles

- Analytical Methods Used to Measure Endocrine Disrupting Compounds in Water, ASCE 2003
- Analysis of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products in Water Using Liquid Chromatography/Tandem Mass Spectrometry, Analytical Chemistry, Nov. 15, 2003.
- Pharmaceuticals, Personal Care Products, and Endocrine Disruptors in Water; Implications for the Water Industry, Environmental Engineering Science, Sep 2003.

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Coagulation and Softening
(Colorado River Water)

- **Coagulation**
  - aluminum sulfate (alum) 30 mg/L
  - ferric chloride (ferric) 28 mg/L
- **Softening**
  - calcium hydroxide (lime) 237 mg/L
  - sodium carbonate (soda ash) 177mg/L
  - pH raised to 11.3 with NaOH

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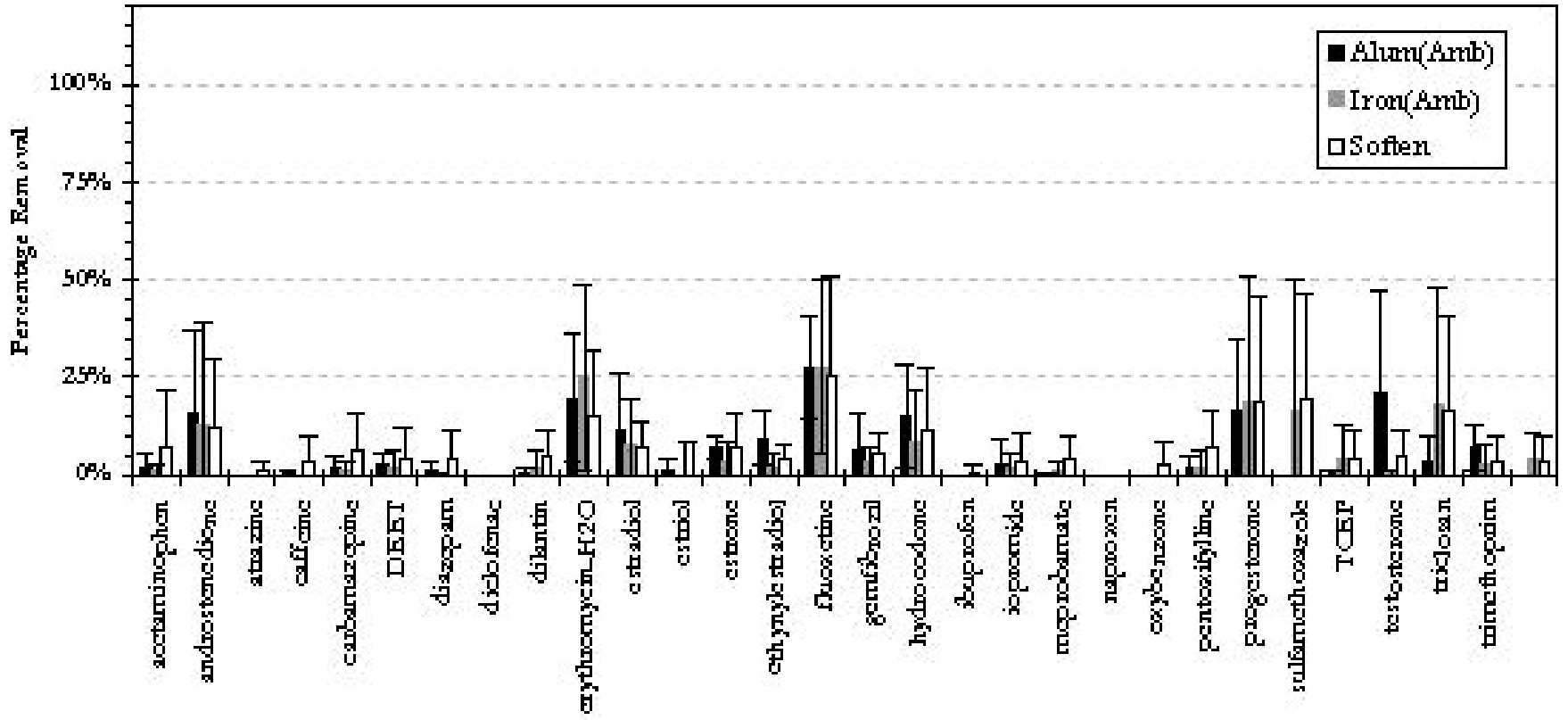
Coagulation and Softening



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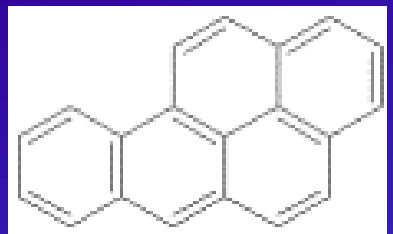
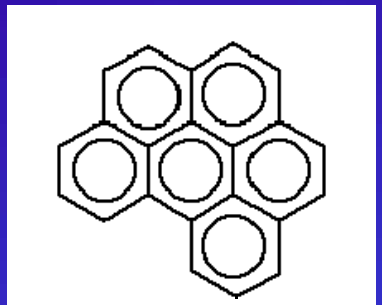
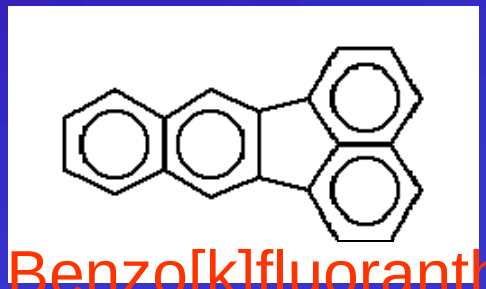
Coagulation/Softening >50% Removal



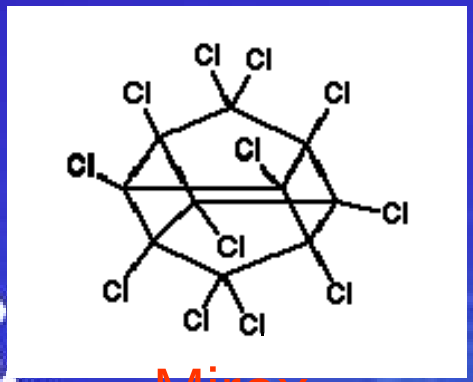
Benzo[a]pyrene [6.13]



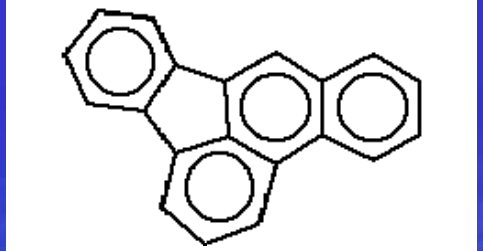
Benzo[g,h,i]perylene [6.63]



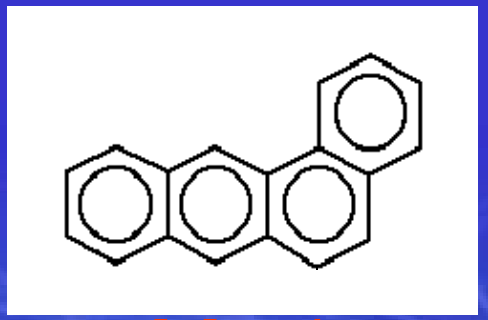
Benzo[k]fluoranthene [6.02]



Mirex [6.89]



Benzo[b]fluoranthene [5.78]



Benzo[a]anthracene [5.76]

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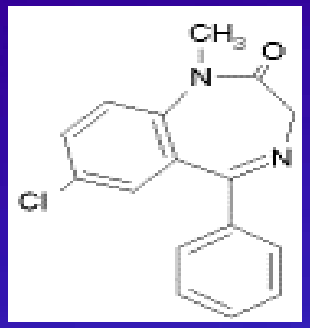
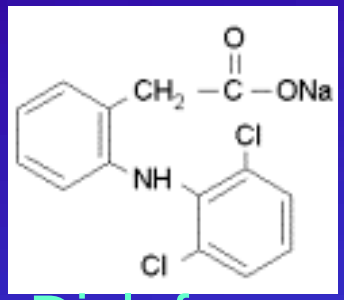
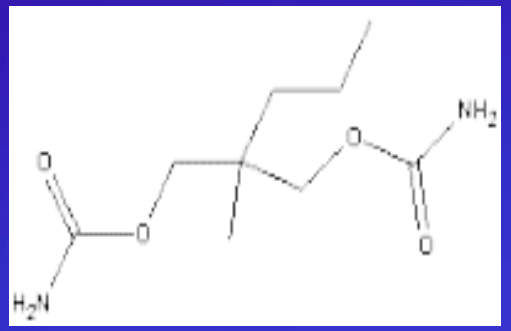
Coagulation/Softening <10% Removal



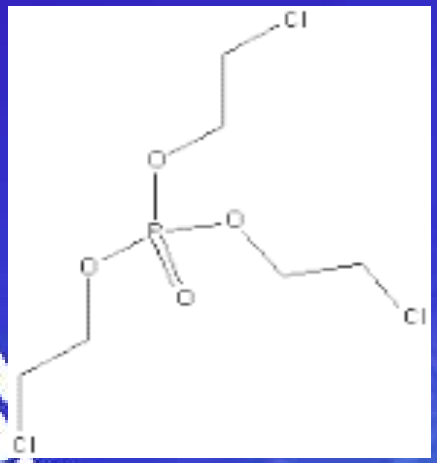
Diazepam
[2.82]



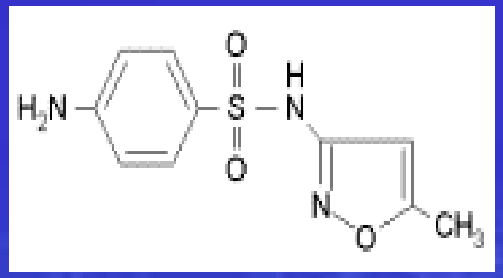
Diclofenac
[0.7]



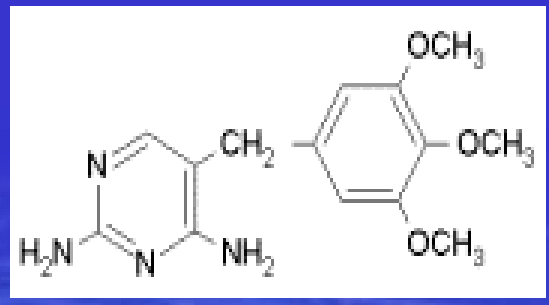
Meprobamate
[0.7]



TCEP
[1.44]



Sulfamethoxazole
[0.89]



Trimethoprim
[0.91]

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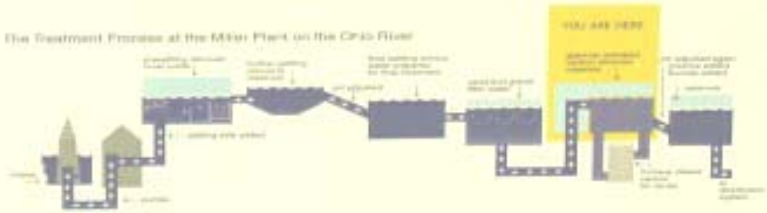
GAC Contactors

Post Filtration Treatment Process

GRANULAR ACTIVATED CARBON

Water treated by the GAC process needs about 2/3 less chlorine than without GAC. Chlorine is required to disinfect water.

- Water which has been filtered through sand is then passed through twelve GAC Contactors, each containing 11.4 feet of carbon (600,000 pounds) to remove a broad spectrum of organic substances.
- In all twelve contactors there are 7.2 million pounds of granular carbon.
- Each contactor is 30 feet by 65 feet by 26 feet deep. Carbon contact time with the water is about 20 minutes with a flow rate of approximately 125 million gallons per day.
- Carbon has a very large surface area for organics removal. One pound of carbon equals 125 acres of surface area. It is made from coal.



PAC

- 5 mg AC800 PAC/L added as hydrated slurry
- Mixed for 4 hours
- Filtered through GF/F filter
- Preserved for sample analysis

GAC

- Rapid Small Scale Column Tests (RSSCT)
- Hydrodarco 4000 lignite-based GAC
- 7.6 minute empty-bed contact time simulation

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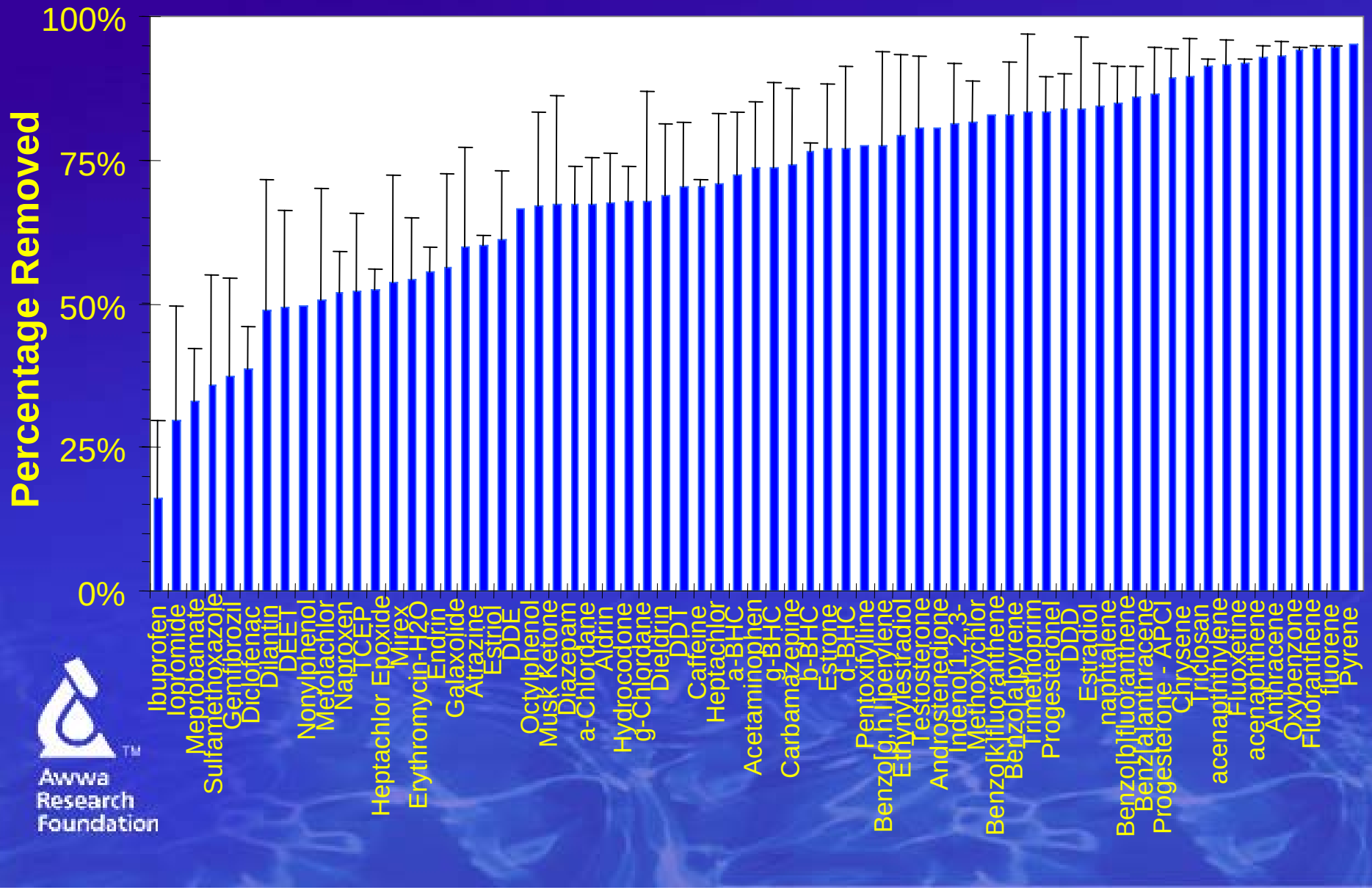
Average PAC Removal (5ppm-WPM)



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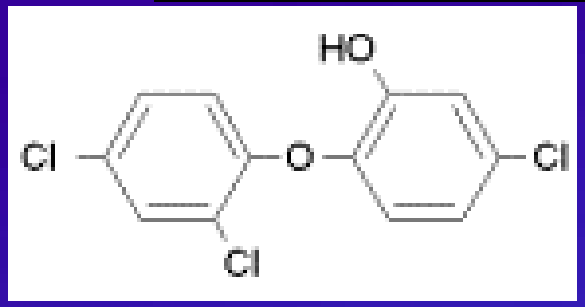
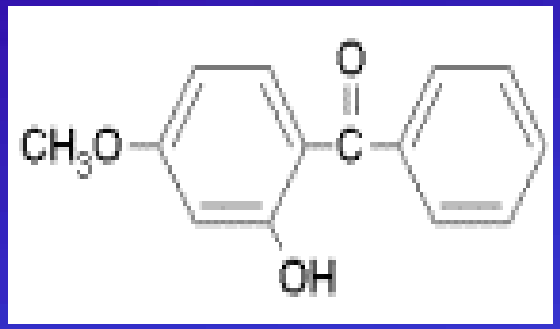
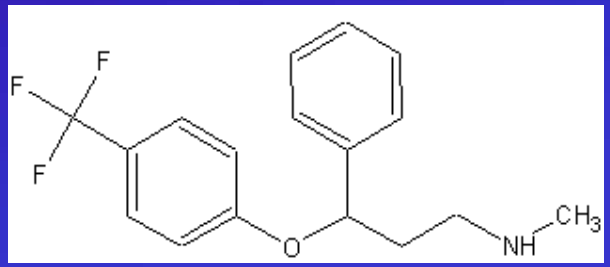
PAC - >90% Removal



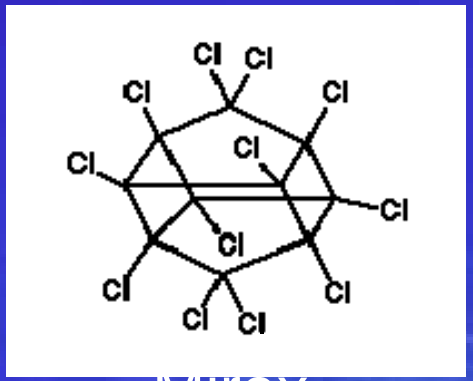
Triclosan
[4.76]



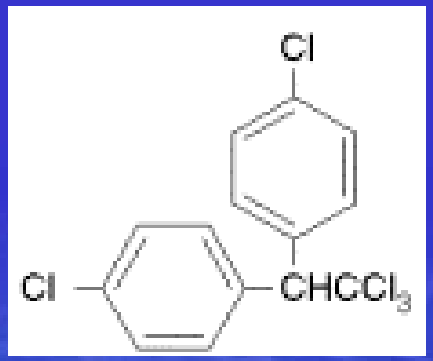
Oxybenzone
[3.79]



Fluoxetine
[4.23]



Mirex
[6.89]



DDT
[6.91]

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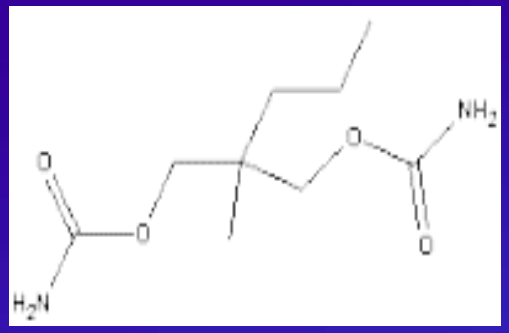
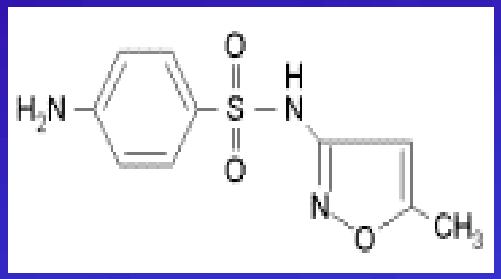
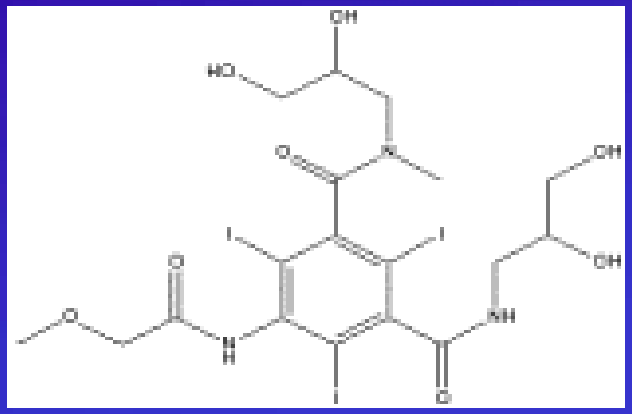
PAC - <50% Removal



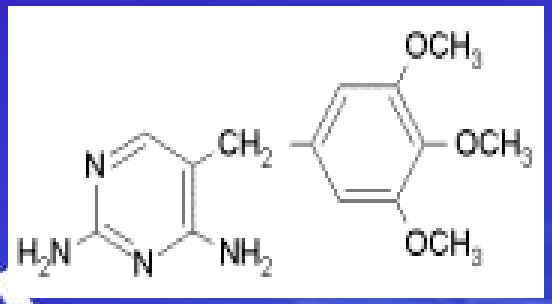
Meprobamate
[0.7]



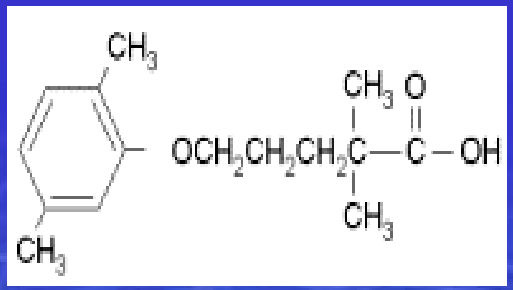
Sulfamethoxazole
[0.89]



Iopromide
[-2.05]



Trimethoprim
[0.91]



Gemfibrozil
[4.77]
pKa 4.7 = 100% ionized

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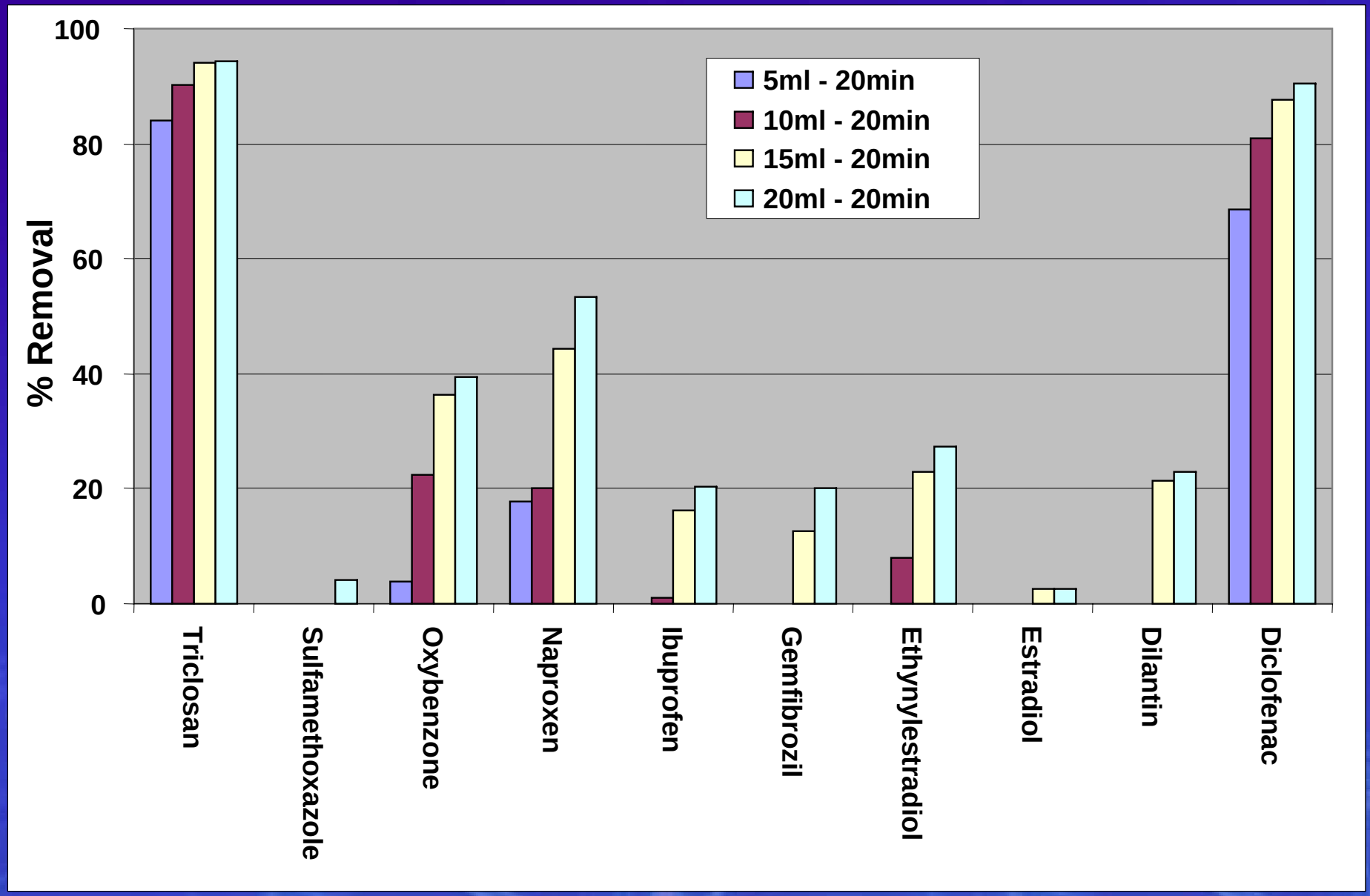
GAC – RSSCT

	20,000 BV	27,500 BV	35,000 BV	45,000 BV	65,000 BV	90,000 BV
Analyte	**ppt**	**ppt**	**ppt**	**ppt**	**ppt**	**ppt**
Hydrocodone	<2.0	<2.0	<2.0	4.1	11	45
Trimethoprim	<2.0	<2.0	<2.0	<2.0	8.3	37
Acetaminophen	<2.0	<2.0	7.6	17	45	108
Caffeine	<20	<20	<20	<20	29	90
Erythromycin-H_2O	<2.0	<2.0	<2.0	<2.0	<2.0	2.8
Sulfamethoxazole	25	46	80	103	119	184
Fluoxetine	<2.0	<2.0	<2.0	<2.0	<2.0	7.3
Pentoxifylline	<2.0	<2.0	<2.0	2.7	11	41
Meprobamate	12	29	56	93	131	217
Dilantin	<2.0	5.8	12	25	45	96
TCEP	<20	24	<20	40	78	159
Carbamazepine	<2.0	<2.0	<2.0	4.0	14	51
DEET	<2.0	9.0	4.6	27	51	121
Atrazine	<2.0	<2.0	<2.0	13	31	93
Diazepam	<2.0	<2.0	<2.0	<2.0	8.2	36
Oxybenzone	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Estriol	<10	<10	<10	<10	7.3	35
Ethynylestradiol	<2.0	<2.0	<2.0	<2.0	4.5	22
Estrone	<2.0	<2.0	<2.0	2.5	5.0	20
Estradiol	<2.0	<2.0	<2.0	<2.0	<2.0	12
Testosterone	<2.0	<2.0	<2.0	<2.0	<2.0	9.4
Progesterone	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Androstenedione	<2.0	<2.0	<2.0	<2.0	<2.0	8.7
Iopromide	20	38	61	96	126	191
Naproxen	<2.0	2.2	5	10	30	63
Ibuprofen	12	26	45	70	103	154
Diclofenac	<2.0	2.8	6.3	14	36	72
Triclosan	<2.0	<2.0	<2.0	<2.0	<2.0	7.6
Gemfibrozil	<2.0	<2.0	4.7	12	36	84

Magnetic Ion-Exchange (MIEX)

- 5, 15, and 20 mL slurry/L water for 10 min
- 5, 10, 15, and 20 mL slurry/L water for 20 min
- Experiments conducted in batch and pilot

MIEX


100
80
60
40
20
0
% Removal
5ml - 20min
10ml - 20min
15ml - 20min
20ml - 20min
Triclosan
Sulfamethoxazole
Oxybenzone
Naproxen
Ibuprofen
Gemfibrozil
Ethynylestradiol
Estradiol
Dilantin
Diclofenac

Membranes & UV AOP

- Full-scale water reuse systems
- MF – RO – UV/peroxide – MBR

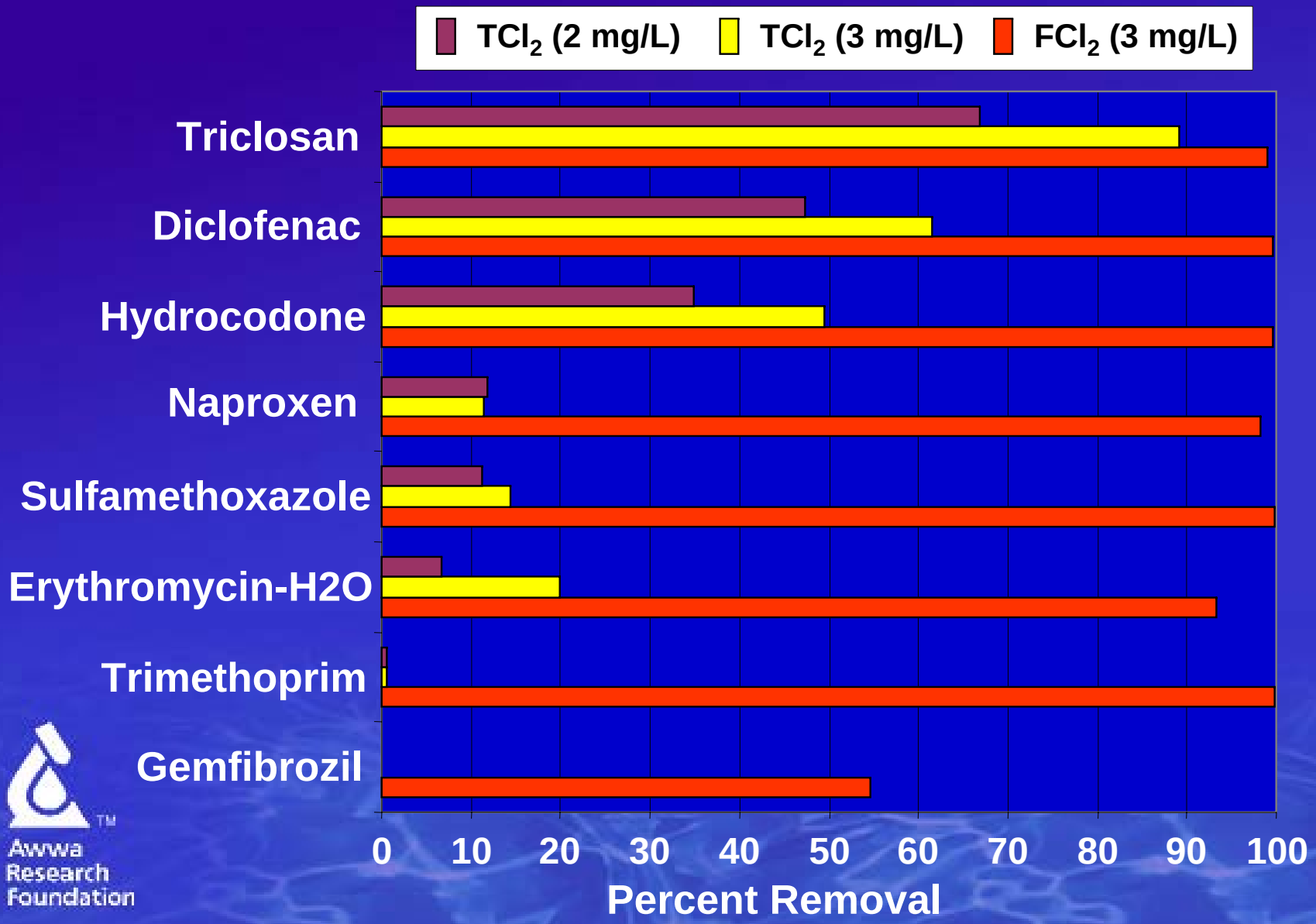
all units in ng/L	MF Influent	MF Effluent	RO Effluent	UV Influent	UV Effluent
Hydrocodone	48	51	<1.0	<1.0	<1.0
Trimethoprim	209	227	<1.0	<1.0	<1.0
Acetaminophen	<10	<10	<1.0	<1.0	<1.0
Caffeine	960	994	4.6	5.7	4.7
Erythromycin-H_2O	180	181	<1.0	<1.0	<1.0
Sulfamethoxazole	940	1030	1.9	2.1	<1.0
Fluoxetine	<10	<10	<1.0	<1.0	<1.0
Pentoxifylline	32	33	<1.0	<1.0	<1.0
Meprobamate	260	260	<1.0	<1.0	<1.0
Dilantin	160	180	<1.0	<1.0	<1.0
TCEP	360	370	13	<5.0	<5.0
Carbamazepine	220	237	<1.0	<1.0	<1.0
DEET	*2480*	*2430*	4.1	5.0	2.0
Atrazine	<10	<10	<1.0	<1.0	<1.0
Diazepam	<10	<10	<1.0	<1.0	<1.0
Oxybenzone	49	77	5.7	6.4	1.9
Estriol	<50	<50	<1.0	<5.0	<5.0
Ethynylestradiol	<10	<10	<1.0	<1.0	<1.0
Estrone	114	158	<1.0	<1.0	<1.0
Estradiol	10	14	<1.0	<1.0	<1.0
Testosterone	<10	<10	<1.0	<1.0	<1.0
Progesterone	<10	<10	<1.0	<1.0	<1.0
Androstenedione	<10	<10	<1.0	<1.0	<1.0
Iopromide	154	131	<1.0	<1.0	<1.0
Naproxen	536	621	1.2	<1.0	<1.0
Ibuprofen	441	500	<1.0	<1.0	<1.0
Diclofenac	50.0	59	<1.0	<1.0	<1.0
Triclosan	44	64	<1.0	<1.0	<1.0
Gemfibrozil	*3000*	*3750*	2.9	1.8	1.1

Analyte (ng/L)	Raw Waste Water	Advanced Primary Effluent	MBR Effluent	RO Permeate
Hydrocodone	<100	**34**	**48**	<1.0
Trimethoprim	**682**	**160**	**15**	<1.0
Acetaminophen	**20400**	**4310**	<1.0	<1.0
Caffeine	**52600**	**6780**	**7.3**	<1.0
Erythromycin-H_2O	**330**	**9.4**	**105**	<1.0
Sulfamethoxazole	**147**	**104**	**258**	<1.0
Fluoxetine	<100	**4.4**	**4.8**	<1.0
Pentoxifylline	<100	**6.5**	<1.0	<1.0
Meprobamate	**480**	**95**	**237**	**1.3**
Dilantin	**115**	**22**	**72**	<1.0
TCEP	**393**	**160**	**192**	**6.5**
Carbamazepine	**323**	**146**	**209**	<1.0
DEET	**679**	**176**	**36**	**2.3**
Atrazine	<100	<1.0	<1.0	**<1.0**
Diazepam	<100	**1.1**	**2.8**	<1.0
Oxybenzone	**868**	**185**	**3.0**	<1.0
Estriol	**199**	**75**	<1.0	<1.0
Ethynylestradiol	<100	<1.0	<1.0	<1.0
Estrone	<100	**36**	**6.9**	<1.0
Estradiol	<100	<1.0	<1.0	<1.0
Testosterone	<100	**22**	<1.0	<1.0
Progesterone	<100	**21**	<1.0	<1.0
Androstenedione	<100	**59**	<1.0	<1.0
Iopromide	<100	<1.0	**3.2**	<1.0
Naproxen	**24800**	**532**	**16**	<1.0
Ibuprofen	**72000**	**645**	**4.2**	<1.0
Diclofenac	<100	**7.0**	**12**	<1.0
Triclosan	**4280**	**147**	**5.7**	<1.0
Gemfibrozil	<100	**305**	**26**	<1.0

Bench Scale Experiments

- Chlorine, chloramine, UV, and Ozone
- Ozone and Chlorine dose based on demand curves
- Medium pressure UV disinfection dose used in full-scale application using Colorado River
- 24 hr contact time for chlorine/chloramine experiments
- Compounds spiked from 100-300 ng/L

Free Chlorine vs Chloramine



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Chlorine 3.5 mg/L 24 hr

<30% Removal	30-70% Removal	>70% Removal
Testosterone	Ibuprofen	Estriol
Progesterone	Metolachlor	Ethynylestradiol
Androstenedione	Gemfibrozil	Estrone
Caffeine		Estradiol
Fluoxetine		Erythromycin-H_2O
Meprobamate		Sulfamethoxazole
Diazepam		Triclosan
Dilantin		Trimethoprim
Carbamazepine		Naproxen
DEET		Diclofenac
Atrazine		Hydrocodone
Galaxolide		Acetaminophen
TCEP		Musk Ketone
Iopromide		
Pentoxifylline		

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<30% Removal	30-70% Removal	>70% Removal
Testosterone	Sulfamethoxazole	
Progesterone	Triclosan	
Androstenedione	Diclofenac	
Estriol	Acetaminophen	
Ethynylestradiol		
Estrone		
Estradiol		
Erythromycin-H_2O		
Trimethoprim		
Naproxen		
Hydrocodone		
Ibuprofen		
Caffeine		
Fluoxetine		
Meprobamate		
Diazepam		
Dilantin		
Carbamazepine		
DEET		
Atrazine		
Galaxolide		
TCEP		
Iopromide		
Pentoxifylline		
Metolachlor		
Gemfibrozil		
Musk Ketone		

UV 40mJ/cm^2

Ozone 2.5 mg/L

<30% Removal	30-70% Removal	>70% Removal
Musk Ketone	Meprobamate	Testosterone
TCEP	Atrazine	Progesterone
	Iopromide	Androstenedione
		Estriol
		Ethynylestradiol
		Estrone
		Estradiol
		Erythromycin-H2O
		Sulfamethoxazole
		Triclosan
		Trimethoprim
		Naproxen
		Diclofenac
		Ibuprofen
		Hydrocodone
		Acetaminophen
		Carbamazepine
		Dilantin
		Diazepam
		Caffeine
		Fluoxetine
		DEET
		Metolachlor
		Galaxolide
		Pentoxifylline
		Gemfibrozil

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Ozone Kinetic Summary

2 Minutes Contact Time	24 Minutes Contact Time			
> 95% Removal	> 80% Removal	50-80% Removal	20-50% Removal	< 20% Removal
Acetaminophen	Androstenedione	DEET	Atrazine	TCEP
Carbamazepine	Caffeine	Diazepam	Iopromide	
Diclofenac	Pentoxifylline	Dilantin	Meprobamate	
Erythromycin-H_2O	Progesterone	Ibuprofen		
Estradiol	Testosterone			
Estriol				
Estrone				
Ethynylestradiol				
Fluoxetine				
Gemfibrozil				
Hydrocodone				
Naproxen				
Oxybenzone				
Sulfamethoxazole				
Triclosan				
Trimethoprim				

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Full-scale Treatment

- **Site selection**
  - likely occurrence
  - treatment processes
  - 18 U.S. utilities thus far
- **NO SPIKING**
  - limited to detectable compounds
  - prescreening
  - time of year important
  - interpretations challenging – simultaneous processes

Conventional Chlorine

	Raw ng/L	Finished	% Removal	%Predicted
Hydrocodone	1.9	<1.0	>47	>99
Trimethoprim	2.2	<1.0	>55	>99
Acetaminophen	1.5	<1.0	>33	>99
Caffeine	74	86	0	18
Erythromycin	3.2	<1.0	>69	>99
Sulfamethoxazole	35	<1.0	>97	>90
Meprobamate	10	8.0	20	13
Dilantin	13	7.2	45	18
TCEP	19	17	11	4
Carbamazepine	20	3.6	82	25
DEET	*28*	32	0	14
Atrazine	25	27	0	4
Iopromide	46	17	63	25
Naproxen	16	1	>94	>93
Ibuprofen	10	21	0	39
Triclosan	2.7	<1.0	>63	>99
Gemfibrozil	5.8	<1.0	>83	75

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Conventional Chlorine

	ng/L Raw	Finished	% Removal	% Predicted
Atrazine	42	40	5	4
Sulfamethoxazole	27	<1.0	>96	>90
Ibuprofen	24	32	0	39
Caffeine	11	10	9	19
TCEP	11	6.5	41	4
Gemfibrozil	11	4.2	62	75
Naproxen	10	<1.0	>90	>93
Carbamazepine	9.6	5.7	41	25
DEET	8.8	7.5	15	15
Dilantin	5.3	4.4	17	18
Meprobamate	4.0	3.8	5	13
Erythromycin	3.0	<1.0	>67	>96
Trimethoprim	2.3	<1.0	>57	>98
Triclosan	1.1	<1.0	>9	>97

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Full Scale Ozone

	Raw	Finished	% Removal	Predicted
Caffeine	4.1	<1.0	>99	>99
Sulfamethoxazole	11	<1.0	>99	>99
Meprobamate	13	9.4	28	50
Dilantin	3.1	1.5	52	80
TCEP	5.0	6.5	0	10
Carbamazepine	3.5	<1.0	>99	>99
DEET	4.0	2.0	50	70
Atrazine	1.4	<1.0	>50	50
Estrone	1.4	<1.0	>50	>99
Testosterone	1.0	<1.0	>50	>99

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Full Scale Ozone

	Raw	Finished	% Removal	Predicted
Sulfamethoxazole	9.7	<1	>90	>99
Meprobamate	11	5.8	47	50
Dilantin	3.2	<1	>70	80
TCEP	4.2	4.2	0	10
Carbamazepine	2.4	<1	>60	>99
DEET	3.4	1.4	59	70
Atrazine	1.4	<1	>30	>40

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Full Scale UV

	Pre-UV	Post-UV	% Removal	Predicted
Caffeine	25	27	0	3
Erythromycin	2.5	2.6	0	2
Sulfamethoxazole	1.7	2.1	0	43
Meprobamate	10	12	0	5
Dilantin	1.5	2.1	0	5
TCEP	21	22	0	0
Carbamazepine	2.2	2.8	0	3
DEET	3.9	4.6	0	5
Atrazine	8.0	8.5	0	5
Iopromide	7.3	7.8	0	11
Ibuprofen	6.2	8.1	0	7
Gemfibrozil	9.5	10	0	2

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Full Scale UV

	Raw (ng/L)	Finished (ng/L)	% Removal	Predicted
Atrazine	28	29	0	5
Caffeine	24	12	50	3
TCEP	19	15	21	0
Meprobamate	8.0	8.0	0	5
Gemfibrozil	7.4	2.4	68	2
Sulfamethoxazole	5.8	<1.0	>83	43
DEET	5.0	4.1	18	5
Iopromide	4.1	4.6	0	11
Ibuprofen	2.4	2.7	0	7
Acetaminophen	1.8	<1.0	>44	18
Dilantin	1.3	1.1	15	5
Carbamazepine	1.2	<1.0	>17	3
Erythromycin	1.0	<1.0	0	10

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Summary

- **GAC extremely effective**
  - must be “regenerated”
  - efficiency reduced by NOM

- **PAC excellent for most compounds**
  - **>80% removal for all compounds in DI water**
  - **less effective with CR water**
    - **blocking/competition with NOM**
    - **Compounds with < 50% removal generally had log Kow <1**

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Summary

- Membranes:
  - removal based on structure (MW, Kow, MV) AND membrane surface (pore size, charge, thickness)
  - log Kow > 3 compounds well removed by NF and UF
- Biological
  - Selective removal, compound specific

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Summary

- MIEX
  - Limited utility for contaminants studied
- UV
  - Ineffective at disinfection dose (~40 mJ/cm^2)
  - Selectively effective at oxidative dose (~1000 mJ/cm^2)

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Summary

- Coagulation/Softening generally poor:
  - Effective for compounds bound to particles
  - Most compounds with log K_{ow} > 5 limited removal
    - DDTs [6], galaxolide [5.9], octylphenol [5.5], BAP [6.1]

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Summary

- Chlorination/Ozonation
- - Chlorine good for phenolics, less effective for ketones
  - PPCPs, E2, EE2, octylphenol well removed (90 - >99%)
  - testosterone, progesterone, androstendione poorly removed
  - OC pesticides poorly removed
- - Ozone generally more effective than chlorine
  - Ozone/peroxide (AOP) slightly more effective than ozone alone
  - Higher peroxide doses likely would improve removal

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Summary

- EDCs/PPCPs can be reduced by treatment
- Ozone, carbon, and RO very effective
- Treatment strategies that *combine* processes would be most effective
- No treatment process or processes will ever remove all organic compounds to below detection of sensitive analytical instruments!

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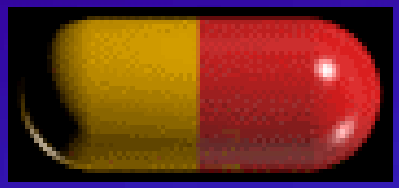
Final Thoughts



- But, what % removal is appropriate?
- Detection does not infer toxicity!
- We MUST understand the toxicological relevance at environmentally realistic concentrations!!!
- WHAT IS THE COST/BENEFIT RATIO?

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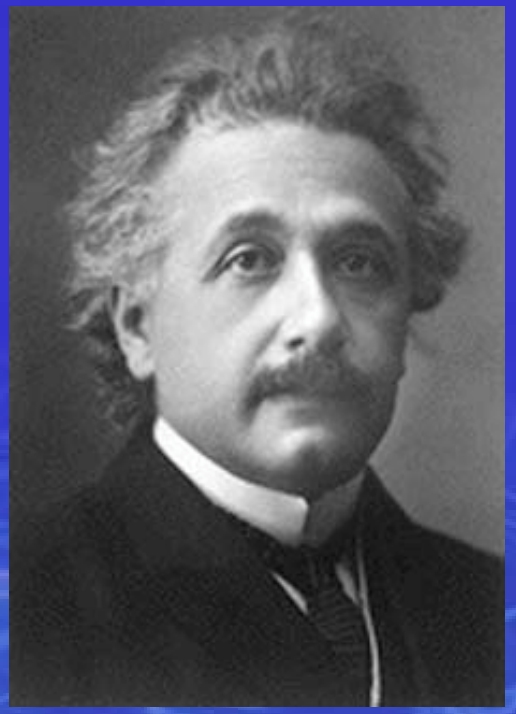
"Not everything that can be counted counts and not everything that counts can be counted "

– attributed to Albert Einstein



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Additional Information -

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