

Controlling Algal Metabolites in Drinking Water

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Kansas River Algae Workshop

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Overview

◆ Introduction

◆ Source Control

◆ Treatment

- General Considerations

- Removing Algae (intracellular metabolites)

- Removing Dissolved Algal Metabolites

- Tools for Operators (Neemann et al.)



Introduction

- ◆ **Metabolites of Primary Concern**
 - **Health: Algal Toxins**
 - **Aesthetics (consumer satisfaction):
Taste- and Odor-Causing Compounds**
- ◆ **Physical State:**
 - **Particulate (intracellular)**
 - **Dissolved (extracellular)**



Introduction (cont'd)

◆ Algal Toxins

- Hepatotoxins (liver toxins)

- > Microcystins (>70), Nodularins, Cylindrospermopsins

- Neurotoxins

- > Anatoxins, Saxitoxins

- Dermatotoxins (skin irritations)

- > Lyngbyatoxins, Lipopolysaccharides

- Others (known and unknown)



Introduction (cont'd)

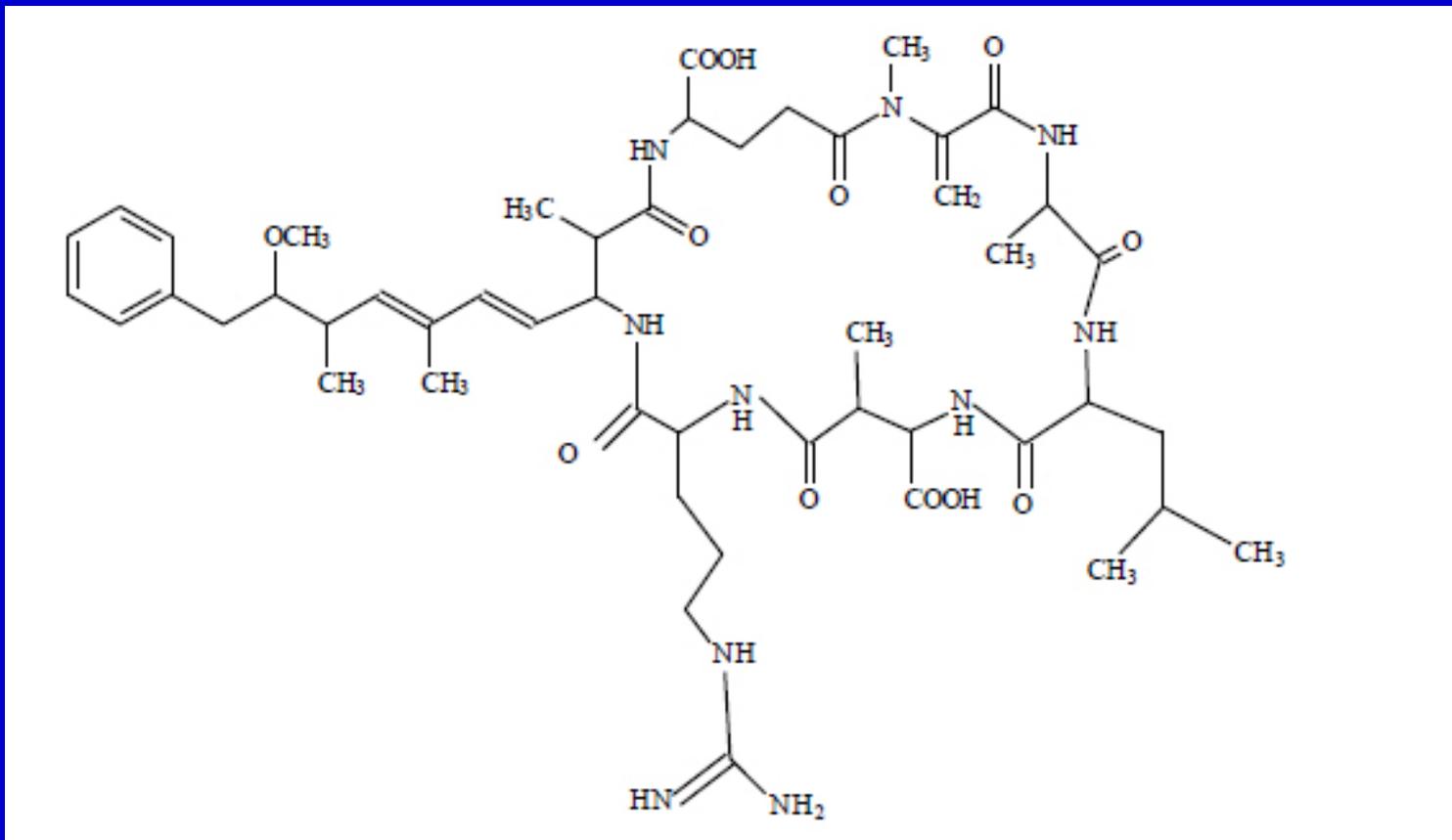
◆ Metabolites Vary

- Molecular weight and size
- Structure and chemical reactivity
- Charge
- Biodegradability
- Source (algal species, life stage, location)
- Effects: toxicity, threshold odor, etc.
- Physical properties: solubility, adsorbability, rate of diffusion, etc.



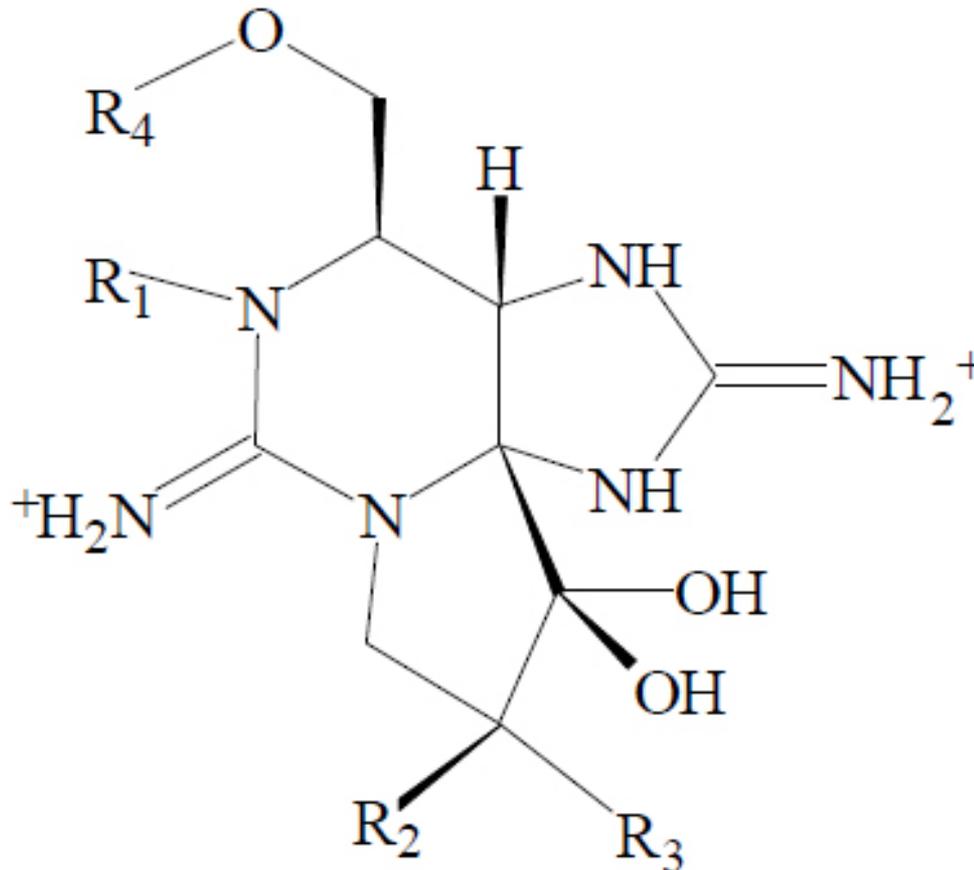
Introduction (cont'd)

◆ Microcystin-LR (cyclic peptide)



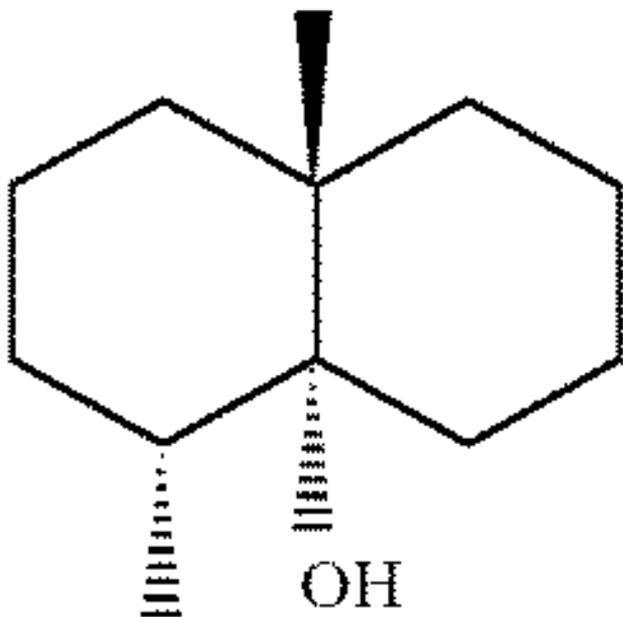
Introduction (cont'd)

◆ Saxitoxins (general structure)

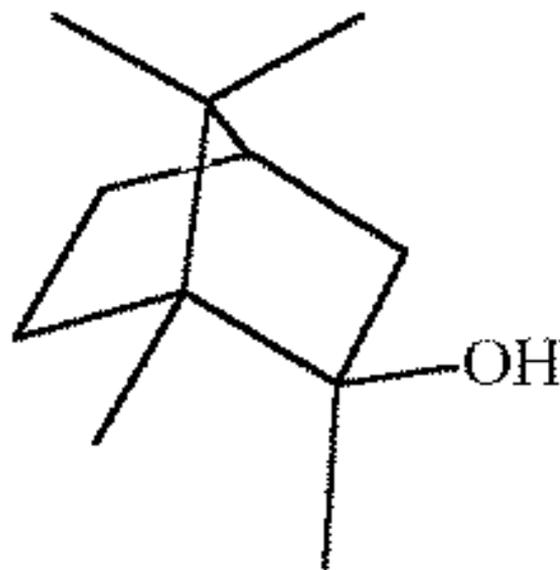


Introduction (cont'd)

◆ T&O-Causing Compounds



Geosmin



MIB



Treatment Objectives

- ◆ Drinking Water MCLs: None established
- ◆ EPA's CCL3: anatoxin-a, microcystin-LR, and cylindrospermopsin
- ◆ WHO “provisional guideline value” for microcystin-LR: 1 $\mu\text{g/L}$
- ◆ Australian “interim guideline value” for saxitoxins: 3 $\mu\text{g/L}$



Introduction (cont'd)

◆ Challenges

- Episodic events
 - > Sometimes fleeting
 - > Relatively unpredictable
 - > Varying in frequency and severity
- Lack of simple cause & effect relationships
- Analytical limitations
 - > Cost, timeliness, number of analytes determined
- Uncertain effectiveness of control options
- Numerous compounds having diverse properties



Source Control

- ◆ **Watershed Management**
- ◆ **Lake Management**
- ◆ **Management of River Supplies**



Source Control (cont'd)

◆ Watershed Management

● Reduce nutrient influx

- > Best to control phosphorus
- > Nitrogen control can backfire!

● Reduce sediment influx

- > May help control phosphorus
- > Helps maintain reservoir depth
- > May increase photosynthesis



Source Control (cont'd)

◆ Lake Management

- Chemical control of algae
- Aeration / circulation / destratification
- Phosphorus precipitation / inactivation
- Water quality manipulation (e.g., N:P)
- Sediment covering, flushing, etc.
- Biomanipulation
- Wetlands construction
- Dredging



Source Control (cont'd)

◆ Lake Management (cont'd)

- Many approaches can be taken.
- Techniques that reduce cyanobacteria are likely to be helpful.



Source Control (cont'd)

◆ Management of River Supplies

- Watershed management
- Lake / reservoir management (if applicable)
- Adjust upstream withdrawal depth
 - > Cyanobacteria are typically found in a particular depth range (some can control buoyancy)
 - > Trade offs likely (e.g., T&O versus Fe & Mn)



Source Control (cont'd)

◆ Management of River Supplies (cont'd)

- Source switching / blending

- > e.g., Des Moines: blending based on algal counts (Opflow, May 2012)

- Off-stream reservoirs

- > e.g., Cincinnati: off-stream reservoir with ability to add coagulants and PAC

- Riverbank filtration (or alluvial wells)

- > Removes algal cells
- > Attenuates peak metabolite concentrations
- > Some metabolites may adsorb or degrade



Factors Influencing Metabolite Production by Cyanobacteria

- ◆ Nutrient inputs
- ◆ Water quality, especially turbidity
- ◆ Rainfall, season, sunlight, wind speed, temperature (stratification)
- ◆ Lake morphology
- ◆ Microbial community composition and growth-stage & strain of producers
- ◆ Natural decomposition



Cyanobacterial Blooms

(Hoehn & Long, 2002)

- ◆ Cyanobacteria grow best in non-turbulent, warm rivers, lakes, and reservoirs.
- ◆ Blooms are enhanced by over-abundance of N and P (especially P).
- ◆ Not all blooms are harmful algal blooms (“HABs”).
- ◆ Toxic and non-toxic forms can exist in the same bloom.
- ◆ Toxic species are microscopically indistinguishable from non-toxic species.



Source Control – Summary

- ◆ Effective measures reduce the frequency and severity of events (in the long term), but are not expected to eliminate them in Kansas.
- ◆ Some measures may make matters worse.
- ◆ Over time, without intervention, the frequency and severity of events is expected to increase.
- ◆ When problems arise, water treatment plant operators will strive to continue producing safe drinking water; but source control and other measures help improve their chances of success.



Treatment

- ◆ Removing Algae (intracellular metabolites)
- ◆ Removing Dissolved Algal Metabolites
- ◆ Tools for Operators (Neemann et al.)



Removing Algae (and Intracellular Metabolites)

◆ Intracellular vs Extracellular Metabolites

- Depends on cell health, growth phase, etc.
- The intracellular fraction can be >95% for healthy *Microcystis* but $\leq 50\%$ for *Cylindrospermopsis*.

◆ Avoid Pre-Oxidation

- Generally causes cell lysis
- May in some cases be helpful, but
 - > Data are limited
 - > Risk generally exceeds rewards
 - > Possible exception: KMnO_4 and selected species
- More on this later in the workshop



Removing Algae (cont'd)

- ◆ **Avoid Other Causes of Cell Lysis**
 - Hydraulic shear (rapid mixing)
 - Sudden, large pH changes
 - Solids storage (cells can lyse in <1 d)
 - > Also consider return flows



Removing Algae (cont'd)

◆ Pretreatment

- Microstraining (not recommended for river supplies in Kansas)
- Presedimentation
 - > Preferably with coagulant addition
 - > Avoid pre-oxidation if possible
 - > Discharge solids promptly
- Riverbank filtration



Removing Algae (cont'd)

◆ Conventional Treatment

● Coagulation / flocculation / sedimentation

> Optimize coagulation for algae removal

- Algae differ (from each other and from other solids)
- Jar testing and algae counting recommended
- Consider pH (<7 usu. better), coagulant type, dosage, mixing, and polymer addition

> Optimize flocculation (avoid floc shear)

> Discharge solids promptly

> Avoid solids recirculation and return flows

● Coagulation / flocculation / DAF

> DAF not recommended for river supplies in Kansas



Removing Algae (cont'd)

◆ Conventional Treatment (cont'd)

● Rapid sand filtration

- > Increase backwashing frequency (reduce filter run times, perhaps to as little as 24 hours)
- > Eliminate, minimize, or treat return flows

● Lime softening

- > May lyse cells, so removing algae during pretreatment is preferable
- > Solids recirculation often an integral part of the process, so prompt discharge of solids or eliminating return flows may be problematic
- > Increased pH may influence removal or oxidation of metabolites



Removing Algae (cont'd)

◆ Membrane Filtration (MF/UF)

- Expected to readily remove cyanobacteria
 - > Most cells are $>1 \mu\text{m}$ in size
- Pretreatment recommended, to reduce fouling and potential for cell lysis
- Increased BW frequency may reduce toxin release (may be needed when algae are present)
- Submerged membranes less likely to shear cells than pressurized membranes, but cells more likely to accumulate and die
- Dead-end operation less likely to shear cells than crossflow operation



Removing Dissolved Metabolites

◆ Physical Processes

- Activated Carbon Adsorption
- Membrane Processes

◆ Chemical Oxidation

- Chlorine, Ozone, Permanganate, AOPs, etc.
- To Be Addressed by Neemann et al.

◆ Biological Processes

- Biofiltration
- Riverbank Filtration



Activated Carbon Adsorption

- ◆ Isotherms and Their Significance
- ◆ Powdered Activated Carbon (PAC)
- ◆ Granular Activated Carbon (GAC)



Adsorption Isotherms

◆ Terminology

- C = solution concentration
- q = surface concentration
= $(C_0 - C) / \text{adsorbent dosage}$

◆ Commonly Used Models

- Langmuir: $q = QbC/(1 + bC)$
 - > Q and b are constants
 - > Assumes adsorption of a single layer of molecules
 - > Maximum adsorption (Q) is a function of surface area
- Freundlich: $q = K_F C^{(1/n)}$
 - > K_F and $1/n$ are constants
 - > Yields a linear log-log plot (in theory)



A Freundlich Isotherm for MIB

(AWWA, *Water Quality & Treatment*, 5th ed.)

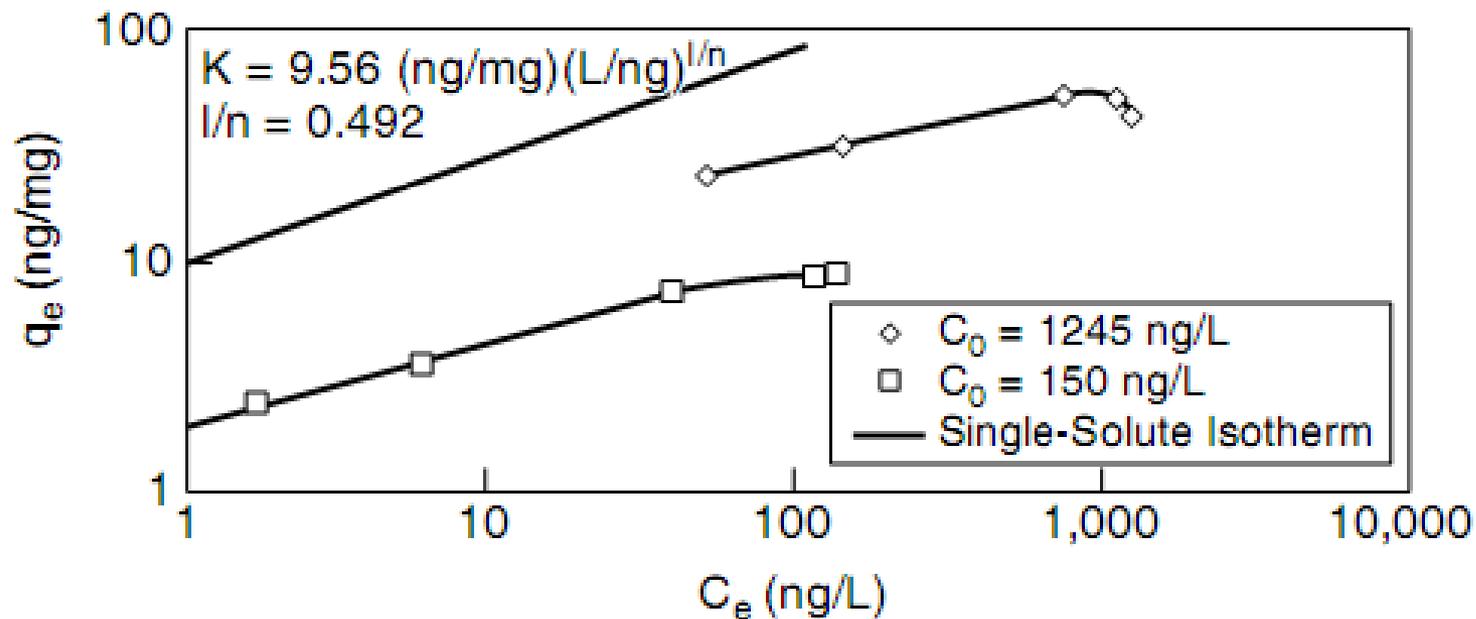


FIGURE 13.6 Effect of initial concentration on MIB capacity in Lake Michigan water. (Source: Gillogly et al., 1998b.)



Adsorption Isotherms (cont'd)

◆ Significance of Adsorption Isotherms

- If $C = 0$, $q = 0$, so adsorption cannot achieve 100% removal. (There is no origin on a Freundlich isotherm plot.)
- A higher isotherm is better – less adsorbent is needed to reach a given treatment objective.
- The relevant point on the isotherm depends on the nature of the treatment system.
- Completely mixed reactors (similar to many PAC systems) approach equilibrium with the effluent concentration. A higher dosage is required to reach a lower value of C because q decreases as C decreases.



Adsorption Isotherms (cont'd)

- ◆ **Significance of Adsorption Isotherms (cont'd)**
 - Columns approach equilibrium with the influent concentration, so are more efficient in theory, but:
 - > Competition from other adsorbates is magnified.
 - > “Unused” portions of the column can be preloaded with competing substances.
 - > Chromatographic displacement can occur.
 - > Desorption can occur if the influent concentration drops or due to competition.
 - Competing adsorbates lower the isotherm, indicating that a higher dosage is required to achieve a given treatment objective.



Adsorption Isotherms (cont'd)

- ◆ **Significance of Adsorption Isotherms (cont'd)**
 - If equilibrium is not reached in practice, q will be lower than predicted by an equilibrium isotherm, and a higher adsorbent dosage will be required.
 - Non-equilibrium isotherms are widely used for applications involving PAC, but must be determined using the appropriate contact time.
 - In a single-solute system, only one isotherm is possible at equilibrium, regardless of what parameters are varied.
 - In a multi-solute system, the isotherm depends on the initial concentration; but investigators have found that percent removal appears not to vary with initial concentration.



Percent MIB Remaining as a Function of PAC Dosage (AWWA, WQ&T, 5th ed.)

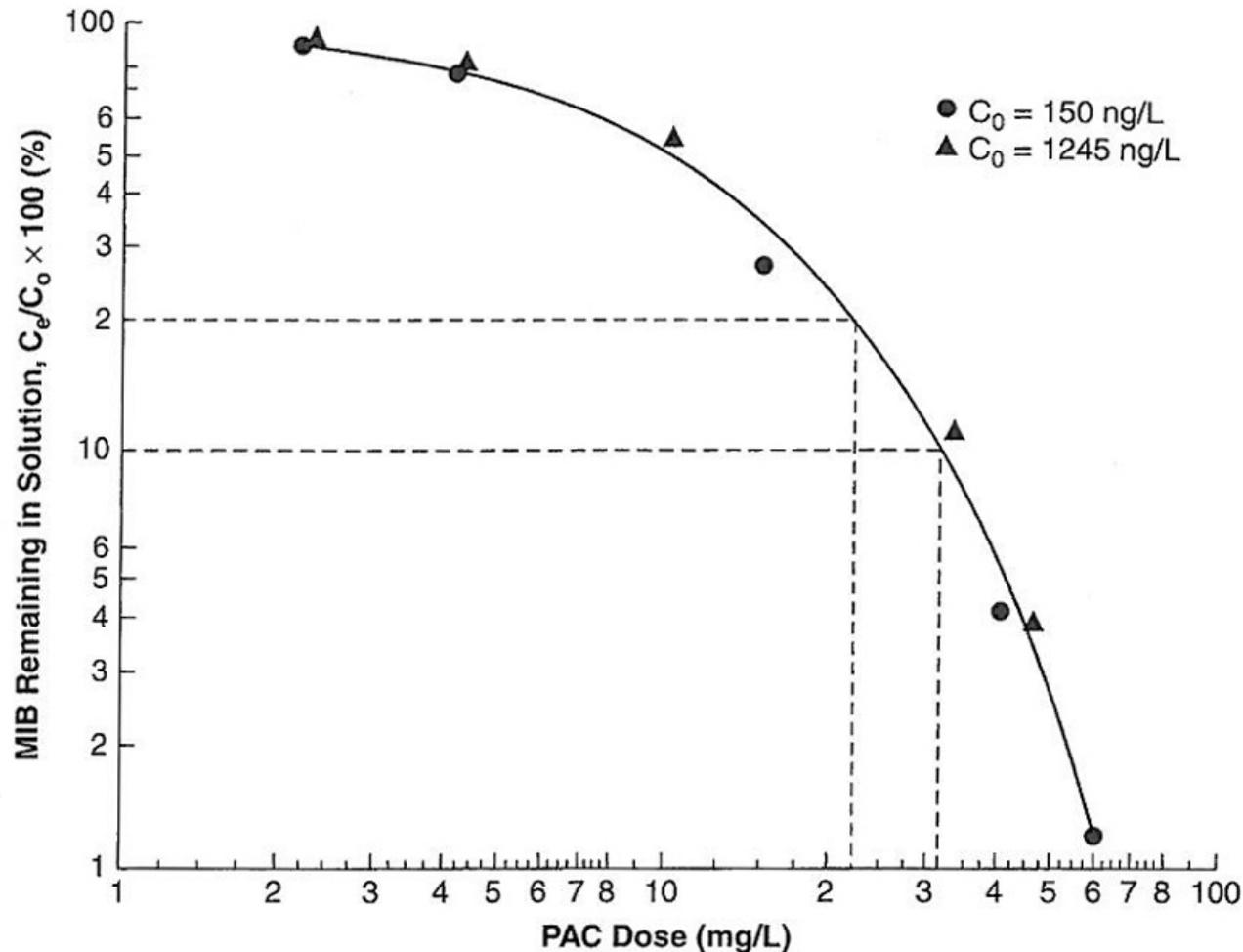


FIGURE 14-12 Percent MIB remaining as a function of PAC dose. (Source: Gillogly et al., 1998b.)



Adsorption (cont'd)

◆ Factors Influencing Adsorption

● Characteristics of the Adsorbent

- > Surface area, pore volume, hydrophobicity, charge, ...

● Characteristics of the Adsorbate

- > Solubility, molecular weight, charge, functional groups present, ...

● Characteristics of the Solution

- > pH, temperature, ionic strength, competing solutes (e.g., natural organic matter), ...

● Thus, each application is somewhat unique.



PAC Adsorption

- ◆ Widely used, but not always optimally
- ◆ Pros:
 - Can be used only when needed
 - Broadly effective for organic contaminants
 - Relatively low capital cost
- ◆ Cons:
 - PAC is inefficiently used in most reactors.
 - > Equilibrium is not reached.
 - > PAC capacity is limited by the effluent concentration.
 - Can cause gray water if incompletely removed.
 - Not readily regenerable; normally used once.



Factors Influencing PAC Adsorption

- ◆ PAC type and dosage
- ◆ Application point(s)
- ◆ Contact time (and “floatability”)
- ◆ Order of chemical addition
 - Cl₂, ClO₂, KMnO₄, Polymer
 - Lime
- ◆ Reactor type



PAC Cost Evaluation Example (MIB)

Source: AWWA Standard B600

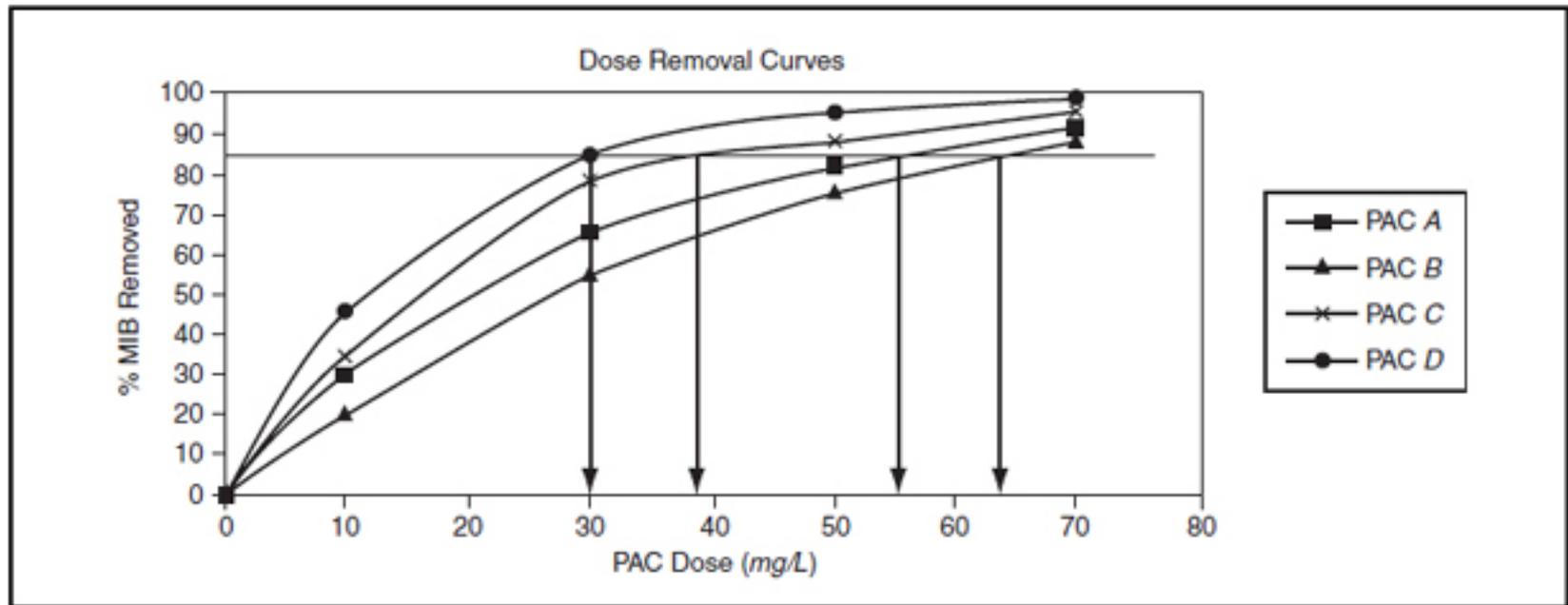


Figure B.1 Example of calculation of PAC dose-equivalent performance factors



PAC Cost Evaluation Example (MIB)

(cont'd)

Table B.1 Example weighted cost determined by performance factors

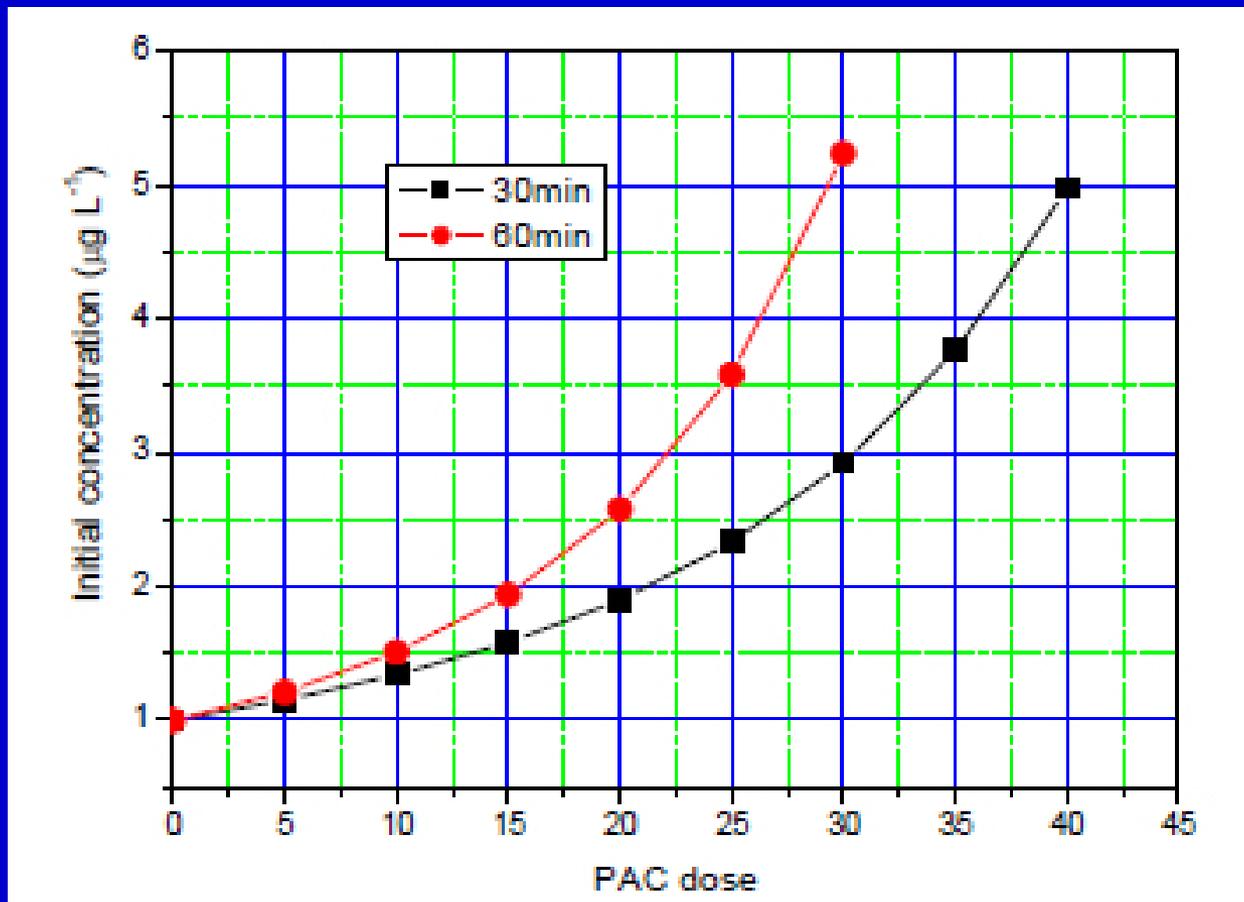
PAC	Cost/Ton	Performance Factor	Weighted Cost
<i>D</i>	\$1,000	1.00	\$1,000
<i>C</i>	\$895	1.27	\$1,137
<i>A</i>	\$1,010	1.83	\$1,848
<i>B</i>	\$800	2.10	\$1,680



The Effect of Contact Time

(Source: GWRC, 2009)

- ◆ PAC dosage to reduce toxin to 1 $\mu\text{g/L}$



PAC Application Points

(AWWA & ASCE, *Water Treatment Plant Design*, 4th ed., 2005)

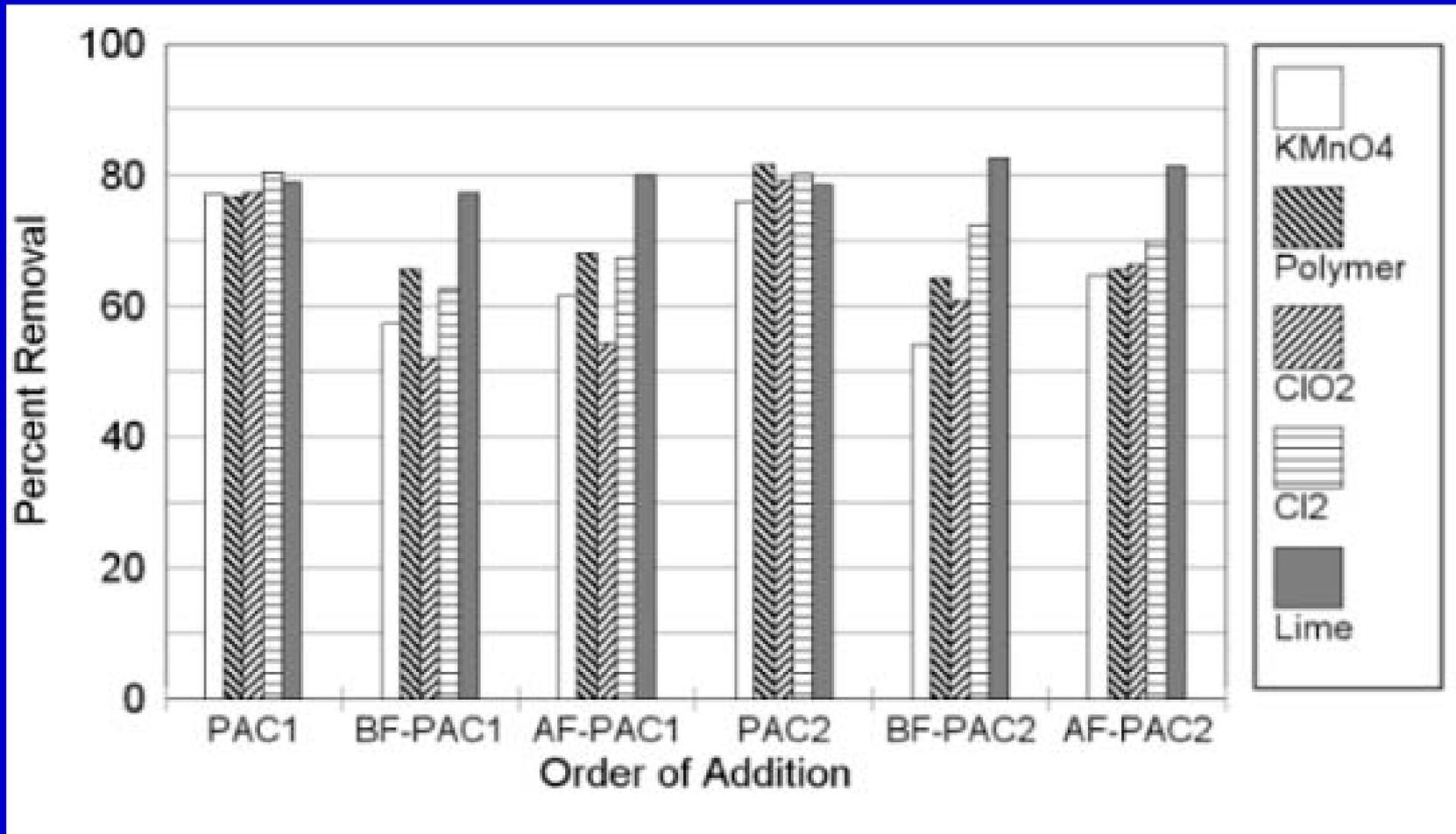
TABLE 14.2 Advantages and Disadvantages of Different PAC Application Points

Point of addition	Advantages	Disadvantages
Intake	Long contact time, good mixing	Some substances may adsorb that otherwise would be removed by coagulation, thus increasing the activated carbon usage rate
Slurry contactor preceding rapid mix	Excellent mixing for the design contact time; no interference by coagulants; additional contact time possible during flocculation and sedimentation	A new basin and mixer may have to be installed; some competition may occur from molecules that otherwise would be removed by coagulants
Rapid mix	Good mixing during rapid mix and flocculation; reasonable contact time	Possible reduction in rate of adsorption because of interference by coagulants; contact time may be too short for equilibrium to be reached for some contaminants; some competition may occur from molecules that otherwise would be removed by coagulation
Filter inlet	Efficient use of PAC	Possible loss of PAC through the filters and into the distribution system

Source: Adapted from I. N. Najm et al., 1991.



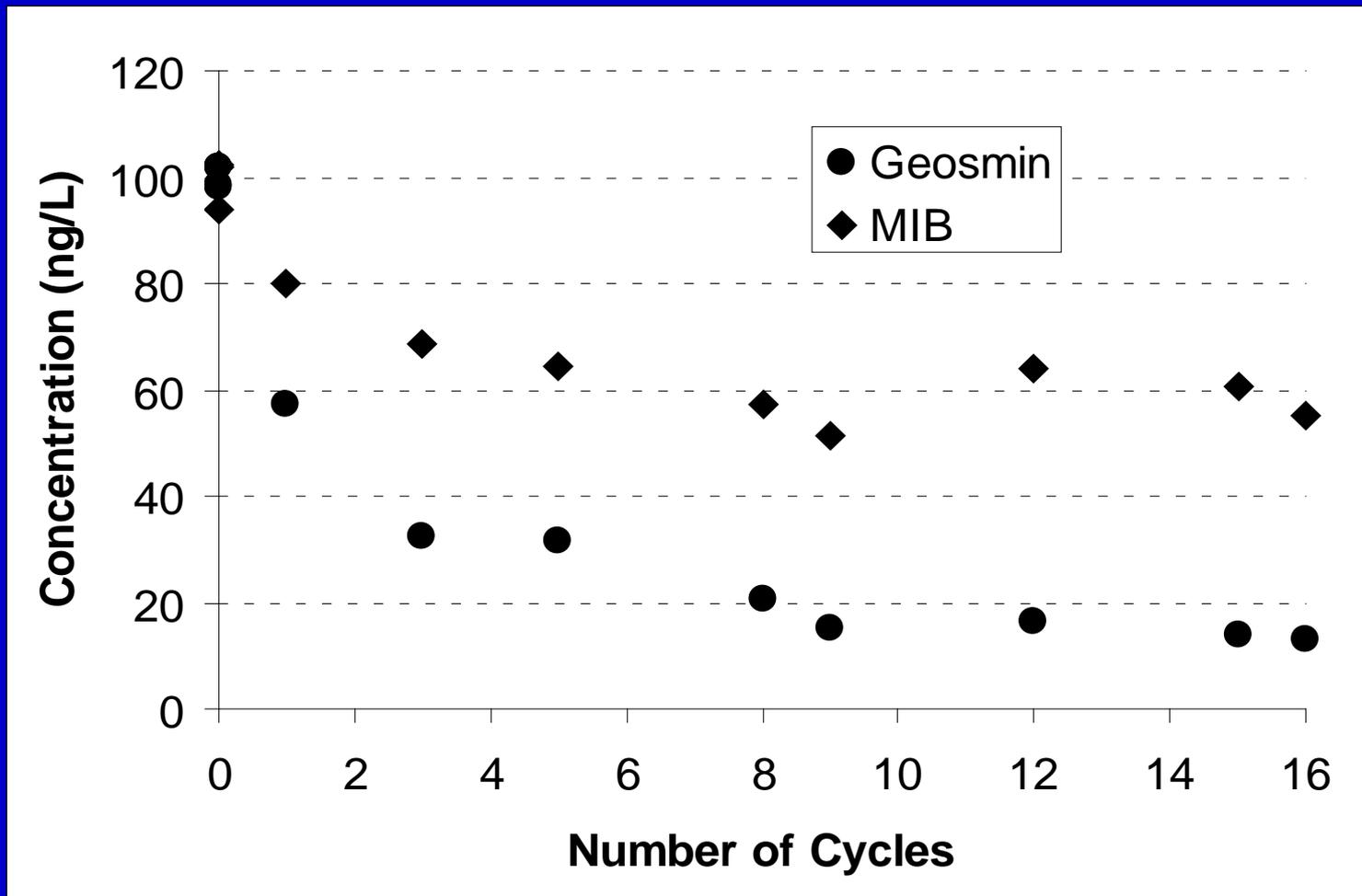
Effect of Order of Chemical Addition on Geosmin Removal (Pan et al., 2002)



BF = 5 min before; AF = 5 min after; 30 min contact



PAC Adsorption in a Simulated Solids-Contact Reactor (Pan et al., 2002)



Algal Toxin Removal Using PAC

- ◆ **Source: Global Water Research Coalition (GWRC), 2009**
- ◆ **Microcystins**
 - Use a PAC with a high volume of pores >1 nm (typ. a low density PAC).
 - Extent of removal (required dosage) varies widely, so test several PACs (as described above).
 - MC-LA is as toxic as MC-LR but harder to remove.



Algal Toxin Removal Using PAC (cont'd)

◆ Microcystin Mixtures

- “The presence of a mixture of toxins does not appear to affect the [required] doses.” (This is as expected. Their concentrations are low enough that they should behave independently of one another.)
- “Therefore, for a mixture ... add the doses for each toxin individually.” (This is not correct! If they adsorb independently, the highest dosage required for one toxin should remove all the others. If they do influence one another, a higher dosage will be needed, but the effect is not additive.)



Algal Toxin Removal Using PAC (cont'd)

◆ Saxitoxins

- Smaller than microcystins, so smaller pores more effective
- PAC with a high iodine numbers or a surface area $>1,000 \text{ m}^2/\text{g}$ may be suitable.
- PACs effective for geosmin and MIB are generally effective for saxitoxins.

◆ Cylindrospermopsin and Anatoxin-A

- Limited data, but PACs effective for microcystins appear to also be effective for cylindrospermopsin and anatoxin-a.



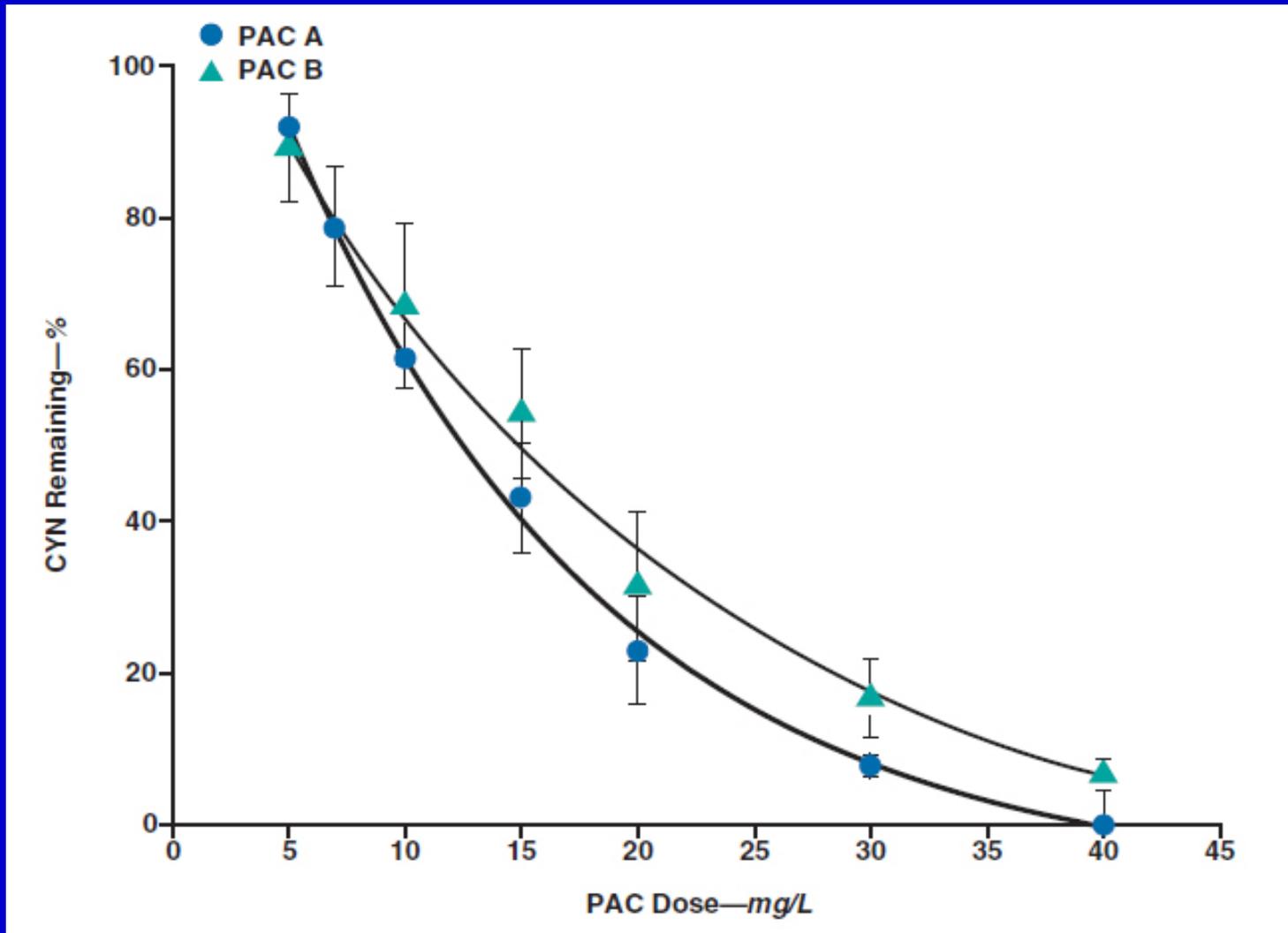
Algal Toxin Removal Using PAC (cont'd)

◆ Recommendations (DOC = 5 mg/L; θ = 60 min.)

Toxin		Inlet concentration ($\mu\text{g L}^{-1}$)	PAC dose (mg L^{-1})	Type of PAC
microcystins	m-LR	1-2	12-15	Wood-based, chemically activated, or high mesopore coal, steam activated **NR-not recommended
		2-4	15-25	
	mLA	1-2	30-50	
		2-4	NR**	
	mYR	1-2	10-15	
		2-4	15-20	
	mRR	1-2	8-10	
		2-4	10-15	
cylindrospermopsin		1-2	10-20	As above
		2-4	20-30	
saxitoxin		5-10 STX eq	30-35	Coal wood or coconut, steam activated



Cylindrospermopsin Removal Using PAC (Ho et al., 2008)



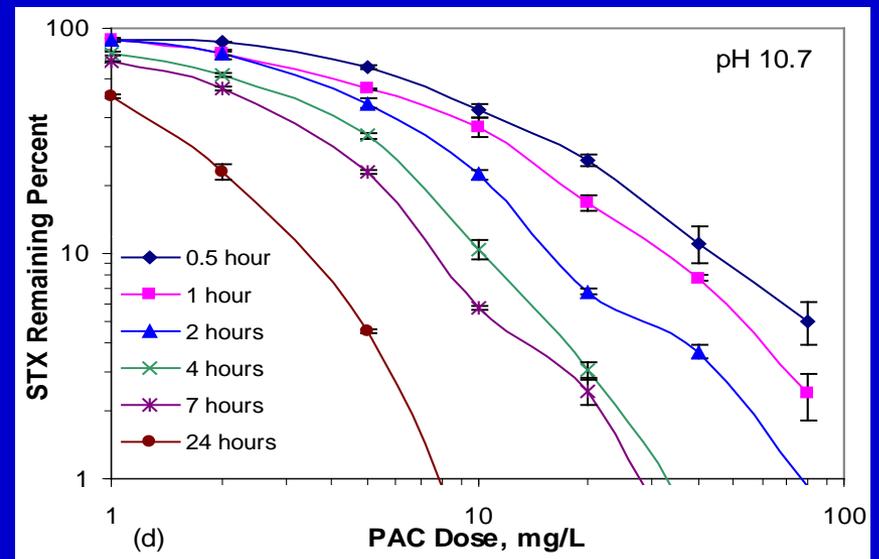
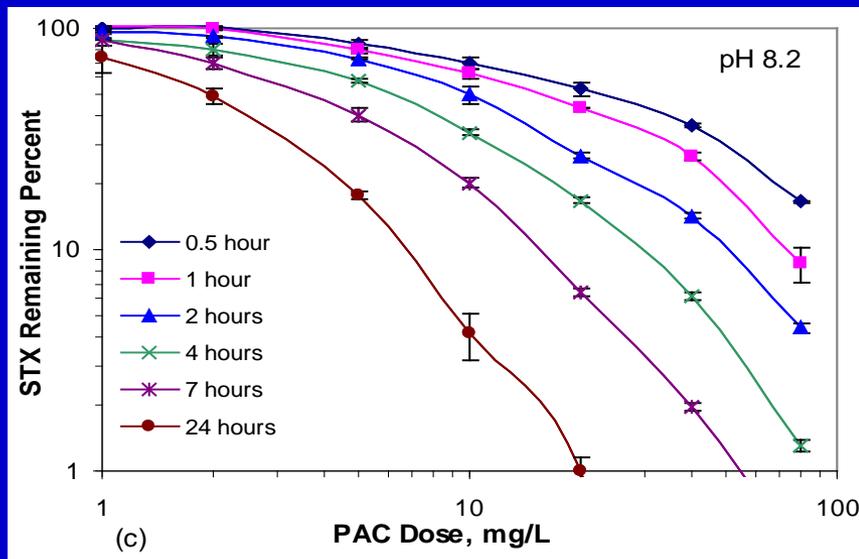
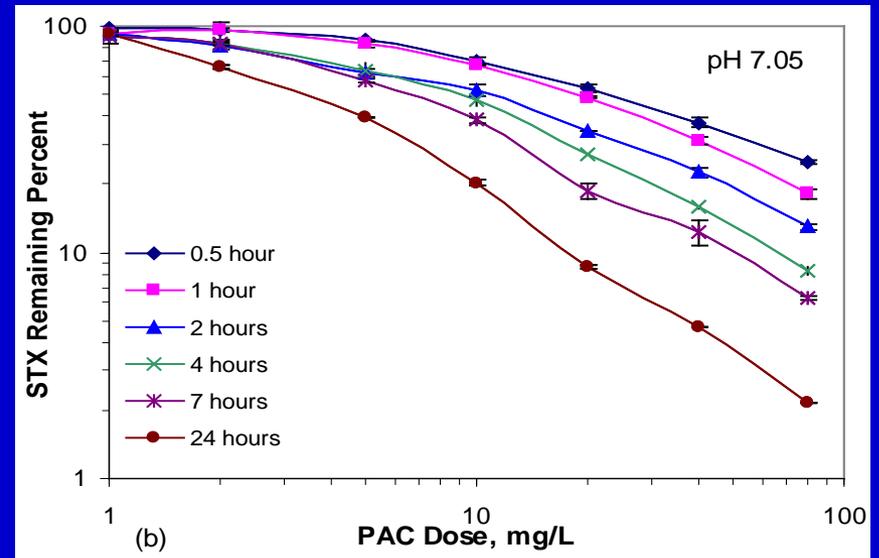
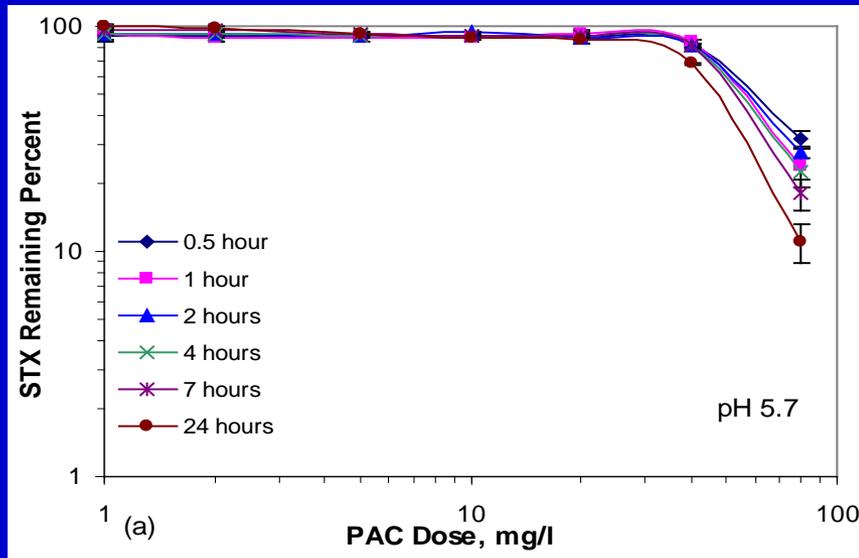
Saxitoxin Removal Using PAC (Adams, 2012)

◆ Experimental Conditions

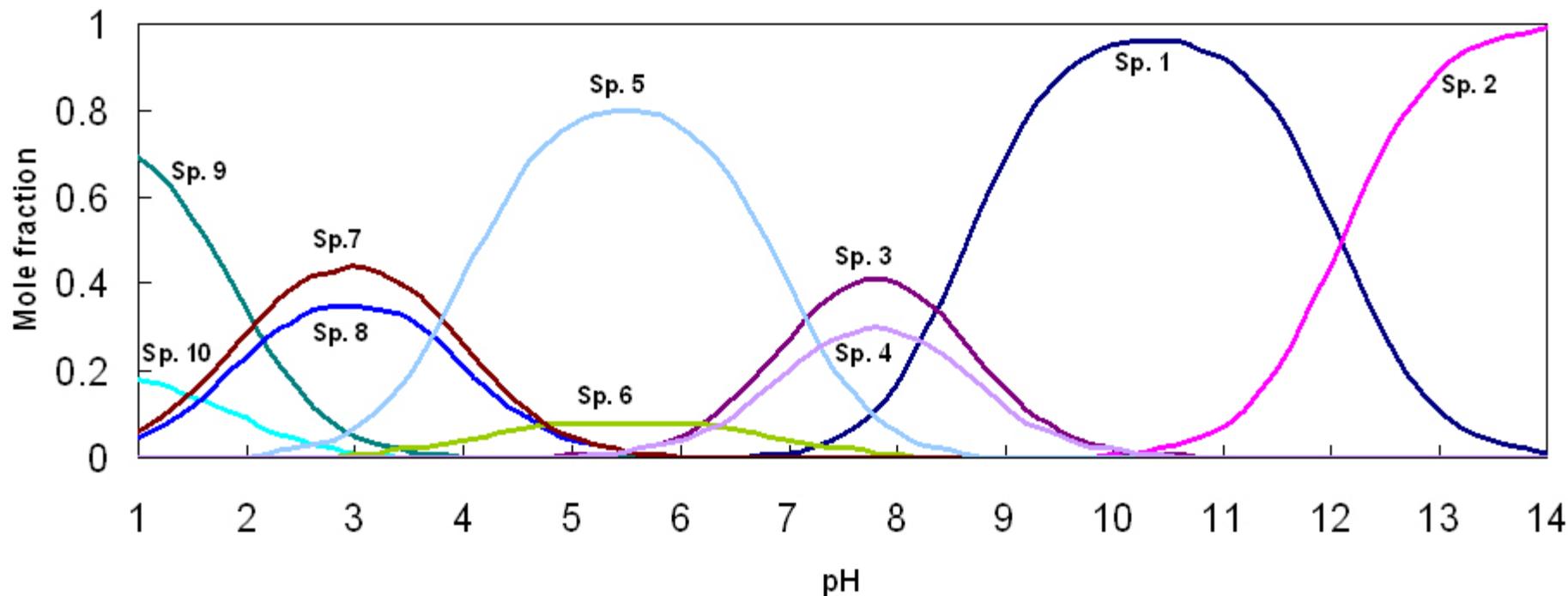
- Temperature: 20-22 °C
- PAC type: WPH (Calgon)
- Initial STX concentration: 25 ppb
- pH: 5.7, 7.05, 8.2, 10.7
- Waters
 - > DI water
 - > Water from Bray pond (BPW) in Rolla



Saxitoxin Adsorption in DI Water

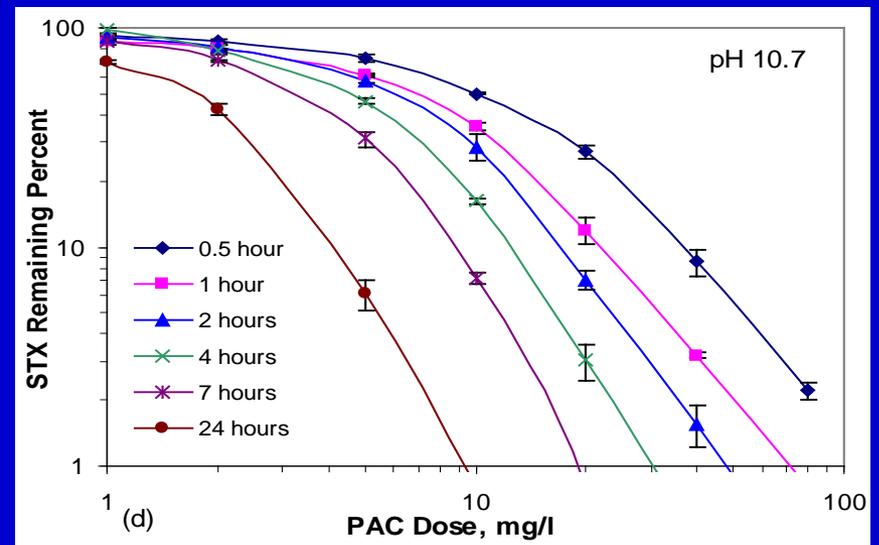
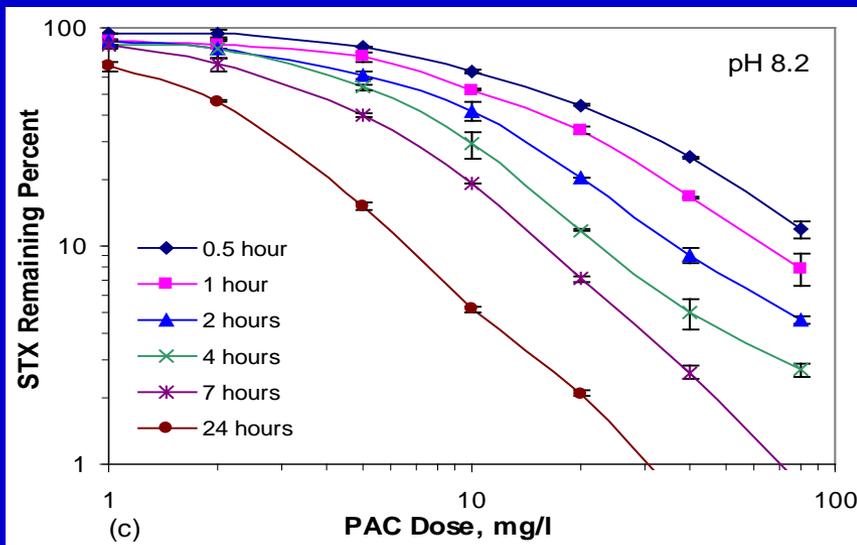
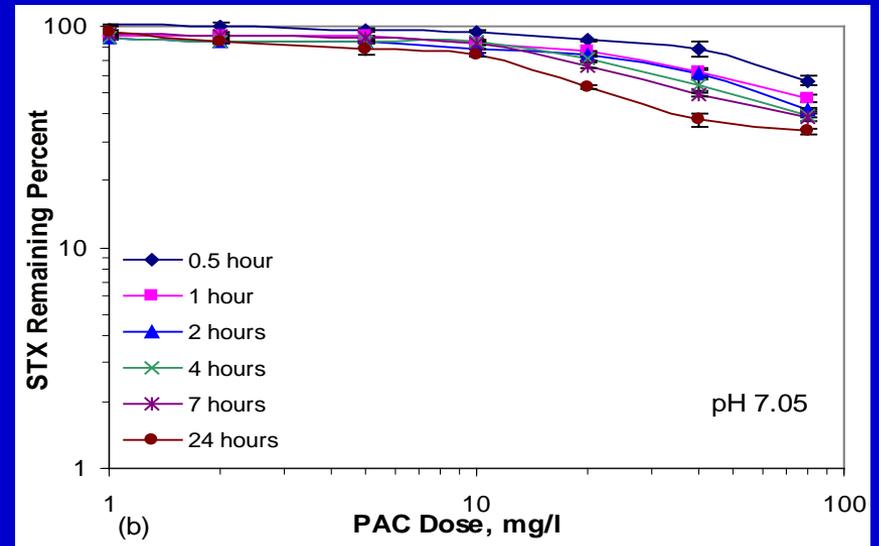
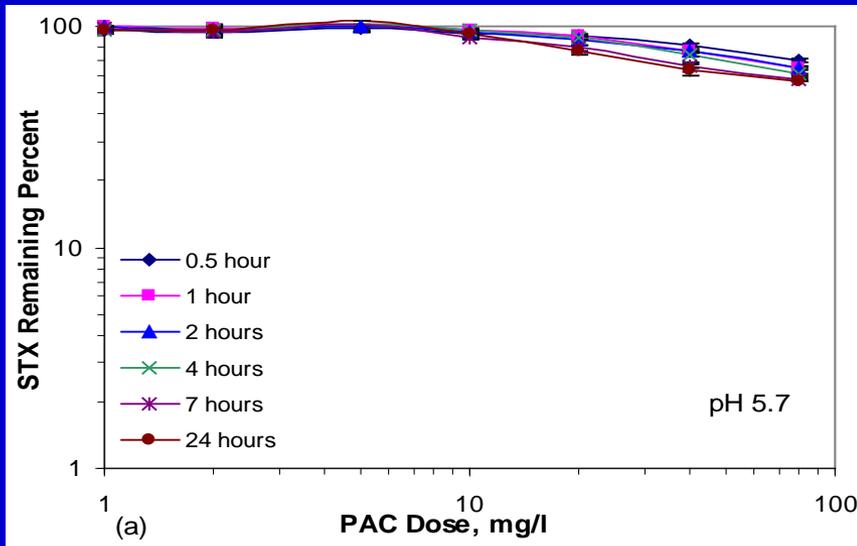


Speciation of Saxitoxin

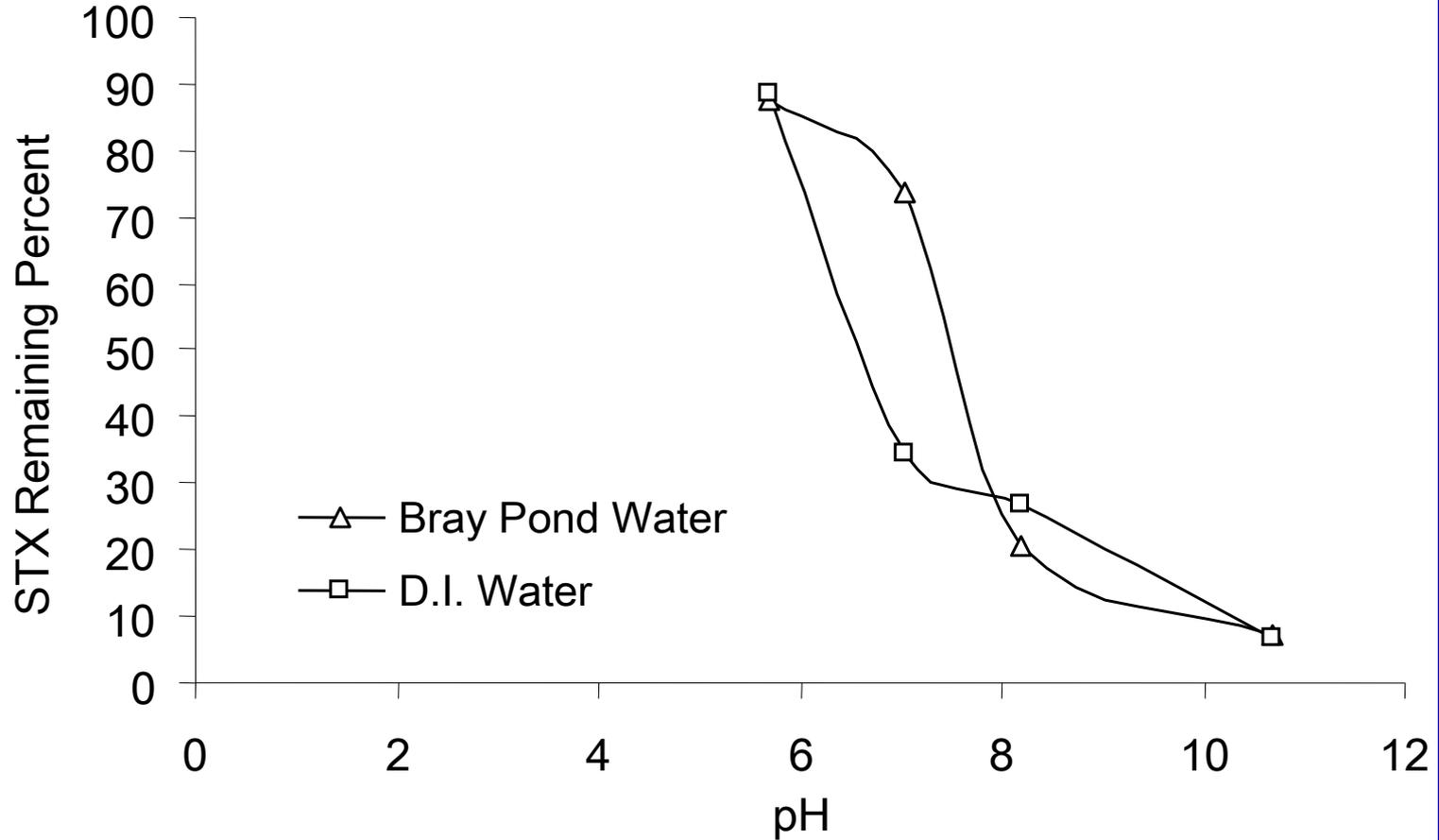


Major reference: Hilal, Said, S. W. Karickhoff and L. A. Carreira, "A Rigorous Test for SPARC's Chemical Reactivity Models: Estimation of More Than 4300 Ionization pKa's," *Quant. Struc. Act. Rel.*, 14, 348, 1995.

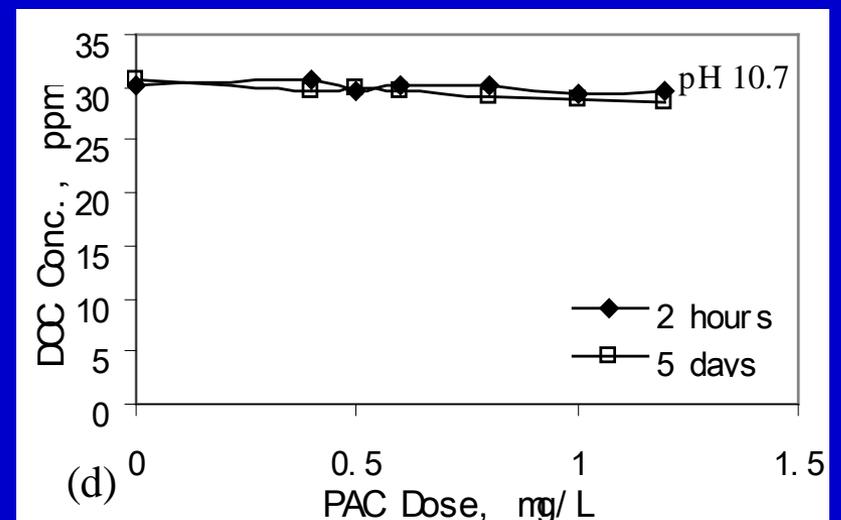
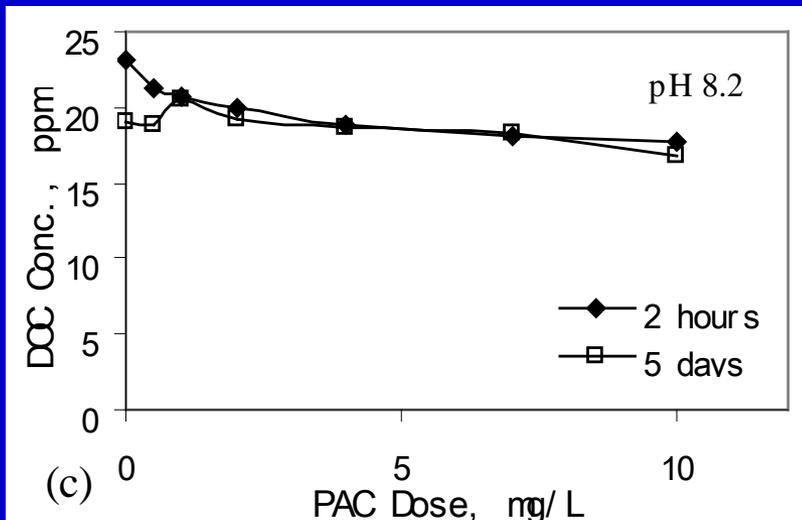
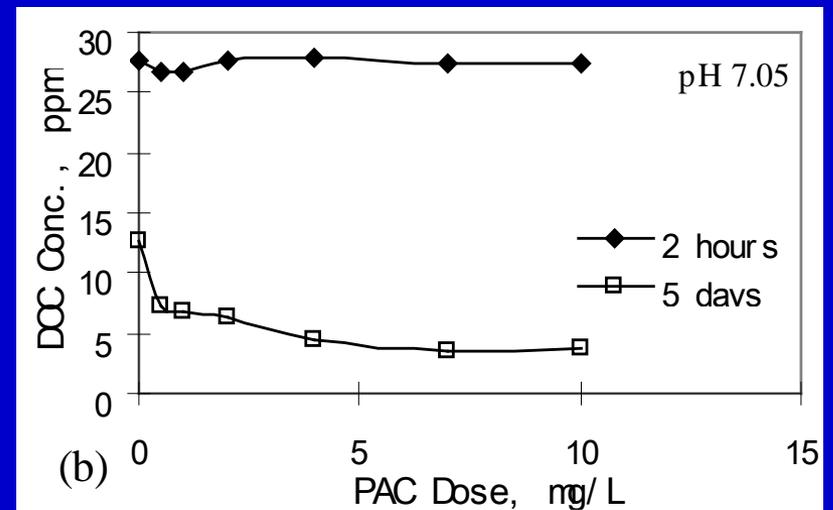
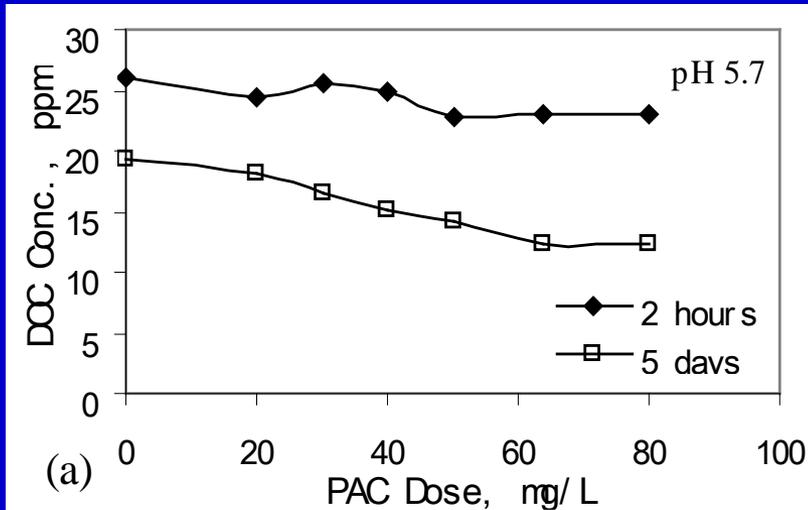
Adsorption in Bray Pond Water



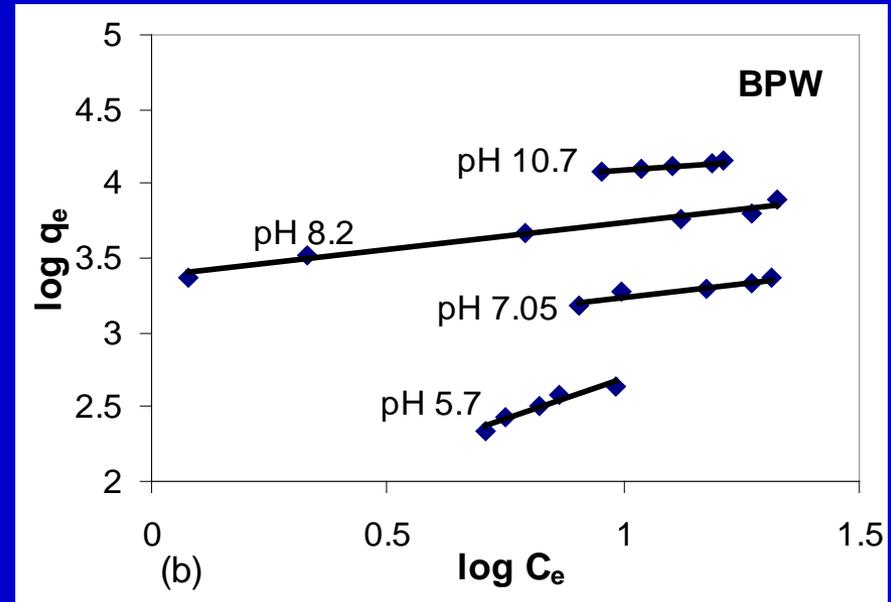
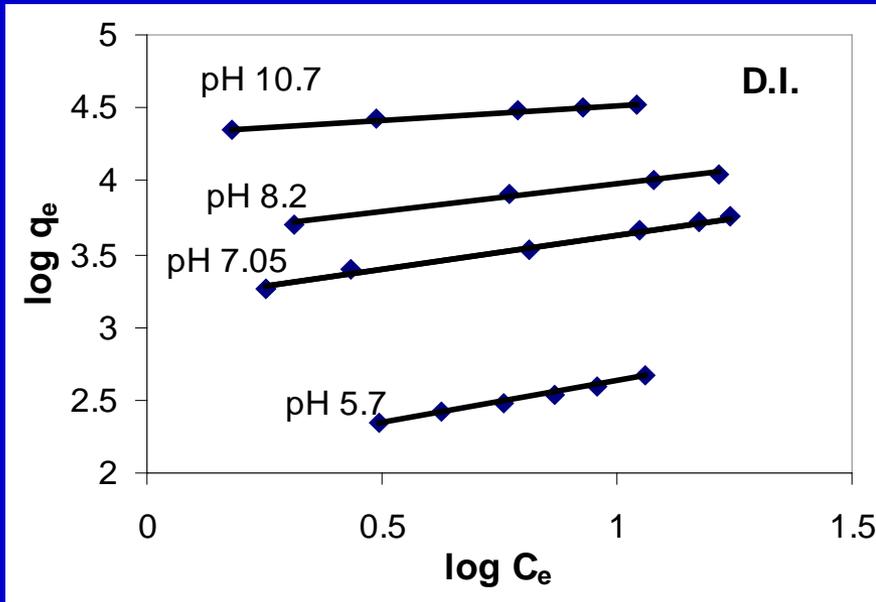
Effect of pH on Adsorption



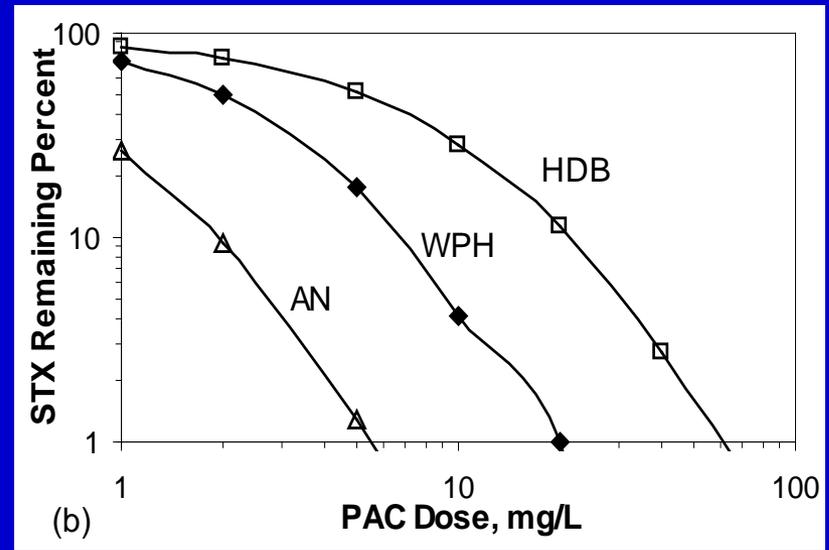
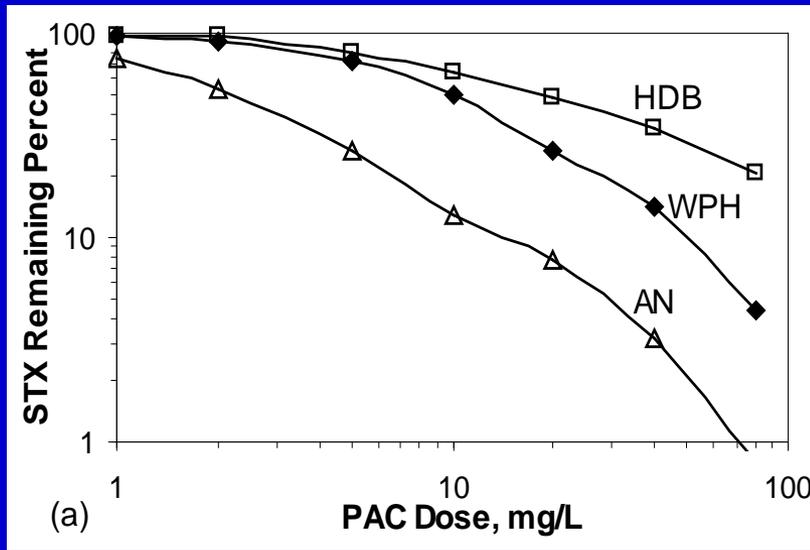
TOC Removal Versus pH



Effect of pH on PAC Adsorptive Capacity for Saxitoxin



Effect of Carbon Type



HDB = Hydrodarco B, lignite based (Norit)

WPH = bituminous coal based (Calgon)

AN = Aqua Nuchar, wood based (MeadWestvaco)

GAC Adsorption

◆ Pros:

- Continuous protection; present when needed
- Greater capacity than PAC (in theory)
- May facilitate biodegradation

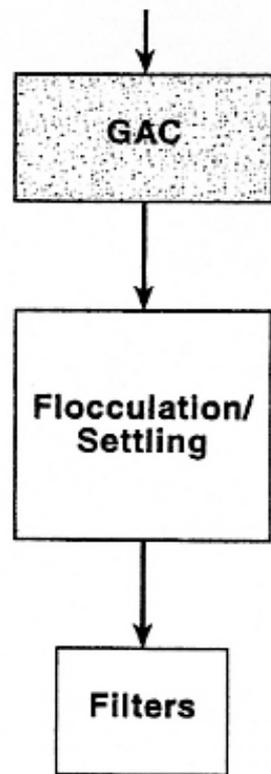
◆ Cons:

- Capacity continuously consumed
- Higher capital cost than PAC
- More subject to competition than PAC
- Empty bed contact time (EBCT) usu. limited
- Preloading (premature exhaustion)
- Chromatographic displacement
- Desorption can occur if C_0 drops

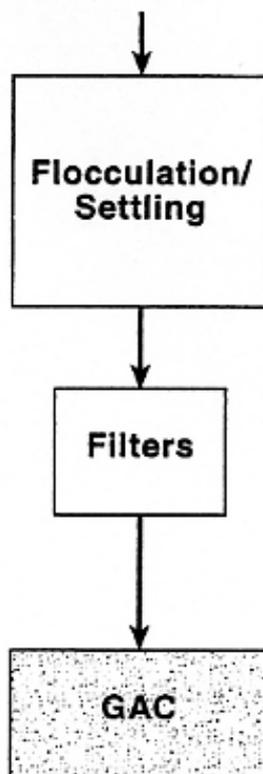


GAC Contactor Configurations

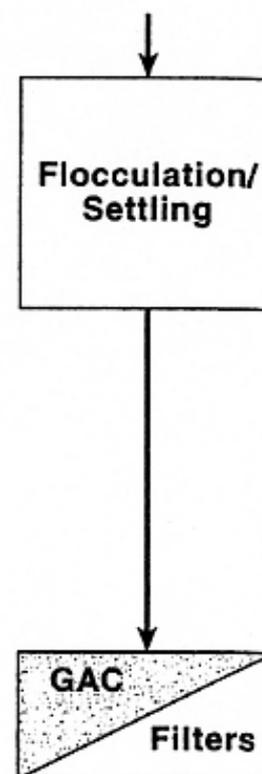
(*Water Treatment Plant Design*, 4th ed., 2005)



Prefiltration



Postfiltration

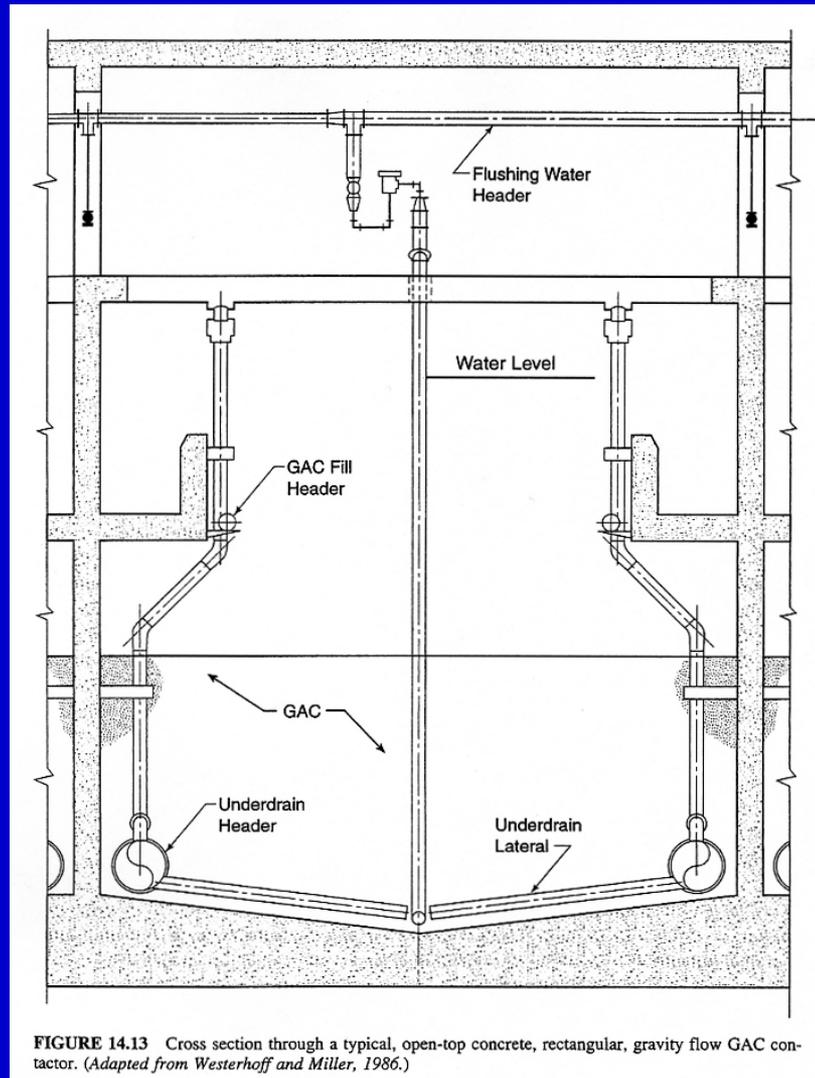


**Filtration/
Adsorption**

FIGURE 14.2 Basic options for locating GAC treatment.



A Concrete Gravity-Flow GAC Contactor (WTPD, 4th ed., 2005)



Geosmin and MIB Removal by PAC and GAC in Full-Scale Treatment Plants

Plant	Operating Condition	%Removal	
		Geos.	MIB
PAC	15-31 mg/L PAC	65	44
GAC1	24", EBCT 5.5-9.4 min	32.5	--
GAC2	28", EBCT 8.7 min	42	--

(Pan et al., 2002)



Effect on Organic Matter on Atrazine Adsorption (WQ&T, 6th ed.)

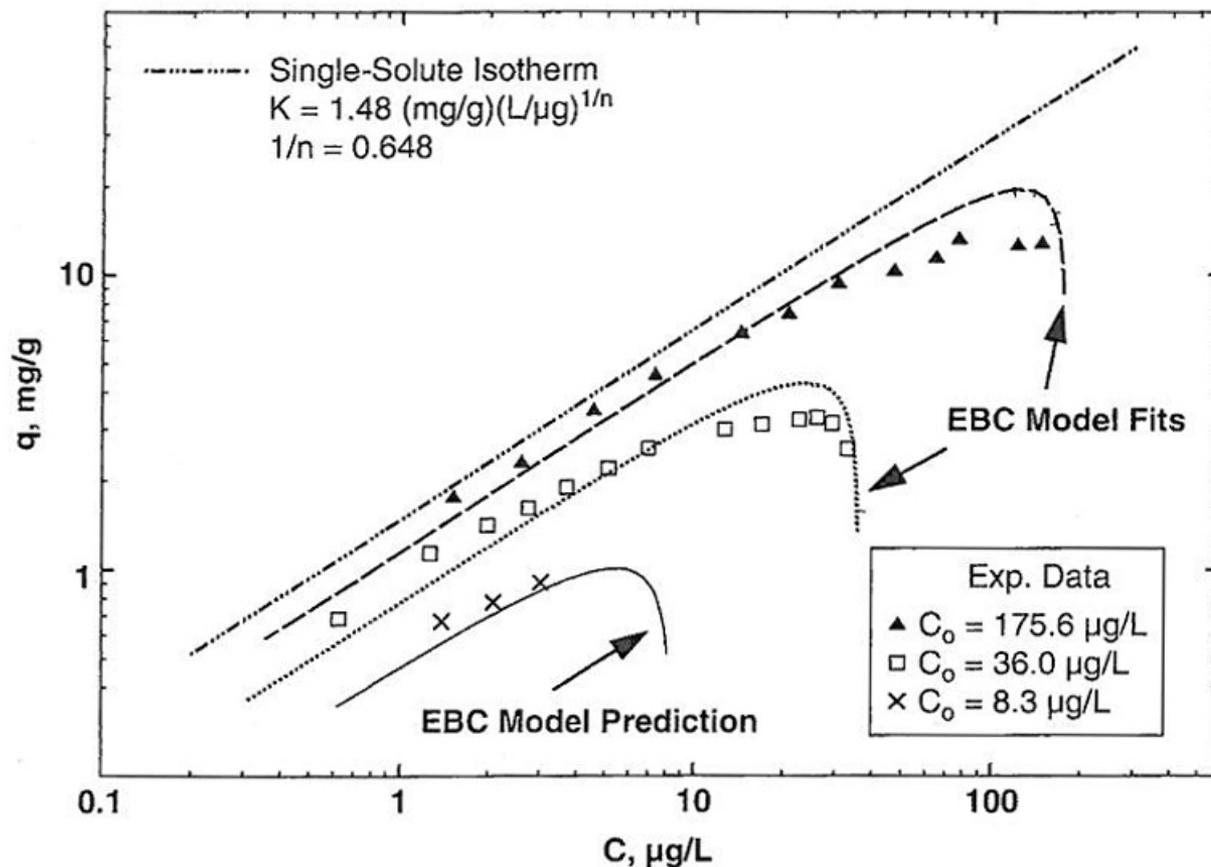


FIGURE 14-11 EBC model results for atrazine isotherms in Illinois groundwater. (Source: Reprinted with permission from D. R. U. Knappe et al. (1998), Predicting the capacity of powdered activated carbon for trace organic compounds in natural waters. Environmental Science & Technology 32, 1694–1698. Copyright © 1998, American Chemical Society.)



Effect of TOC on MIB Removal (WQ&T, 6th ed.)

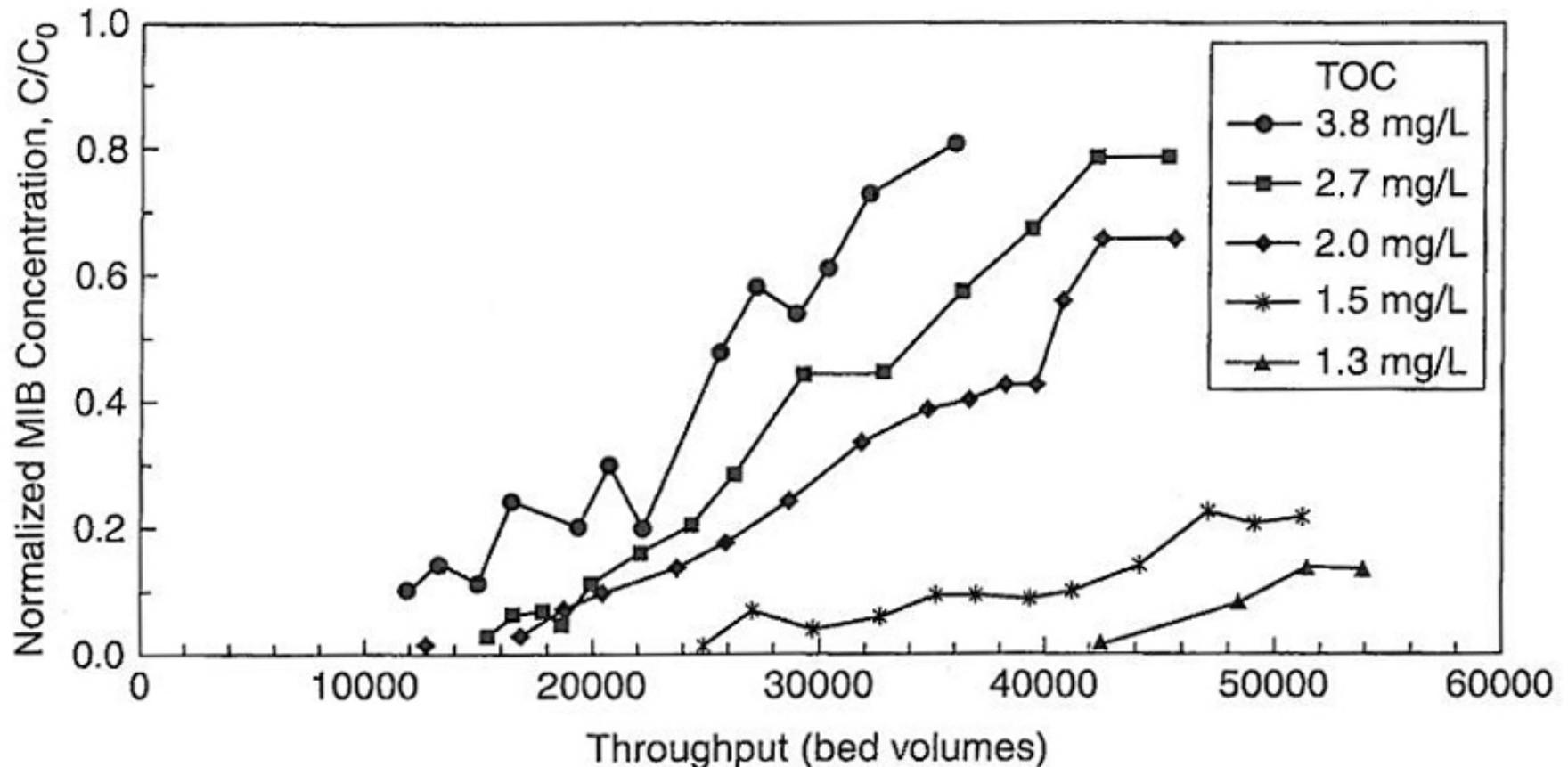


FIGURE 14-26 Impact of background TOC on MIB breakthrough in RSSCTs; MIB $C_0 = 100$ ng/L, EBCT = 10 minutes, bituminous 12×40 mesh GAC. (Source: Adapted with permission from Kim, 2006.)

NOM Preloading Effect (WQ&T, 6th ed.)

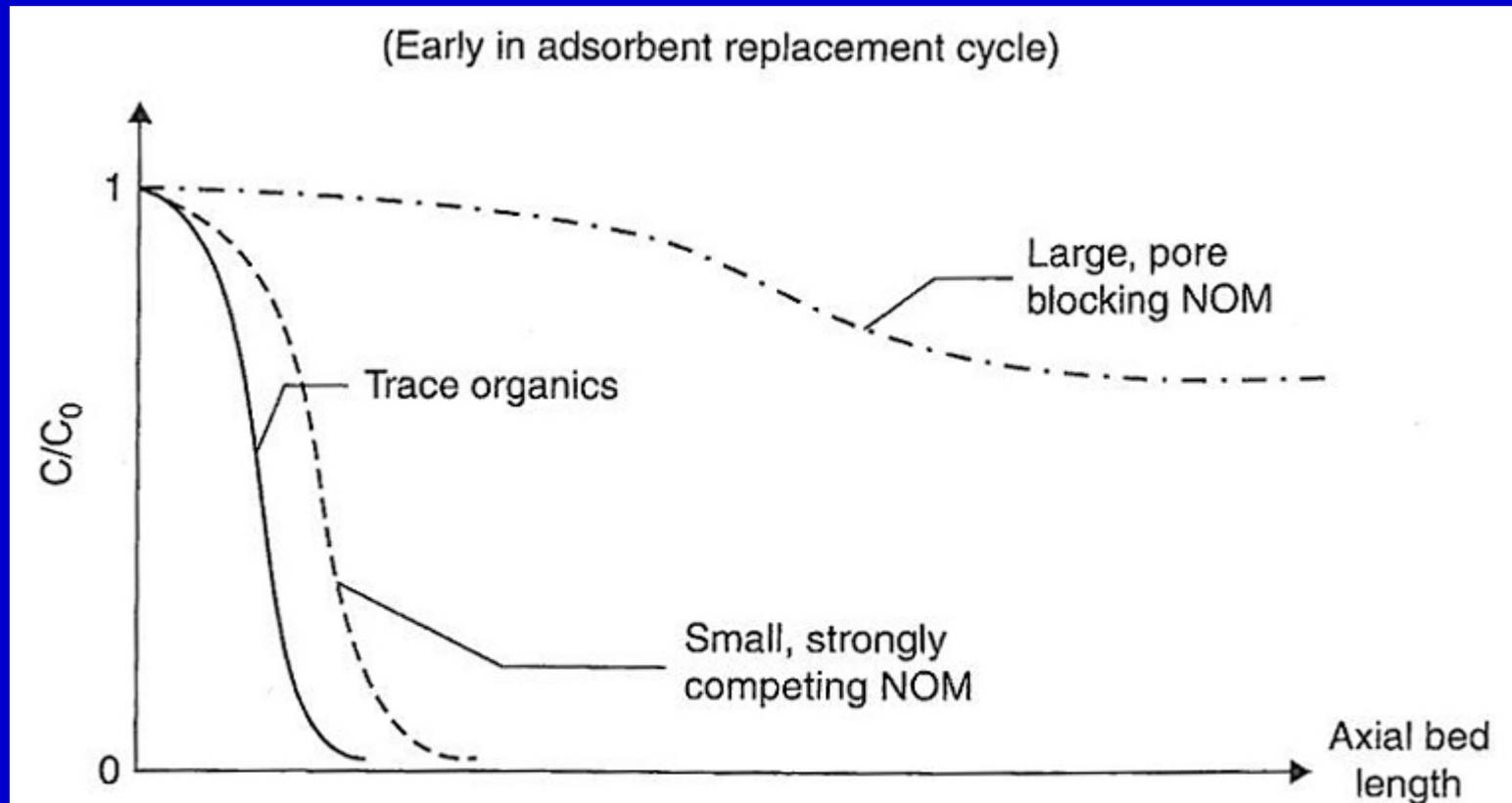


FIGURE 14-14 Conceptual illustration of NOM preloading along length of GAC bed. (Source: L. Schideman et al. (2007), *Application of a three-component competitive adsorption model to evaluate and optimize granular activated carbon systems*. *Water Research* 41(15), 3289–3298. Copyright © 2007, with permission from Elsevier.)



Chromatographic Displacement (WQ&T, 6th ed.)

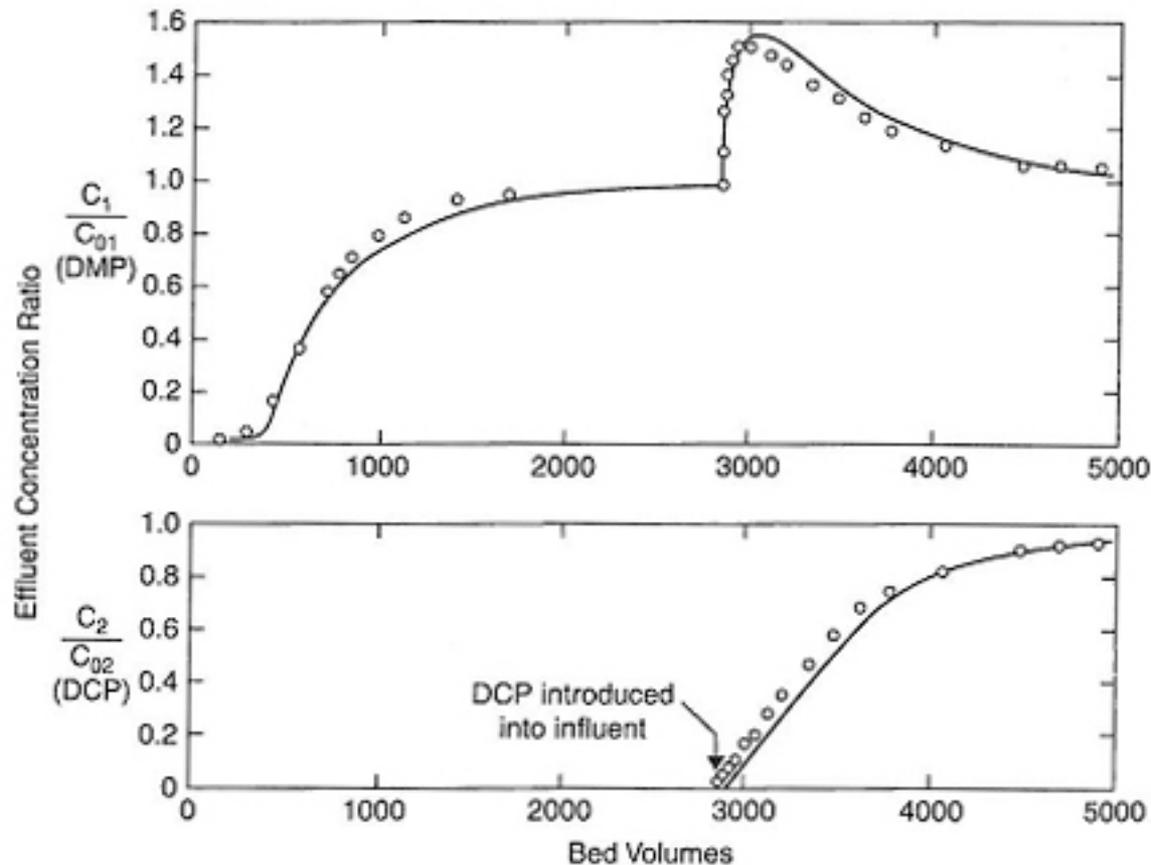
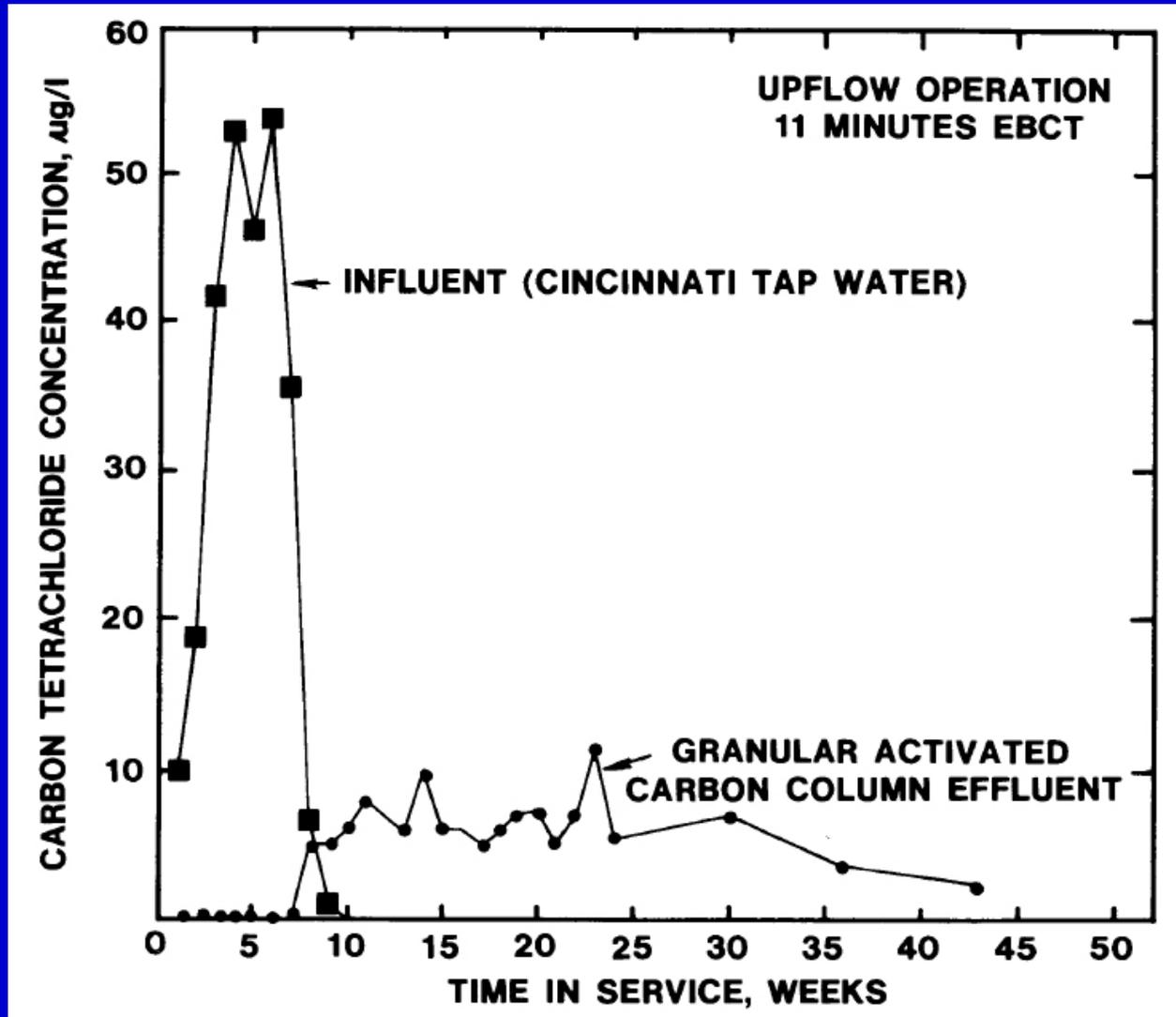


FIGURE 14-5 Breakthrough curves for sequential feed of DMP and DCP to a GAC adsorber ($C_{01} = 0.990$ mmol/L, $C_{02} = 1.02$ mmol/L, EBCT = 25.4 seconds). (Source: W. E. Thacker, J. C. Crittenden, and V. L. Snoeyink, *Modeling of adsorber performance: Variable influent concentration and comparison of adsorbents*. *Journal Water Pollution Control Federation* 56:243, with permission. Copyright © 1984, Water Environment Federation, www.wef.org.)



Compounds Can Desorb from GAC (Symons, 1978)



GAC Adsorption

◆ General Recommendations

- Use a GAC with a smaller grain size and higher uniformity coefficient when possible.
- Compare GACs using isotherm tests.
- Use rapid small-scale column tests (RSSCTs) to predict column performance.
- Monitor performance (age, volume treated, metabolite removal, DOC and UV-254 removal, influent water quality) and chart / store performance data to guide future decisions.



Membrane Processes

◆ Pressure Driven

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse Osmosis (RO)

◆ Electrically Driven

- Electrodialysis (ED)
- Electrodialysis Reversal (EDR)



Membrane Processes (cont'd)

- ◆ RO & NF remove dissolved ions and are expected to remove algal metabolites reasonably well, esp. the larger ones.
- ◆ MF & UF remove particles (incl. algal cells) but not dissolved molecules, unless the molecules are first adsorbed onto particles (e.g., PAC).
- ◆ ED & EDR pull ions through ion exchange membranes and do not remove particles or large dissolved molecules, especially unionized molecules.



Integrated Membrane Systems (IMS) for T&O and Toxin Control (Dixon et al., 2012)

Table ES.1.

Summary of results of cyanobacteria and dissolved metabolite removal through different stages of the IMS investigated in this project; N-negligible, * - low, ** - moderate, * - high, *** - excellent, n/a – not applicable**

	Coagulant	Membrane	Cell Removal	MIB/GSM	MCYST	STX	CYN	Flux retention
UF	none	PVDF	***	-	-	N	N	*
	Alum	PVDF	***	-	-	N	N	*
	ACH	PVDF	***	-	-	N	N	**
	HPAC	PVDF	***	-	-	N	N	***
PAC-UF	Alum	PVDF	***	-	-	*	**	**
	ACH	PVDF	***	-	-	***	**	***
	HPAC	PVDF	***	-	-	***	**	****
PAC-MF	None	PES	***	***	-	-	-	
NF	n/a	tight	n/a	**	***	-	***	**
		loose	n/a	*	**	-	*	**

Biological Processes

- ◆ Riverbank filtration
- ◆ Biologically active filters
 - Nitrifying filters
 - Sand or GAC filters used to remove assimilable organic carbon after ozonation
- ◆ Most GAC filters
- ◆ Others (Rittmann et al., 2012)



Biological Processes

- ◆ **Some metabolites are biodegradable under certain conditions:**
 - Microcystins
 - Cylindrospermopsin
 - Geosmin and MIB
- ◆ **However, “low toxicity saxitoxins can be converted to the more toxic variants [by] biological activity on an anthracite filter.” (GWRC, 2009)**



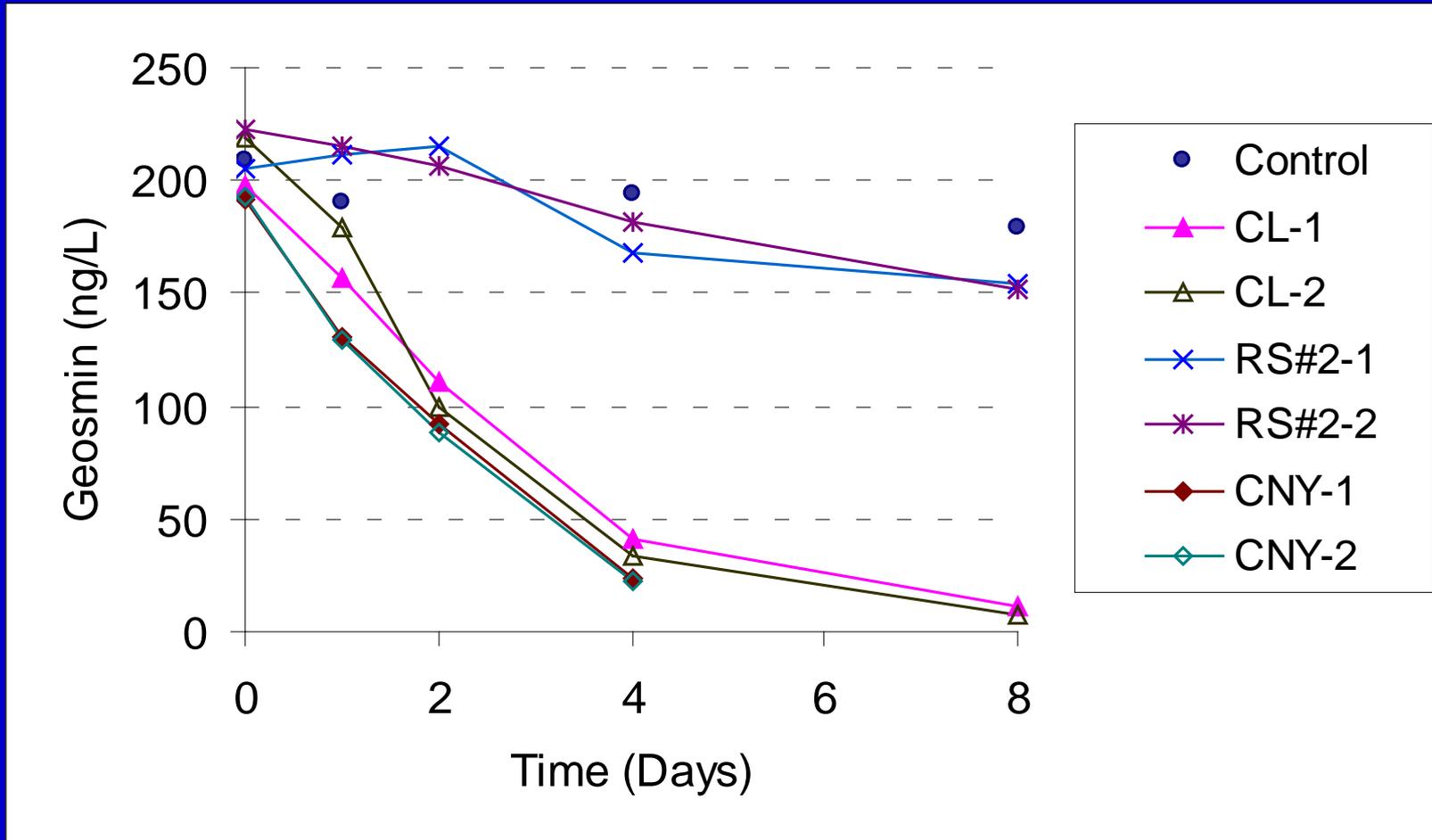
Biological Processes

◆ Factors Influencing Metabolite Biodegradation

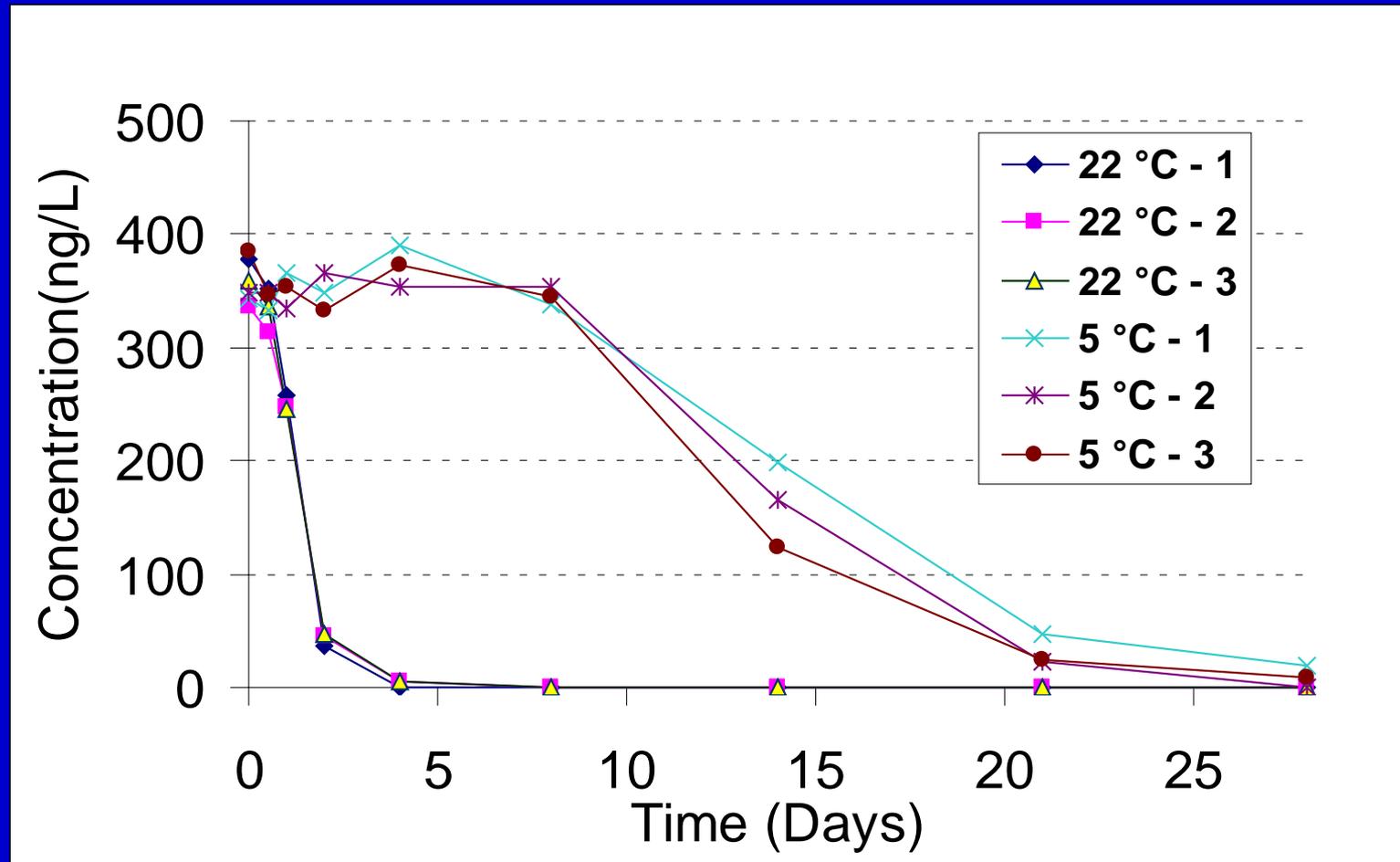
- Water temperature
- Season
- State (intracellular vs dissolved)
- Growth substrate
- Microbial community composition
- Time required for acclimation
- Metabolite characteristics
- Biocide addition (e.g., chlorine prior to filtration)



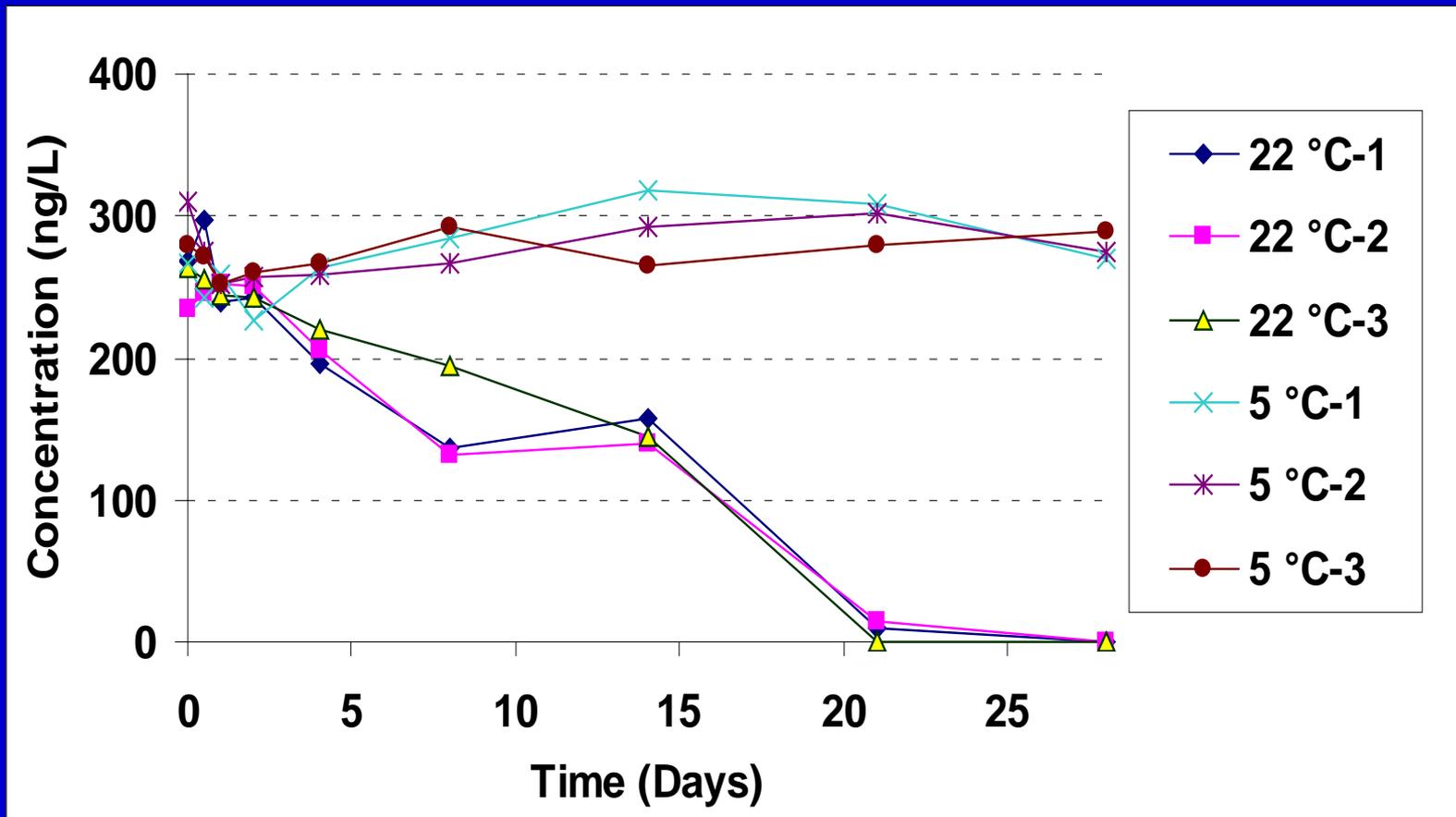
Biodegradation of Geosmin in Waters Collected in June, 2000 (Pan et al., 2002)



Geosmin Degradation at 5 and 22 °C in Clinton Lake Water (Pan et al., 2002)



MIB Degradation at 5 and 22 °C in Clinton Lake Water (Pan et al., 2002)



Riverbank Filtration

◆ Recommendations (GWRC, 2009):

- Extra-cellular microcystin < 50 µg/L
- Middle to fine grained sandy aquifer
- Aerobic conditions
- Temperatures > 15 °C
- Residence times > 7 d

◆ Notes:

- “For suboptimal conditions, residence times need to be much higher (> 70 d).”
- “In environments without an adapted microbial community, lag phases of up to one week may occur ...”



Biological Processes

- ◆ May be effective under certain conditions, but:
 - Data limited
 - Could potentially make matters worse (e.g., in the case of saxitoxins)
 - May be difficult to reliably control
 - May require acclimation, bringing effectiveness into question under transient conditions
 - Generally not proven to be reliably effective
- ◆ Best viewed as a side-benefit of riverbank filtration, ozone-GAC, biofiltration, etc.



Concluding Remarks

- ◆ Source control should be practiced, but is likely to be only moderately successful in eliminating T&O and algal toxin problems in Kansas.
- ◆ Remove algal cells intact when possible.
- ◆ In general, activated carbon adsorption and selected oxidation processes can provide a reasonable degree of control of many metabolites at a cost that may be considered reasonable.
- ◆ More and better data, especially site-specific data, are needed to guide decisions, especially when decisions must be made quickly. (Utilities should consider preparing emergency response plans focused on algal toxins.)



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That's all folks!!

