Wastewater and Treatment

Gretchen Onstad

ENV H 111

11/17/11

Water Security – US EPA

- To assess and reduce consequences, threats, and vulnerabilities to potential **terrorist attacks**
- To plan for and practice response to **natural disasters**, emergencies and incidents
- To develop new security technologies to
  - detect and monitor contaminants
  - prevent security breaches

water.epa.gov

2002 Water Security Legislation

- Public Health Security and Bioterrorism Preparedness and Response Act (Bioterrorism Act), Title IV requires…
  - US EPA to provide:
    - Information on potential threats to water systems
    - Strategies for responding to potential incidents
    - Information protection protocols for vulnerability assessments in its possession
    - Research studies in areas relevant to water security
  - Community water system serving more than 3,300 persons to:
    - Conduct a vulnerability assessment
    - Submit a certified copy to the EPA Administrator
    - Respond by preparing an emergency response plan
    - Send copy to EPA Administrator within 6 months of completion
    - Full implementation by 2004

Response to Bioterrorism Act

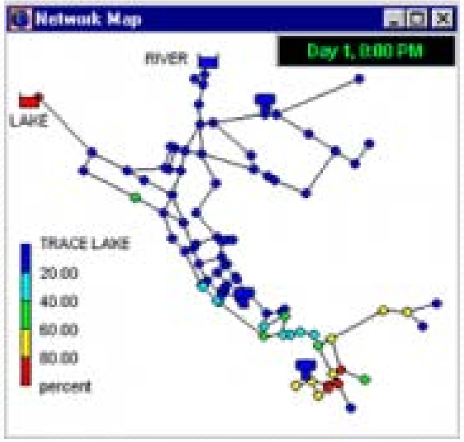
- Water/Wastewater Agency Response Network
  - State-level organization for mutual aid and assistance to other utilities
- All-hazards approach prepares for bioterrorism and
  - Natural disasters: hurricanes, floods, tornadoes, earthquakes, icestorms, wildfires
  - Supports utility needs in the event of terrorist attack
    - Protection
    - Detection
    - Response
    - Recovery



Roberson & Morley (2006) J. AWWA

Integrating Water Security and Water Quality Research

- Current Security Research
  1. Online Monitoring
  2. Software
     - Hydraulic & water quality modeling
  3. Policies and Procedures
- Development Needs
  - Real-time microbial monitoring
  - Tools that identify specific contaminants and sources
  - Direct linkage between contamination events and public health outcomes



Hydraulic model using EPANET (www.epa.gov)

Speight et al. (2010) J. AWWA

Water Contaminants

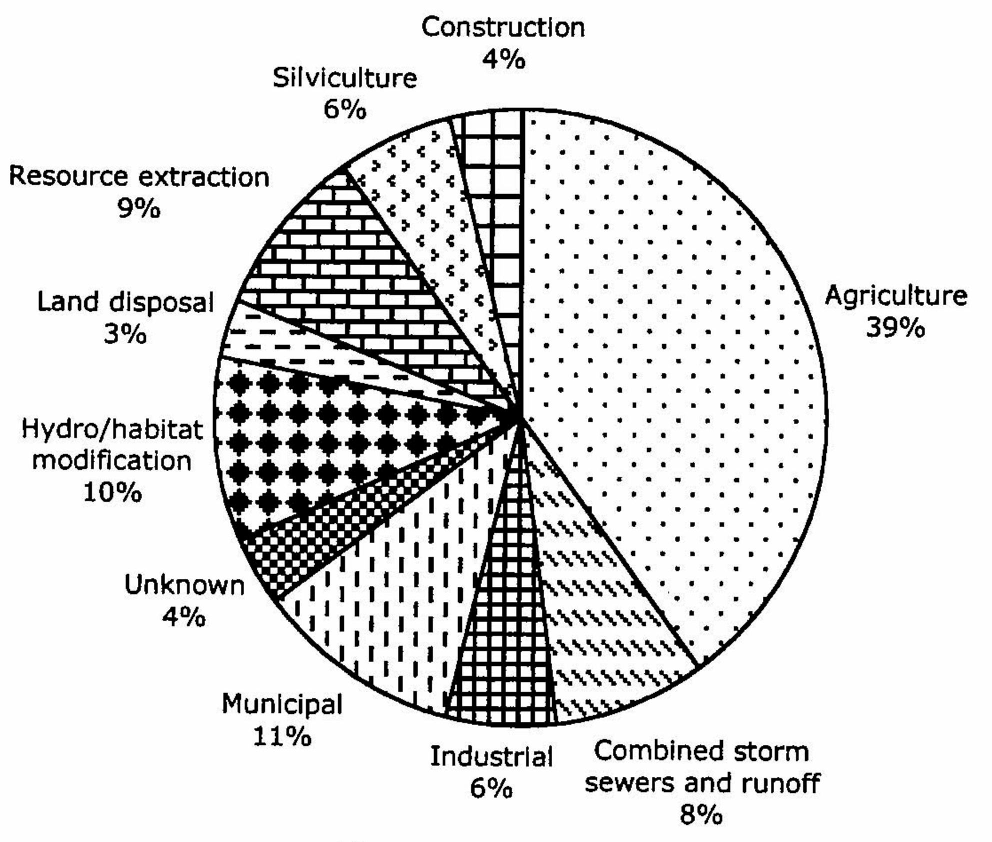


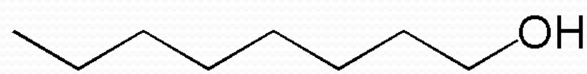
Figure 8.3 Sources of pollution in U.S. rivers

Moeller (2005) Envir Health

Water Chemistry & Equilibria

Liquid-liquid extraction

- Salts: $NaCl_{(s)} + H_2O \rightarrow Na^+ + Cl^- + H_2O$
- Ionic compounds and pH scale (0-14)
  - $CH_3COOH \leftrightarrow CH_3COO^- + H^+$
  - Acidity constant: K_a or pK_a
- Partitioning
  - Air-Water: Henry's Constant, $K_H = C_A/C_W$
  - Octanol-Water: K_{OW}



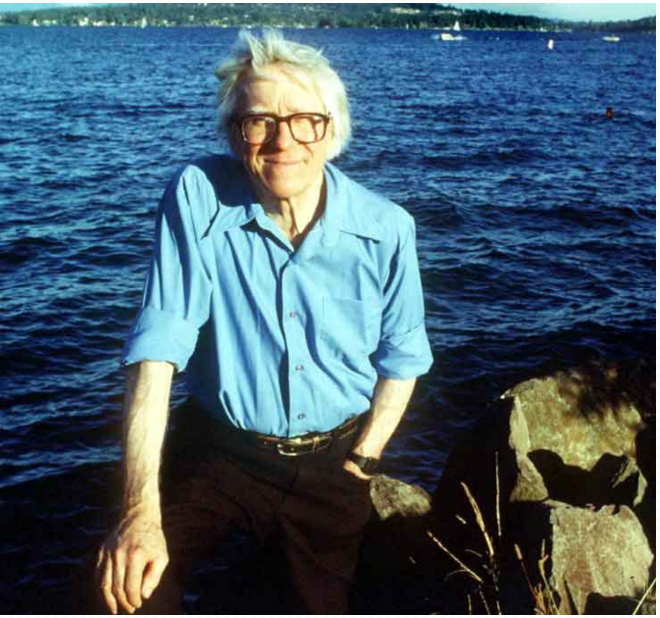
  - Soil-Water: K_d
  - Biomass-Water: Bioconcentration Factor, BCF
- Solubility: Hydrophilic vs Hydrophobic interactions

Lake Washington

Is dilution the solution to pollution?

WARNING
POLLUTED WATER
UNSAFE
FOR BATHING

James Ellis



W. Thomas Edmondson

Rescuing Lake “Stinko” *

- Pollution of Lake and Sound
  - 10 sewage treatment plants dumping effluent into Lake Washington
  - Stormwater caused sewage overflow
  - Untreated sewage to Puget Sound
- 1953 – Jim Ellis, “Father of Metro”
  - Campaign to address problems of population growth & suburbanization
- 1955 – UW Ecology Prof. Edmondson
  - observed increased cyanobacterial algae growth and high phosphorus
  - Predicted eutrophication of Lake WA
  - Shared findings with Ellis and community

* Seattle P.I. (1963)

Aging of a lake

- Caused by algal growth that depletes oxygen, kills fish, and steadily degrades water quality
- Trophic Stages
  - Oligotrophic
  - Mesotrophic
  - Eutrophic
  - Hypereutrophic

↑ Clarity, Water quality, Dissolved O_2

↓ Nutrients, Primary productivity, Algal growth

Redfield Equation: Algal growth

$$106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122\ H_2O + H^+$$

(+ trace elements and energy)

Photosynthesis ↓ ↑ *Respiration*

$$\{C_{106}H_{263}O_{113}N_{16}P_1\} + 138\ O_2$$

algal protoplasm

Redfield, A.C. *et al.* (1966) In *The Sea,* Vol 3, Wiley, NY.

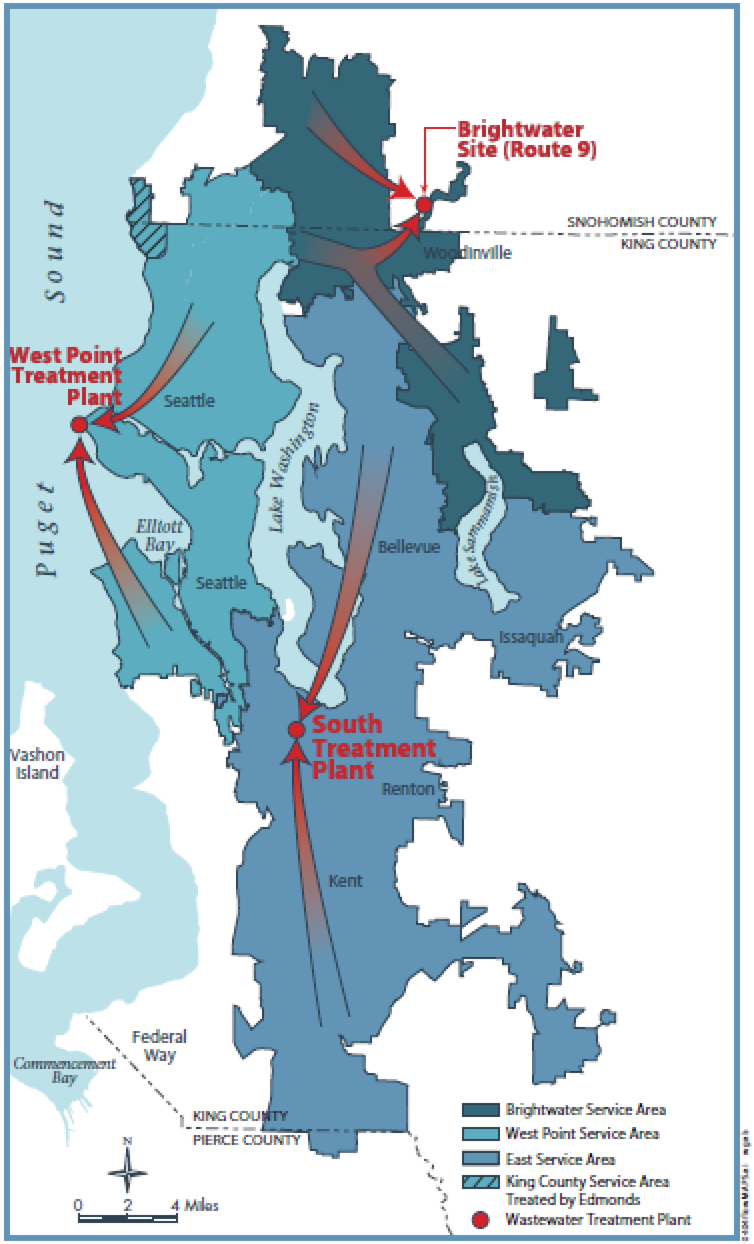
METRO

- Municipality of Metropolitan Seattle
- 1958 – voted to authorize Metro to address wastewater treatment for region (completed by 1967)
  - Build sewer system
  - Close sewage treatment plants on Lake Washington
  - Treat sewage entering Puget Sound
- 1960's – Eutrophication of Lake Washington
- 1968 – Improved water clarity & quality: nutrients decline, algal blooms rare, dissolved oxygen increases
- 1972 – Metro takes over transportation
- 1994 – Metro incorporated into King County

Children posing at Matthews Beach in favor of a new METRO to improve Lake Washington water quality, 1958. Seattle Municipal Archive, www.historylink.org

Metro - King County Wastewater Treatment

- 1965: **Renton (South)**
  - Primary + Secondary treatment
  - doubled capacity in 1985
- 1966: **West Point**
  - Primary treatment
  - upgraded with Secondary treatment in 1995
- 2011: **Brightwater**
  - Primary + Secondary
  - opened in Sept



Wastewater Treatment Processes

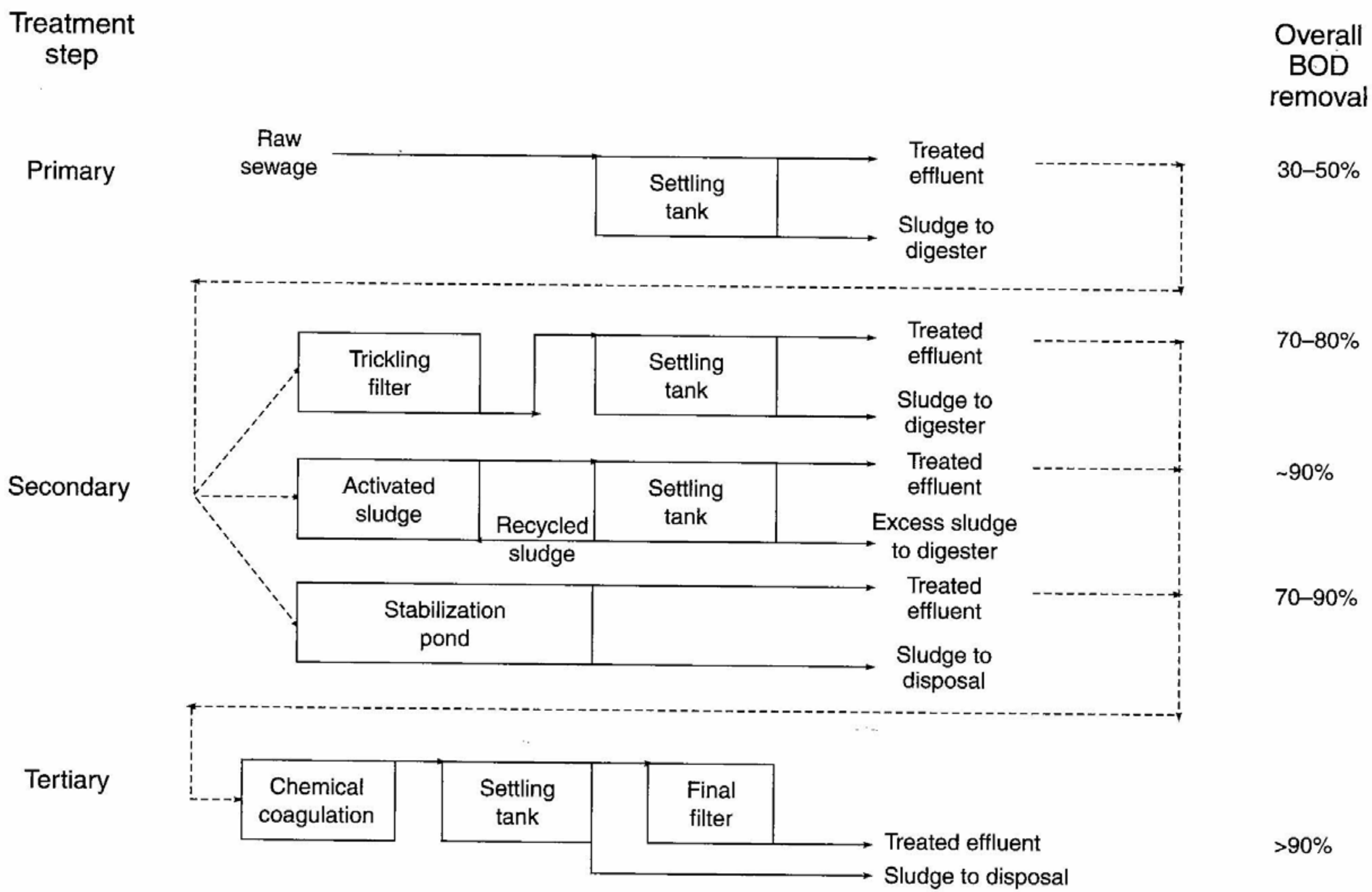


Figure 8.5 Primary, secondary, and tertiary stages in the treatment of municipal sewage

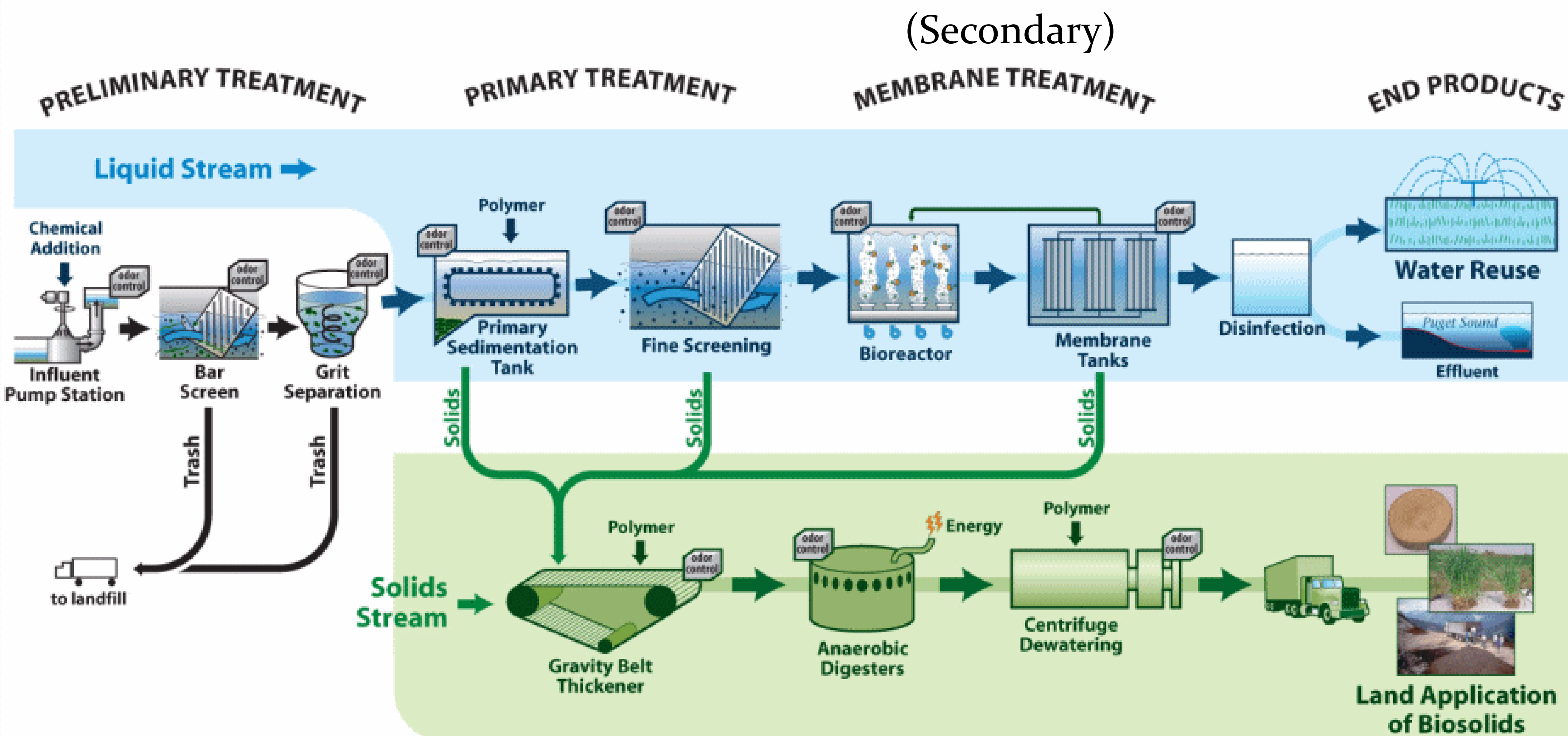
Moeller (2005) Environ. Health

BOD: Biological Oxygen Demand

Wastewater Treatment Processes

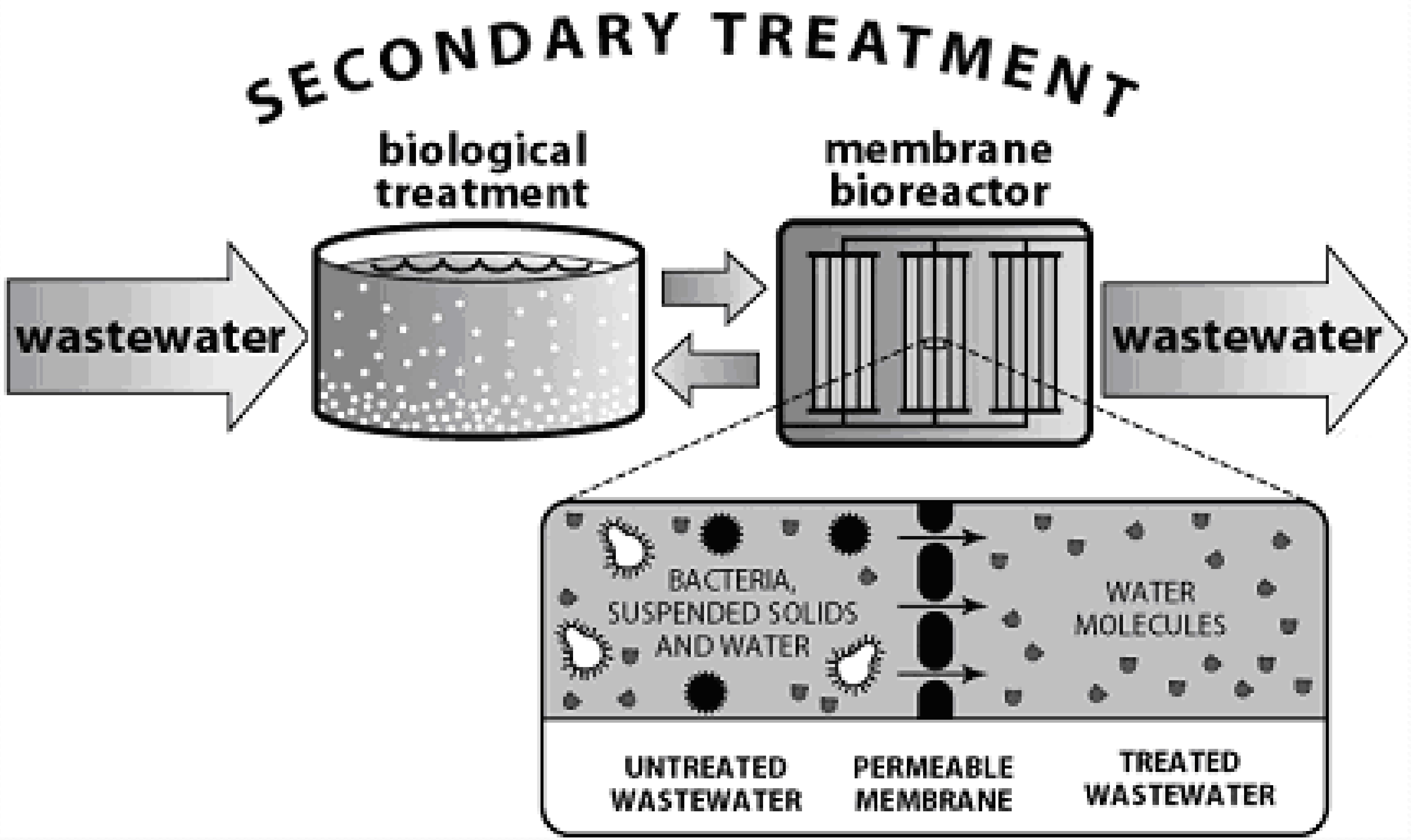
- Primary
  - Settling of solids out of liquid waste
- Secondary
  - Biological oxidation of organic matter in liquid waste
    - Trickling Filter
    - Activated Sludge
    - Stabilization Basin
- Tertiary
  - Process depends on required effluent quality
    - Organic compound removed by granular activated carbon (adsorptive filtration) and ozone disinfection
    - Heavy metals and viruses by coagulation & sedimentation

Brightwater Treatment System



www.kingcounty.gov

Brightwater Membrane Bioreactor



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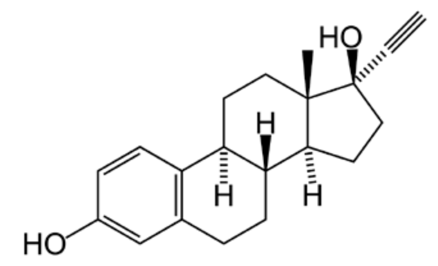
Wastewater Treatment Targets

- Oxygen demand
  - Primary and secondary treatment
- Pathogens
  - Disinfection, digestion
- Nutrients
  - Tertiary treatment
- Chemical toxicants
  - Incidental to other processes
- Industrial waste
  - Pretreatment by industry

Water-Pollution Regulations

- Water Pollution Control Act of 1948 and amendments:
  - 1956 – Standards for interstate and navigable waters
  - 1972 – Secondary treatment required for wastewater
- **Clean Water Act** of 1977
  - Treatment of point sources of industrial waste
  - Standards for discharge into sewers or public waters
    - Required secondary sewage treatment
- Water Quality Act of 1987
  - Control of nonpoint sources of waste
- Wet Weather Control Act of 2000
  - Nonpoint sources of pollution in stormwater

Endocrine disruptors from agriculture & WW effluent



17-α-ethinyl estradiol

- Endocrine disruptors
  - Pharmaceuticals: ethinyl estradiol, steroid hormones
  - Plasticizers: nonyl phenol
  - Pesticides: atrazine
- Key studies:
  - WW effluent changes gender of fish in British streams
    - Jobling et al (1998) Environ Sci Technol 32:2498-2506
  - USGS study of US streams
    - Kolpin et al (2002) Environ Sci Technol 36:1202-1211
  - Atrazine changes gender of frogs
    - Hayes et al (2010) PNAS 207:10:4612–4617

USGS study: Kolpin et al (2002)

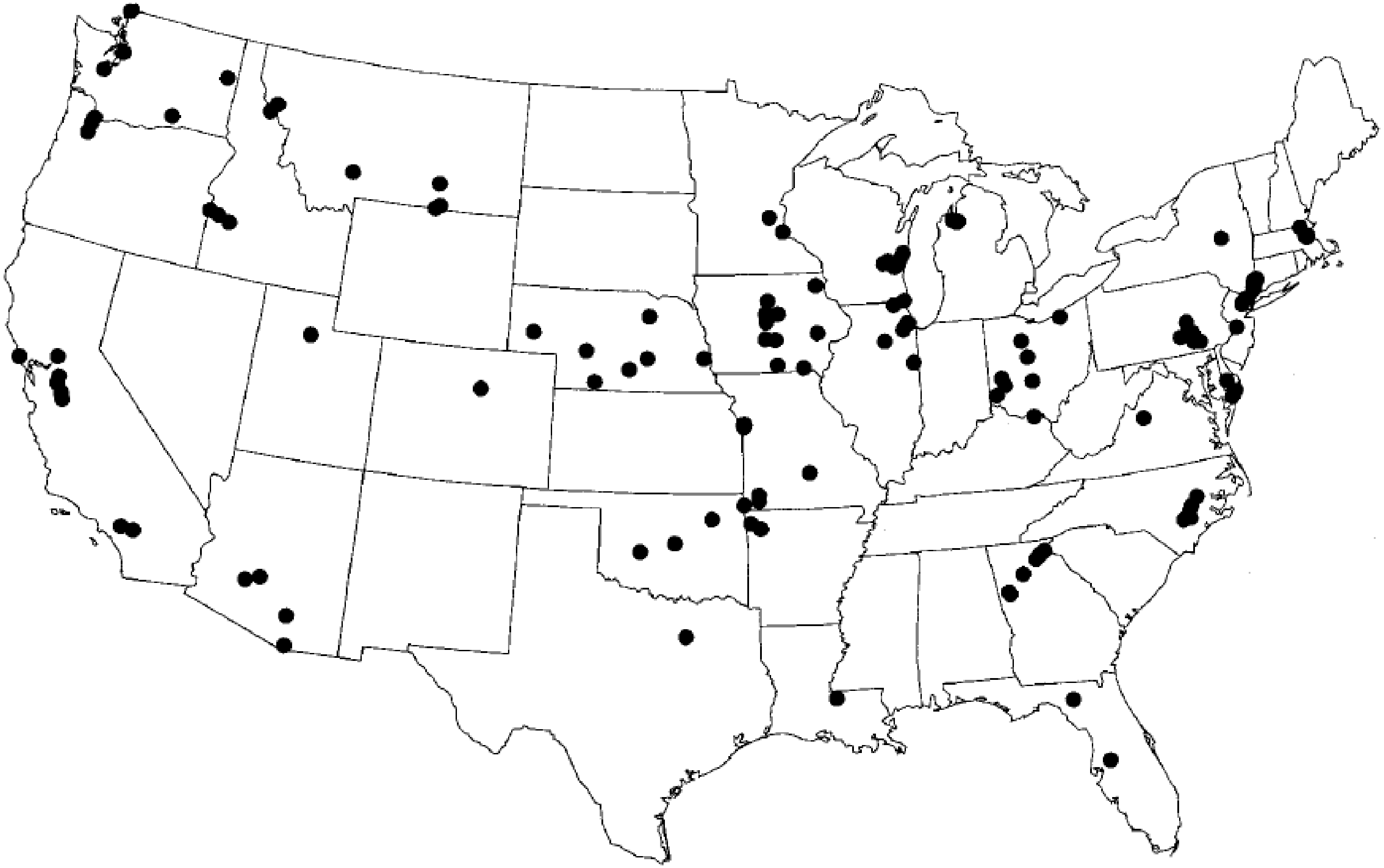


FIGURE 1. Location of 139 stream sampling sites.

USGS study: Kolpin et al (2002)

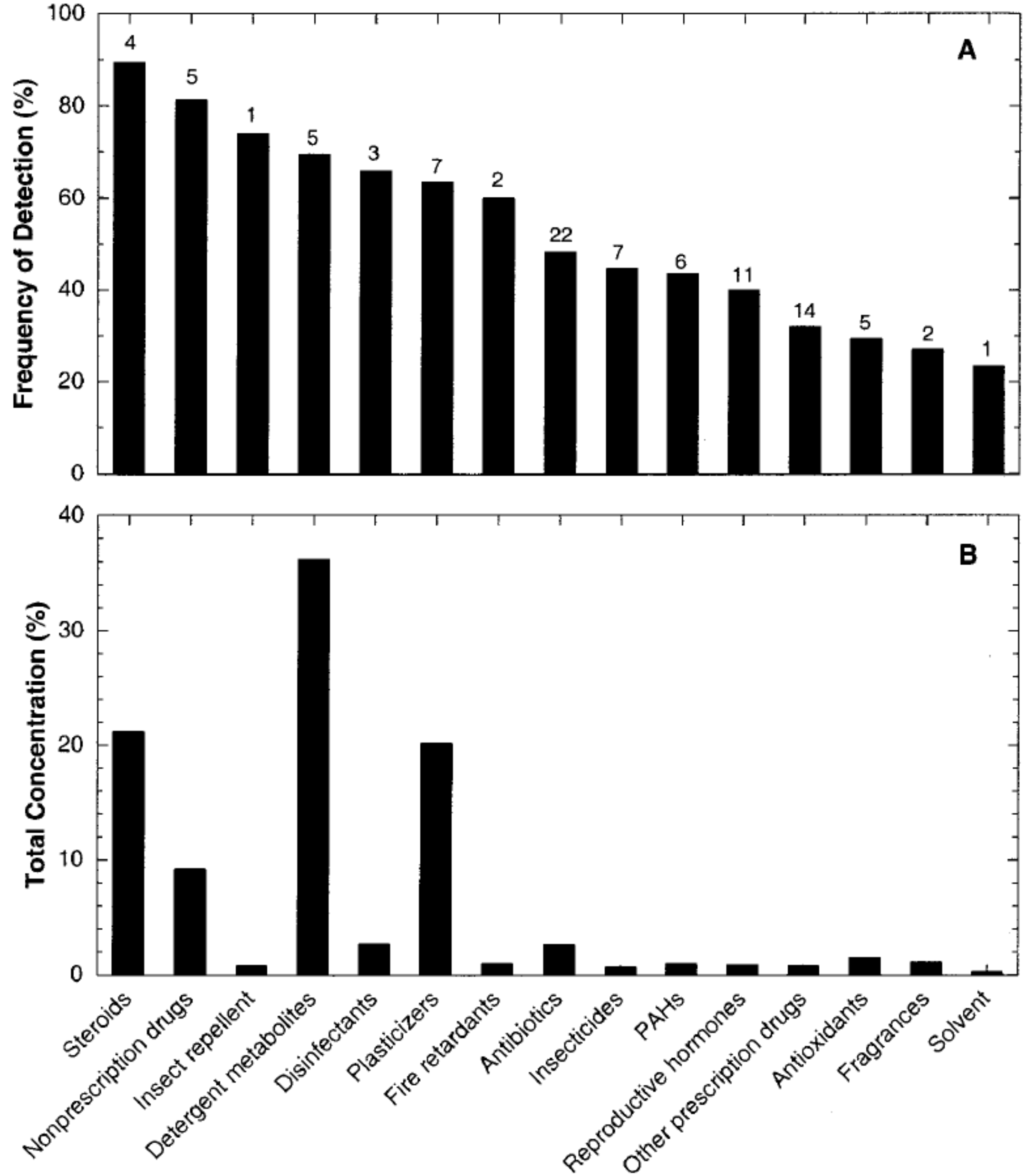


FIGURE 4. Frequency of detection of organic wastewater contaminants by general use category (4A), and percent of total measured concentration of organic wastewater contaminants by general use category (4B). Number of compounds in each category shown above bar.

References

- Edzwald, J.K. (2011) Water Quality & Treatment: A Handbook on Drinking Water, Sixth Edition, American Water Works Association (AWWA), Denver, CO.
- Moeller, D. (2005) Environmental Health, 3rd Ed., Harvard University Press, Boston, Mass.
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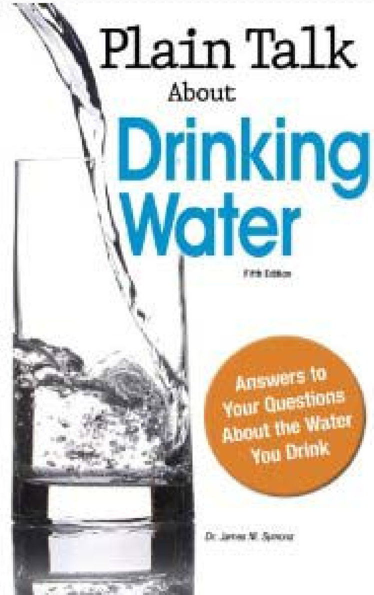
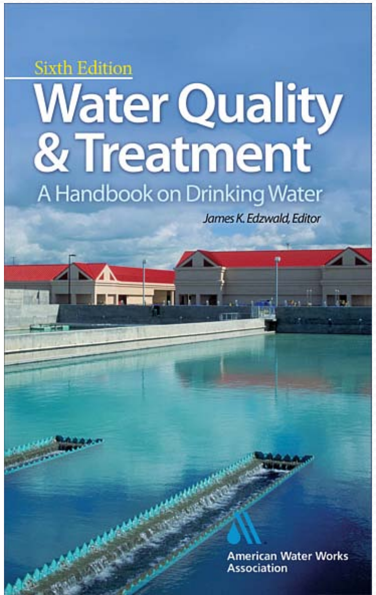
- Speight, V.; Grayman, W.; Khanal, N. (2010) *Jour. AWWA*, 102 (2), 30-33.
- Symons, J.M. (2010) Plain Talk About Drinking Water: Questions and Answers About the Water You Drink. American Water Works Association
- Web links: Historylink.org, Kingcounty.gov,, seattle.gov Wikipedia.org, EPA.gov, kentsimmons.uwinnipeg.ca, www.washington.edu/research/pathbreakers/1955c.html





The Free Online Encyclopedia of Washington State History

American Water Works Association
The Authoritative Resource on Safe Water

Portable Water Treatment and Trihalomethane Formation

ENVH 432: Sampling & Analysis II
Environmental Health undergraduates
Data from 2008-2009 courses
Undergraduate Researcher: Benjamin Vellek

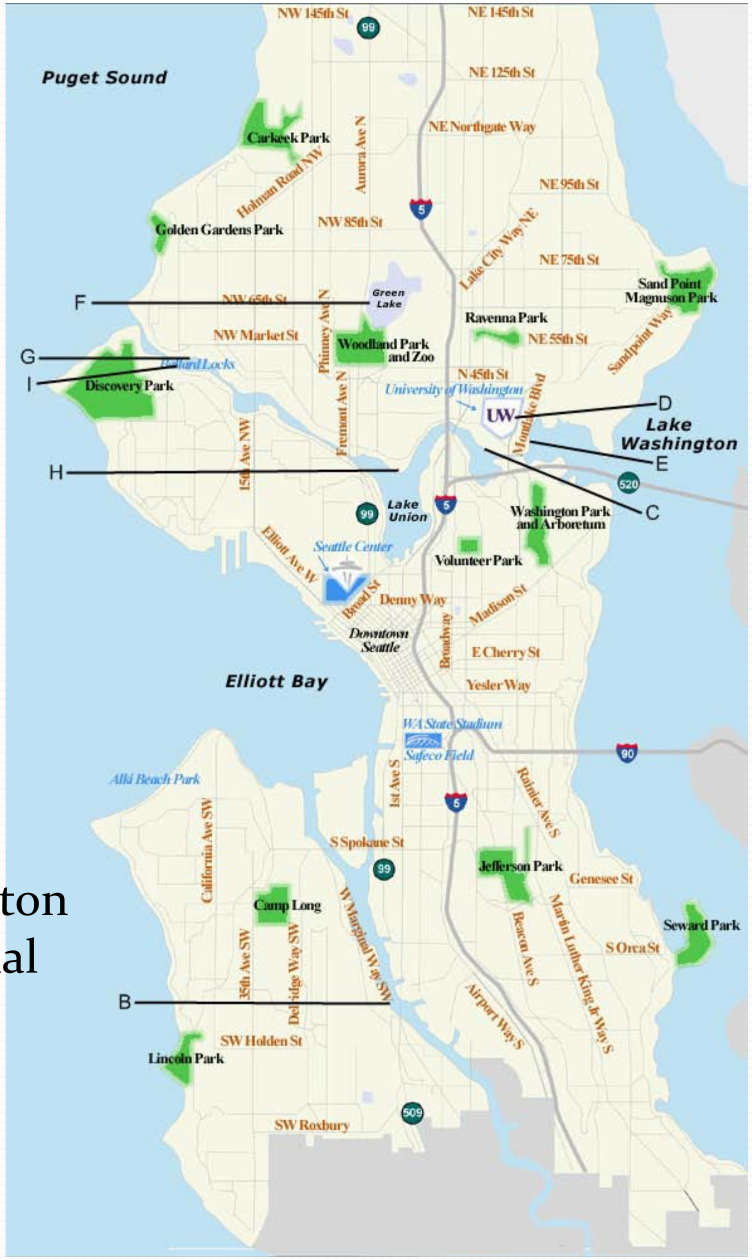
Camping Water Treatment

- Questions:
  - Will treatment techniques exceed maximum contaminant limit (MCL) of 80 ug/L for THM4?
  - How do treatments compare?
  - What THMs are formed from different source DOC?
  - How does THM formation relate to chlorine consumption?

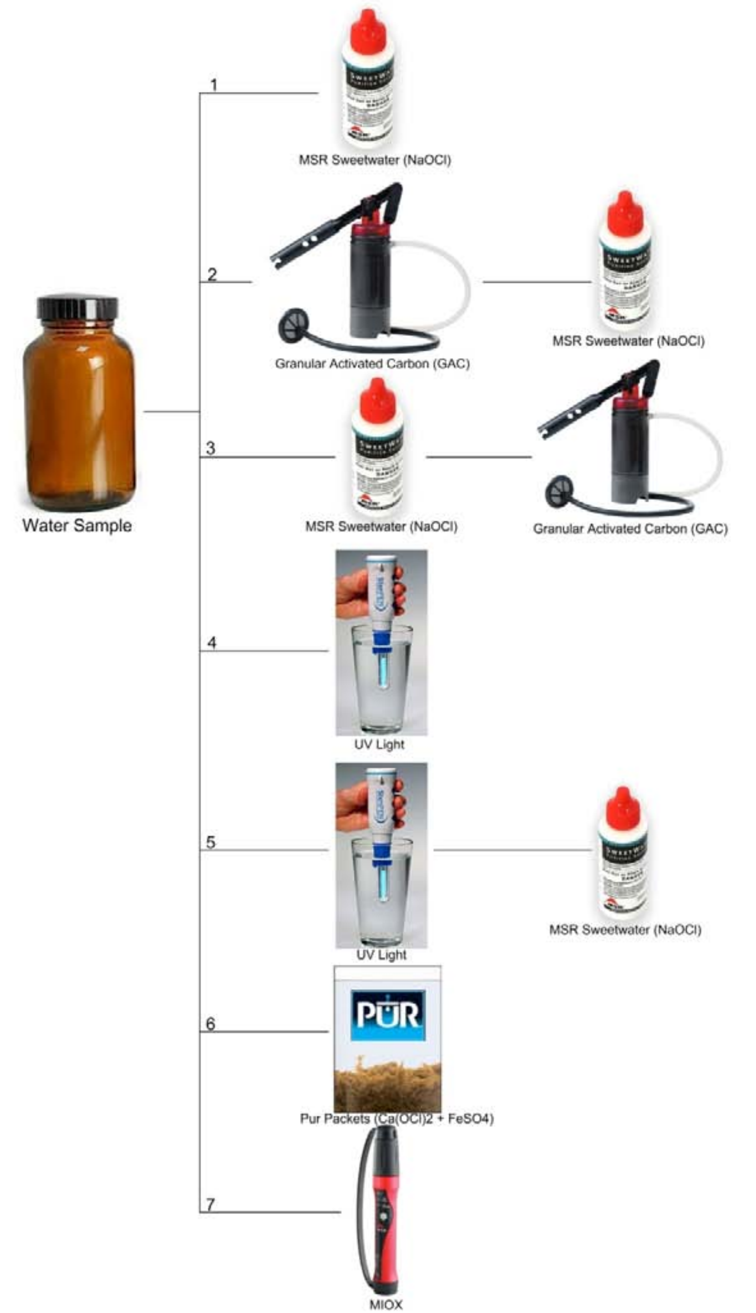
Sampling Locations DOC Sources

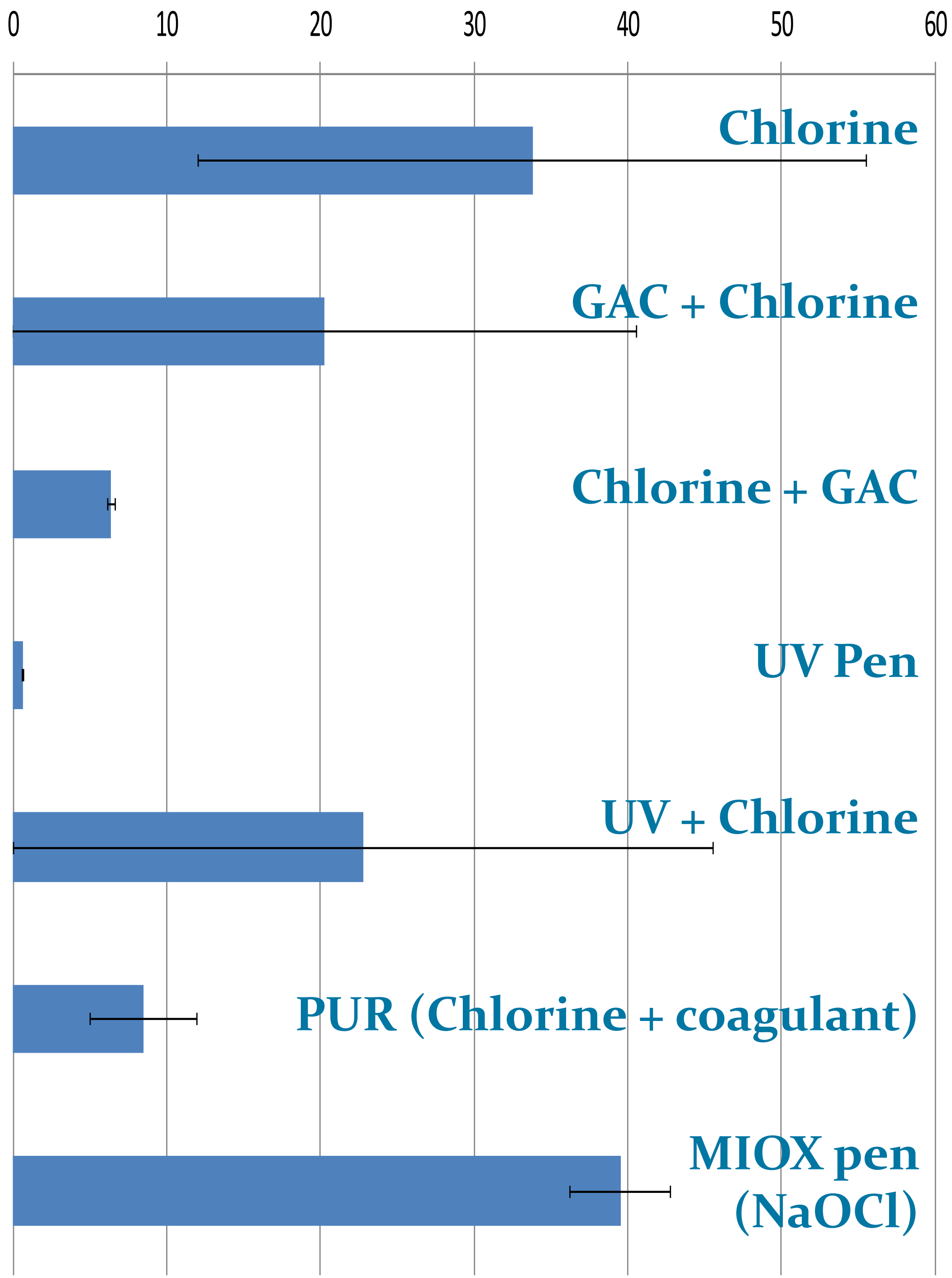
Location	Letter
Silver Lake, Everett	A
Duwamish River	B
Portage Bay	C
Drumheller Fountain	D
Union Bay Waterfront Activities Center	E
Green Lake	F
Ballard Locks	G
Gas Works Park	H
Ship Canal Trail	I

Lake Washington Ship Canal



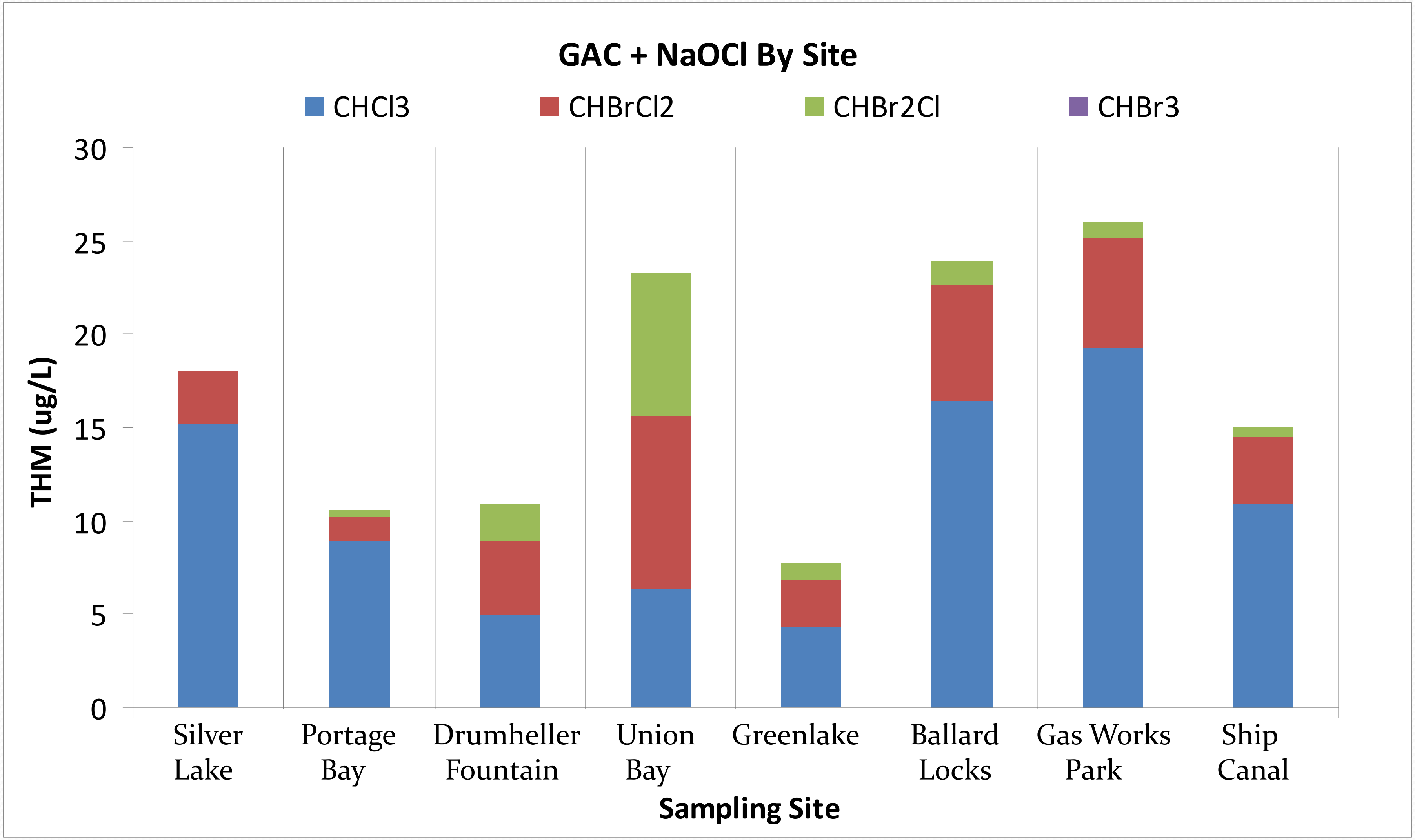
Portage Bay: THMs (μg/L)



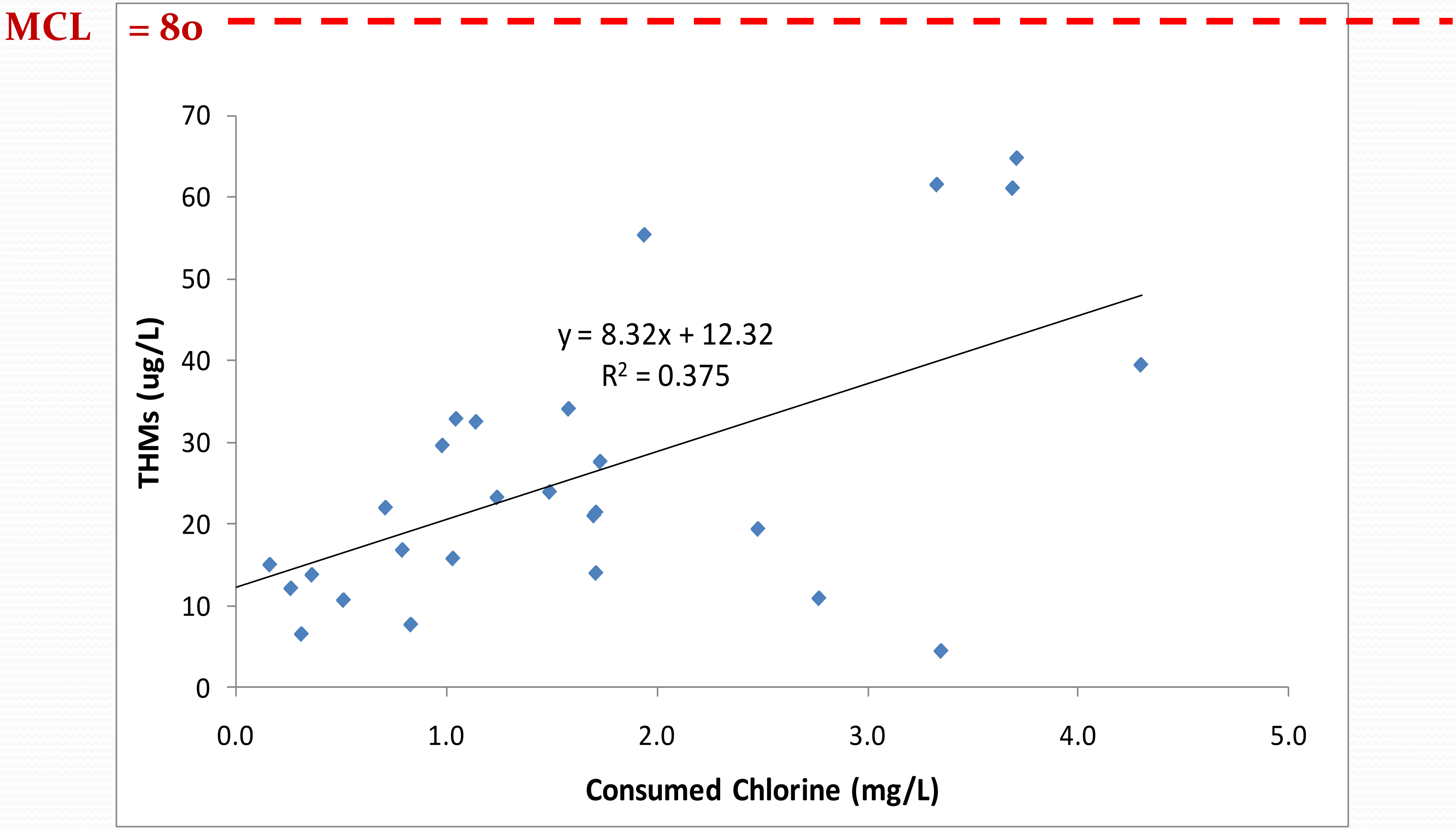


GAC + NaOCl

THM Speciation



THMs and Chlorine Consumption



Disinfectant	Formula	Regulated DBPs	Target Organism
Chlorine Hypochlorite	Cl_2 $NaOCl$	THMs & HAAs	Giardia, most bacteria & viruses
Chlorine Dioxide	ClO_2	Chlorite Less THMs	Cryptosporidium Giardia, viruses
Chloramines	NH_2Cl	Less THMs	Giardia, viruses
Ozone	O_3	Bromate	Cryptosporidium Giardia, viruses, bacteria
Ultraviolet radiation	UV	none	Cryptosporidium Giardia, viruses, bacteria

Oxidation Kinetics of Freshwater Cyanotoxins

Gretchen Onstad and Urs von Gunten

Swiss Federal Institute of Aquatic Science and Technology, EAWAG

"TOXIC – Barriers Against Cyanotoxins in Drinking Water"

European Union Water Initiative

Cyanobacteria and -toxins

- Blue-green algae = photosynthetic bacteria
- Cyanobacterial “blooms” $\rightarrow$ eutrophic waters (temp, nutrients, sunlight, stratification)
- Early warning important for water resource protection and <u>Drinking Water Treatment:</u>
  - Removal of cell-bound toxins by filtration
  - Removal of free dissolved toxins
    - Oxidation by ozone or chlorine
    - Adsorption onto GAC or PAC

Toxicity

- **Microcystin-LR:** Hepatotoxin
  - Toxicity: side chain ADDA
  - Damages **liver** cells→death by fatal circulatory shock or liver failure
  - WHO drinking water guideline **1μg/L MCLR**
- **Cylindrospermopsin:** Hepato-, Cyto-, Genotoxin
  - Toxicity: Uracil-RNA or Uracil-DNA
  - Suppresses protein synthesis or causes DNA strand breakage
  - Target organs: **liver** and **kidneys**
  - Proposed WHO drinking water guideline **1 μg/L CYN**
- **Anatoxin-a:** Neurotoxin
  - Toxicity: simulates acetylcholine
  - Overstimulates **respiratory muscles** → death by paralysis
  - NO proposed WHO drinking water guideline for ANTX

Selective Oxidation of Key Functional Groups in Cyanotoxins during Drinking Water Ozonation

GRETCHEN D. ONSTAD,[‡,†]
SABINE STRAUCH,[‡] JUSSI MERILUOTO,[§]
GEOFFREY A. CODD,[‖] AND
URS VON GUNTEN[*,‡,⊥]

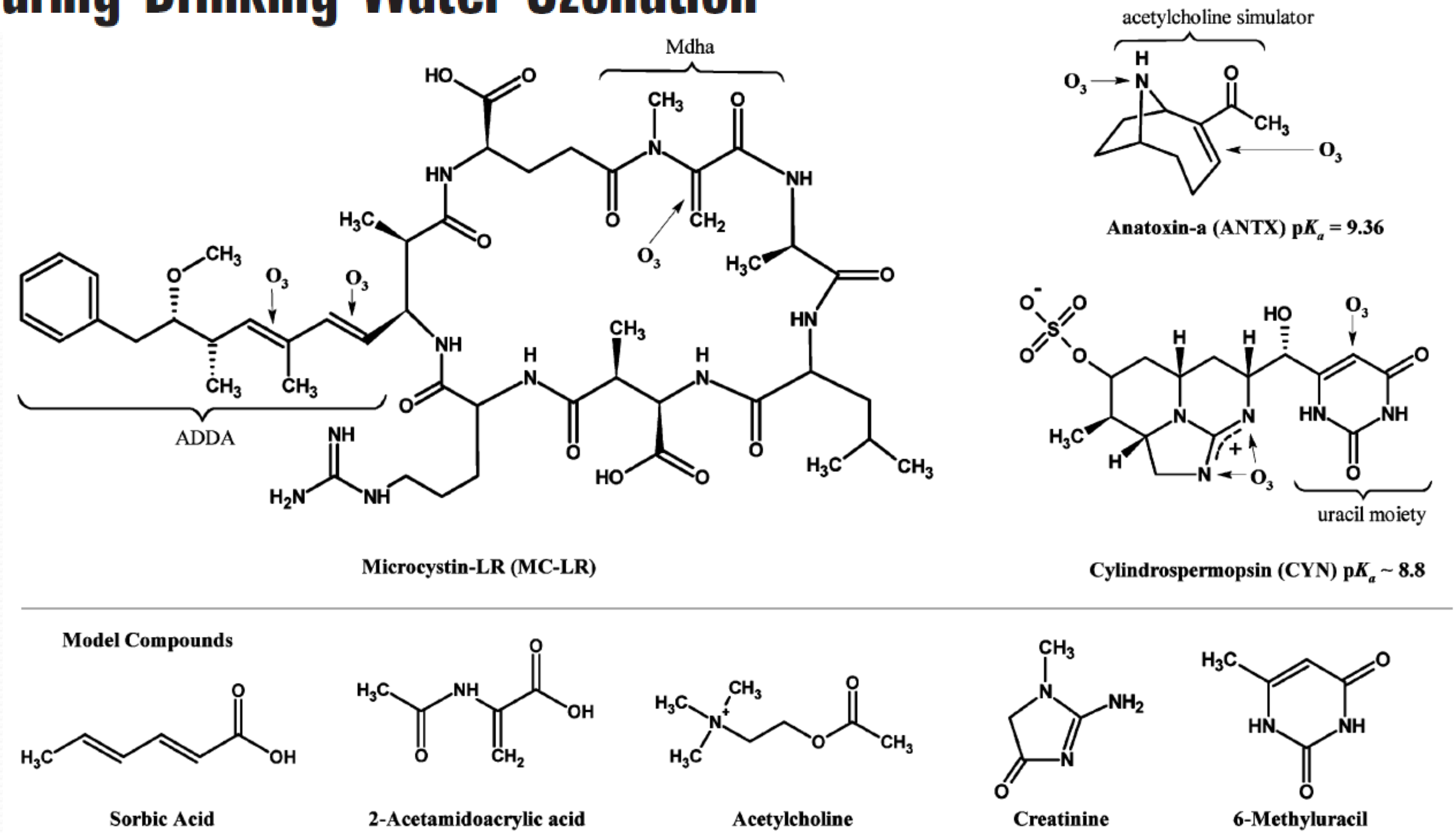


FIGURE 1. Structures of target cyanotoxins, model compounds, and proposed sites of ozone attack.

Onstad et al. **2007** *Environ. Sci. Technol.* **41, 4397-4404**

pH Dependence

DBP formation

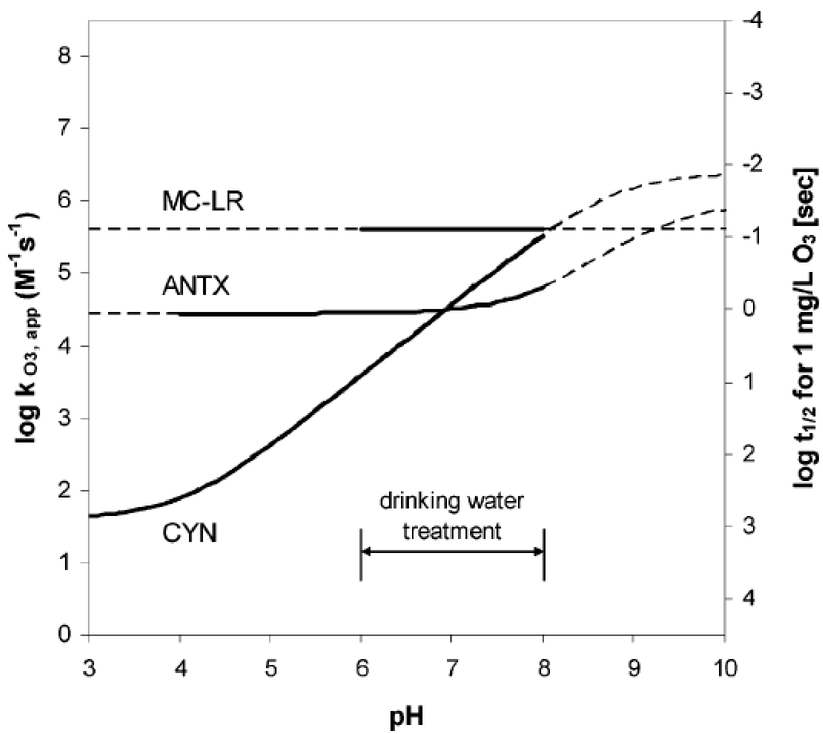


FIGURE 4. pH dependence of the rate constants for the reaction of cyanotoxins with ozone. Half-life times are given for an ozone concentration of 1 mg/L: MC-LR, microcystin-LR; CYN, cylindrospermopsin; ANTX, anatoxin-a.

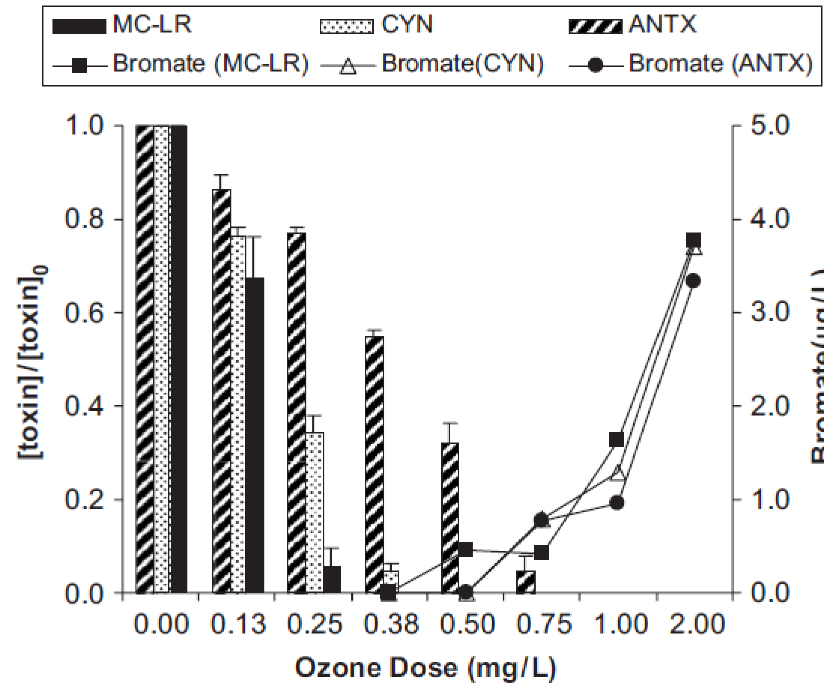


Fig. 5 – Relative decrease of cyanotoxin and increase of bromate formation as a function of the ozone dose. Error bars indicate standard deviation. Experimental conditions: pH 8, 20 °C, 3.6 mg/L DOC, 100 µg/L ammonia, 3.6 mM alkalinity as HCO_3^- and 50 µg/L Br^-.

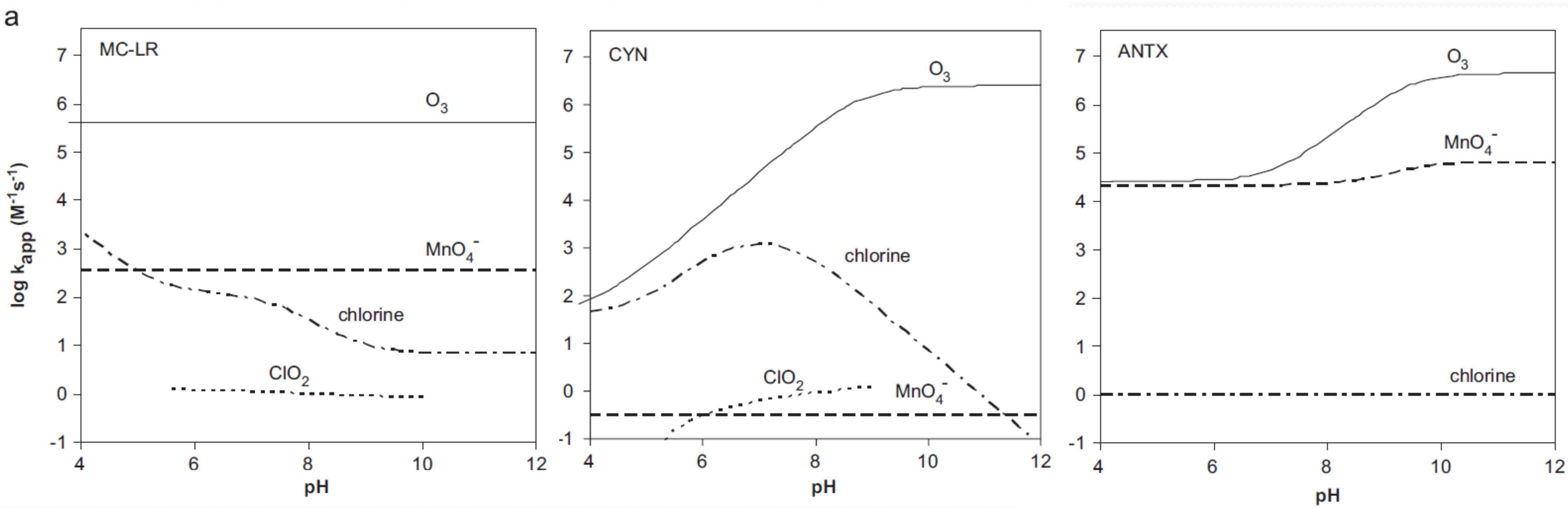
Onstad et al. **2007** *ES&T* **41, 4397-4404;** Rodríguez et al. **2007** *Water Research* **41, 3381–3393**

Oxidative elimination of cyanotoxins: Comparison of ozone, chlorine, chlorine dioxide and permanganate

O_3 HOCl ClO_2 MnO_4^-

Eva Rodríguez[a], *Gretchen D. Onstad*[b,1], *Tomas P.J. Kull*[c], *James S. Metcalf*[d], *Juan L. Acero*[a,*], *Urs von Gunten*[b,e,**]

WATER RESEARCH 41 (2007) 3381–3393



pH 7

MCLR: $O_3 > MnO_4^- > HOCl > ClO_2 > NH_2Cl$

CYN: $O_3 > HOCl >> ClO_2 > MnO_4^- \approx NH_2Cl$

ANTX: $O_3 \approx MnO_4^- >> ClO_2 > HOCl > NH_2Cl$

TOXIC project outcomes

- Cyanotoxin removal by water treatment efficient if:
  - raw water management and early warning systems
  - application of precise and optimized analytical techniques
  - optimized treatment trains
- 2009 CCL3 (US)
  - These 3 cyanotoxins for prioritized research (among 104 chemical contaminants)