Case Against Disinfection of Municipal Wastewater Effluents and CSOs

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Overview

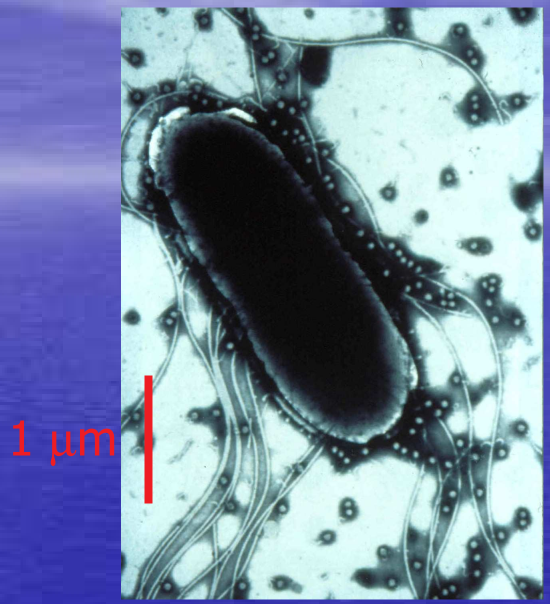
- Background / Goals of Disinfection
- Microbiology
- Chemistry/Characteristics of Disinfectants
- Range of Disinfection Approaches
- Case Study – MWRDGC (Chicago)
- Effects of Disinfection
  - Microorganisms (bacteria, viruses)
  - Effluent Chemistry
  - Effluent Toxicity
- Recommendations

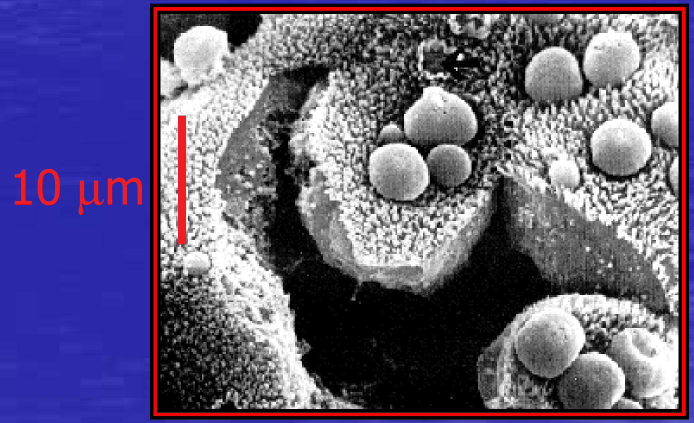
Background

- Goal of WW Disinfection = Reduce risk of exposure to waterborne pathogens … without introducing other risks
- Research Goal: Assess effects of municipal wastewater disinfection
- Central Questions:
  1. Should municipal CSO discharges be disinfected prior to discharge?
  2. If/When yes, then how?
     - Chlorination/dechlorination
     - UV

Wastewater Microbiology

- Bacteria
  - Diverse
  - Pathogens/non-pathogens
- Viruses
  - Enteric (highest risk)
  - Others
- Protozoa
  - *Giardia*
  - *Cryptosporidium*
- Diverse Microbiology
  - Indicator Organisms
  - Coliform Bacteria (*E. coli*)





Chlorine - Background

- Long history of use
- Effective for inactivation of bacterial indicators
- Drawbacks:
  - Toxicity associated with residual; S(IV)-dechlor
  - DBP formation; recalcitrant to S(IV)
  - Some resistant pathogens
  - Microbial repair/regrowth

Chlorine Chemistry/Toxicity

- All Residual Chlorine Expresses Toxicity
- Free Chlorine
  - $HOCl + OCl^-$
  - Bacteria ++; Viruses +/-; Protozoa –
  - Dechlorination: Yes
- Inorganic Combined Chlorine
  - $NH_3 + HOCl \rightarrow NH_2Cl + H_2O$
  - Bacteria +; Viruses -; Protozoa –
  - Dechlorination: Yes
- Organic Combined Chlorine
  - $RNH_2 + HOCl \rightarrow RNHCl + H_2O$
  - Bacteria -; Viruses -; Protozoa –
  - Dechlorination: Not always

UV - Background

- Recent emergence as an alternative to Cl
- Broad-spectrum antimicrobial agent
  - Bacteria ++
  - Viruses +
  - Protozoa ++
- Little DBP formation
- Drawbacks
  - Microbial repair/regrowth
  - Familiarity, design standards

Range of Disinfection Approaches

- No Disinfection
  - Western Europe
  - MWRDGC (Chicago)
- "Conventional Disinfection" (Indiana)
  - Indicator bacteria < 200 cfu/100 mL
  - Residual Cl limit (dechlorination)
  - Seasonal or year-round application
- Reuse (*e.g., Title 22*)
  - Total Coliforms < 2.2/100 mL
  - Virus inactivation/removal > 5 $\log_{10}$ units
  - More extensive than "conventional"

Typical Operating Conditions

Chlorine

- "Conventional Disinfection"
  - C = 1-2 mg/L (as Cl_2)
  - T = 20-40 minutes
  - CT ≈ 40-80 mg·min/L
- Reuse (*Title 22*)
  - Filtration
  - T ≥ 90 minutes
  - CT ≈ 400-1000 mg·min/L (free or combined)

UV

- RED = reduction equivalent dose (biodosimetry)
  - Experiment-based system characterization, validation
  - History of use, although better methods exist now
- "Conventional Disinfection"
  - RED ≈ 20-40 mJ/cm^2
- Reuse (*Title 22*)
  - Filtration
  - RED ≈ 140-200 mJ/cm^2

MWRDGC (Chicago) Case Study: Chlorination

- Initiated Chlorination in July 1972
- Immediately Initiated Testimony Before Illinois Pollution Control Board
- Extensive Research on Effects of Disinfection
- As Much as 90% Effluent

MWRDGC Case Study: Results

- Bacterial quality improved only within 10-15 river miles (no change beyond)
- Poor virus control (free chlorine)
- Adverse Effects on fish population, ecological diversity
- Nuisance organisms (insects)
- DBPs (4700 lbs chloroform/day)
- Lobbied Illinois EPA
  - Disinfection discontinued at four largest facilities (Stickney, Northside, Calumet, Lemont)
  - Seasonal disinfection at other facilities

Effects of Disinfectants

- Bacteria
  - Inactivation (indicator)
  - Repair/Regrowth (indicator, community)
- Viruses (Highest Risk)
- Effluent Chemistry
- Effluent Toxicity

Bench-Scale Disinfection

- Exposure scenarios designed to provide compliance with discharge regulations (NPDES)
  - Indicator bacteria (coliforms, enterococcus)
  - Residual chlorine
- Chlorine
  - Batch
  - 2.0 mg/L (as Cl_2)
  - 40-60 minutes (dechlorination)
- UV Dose = 20 mJ/cm^2
  - Batch
  - Collimated beam
- Methods allowed tight control, repeatability of disinfectant exposure
- Samples collected from several facilities (range of treatment, particularly as related to reduced-N)

Bacterial Responses: Repair/Regrowth

- Long-Term Respirometry
- Four 1-L samples
  - Two Controls
  - Chlor / Dechlor
  - UV
- Time-Course Monitoring (6 days)
  - Fecal Coliforms
  - Total Bacterial Concentration (TBC)
  - O_2 Uptake

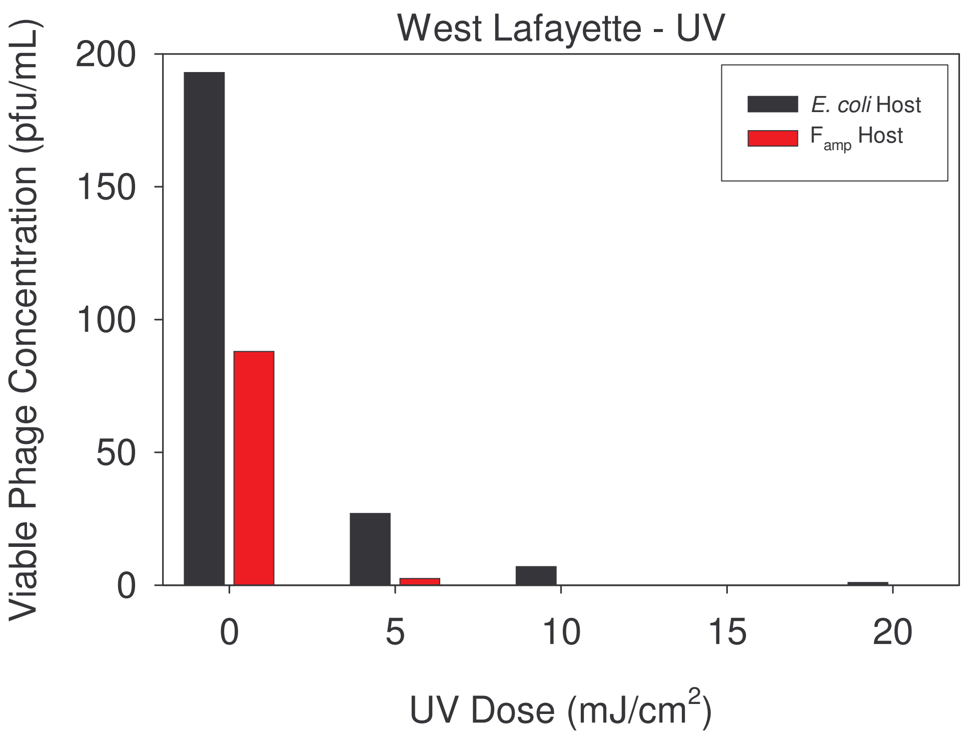
Bacterial Responses: Repair/Regrowth

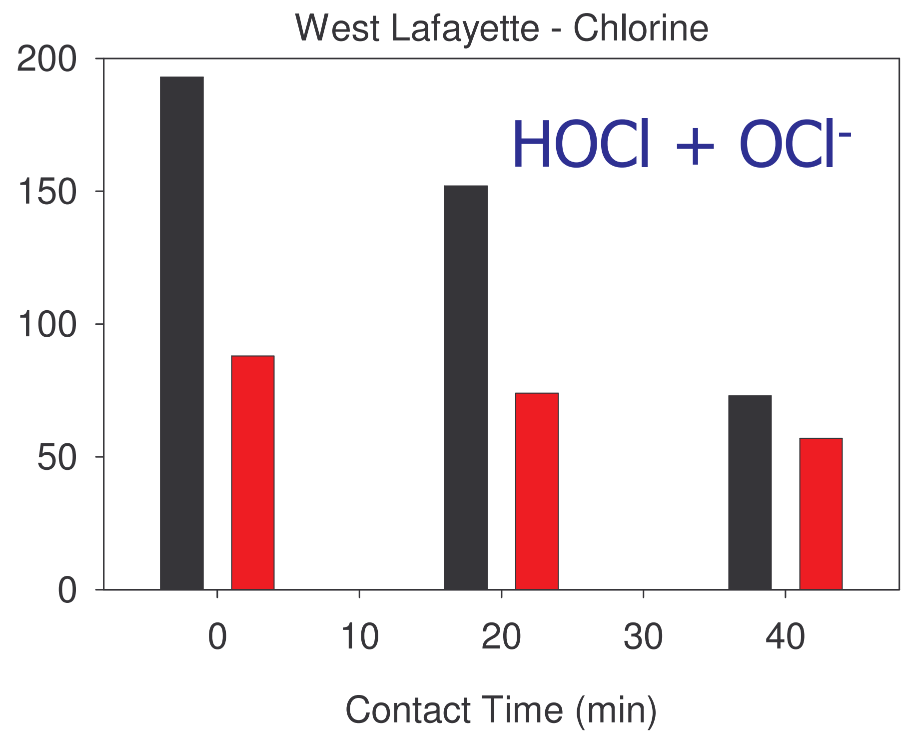
- Effective Inactivation of Fecal Coliforms by Both Disinfectants
  - NPDES Permit Compliance
  - Short Term
- UV: Post-Exposure Decline in TBC, FC
- Cl: Post-Exposure Increase in TBC, FC
- Effects of Disinfection
  - Beneficial for Short-term Bacterial Control
  - Little or No Long-Term Benefit
  - Similar to MWRDGC

Viral Responses: Indigenous Coliphage

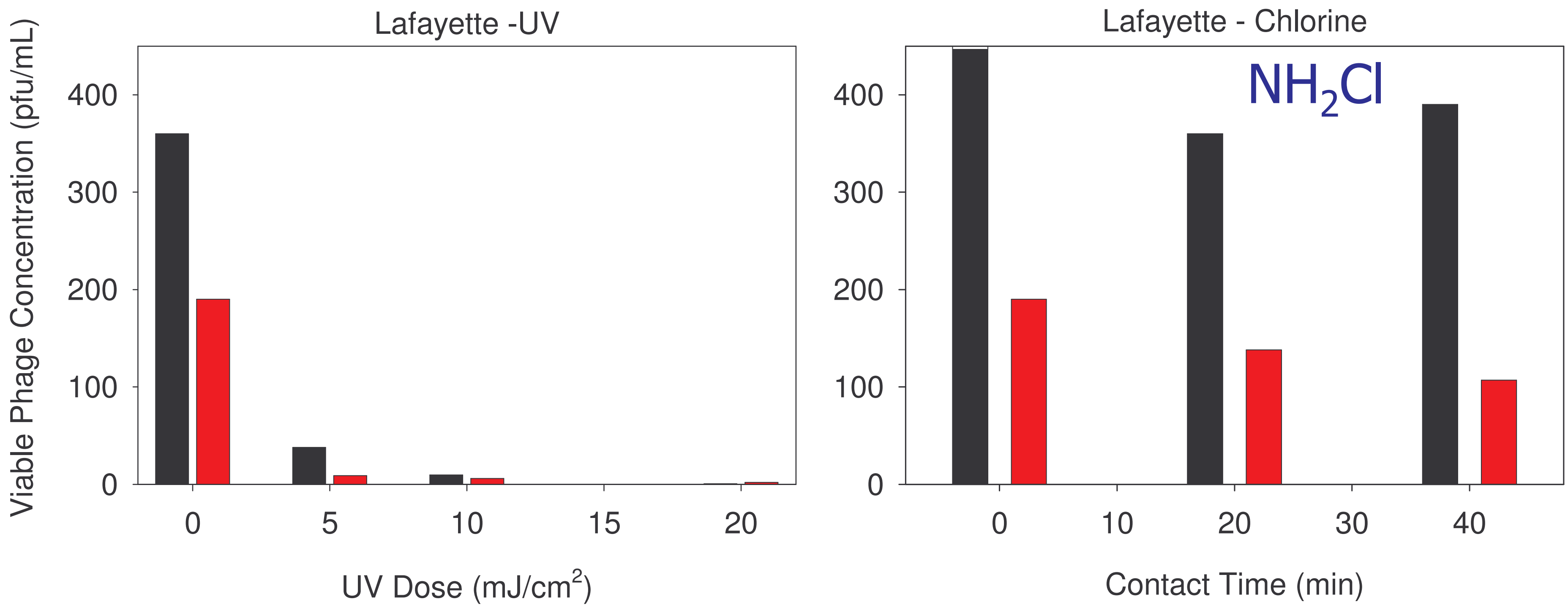
- Virus = Obligate Parasite
- Infection/Reproduction with Suitable Host
- Bacteriophage
  - Infects bacterial cells
  - Disinfectant resistance similar to enteric viruses
- Bacterial Hosts
  - *E. coli* C-3000
  - *E. coli* F_{amp}
- Inactivation Responses
  - Range of doses
  - UV and Cl
- Nucleic Acid Content (species diversity)

Indigenous Bacteriophage (Virus) Responses to Disinfectants (Nitrified Effluent)





Indigenous Bacteriophage (Virus) Responses to Disinfectants (Non-Nitrified Effluent)



Indigenous Bacteriophage: Species Diversity (DNA vs. RNA)

Facility	Disinfectant	Host Strain	DNA Isolates	RNA Isolates
West Lafayette	Free Cl	*E. coli* C-3000	7	4
	Free Cl	*E. coli* F_{amp}	3	2
	UV	*E. coli* C-3000	0	0
	UV	*E. coli* F_{amp}	0	3
Lafayette	Combined Cl	*E. coli* C-3000	6	0
	Combined Cl	*E. coli* F_{amp}	4	2
	UV	*E. coli* C-3000	0	0
	UV	*E. coli* F_{amp}	0	0
Chicago	Free Cl	*E. coli* C-3000	0	0
	UV	*E. coli* C-3000	2	2

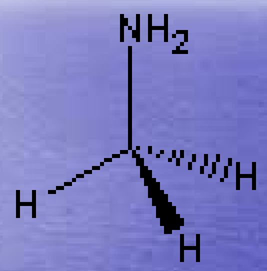
Viral Responses: Responses to Disinfectants

- Chlorine Ineffective for Virus Control
  - Free Chlorine
  - Combined Chlorine
- UV Generally More Effective for Virus Control
  - Virus Inactivation
  - Species Diversity
- Risk Reduction Minimal in Either Case

NPDES Permit Limitations: West Lafayette (example)

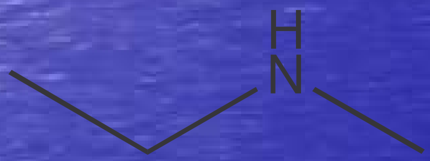
"At all times the discharge from any and all point sources specified within this permit shall not cause receiving waters … to contain substances in concentrations which on the basis of available scientific data are believed to be sufficient to injure, be chronically toxic to, or be carcinogenic, mutagenic, or teratogenic to humans, animals, aquatic life, or plants."

Chlorination of Aliphatic Amines - Precursors

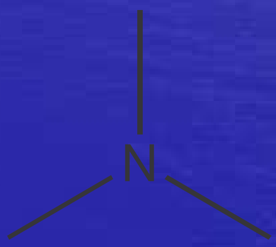


Methylamine

n-Propylamine



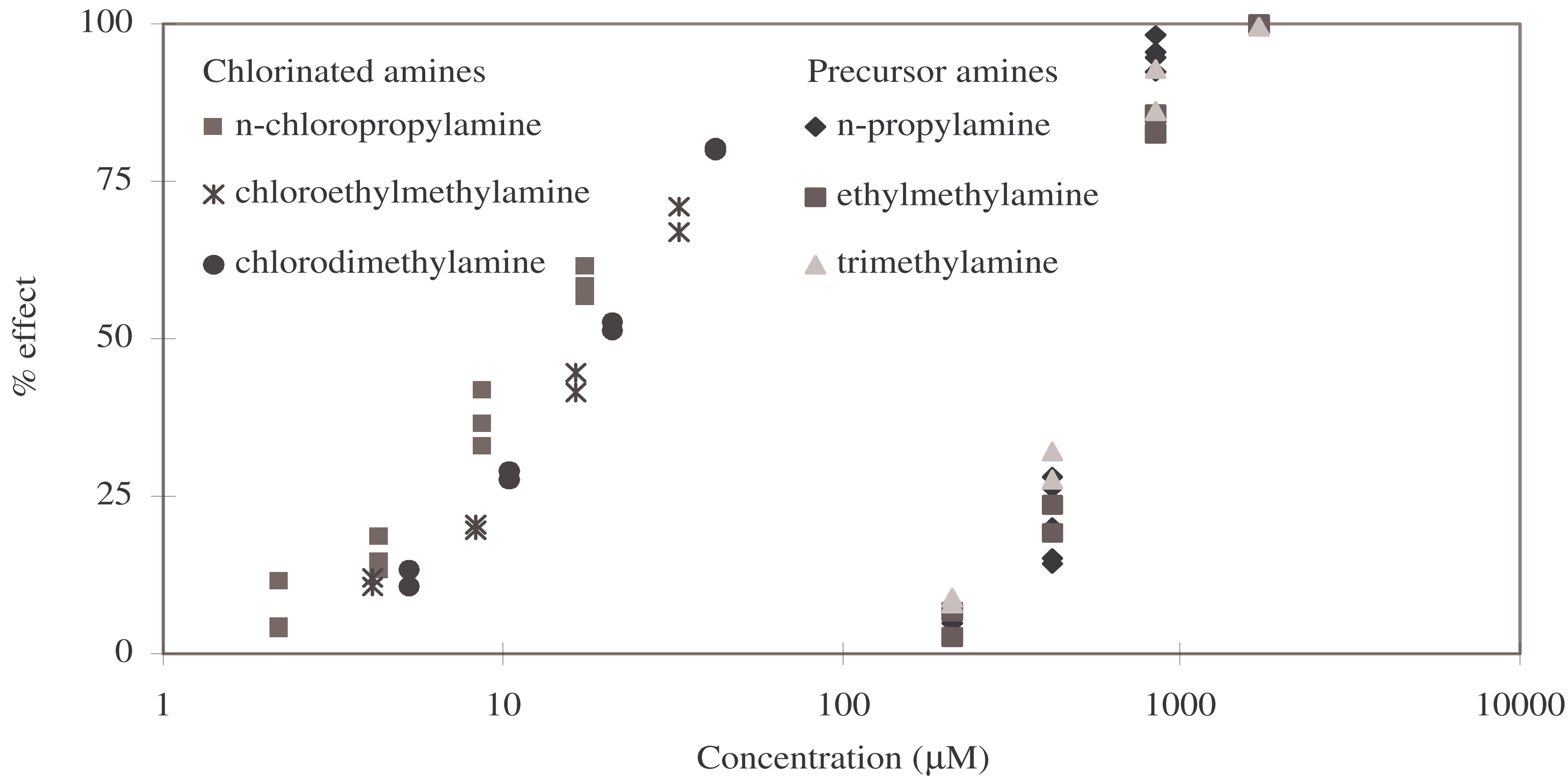
Methylethylamine



Trimethylamine

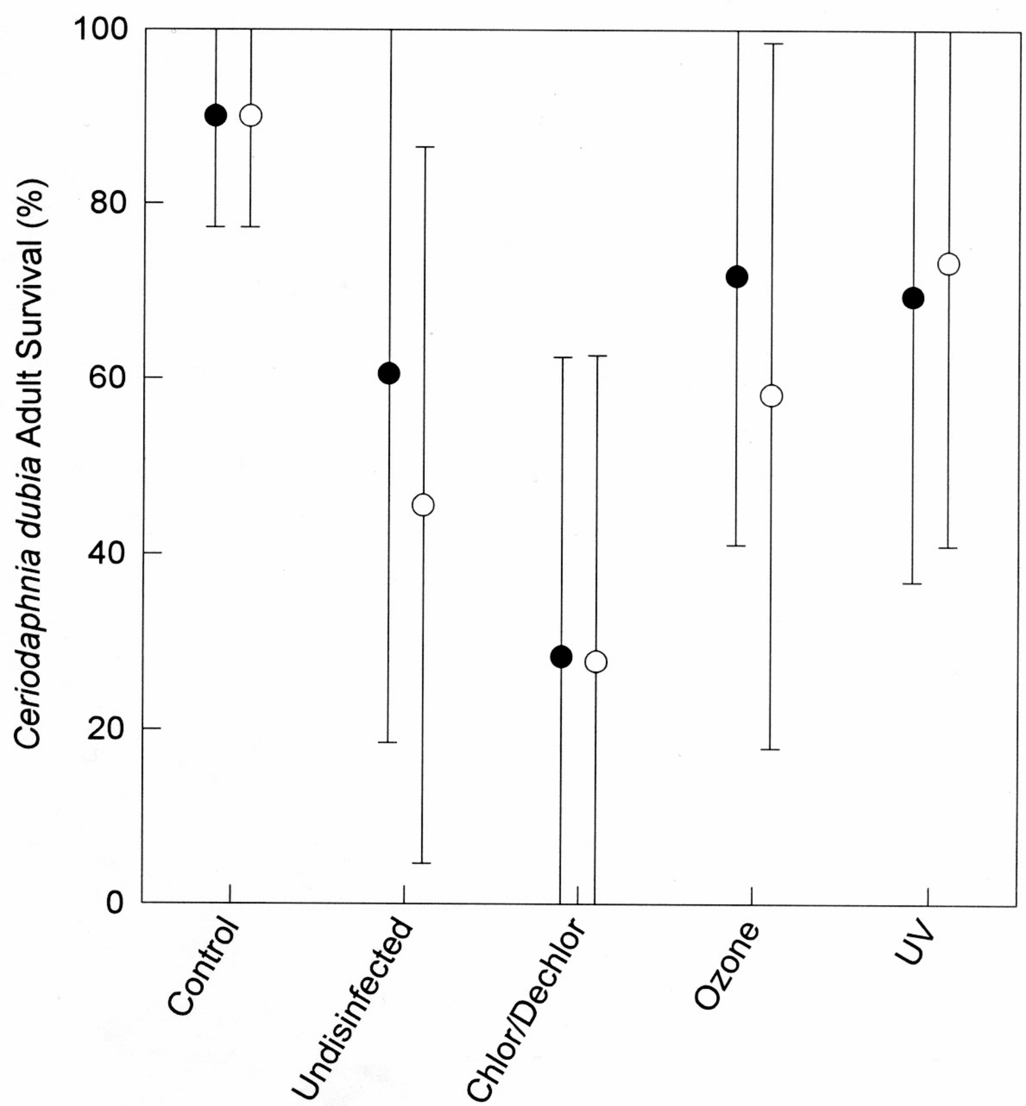
Formation of Organic Chloramines

Chlorination of Aliphatic Amines: Toxicity (Microtox)



Effluent Toxicity Testing
Ceriodaphnia dubia

Effects of Disinfection on Effluent Toxicity



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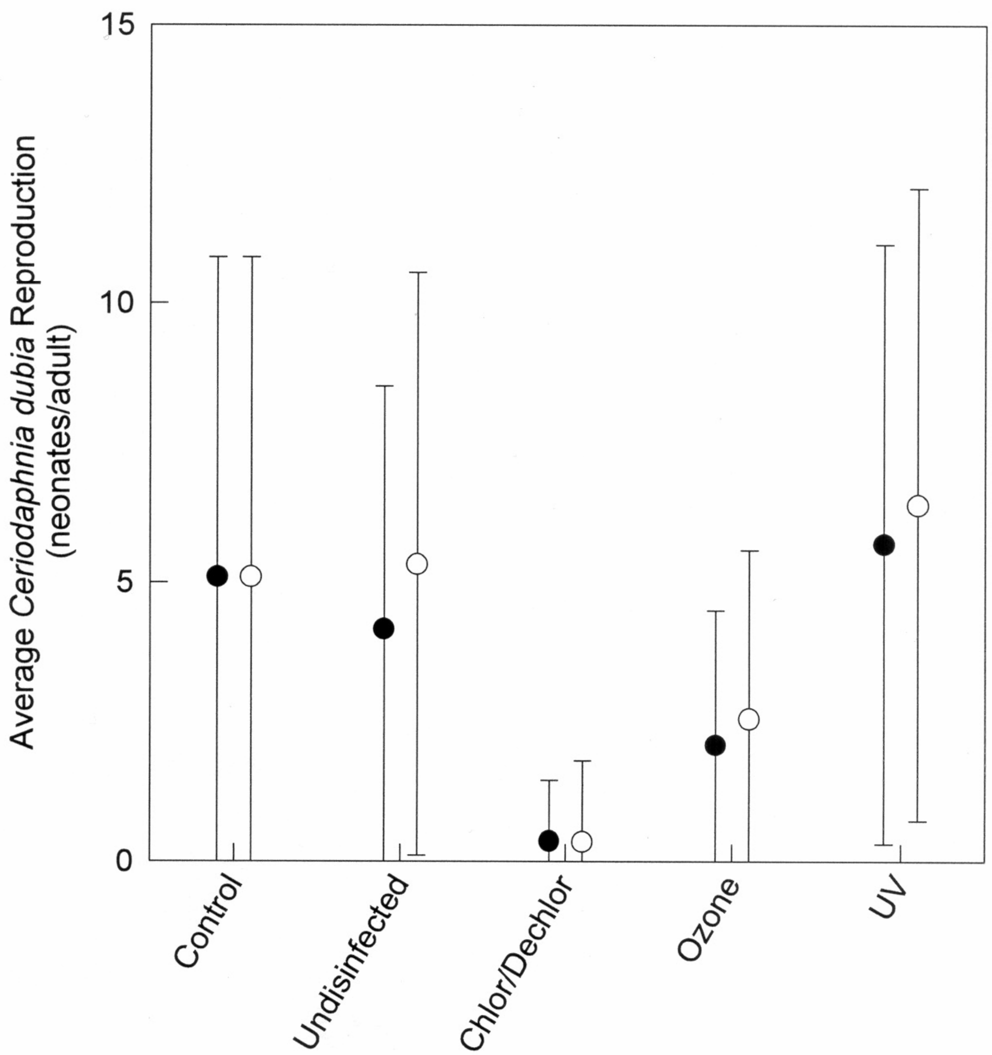


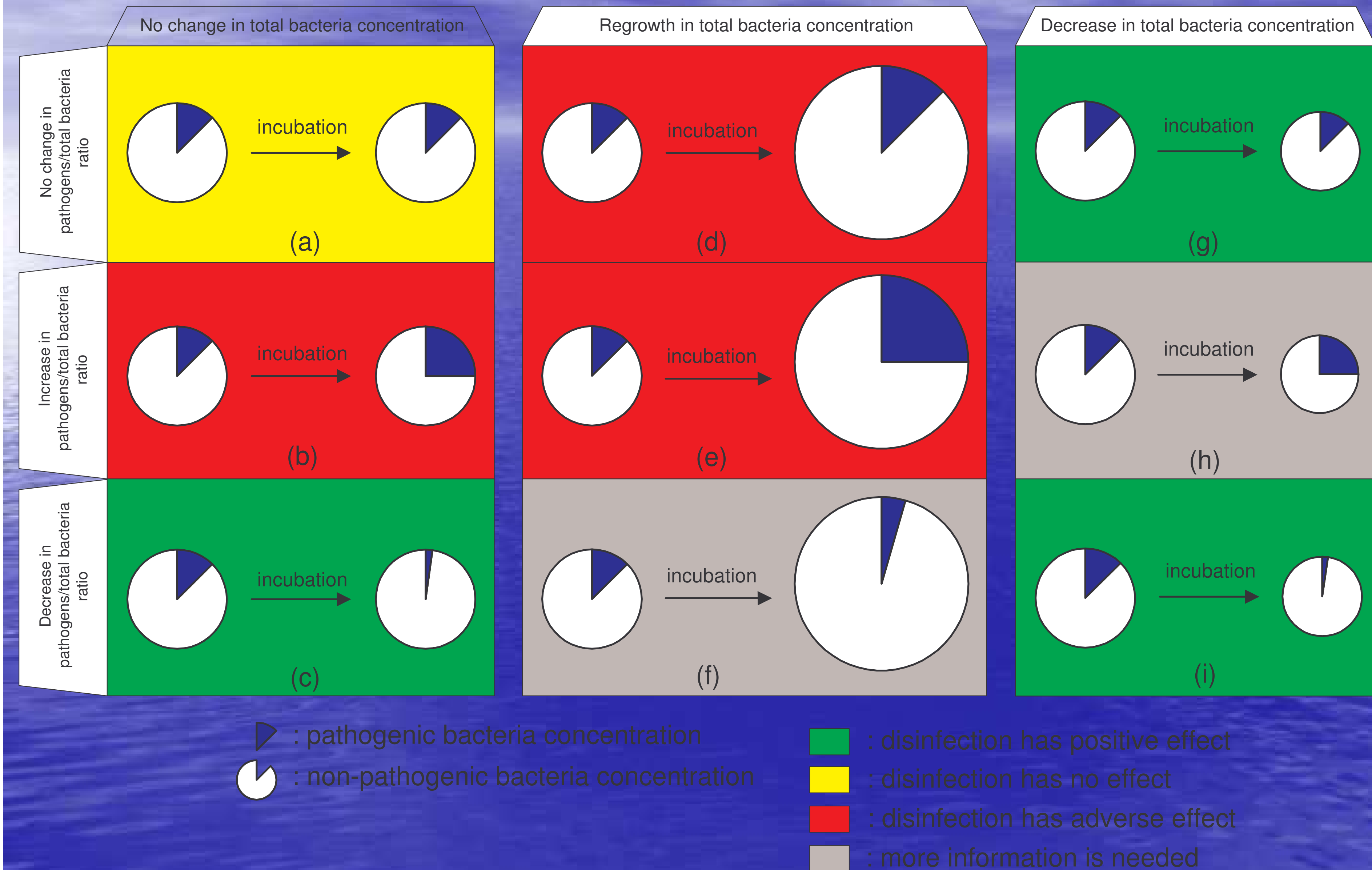
Summary and Conclusions

- Bacterial Control by Conventional Disinfection
  - Short Term
  - Local
  - UV > Cl
- Viral Control by Conventional Disinfection
  - Modest
  - UV > Cl
- Chemistry / Toxicology (chlorinated amines)
  - Stable
  - Toxic

Summary and Conclusions

- Should we disinfect?
  - Decision is case specific
  - Yes, when direct human contact likely
  - Otherwise, benefits are questionable
- If disinfection needed, how?
  - Decision is case specific
  - UV > Cl (for assays conducted in this research)
- Should we disinfect CSO discharges?
  - Chlorine: No (Microbiology, Chemistry, Toxicology)
  - UV: Probably No (Poor Water Quality)

Bacterial Responses: Repair/Regrowth



Treatment	Location	Incubation Time (hours)					
		24	48	72	96	120	144
Control w/o	Lafayette	i	i	c	f (-)	i	i
	St. Petersburg	f (-)	f (-)	c,i	c,i	i	i
	W. Lafayette	f (+)	i	i	i	i	i
	Tampa	i	i	i	i	i	i
Control w/	Lafayette	i	i	c,f (-)	f (-)	c,i	c,i
	St. Petersburg	f (-)	f (-)	f (-)	i	c,i	i
	W. Lafayette	e	i	i	i	i	i
	Tampa	i	i	i	i	i	i
UV	Lafayette	e	b	h (+)	h (+)	h (+)	i
	St. Petersburg	e	e	e	e	a	h (+)
	W. Lafayette	f (-)	f (-)	f (-)	f (-)	i	i
	Tampa	e	e	h (+)	h (+)	h (+)	h (±)
Chlor / Dechlor	Lafayette	e	e	e	e	e	e
	St. Petersburg	e	e	e	f (+)	e	e
	W. Lafayette	f (-)	f (-)	f (-)	f (-)	f (-)	e
	Tampa	f (-)	e	e	f (-)	e	f (-)

Bacterial Responses: Repair/Regrowth West Lafayette Samples

Treatment	TBC_0	TBC_{144}	FC_0	FC_{144}
UV	5.63×10^7	3.69×10^7	55	0
Chlor / Dechlor	6.31×10^7	2.16×10^8	9	500
Control w/	7.16×10^7	4.54×10^7	9850	175
Control w/o	6.61×10^7	4.77×10^7	9350	475

Effects of Disinfection on Effluent Toxicity