WAHC World Aquatic Health™ Conference

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Cyanuric Acid
CMAHC Ad Hoc Committee Report

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Sponsors: Michael Beach, Doug Sackett

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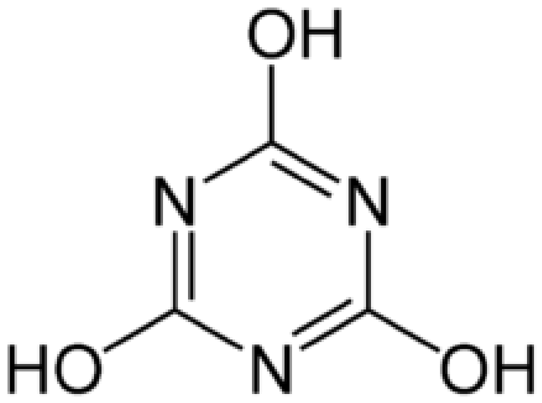
MAHC CYA Ad Hoc Committee: Charge

- Balanced, objective examination of the effects of CYA on risk of disease transmission from routine use (not AFR)
- Provide guidance to define future limits, based on:
  - CYA + chlorine chemistry
  - Literature on effects of CYA on microbial inactivation kinetics
  - Calculated risk to bathers
- Summarize assumptions, results and conclusions

Overview

- CYA & chlorine chemistry
- Kill rates based on HOCl
- CYA/FC ratio
- Steady-State pathogen model
- Example results
- Discussion/recommendations

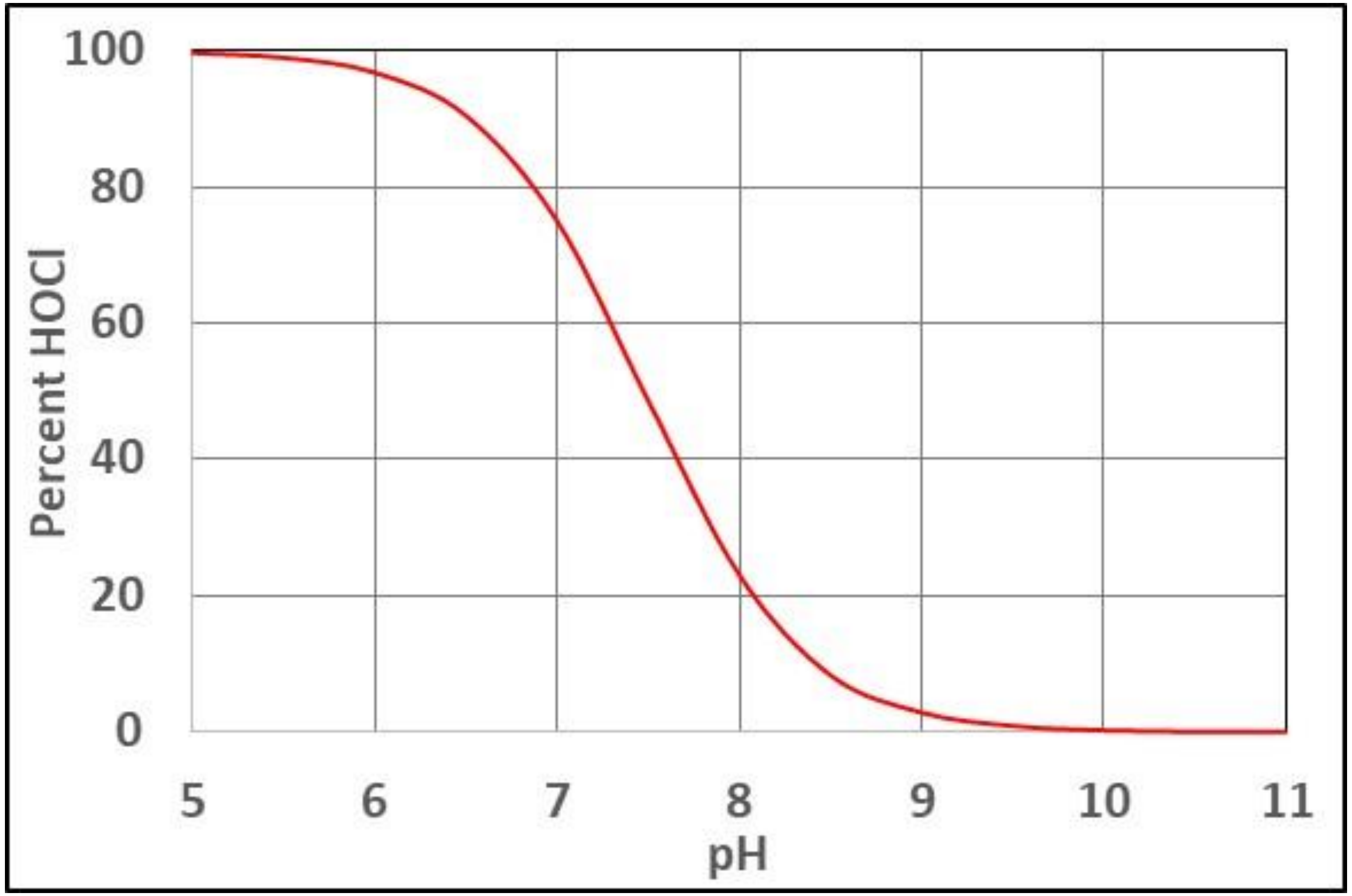


Cyanuric acid

HOCl as a Function of pH

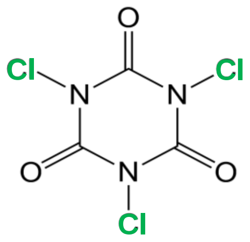
$$HOCl \rightleftharpoons H^{+} + OCl^{-}$$

HOCl is the primary active sanitizer in chlorine pools



FC/Cyanuric Acid Equilibria (O'Brien, 1974)

Cl_3Cy



$\rightleftharpoons$

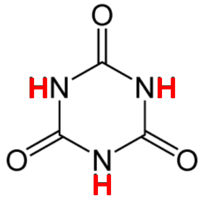
$HCl_2Cy \rightleftharpoons Cl_2Cy^-$

$\rightleftharpoons \quad \rightleftharpoons$

$H_2ClCy \rightleftharpoons HClCy^- \rightleftharpoons ClCy^{2-}$

$\rightleftharpoons \quad \rightleftharpoons \quad \rightleftharpoons$

$H_3Cy \rightleftharpoons H_2Cy^- \rightleftharpoons HCy^{2-} \rightleftharpoons Cy^{3-}$



$$HOCl \rightleftharpoons H^+ + OCl^-$$
$$HOCl + H_2Cy^- \rightleftharpoons HClCy^- + H_2O$$

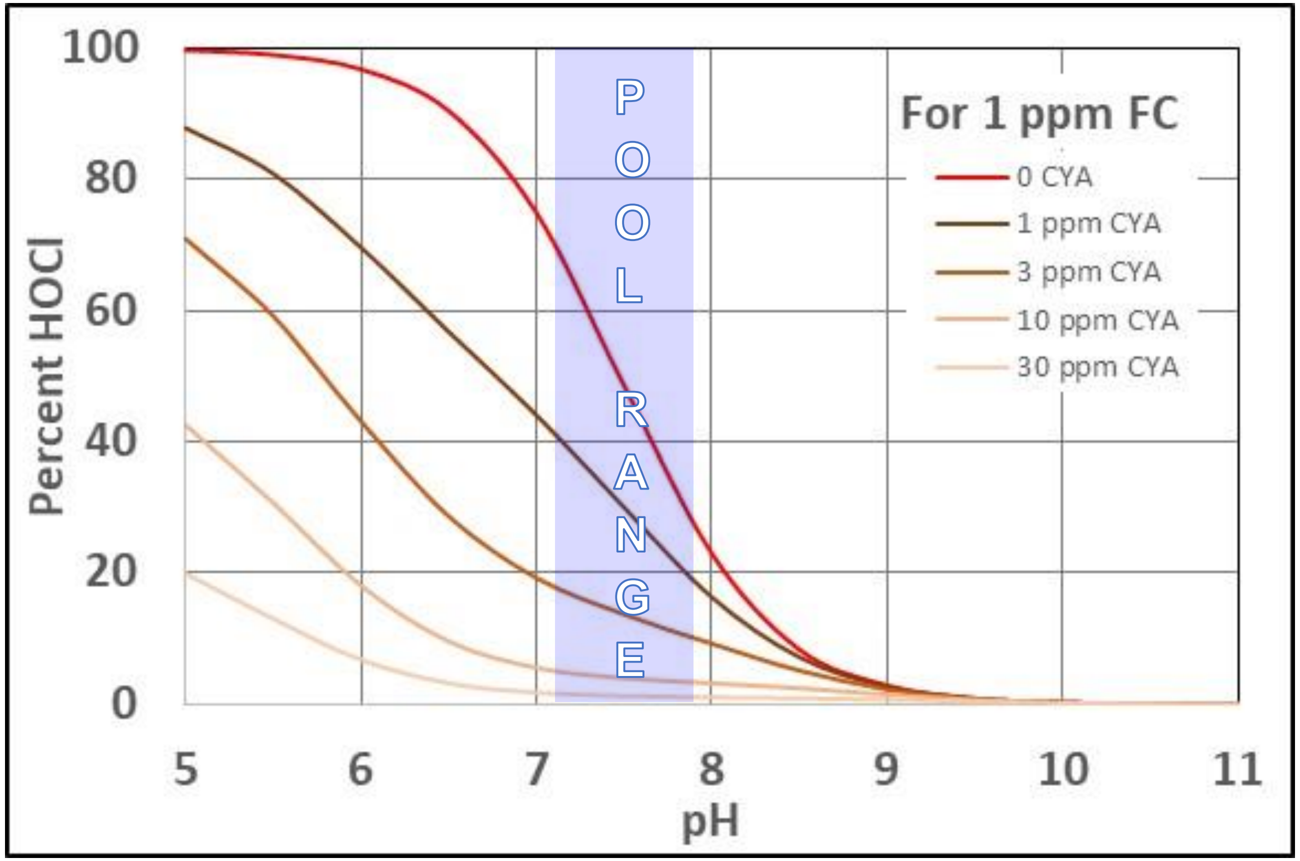
- Equilibrium constants known
- Concentrations of all forms can be calculated using an equilibrium model

Calculations

- Input: Free chlorine, CYA, pH, temp, TDS
- Output: HOCl, OCl^-, and each Cl-Cy species

HOCl as a Function of pH: Effect of CYA

$$HOCl \rightleftharpoons H^+ + OCl^-$$
$$HOCl + H_2Cy^- \rightleftharpoons HClCy^- + H_2O$$



- As the CYA concentration increases, the percent HOCl decreases.
- The curve flattens out between pH 7 and 8.
- Even a small amount of CYA has a big effect on HOCl concentration

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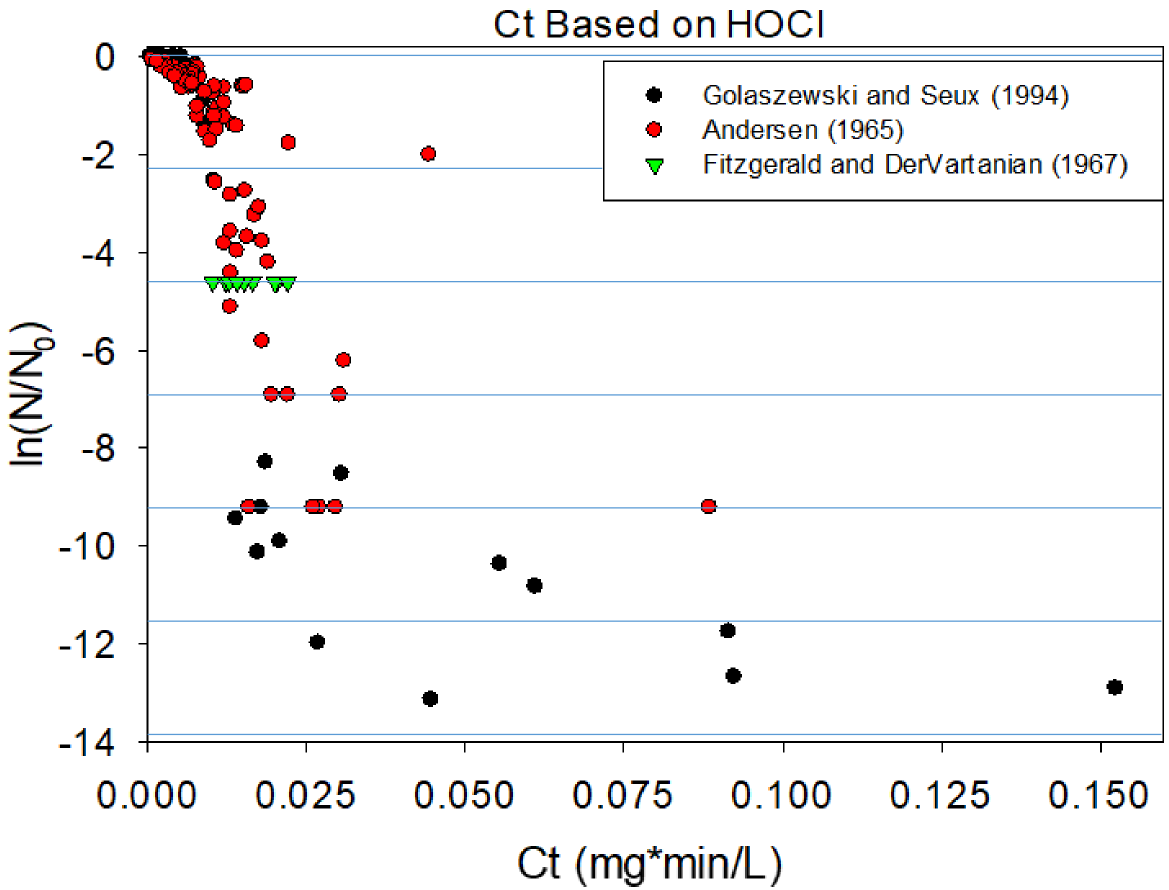
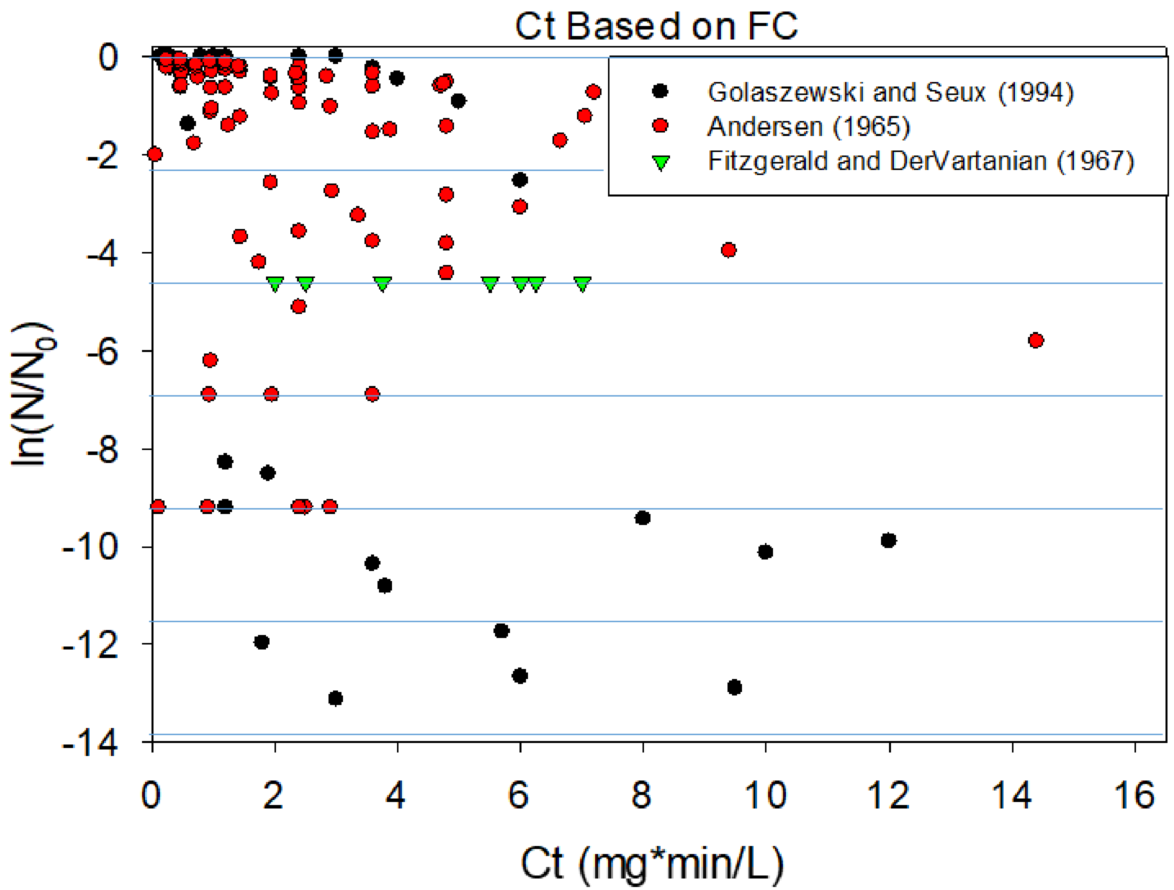
Kill Times Based on HOCl instead of Free Chlorine
Streptococcus faecalis

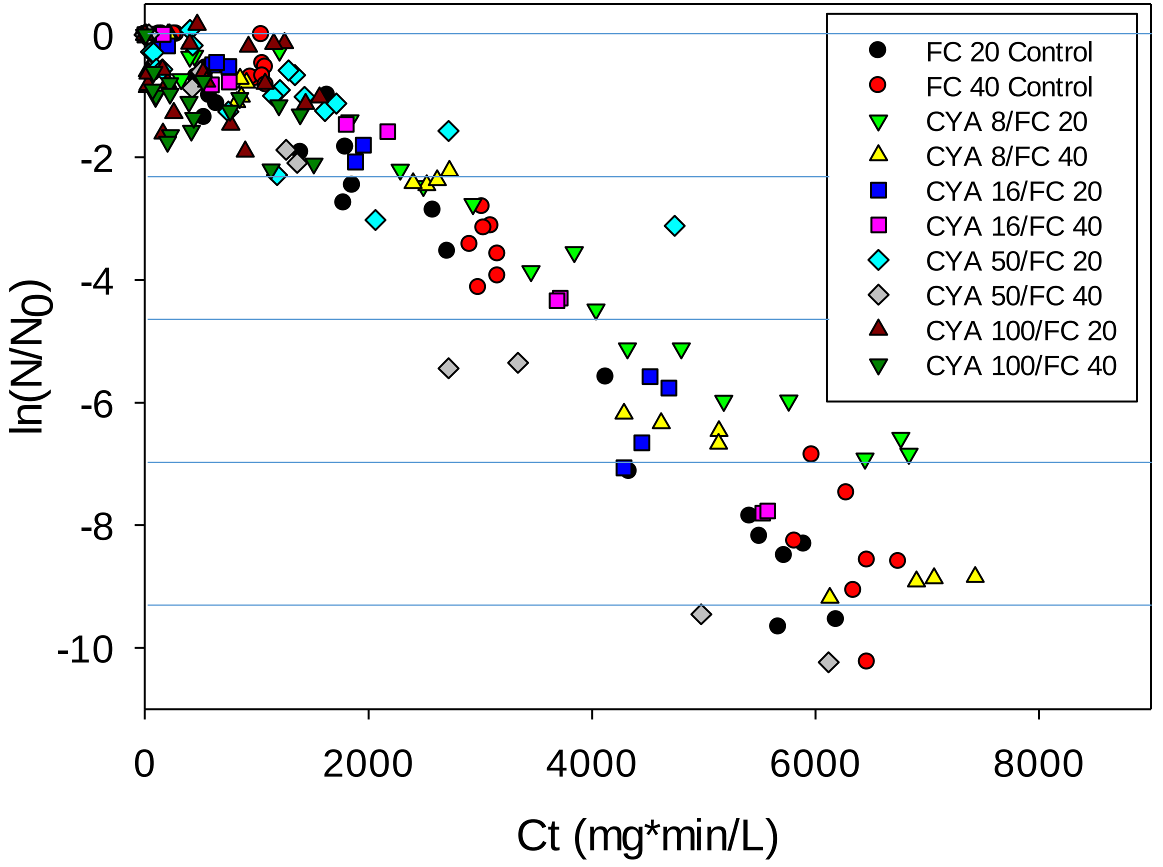




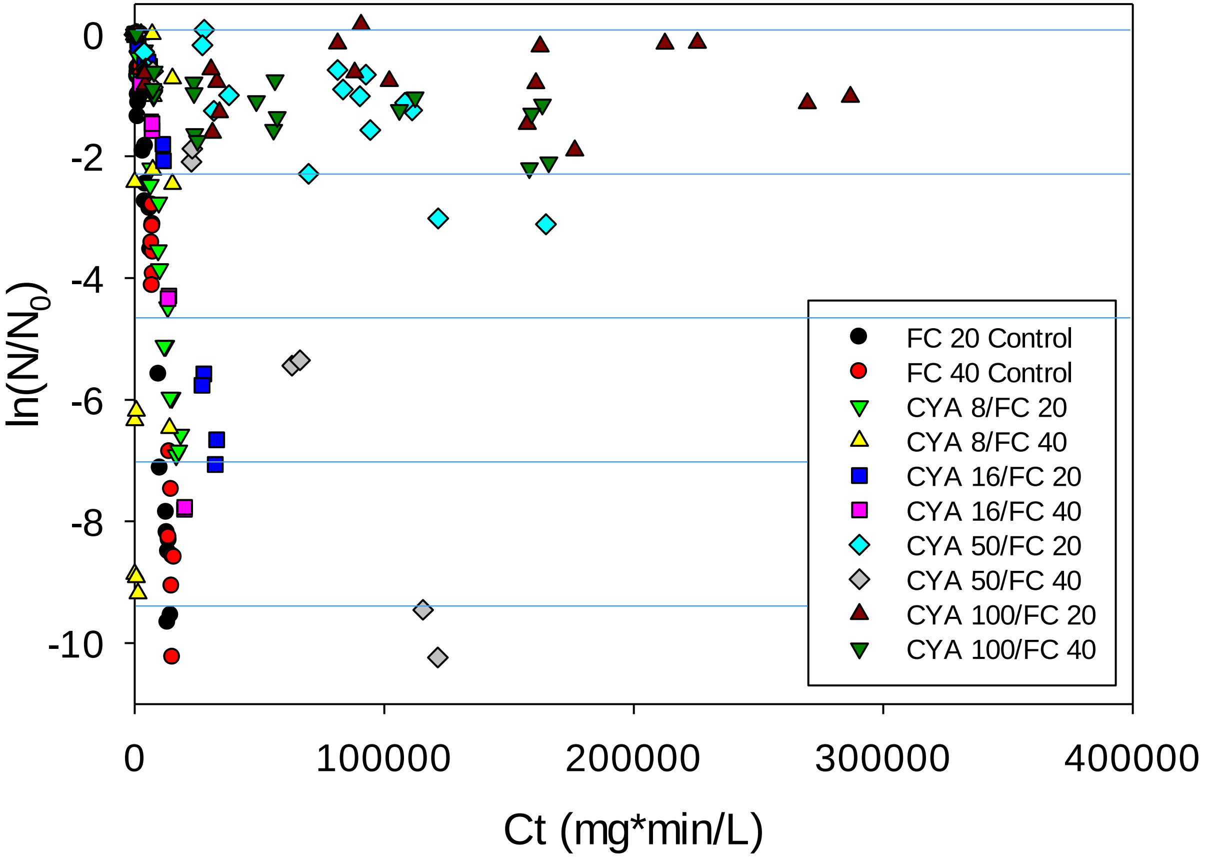
HOCl, Not FC, Is the Active Sanitizer

C. parvum Inactivation Kinetics

Ct Based on HOCl



Ct Based on Available Chlorine



Data From: Murphy et al., 2015.

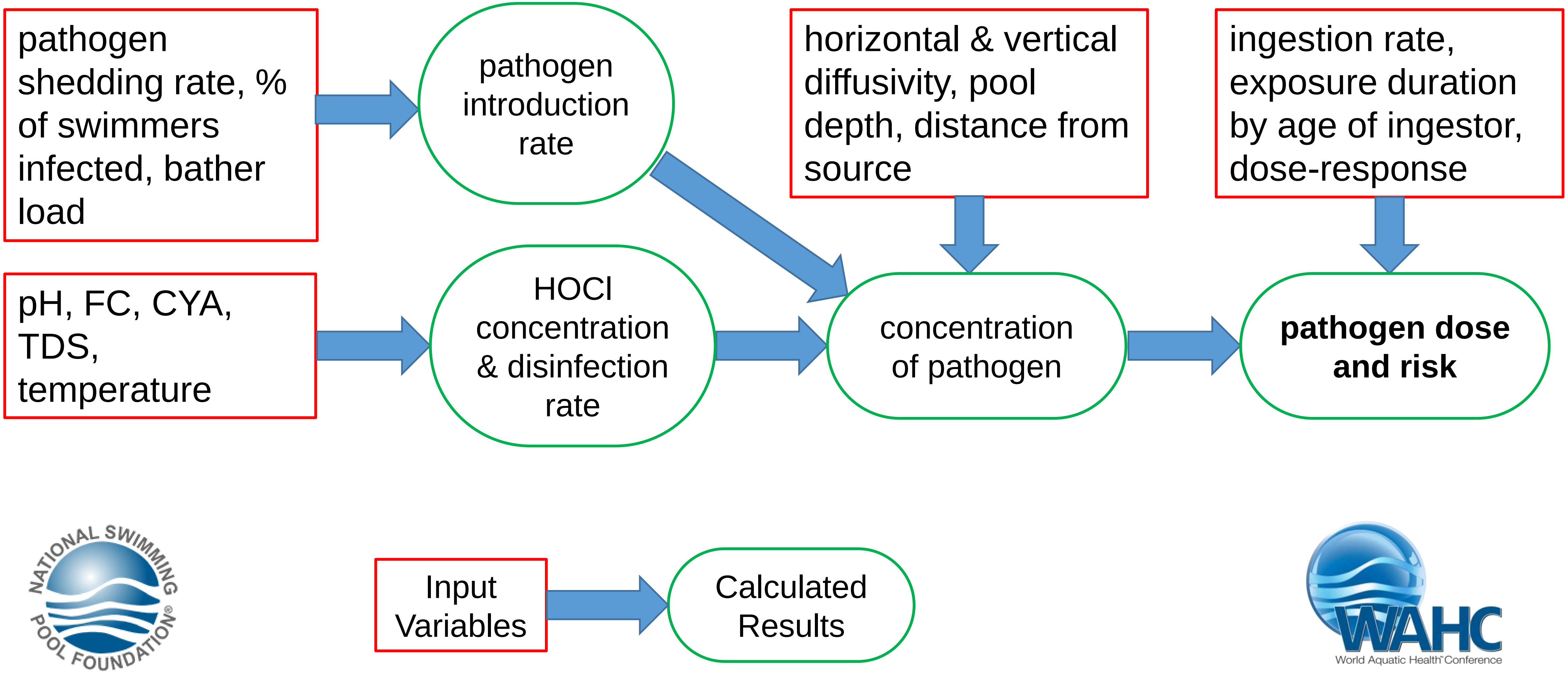
Free Chlorine (FC) and CYA

- Constant CYA/FC ~ Constant HOCl
- Table shows CYA/FC = 20
- Disinfection efficacy remains nearly constant
- Recommendation: Control the CYA/FC ratio, not FC and CYA separately

Inputs		Output
CYA (ppm)	FC (ppm)	HOCl (ppm)
20	1.0	0.0196
30	1.5	0.0199
40	2.0	0.0201
50	2.5	0.0202
60	3.0	0.0202
70	3.5	0.0203
80	4.0	0.0203
90	4.5	0.0203

The Steady-State Pathogen Model

Model Components/Logic



Three Examples: Basic Inputs

The following parameters are used for the examples:

Input Parameter	Value
FC	2 ppm
CYA	90 ppm
pH	7.5
water temp.	25°C
TDS	1000 ppm
ingestor	children

Input Parameter	Value
diffusivity (horiz.)	500 cm^2/min
diffusivity (vert.)	500 cm^2/min
pool depth	3 ft.
distance from nearest source	1.5 ft. horizontal 1.5 ft. vertical
ingestion rate	24.2 mL/hr
exposure duration	1.9 hr (per visit)

The examples presented here are not associated with accidental fecal release events.
The examples represent routine fecal sloughing.
Risk not estimated based on an outbreak.

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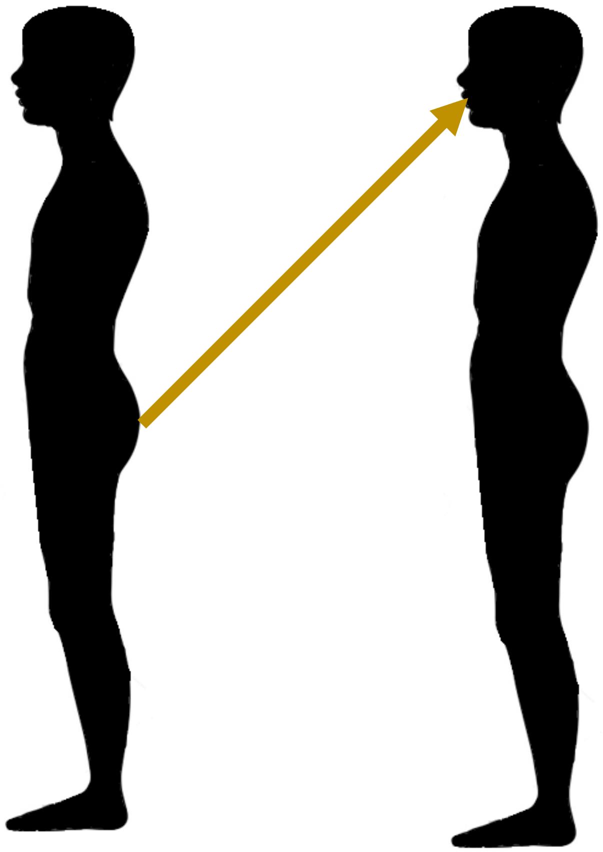
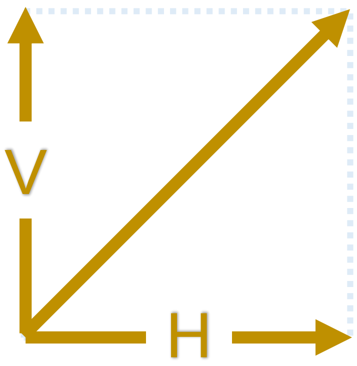
Bather Spacing – Single Source Model Example: *E. Coli*



Input Parameter	Value
distance from nearest source	1.5 ft. horizontal 1.5 ft. vertical



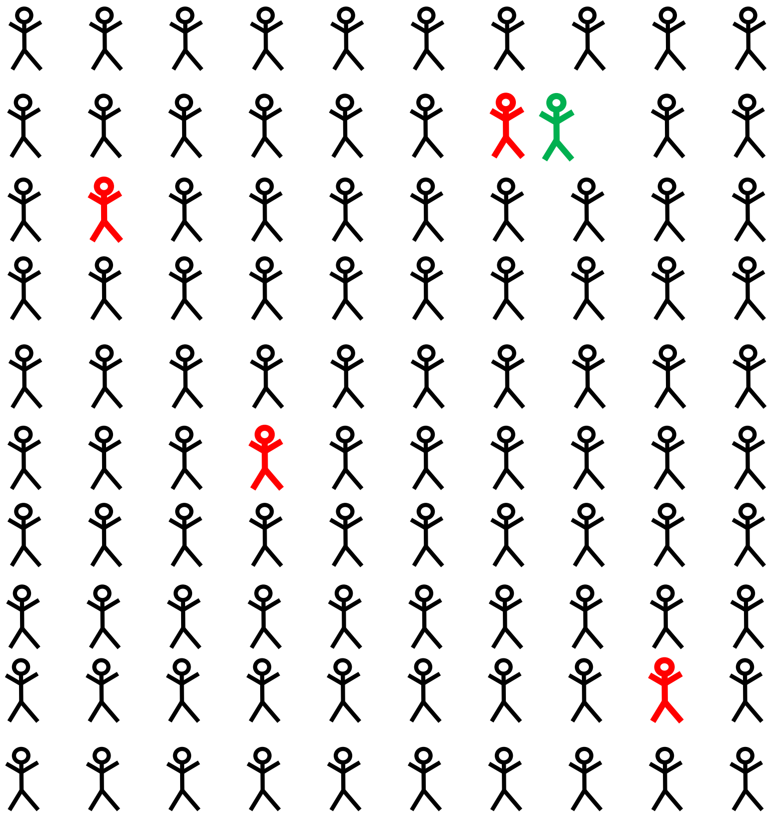
Example: *E.* coli O157:H7

Input Parameter	Value
shedding rate (1st 15 min.)	medium (14,000 CFU/bather/min)
CT (Free chlorine, pH 7.5)	0.25 ppm min

Input Parameter	Value
% of bathers infected	N/A
dose-response “k”	2.18×10^{-4}

- HOCl concentration = 0.0087 ppm
- Calculated *E. coli* concentration = 0.09 CFU/100 mL
- Calculated probability of infection = 0.0009% per event

Bather Spacing – Infinite Sources Model Example: *Giardia*



Input Parameter	Value
distance from nearest source	1.5 ft. horizontal 1.5 ft. vertical
% of bathers infected	4.4% *Giardia*
Bather load	1 bather/15 sq. ft.

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Example: *Giardia*

Input Parameter	Value
shedding rate (1st 15 min.)	medium (232 cysts/bather/min)
CT (Free Chlorine, pH 7.5)	45 ppm min

Input Parameter	Value
% of bathers infected	4.4%
Bather load	1 bather/15 sq. ft.
dose-response "k"	1.99×10^{-2}

- HOCl concentration = 0.0087 ppm
- Calculated *Giardia* concentration = 0.13 cysts/100 mL
- Calculated probability of infection = <u>0.12% per event</u>

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Example: *Cryptosporidium parvum*
(asymptomatic bathers, no diarrhea)

Input Parameter	Value
shedding rate (1st 15 min.)	medium (2.84 cysts/bather/min)
CT (Free chlorine, pH 7.5)	15,300 ppm min

Input Parameter	Value
% of bathers infected	0.4%
Bather load	1 bather/15 sq. ft.
dose-response "k"	5.72×10^{-2}

- HOCl concentration = 0.0087 ppm
- Calculated oocyst concentration = 0.005 oocysts/100 mL
- Calculated probability of infection = <u>0.014% per event</u>

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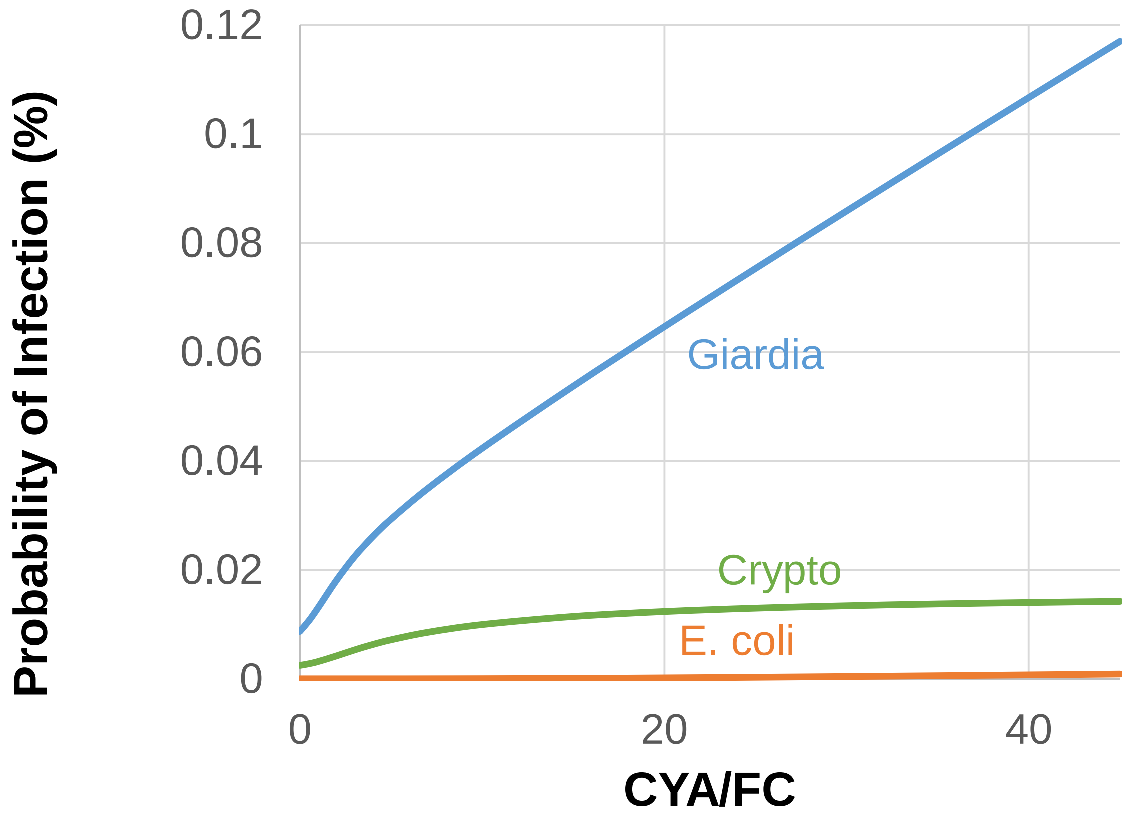
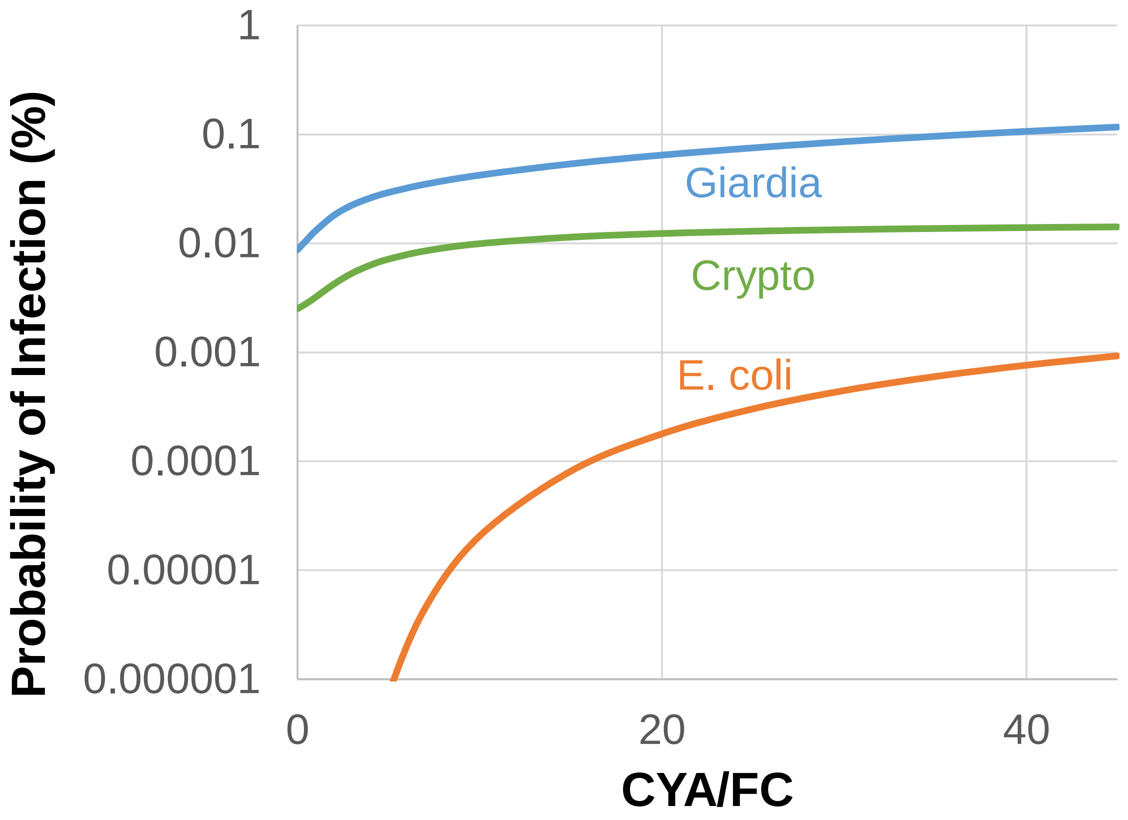
Sample Results: *E. coli, Cryptosporidium parvum & Giardia*





Accidental Fecal Release (AFR)

- Volume of fecal matter in AFR > 500x higher than fecal sloughing
- Concentration of *Crypto* in those with diarrhea may be > 10x higher than those without diarrhea
- Disinfection from chlorine ~340x slower for *Crypto* vs. *Giardia*

Recreational Water-associated Outbreaks of Acute Gastrointestinal Illness (AGI) United States, 2003-2012

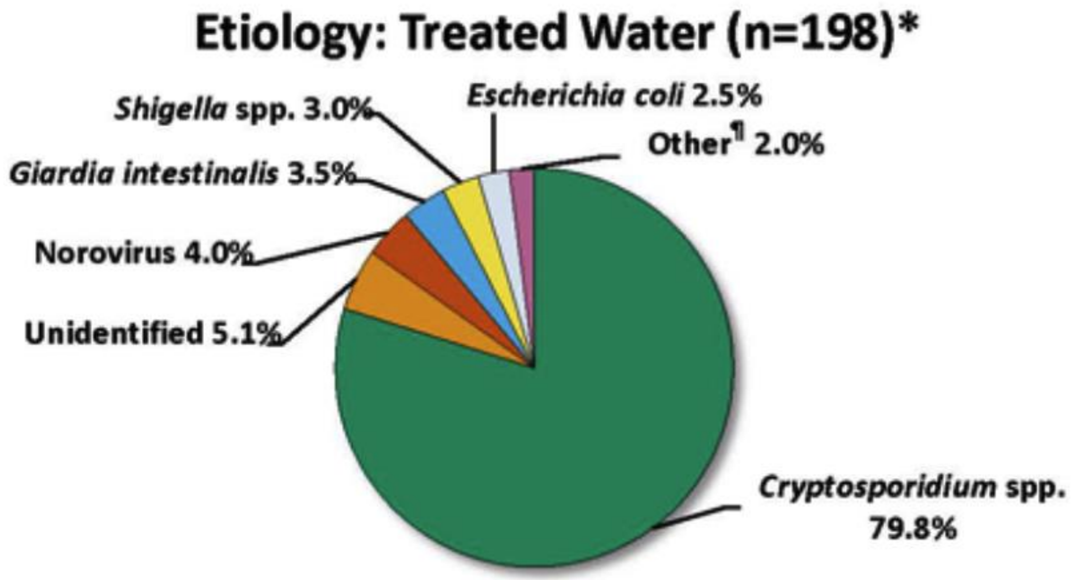


Chart From: CDC, 2015.

Observations

- The probability of infection affected by many factors
- The probability of infection increases as CYA/FC increases

For these examples

- The increase in risk from *E. coli* is inconsequential to public health as long as chlorine residual is present
- The increase in risk from *Giardia* is greater than *E. coli* or *Crypto*
- 0.12% risk from *Giardia* with current MAHC limits (2 ppm FC, 90 ppm CYA) gained the attention of the ad hoc committee

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Relative Risk with CYA/FC Ratios

Pathogen, age group, shedding rate	% Risk at ratio = 45*	% Risk at ratio = 20	Relative risk
***Giardia*, children, medium**	0.117	0.0646	1.8
***Giardia*, adults, medium**	0.0259	0.0143	1.8
***E. coli* 0157:H7, children, medium**	0.000926	0.000178	5.2
***E. coli* 0157:H7, adults, medium**	0.000204	0.0000393	5.2

Input parameters:

- 90 ppm CYA / 2 ppm FC
  *current MAHC limits
- 40 ppm CYA / 2 ppm FC
- pH 7.5
- 500 cm^2/min diffusivity
- 1.5 ft. to source

$$\text{Relative Risk} = \frac{\%\text{ Risk at } CYA/FC=45}{\%\text{ Risk at } CYA/FC=20},\ e.g.\ \frac{0.117}{0.0646} = 1.8$$

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Discussion and Recommendations

- The results provide general trends only
- HOCl is the active sanitizer
- HOCl is approximately constant when the CYA/FC ratio is constant
- Acceptable CYA and FC concentrations should be based on a CYA/FC ratio
- Current MAHC limits give a CYA/FC ratio of 45
  - Maximum 90 ppm CYA, Minimum 2 ppm FC
- Reduce the CYA/FC ratio to 20?
  - Minimal impact on pool operation and costs?
  - Lower *E. coli* risk ~5 fold and *Giardia* risk ~2 fold

Discussion and Recommendations

- What is an acceptable risk?
- Any unintended consequences?

How to maintain a 20 CYA/FC ratio

CYA (ppm)	FC (ppm as Cl_2)
≤20	1.0
30	1.5
40	2.0
50	2.5
60	3.0
70	3.5
80	4.0
90	4.5

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Thank you