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CEE/EHS 597B

Meeting #2: Treatment for Small Water Systems

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Purposes for Water Treatment

- Disinfection
- Removal of Turbidity
- Removal of Color, and Tastes & Odors
- Removal of Iron & Manganese
- Hardness removal
- Protection from Toxic Organics and Inorganics

#1 concern

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Drinking Water Treatment Processes

- Gas Transfer (stripping)
- Oxidation
- Coagulation & Flocculation
- Sedimentation or Flotation
- Softening
- Adsorption
- Disinfection

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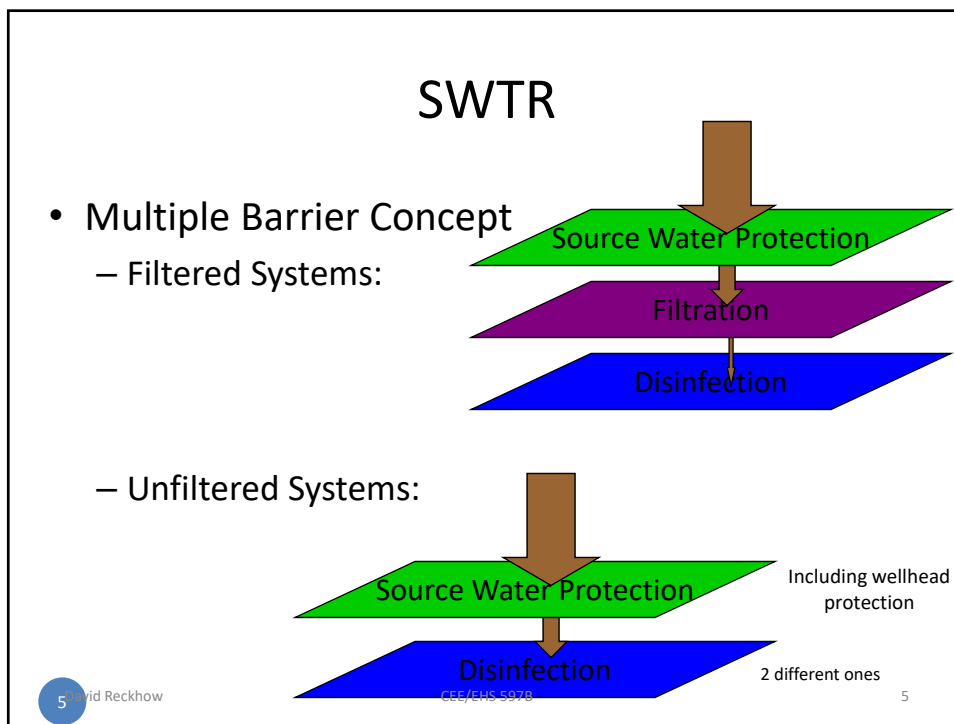
Source Waters

- Groundwaters
 - constant quality
- Rivers
 - variable quality
 - storm events, runoff
 - increases in turbidity, pathogens, coliforms
 - Wastewater inputs
 - Agricultural runoff
 - Accidental spills
- Reservoirs & lakes
 - less variation than rivers
 - seasonal blooms of alae in nutrient rich reservoirs
 - oxygen can be depleted from bottom; causing Fe/Mn problems
 - reservoir turnover in fall & spring

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Log Removal

- **Meaning of “Log Removal or Inactivation”**
 - Removal: remove organisms from the water
 - Inactivation: make organisms non-infectious by use of disinfection
 - Let N_0 be the number concentration of microorganisms in raw water
 - Let N be the number concentration of microorganisms after treatment
 - N/N_0 = fraction remaining after treatment
 - $100 \times (N_0 - N)/N_0$ = percent removal (or inactivation)
 - $\text{Log}(N_0/N)$ = the log removal (or inactivation)
 - Relation between % removal and log removal:

% Removal	Log Removal	N, if $N_0 = 10,000/L$
90	1	1000
99	2	100
99.9	3	10
99.99	4	1

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SWTR (cont.)

- Requirements for Filtered Supplies

Type of Filtration	Log ₁₀ Removal Allowed By Filtration		Remaining Log ₁₀ Inactivation by Disinfection	
	<i>Giardia</i>	Viruses	<i>Giardia</i>	Viruses
Conventional	2.5	2.0	0.5	2.0
Direct	2.0	1.0	1.0	3.0

- Requirements for Unfiltered Supplies

- Meet source water quality criteria
- Provide all Pathogen removal by Disinfection
 - 3 log *Giardia*, 4 log viruses

The TT approach, rather than MCL

Requires a certain CT

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Treatment vs Sources

- Surface water

- Major water quality concerns
 - Pathogens
 - Turbidity
 - Color & TOC
 - Taste & odor

- Typical treatment

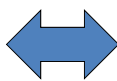
- “conventional” coagulation-filtration
- Some use advanced treatment

- Groundwater

- Major water quality concerns
 - Fe/Mn
 - Hardness
 - Arsenic, perchlorate
 - VOCs & pesticides

- Typical treatment

- Disinfection only
- Softening
- Aeration
- Pressure filtration



Crossover is not uncommon



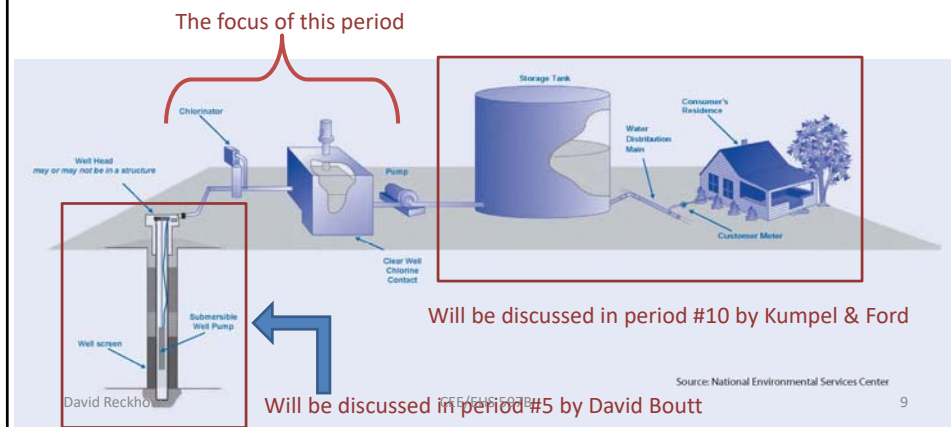
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Simple Groundwater systems

- “Groundwater Treatment Process”
 - From RCAP reading, pg 10-11



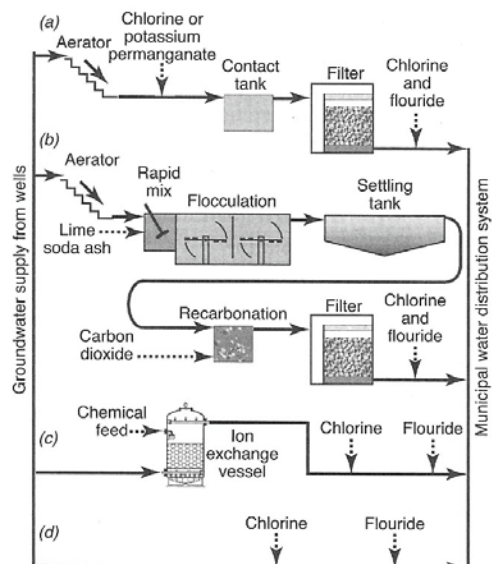
Groundwater Treatment

- More realistically, there are many options or needs:
 - a. Fe/Mn removal
 - b. Precip. Softening
 - c. Ion exchange
 - d. Simple disinfection

From: [Water and Wastewater Technology by Hammer and Hammer, 6th edition \(2008\)](#)
 H&H, fig 7-25, pg.250

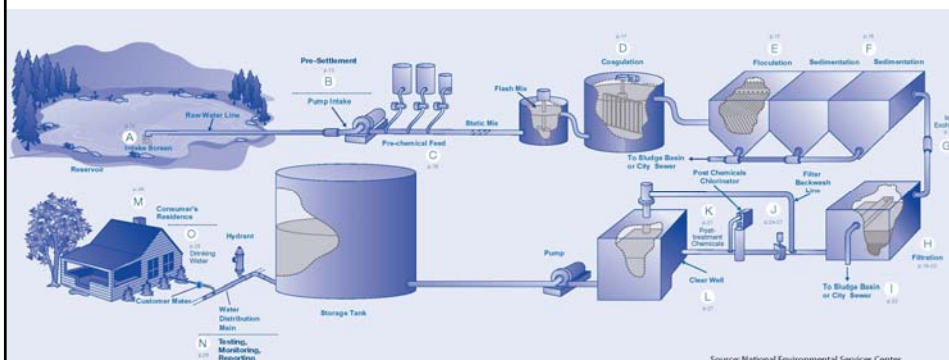
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Surface Water

- Again from RCAP, pg/ 14-15



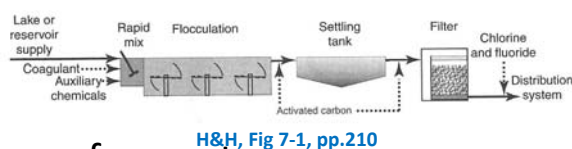
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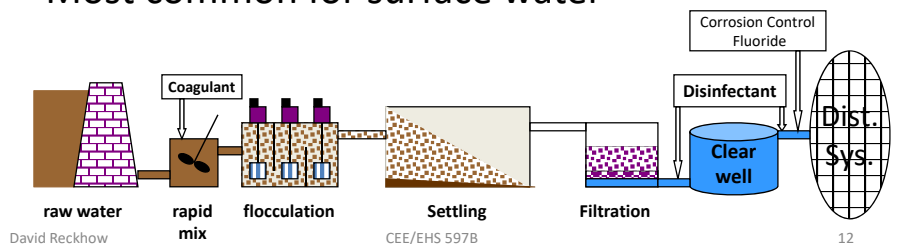
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Conventional Treatment

- Coagulation & solids separation
 - rapid mix, flocculation, settling, filtration
- Disinfection
 - including clearwell for contact time
- Most common for surface water



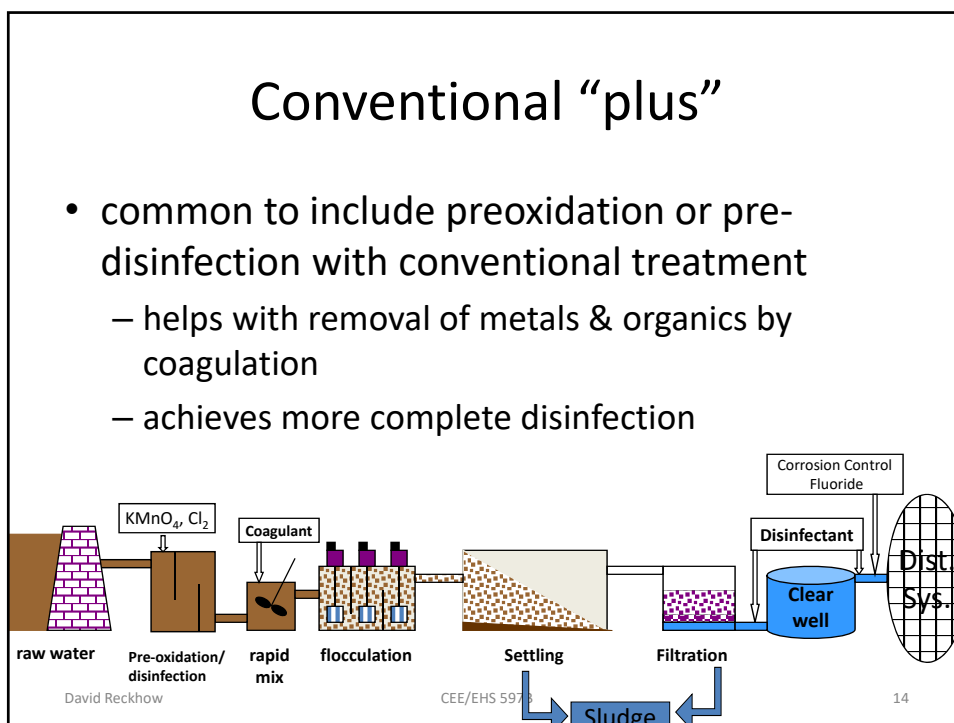
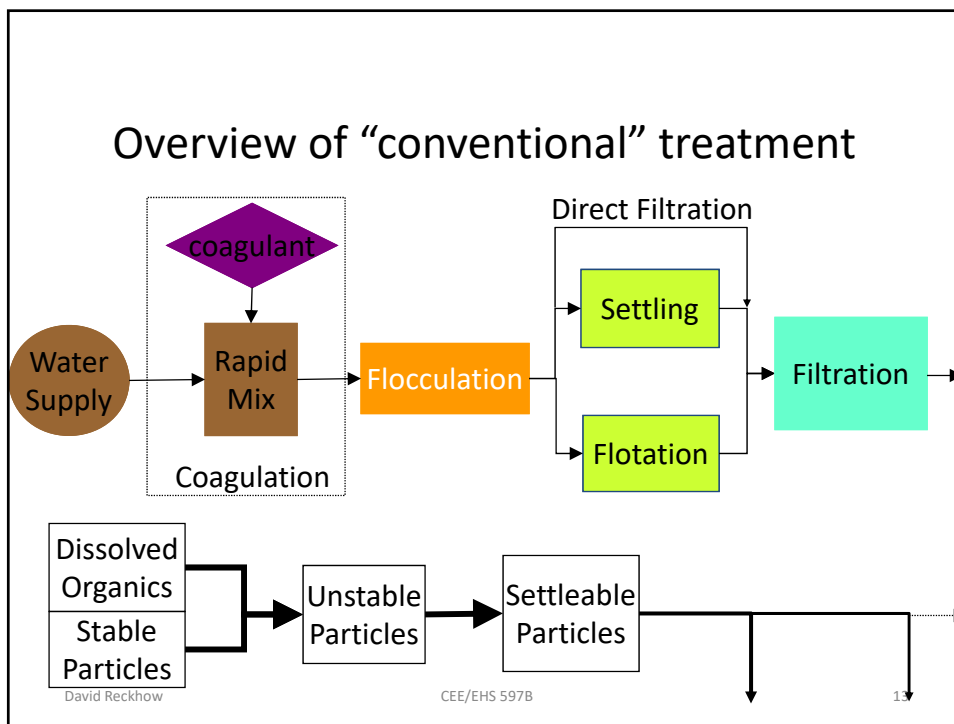
H&H, Fig 7-1, pp.210



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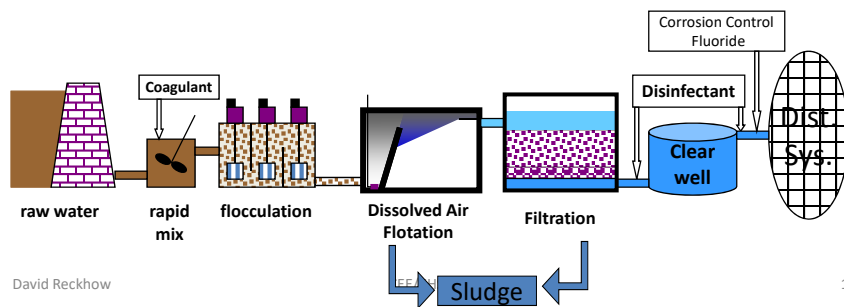
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Dissolved Air Flotation (DAF)

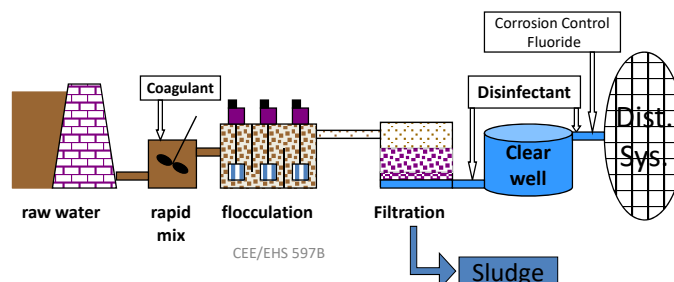
- uses very small air bubbles to cause “floc” to float, instead of relying on gravity to make them sink



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Direct Filtration

- No settling or flotation
 - goes “directly” from flocculation to filtration
 - works well for some low color, low turbidity waters



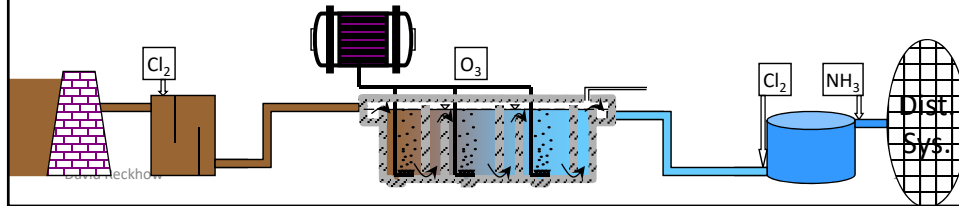
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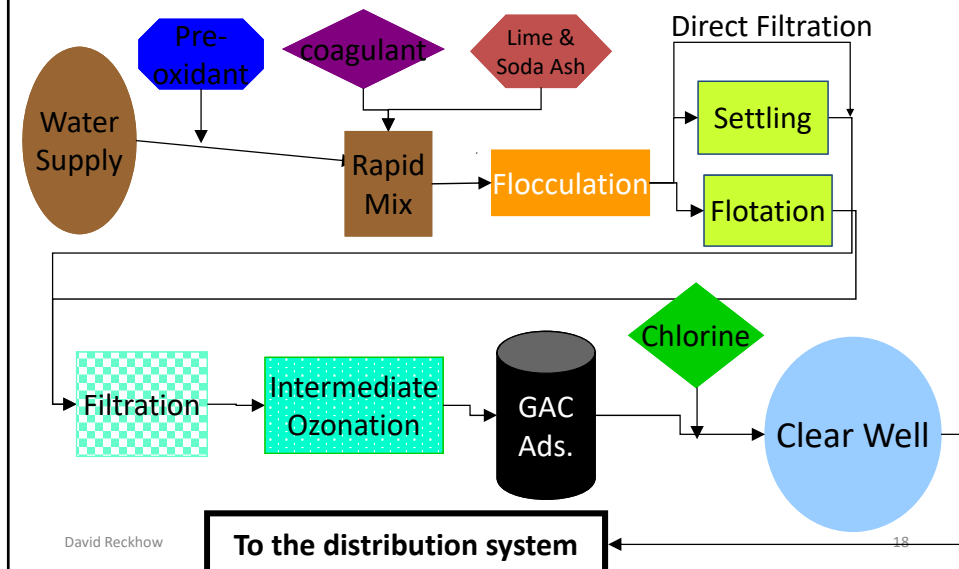
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Ozone Plant

- Many types
 - Simplest type: ozone, non-filtration shown below
 - examples: MWRA (Boston), Portland ME

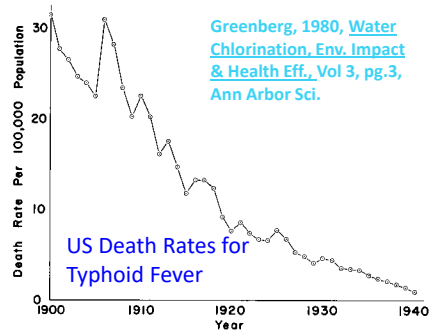


An advanced water treatment process



Disinfection

- 1-2 punch of filtration & chlorination






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Melosi, 2000, [The Sanitary City, John Hopkins Press](#) CEE/EH



Disinfection of PWS

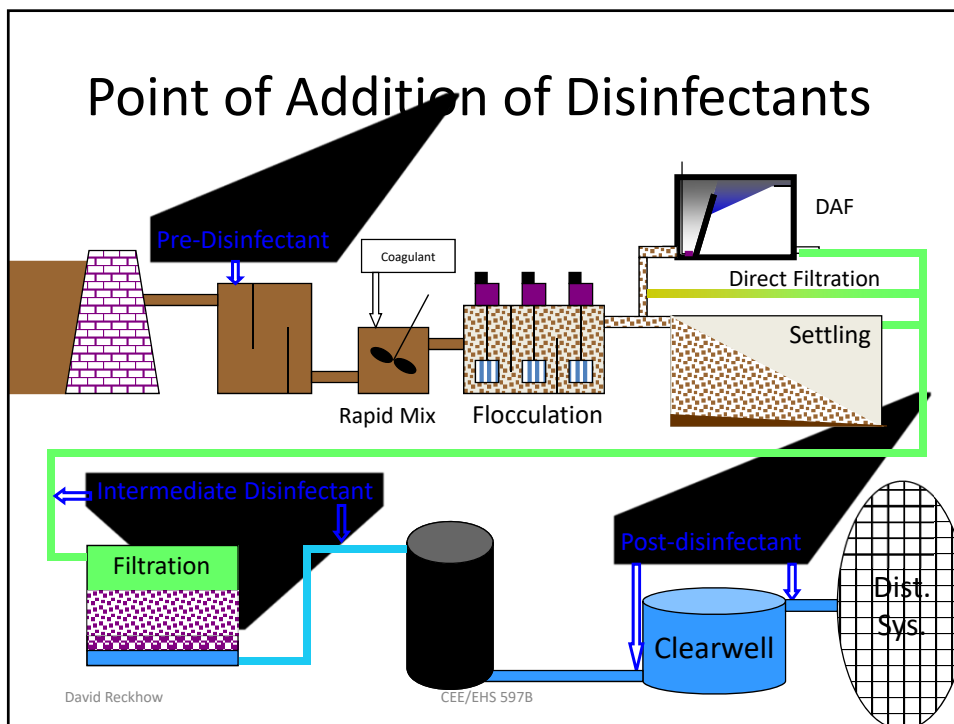
- One of the greatest achievements in public health during the 20th century
 - US Centers for Disease Control (CDC)
- One of the greatest engineering feats of the 20th century
 - National Academy of Engineering

Disinfection

- Kill or inactivate pathogens
 - Bacteria, viruses protozoa
 - Methods
 - Heat: boil water
 - Expose to UV light  Small scale, for emergencies
 - Add Chemical Oxidants  Slowly becoming more common
 - Chlorine (Cl_2 , HOCl or OCl⁻)
 - Chloramines (NH_2Cl or NHCl_2)
 - Ozone (O_3)
 - Chlorine Dioxide (ClO_2)
-  By far the most common
- Primary purpose for drinking water treatment

Application Points

- Primary Disinfection
 - removal or inactivation of pathogens by “treatment technique” or TT approach
 - CT concept
 - done in the treatment plant, sometimes as a first step
 - can be: free chlorine, ozone, chlorine dioxide or UV light
- Secondary Disinfection
 - Added as the last step just prior to entry into distribution system
 - intended to maintain a residual of disinfectant throughout the distribution system
 - Minimize growth on pipe walls, some protection against re-contamination, or maybe just a “sentinel”
 - usually free or combined chlorine, sometimes chlorine dioxide



Treatment vs Sources

<ul style="list-style-type: none"> • Surface water <ul style="list-style-type: none"> – Major water quality concerns <ul style="list-style-type: none"> • Pathogens • Turbidity • Color & TOC • Taste & odor – Typical treatment <ul style="list-style-type: none"> • “conventional” coagulation-filtration • Some use advanced treatment 	<p>↔</p> <p>Crossover is not uncommon</p> <p>↔</p>	<ul style="list-style-type: none"> • Groundwater <ul style="list-style-type: none"> – Major water quality concerns <ul style="list-style-type: none"> • Fe/Mn • Hardness • Arsenic, perchlorate • VOCs & pesticides – Typical treatment <ul style="list-style-type: none"> • Disinfection only • Softening • Aeration • Pressure filtration
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Forms of Chlorine applied to water

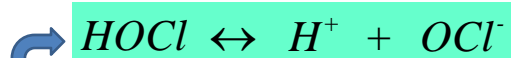
- Chlorine gas
 - Cl_2 Traditional method
- Sodium Hypochlorite liquid (Hypo)
 - NaOCl Becoming more common
- Calcium Hypochlorite solid
 - Ca(OCl)_2
- Other forms
 - Organic-N based compounds and resins

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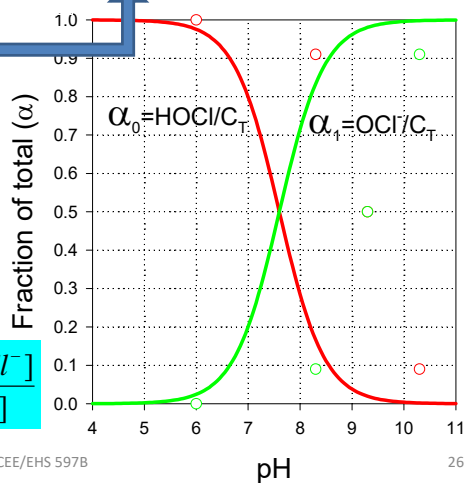
Chlorine Cont.



The hypochlorous acid ionizes to hypochlorite.

Although both hypochlorous acid and hypochlorite are disinfectants, hypochlorous acid is much more powerful. The equilibrium reaction is:

$$K_a = 3.16 \times 10^{-8} = 10^{-7.5} = \frac{[\text{H}^+][\text{OCl}^-]}{[\text{HOCl}]}$$



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Question

- At pH 8.5, the percent of the total free chlorine that is in the most effective form is:
 - 0%
 - 9%
 - 27%
 - 50%
 - 73%
 - 91%
 - 100%



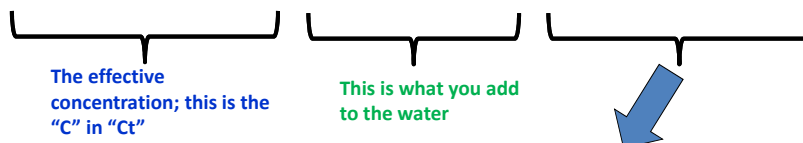
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Chlorine demand I

- Chlorine reacts quickly with substances in water so that the effective residual is always less than the dose
- Chlorine residual = chlorine dose – chlorine demand



- Chlorine demand is usually measured for a particular water and it may depend on the contact time and dose
 - It may be estimated from known water quality

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Chick-Watson Law

- The extent of inactivation is a function of the specific lethality (λ) of the disinfectant-organism couple, the disinfectant concentration (C), and the time of contact (t) with the disinfectant.

$$\ln\left(\frac{N}{N_0}\right) = -\lambda Ct$$

and $k = \lambda C$

$$\{Ct\}_{x \log} = 2.3x/\lambda$$

Chick-Watson II

- Use of Ct values for various “log removals” is general practice
 - Here is how Ct corresponds to specific lethality of Chick’s Law (for $n=1$)

% Removal	Log Removal	N, if $N_0 = 10,000/L$	Ct
90	1	1000	$2.3/\lambda$
99	2	100	$4.6/\lambda$
99.9	3	10	$6.9/\lambda$
99.99	4	1	$9.2/\lambda$

- Model is not always accurate, but it is usually a good first approximation

Specific Lethality (λ) at 20°C

- General hierarchy
 - Disinfectants: $O_3 > ClO_2 > HOCl > OCl^- > NHCl_2 > NH_2Cl$
 - Organisms: bacteria > viruses > protozoa

Units:
L/mg-min

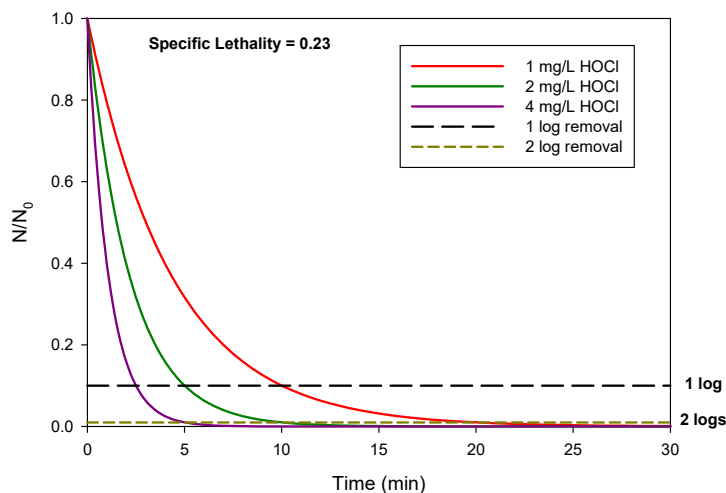
Some may change with
pH, dose; all are
affected by temperature

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Disinfectant	E. coli	Poliovirus I	Entamoeba histolytica Cysts
O_3	2300	920	3.1
HOCl	120	4.6	0.23
ClO_2	16	2.4	
OCl^-	5.0	0.44	
$NHCl_2$	0.84	0.00092	
NH_2Cl	0.12	0.014	

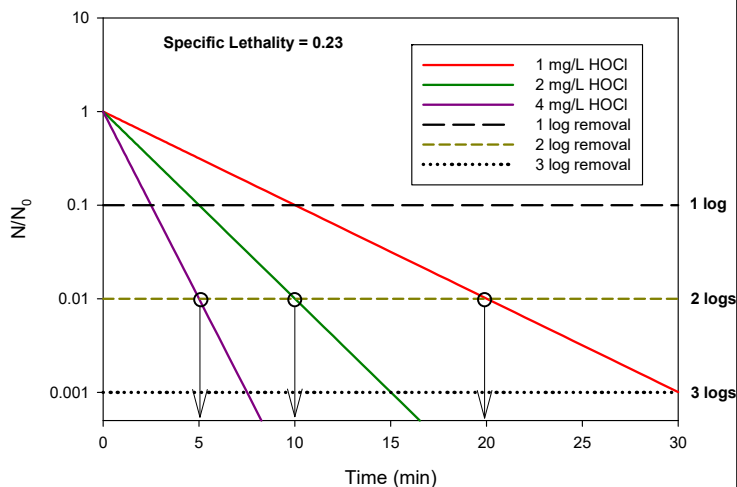
Chick-Watson Law: HOCl & Giardia

- Direct plot



Chick-Watson Law: HOCl & Giardia

- Log plot



Ct values for *Giardia lamblia* cysts

H&H, Table 7-4, pg.245

	PH	LOG INACTIVATION	WATER TEMPERATURE				
			0.5°C [(mg/l) · min]	5°C [(mg/l) · min]	10°C [(mg/l) · min]	15°C [(mg/l) · min]	20°C [(mg/l) · min]
Free chlorine ^a	6	0.5	25	18	13	9	7
	6	1.0	49	35	26	18	13
	7	0.5	35	25	19	13	9
	7	1.0	70	50	37	25	18
	8	0.5	51	36	27	18	14
8	1.0	101	72	54	36	27	
Preformed chloramine	6-9	0.5	640	370	310	250	190
	6-9	1.0	1300	740	620	500	370
Chloride dioxide	6-9	0.5	10	4.3	4.0	3.2	2.5
	6-9	1.0	21	8.7	7.7	6.3	5.0
Ozone	6-9	0.5	0.48	0.32	0.23	0.16	0.12
	6-9	1.0	0.97	0.63	0.48	0.32	0.24

^aFree chlorine values are based on a residual of 1.0 mg/l.

Source: Adapted from Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources. U.S. Environment Protection Agency.

Ct values for Viruses

- For Viruses at various temperatures
 - pH 6-9

H&H Table 7-5, pg 245

	LOG INACTIVATION	WATER TEMPERATURE				
		0.5°C [(mg/l) · min]	5°C [(mg/l) · min]	10°C [(mg/l) · min]	15°C [(mg/l) · min]	20°C [(mg/l) · min]
Free chlorine	2.0	6	4	3	2	1
	3.0	9	6	4	3	2
	4.0	12	8	6	4	3
Preformed chloramine	2.0	1200	860	640	430	320
	3.0	2100	1400	1100	710	530
Chlorine dioxide	2.0	8.4	5.6	4.2	2.8	2.1
	3.0	25.6	17.1	12.8	8.6	6.4
Ozone	2.0	0.9	0.6	0.5	0.3	0.2
	3.0	1.4	0.9	0.8	0.5	0.4

Source: Adapted from *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*. U.S. Environmental Protection Agency.

Cl₂ gas: larger installations

- 1 ton cylinders
 - With small (150 lb) vertical tanks in background
- Requires separate sealed room or bldg.



Commercial Chlorinator

- feed

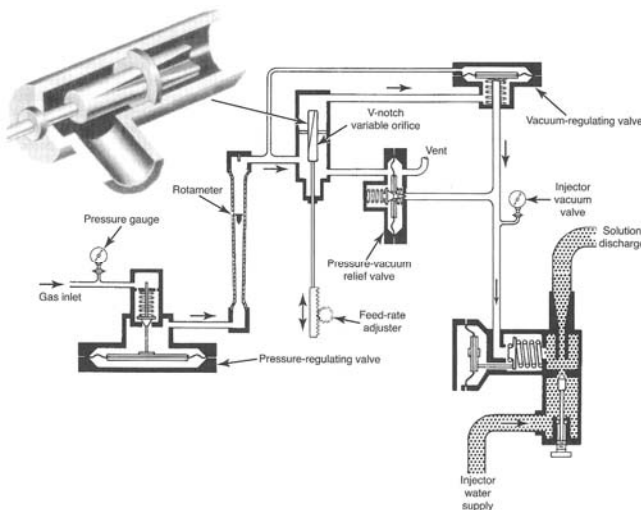


Fig 7-18; pg. 236 in H&H

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Large chlorinator

- Vacuum created at aspirator injector

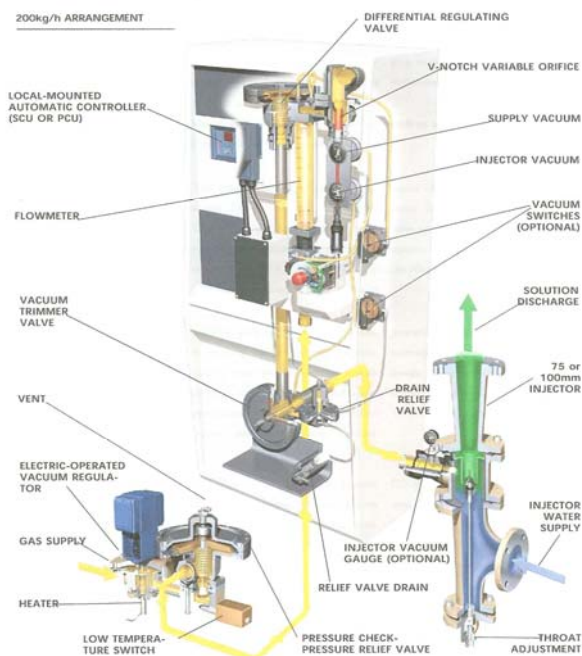
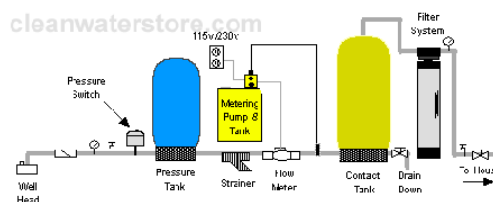


Figure courtesy of Wallace & Tiernan Co.

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Dose control

- Flow pacing
 - Small home system



- Full-scale municipal system

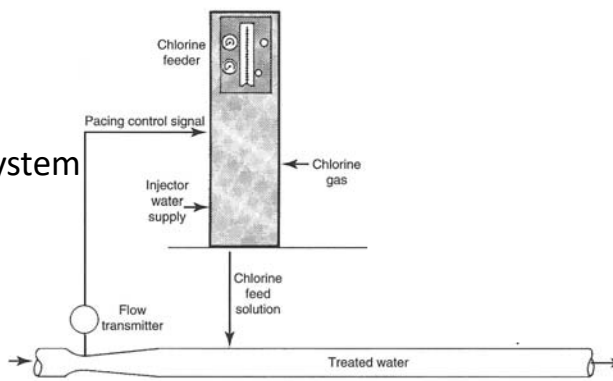


Fig 7-19; pg. 237 in H&H

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Dose control

- Feed back system
 - Adjusts for varying chlorine demand

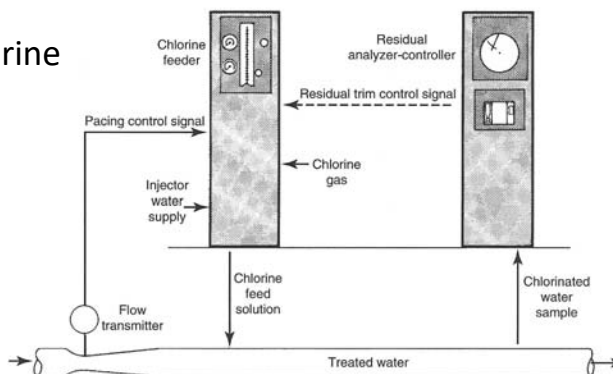
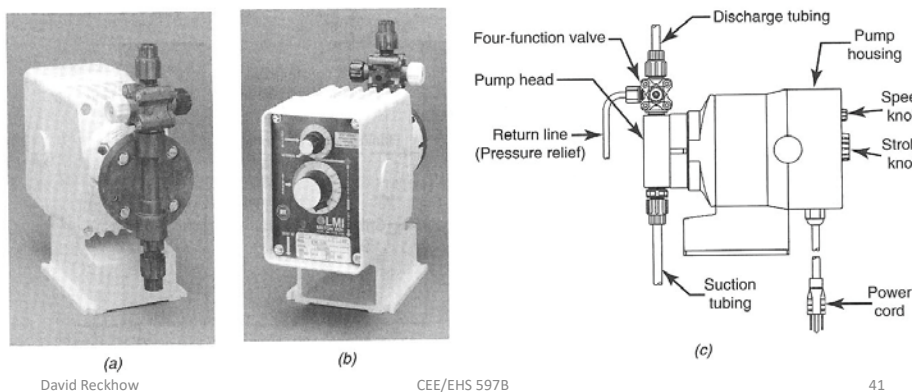


Fig 7-19; pg. 237 in H&H

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Hypochlorite Dosing

- Positive displacement pump
- Need chlorine resistant materials



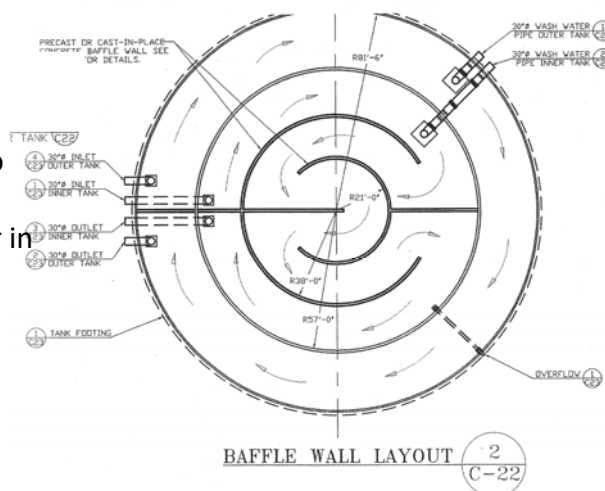


- Chlorine feeding system



Northampton's Ground Storage

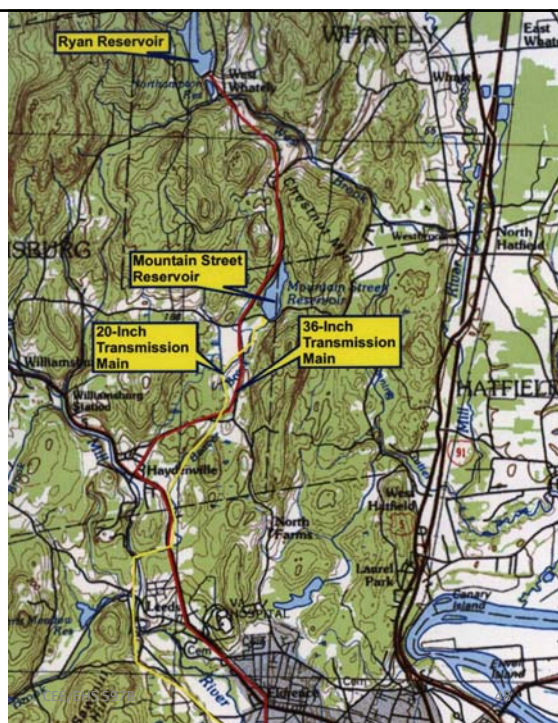
- 4.0 MG
- Two Concentric cells
 - Can be isolated to service one while keeping the other in service
- NaOCl added just prior to entry



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Raw Water

- Reservoirs &
- Transmission Mains



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Clearwell



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Clearwell



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Clearwell

- From the plant site



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Clearwell

- Dropping a panel into position



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Clearwell



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Northampton Ground Storage

- Finished water storage at plant
- Know as a “Clearwell”
 - View from Outer ring
 - Under construction



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Clearwell

- Exit



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Clearwell

- In c



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Clearwell or Ground Storage

- Multi-purpose
 - Chlorine contact tank for achieving “Ct”
 - Giardia controls
 - 3 log Giardia is more restrictive than 4 log virus when using chlorine
 - 2.5 log credit given for Giardia (clarification + filtration), leaving 0.5 log for Ct
 - Northampton has decided to see 1.0 log for Ct
 - Buffering system flows
 - Fire Flow
 - Backwash Storage

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End of Class #2

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