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CEE/EHS 597B

Meeting #2: Treatment for Small Water Systems

Dave Reckhow

Purposes for Water Treatment

- Disinfection #1 concern
- Removal of Turbidity
- Removal of Color, and Tastes & Odors
- Removal of Iron & Manganese
- Hardness removal
- Protection from Toxic Organics and Inorganics

Drinking Water Treatment Processes

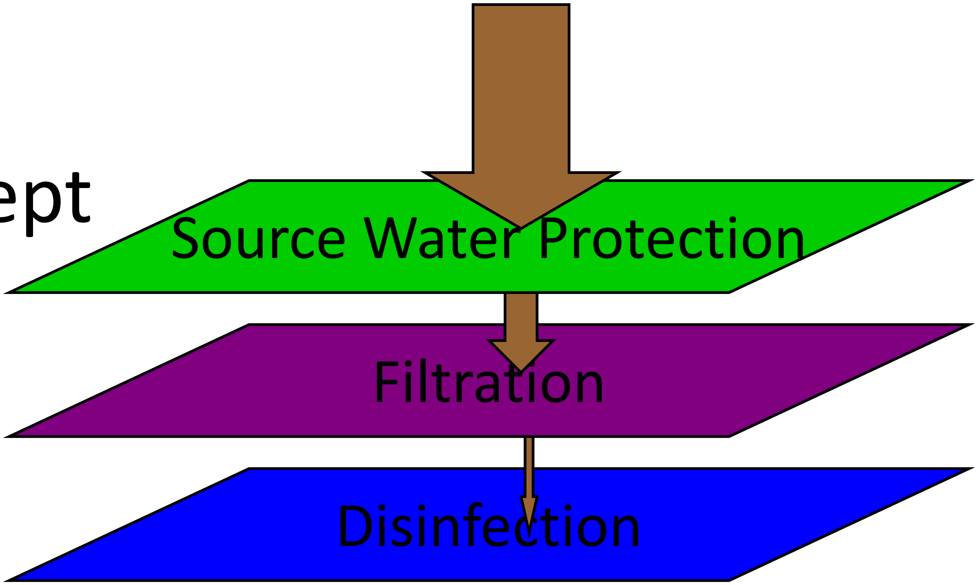
- Gas Transfer (stripping)
- Oxidation
- Coagulation & Flocculation
- Sedimentation or Flotation
- Softening
- Adsorption
- Disinfection

Source Waters

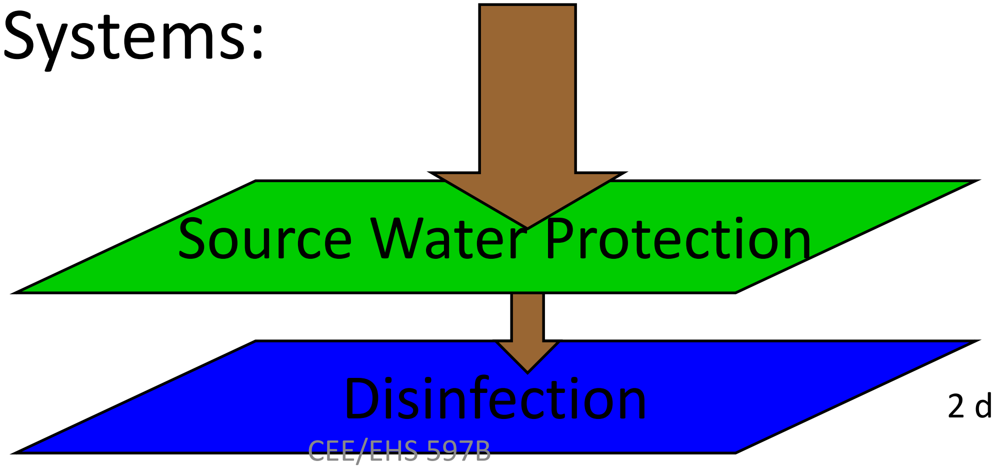
- Groundwaters
  - constant quality
- Rivers
  - variable quality
    - storm events, runoff
      - increases in turbidity, pathogens, coliforms
    - Wastewater inputs
    - Agricultural runoff
    - Accidental spills
- Reservoirs & lakes
  - less variation than rivers
    - seasonal blooms of alae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

SWTR

- Multiple Barrier Concept
  - Filtered Systems:



  - Unfiltered Systems:



Including wellhead protection

2 different ones

Log Removal

- **<u>Meaning of "Log Removal or Inactivation</u>"**
  - **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 x (N_0 – N)/N_0 = percent removal (or inactivation)**
  - **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

SWTR (cont.)

- Requirements for Filtered Supplies

Type of Filtration	Log_{10} Removal Allowed By Filtration		Remaining Log_{10} Inactivation by Disinfection	
	Giardia	Viruses	*Giardia*	Viruses
Conven-tional	2.5	2.0	0.5	2.0
Direct	2.0	1.0	1.0	3.0

The TT approach, rather than MCL

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

Requires a certain CT

Treatment vs Sources

- Surface water
  - Major water quality concerns
    - Pathogens
    - Turbidity
    - Color & TOC
    - Taste & odor
  - Typical treatment
    - “conventional” coagulation-filtration
    - Some use advanced treatment

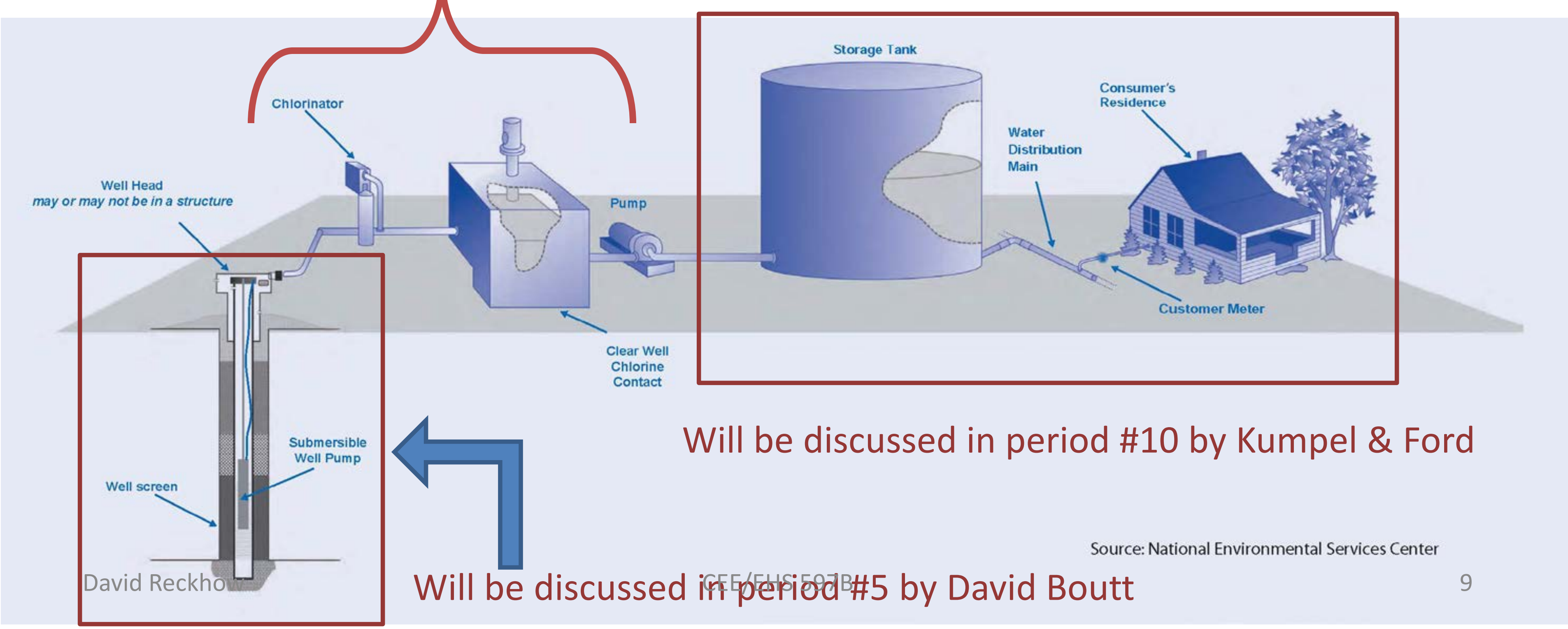
Crossover is not uncommon

- Groundwater
  - Major water quality concerns
    - Fe/Mn
    - Hardness
    - Arsenic, perchlorate
    - VOCs & pesticides
  - Typical treatment
    - Disinfection only
    - Softening
    - Aeration
    - Pressure filtration

Simple Groundwater systems

- "Groundwater Treatment Process"
  – From RCAP reading, pg 10-11

The focus of this period

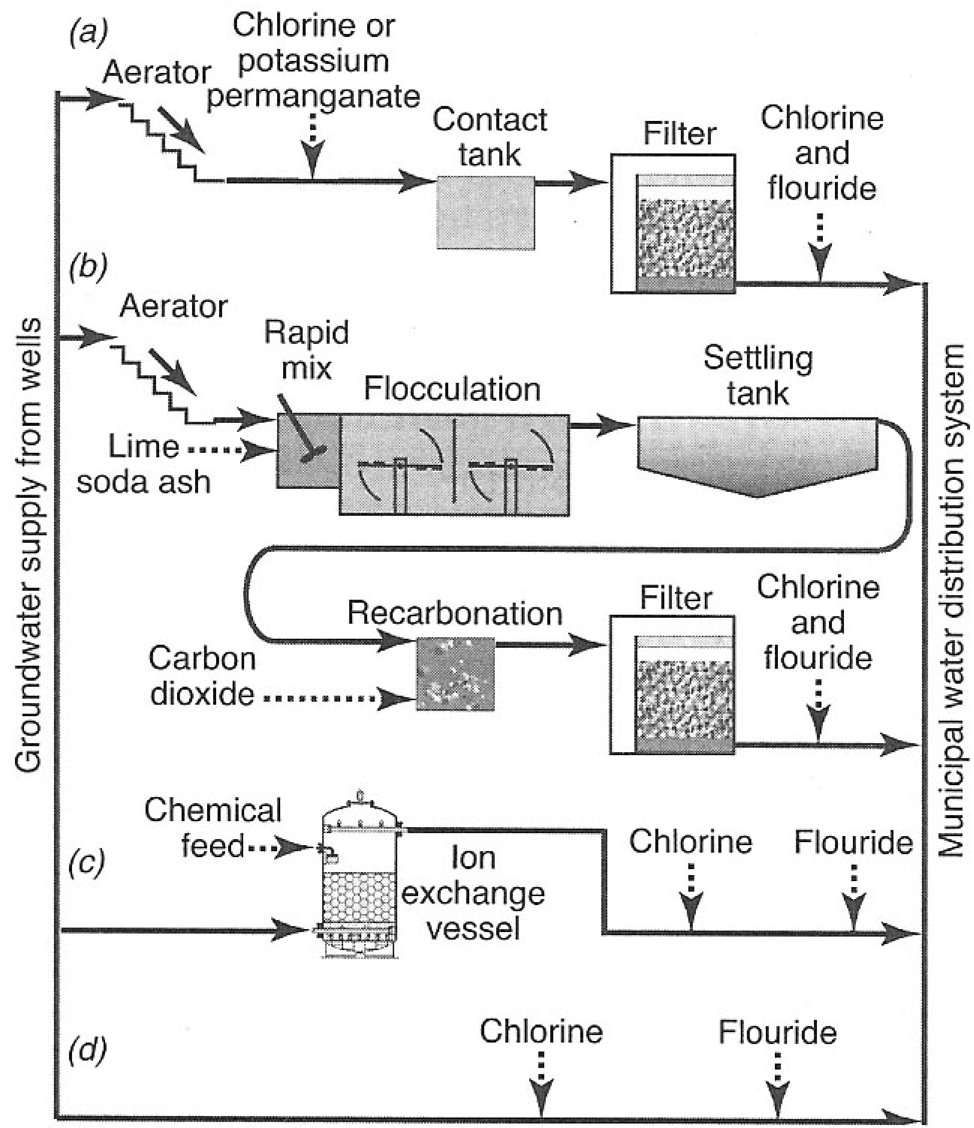


Will be discussed in period #10 by Kumpel & Ford

Will be discussed in period #5 by David Boutt

Groundwater Treatment

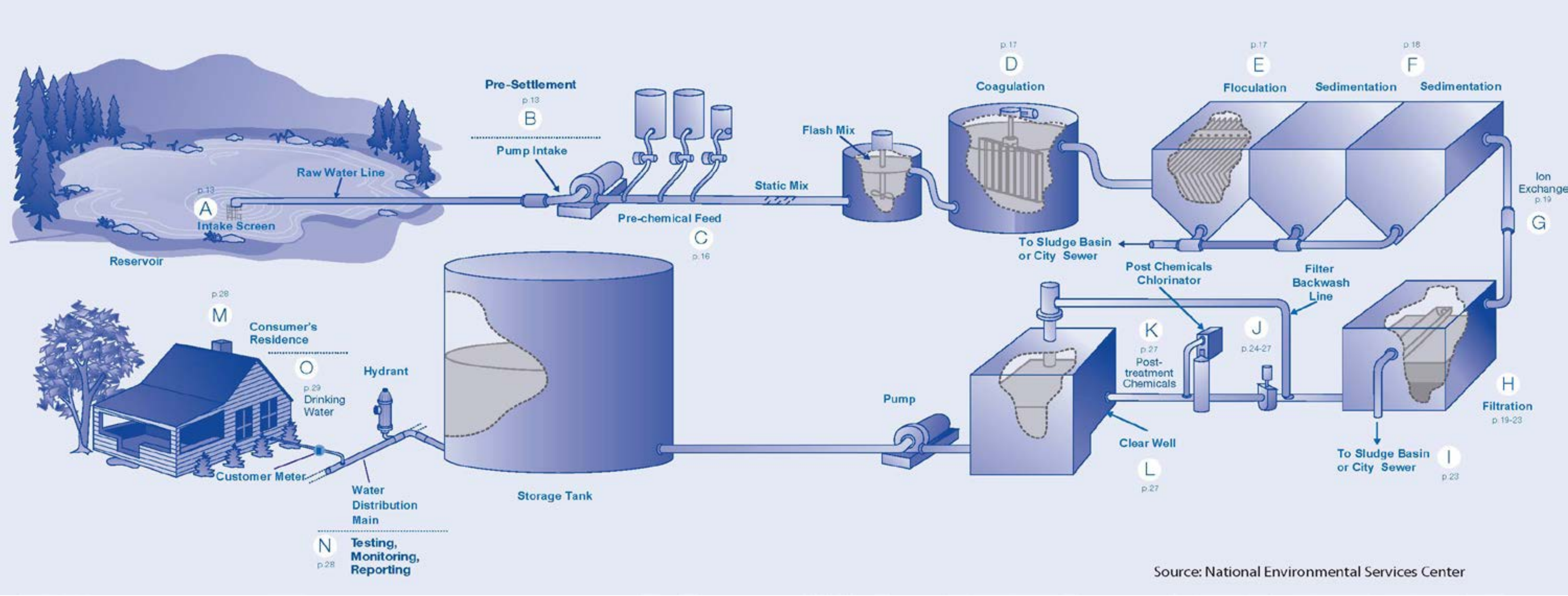
- More realistically, there are many options or needs:
  a. Fe/Mn removal
  b. Precip. Softening
  c. Ion exchange
  d. Simple disinfection



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

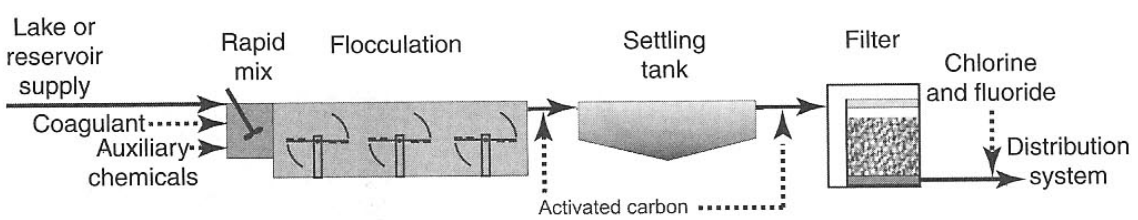
Surface Water

- Again from RCAP, pg/ 14-15

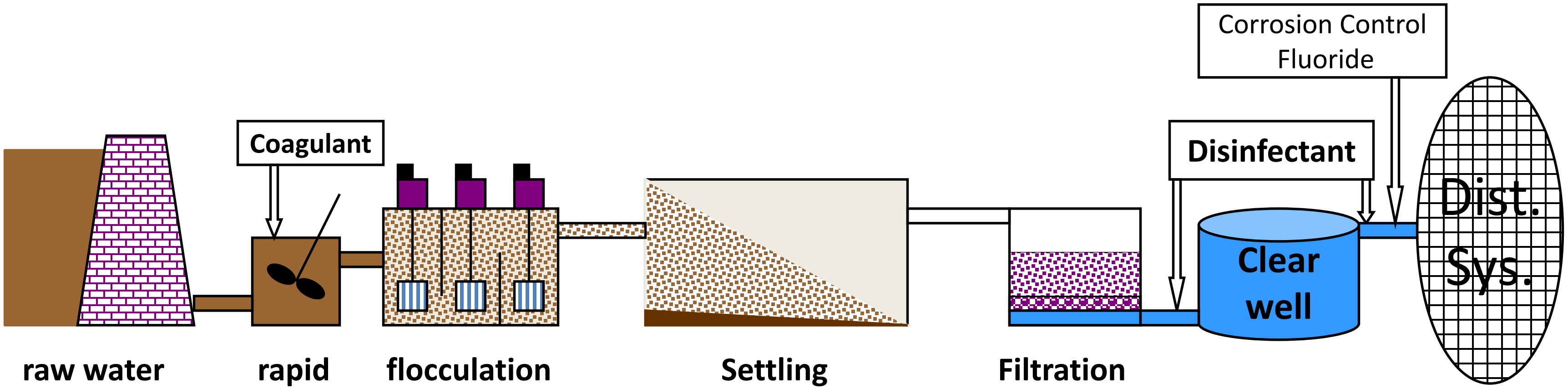


Conventional Treatment

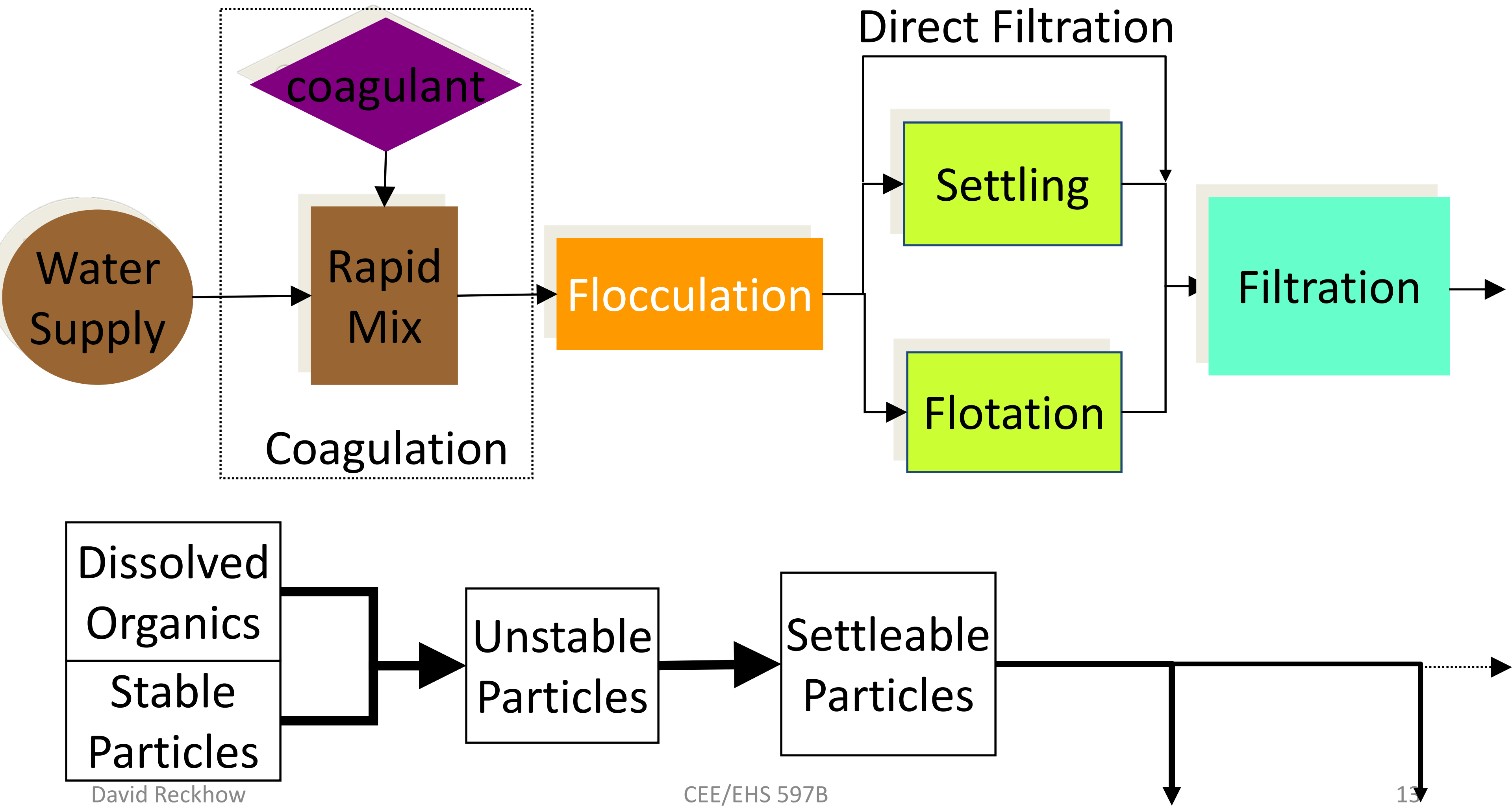
- Coagulation & solids separation
  - rapid mix, flocculation, settling, filtration
- Disinfection
  - including clearwell for contact time
- Most common for surface water



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

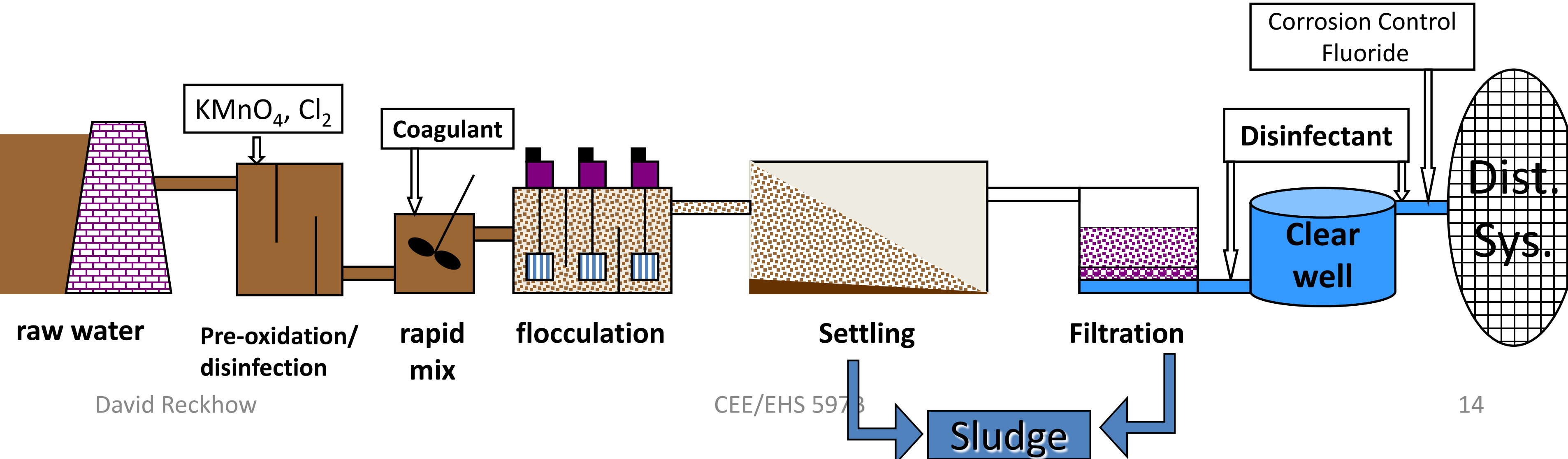


Overview of "conventional" treatment



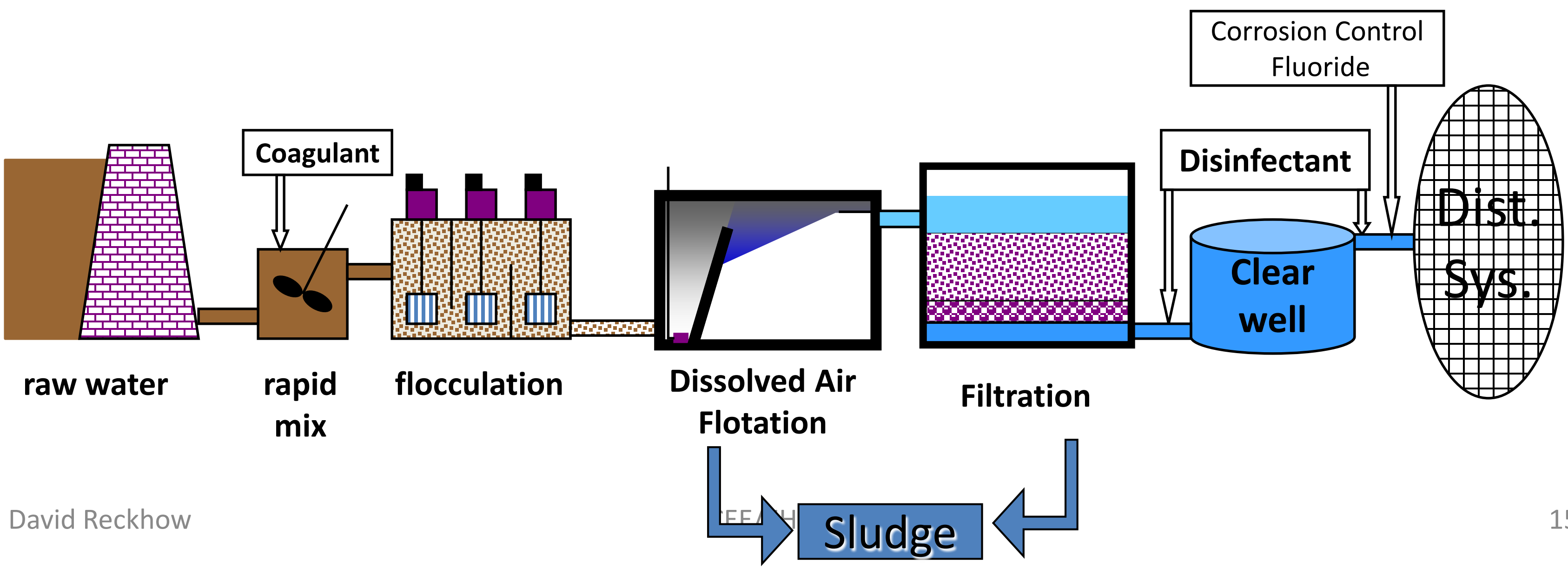
Conventional "plus"

- common to include preoxidation or pre-disinfection with conventional treatment
  - helps with removal of metals & organics by coagulation
  - achieves more complete disinfection



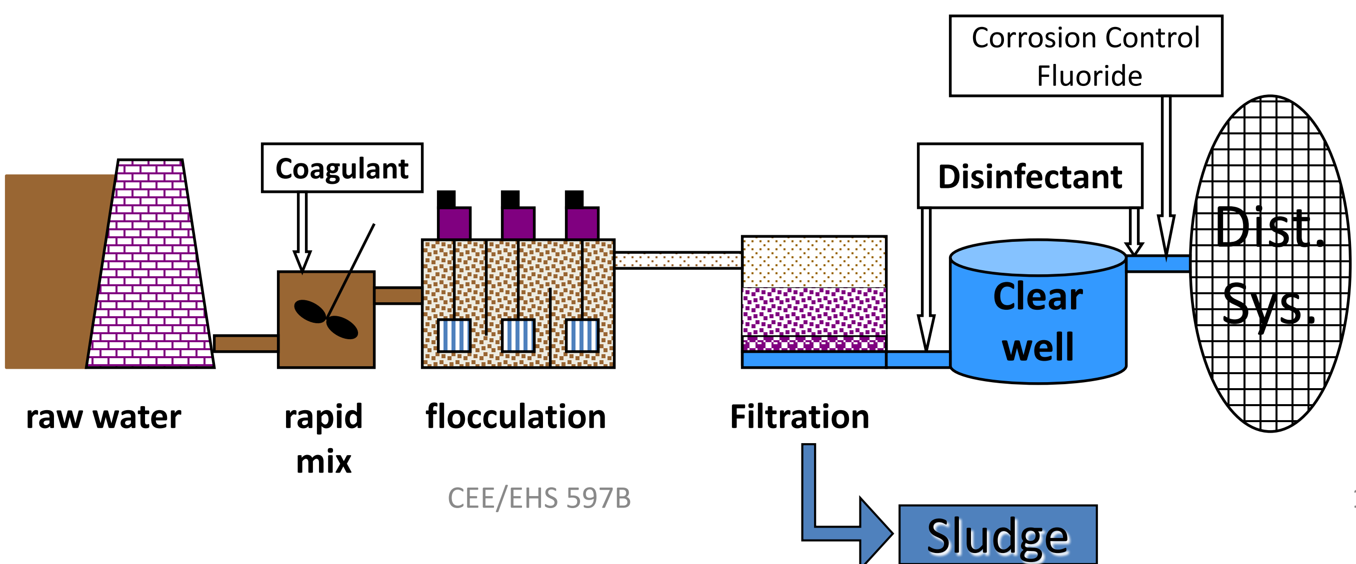
Dissolved Air Flotation (DAF)

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



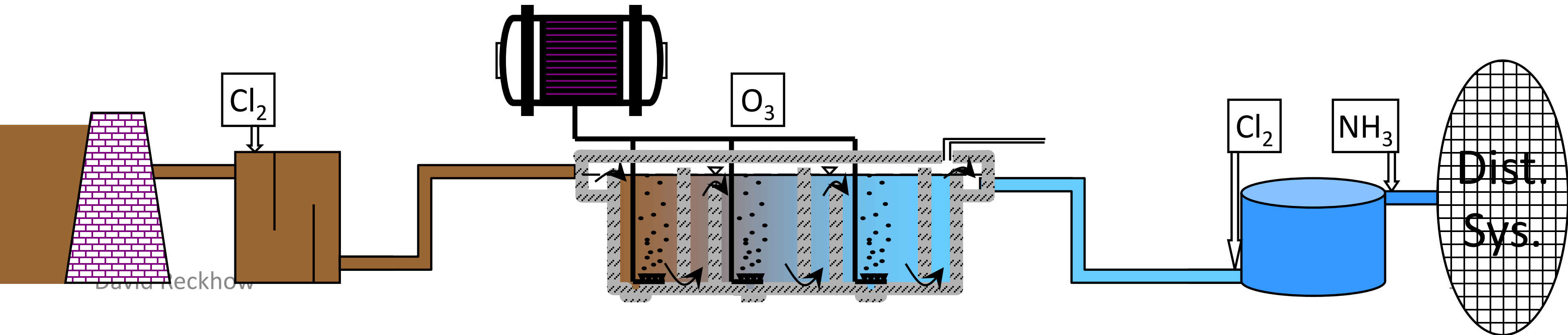
Direct Filtration

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

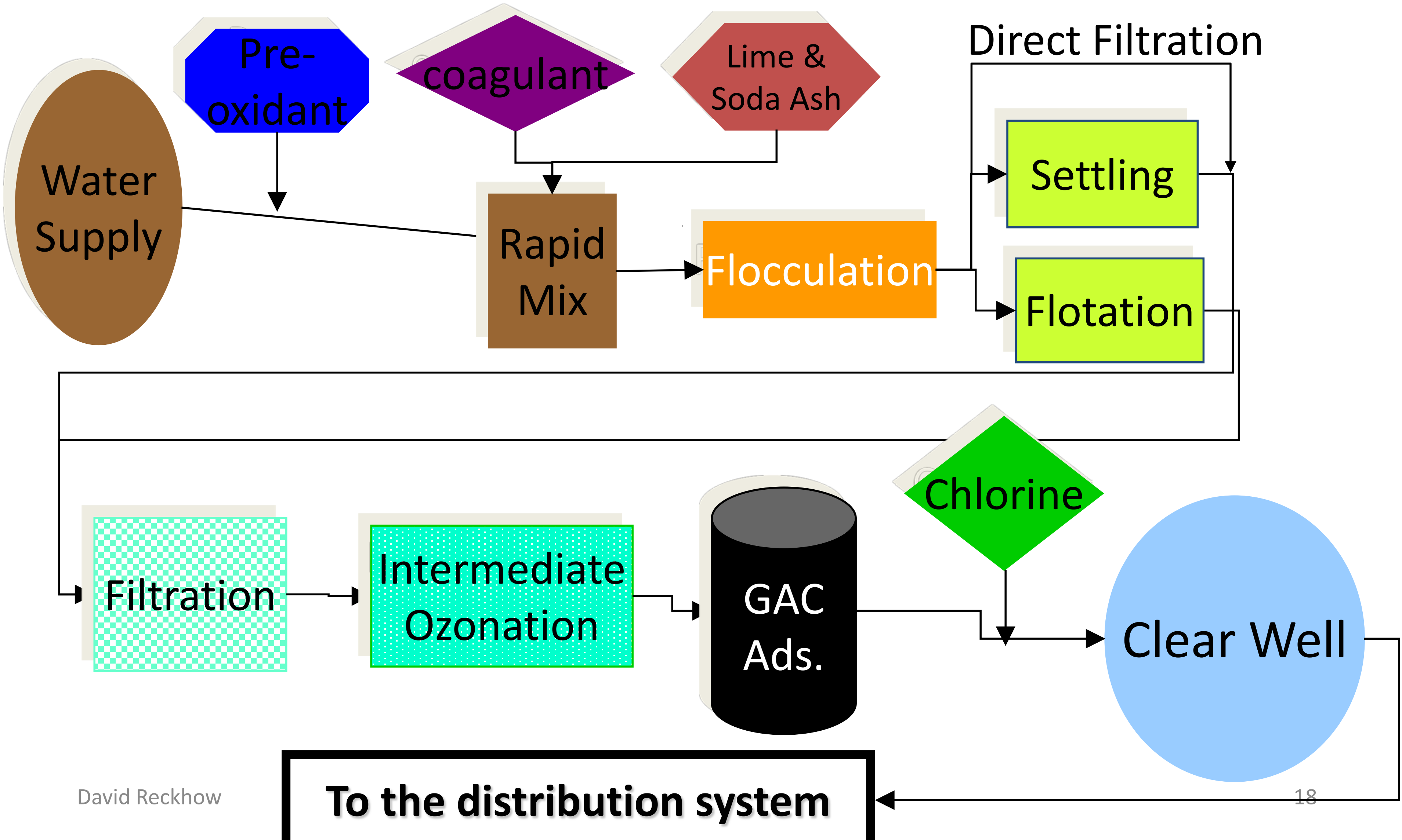


Ozone Plant

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

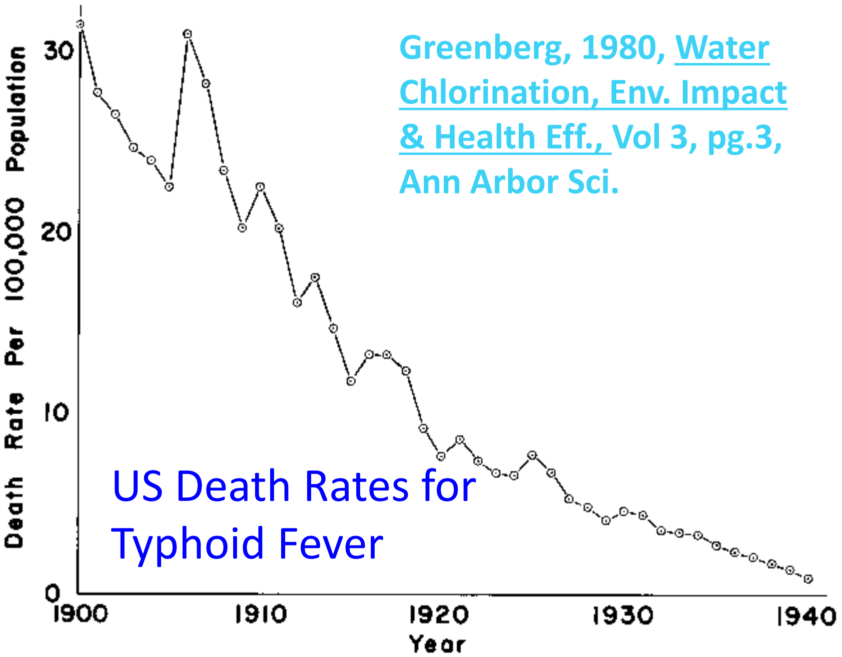


An advanced water treatment process



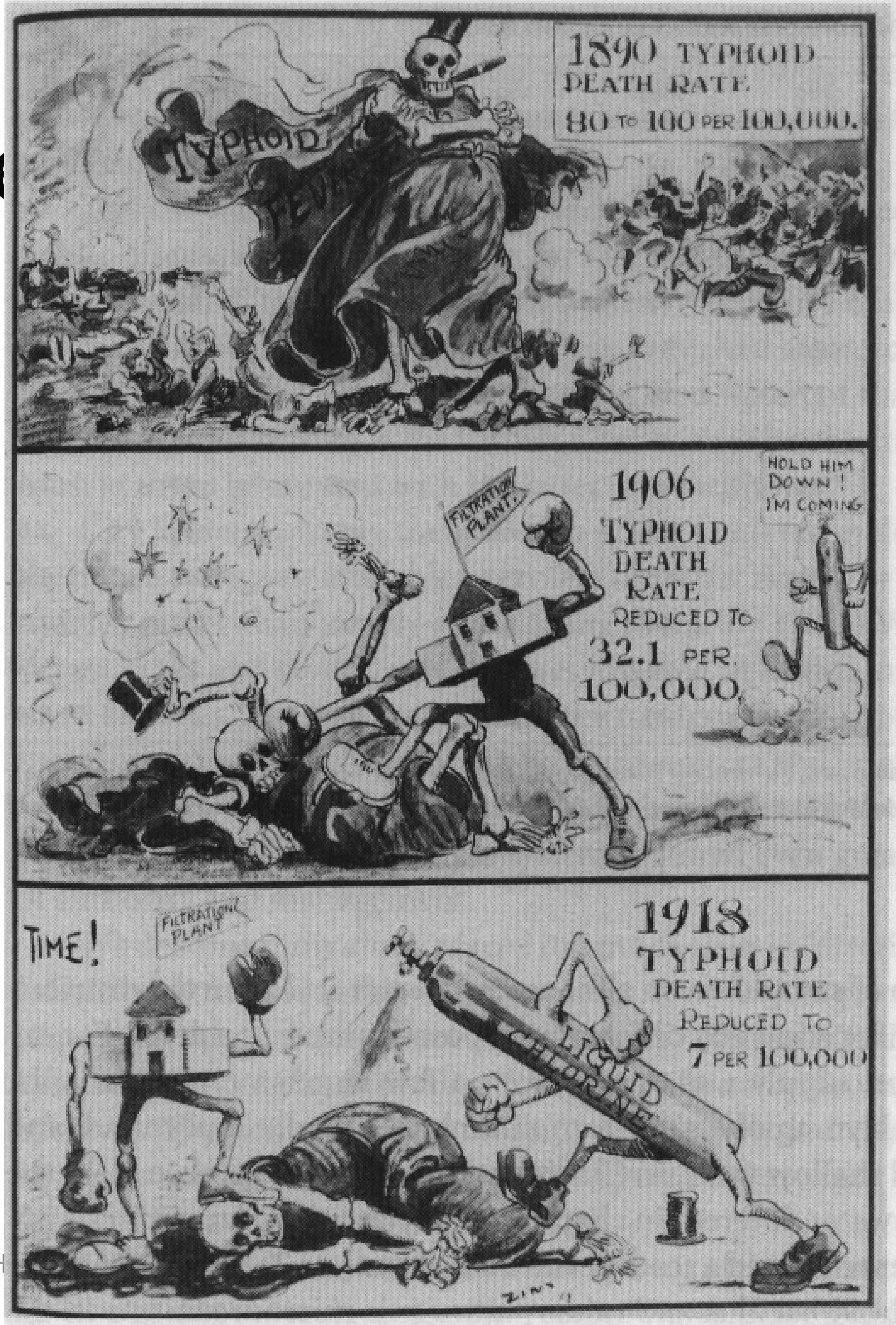
Disinf

- 1-2 punch of filtration & chlorination



Greenberg, 1980, Water Chlorination, Env. Impact & Health Eff., Vol 3, pg.3, Ann Arbor Sci.

US Death Rates for Typhoid Fever



Melosi, 2000, The Sanitary City, John Hopkins Press

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

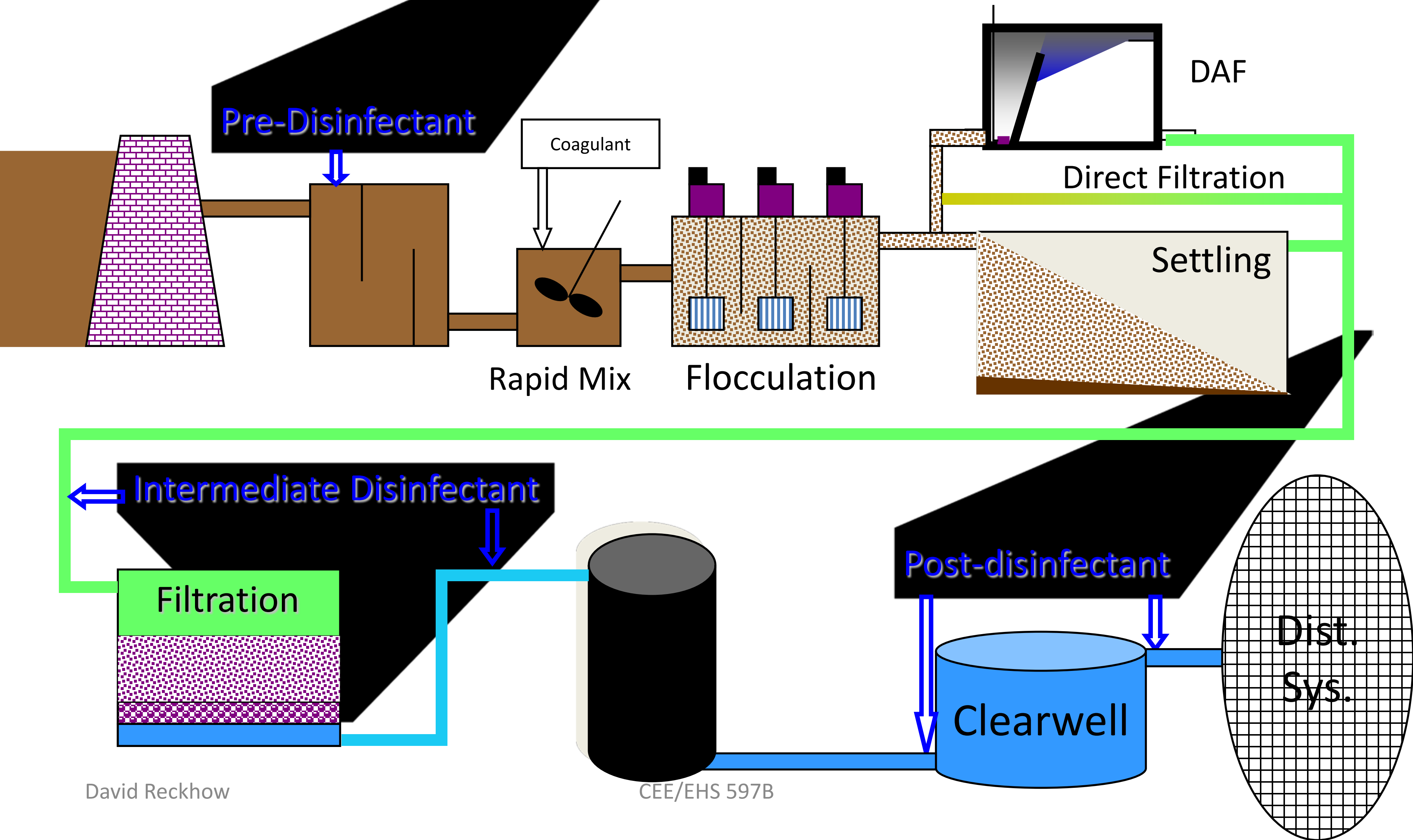
- Kill or inactivate pathogens
  - Bacteria, viruses protozoa
- Methods
  - Heat: boil water
  - Expose to UV light → **Small scale, for emergencies**
  - Add Chemical Oxidants → **Slowly becoming more common**
    - Chlorine (Cl_2, HOCl or OCl^-)
    - Chloramines (NH_2Cl or $NHCl_2$)
    - Ozone (O_3)
    - 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

Point of Addition of Disinfectants



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    - Softening
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    - Pressure filtration

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

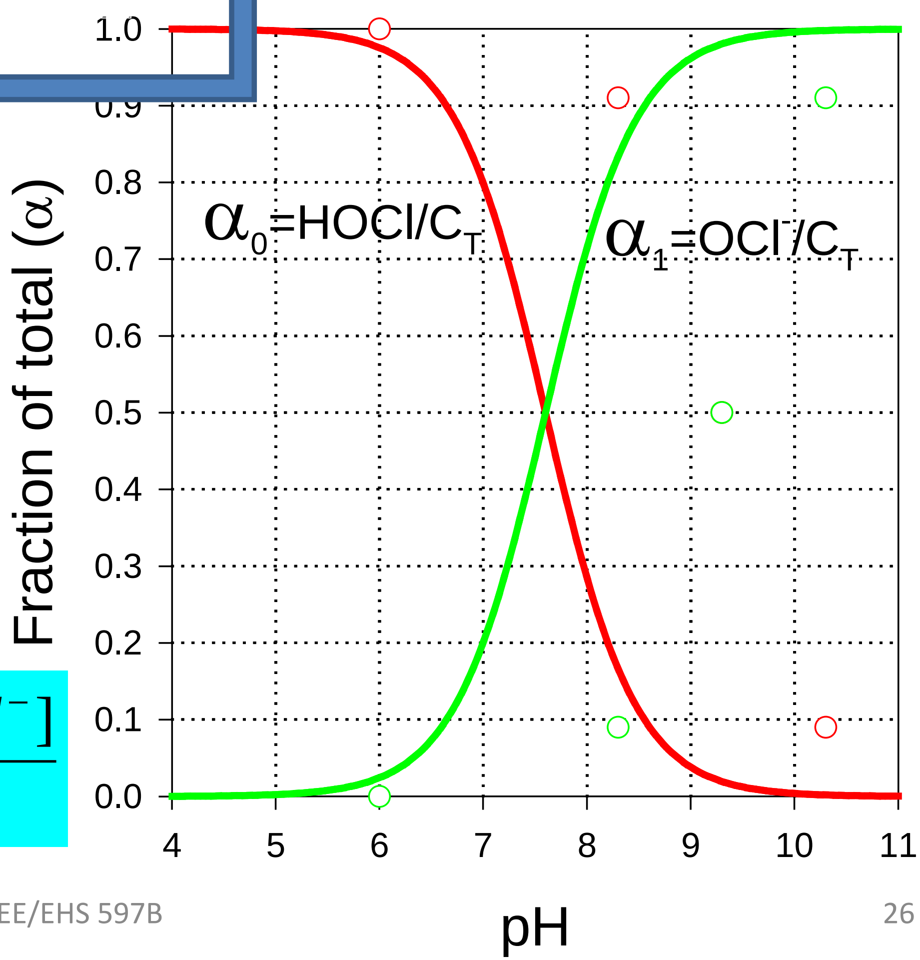
Chlorine Cont.

$$HOCl \leftrightarrow H^+ + OCl^-$$

The hypochlorous acid ionizes to hypochlorite.

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

$$K_a = 3.16x10^{-8} = 10^{-7.5} = \frac{[H^+][OCl^-]}{[HOCl]}$$



Question

- At pH 8.5, the percent of the total free chlorine that is in the most effective form is:
  A. 0%
  B. 9%
  C. 27%
  D. 50%
  E. 73%
  F. 91%
  G. 100%

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

The effective concentration; this is the "C" in "Ct"

This is what you add to the water

  - 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

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.

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

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

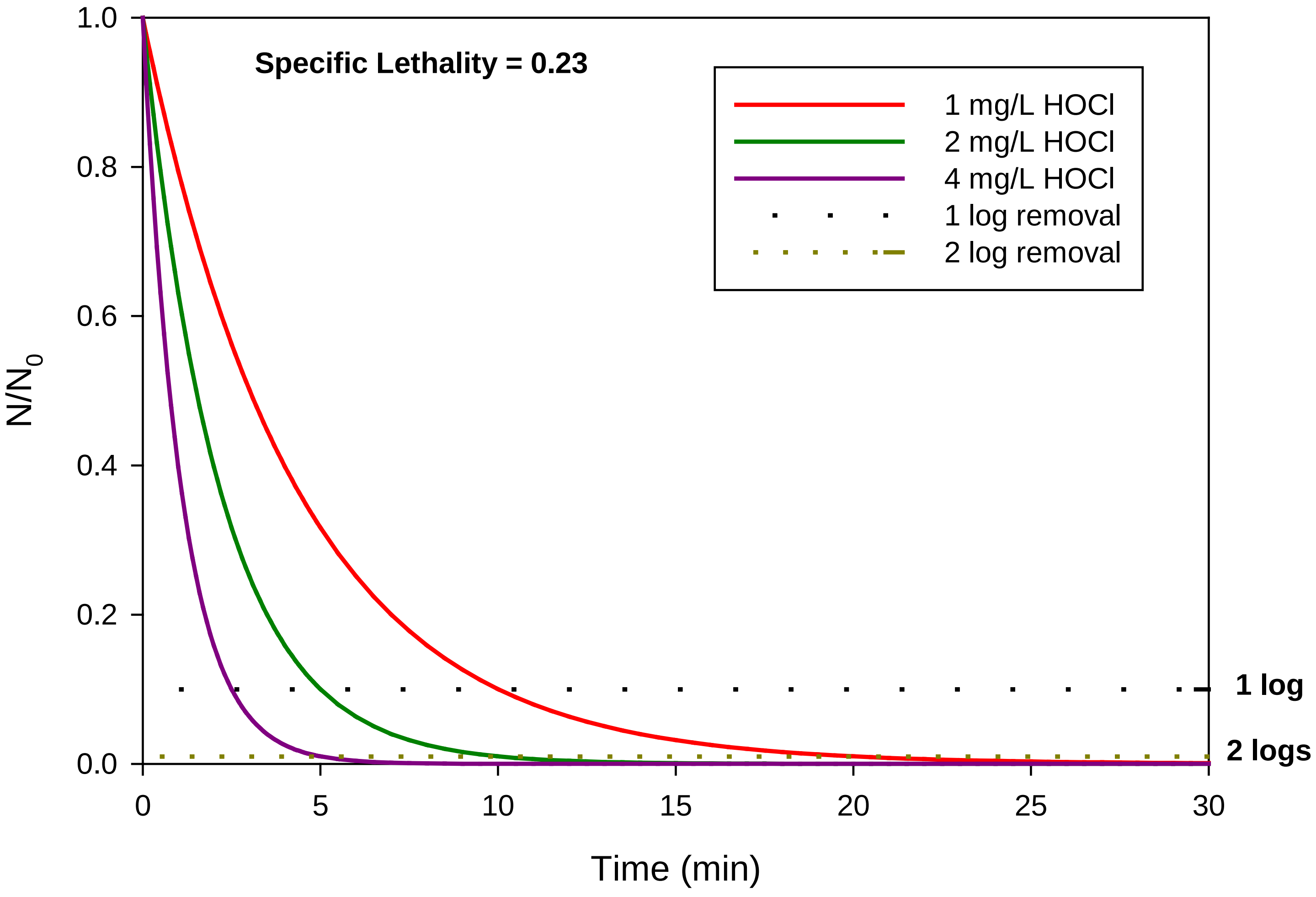
Units: L/mg-min

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	

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

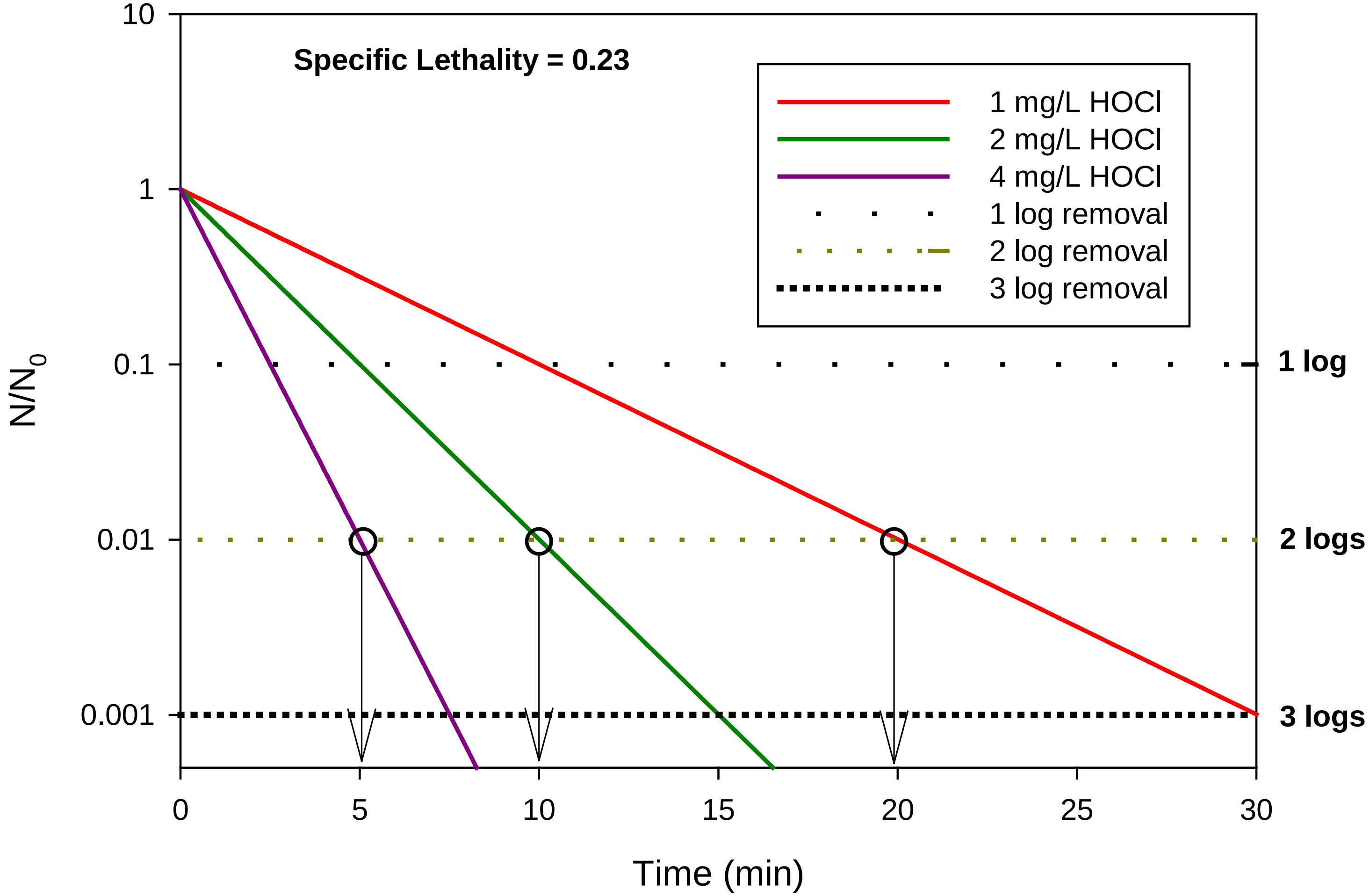
Chick-Watson Law: HOCl & Giardia

- 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

[a]Free 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. Environmental Protection Agency.

Ct values for Viruses

- For Viruses at various temperatures
  - pH 6-9

H&H Table 7-5, pg 245

		Water Temperature				
	Log Inactivation	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.

Cl_2 gas: larger installations

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

Commercial Chlorinator

- feed

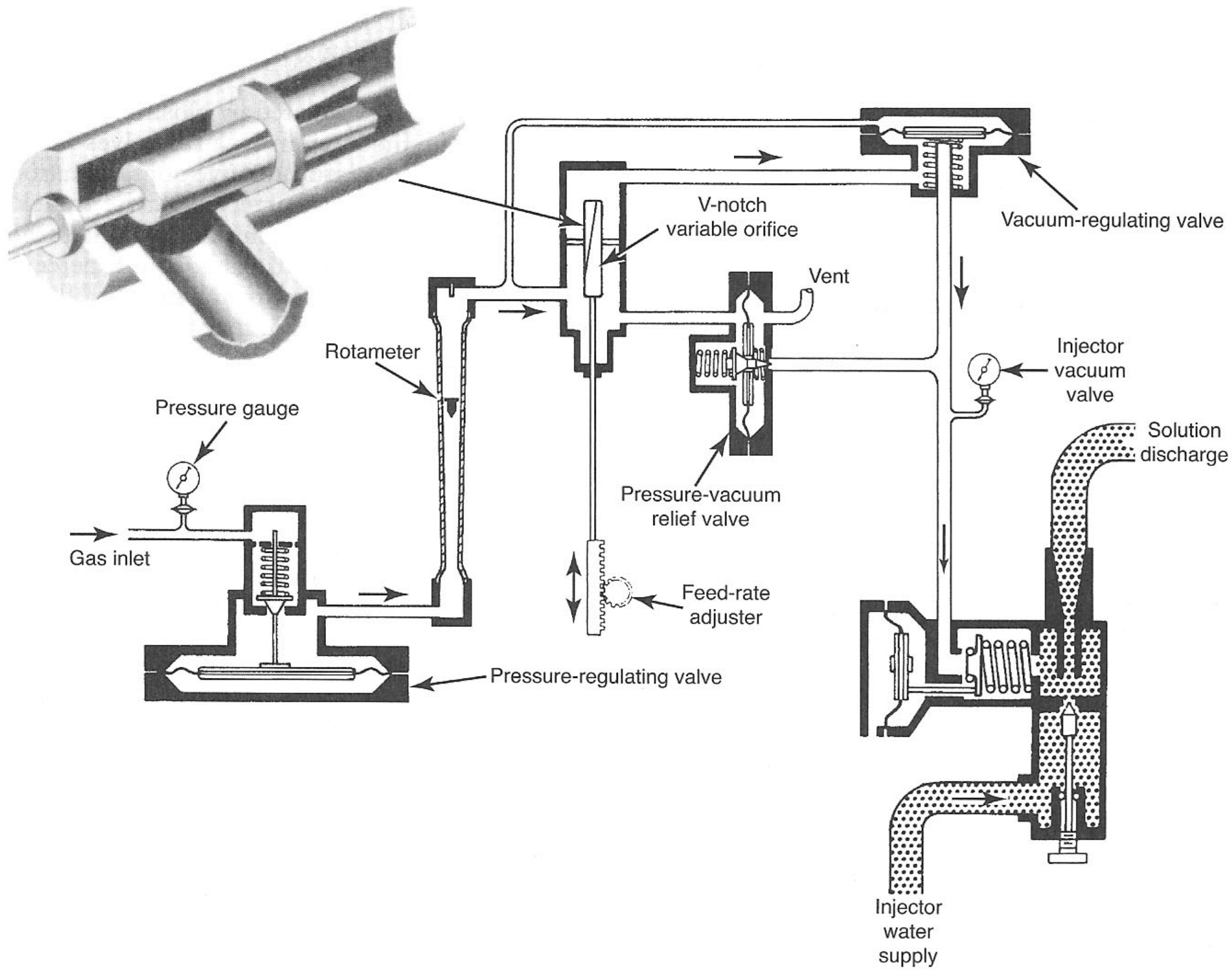


Fig 7-18; pg. 236 in H&H

Large chlorinator

- Vacuum created at aspirator injector

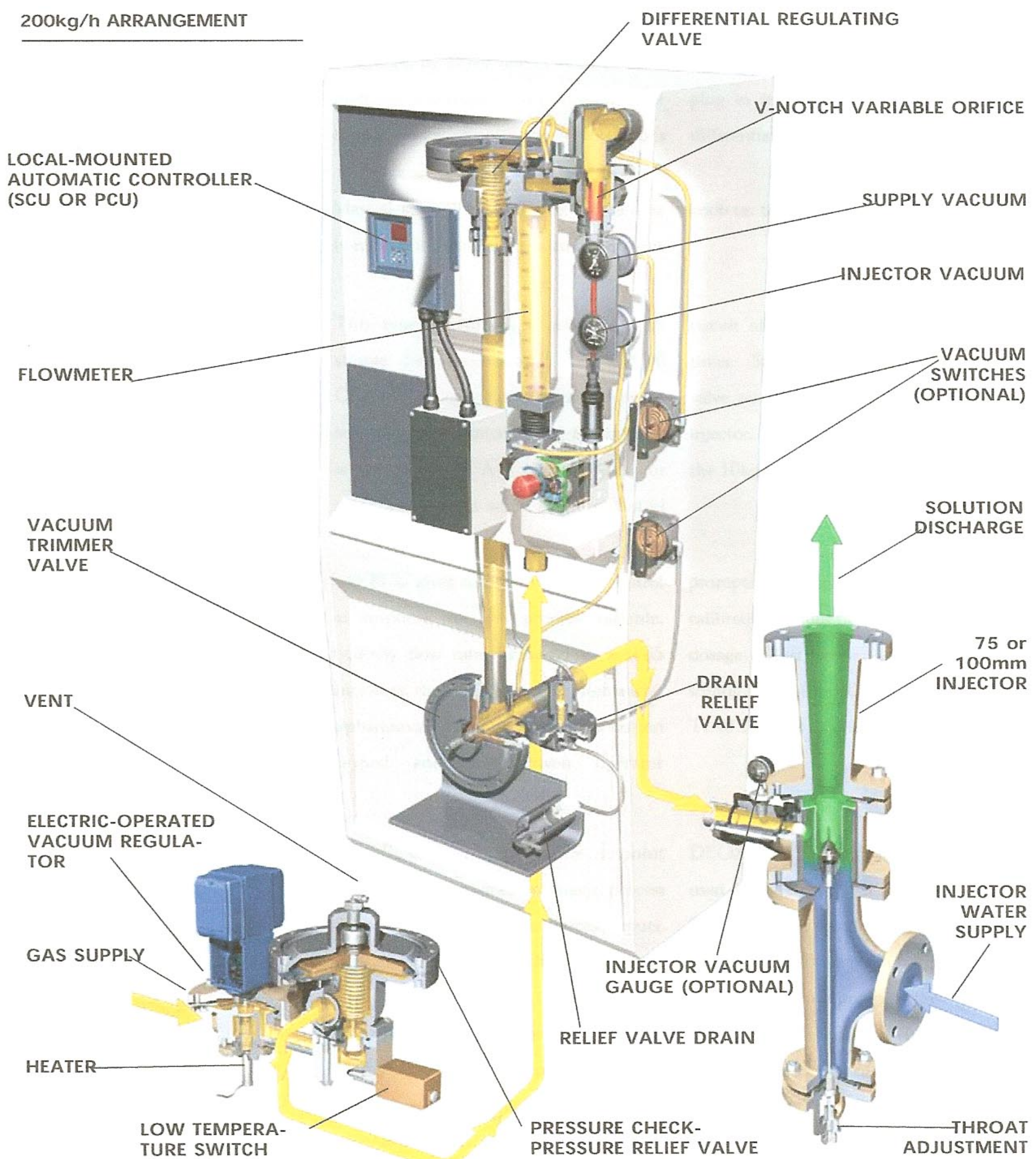
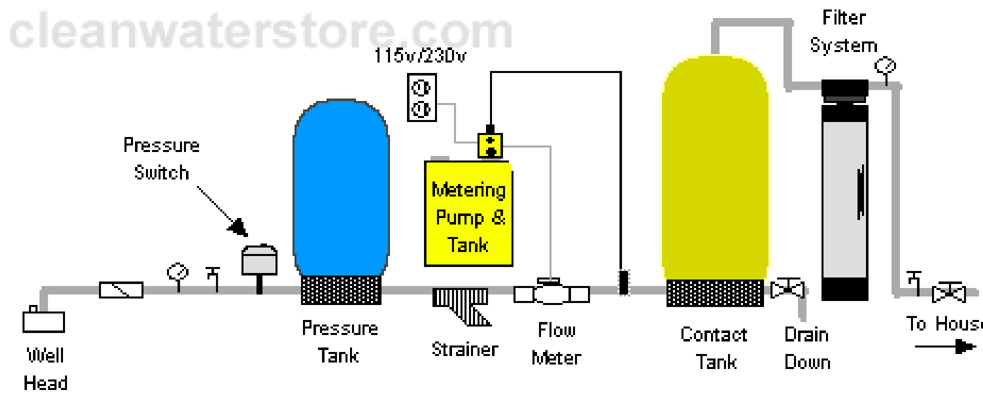


Figure courtesy of Wallace & Tiernan Co.

Dose control

- Flow pacing
  - Small home system



  - Full-scale municipal system

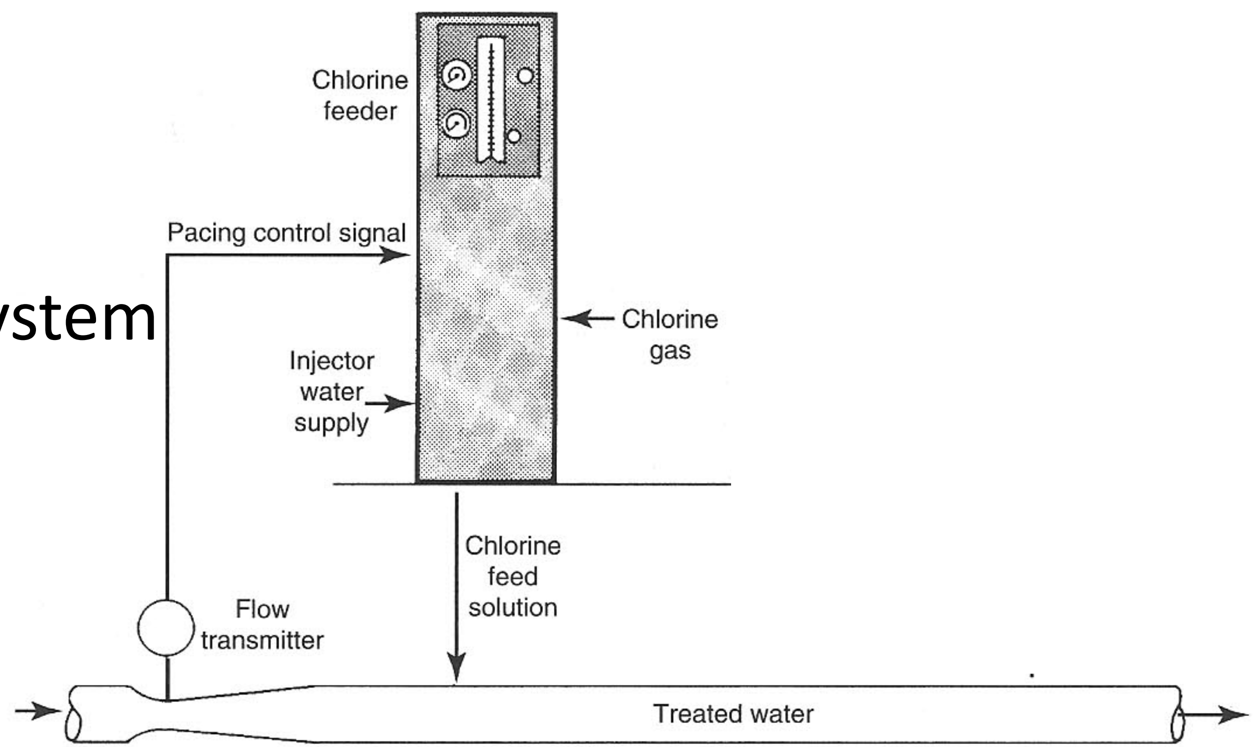


Fig 7-19; pg. 237 in H&H

Dose control

- Feed back system
  - Adjusts for varying chlorine demand

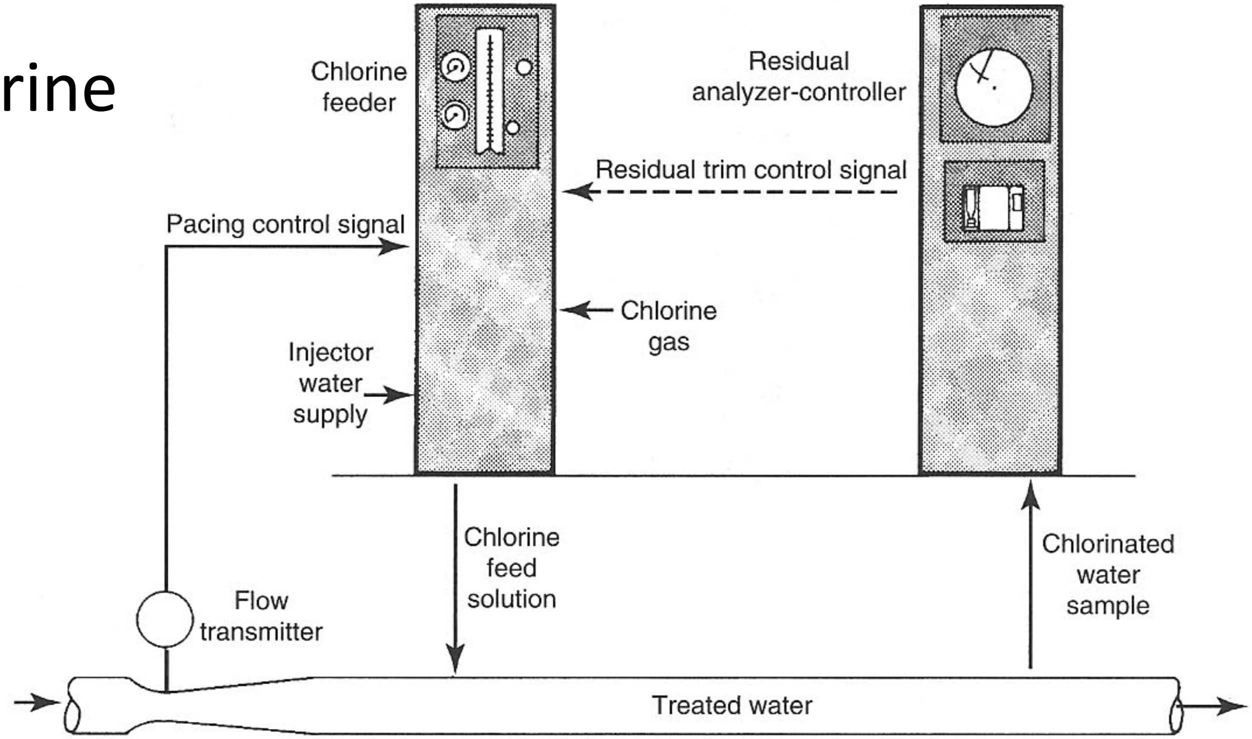
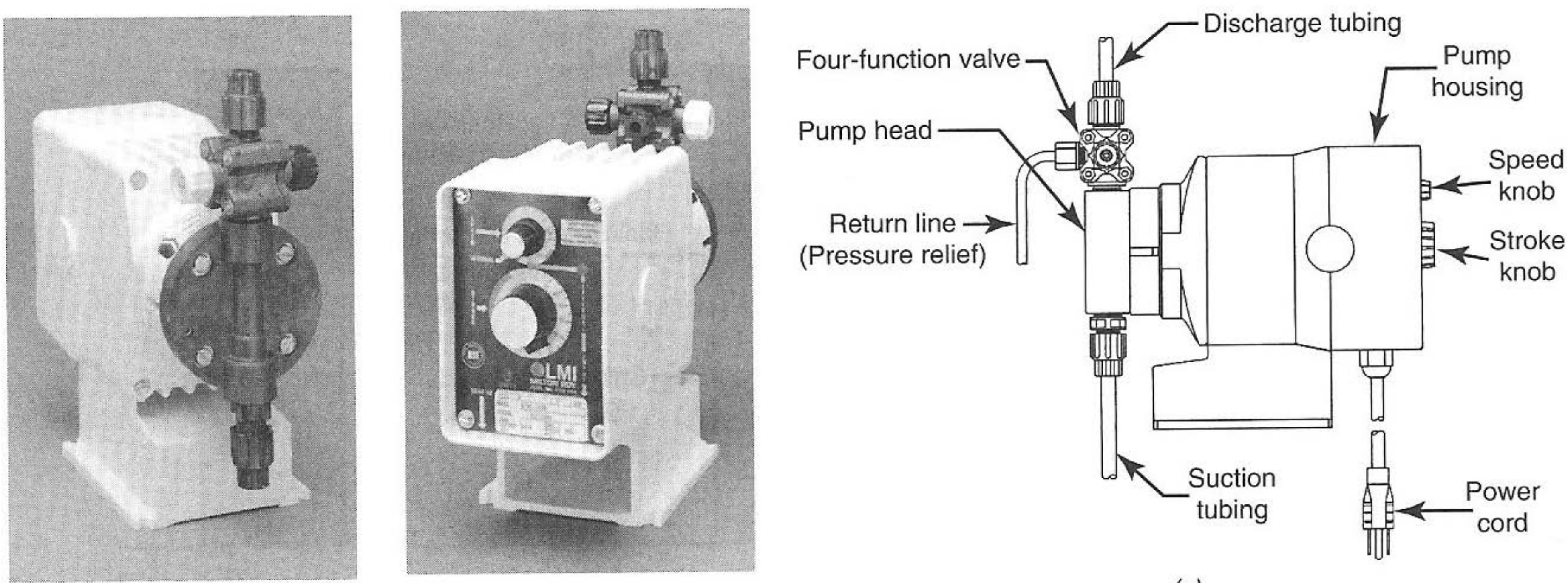


Fig 7-19; pg. 237 in H&H

Hypochlorite Dosing

- Positive displacement pump
- Need chlorine resistant materials

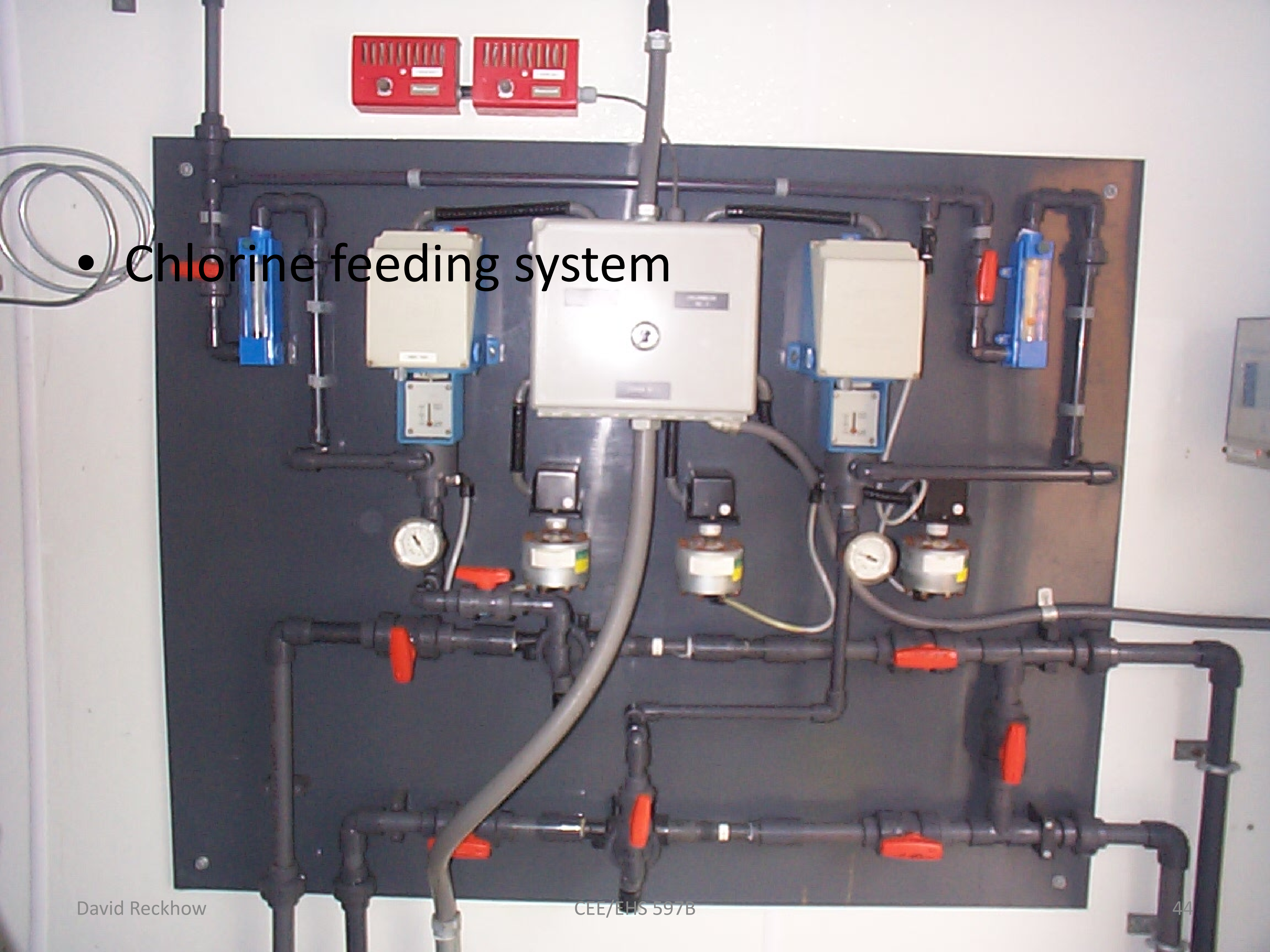


(a) (b) (c)

- Chlorine tanks
  - Left side is currently feeding
  - Right side is on reserve


CAUTION
CHLORINE TANKS
FULL
CAUTION
CHLORINE TANKS
EMPTY
INHALATION HAZARD

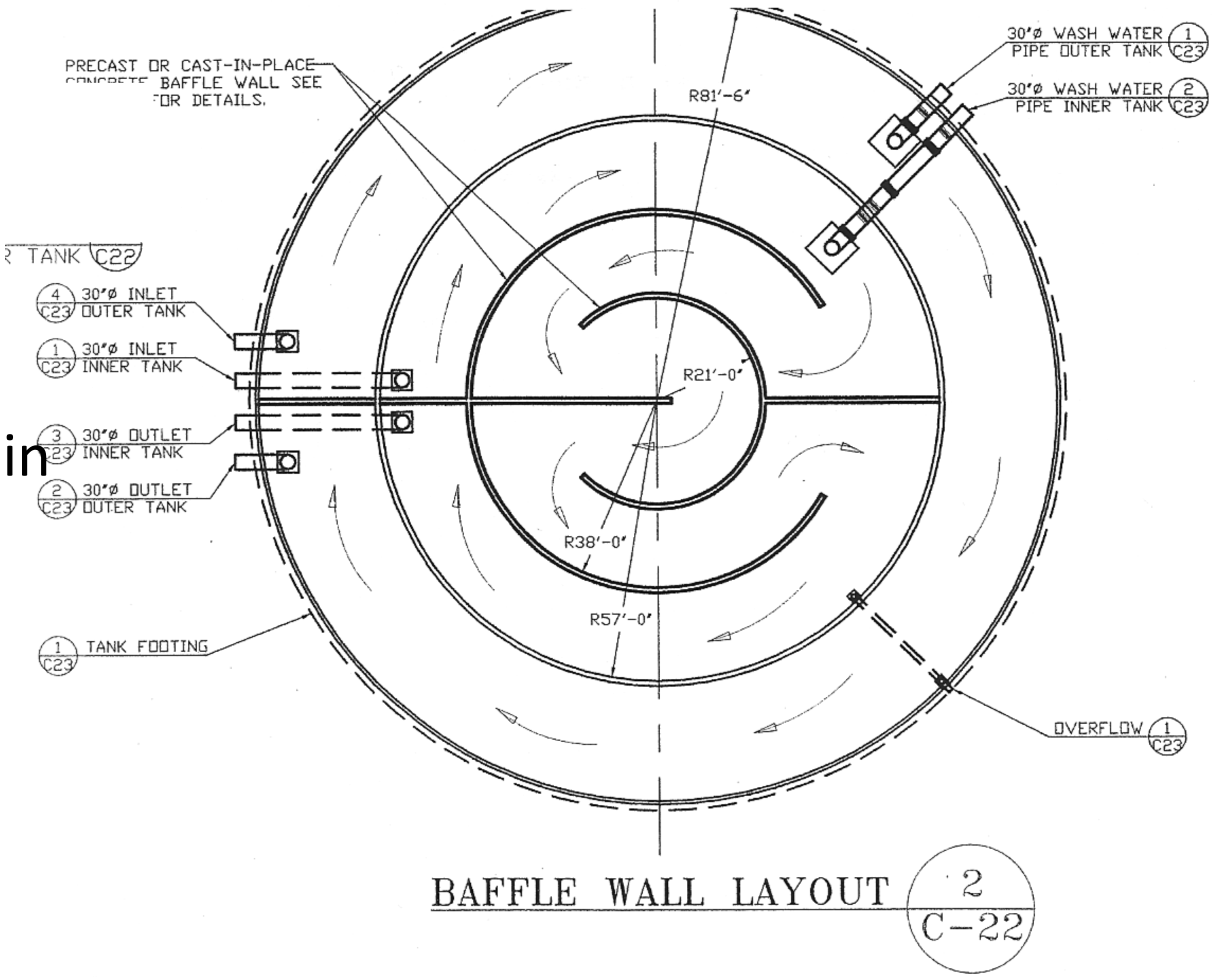
- Chlorine feeding system



- Dose adjustment knob

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



Raw Water

- Reservoirs &
- Transmission Mains

Clearwell

Clearwell

Clearwell

Clearwell

Clearwell

Clearwell

- From the plant site

Clea

- Dropping a panel into position

Clearwell

Northampton Ground Storage

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

Clearwell

- Exit

Clearwell

- In c

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

End of Class #2

- To next Lecture