CE 404

Dr. Isam Alyaseri
Environmental Science and Engineering

Part-1 Drinking water treatment

ialyase@gmail.com

Environmental Engineering

*What do environmental engineers **do**?*

In general:

The application of scientific and engineering principles to minimize the adverse effects of human activity on the environment and to safeguard human health and welfare

Class Activity

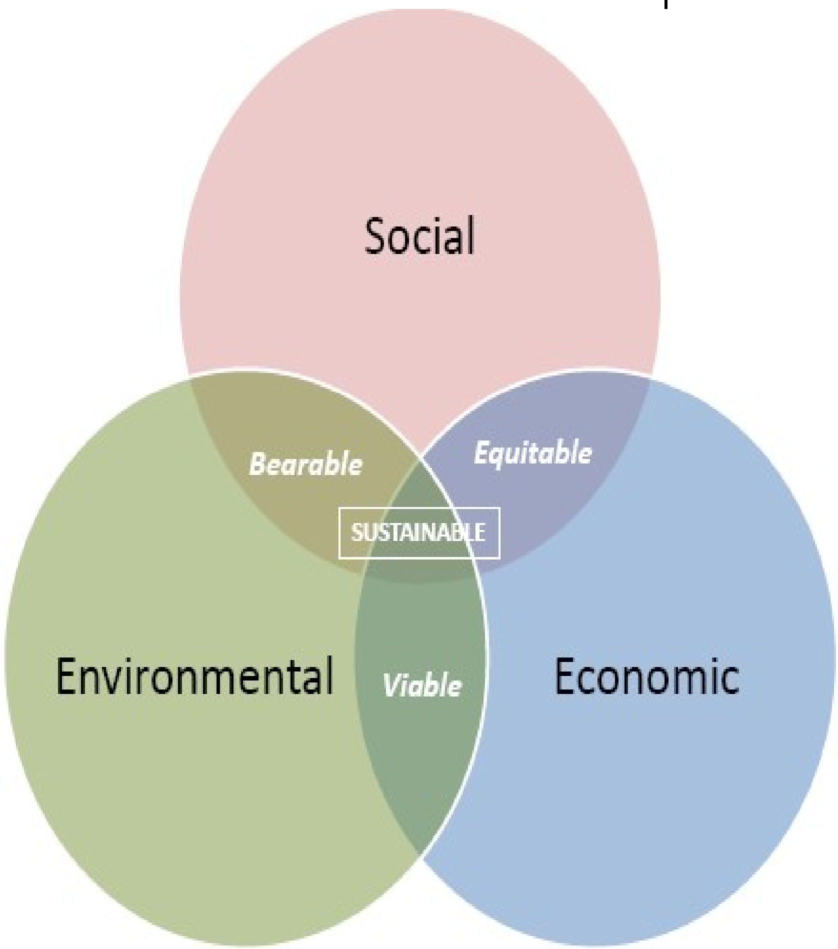
*Why do **you** need to know stuff about environmental engineering?*

Sustainability

What do you know about sustainability?

Sustainability

- Sustainable System:
  A system or process is sustainable if it can be continued indefinitely, without depleting any of the material or energy resources required to keep it running (Wright, 2004).
- Sustainable Society: A society in balance with the natural world, continuing generation after generation, neither depleting its resource base by exceeding sustainable yields nor producing pollutants in excess of nature's capacity to absorb them (Wright, 2004).



Wright, T. Richard. (2004). Environmental Science. 9th Edition, ISBN:0-13-1920219.

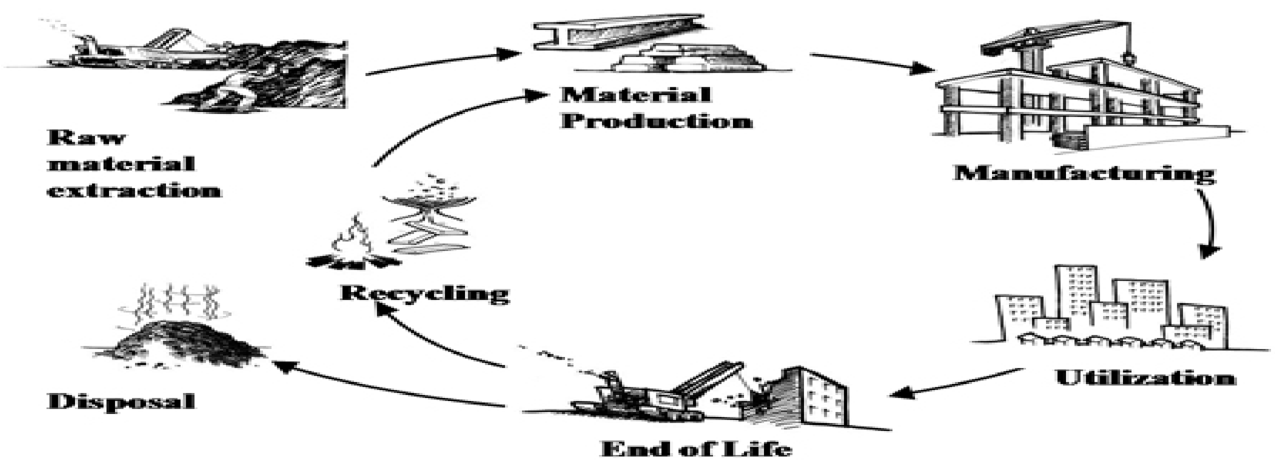
صنع الله الذي أتقن كل شيء

والأرض مددناها وألقينا فيها رواسي وأنبتنا فيها من كل شيء موزون

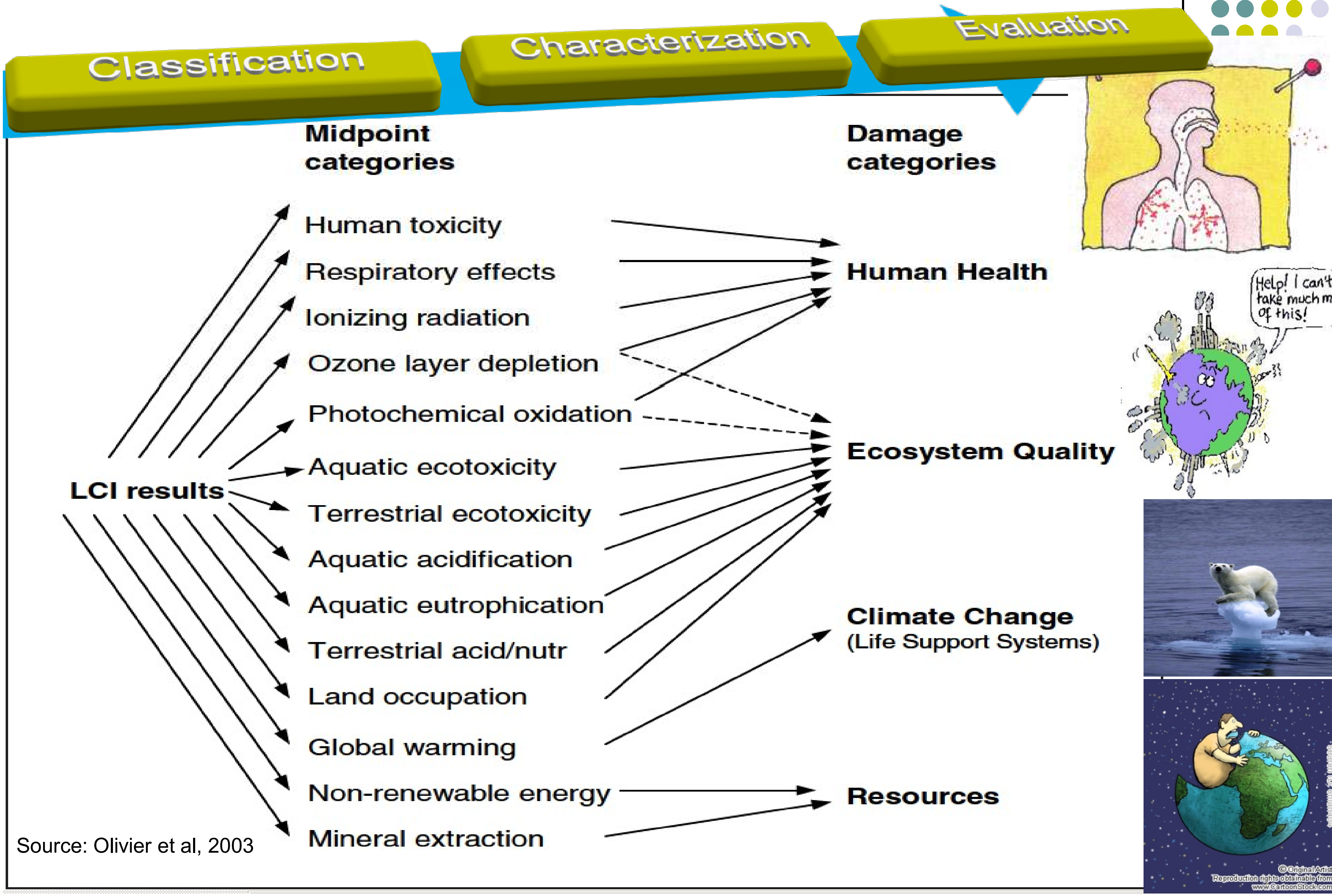
Where are the regulations???

LCA

- Cradle-to-Cradle Analysis or Life Cycle Assessment
- “An evaluation of the environmental effects associated with any given activity from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth” (Vigon et al, 1993).



Impact Assessment Method



Source: Olivier et al, 2003

Home Work #1

Answer the following questions.

1. What is sustainability?
2. How does it pertain to civil engineering?
3. What are the potential pros and cons of integrating sustainability into projects/policies?

Home Work #2

- Report to your class any unsustainable action in your home town

Water, Part 1

Lectures

10 states standards

Handouts

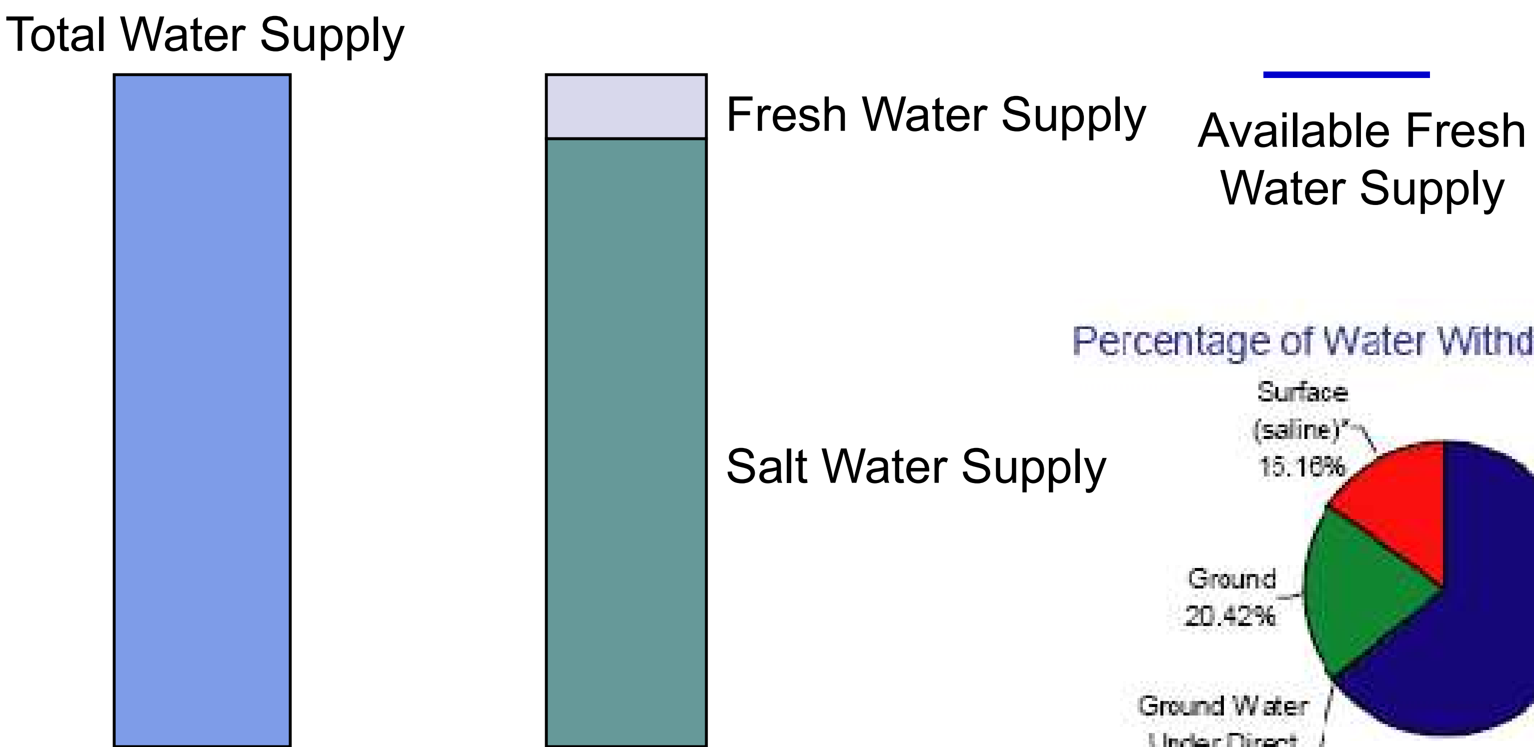
Text book in library

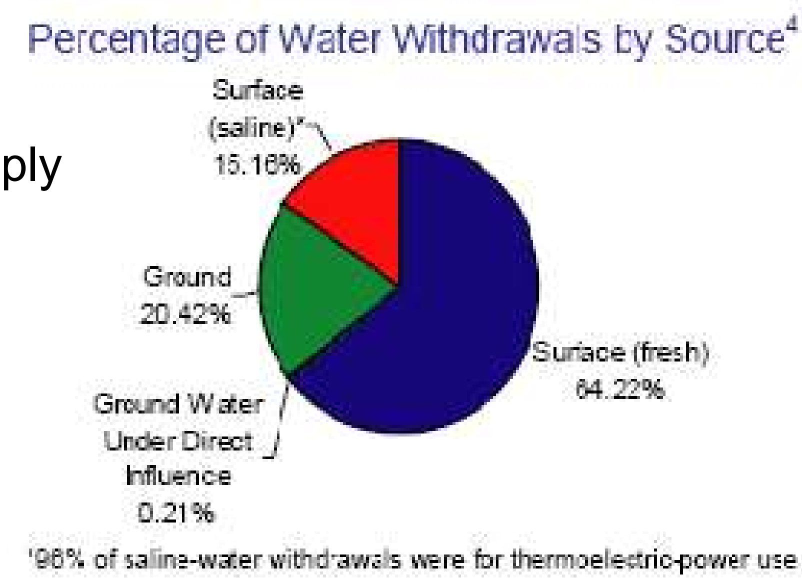
Water

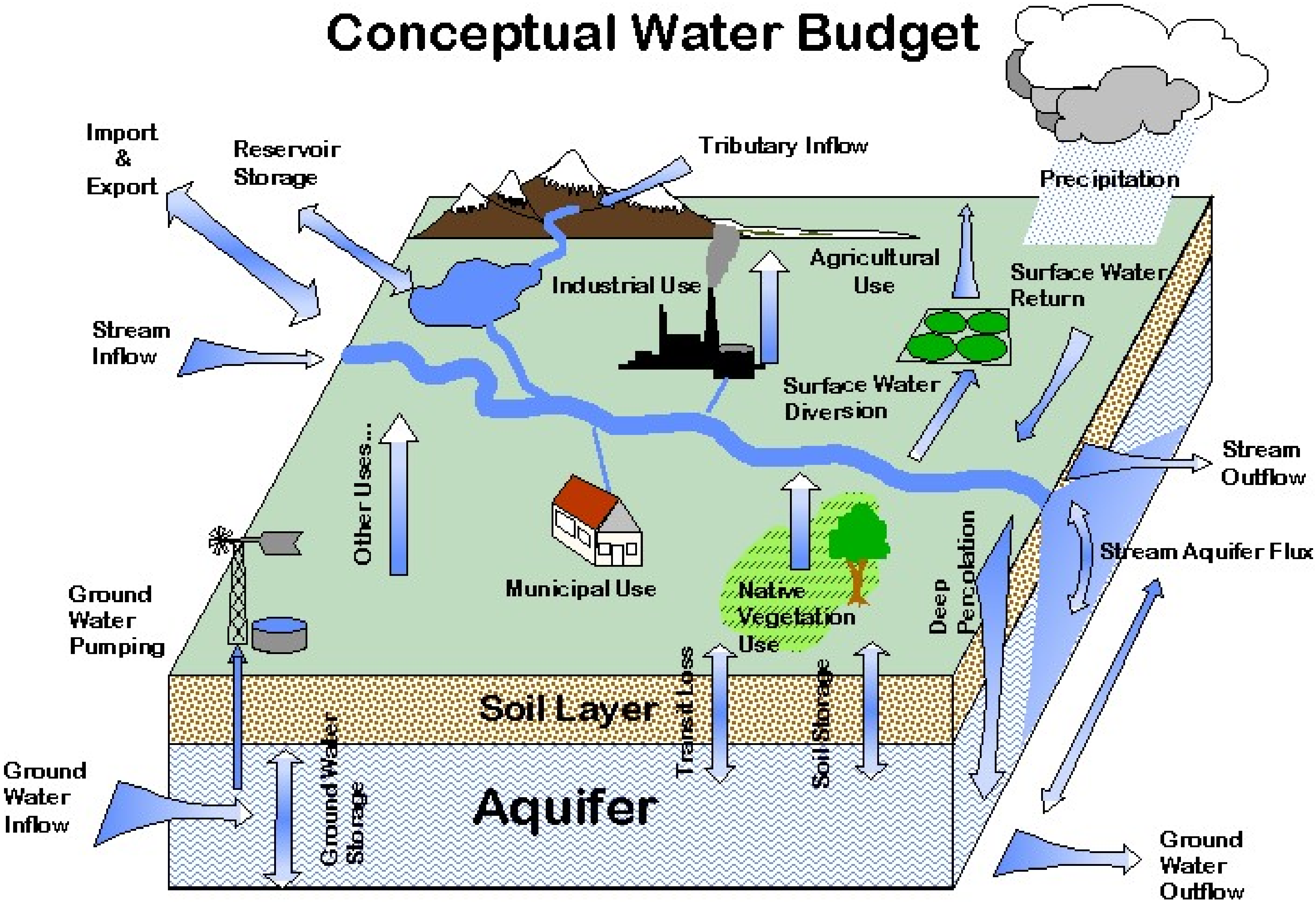
- Water gave the world its early civilizations

WATER QUANTITY & SOURCES

Water on Earth

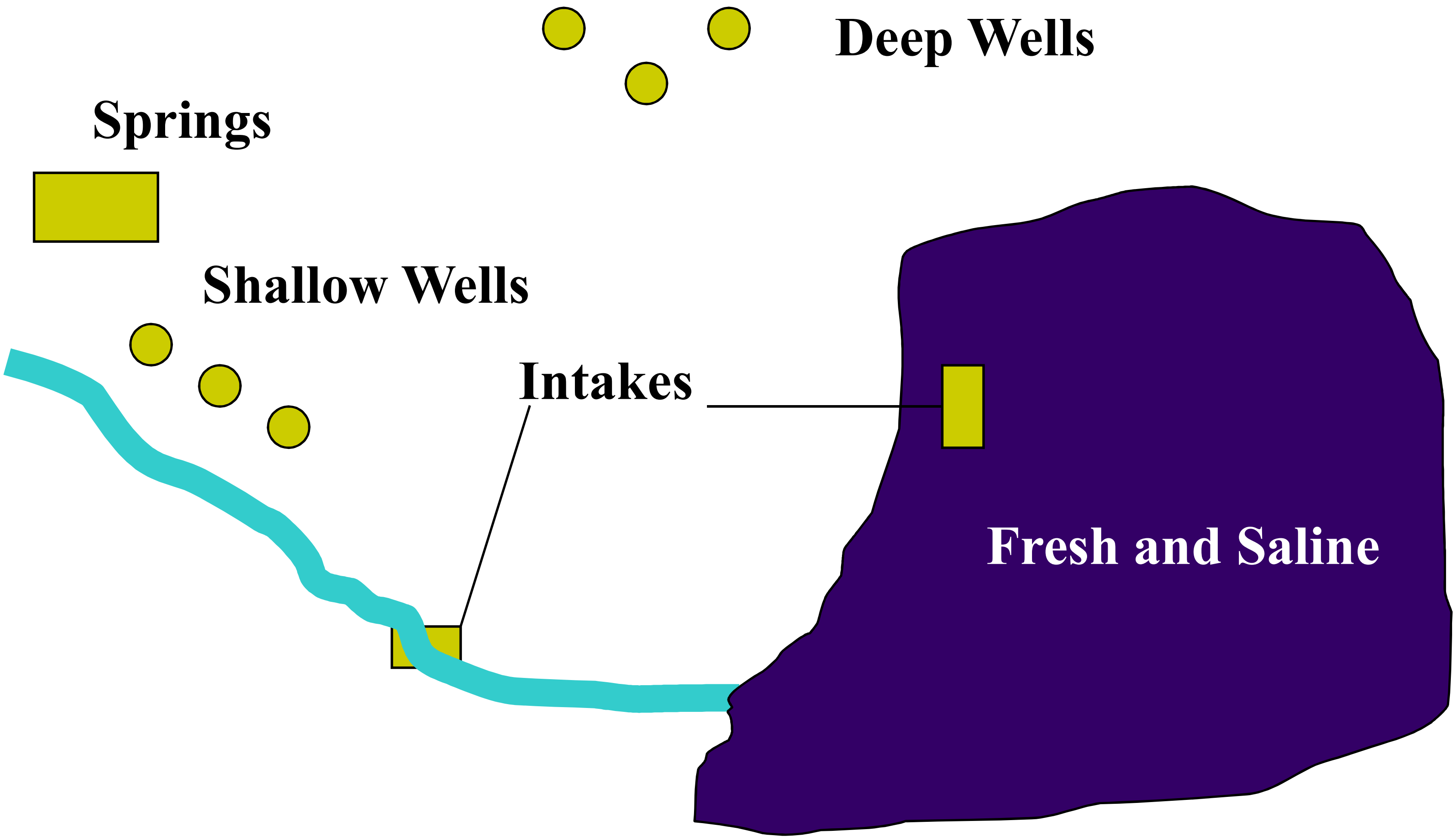




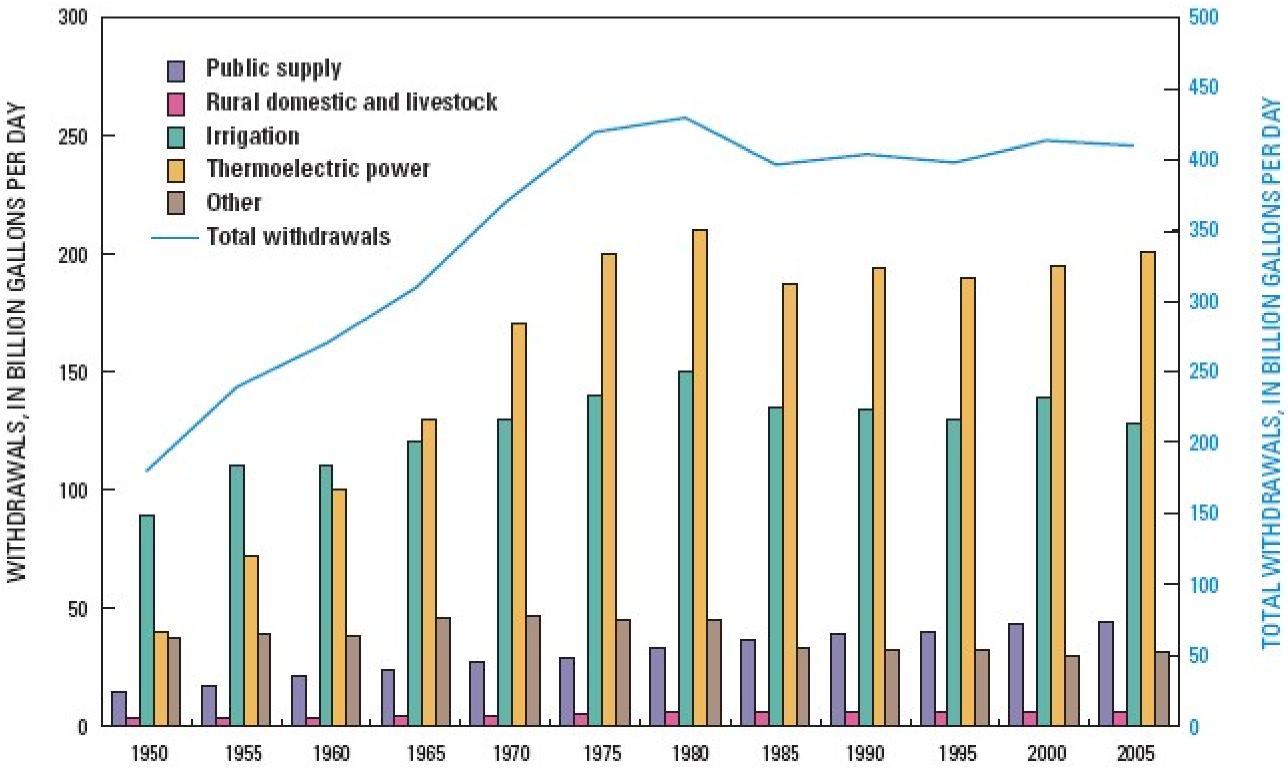

Conceptual Water Budget
Import & Export
Reservoir Storage
Tributary Inflow
Precipitation
Stream Inflow
Industrial Use
Agricultural Use
Surface Water Return
Surface Water Diversion
Other Uses...
Municipal Use
Stream Outflow
Stream Aquifer Flux
Native Vegetation Use
Deep Percolation
Ground Water Pumping
Soil Layer
Transit Loss
Soil Storage
Ground Water Inflow
Ground Water Storage
Aquifer
Ground Water Outflow

Source: EPA

Potable Water Sources

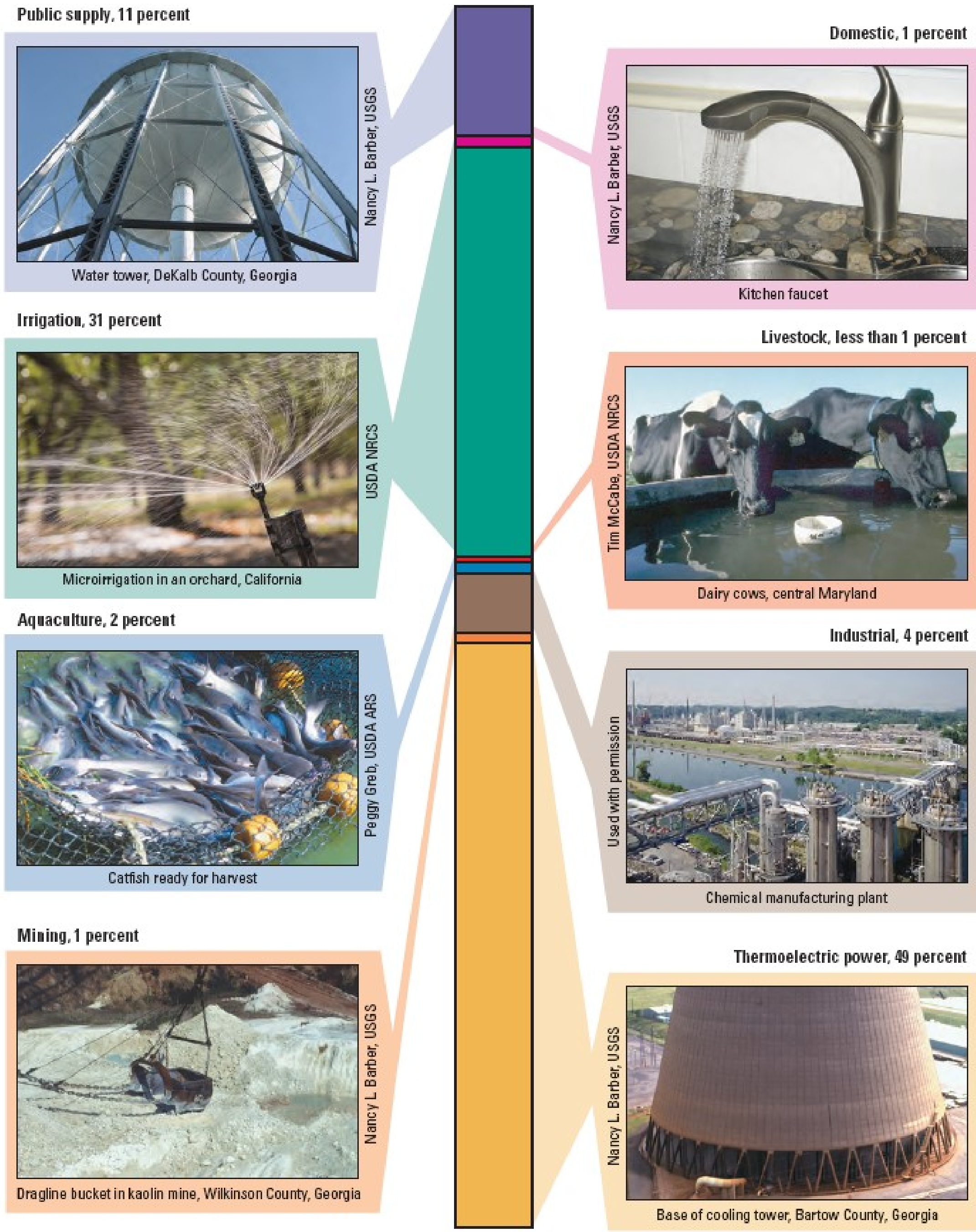


U.S. Water Use



Public supply
Rural domestic and livestock
Irrigation
Thermoelectric power
Other
Total withdrawals
WITHDRAWALS, IN BILLION GALLONS PER DAY
TOTAL WITHDRAWALS, IN BILLION GALLONS PER DAY
0
50
100
150
200
250
300
350
400
450
500
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

U.S. Water Withdrawals in 2005



WATER QUALITY

Water Quality Tests

- Physical properties

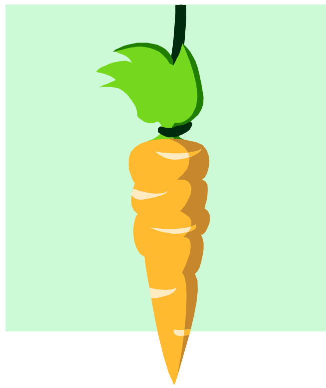
Suspended solids, TDS, Turbidity, Color, pH, temperature.

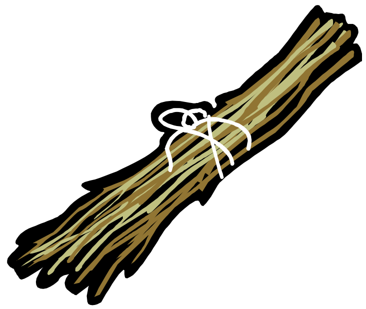
- Chemical properties

Residual chlorine, hardness, alkalinity, sodium concentration, iron, manganese, lead, mercury, arsenic, nitrate, THMs, etc.

- Bacteriological tests

E. coli, total coliforms, cryptosporidium, etc.





REVIEW:
LAWS AND REGULATIONS

The Process

Public concern and/or a recognition of link between cause and effect

↓

Law

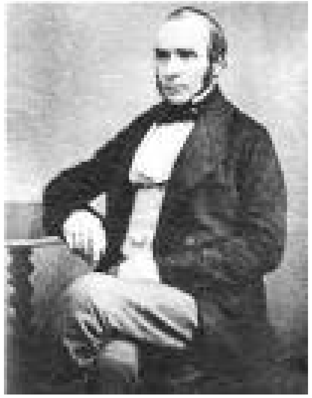
↓

Regulations

DRINKING WATER LEGISLATION

Connection between Diseases and Contaminated Water

- 1854 epidemic of cholera in London
- John Snow: public health physician
- Water pump in Broad Street, London
- Intake down stream of waste discharge



Water Treatment

- Dysentery, cholera, typhoid, etc
- Late 19th Century → chlorination on emergency bases
- 1908, 1st attempt in U.S. to disinfect water public supply
- TSS, Turbidity, organics and in-organics toxics?
- Need for regulations

U.S. Public Health Service Standards

- USPHS, 1914
- Mainly bacteriological standards (<100 organisms/mL)
- Not adequate to deal with organic pollutants in water
- Raise of public awareness
- Discover of THMs in 1974

Why Need More Regulations?

- Milwaukee, Wisconsin 1993 outbreak
- Cryptosporidium was not regulated by that time
- 403000 became ill with the stomach cramps, fever, diarrhea and dehydration
- 104 death

Example:
Safe Drinking Water Act

- SDWA, 1974
  - To develop national program to protect water quality
  - Cover both chemical and microbial contamination
  - Conduct studies and researches
  - Set standards
  - Regulate the routine monitoring and report to EPA

Safe Drinking Water Act

- Objective: No known or anticipated health effect would occur from drinking water

MCLs
Health Risk and Cost Analysis

- Risk reduction
- Costs
- Evaluating alternatives
- Subgroups and general population
- Risk of compliance
- Uncertainty in the data

MCLs

- Enforceable
- Based on no adverse effect on human health
- Consider costs, technology available, regulatory and other feasibility options
- Based on risk management
- Field examination not lab

Activity

What are the differences between primary and secondary standards?

A. Enforceability
B. Purpose
C. Size of plant covered

DRINKING WATER TREATMENT

Drinking Water Treatment

- Primary goal: Prevention of disease
- Secondary goals:
  - Good taste, odor, and color
  - Low hardness
  - Meet irrigation and fire protection needs

Planning for your Project

- Preliminary study
- Master planning
- Future population, water supply area, water quality, water standards, planning period.
- Pilot plant : pinch scale, then pilot scale
- Meet the standards:
  - primary you have to meet
  - Secondary better to meet
- Other considerations:
- Initial costs, operation costs, and construction time

Planning for your Project

- Available motors and pumps
- Alternative processes for future
  - ➢ Change in quality requirements, expansion.
- Design based on max daily water demand per capita (gpcd)
- Hydraulic grade across plant: use gravity as possible
- Geotechnical considerations:
- Excavation and fill, GW level, soil pressure, and seismicity site

Structural Consideration

- Water bearing (leak proof)
- Resist lifting force when the tank is empty
- Min 8 inches wall thickness for the tanks
- Thermal (expansion joint)
- Water hummer

Instrumentation/Control

- Continuous operations
- Automatic execution of correction measures
- Minimum potential of human errors
- Control/Monitor remote equipment
- Supervisor Control and Data Acquisition (SCADA)

Selection of Water Source

- Quantity of water required
- Quality of raw water
- Climatic conditions
- Potential difficulties in constructing the intake
- Operator safety
- Operation and maintenance costs
- Possibility of future contamination in source
- Expansion possibilities

Plant Size

- Different from plant to another
- Use the following equation for rough estimation for area for conventional treatment:

$$A \geq Q^{0.7}$$

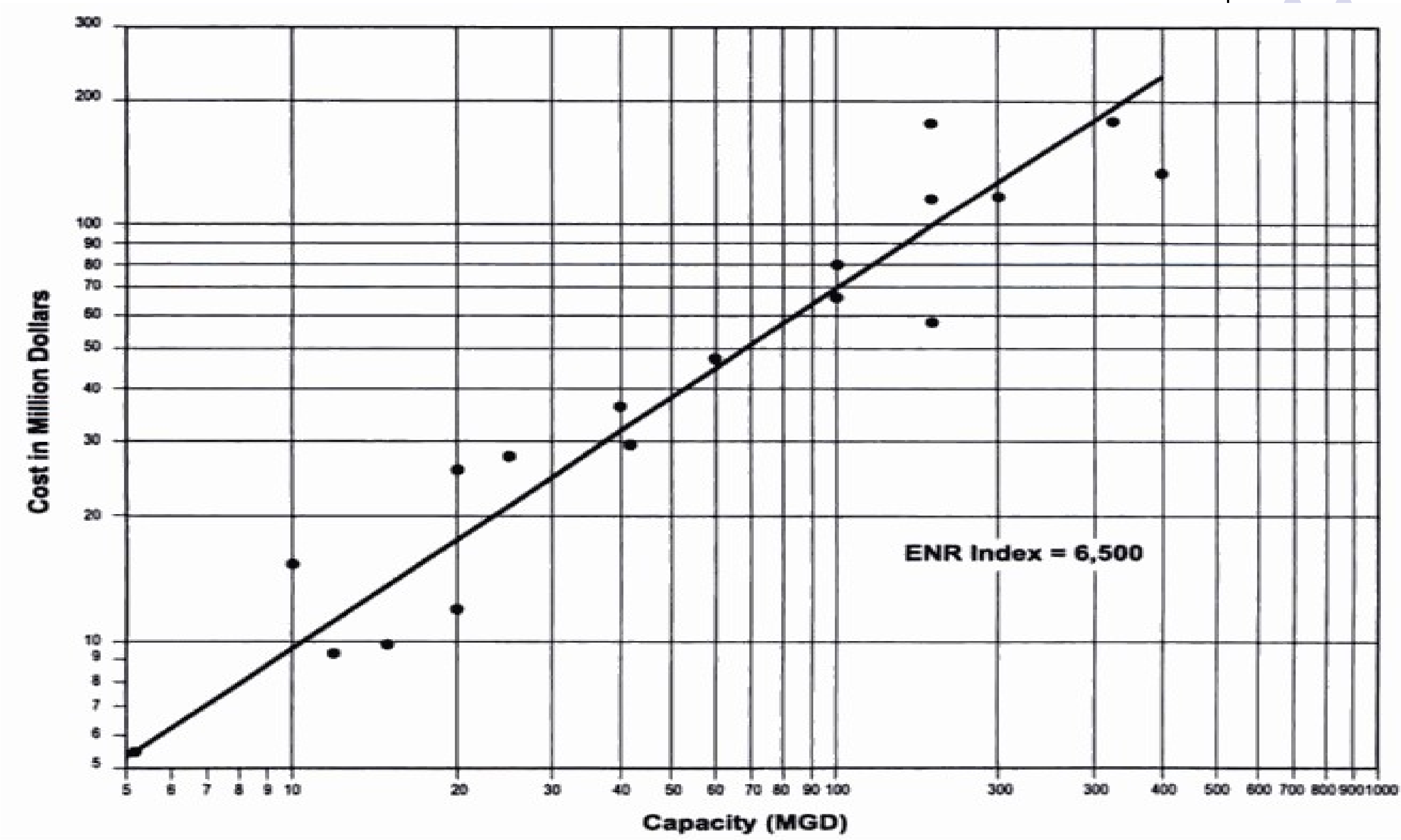
- Where:

A = plant area required in acre (1 acre = 0.405 hectare)

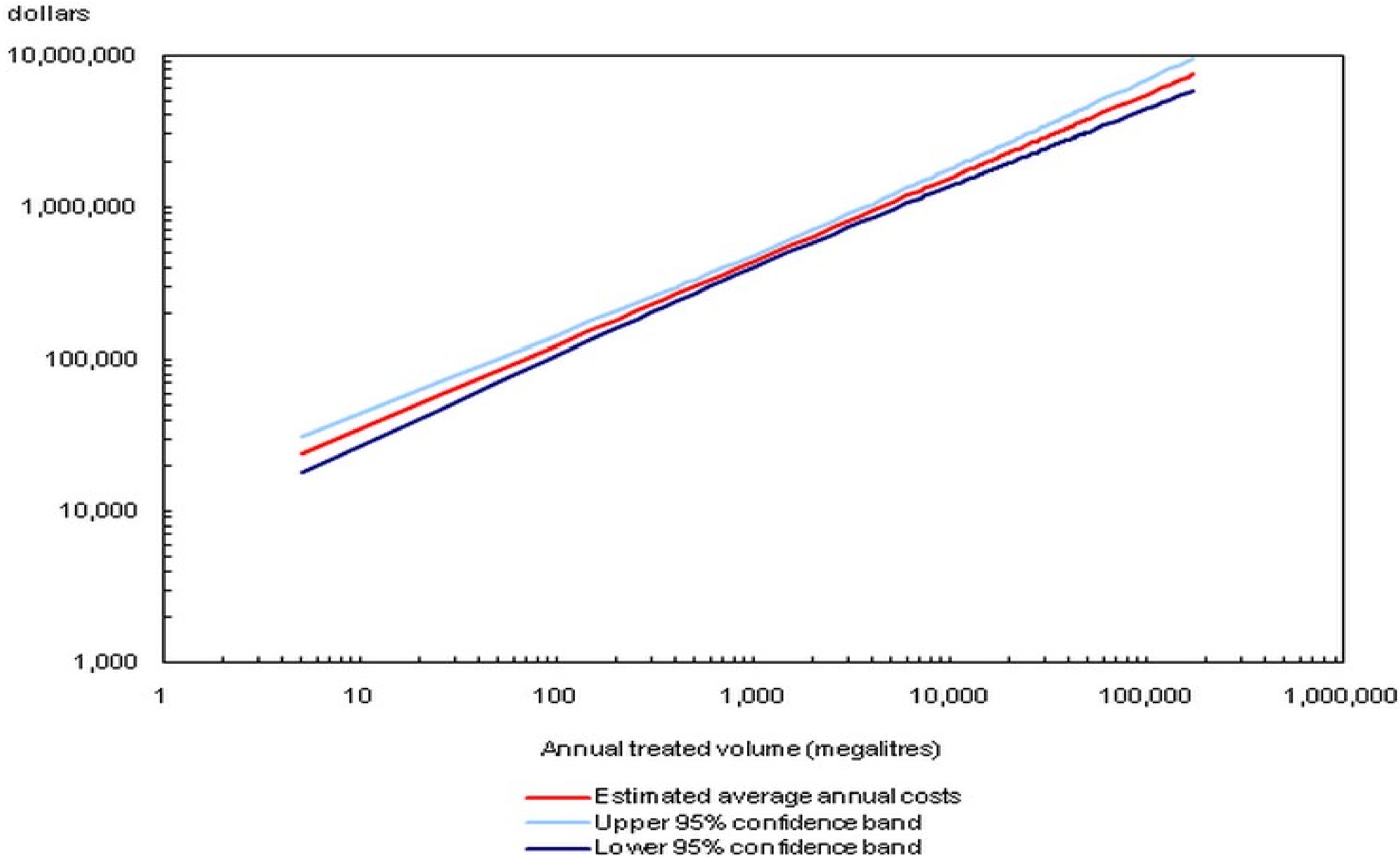
Q = ultimate plant capacity in MGD (1 MGD = 3.784E+3 m^3/d)

Water Level Consideration

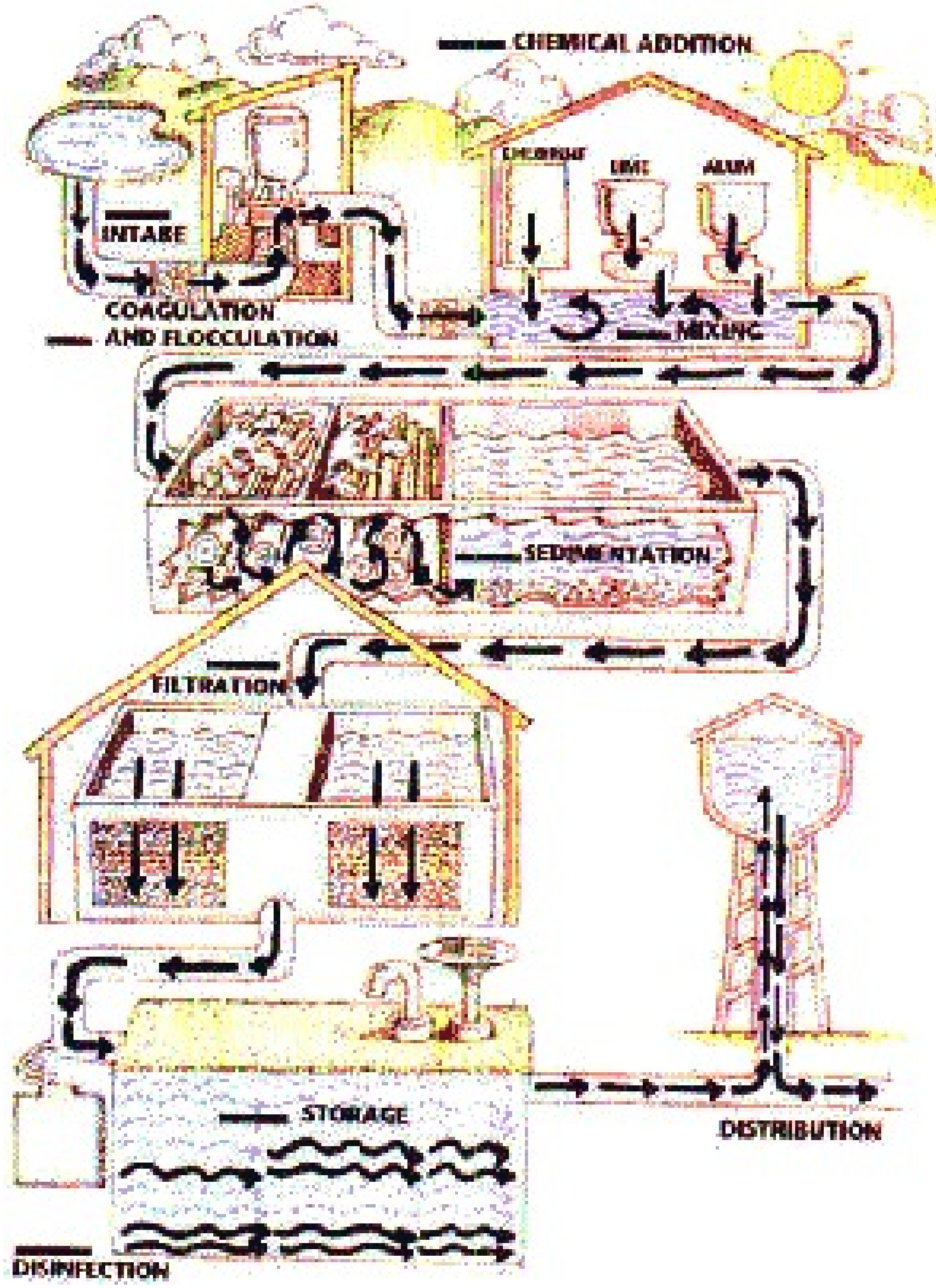
Construction Cost for Conventional Water Treatment Plant



Estimated average annual operation and maintenance costs versus annual treated volume for conventional drinking water plants treating surface water



Process for POTWs



Intake

Surge Tank

Horizontal
Centrifugal Pump

Screw

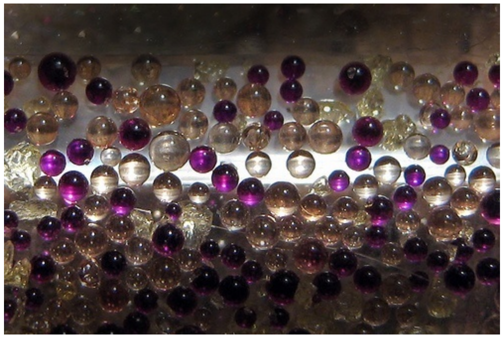
Alrumaitha WTP Intake

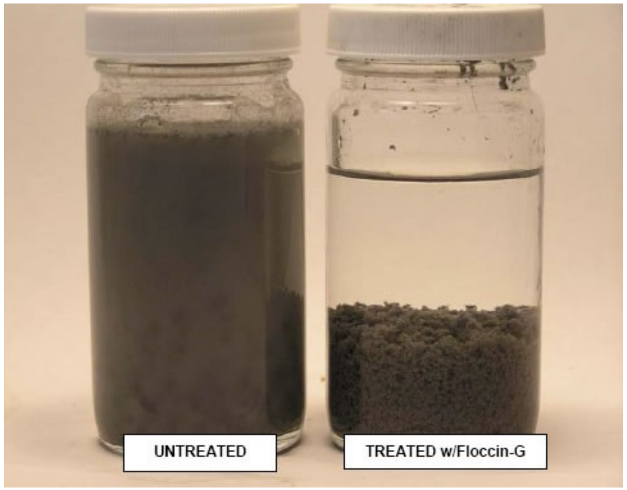
General Water Treatment

Conventional

Vs.

Advanced





Units

ppm vs. mg/L

1 ppm is equivalent to 1 minute in:

a) 1 day
b) 2 years
c) 6 weeks

Approximations and Sig Figs

- How should an engineer report the estimate of the construction cost? Why?

a) $56,078.34

b) $56,078

c) $56,080

d) $56,000

- Why is the number of significant figures in your final answer important? In the words, what does the number of significant figures in your final answer reflect?

- Should you round throughout a calculation or at the end (i.e., the final answer) or both? Why?

Reminder Hints for Quantitative Problems

- Write down the general equation.
- Write down your units throughout! And use them to come up with your final units.
- Be reasonable with sig figs.
- Ignore irrelevant data.
- If your answer doesn't make sense, check. If your check gives you the same answer, state why it doesn't make sense.

Softening

Why?

Why do we soften water?

Why?

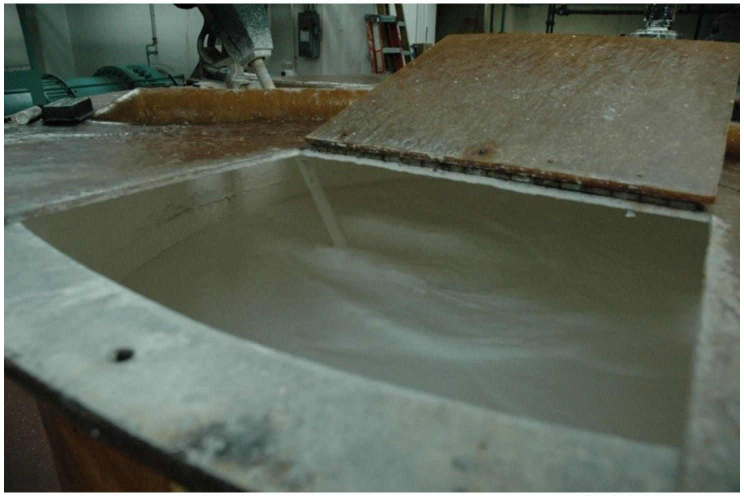

Nasty soap scum
Scratchy, dull laundry
Clogged pipes
Spotty dishes

What?

What is hardness?

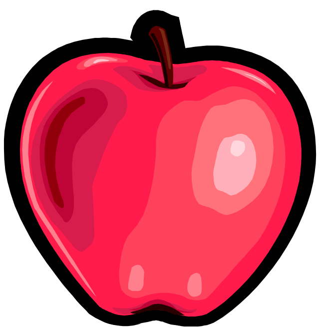
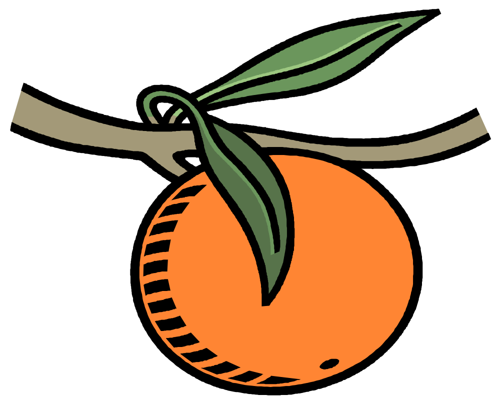
How?

How do we soften water?



Units

How do we get to from mg/L of ions to mg/L as $CaCO_3$?

 ±  = ?

Example

Find total hardness (in mg/L as $CaCO_3$) of water containing:

Ca^{2+} = 80 mg/L, Mg^{2+} = 30 mg/L,

Pb^{2+} = 160 mg/L, Fe^{3+} = 50 mg/L

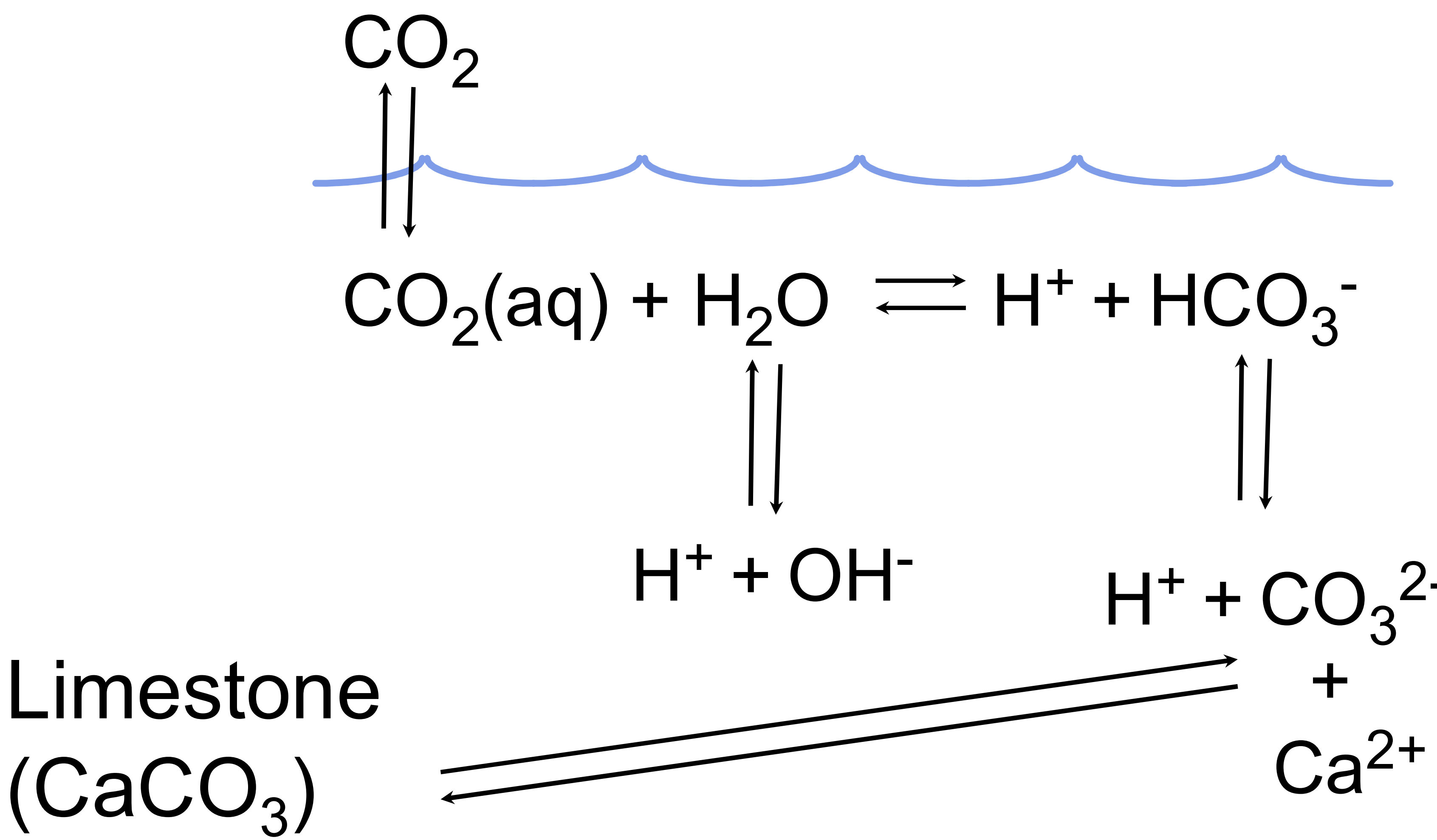
Na^{+} = 72 mg/L, K^{+} = 6 mg/L

Cl^{-} = 100 mg/L, SO_4^{2-} = 201 mg/L,

HCO_3^{-} = 165 mg/L

pH = 7.5

Calculating Alkalinity



Alkalinity

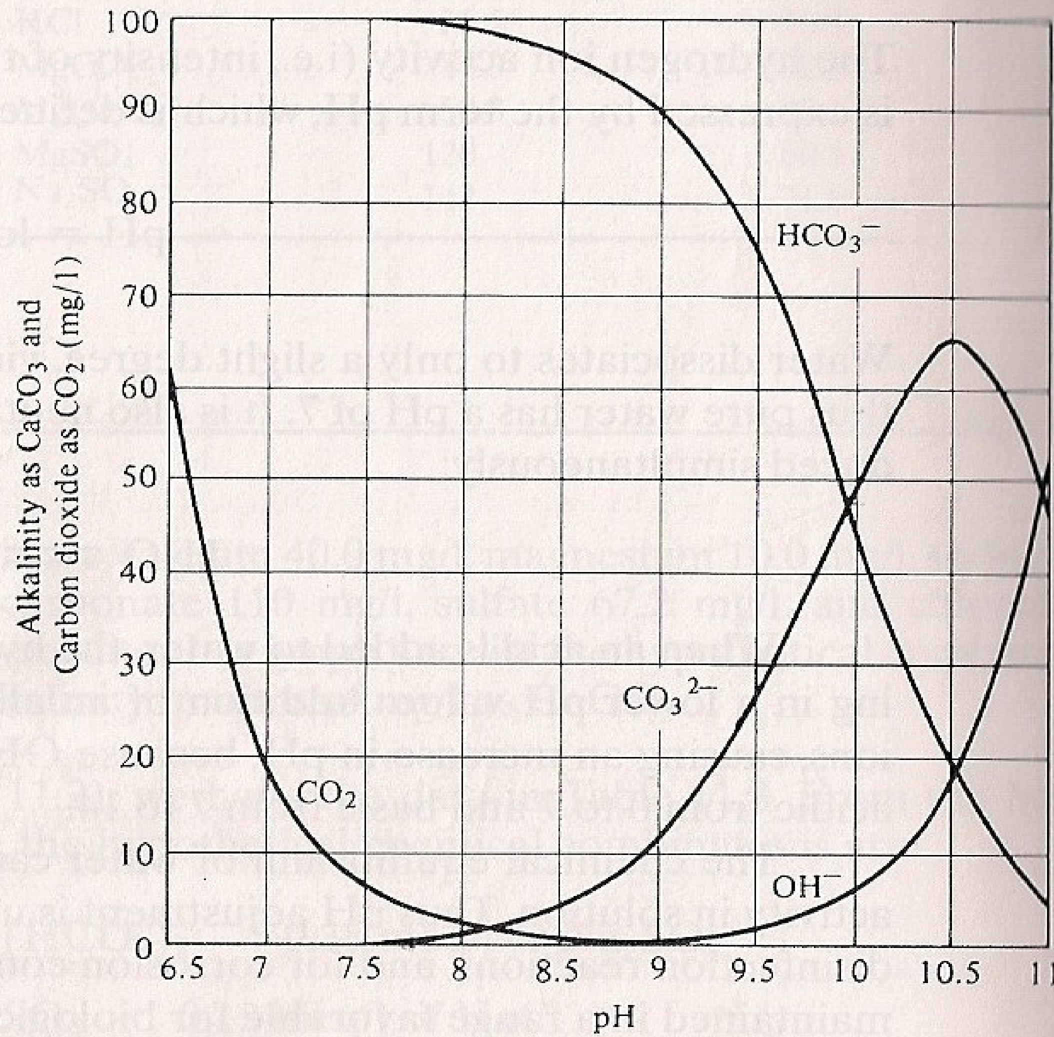


FIGURE 11.2 Carbon dioxide and various forms of alkalinity relative to pH in water at 25°C.

Source: Viessman W. and Hammer M. 2005. Water Supply and Pollution Control. 7th Edition, Pearson Prentice Hall, Upper Saddle River, NJ

More on Total Hardness

$$TH = CH + NCH$$

Example

Find carbonate and non-carbonate hardness of water containing:

Ca^{2+} = 80 ppm, Mg^{2+} = 30 ppm,

Fe^{3+} = 78 ppm

Na^{+} = 72 ppm, K^{+} = 6 ppm

Cl^{-} = 160 ppm, SO_4^{2-} = 250 ppm,

Alk. = 265 ppm pH = 7.5

Reminder

- Calculate TH and ALK.
- Determine CH.
- Calculate NCH.

“Speciation”

CCH:

CCH + Lime ↔ Sludge + H_2O

CNCH:

CNCH + Soda Ash ↔ Sludge + Salt

MCH:

MCH + More Lime ↔ Extra Sludge + H_2O

MNCH:

MNCH + Soda Ash + Lime ↔ Extra Sludge + Salt

Home Work #3

Find the speciation of the hardness of water containing:

Ca^{2+} = 80 mg/L, Mg^{2+} = 30 mg/L,

Na^{+} = 72 ppm, K^{+} = 6 ppm

Cl^{-} = 100 ppm, SO_4^{2-} = 201 ppm,

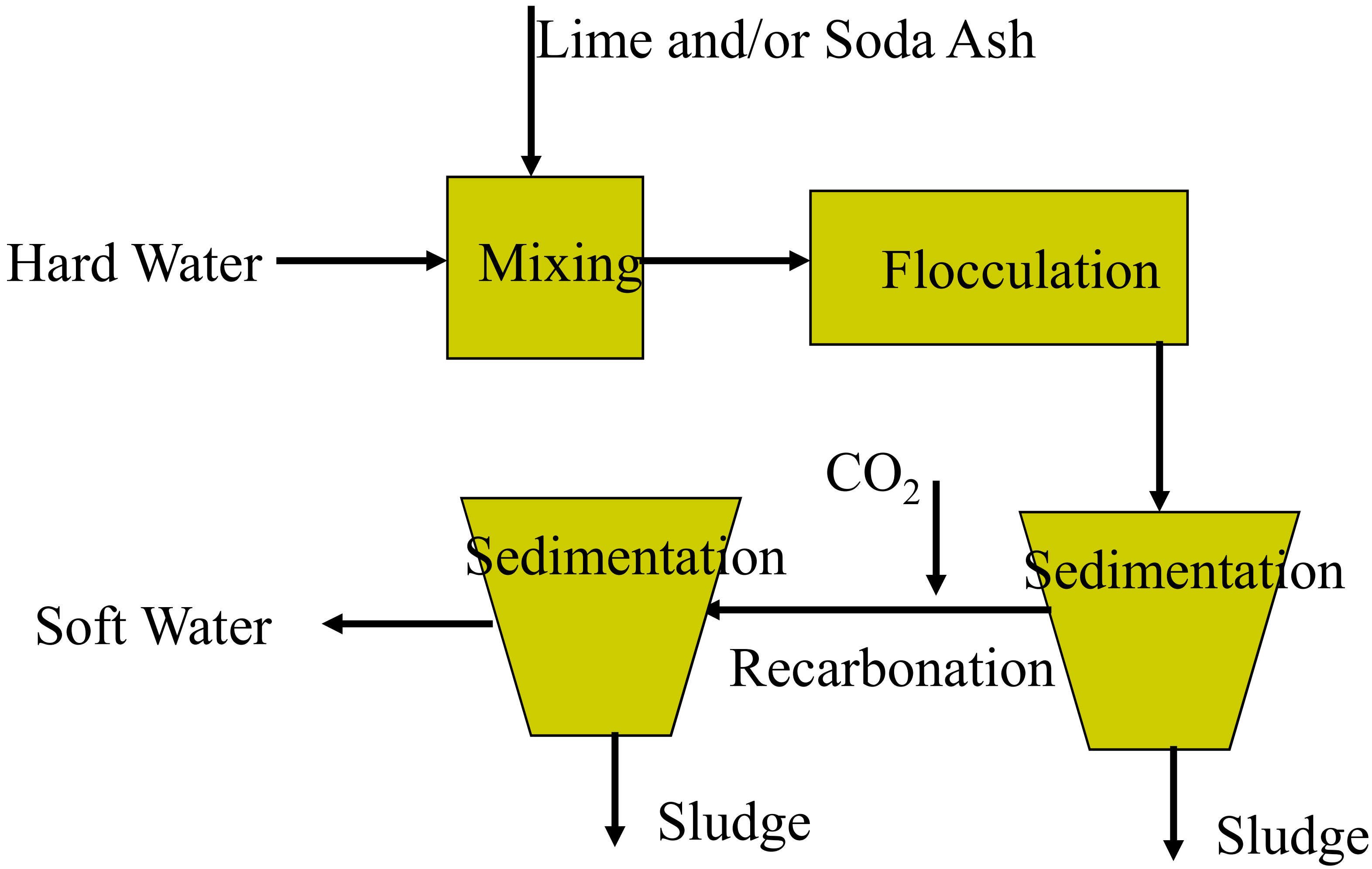
HCO_3^{-} = 165 mg/L

pH = 7.5

Reminder

- Calculate
  1. CCH.
  2. CNCH
  3. MCH
  4. MNCH
- Check your calculations!

Lime-Soda Softening



Lime-Soda Softening

CO_2:

$CO_2 + 1\ Ca(OH)_2 \leftrightarrow 1\ CaCO_3 \downarrow + H_20$

CCH:

$Ca(HCO_3)_2 + 1\ Ca(OH)_2 \leftrightarrow 2\ CaCO_3 \downarrow + 2\ H_2O$

CNCH:

$CaSO_4 + 1\ Na_2CO_3 \leftrightarrow 1\ CaCO_3 \downarrow + Na_2SO_4$

$CaCL_2 + 1\ Na_2CO_3 \leftrightarrow 1\ CaCO_3 \downarrow + 2NaCL$

MCH:

$Mg(HCO_3)_2 + 1\ Ca(OH)_2 \leftrightarrow 1\ CaCO_3 \downarrow + MgCO_3 + 2\ H_2O$

$MgCO_3 + 1\ Ca(OH)_2 \leftrightarrow 1\ Mg(OH)_2 \downarrow + 1\ CaCO_3 \downarrow$

MNCH:

$MgCL_2 + 1\ Ca(OH)_2 \leftrightarrow 1\ Mg(OH)_2 \downarrow + 1\ CaCL_2$

$CaCL_2 + 1\ Na_2CO_3 \leftrightarrow 1\ CaCO_3 \downarrow + 2NaCL$

$MgSO_4 + 1\ Na_2CO_3 \leftrightarrow MgCO_3 + Na_2SO_4$

$MgCO_3 + 1\ Ca(OH)_2 \leftrightarrow 1\ Mg(OH)_2 \downarrow + 1\ CaCO_3 \downarrow$

Example – Softening

Component	mg/L
CO_2	8.8 as CO_2
Ca^{2+}	70
Mg^{2+}	9.7
Na^{+}	6.9
ALK	115 as $CaCO_3$
SO_4^{2-}	96
Cl^{-}	10.6

To solubility limits with 90% quicklime, 90% soda ash

5 MGD flowrate

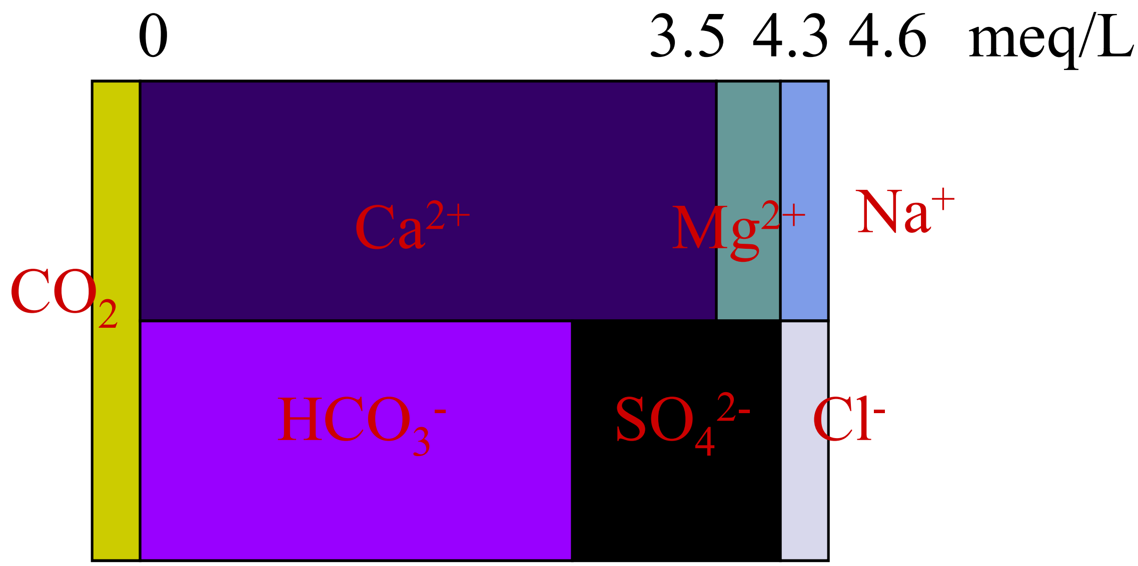
Example continued

First: Determine TH

Component	mg/L	EW	meq/L
CO_2	8.8 as CO_2	22	0.40
Ca^{2+}	70	20	3.50
Mg^{2+}	9.7	12.2	0.80
Na^{+}	6.9	23	0.30
ALK	115 as $CaCO_3$	50	2.30
SO_4^{2-}	96	48	2.00
Cl^{-}	10.6	35.5	0.30

Example continued

Second: Determine speciation



Example continued

Third: Determine chemical amounts

Component	meq/L	Lime	Soda Ash
CO_2	0.40	0.4	0
CCH	2.3	2.3	0
CNCH	1.2	0	1.2
MCH	0	0	0
MNCH	0.8	0.8	0.8
Excess	1.25	1.25	
Total		4.75	2.0

Assumptions

ALWAYS clearly state you are making an assumption and what that assumption is.

Examples: Assume purity = 98%

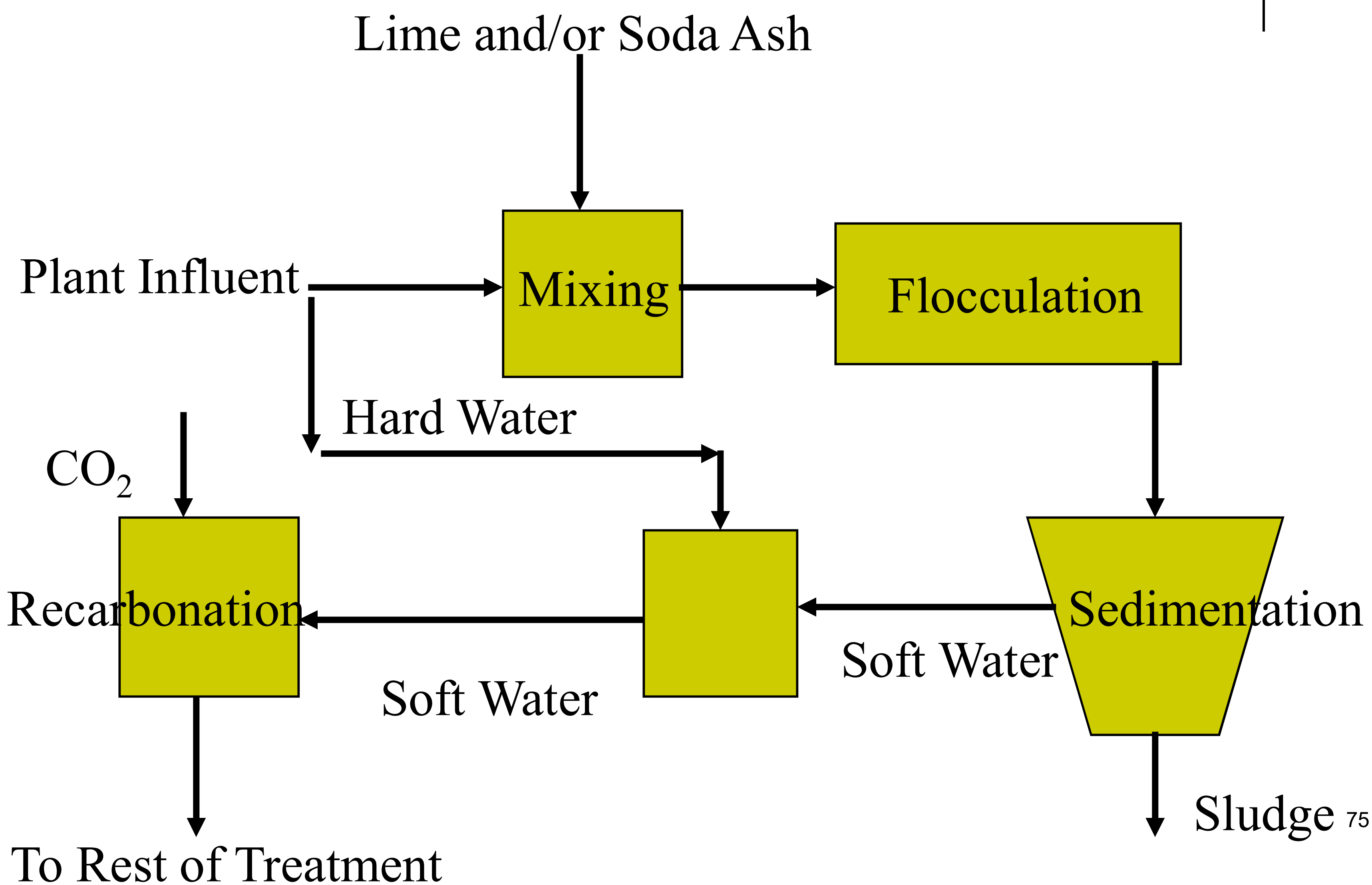
Assume generation = 4.2 lb/c/d

Example continued

Fourth: Determine sludge quantity

Component	meq/L
Ca^{2+}	3.50
Mg^{2+}	0.80
Lime	4.75
Soda ash	2.0
Residual Ca^{2+} hardness	0.6
Residual Mg^{2+} hardness	0.2

Split Treatment - LS Softening



Home Work #4

- Calculate the quantities of quicklime and soda ash required to soften 5.5 MGD of the following water to the practical solubility limit using split treatment and the desired magnesium concentration is 40 mg/L as CaCO3. Also calculate the flow rate of sludge in gpd (thicken to 6%).

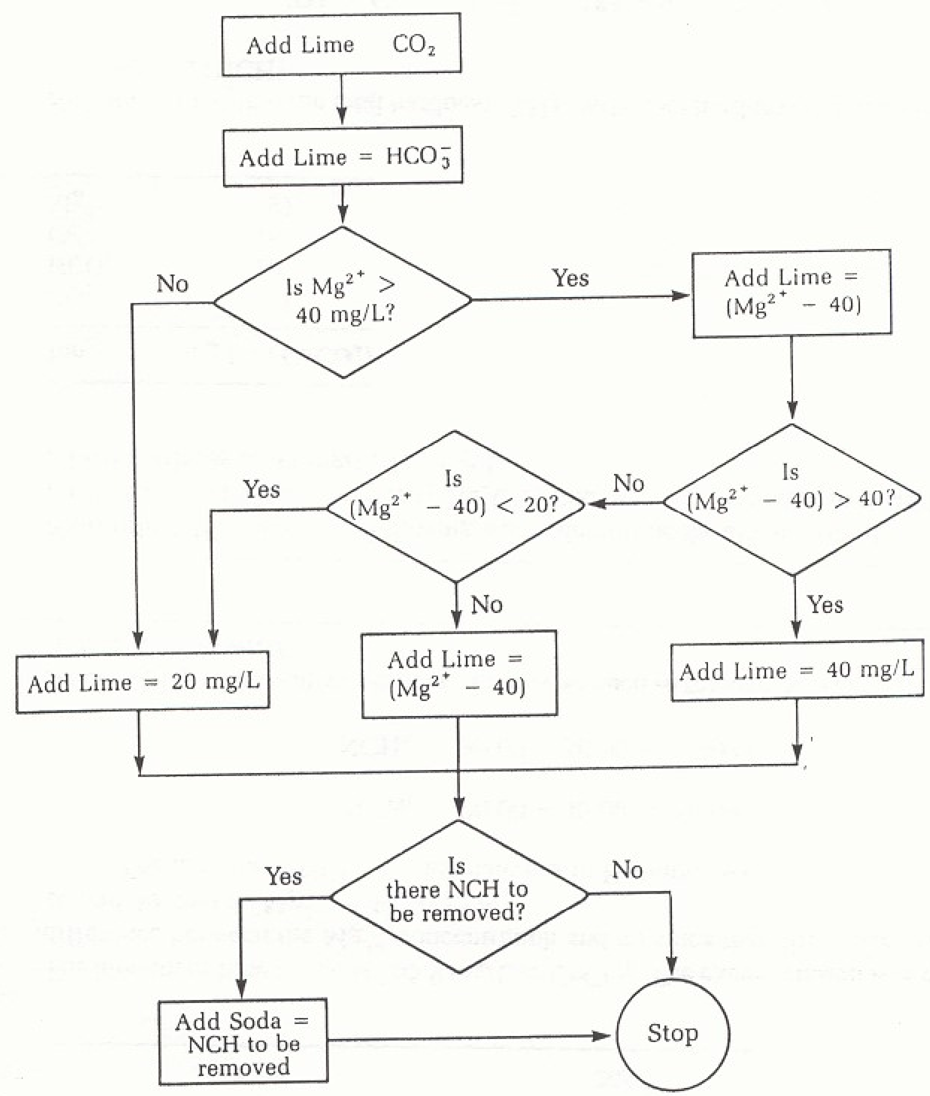
Ions	mg/L
CO_2	8.2
Ca^{2+}	140.0
Mg^{2+}	68.0
Na+	46.0
Cl^-	90.0
SO_4^{2-}	374.4
Alkalinity	210 as CaCO3
pH	6.9

Selective Ca^{2+} Removal

If $Mg^{2+} \leq 40$ mg/L as $CaCO_3$

(maximum Mg hardness)

Excess Lime



Add Lime CO_2
Add Lime = HCO_3^-
Is Mg^{2+} > 40 mg/L?
No
Yes
Add Lime = (Mg^{2+} − 40)
Is (Mg^{2+} − 40) > 40?
No
Yes
Is (Mg^{2+} − 40) < 20?
Yes
No
Add Lime = 20 mg/L
Add Lime = (Mg^{2+} − 40)
Add Lime = 40 mg/L
Is there NCH to be removed?
Yes
No
Add Soda = NCH to be removed
Stop

Examples

Can selective Ca^{2+} removal be used if all the hardness is Ca^{2+} and Mg^{2+}?

1. TH = 210 mg/L as $CaCO_3$
   Ca^{2+} = 120 mg/L as $CaCO_3$

2. TH = 180 mg/L as $CaCO_3$
   Ca^{2+} = 138 mg/L as $CaCO_3$

Example Continued

TH = 180 mg/L as $CaCO_3$

Ca^{2+} = 138 mg/L as $CaCO_3$

Mg^{2+} = 42 mg/L as $CaCO_3$

Calculate the amount of quicklime and soda ash required in meq/L if you (1) remove the Mg^{2+} and (2) leave the Mg^{2+} (selective Ca^{2+} removal). Assume ALK = 105 mg/L as $CaCO_3$ (pH=6.9) and CO_2 = 20 mg/L as $CaCO_3$.

Other Benefits of LS Softening

- Removal of other metals, arsenic, & uranium
- Reduction of solids, turbidity, & TOC
- Inactivation of bacteria & viral removal
- Prevention of corrosion
- Removal of excess fluoride

Softening

- Softening reaction:

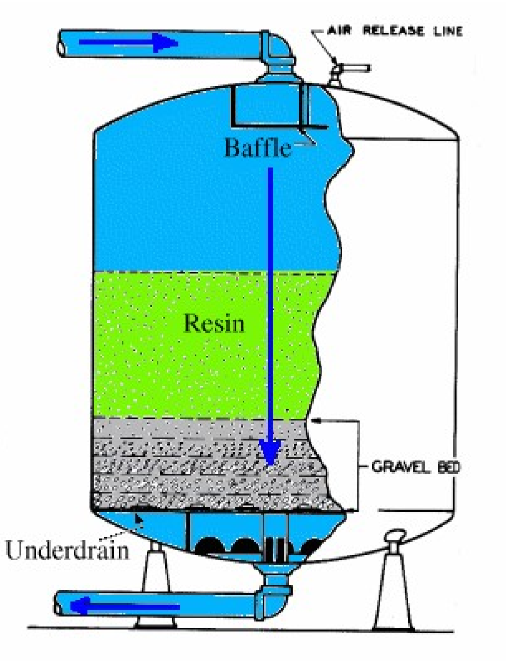
$Na_2R + Ca(HCO_3)_2 \leftrightarrow CaR + 2\ Na(HCO_3)$

- Regeneration reaction

$CaR + 2\ NaCl \leftrightarrow Na_2R + CaCl_2$

Ion Exchange Softening

Ion Exchange Softening

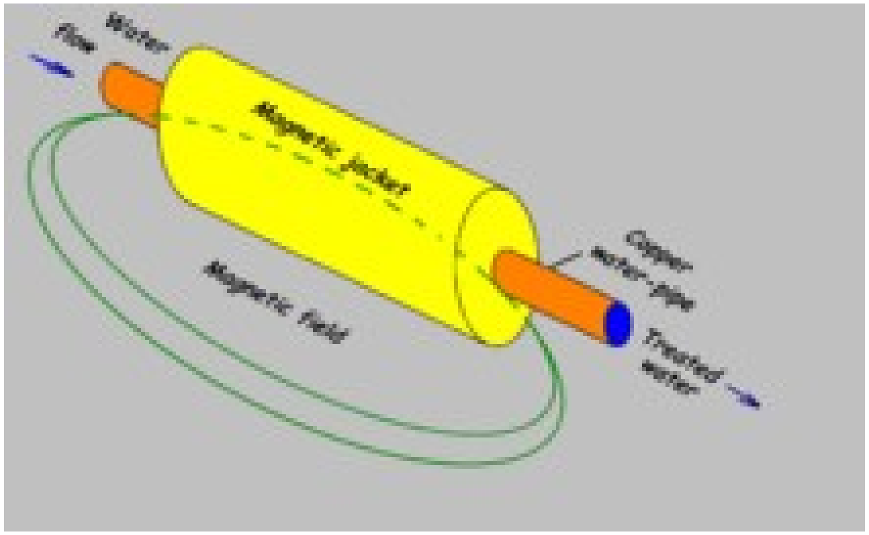


Example

An ion exchange water softener has 0.1 m^3 of ion-exchange resin with an exchange capacity of 57 kg/m^3. The occupants use 2,000 L of water per day. If the water contains 280.0 mg/L of hardness as $CaCO_3$ and it is desired to soften it to 85 mg/L as $CaCO_3$, how much should be bypassed? What is the time between regeneration cycles?

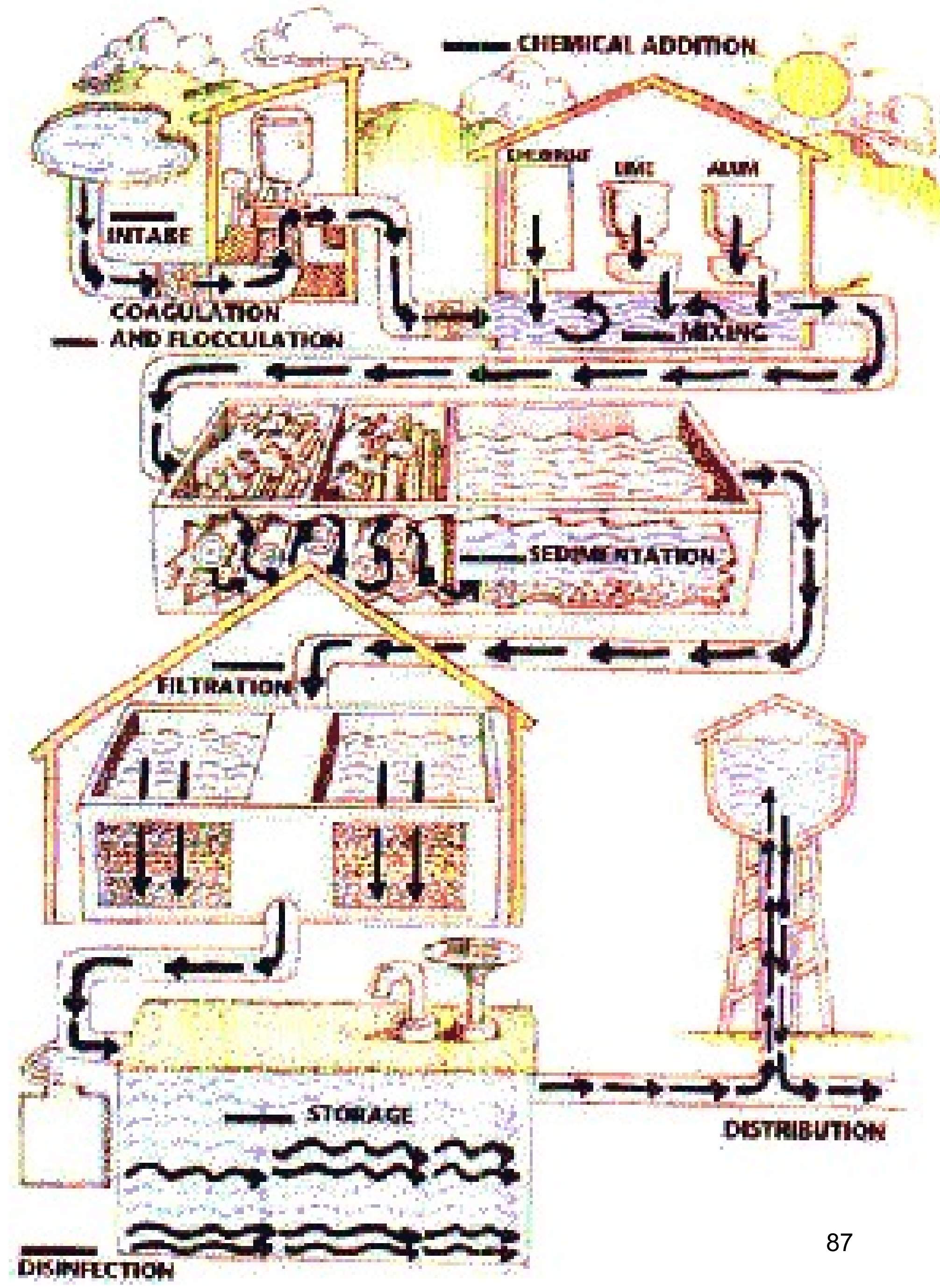
Other Softening Methodologies!

- Magnetic water treatment.
- Also known as anti-scale magnetic treatment (AMT)
- Non-chemical alternative
- Passing water through a magnetic field
- Still unproven and unscientific.

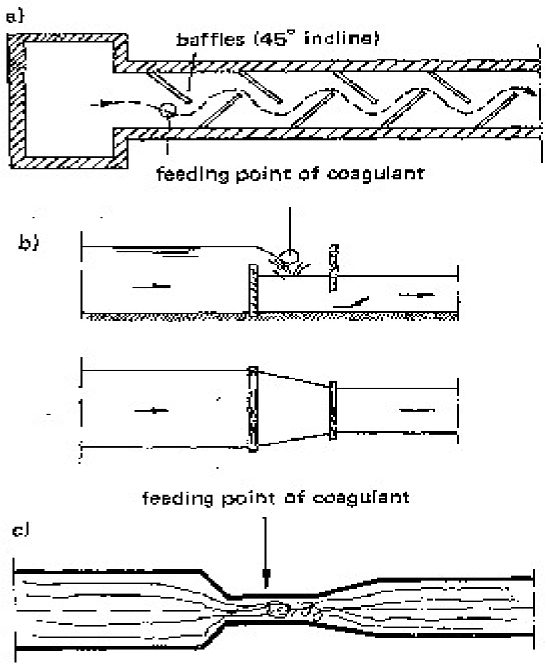


MIXING

Objective: **quickly and uniformly disperse chemicals into water**



Mixing



Baffled Channels

Hydraulic Pump or Jump

In line blender or static mixer

Rapid Mix Tank

Parshall Flume

Fine Air Diffusers

Flash Mixer in Al-Rumaitha WTP

Flash Mixer in Al-Rumaitha WTP

Design Equation:
Hydraulic Retention Time

$$\bar{t} = \theta = \frac{V}{Q}$$

In-Class Activity

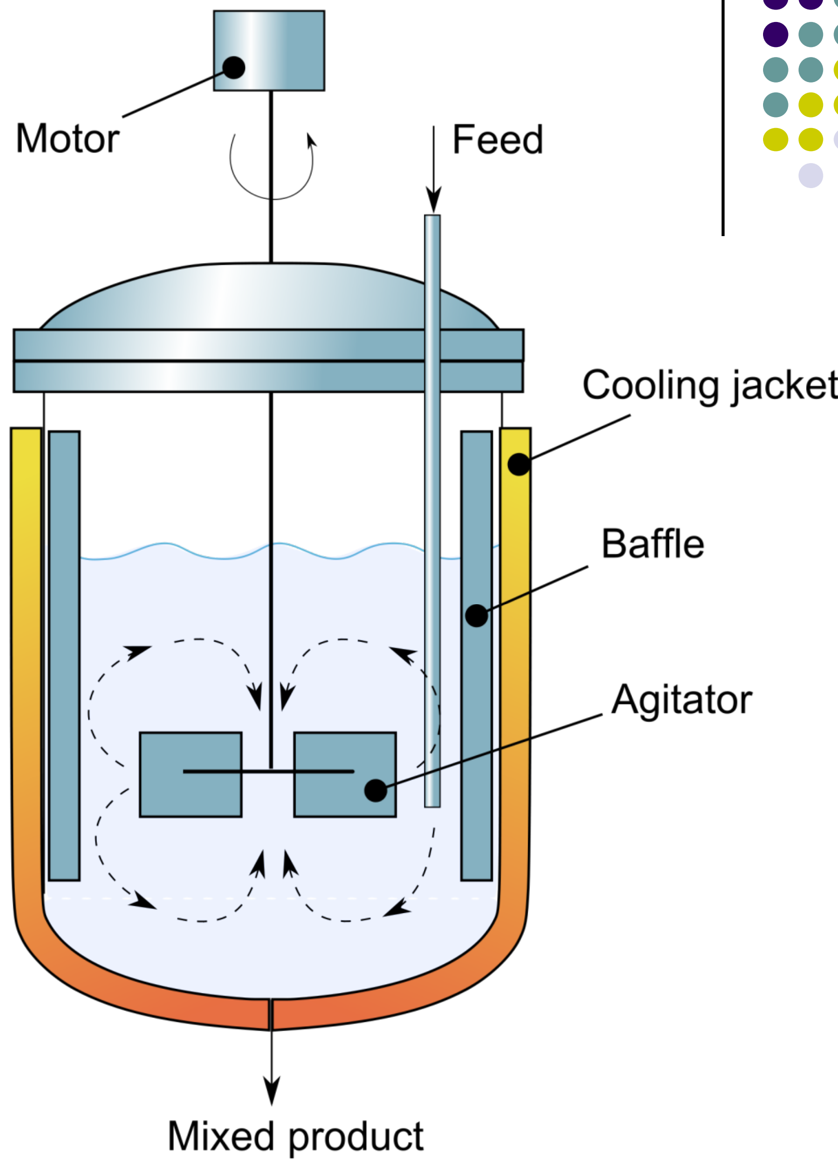
A 0.5-MGD water treatment plant will use one flash mixer designed for a 1-minute retention time. Determine the diameter of the mixer. Assume the water depth will equal 80% of the diameter.

Rapid Mixing

- Agitators

1. Mechanical agitation (e.g. paddles)
2. Pneumatic agitator
3. Baffle basin

GT value



Rapid Mixing

- Inline mixing
- Typical detention time 20-60 sec
- 10 States Standards 4.2.2.a
- Fluid depth is 1 to 1.25 times the basin diameter
- Rotary mixing devices: turbine impellers

Impellers diameter = 30% to 50% of tank diameter

- Small baffles

Extending to the tank 10% of the tank width to minimize vortexing so more power will be imparted to the liquid

- Paddle vs. propeller impellers

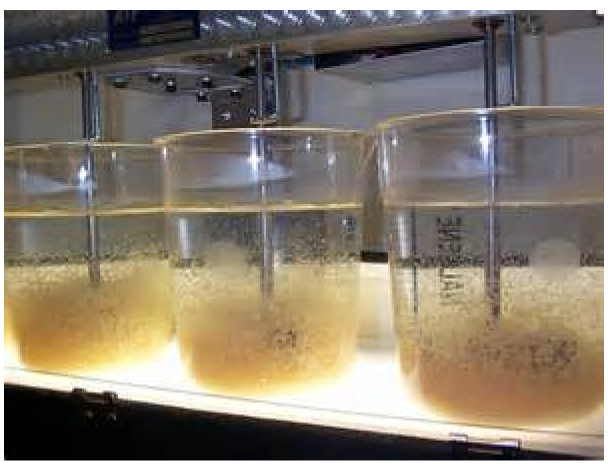
Rapid Mixing

TABLE 8.1 *Detention Times and Velocity Gradients of Rapid-Mixing Basins*

DETENTION TIME (sec)	G (fps/ft or sec^{-1}; mps/m or s^{-1})
20	1000
30	900
40	790
50 or more	700

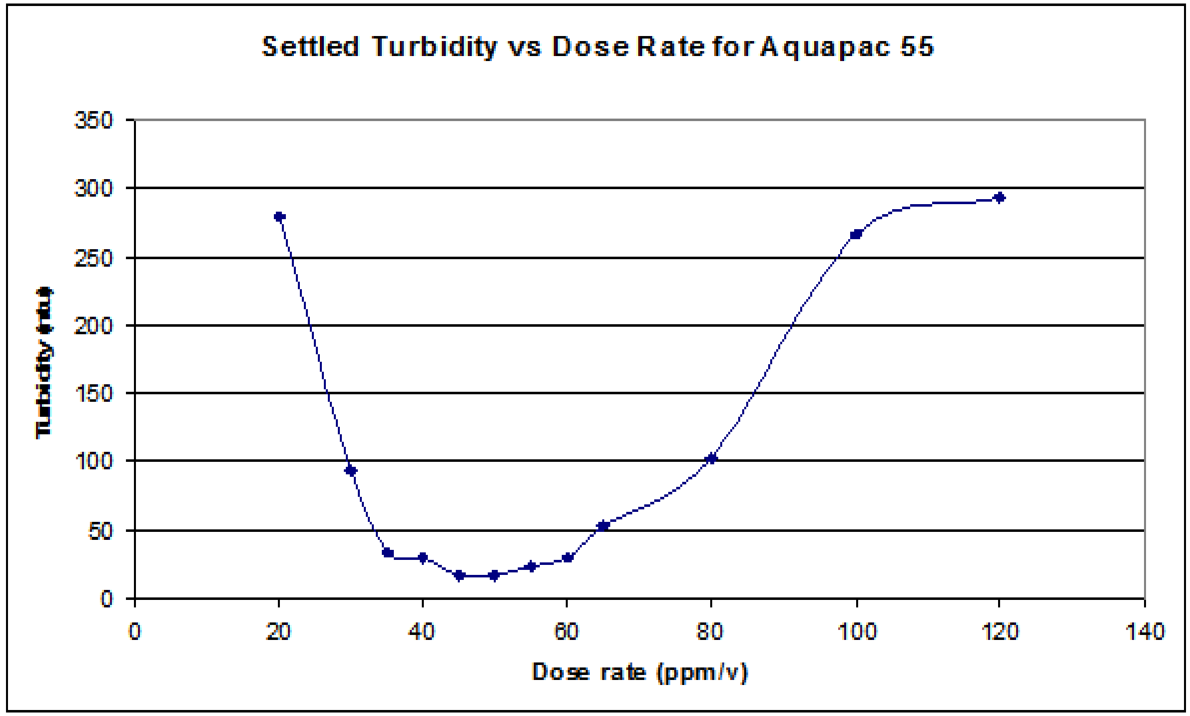
Rapid Mixing

- Volume of rapid mix tank < 8 cubic meter
- Coagulant consume alkalinity
- 1 meq/L of coagulant → consume 1 meq/L alkalinity → produce 1 meq/L chemical sludge



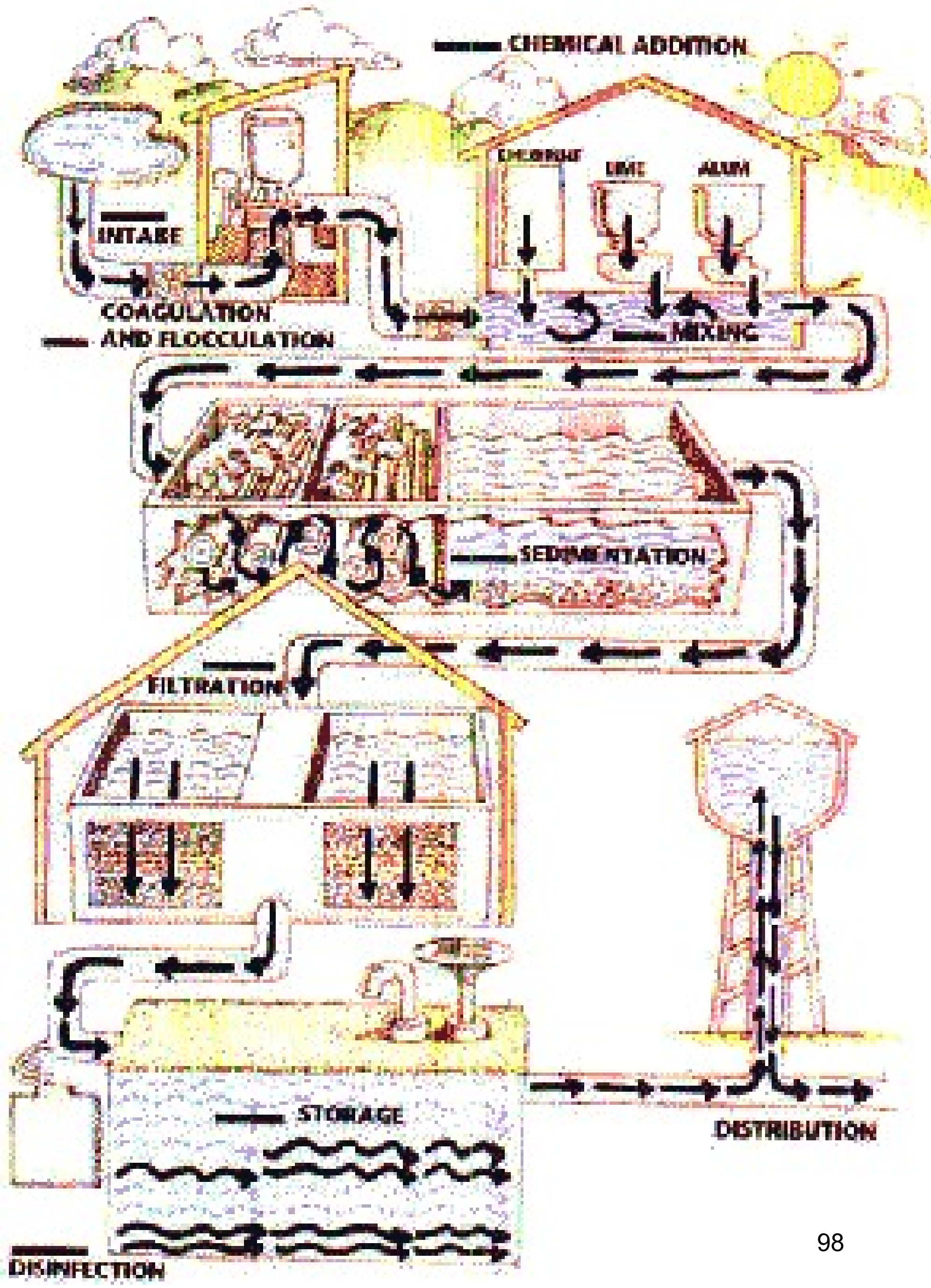
Jar Test

- Dose selection



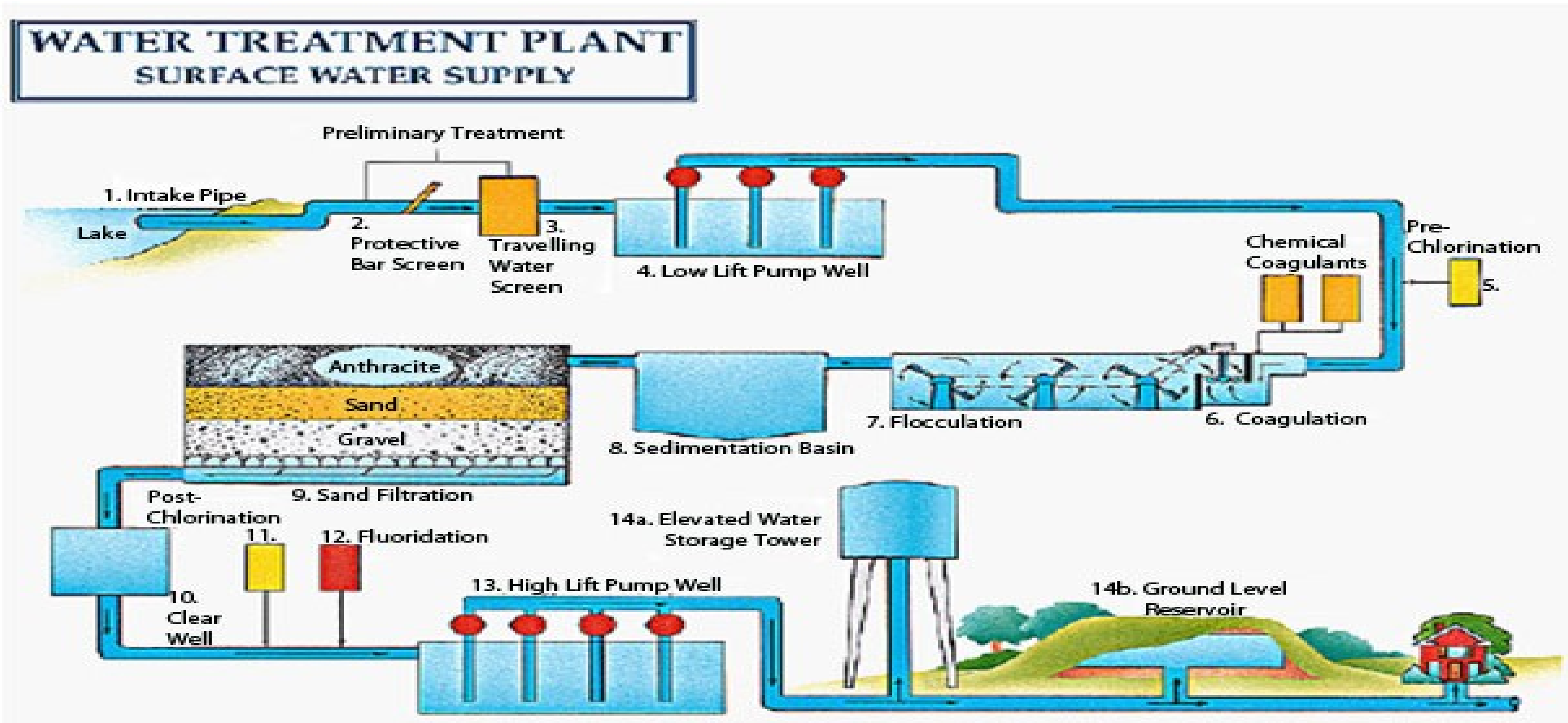
SOLIDS REMOVAL

Coagulation and Flocculation



Flocculation

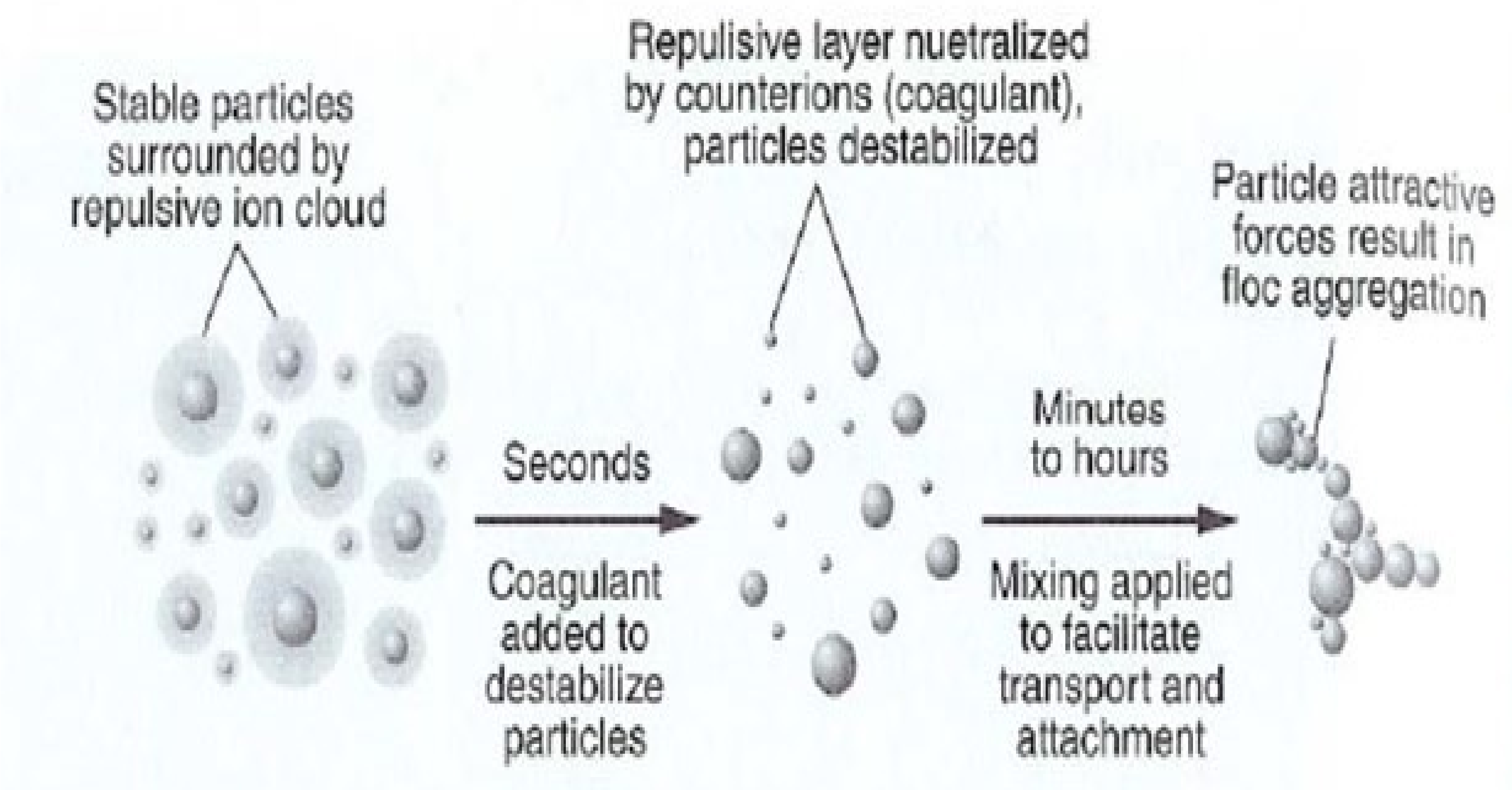
Promote growth of flocs to a size that can be removed by sedimentation and filtration.



Solids by Size
(Section 9.1.3)

Classification	Diameter (mm)
Dissolved	< 0.000 001
Colloidal	0.000 001 - 0.001
Suspended	0.001 - 0.1
Particulate	> 0.1

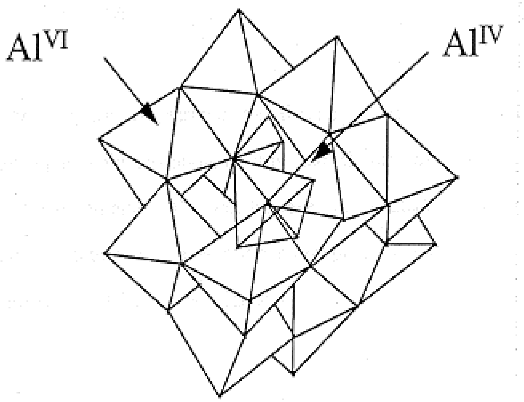
Flocculation



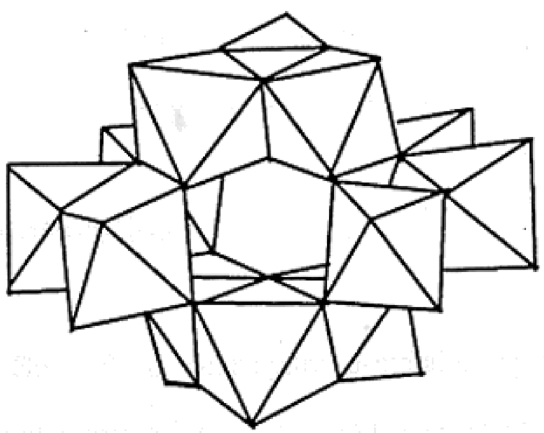
Flocculation

- Gentle agitation or stirring
- Power imparted by mechanical or pneumatic agitation
- Mechanical agitation with paddle wheels
- Tapered flocculation: decreasing in velocity gradient (G)

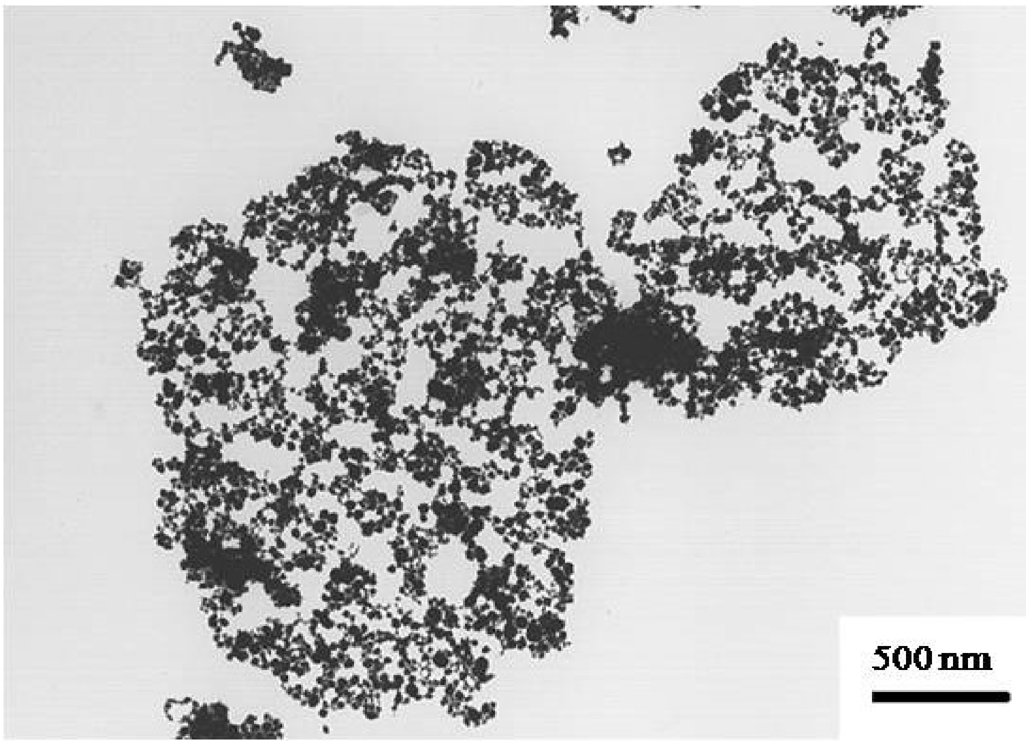
Coagulation & Flocculation



Al -13 Polycation



Fe-12 Polycation



Chemical Name	Chemical Formula	Primary Coagulant	Coagulant Aid
Aluminum sulfate (Alum)	$Al_2(SO_4)_3 \cdot 14\ H_2O$	X	
Ferrous sulfate	$FeSO_4 \cdot 7\ H_2O$	X	
Ferric sulfate	$Fe_2(SO_4)_3 \cdot 9\ H_2O$	X	
Ferric chloride	$FeCl_3 \cdot 6\ H_2O$	X	
Cationic polymer	Various	X	X
Calcium hydroxide (Lime)	$Ca(OH)_2$	X*	X
Calcium oxide (Quicklime)	CaO	X*	X
Sodium aluminate	$Na_2Al_2O_4$	X*	X
Bentonite	Clay		X
Calcium carbonate	$CaCO_3$		X
Sodium silicate	Na_2SiO_3		X
Anionic polymer	Various		X
Nonionic polymer	Various		X

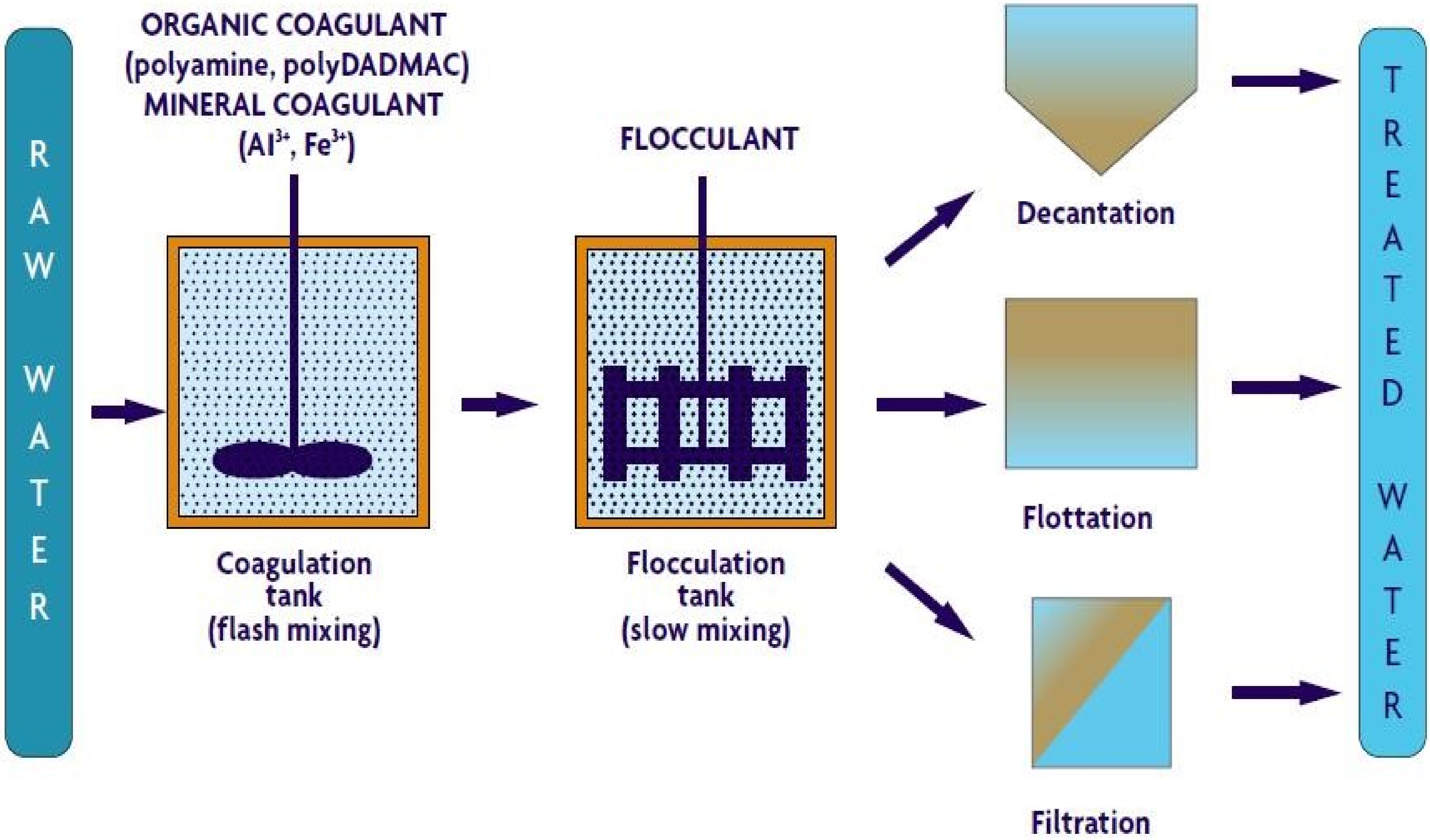
Flocculator

Vertical Shaft Type

Horizontal Shaft Type

Baffled Flow Type

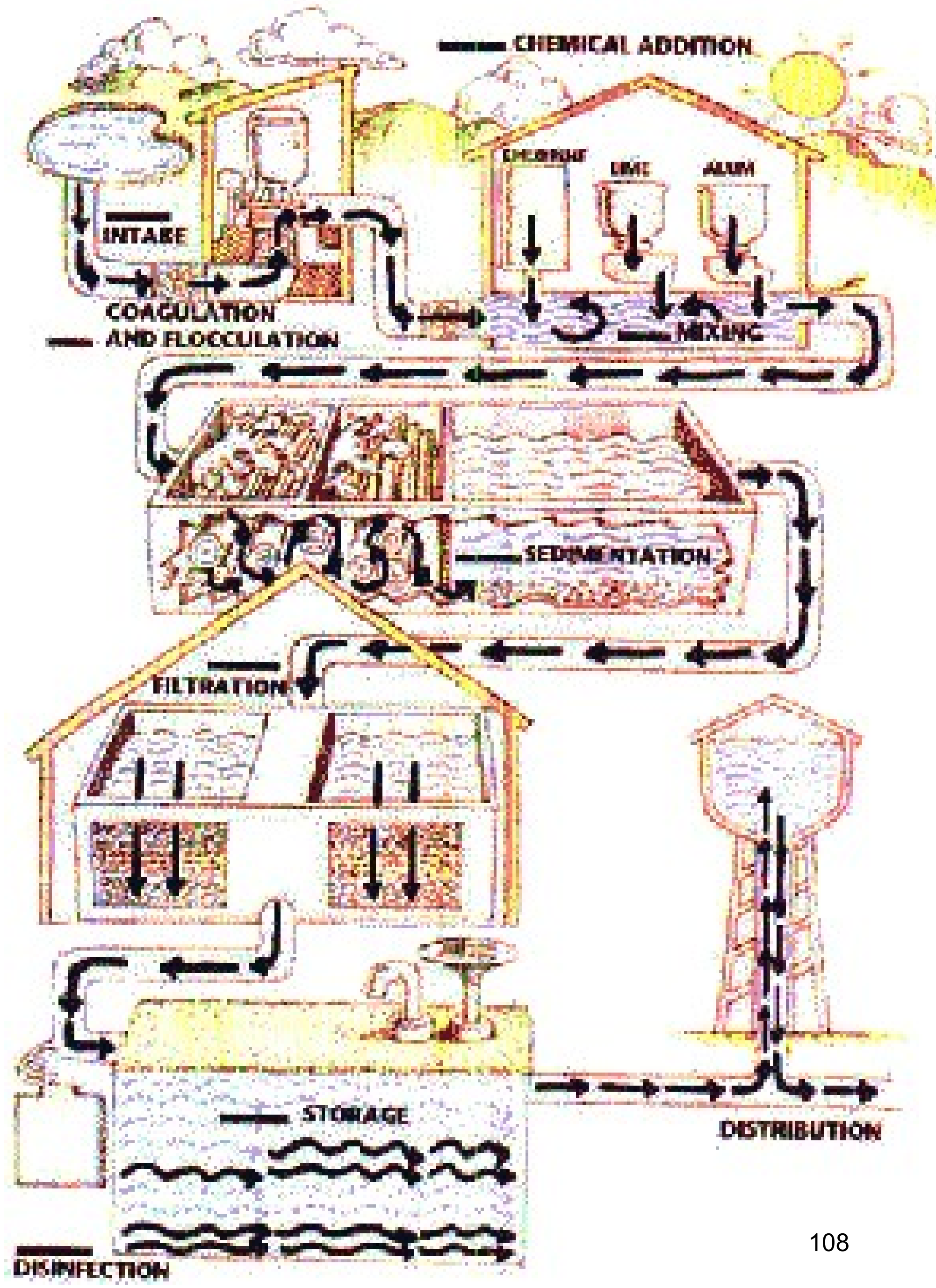
Flocculation



Example

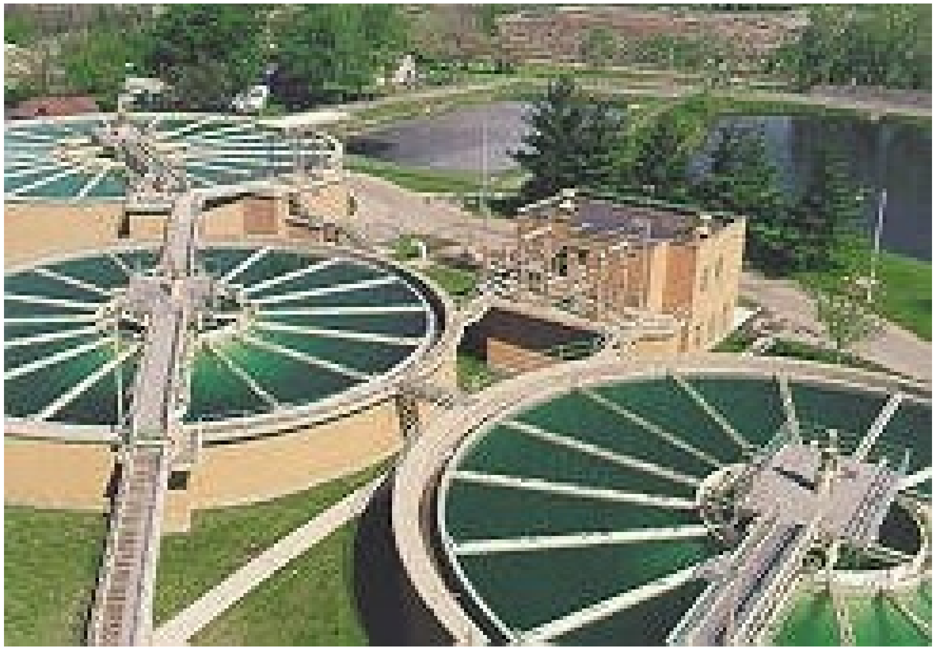
- 110 mg/L of a ferric salt containing 20% Fe^{3+} is used to coagulate a water. How many mg/L of natural alkalinity are consumed?

Sedimentation



Sedimentation

Purpose: Remove solids

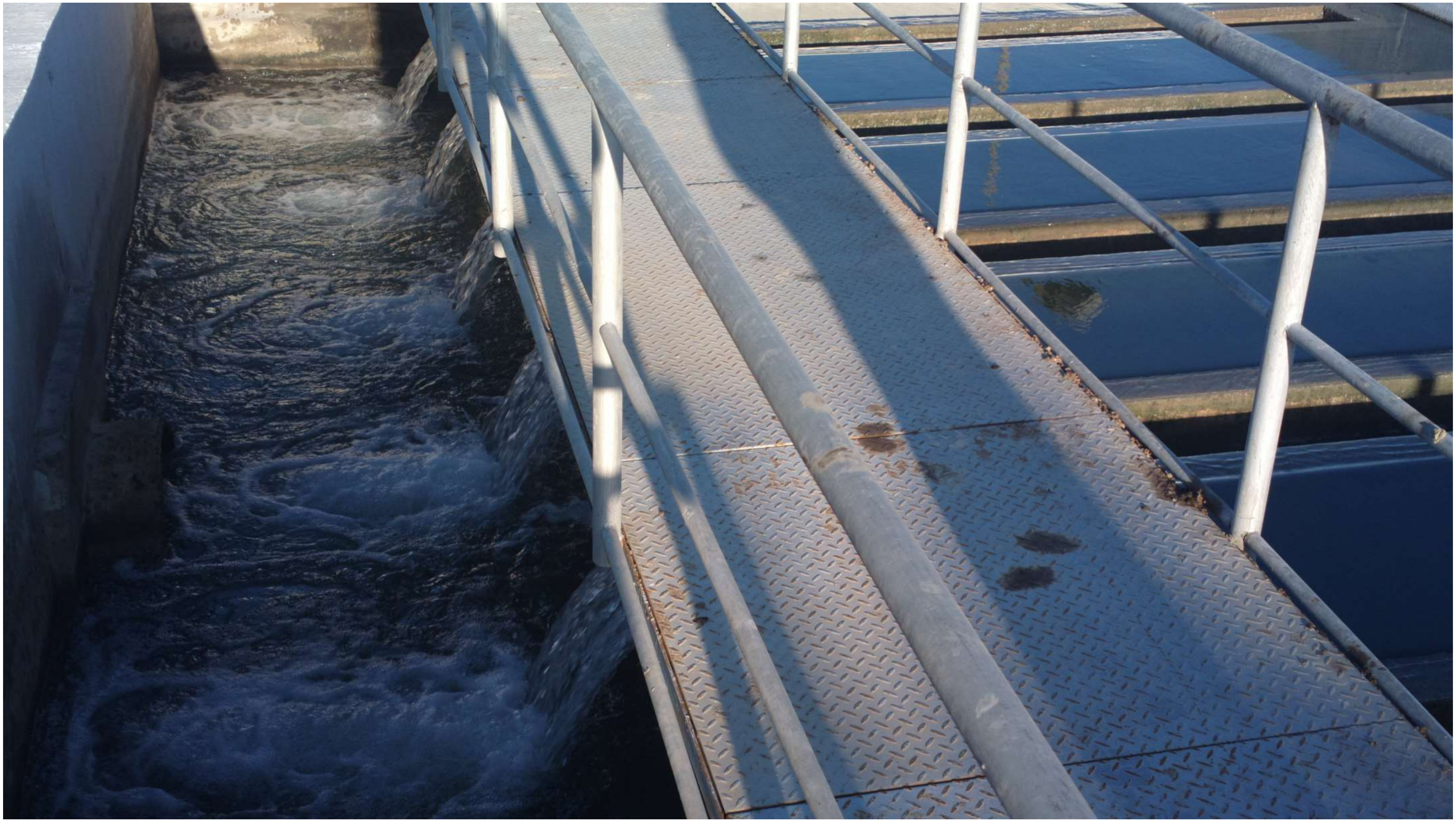


Sedimentation: Another View

Sedimentation

- Sludge concentrators and sludge removal
  - 10-States Standards 4.2.5.6 and 7
  - Detention period 10-States Standards 4.2.5.9
- Inlet and outlet design to maintain velocities suitable for settling in the basin
  - Weirs or orifices constructed so that water at the surface of the unit does not travel over 10 feet horizontally to the collection trough
    10-States Standards 4.2.5.9

Clean water leaves sedimentation tank to sand filters in Al-Rumaitha WTP



Clean water leaves sedimentation tank to sand filters in Al-Rumaitha WTP: weir discharge

Design Equation: Overflow Rate

$$OFR = v_o = \frac{Q}{A_s}$$

In-Class Activity

The detention time and overflow rate for a circular settling basin were determined to be 1.5 h and 0.5 gpm/ft^2, respectively. The flow rate will be 250,000 gpd. Calculate the dimensions of the basin.

In-Class Activity

A 2-MGD water treatment plant will use two rectangular sedimentation basins designed for a 3-hour total detention time. If the basins will be twice as long as wide, what will be their dimensions? What will be the OFR for each basin? Assume the water depth will equal the width.

1-Assume parallel flow.

2-Assume series flow.

Assignment #5

A water treatment plant is being designed to process 13 MGD of surface water with chemical coagulation, sedimentation and filtration. Jar testing and pilot-plant analysis indicate that an alum dosage of 40 mg/L with flocculation at a Gt value of 80,000 produces optimum results at the expected water temperature of 15^{o}C.

The rapid mix and flocculation design are to conform to the *Recommended Standards for Water Works* by the "Great Lakes–Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers".

The flocculation should be done with three sets of cross-flow, horizontal paddle wheels. Each flocculation basin should be a maximum of 40 ft wide and 16 ft deep in order to connect appropriately with the sedimentation basin. Each set of paddle wheels shouldn't exceed a length of 7 feet on a single axle along the shaft. The total Gt value for each flocculation basin should be 80,000, but the G value should taper (by 15% in G value) from an above average value for the first paddle wheels, to an average value for the middle paddle wheels, then to a less (by 15% in G value) than average value for the third set of paddle wheels. Determine:

- The monthly alum requirement in lb,
- The number of rapid mix basins and dimensions of each (use square basin, each not to exceed a volume of 8 m^3),
- The rapid mix impeller type (use "turbine, 6 flat blades, vaned disc", see the Handout pp.188, Table 8.2), diameter, and speed of rotation,
- The number of flocculation basins and dimensions of each (design for 3 chambers in each basin)
- The paddle wheel design for flocculation, including

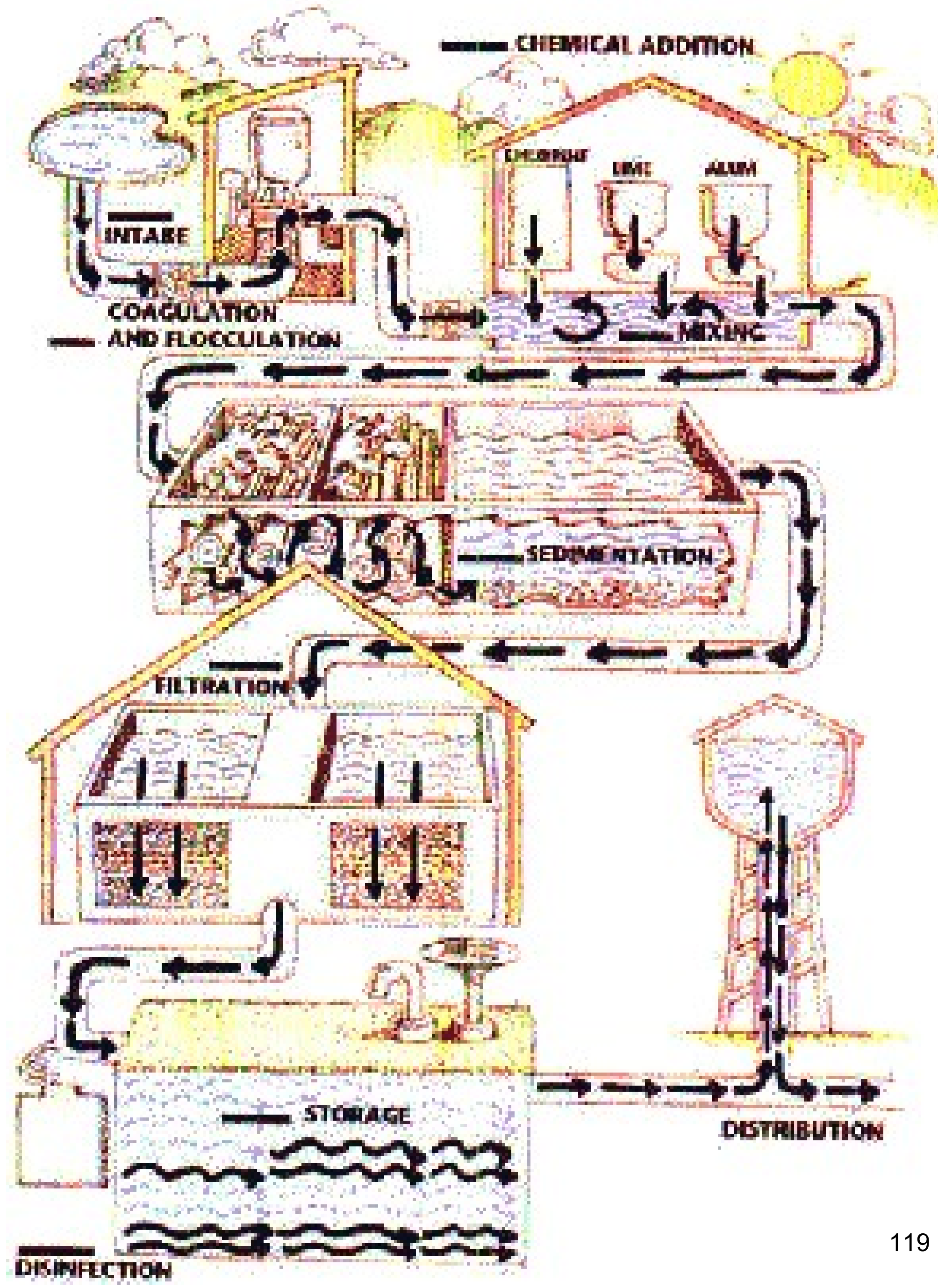
  a) The number and dimensions of boards for each set of paddle wheels,
- b) The rotational speed for each set of paddle wheels
- c) A sketch of plan, side & end views of the flocculation basin, showing the placement of the paddle wheels, complete with major dimensions.

Assignment #6

Prepare a design for a set of rectangular sedimentation tanks to follow the rapid mix and flocculation tanks that you designed for the 13 MGD surface water treatment plant. Overflow weirs should be used for the outflow from the sedimentation tank. The design must satisfy the 10-States Standards. Your design should include the following:

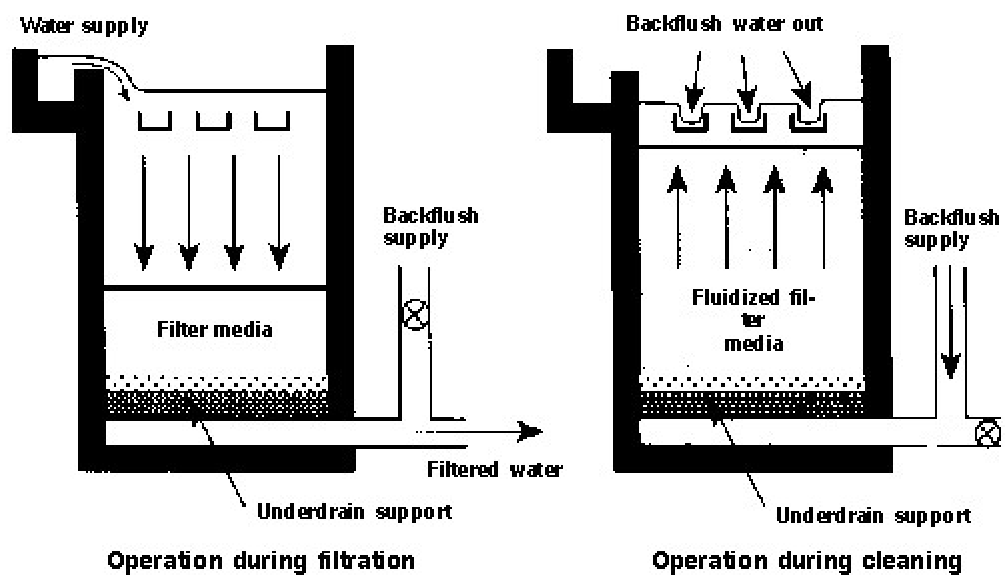
- The length, width and depth of each sedimentation basin, (Assume that sludge collection equipment is available in 2 ft increments from 10 ft to 20 ft.
- The outlet weir box configuration,
- A description of the method of introducing the water into the sedimentation basin and any inlet device(s),
- A sketch of a plan view and side view of one of the sedimentation basins,
- Calculate the surface overflow rate for the sedimentation basin as designed.

Filtration


CHEMICAL ADDITION
LIME
ALUM
INTAKE
COAGULATION
AND FLOCCULATION
MIXING
SEDIMENTATION
FILTRATION
STORAGE
DISTRIBUTION
DISINFECTION

Filtration

- Involves the removal of particulate material suspended in a liquid by passing the liquid through a filter bed comprised of a granular or compressible filter medium (Metcalf and Eddy, 2003)
- Conventional vs. direct
- Main character in filtration: grain size of filter medium
  - Small vs. large



Filtration Methods

Gravity Filters

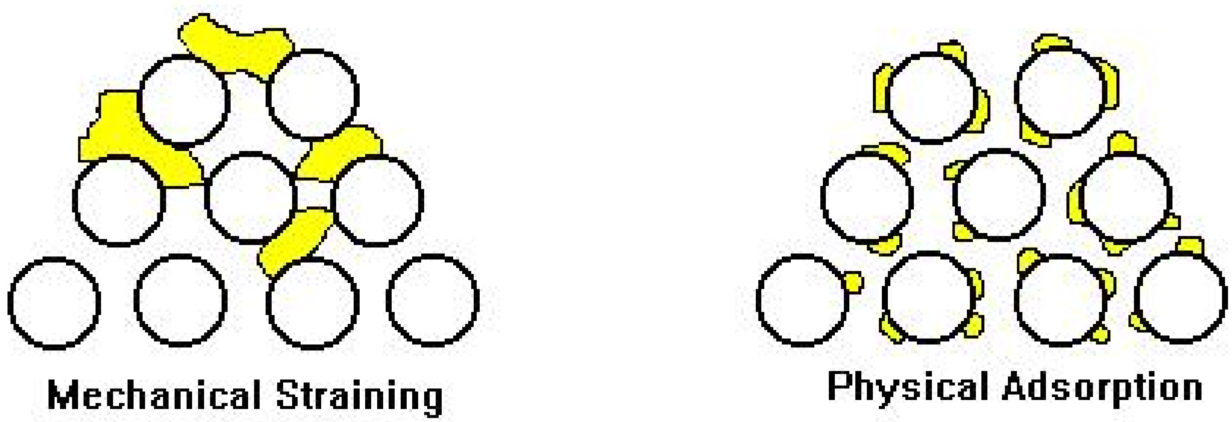
Upflow Filter

Biflow Filter

Pressure Filter

Filtration Mechanisms

Main mechanism: straining and physical adsorption (electro-static-kinetic forces and Vander Waals force
Other mechanisms: impaction, interception, adhesion, and flocculation

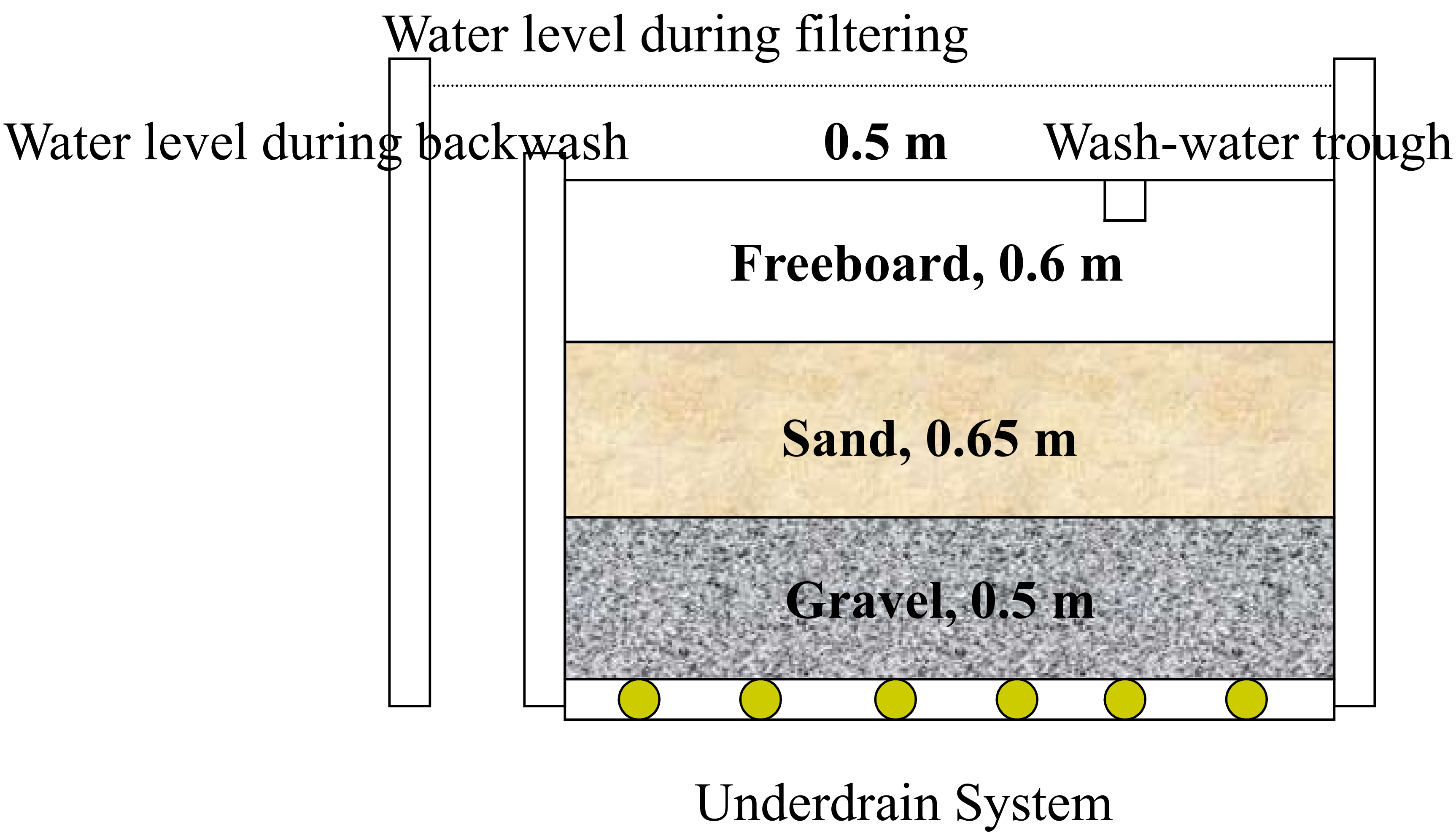


Slow vs. Rapid Sand Filters

Slow vs. Rapid Sand Filters

Criteria	Slow sand filter	Rapid sand filter
Water quality	For high quality (<30NTU)	Any level
Plants	Rural and small towns	Public water supply
Loading rate	0.03-0.05 gpm/ft2	2-5 gpm/ft2
Biological treatment	May have biological treatment	None
regeneration	Months before regeneration	Days for regeneration
Back wash	0.2-0.5% of the filtered water or scrape	1-5% of the filtered water and back wash rate of 15-20 gpm/ft2
Operation and maintenance	low	high

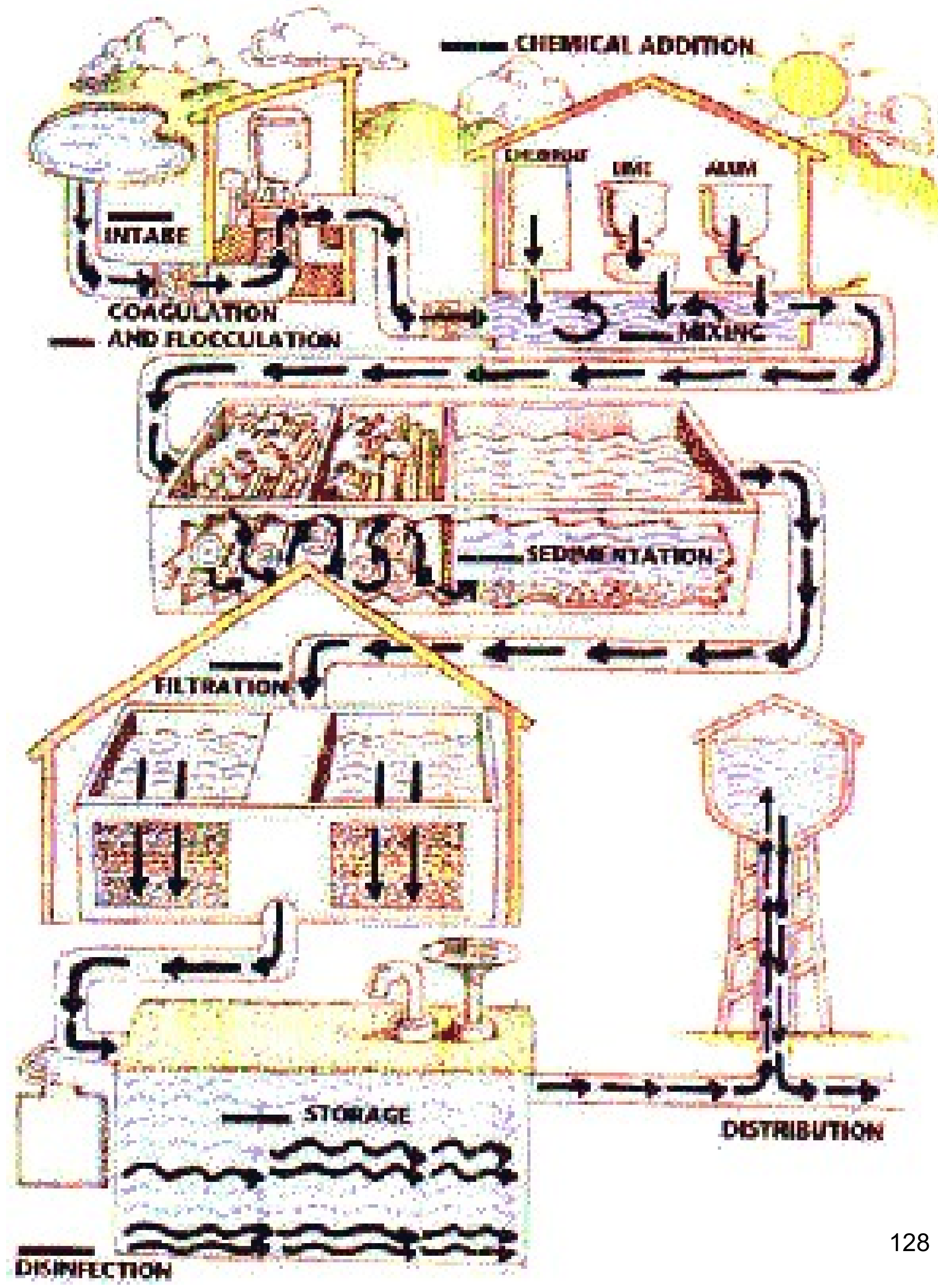
Typical Gravity Filter



Rapid sand filter in Al-Rumaitha WTP

Example

- Sand with a particle diameter of 0.02 inch is used in a sand filter. After use, the depth of the filter is 0.5 ft and the porosity is 0.35. During backwash, the porosity is 0.70. What will be the depth of the filter during backwasing?



Disinfection

Activity - 1

Why is drinking water disinfected?

Activity - 2

Who linked contaminated water to infectious disease?

A. Leonard McCoy
B. John Snow
C. Robert Romano

Activity - 3

In general, what is an indicator organism and why is it used?

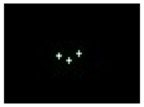
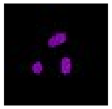
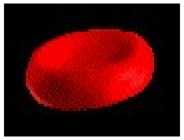
Microbial Indicators

- Hard to identify pathogens and test them
- Easier, cheaper and safer to use indicator
- Ideal indicator?
  - Present when the pathogens present (surviving longer than most known pathogens)
  - Present in fecal material in large number
  - Act like pathogens during treatment process
  - Easily detected
  - Simple and inexpensive to test
  - Have high indicator/pathogen ratio
  - Generally non pathogenic

Major Indicators

- Total Coliforms
  - Aerobic and facultative anaerobic
  - Rod shape and non spore forming bacteria
  - Lactose used as a base to identify bacteria
  - Assess water treatment effectiveness and the presence of fecal contamination
  - Not adequate for protozoan cysts/oocysts and some viruses
- Fecal Coliforms and E-Coli
  - A subset of total califorms group
  - Less effective in assessing treatment due to less density than total califorms
- Heterotrophic Bacteria: Heterotrophic Plate Count HPC
  - Disinfectant present if HPC<500 colonies/mL
- Turbidity
  - Relationship b/w turbidity and total coliforms

Size Comparison

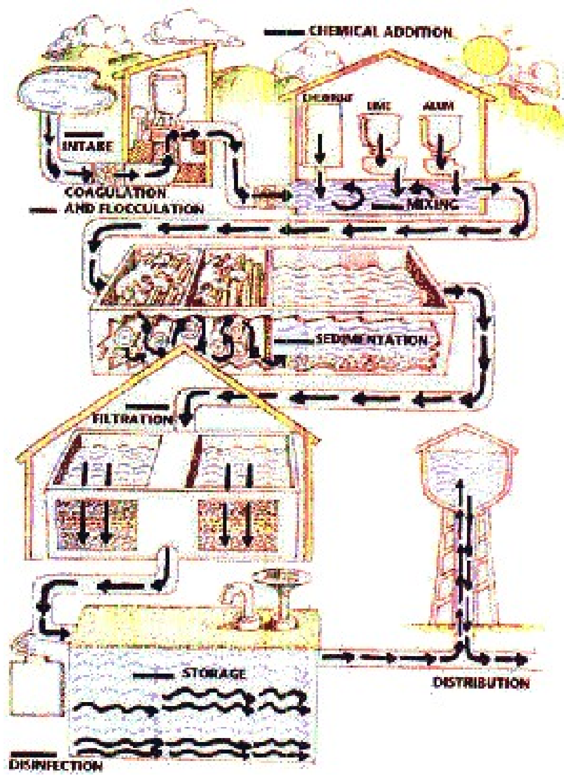
		10 microns	<u>Filter</u>
Virus		0.05 - 0.1 µm	Pass
Bacteria		0.5 - 1.5 µm	Caught
Red Blood Cell		5 µm	Caught

Disinfection Objectives

- 3-log removal of Giardia Lamblia Cysts and 4-log removal of viruses.
- Do not impart toxicity, taste, and odor to the disinfected water.
- Minimize the formation of DBPs.
- Meet the MCLs for the disinfectants and the disinfection byproducts.

Pathogen Removal/Inactivation

Where does this occur in a water treatment plant?



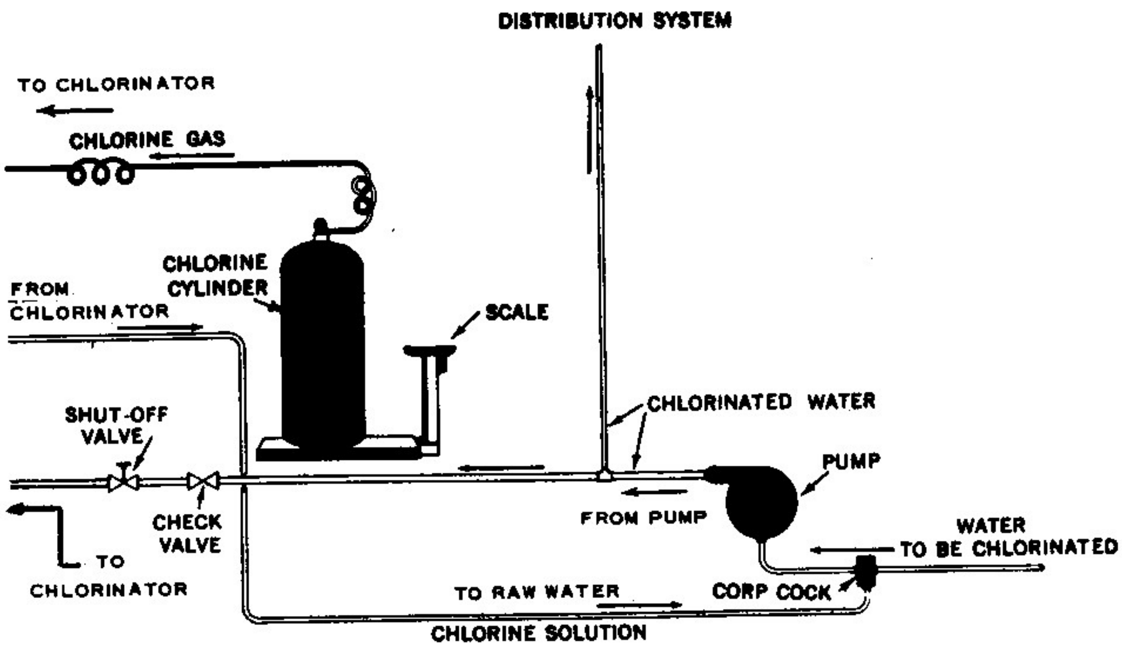
Activity - 5

What are the options for disinfecting water?

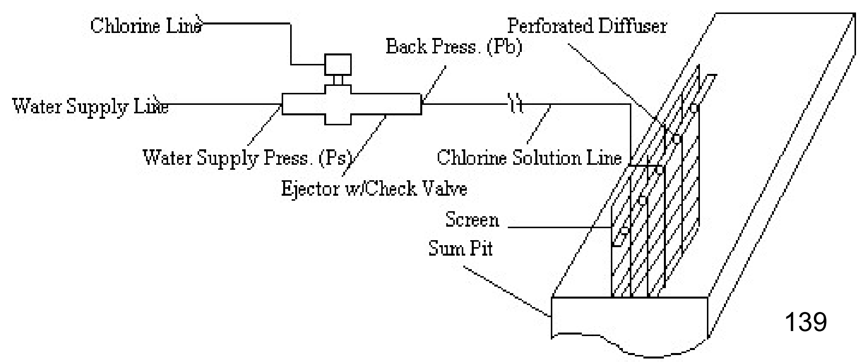
Activity - 6

What are characteristics of the ideal disinfectant?

Chlorination



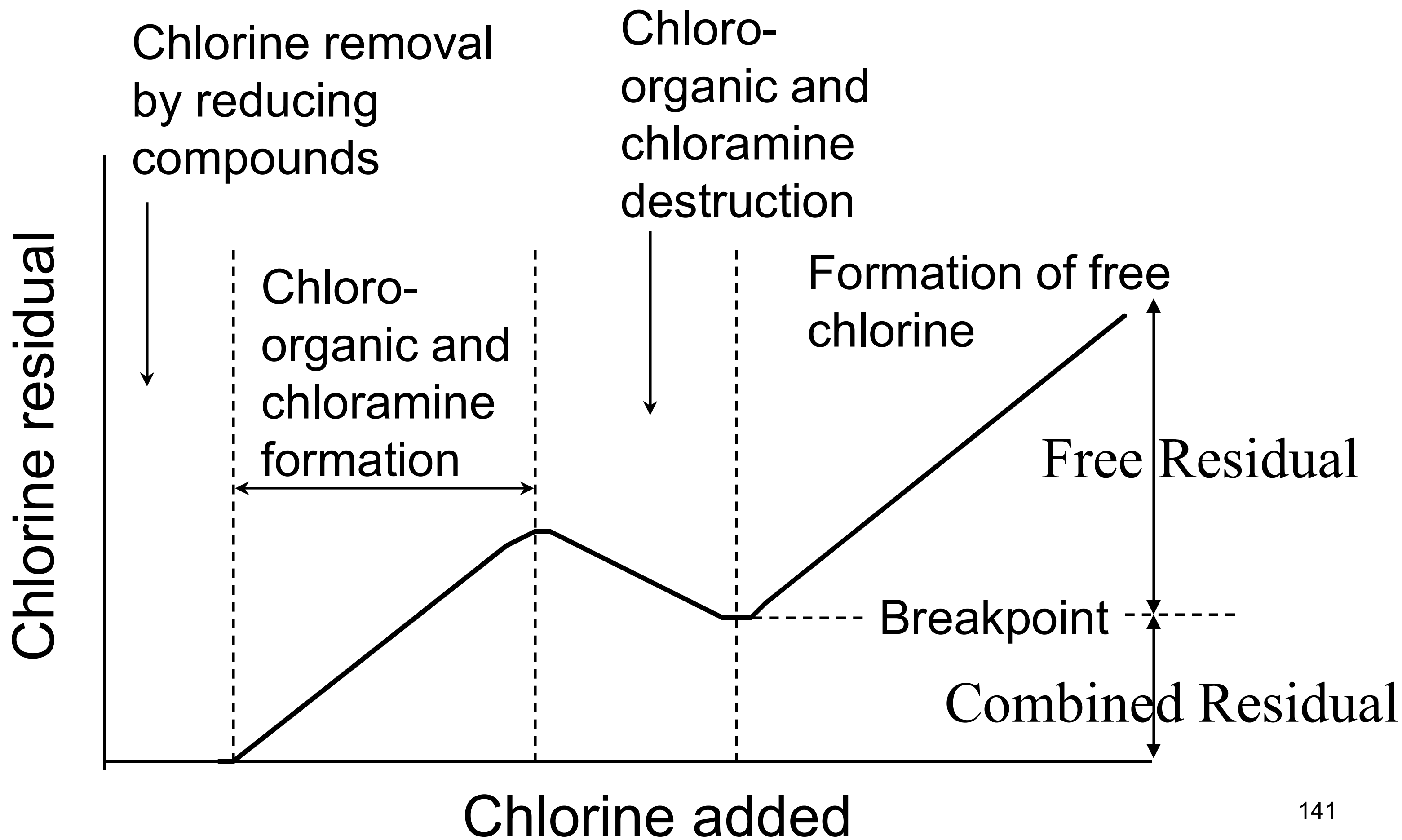
chlorinator



Typical Application in Cooling Water Chlorination

Chlorination

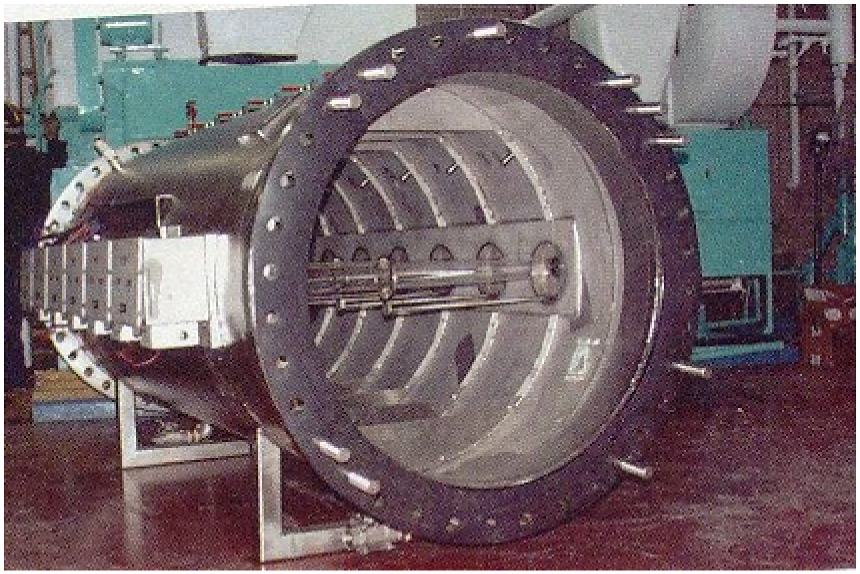
Chlorine Demand or Breakpoint Chlorination

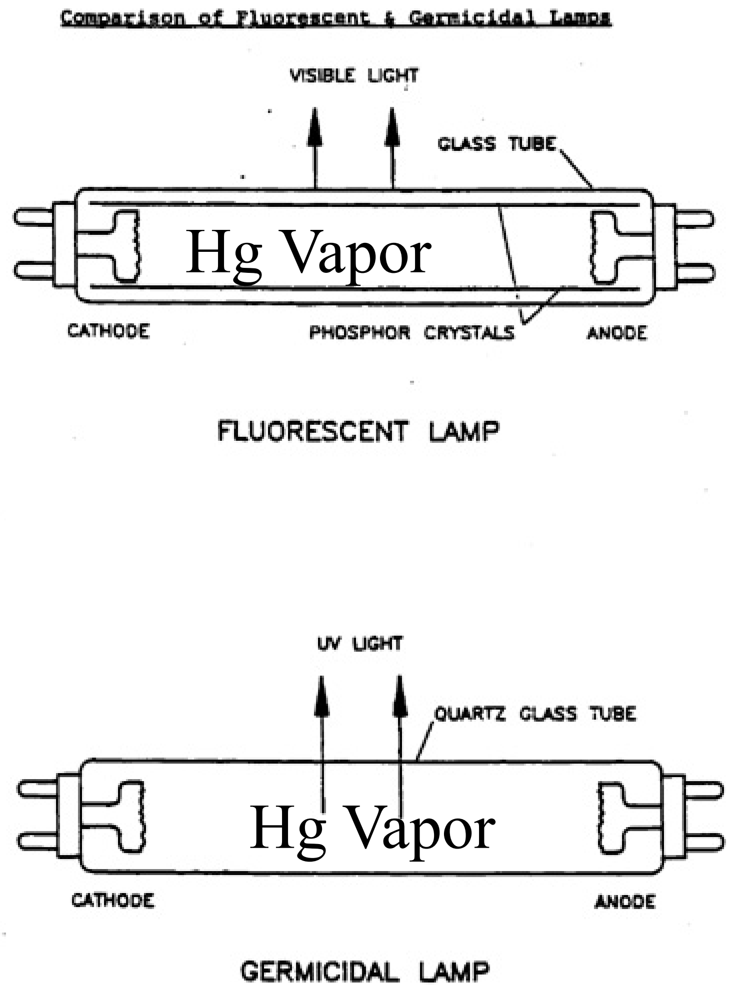


In-Class Activity

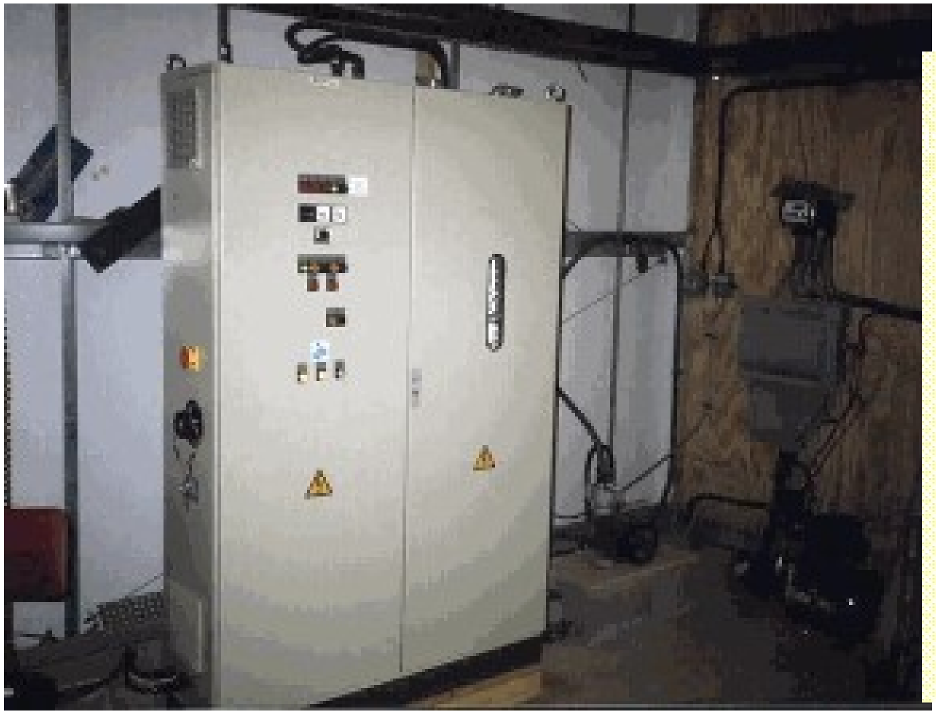
- If 1.5 mg/L of chlorine is being used and the demand is 1.2 mg/L, what is the residual?
- For the same plant, if 550,000 gpd is being treated and chlorine will be bought in 1-ton containers, how long will one container last?

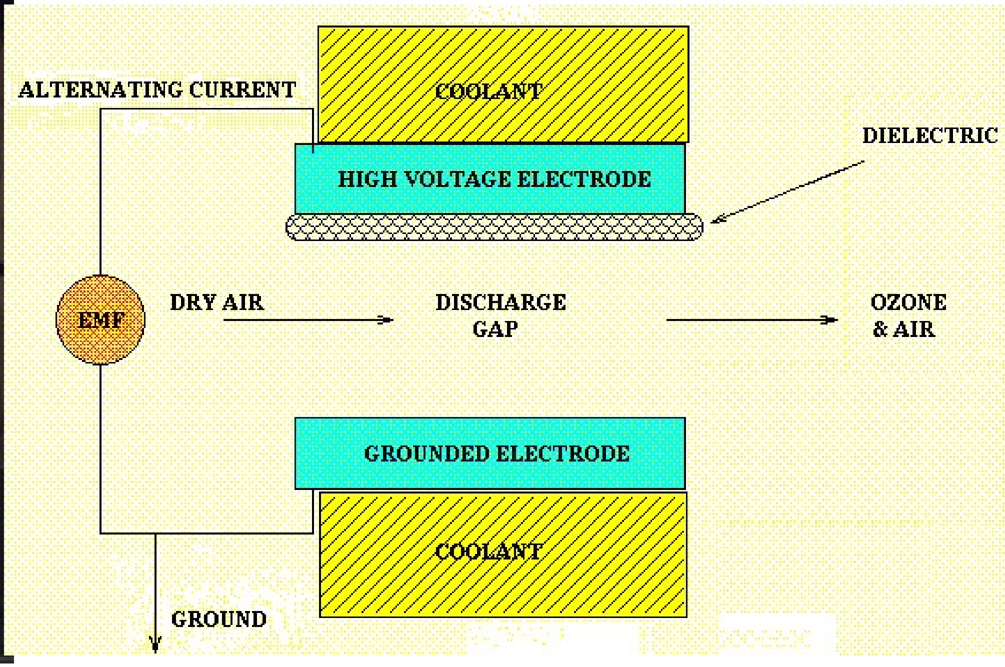
Ultraviolet Light





Ozonation



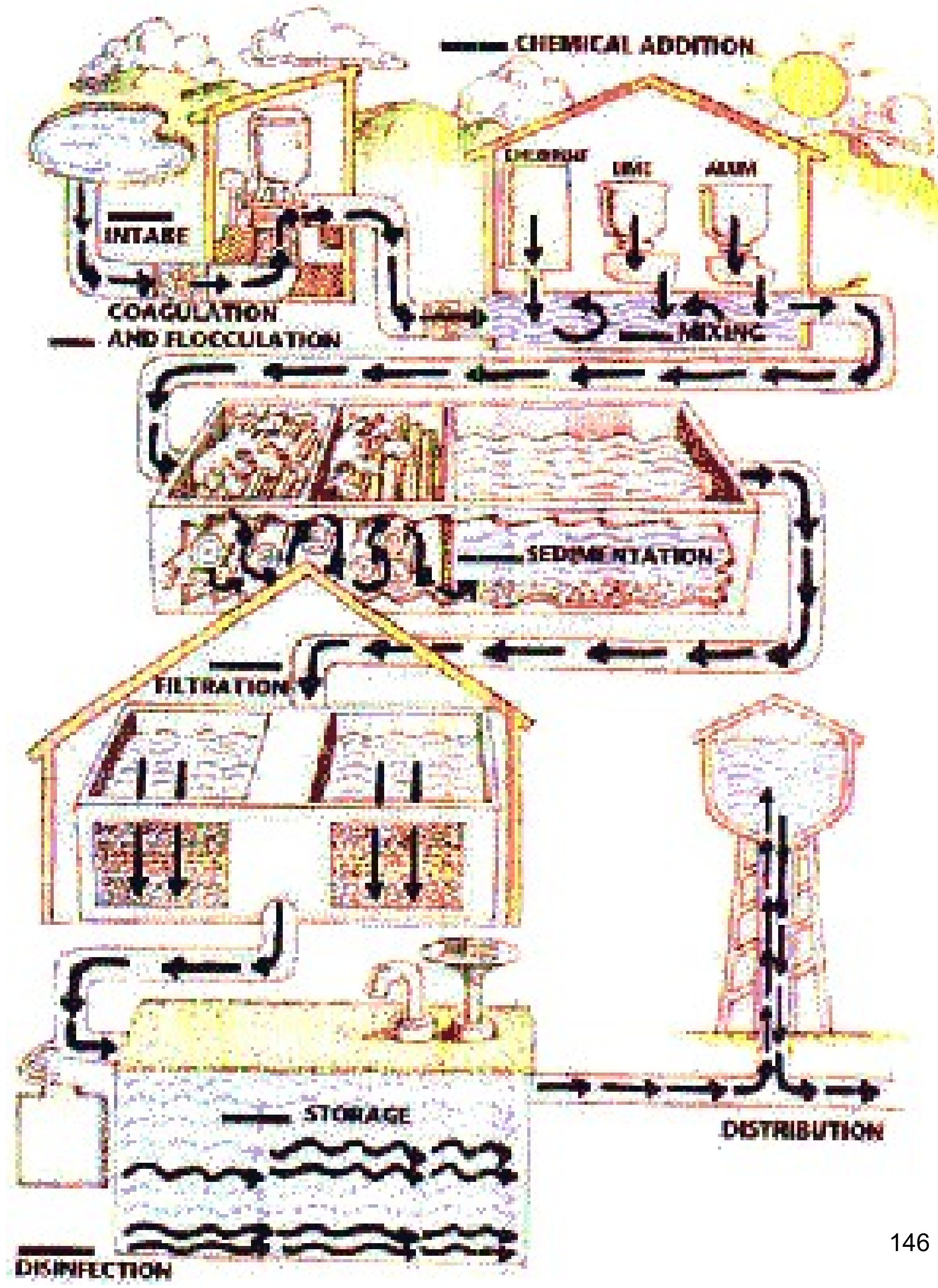

ALTERNATING CURRENT
COOLANT
HIGH VOLTAGE ELECTRODE
DIELECTRIC
EMF
DRY AIR
DISCHARGE GAP
OZONE & AIR
GROUNDED ELECTRODE
COOLANT
GROUND

Activity - 7

Adequate disinfection is a balance between which two variables?

A. Concentration and Time
B. Concentration and Flow rate
C. Flow rate and Surface area

Storage and Distribution



Microbiological Quality in Distribution Systems

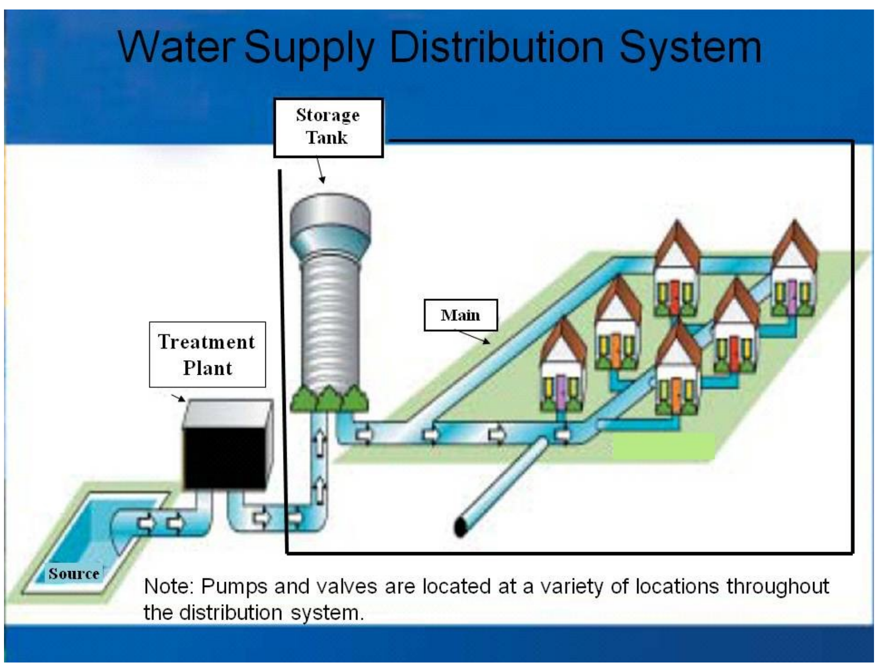
Distribution Systems

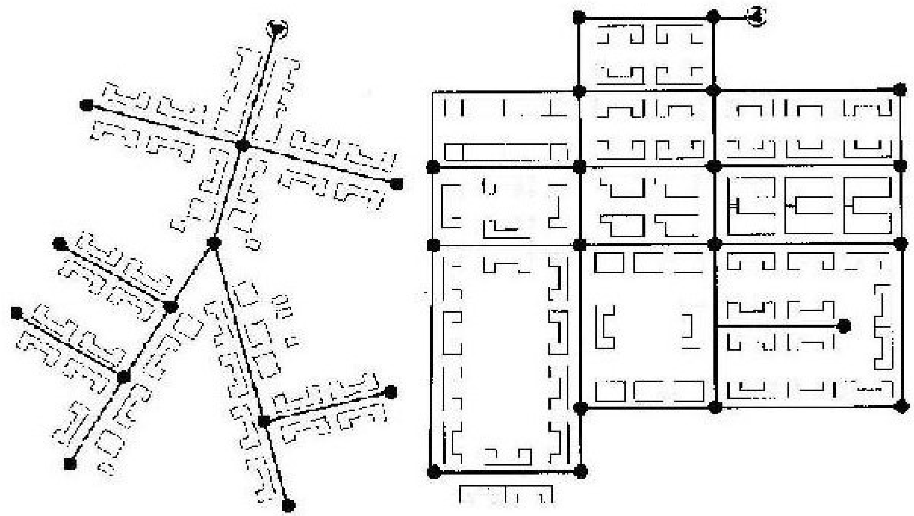
- Pipes

- Reservoir storage
- Pressure pumping

Pipes Network

- A grid with a series of loops to avoid dead ends and to produce circulating system capable of supplying high quality water
- Objective: prevent any intrusion of contamination or occurrence of microbial degradation



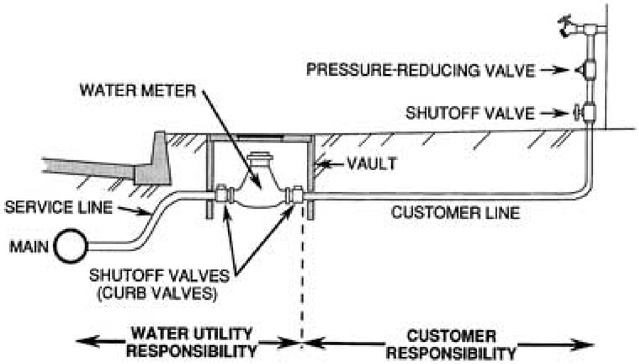


System Components

- Network of mains
- Fire hydrants
- Valves
- Auxiliary pumping
- Chlorination substations
- Storage reservoirs
- Standpipes
- Service lines





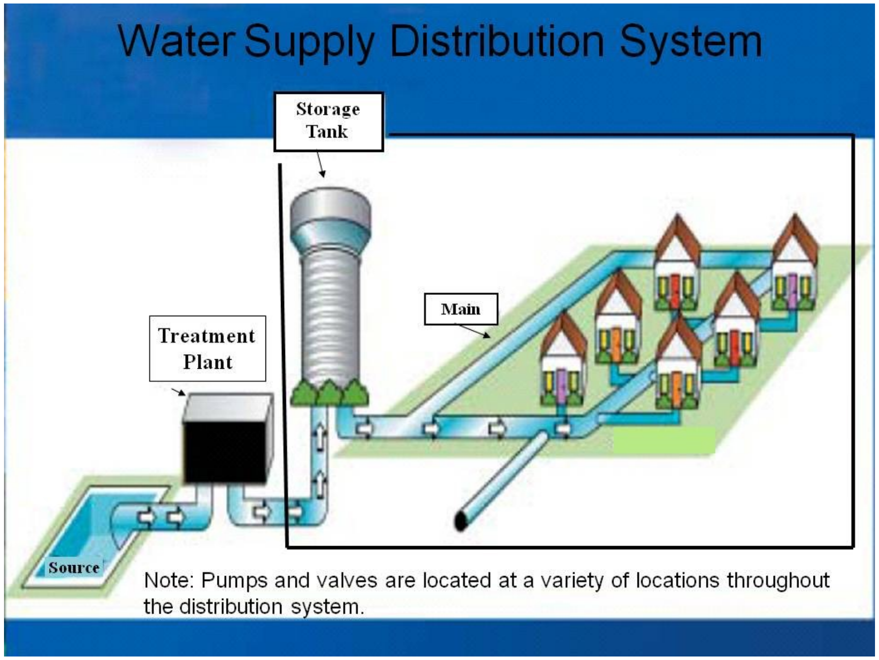
High Lift Pump Station

- Pump water from clear well into distribution system
- Consistent with water treatment capacity, storage, and water demand.

- Works for average of 12 to 18 hours a day
- Arrange with the elevated tank so the tank is emptying during high demand and filling during low.

Distribution System

- Most municipalities adopted standard pressure of:
  - 35-40 psi during normal hours
  - 20-30 psi during max. demands



Pipes Network

- **Consider residential, commercial, industrial, and fire fight demands.**
- **Planning: 3 methods for design**
- **Dead end system**

Not used any more

- **Circle or ring system**

The most common method now

Connected mains around the city

Grid iron system may be used depends on pressure of design

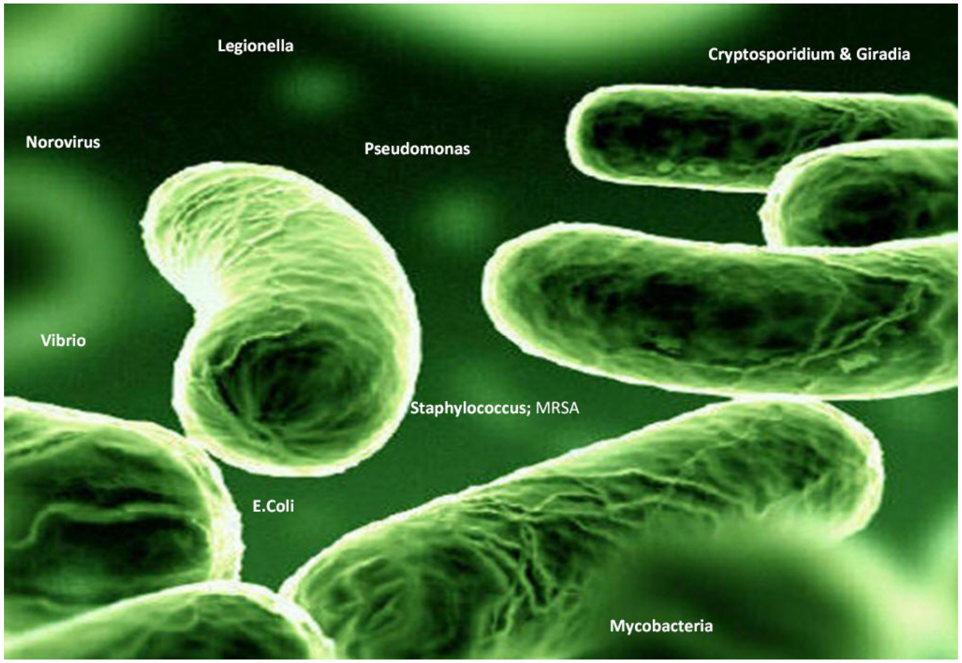
- **Radial system**

Divide the city into districts

Need to install water tank in the center of each district

Growth of Microorganisms

- factors:
  - Physical and chemical characteristics of water
  - System age
  - Type of pipe materials
  - Location (slow flow section, dead ends, area of pipe corrosion activity, etc.)



Contamination of Distribution System

- Corrosion
- Unstable soil
- Fouling
- Land subsidence
- Extreme low temperature
- Physical stresses




AWWA Practices

- During construction
  - Protection of new pipes at the construction site
  - Restriction on the use of joint-packing materials
  - Preliminary flushing of pipe sections
  - Pipe disinfection
  - Final flushing
  - Bacteriological testing for pipes disinfection

Microbial Growth Prevention

- ❑ Contamination prevention
  - ✓ Protect from soil, seepage from water or sewer line leaks, stormwater runoff, and habitation by pets and wildlife
  - ✓ Contamination sources may deposit fecal materials in the interior of the pipes
  - ✓ Providing end covers for these pipes materials
  - ✓ Drainage of standing water from trenches before pipeline assembly
  - ✓ Flushing new or repaired pipes to remove debris

Pipes Jointing Materials

- Gasket seals can be a source of bacterial contamination
- Protected habitat for bacteria in the annular spaces in joints
- Reproduction of bacteria in some joints

- Protection measures:
  - Use nonporous joint seals materials such as molded or tubular plastic rubber and treated paper products
  - Lubricants used in seals must be non-nutritive to avoid bacterial growth in protected joint space
  - Evaluate biological growth potential for joint materials using National Sanitation Foundation (NSF) test method

Storage Reservoir

- To avoid shortness during fluctuating demand
- Provide storage of water during off-peak periods and emergency (e.g. chemical spills in source water, flooding of well fields, transmission line breaks, fire, and power failure)
- Low level vs. high level reservoirs
- Underground vs. ground level storage
- Lined with concrete, gunite, asphalt, or plastic sheet to prevent water loss
- In earthquake zones, have to use reinforced concrete or flat-bed steel compartment

Storage Reservoir

- ❑ Elevated storage with steel and interior coating applied to prevent corrosion
- ❑ Water contamination with solvent-charged air
  - ➢ Organic polymer solvents in bituminous coating may not completely evaporated even after several weeks of ventilation
- ❑ Lining materials
  - ➢ May contain bitumen, chlorinated rubber, epoxy resin, or a tar-epoxy resin that can cause colonization of microbial growth
- ❑ Reservoir cover
  - ➢ Avoid birds excrements, air contamination, and surface water runoff

Microbial Quality Deterioration

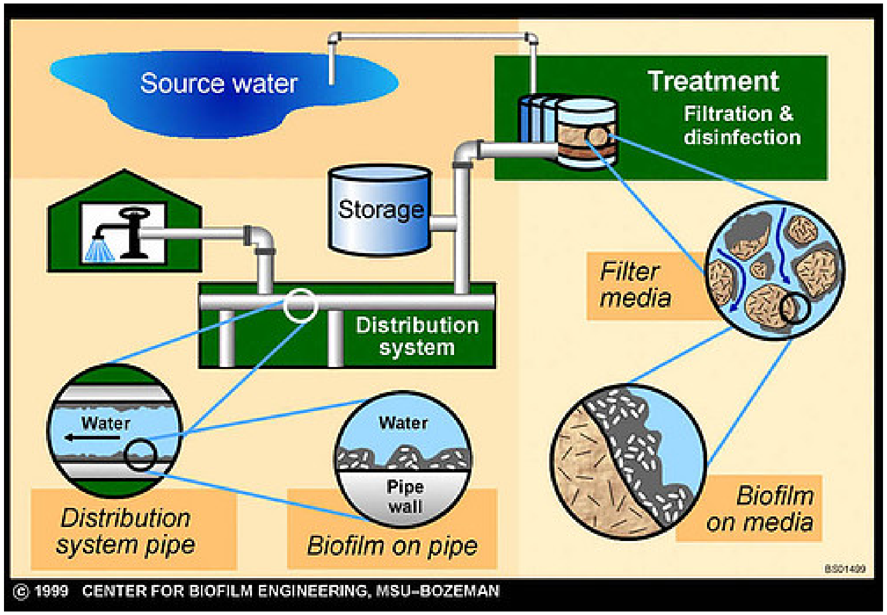
- From source water
- High quality GW can be <1 coliform/100 mL and very sparse heterotrophic bacteria (<10 organism/mL)
- Deteriorated quality (up to10000 HPC) due to:
  - Agricultural fertilizer runoff leach to GW
  - Leachate of toxic and OM from landfill
  - Iron and sulfur compounds that provide nutrients for bacteria
- Surface water
- Bacterial contamination by stormwater runoff
- Decaying algal blooms

Disinfection in Distribution System

- Inactivation of organisms
  - **Disinfection in and out of DWTP**
  - **Pay attention to the lack of sunlight in the distribution system**
- Many organisms survive disinfection
  - **Spore-forming organisms, acid-fat bacteria, gram-positive organisms, pigmented bacteria, fungi, yeast, and protozoan cysts**
- Protozoan cysts and crypto oocytes removed via filtration
- Prevent bacteria from entering distribution system
  - **Mainly through properly operated water treatment process**

Contamination from Treatment

- Some coliforms found in GAC filter during warm periods
- GAC particles found in some treated water with colonized bacteria
- Heterotrophic bacteria found in water treated with GAC more than water treated w/o GAC



Operation and Maintenance

- Main concern about coliforms and other bacterial contamination
- Measures:
  - Examination of heterotrophic bacterial density in addition to total coliform
  - AWWA measures to prevent contamination during construction

Case Study

- City of Halifax, Nova Scotia
- Construction of new supply line
- Klebsiella was detected in distribution system
- Klebsiella usually associated with wood
- Wood left in pipes believed to be responsible for the presence of Klebsiella
- Treatment:
  - ✓ Lime added to processed water to raise pH to 9.1 to deactivate Klebsiella

Operation and Maintenance

- AWWA Practices in new or repaired pipes
- Flushing water at min. velocity of 10 ft/sec after new pipes installation or emergency repair
- Introduce disinfectant and test the coliform bacteria and HPC
- Satisfactory results and line can be placed in service if <1 coliform/100 mL and <500 HPC/mL
- If line bacteriological tests not satisfactory
  - Flush again and put disinfectant (50 mg/L of free chlorine) and holding period of 24 hours
  - Repeat the tests

Disinfectant Stability

- To prevent colonization
- Residual against pathogens with the seepage of contamination into potable water reservoir or pipes
- Chlorine residual
  - **Free chlorine of 0.1-0.3 mg/L**
  - **Chloramines of 0.2-2.0 mg/L**
- Not effective against high intrusion
- Free chlorine is more effective than combined chlorine
- Problem of nitrification
- If convert to free chlorine, may have taste and odor complaints in the beginning

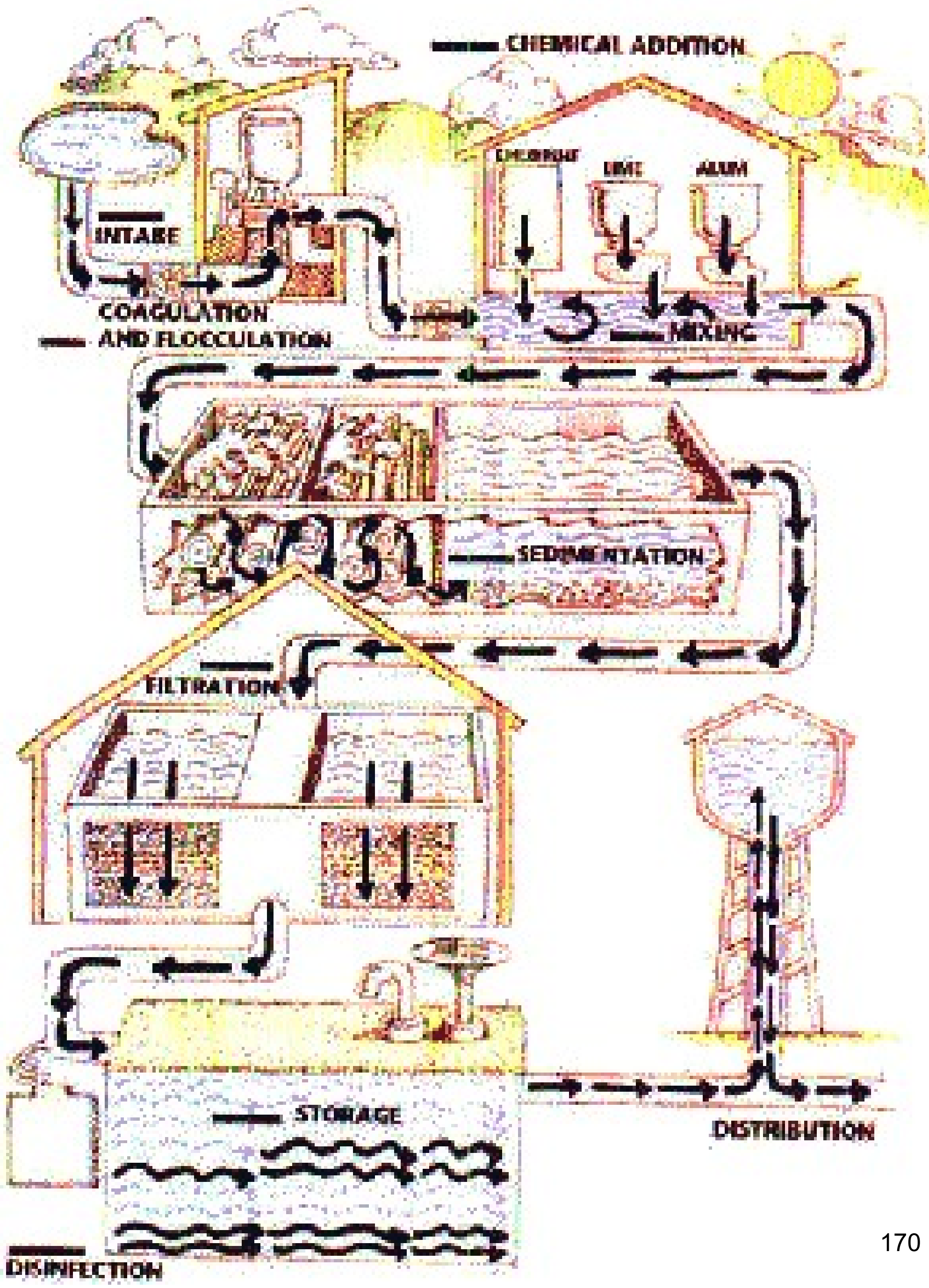
Turbidity and Particle Effects

- Contribute to sediment accumulation
- Accumulate in dead ends and tubercles formed
- May use turbidity for monitoring water quality in system
- If turbidity > 1 NTU, then need to flush distribution system and search for areas of pipes corrosion
- Clay and organic particles may trapped Varity of organisms

Water Supply Storage

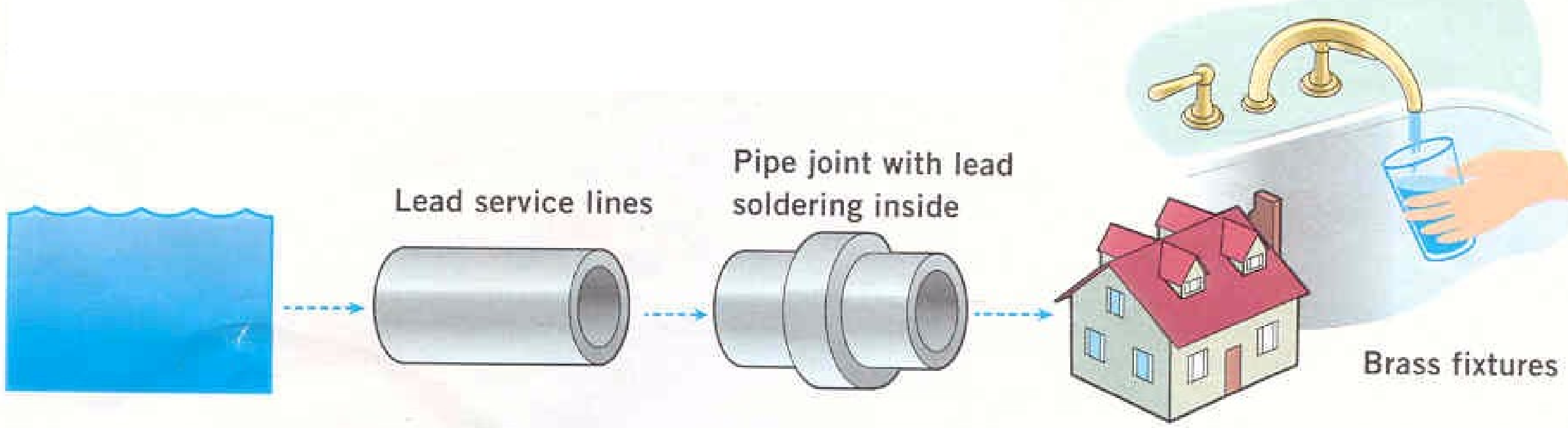
- **Problems:**
  - Prolonged storage time
  - Reduced flow velocity
  - Infrequent cleaning
  - Sediment in the bottom
- **Preventive measures:**
  - Regular scheduled inspection for biofilms that may accumulate on walls or sediments in bottom

Sludge Management

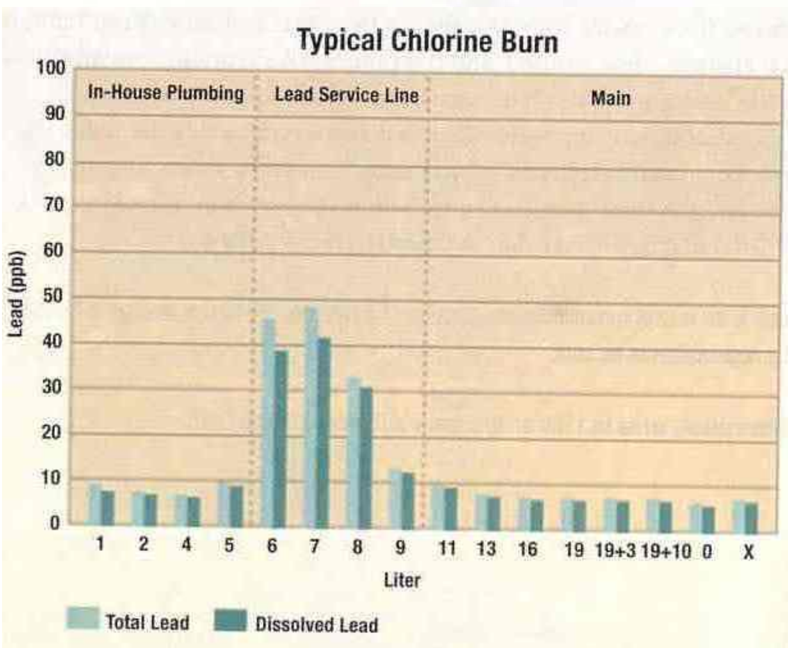


OTHER TREATMENT OPTIONS

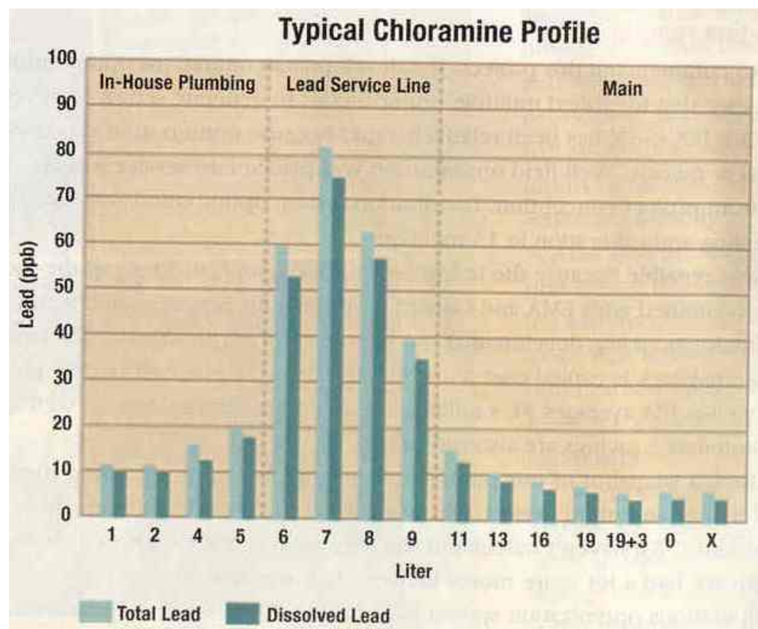
Lead



Lead service lines
Pipe joint with lead soldering inside
Brass fixtures

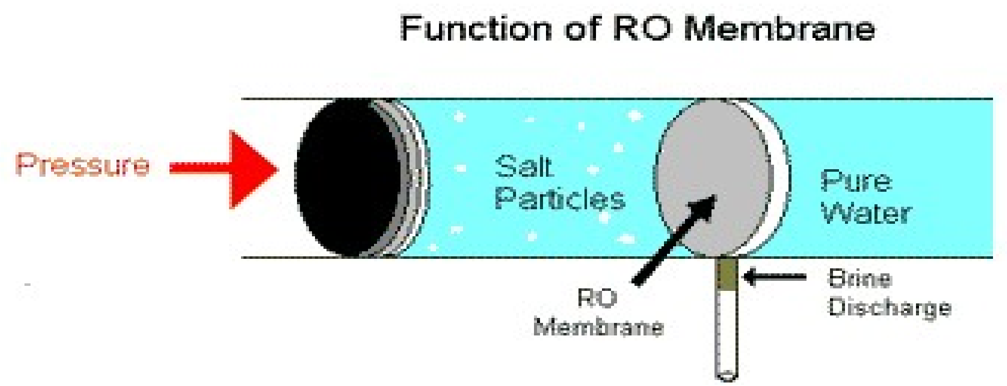


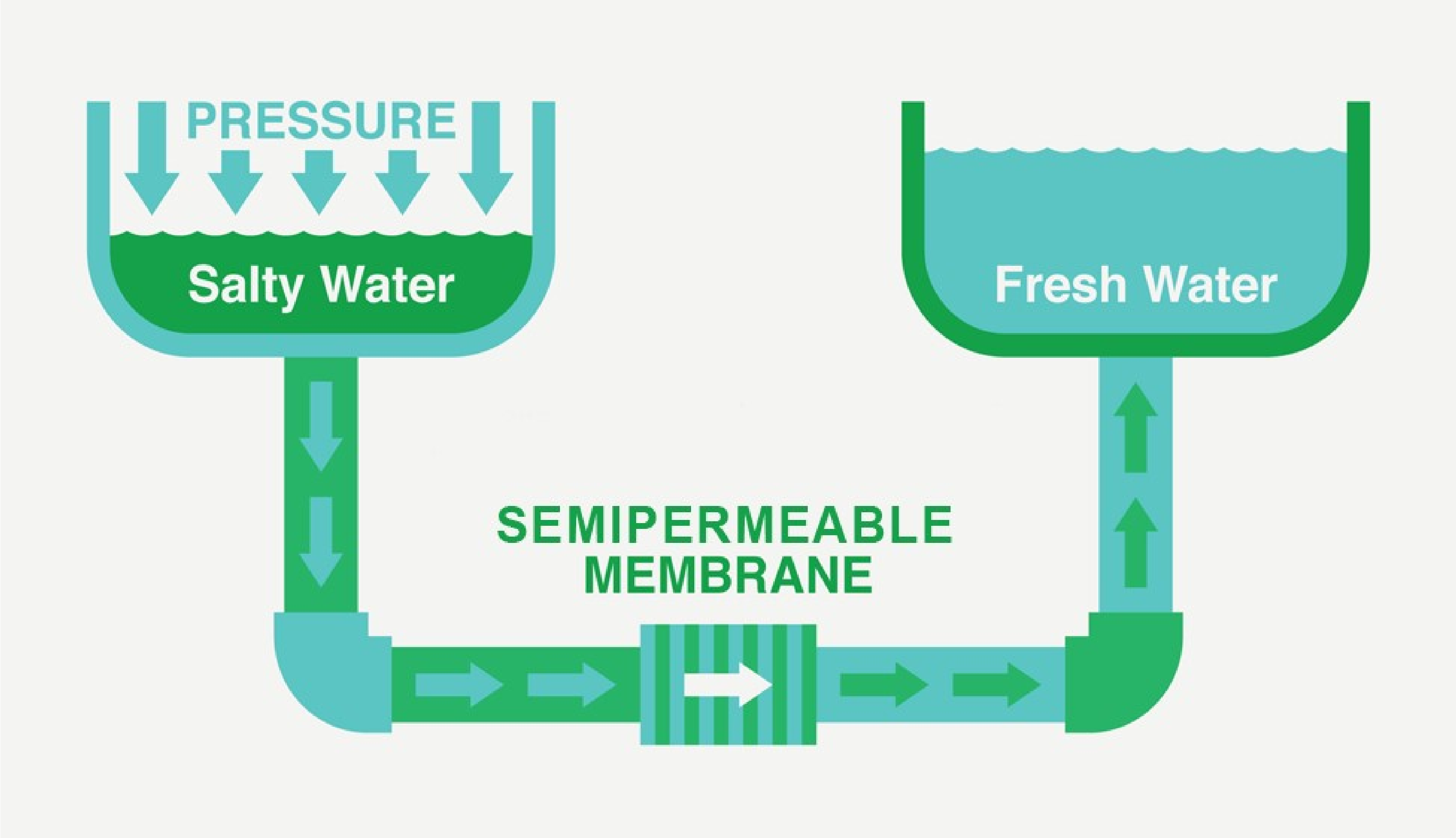
Typical Chlorine Burn
In-House Plumbing
Lead Service Line
Main
Lead (ppb)
100
90
80
70
60
50
40
30
20
10
0
1 2 4 5 6 7 8 9 11 13 16 19 19+3 19+10 0 X
Liter
Total Lead
Dissolved Lead



Typical Chloramine Profile
In-House Plumbing
Lead Service Line
Main
Lead (ppb)
100
90
80
70
60
50
40
30
20
10
0
1 2 4 5 6 7 8 9 11 13 16 19 19+3 0 X
Liter
Total Lead
Dissolved Lead

Membrane Treatment


Function of RO Membrane
Pressure
Salt Particles
Pure Water
RO Membrane
Brine Discharge


PRESSURE
Salty Water
Fresh Water
SEMIPERMEABLE MEMBRANE

Membrane Treatment

- Do you think this is house or WWTP??
- Wyndgate WWTP, St. Louis, MO
- 0.4 MGD

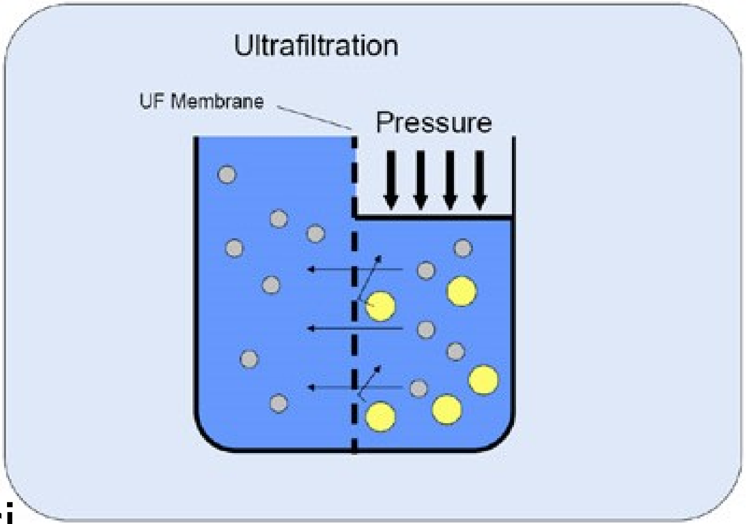
Membrane Processes

Membrane Process	Pores	Pressure	Use
Microfiltration (MF)	>50 nm	Low	Remove TSS, turbidity, protozoan, and some bacteria and viruses
Ultrafiltration (UF)	2-50 nm	Low	Remove macromolecules, colloids, and most bacteria and viruses
Nanofiltration (NF)	<2 nm	high	Remove very small molecules, hardness, and viruses
Reverse Osmosis (RO)	<2 nm	high	Remove very small molecules, color, hardness, sodium, nitrate and other ions

Ultrafiltration

- A membrane filtration in which forces like pressure lead to a separation through a semipermeable membrane
- Most common membrane filtration in drinking water treatment
- Flux in membrane filtration is the flowrate/unit area of membrane

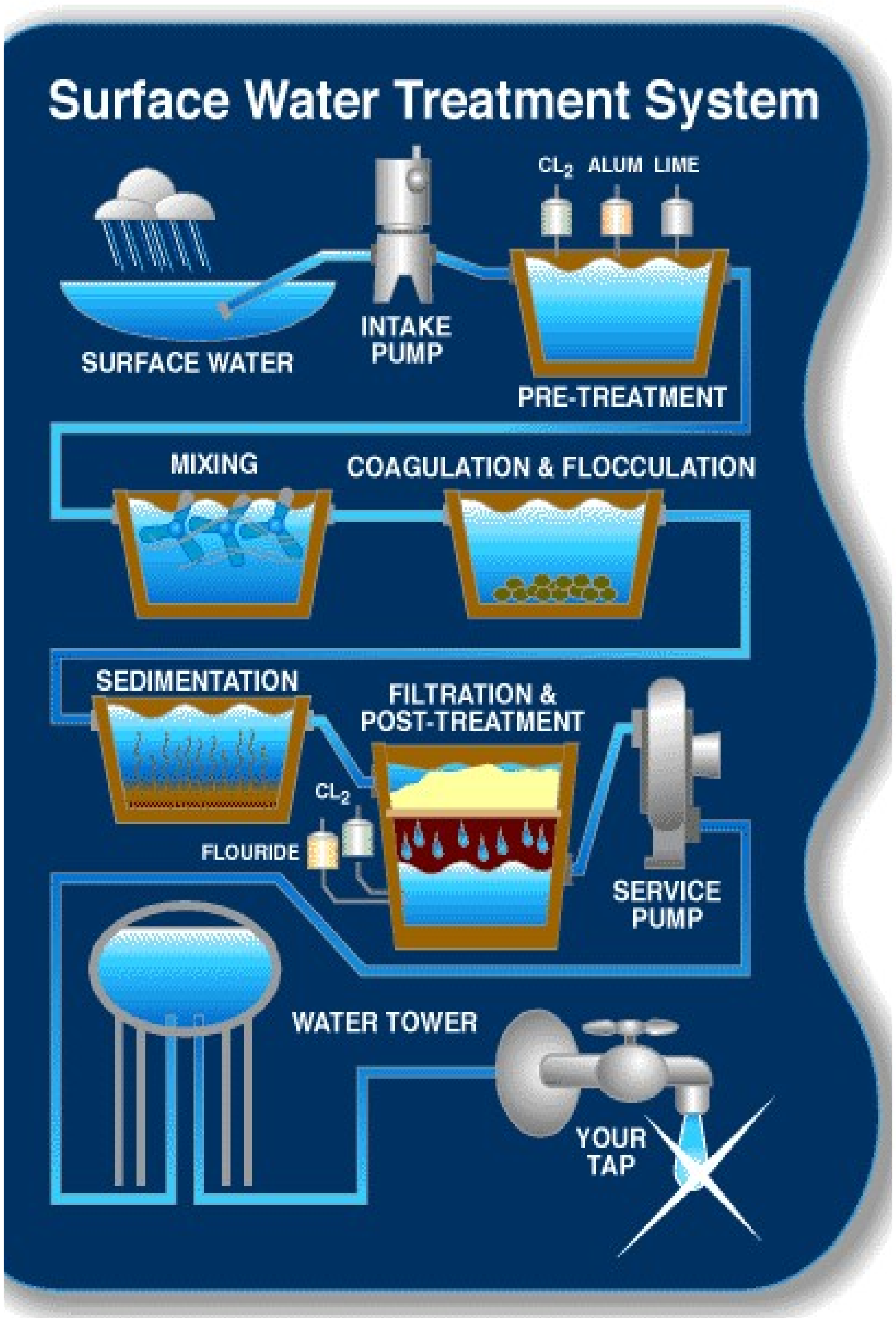
$$flux = \frac{\varepsilon r^2 \int \Delta p}{8 \mu \delta}$$

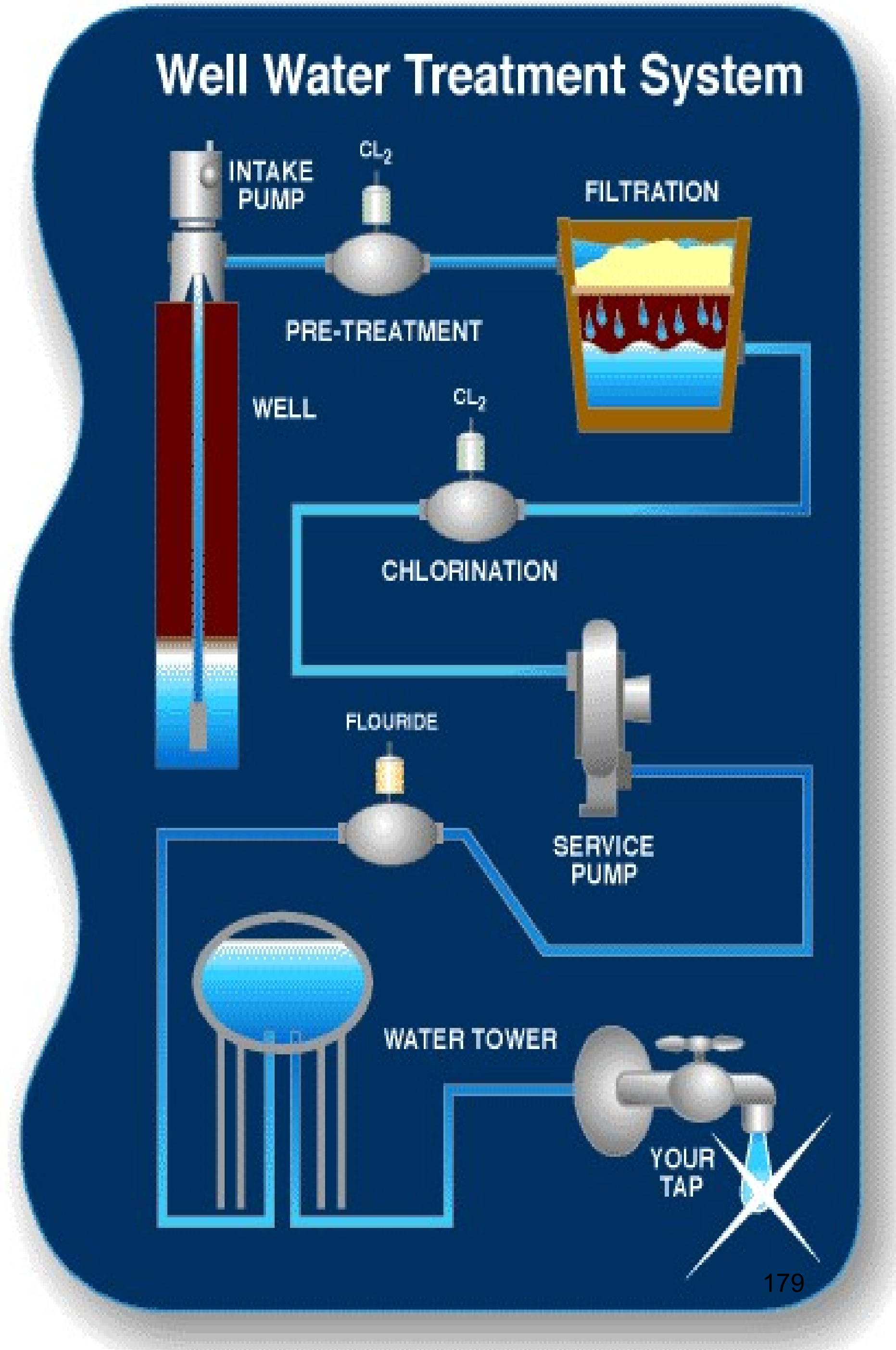


Where:
ε = porosity
r = average pore size
Δp = net pressure drop across the filter, psi
μ = absolute viscosity, 1bf.sec/ft2
Δ = filter thickness, inch

Example

- A water is being ultrafiltered through a membrane that has a porosity of 50%, a pore size of 8.0E-5 inch, and a thickness of 4.0E-3 inch. The water has a viscosity of 2.34E-5 lb.sec/ft2 and experiences a 1.45 psi pressure drop during filtration. What is the volumetric flux during filtration?


Surface Water Treatment System
SURFACE WATER
INTAKE PUMP
CL2
ALUM
LIME
PRE-TREATMENT
MIXING
COAGULATION & FLOCCULATION
SEDIMENTATION
FILTRATION & POST-TREATMENT
CL2
FLOURIDE
SERVICE PUMP
WATER TOWER
YOUR TAP


Well Water Treatment System
INTAKE PUMP
CL2
FILTRATION
PRE-TREATMENT
WELL
CL2
CHLORINATION
FLOURIDE
SERVICE PUMP
WATER TOWER
YOUR TAP

Refreshment

- Example of drinking water treatment processes

http://www.youtube.com/watch?v=tuYB8nMFxQA

https://www.youtube.com/watch?v=_AXtsOYnlXM

http://www.youtube.com/watch?v=20VvpASC2sU

http://www.youtube.com/watch?v=xc4zoS9EgY4