الشركة القابضة
لمياه الشرب والصرف الصحى

برنامج المسار الوظيفي للعاملين بقطاع مياه الشرب والصرف الصحي

البرنامج التدريبي كيميائي مياه

Water treatment technology

Water contaminants

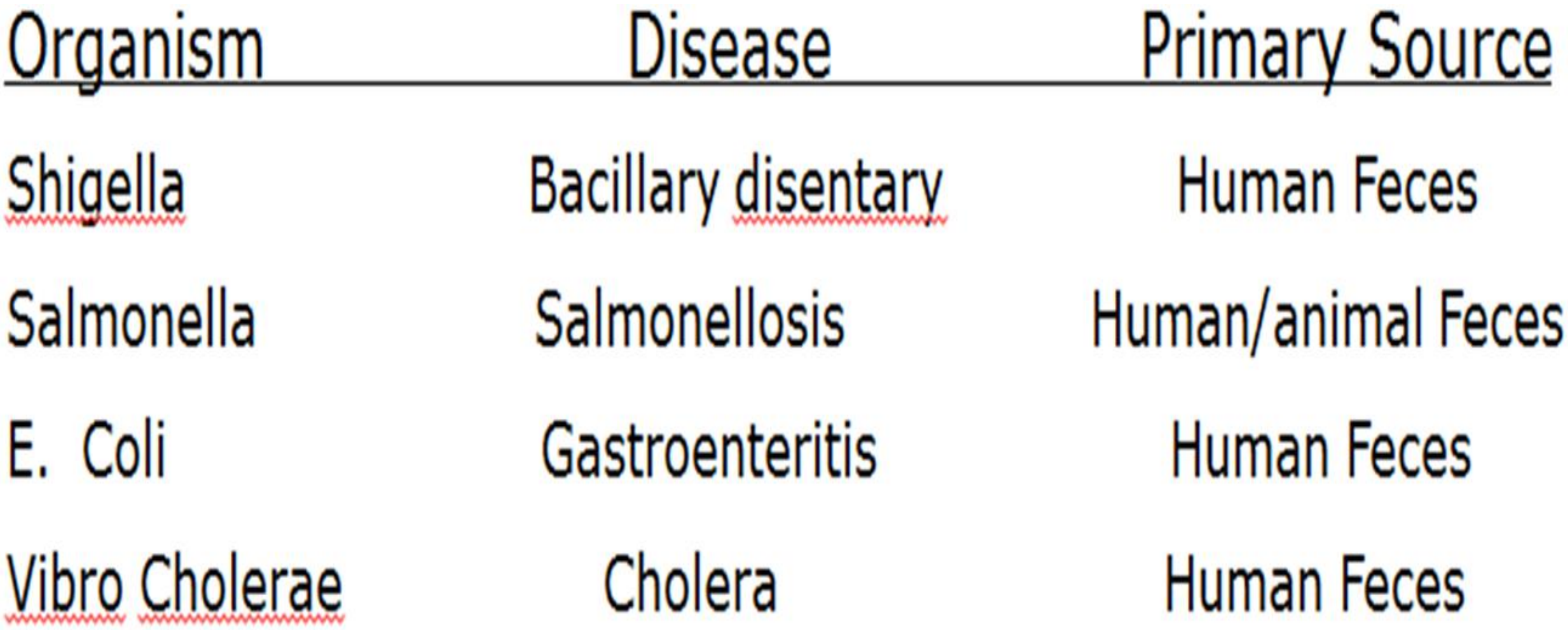
Chemicals

- Inorganics
- Organics
  - Synthetic organic compounds
  - Volatile organic compounds

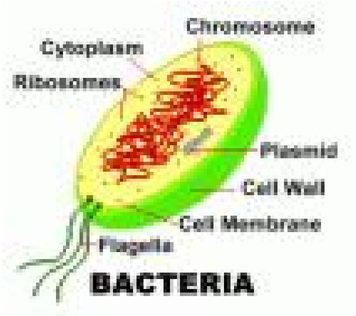
Microbes

- Viruses
- Bacteria
- Protozoa parasites
- Algae

Bacteria

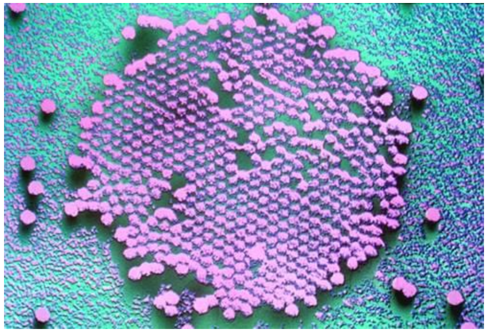


Organism	Disease	Primary Source
Shigella	Bacillary disentary	Human Feces
Salmonella	Salmonellosis	Human/animal Feces
E. Coli	Gastroenteritis	Human Feces
Vibro Cholerae	Cholera	Human Feces



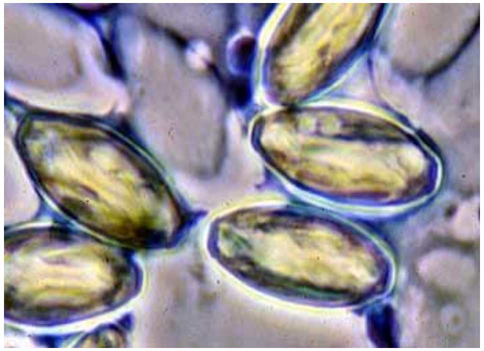
Viruses

Organism	Disease	Primary Source
Hepatitus A	Infectious Hepatitis	Human Feces
Coxsackievirus A&B	Aseptic meningitis	Human Feces
Rotavirus	Gastroenteritis	Human Feces
Adenoviruses	Upper respiratory & Gastrointestianilln	Human Feces



Protozoans

Organism	Disease	Primary Source
Giardia lamblia	Giardiasis	Human/animal Feces
Cryptosporidium	Cryptosporidiosis	Human/animal Feces
Entamoeba histolytica	Aomebic dysentary	Human/animal Feces



Water contaminants (I)

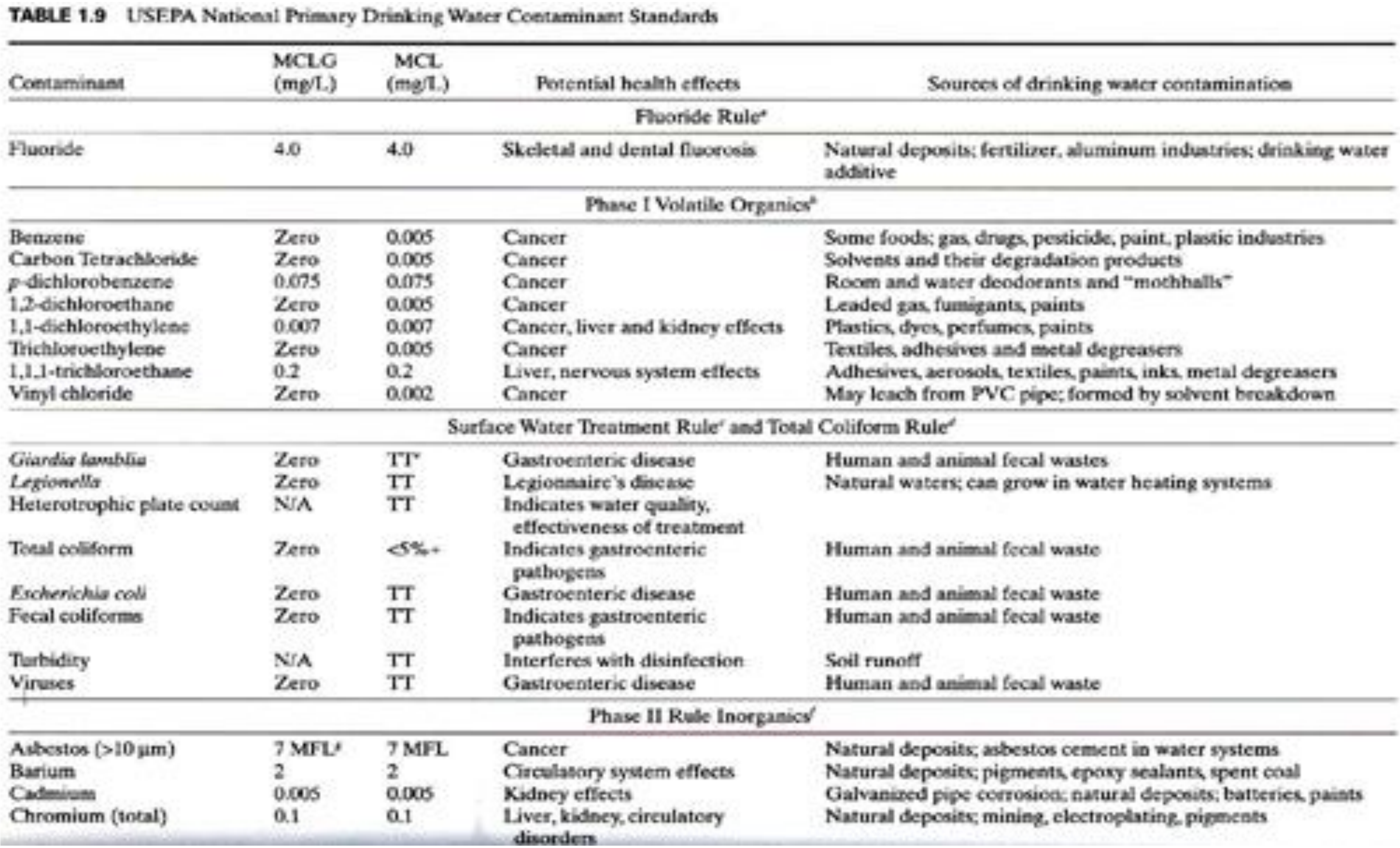
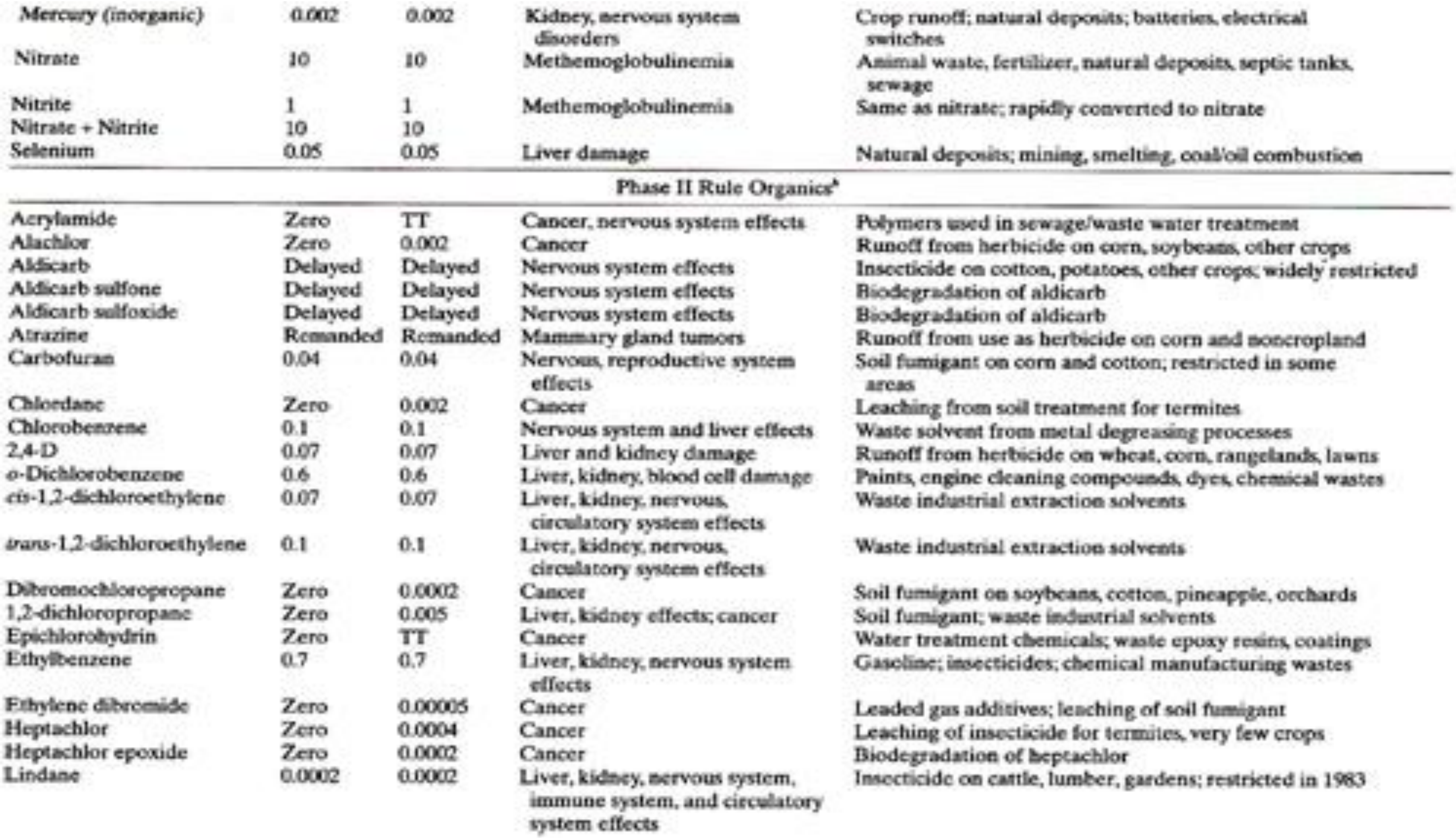


TABLE 1.9 USEPA National Primary Drinking Water Contaminant Standards

Contaminant	MCLG (mg/L)	MCL (mg/L)	Potential health effects	Sources of drinking water contamination
			Fluoride Rule[a]	
Fluoride	4.0	4.0	Skeletal and dental fluorosis	Natural deposits; fertilizer, aluminum industries; drinking water additive
			Phase I Volatile Organics[b]	
Benzene	Zero	0.005	Cancer	Some foods; gas, drugs, pesticide, paint, plastic industries
Carbon Tetrachloride	Zero	0.005	Cancer	Solvents and their degradation products
p-dichlorobenzene	0.075	0.075	Cancer	Room and water deodorants and "mothballs"
1,2-dichloroethane	Zero	0.005	Cancer	Leaded gas, fumigants, paints
1,1-dichloroethylene	0.007	0.007	Cancer, liver and kidney effects	Plastics, dyes, perfumes, paints
Trichloroethylene	Zero	0.005	Cancer	Textiles, adhesives and metal degreasers
1,1,1-trichloroethane	0.2	0.2	Liver, nervous system effects	Adhesives, aerosols, textiles, paints, inks, metal degreasers
Vinyl chloride	Zero	0.002	Cancer	May leach from PVC pipe; formed by solvent breakdown
			Surface Water Treatment Rule[c] and Total Coliform Rule[d]	
Giardia lamblia	Zero	TT[e]	Gastroenteric disease	Human and animal fecal wastes
Legionella	Zero	TT	Legionnaire's disease	Natural waters; can grow in water heating systems
Heterotrophic plate count	N/A	TT	Indicates water quality, effectiveness of treatment	
Total coliform	Zero	<5%+	Indicates gastroenteric pathogens	Human and animal fecal waste
Escherichia coli	Zero	TT	Gastroenteric disease	Human and animal fecal waste
Fecal coliforms	Zero	TT	Indicates gastroenteric pathogens	Human and animal fecal waste
Turbidity	N/A	TT	Interferes with disinfection	Soil runoff
Viruses	Zero	TT	Gastroenteric disease	Human and animal fecal waste
			Phase II Rule Inorganics[f]	
Asbestos (>10 μm)	7 MFL[g]	7 MFL	Cancer	Natural deposits; asbestos cement in water systems
Barium	2	2	Circulatory system effects	Natural deposits; pigments, epoxy sealants, spent coal
Cadmium	0.005	0.005	Kidney effects	Galvanized pipe corrosion; natural deposits; batteries, paints
Chromium (total)	0.1	0.1	Liver, kidney, circulatory disorders	Natural deposits; mining, electroplating, pigments

Water contaminants (II)



Mercury (inorganic)	0.002	0.002	Kidney, nervous system disorders	Crop runoff; natural deposits; batteries, electrical switches
Nitrate	10	10	Methemoglobulinemia	Animal waste, fertilizer, natural deposits, septic tanks, sewage
Nitrite	1	1	Methemoglobulinemia	Same as nitrate; rapidly converted to nitrate
Nitrate + Nitrite	10	10		
Selenium	0.05	0.05	Liver damage	Natural deposits; mining, smelting, coal/oil combustion
		Phase II Rule Organics[a]		
Acrylamide	Zero	TT	Cancer, nervous system effects	Polymers used in sewage/waste water treatment
Alachlor	Zero	0.002	Cancer	Runoff from herbicide on corn, soybeans, other crops
Aldicarb	Delayed	Delayed	Nervous system effects	Insecticide on cotton, potatoes, other crops; widely restricted
Aldicarb sulfone	Delayed	Delayed	Nervous system effects	Biodegradation of aldicarb
Aldicarb sulfoxide	Delayed	Delayed	Nervous system effects	Biodegradation of aldicarb
Atrazine	Remanded	Remanded	Mammary gland tumors	Runoff from use as herbicide on corn and noncropland
Carbofuran	0.04	0.04	Nervous, reproductive system effects	Soil fumigant on corn and cotton; restricted in some areas
Chlordane	Zero	0.002	Cancer	Leaching from soil treatment for termites
Chlorobenzene	0.1	0.1	Nervous system and liver effects	Waste solvent from metal degreasing processes
2,4-D	0.07	0.07	Liver and kidney damage	Runoff from herbicide on wheat, corn, rangelands, lawns
o-Dichlorobenzene	0.6	0.6	Liver, kidney, blood cell damage	Paints, engine cleaning compounds, dyes, chemical wastes
cis-1,2-dichloroethylene	0.07	0.07	Liver, kidney, nervous, circulatory system effects	Waste industrial extraction solvents
trans-1,2-dichloroethylene	0.1	0.1	Liver, kidney, nervous, circulatory system effects	Waste industrial extraction solvents
Dibromochloropropane	Zero	0.0002	Cancer	Soil fumigant on soybeans, cotton, pineapple, orchards
1,2-dichloropropane	Zero	0.005	Liver, kidney effects; cancer	Soil fumigant; waste industrial solvents
Epichlorohydrin	Zero	TT	Cancer	Water treatment chemicals; waste epoxy resins, coatings
Ethylbenzene	0.7	0.7	Liver, kidney, nervous system effects	Gasoline; insecticides; chemical manufacturing wastes
Ethylene dibromide	Zero	0.00005	Cancer	Leaded gas additives; leaching of soil fumigant
Heptachlor	Zero	0.0004	Cancer	Leaching of insecticide for termites, very few crops
Heptachlor epoxide	Zero	0.0002	Cancer	Biodegradation of heptachlor
Lindane	0.0002	0.0002	Liver, kidney, nervous system, immune system, and circulatory system effects	Insecticide on cattle, lumber, gardens; restricted in 1983

Water contaminants (III)

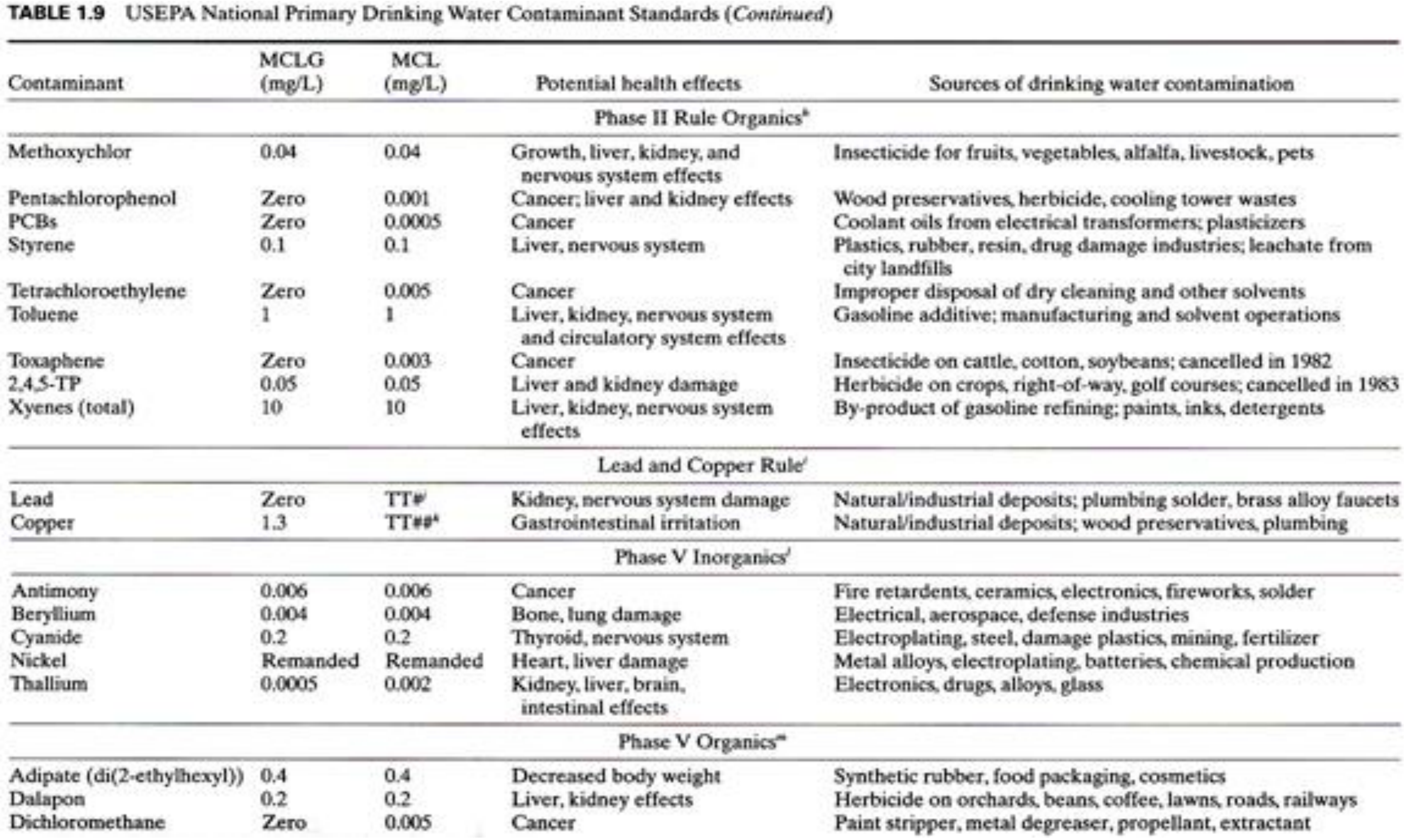
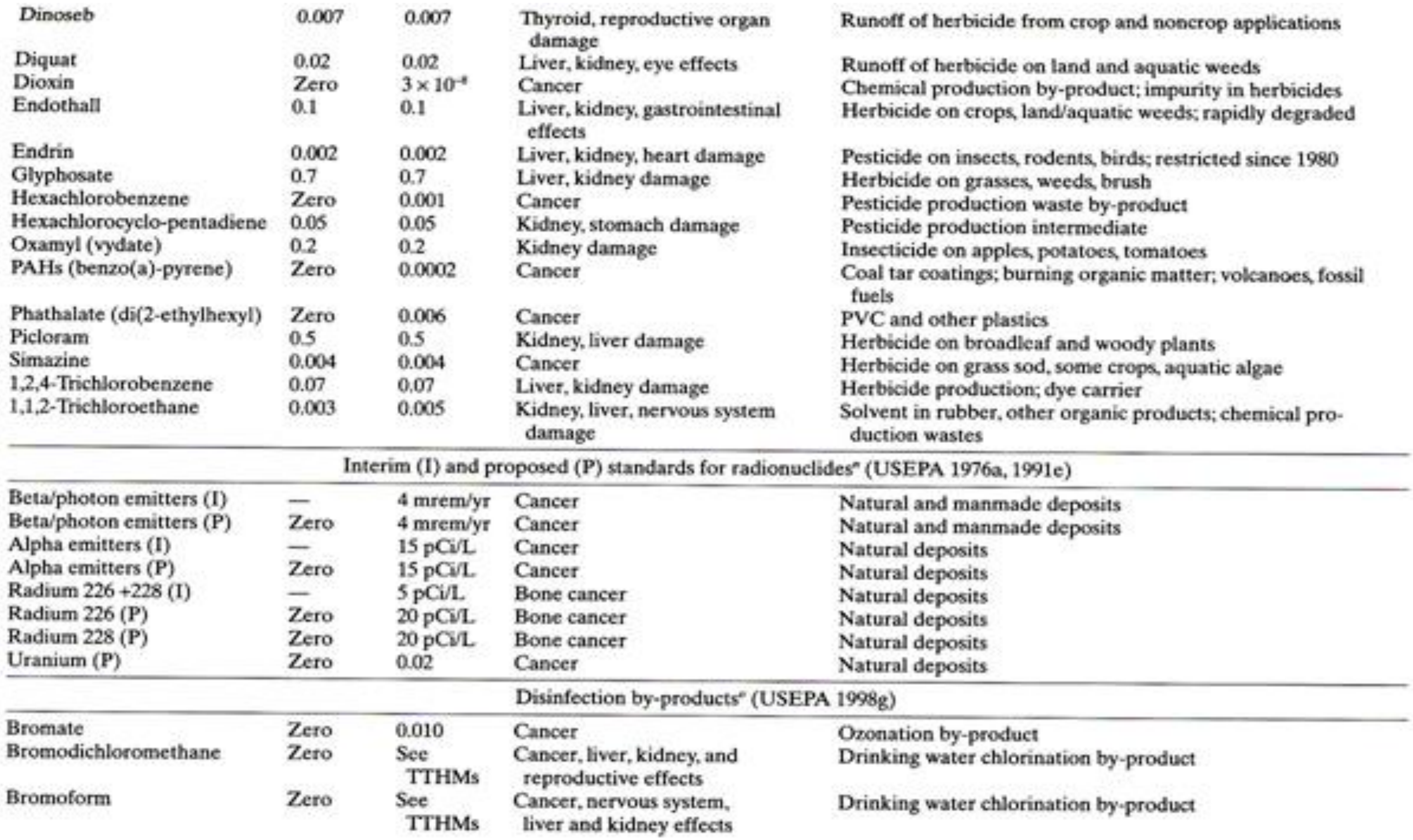


TABLE 1.9 USEPA National Primary Drinking Water Contaminant Standards (*Continued*)

Contaminant	MCLG (mg/L)	MCL (mg/L)	Potential health effects	Sources of drinking water contamination
			Phase II Rule Organics[e]	
Methoxychlor	0.04	0.04	Growth, liver, kidney, and nervous system effects	Insecticide for fruits, vegetables, alfalfa, livestock, pets
Pentachlorophenol	Zero	0.001	Cancer; liver and kidney effects	Wood preservatives, herbicide, cooling tower wastes
PCBs	Zero	0.0005	Cancer	Coolant oils from electrical transformers; plasticizers
Styrene	0.1	0.1	Liver, nervous system	Plastics, rubber, resin, drug damage industries; leachate from city landfills
Tetrachloroethylene	Zero	0.005	Cancer	Improper disposal of dry cleaning and other solvents
Toluene	1	1	Liver, kidney, nervous system and circulatory system effects	Gasoline additive; manufacturing and solvent operations
Toxaphene	Zero	0.003	Cancer	Insecticide on cattle, cotton, soybeans; cancelled in 1982
2,4,5-TP	0.05	0.05	Liver and kidney damage	Herbicide on crops, right-of-way, golf courses; cancelled in 1983
Xyenes (total)	10	10	Liver, kidney, nervous system effects	By-product of gasoline refining; paints, inks, detergents
			Lead and Copper Rule[f]	
Lead	Zero	TT#[g]	Kidney, nervous system damage	Natural/industrial deposits; plumbing solder, brass alloy faucets
Copper	1.3	TT##[h]	Gastrointestinal irritation	Natural/industrial deposits; wood preservatives, plumbing
			Phase V Inorganics[j]	
Antimony	0.006	0.006	Cancer	Fire retardents, ceramics, electronics, fireworks, solder
Beryllium	0.004	0.004	Bone, lung damage	Electrical, aerospace, defense industries
Cyanide	0.2	0.2	Thyroid, nervous system	Electroplating, steel, damage plastics, mining, fertilizer
Nickel	Remanded	Remanded	Heart, liver damage	Metal alloys, electroplating, batteries, chemical production
Thallium	0.0005	0.002	Kidney, liver, brain, intestinal effects	Electronics, drugs, alloys, glass
			Phase V Organics[m]	
Adipate (di(2-ethylhexyl))	0.4	0.4	Decreased body weight	Synthetic rubber, food packaging, cosmetics
Dalapon	0.2	0.2	Liver, kidney effects	Herbicide on orchards, beans, coffee, lawns, roads, railways
Dichloromethane	Zero	0.005	Cancer	Paint stripper, metal degreaser, propellant, extractant

Water contaminants (IV)



Dinoseb	0.007	0.007	Thyroid, reproductive organ damage	Runoff of herbicide from crop and noncrop applications
Diquat	0.02	0.02	Liver, kidney, eye effects	Runoff of herbicide on land and aquatic weeds
Dioxin	Zero	3×10^{-8}	Cancer	Chemical production by-product; impurity in herbicides
Endothall	0.1	0.1	Liver, kidney, gastrointestinal effects	Herbicide on crops, land/aquatic weeds; rapidly degraded
Endrin	0.002	0.002	Liver, kidney, heart damage	Pesticide on insects, rodents, birds; restricted since 1980
Glyphosate	0.7	0.7	Liver, kidney damage	Herbicide on grasses, weeds, brush
Hexachlorobenzene	Zero	0.001	Cancer	Pesticide production waste by-product
Hexachlorocyclo-pentadiene	0.05	0.05	Kidney, stomach damage	Pesticide production intermediate
Oxamyl (vydate)	0.2	0.2	Kidney damage	Insecticide on apples, potatoes, tomatoes
PAHs (benzo(a)-pyrene)	Zero	0.0002	Cancer	Coal tar coatings; burning organic matter; volcanoes, fossil fuels
Phathalate (di(2-ethylhexyl)	Zero	0.006	Cancer	PVC and other plastics
Picloram	0.5	0.5	Kidney, liver damage	Herbicide on broadleaf and woody plants
Simazine	0.004	0.004	Cancer	Herbicide on grass sod, some crops, aquatic algae
1,2,4-Trichlorobenzene	0.07	0.07	Liver, kidney damage	Herbicide production; dye carrier
1,1,2-Trichloroethane	0.003	0.005	Kidney, liver, nervous system damage	Solvent in rubber, other organic products; chemical production wastes
		Interim (I) and proposed (P) standards for radionuclides[a] (USEPA 1976a, 1991e)		
Beta/photon emitters (I)	—	4 mrem/yr	Cancer	Natural and manmade deposits
Beta/photon emitters (P)	Zero	4 mrem/yr	Cancer	Natural and manmade deposits
Alpha emitters (I)	—	15 pCi/L	Cancer	Natural deposits
Alpha emitters (P)	Zero	15 pCi/L	Cancer	Natural deposits
Radium 226 +228 (I)	—	5 pCi/L	Bone cancer	Natural deposits
Radium 226 (P)	Zero	20 pCi/L	Bone cancer	Natural deposits
Radium 228 (P)	Zero	20 pCi/L	Bone cancer	Natural deposits
Uranium (P)	Zero	0.02	Cancer	Natural deposits
			Disinfection by-products[a] (USEPA 1998g)	
Bromate	Zero	0.010	Cancer	Ozonation by-product
Bromodichloromethane	Zero	See TTHMs	Cancer, liver, kidney, and reproductive effects	Drinking water chlorination by-product
Bromoform	Zero	See TTHMs	Cancer, nervous system, liver and kidney effects	Drinking water chlorination by-product

Water contaminants (V)

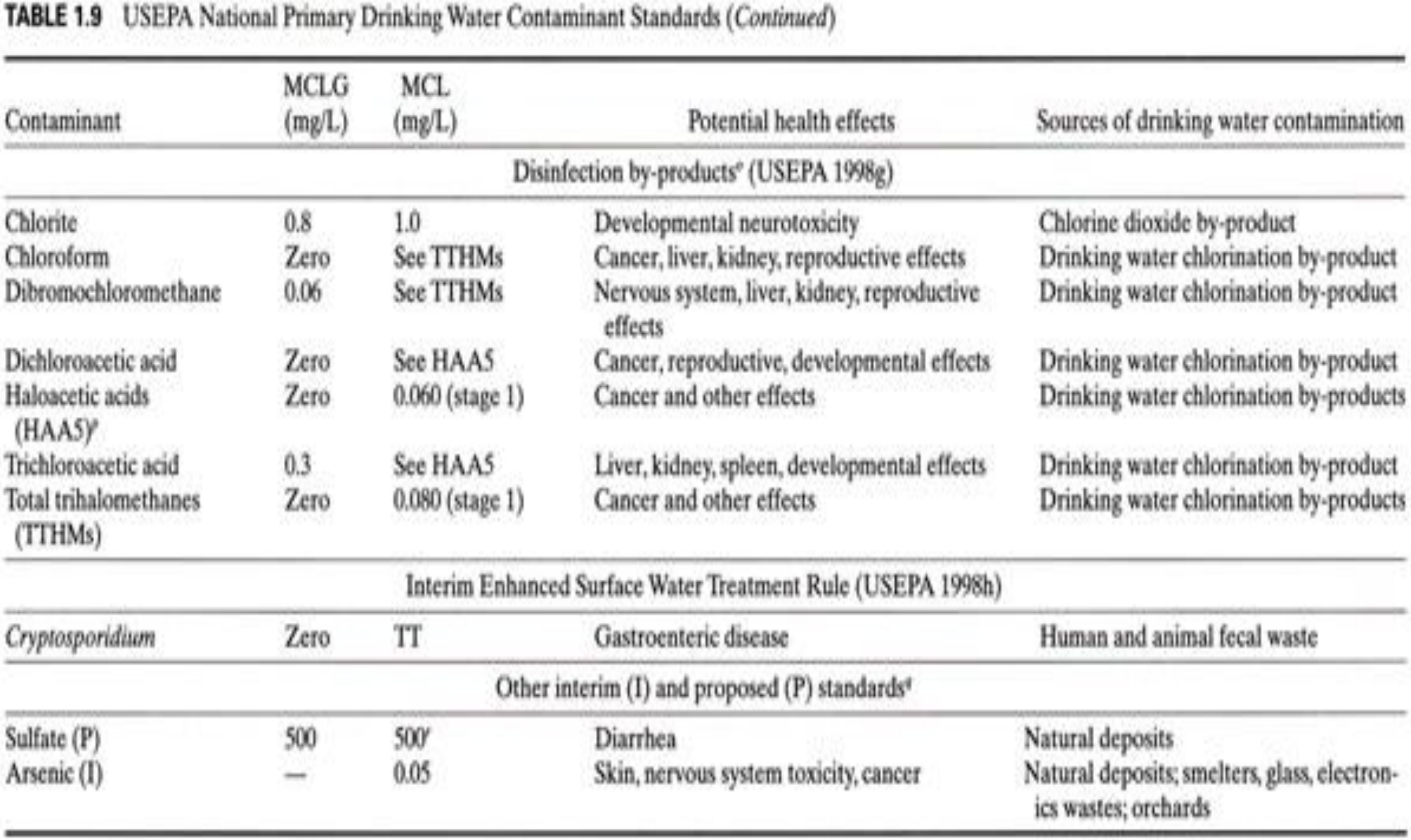


TABLE 1.9 USEPA National Primary Drinking Water Contaminant Standards (*Continued*)

Contaminant	MCLG (mg/L)	MCL (mg/L)	Potential health effects	Sources of drinking water contamination
			Disinfection by-products[e] (USEPA 1998g)	
Chlorite	0.8	1.0	Developmental neurotoxicity	Chlorine dioxide by-product
Chloroform	Zero	See TTHMs	Cancer, liver, kidney, reproductive effects	Drinking water chlorination by-product
Dibromochloromethane	0.06	See TTHMs	Nervous system, liver, kidney, reproductive effects	Drinking water chlorination by-product
Dichloroacetic acid	Zero	See HAA5	Cancer, reproductive, developmental effects	Drinking water chlorination by-product
Haloacetic acids (HAA5)[f]	Zero	0.060 (stage 1)	Cancer and other effects	Drinking water chlorination by-products
Trichloroacetic acid	0.3	See HAA5	Liver, kidney, spleen, developmental effects	Drinking water chlorination by-product
Total trihalomethanes (TTHMs)	Zero	0.080 (stage 1)	Cancer and other effects	Drinking water chlorination by-products
			Interim Enhanced Surface Water Treatment Rule (USEPA 1998h)	
Cryptosporidium	Zero	TT	Gastroenteric disease	Human and animal fecal waste
			Other interim (I) and proposed (P) standards[g]	
Sulfate (P)	500	500[f]	Diarrhea	Natural deposits
Arsenic (I)	—	0.05	Skin, nervous system toxicity, cancer	Natural deposits; smelters, glass, electronics wastes; orchards

Where:

Maximum Contaminant Level Goal (MCLG)

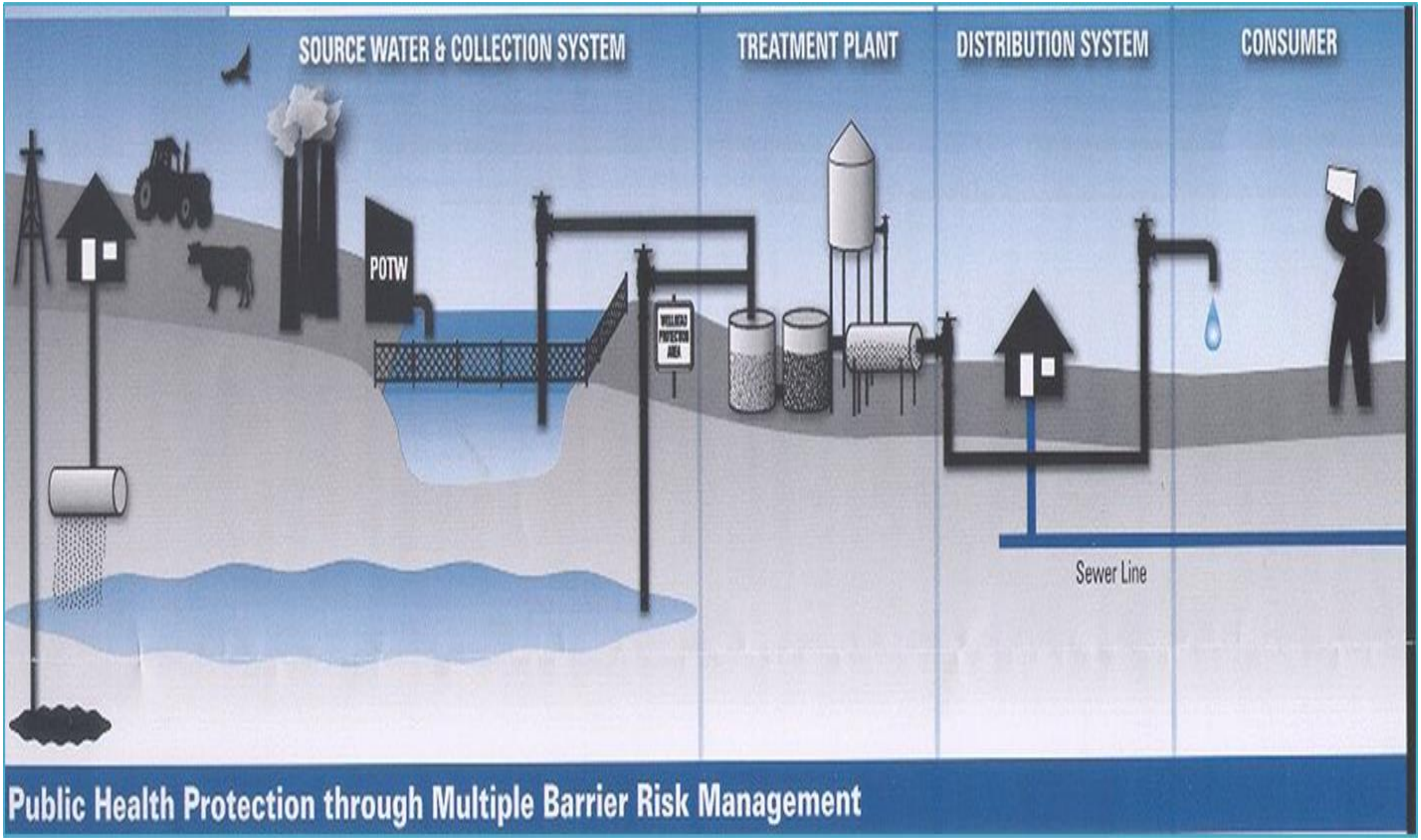
Maximum Contaminant Level (MCL)

Maximum Residual Disinfectant Level Goal (MRDLG)

Treatment Technique (TT)

Maximum Residual Disinfectant Level (MRDL)

Multiple barrier concept for public health protection



Public Health Protection through Multiple Barrier Risk Management

Multiple Barrier Approach to Protect Public Health in Drinking Water

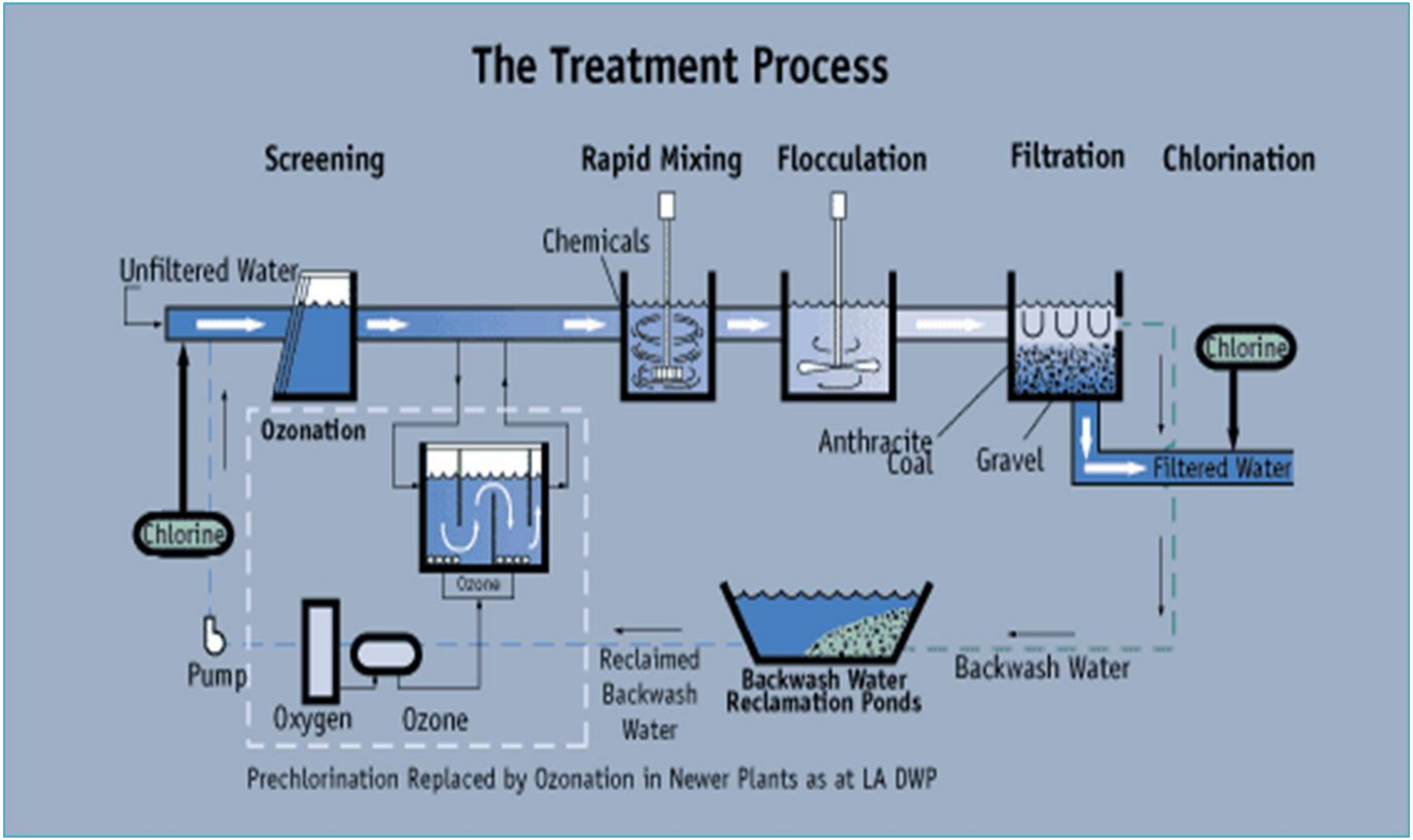
Source Water Protection

Treatment technology

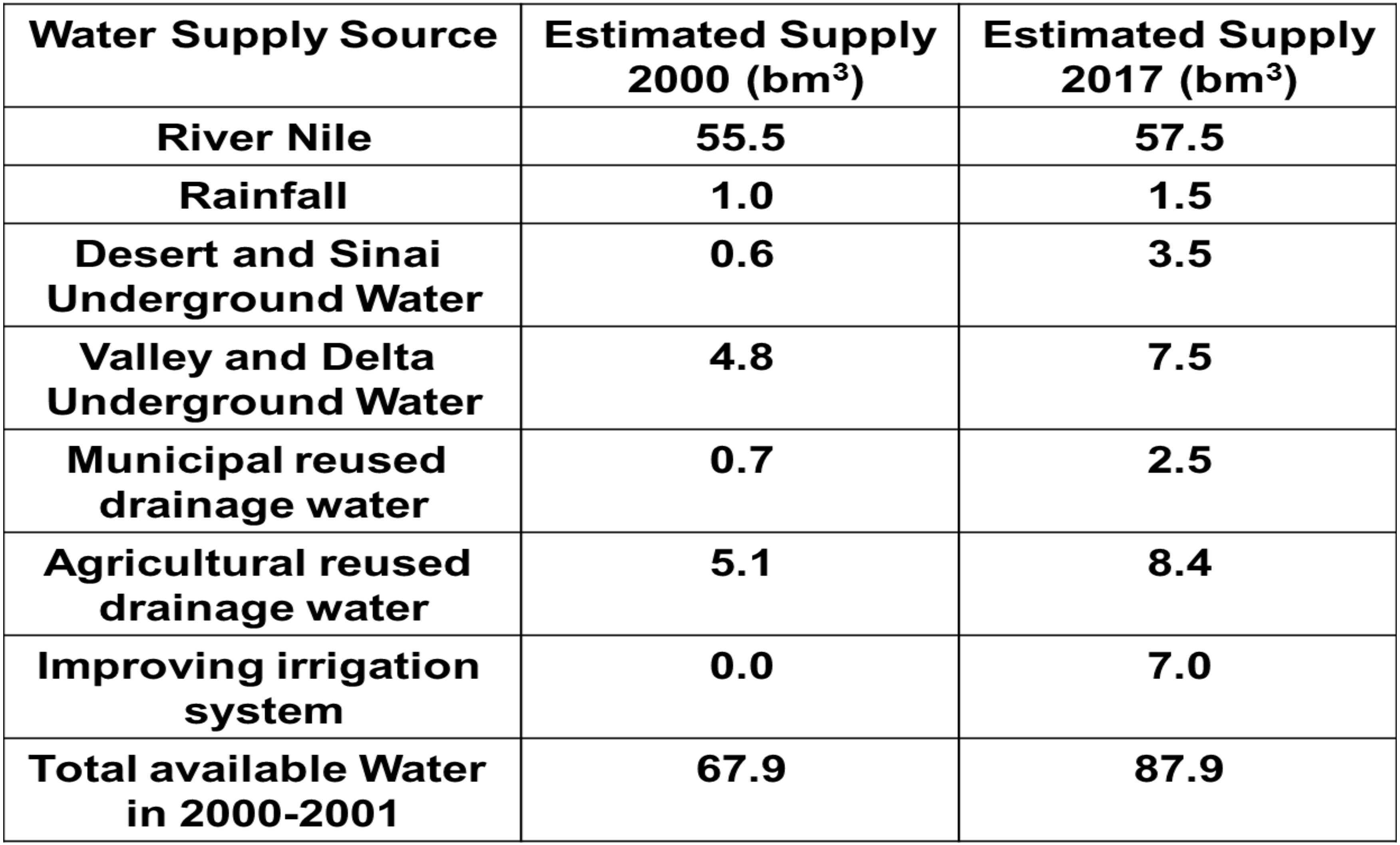
Disinfection

Disinfectant residual in distribution system

Water treatment processes

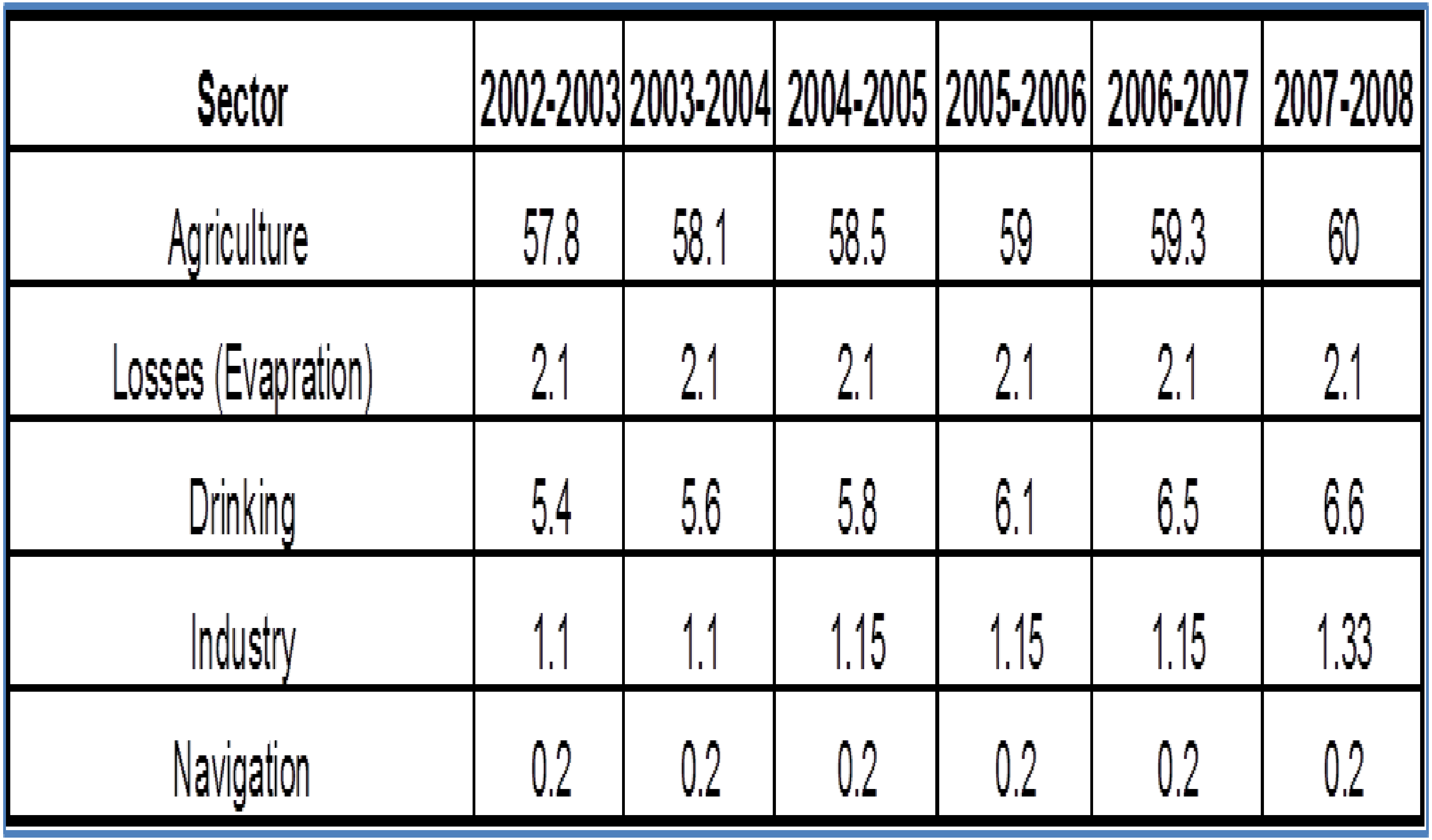


Summary of available water resources



Water Supply Source	Estimated Supply 2000 (bm^3)	Estimated Supply 2017 (bm^3)
River Nile	55.5	57.5
Rainfall	1.0	1.5
Desert and Sinai Underground Water	0.6	3.5
Valley and Delta Underground Water	4.8	7.5
Municipal reused drainage water	0.7	2.5
Agricultural reused drainage water	5.1	8.4
Improving irrigation system	0.0	7.0
Total available Water in 2000-2001	67.9	87.9

Water uses in Egypt



Sector	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008
Agriculture	57.8	58.1	58.5	59	59.3	60
Losses (Evapration)	2.1	2.1	2.1	2.1	2.1	2.1
Drinking	5.4	5.6	5.8	6.1	6.5	6.6
Industry	1.1	1.1	1.15	1.15	1.15	1.33
Navigation	0.2	0.2	0.2	0.2	0.2	0.2

Conventional water treatment

Simple Sorting

Goal: clean water

Source: (contaminated) surface water

Solution: separate contaminants from water

How?

Where are we going?

Unit processes* designed to

- remove particles
- remove dissolved chemicals
- inactivate pathogens

*Unit process: a process that is used in similar ways in many different applications

- sedimentation
- filtration
- …

Unit Processes Designed to Remove Particulate Matter

Screening

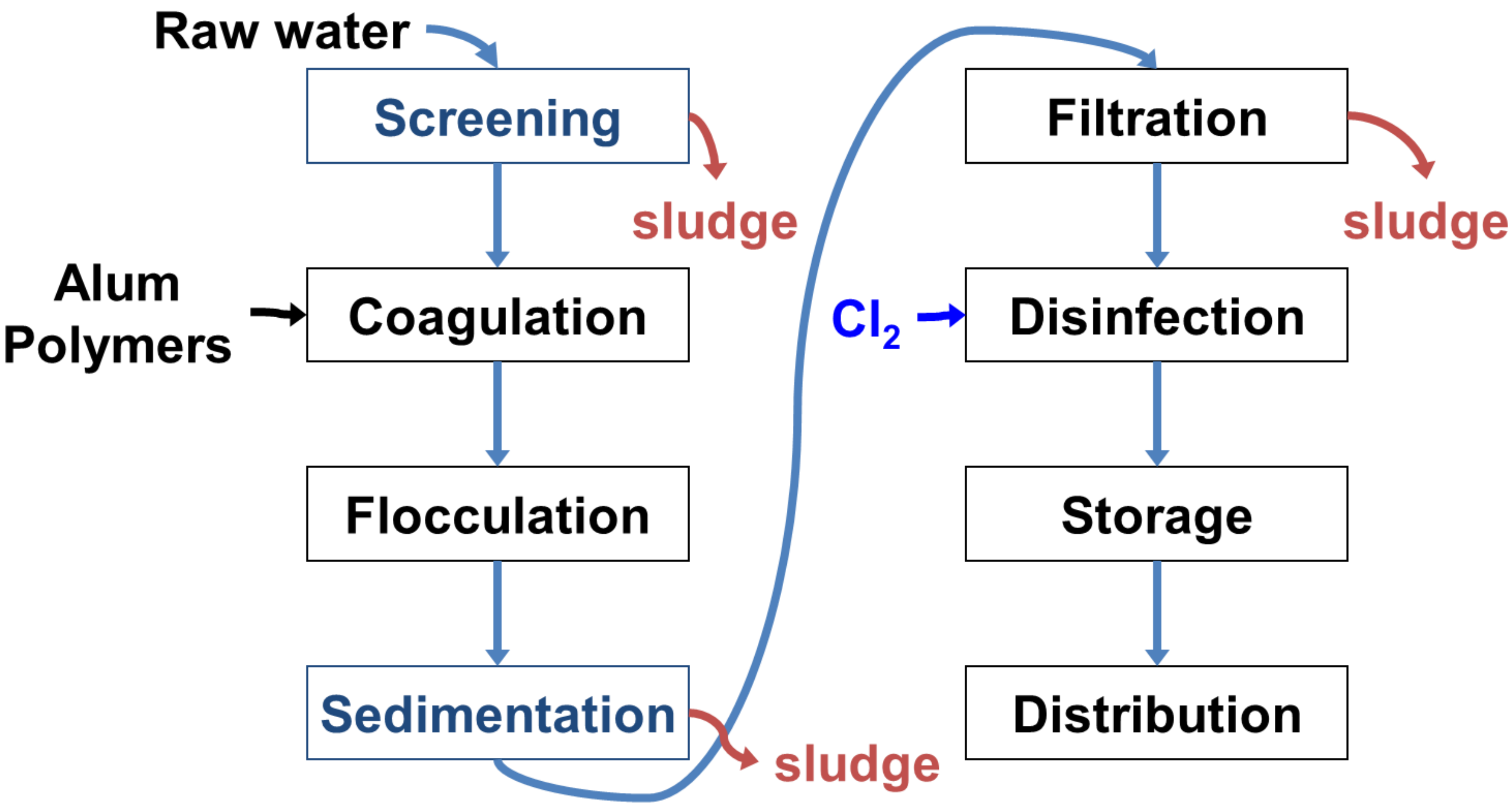
Sedimentation

Coagulation/flocculation

Filtration

- slow sand filters
- rapid sand filters
- diatomaceous earth filters
- membrane filters

Conventional Surface Water Treatment



Raw water

Screening

sludge

Alum
Polymers

Coagulation

Flocculation

Sedimentation

sludge

Filtration

sludge

Cl_2

Disinfection

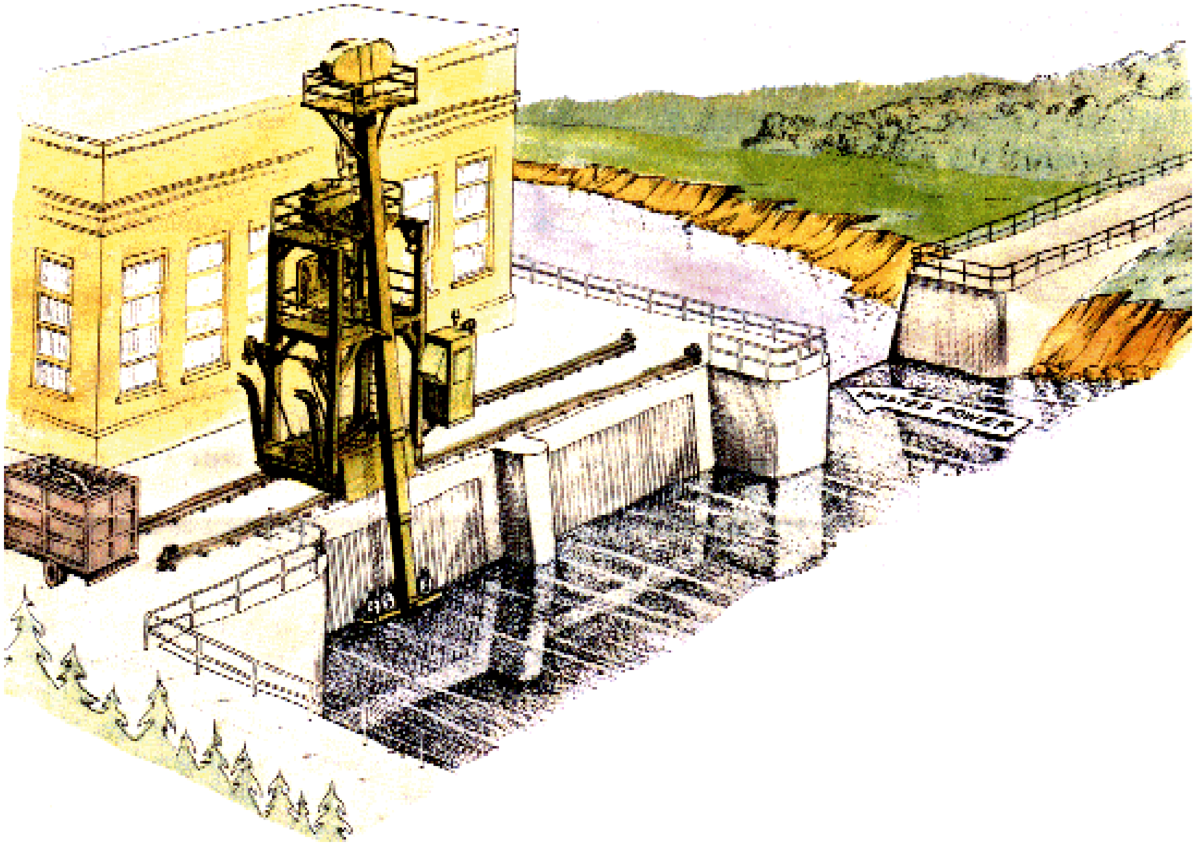
Storage

Distribution

Screening

Removes large solids

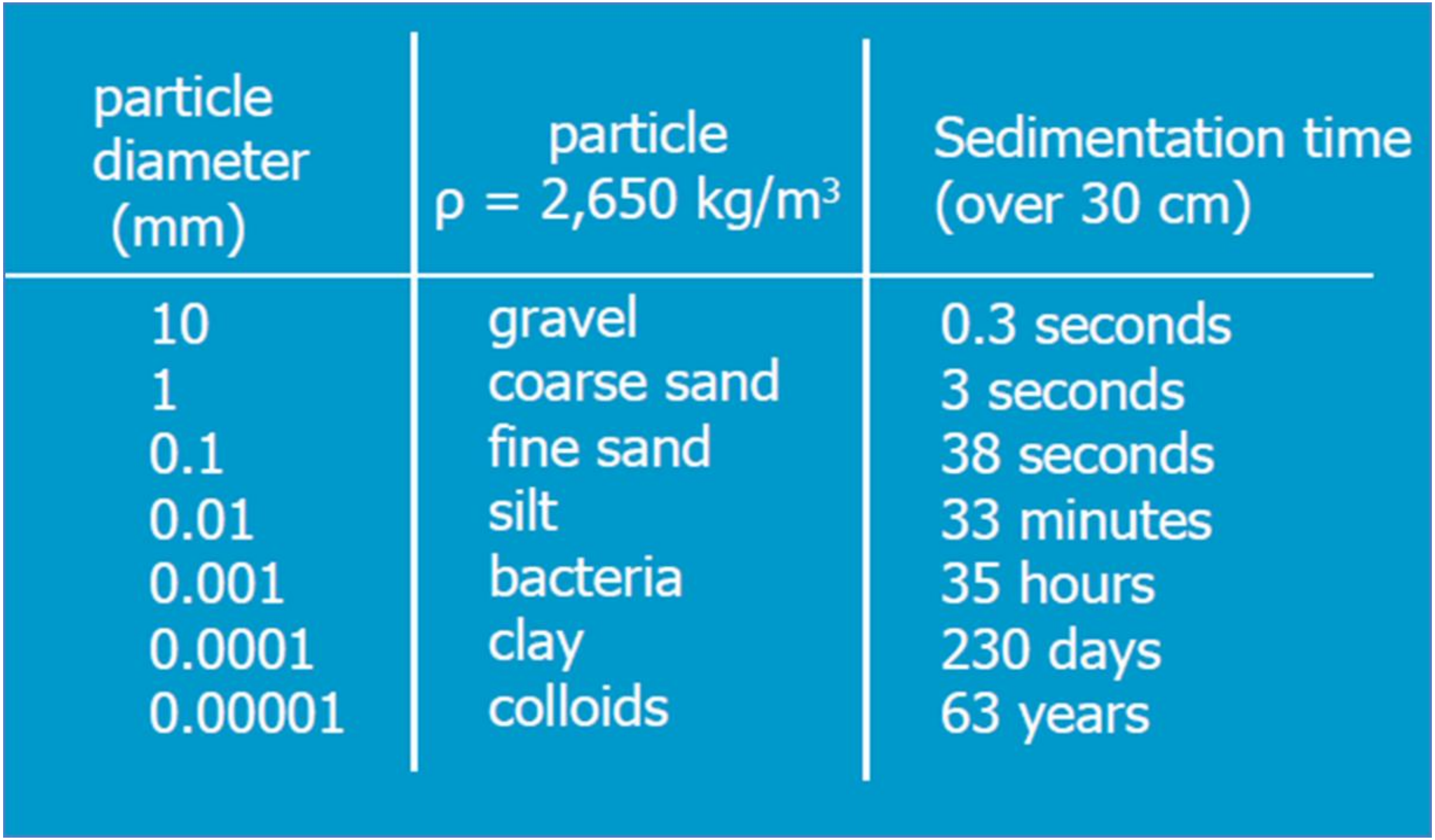
- logs
- branches
- rags
- fish



- Simple process
  - may incorporate a mechanized trash removal system
- Protects pumps and pipes in WTP

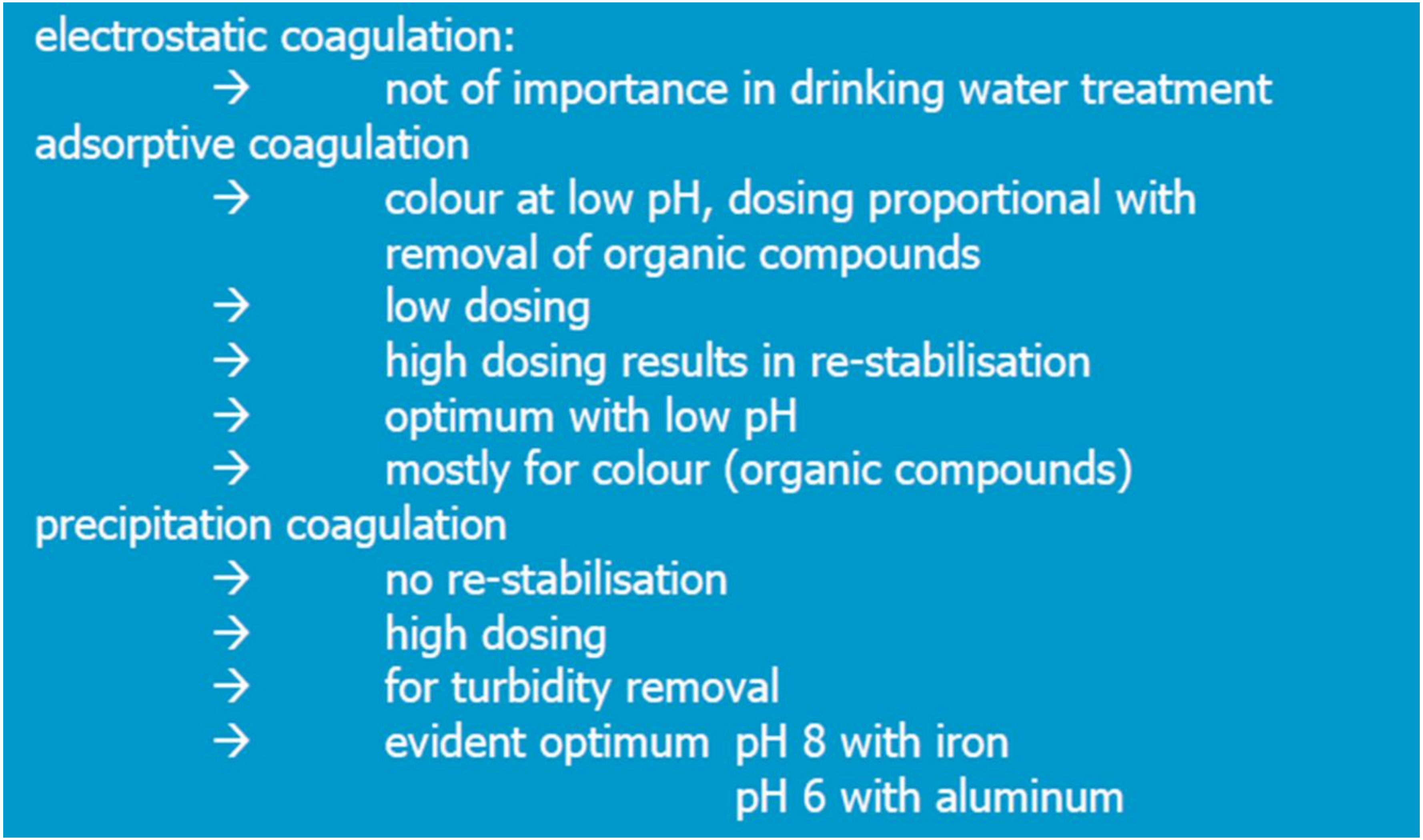
COAGULATION

Settling velocity of particles



particle diameter (mm)	particle $\rho = 2{,}650\ \mathrm{kg/m^3}$	Sedimentation time (over 30 cm)
10	gravel	0.3 seconds
1	coarse sand	3 seconds
0.1	fine sand	38 seconds
0.01	silt	33 minutes
0.001	bacteria	35 hours
0.0001	clay	230 days
0.00001	colloids	63 years

Coagulation theory



electrostatic coagulation:

→ not of importance in drinking water treatment

adsorptive coagulation

→ colour at low pH, dosing proportional with removal of organic compounds

→ low dosing

→ high dosing results in re-stabilisation

→ optimum with low pH

→ mostly for colour (organic compounds)

precipitation coagulation

→ no re-stabilisation

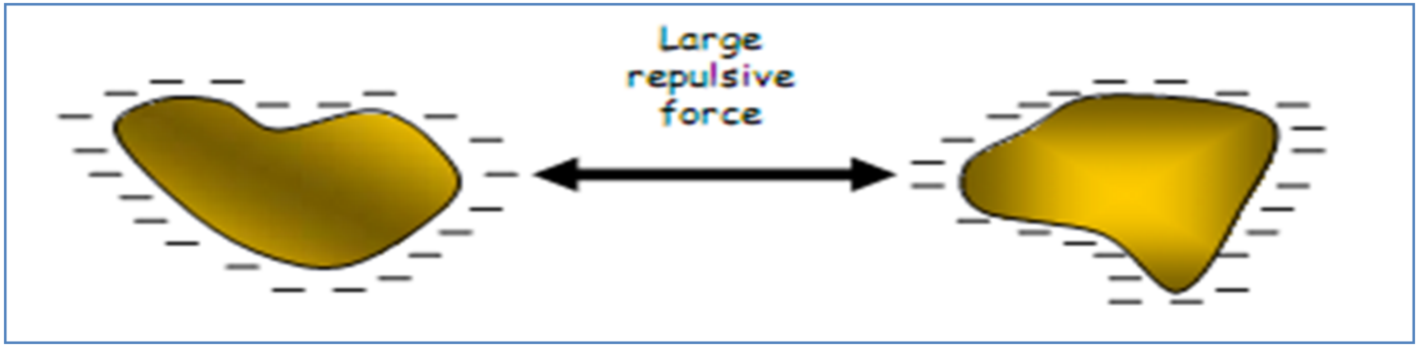
→ high dosing

→ for turbidity removal

→ evident optimum pH 8 with iron
pH 6 with aluminum

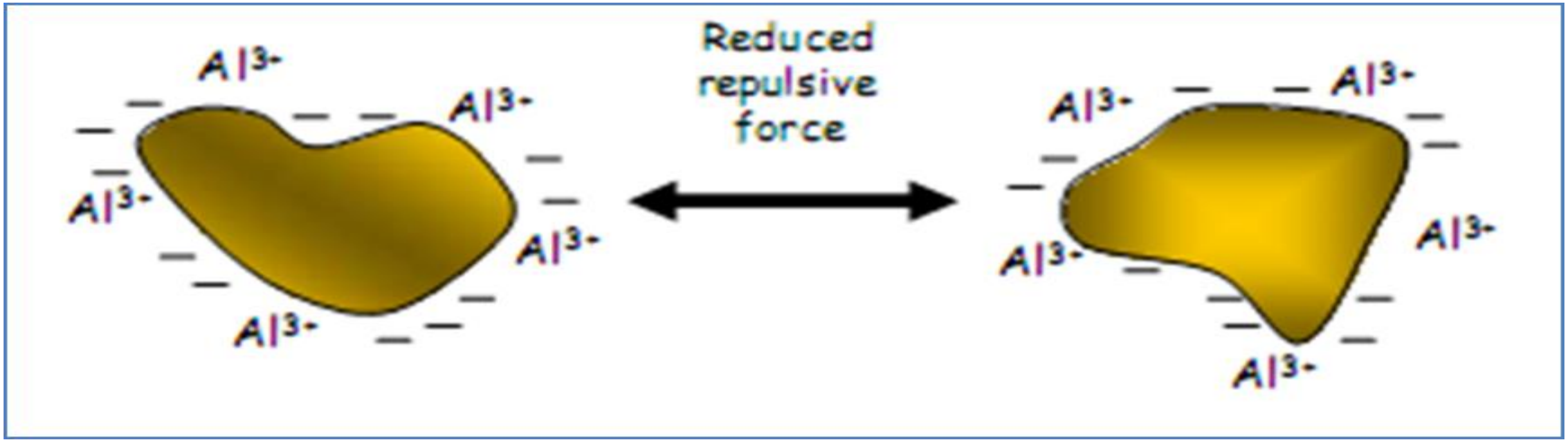
Briefly: There are two major forces acting on colloids:

1) electrostatic repulsion (simply, negative colloids repel other negatively charged colloids)



2)intermolecular, or van der Waals, attraction.

Coagulants can be used to reduce the electrostatic repulsive forces The electrostatic repulsion reduced by the addition of countercharged ions [Al3+]



Zeta Potential Model

The magnitude of these forces is measured by the zeta potential, which is:

$$\boxed{Z = \frac{4\pi q d}{D}}$$

where:

Z is the zeta potential,

q is the charge per unit area,

d is the thickness of the effective charge layer, and

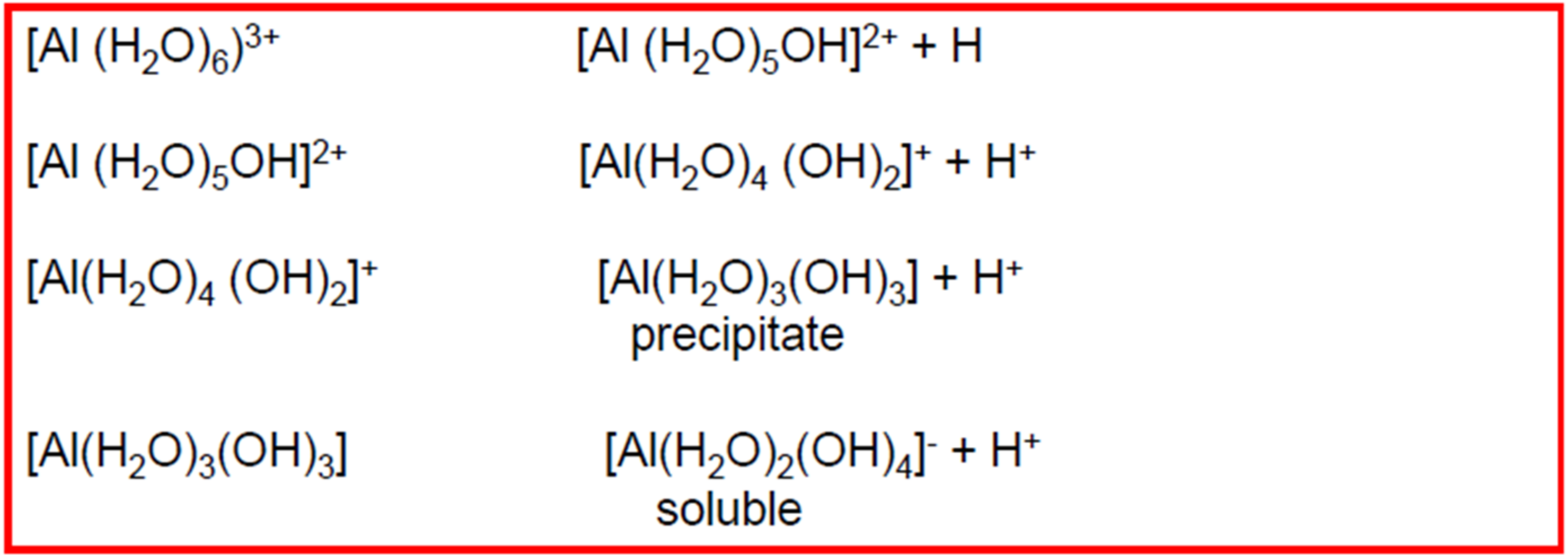
D is the dielectric constant of the liquid.

The greater the zeta potential, the greater are the repulsion forces between the colloids and, therefore, the more stable is the colloidal suspension.

If enough alkalinity is present the H^+-ions formed will be taken away and the precipitate $[Al(H2O)3(OH)3]$ or just $Al(OH)3$will be formed.

At pH-values higher than 7.8 aluminates-ions $[Al(H2O)2(OH)4]^-$or just $Al(OH)4^-$are formed which are negatively charged and soluble in water.

In coagulation with an aluminum compound pH-values higher than 7.8 must be avoided for that reason.



$[Al\ (H_2O)_6)^{3+}$ $[Al\ (H_2O)_5OH]^{2+} + H$

$[Al\ (H_2O)_5OH]^{2+}$ $[Al(H_2O)_4\ (OH)_2]^+ + H^+$

$[Al(H_2O)_4\ (OH)_2]^+$ $[Al(H_2O)_3(OH)_3] + H^+$

precipitate

$[Al(H_2O)_3(OH)_3]$ $[Al(H_2O)_2(OH)_4]^- + H^+$

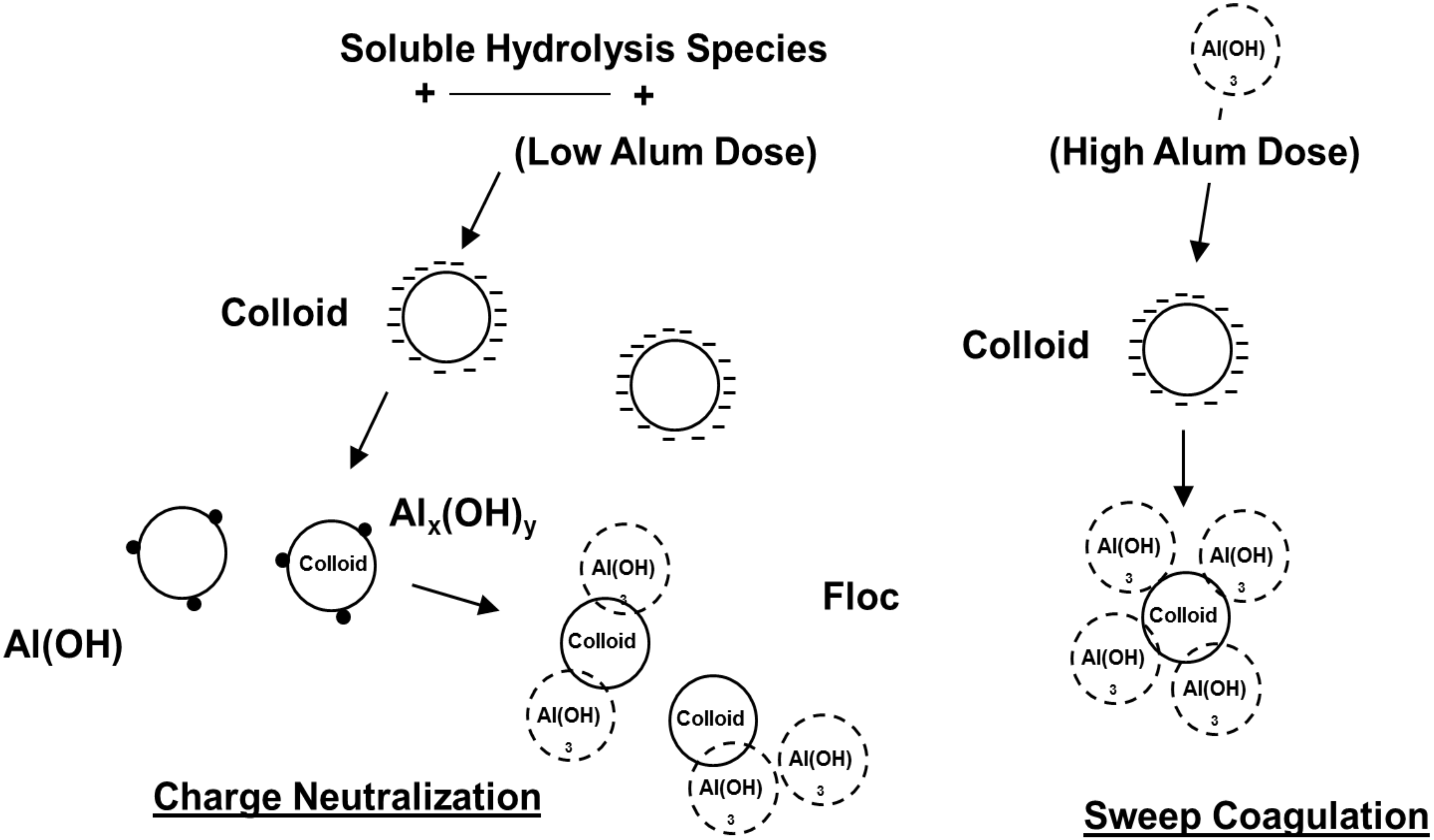
soluble

Coagulation occurs in two ways:

1) By adsorption of soluble hydrolysis coagulant species on the colloid particles and destabilization by charge neutralization. These reactions occur in about 1 second.

2) Sweep floc coagulation where the coagulant exceeds it’s solubility limit and precipitates and traps the colloid particles. Sweep floc coagulation occurs in the range of 1 to 7 seconds.

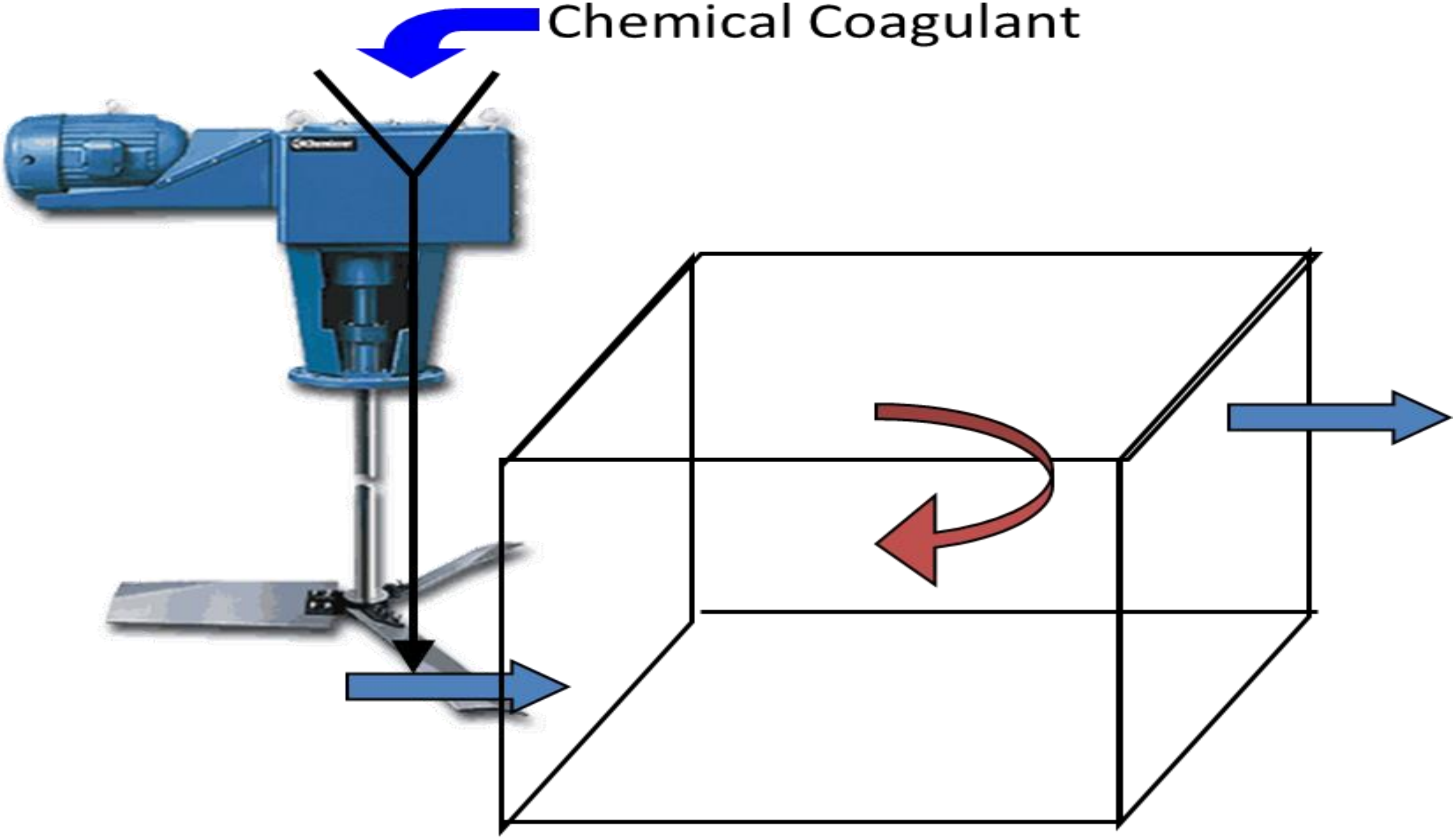
Coagulation with Metal Salts



Coagulation chamber

Intense mixing of coagulant and other chemicals with the water

Generally performed with mechanical mixers



Chemical Coagulant

Rapid mixing

- **mechanical mixers “mechanical mixers dissipate the power in the raw water”**
- **static mixers “gravity forces cause the mixing effect”**

parameters:

-residence time (T)

-velocity gradient (Gc)

Velocity Gradient

Rate of particulate collision G

The parameter expressing mixing intensity

Therefore;

G must be sufficient to give the desired rate of particulate collisions.

G ↑ shear force ↑

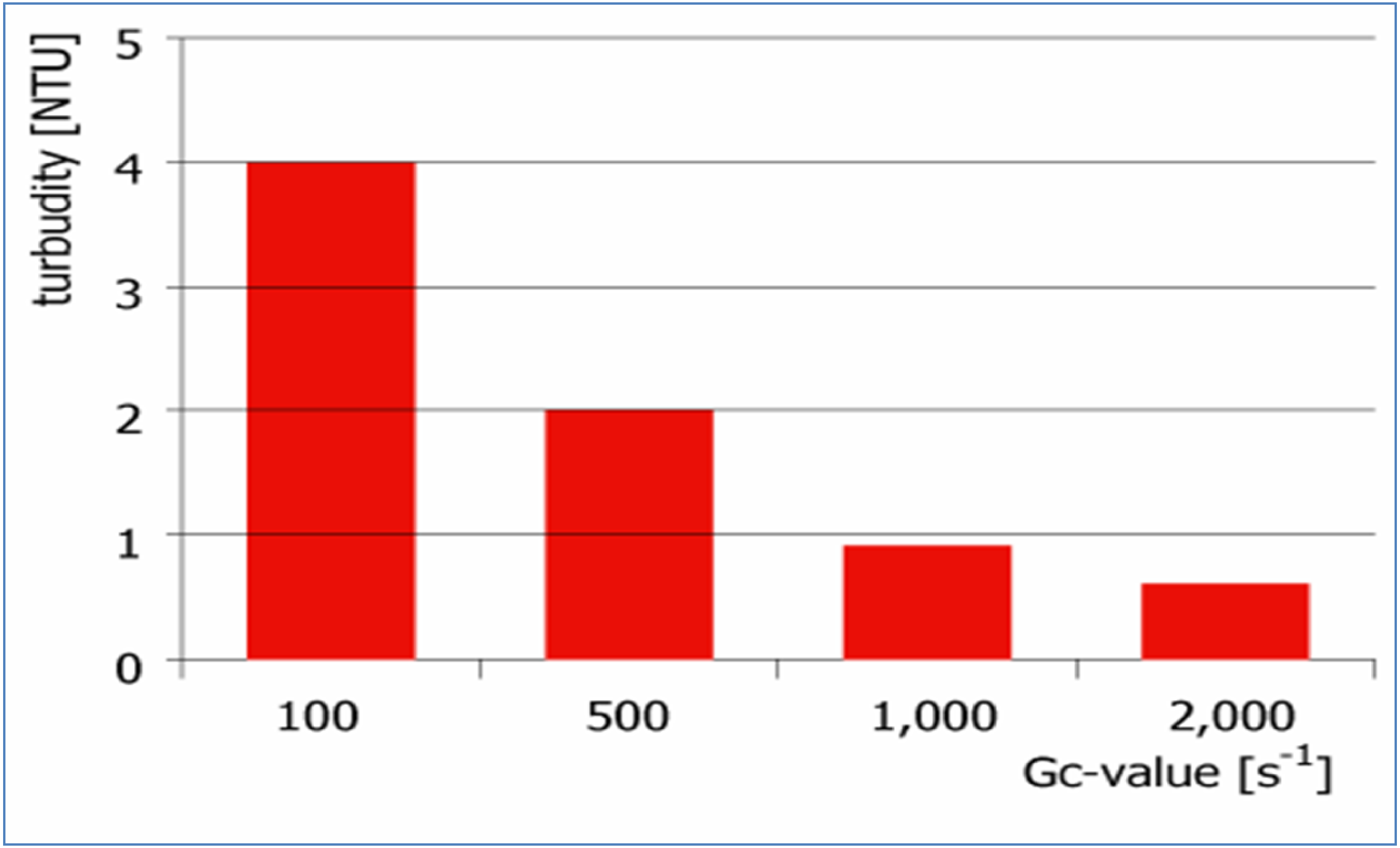
Example:

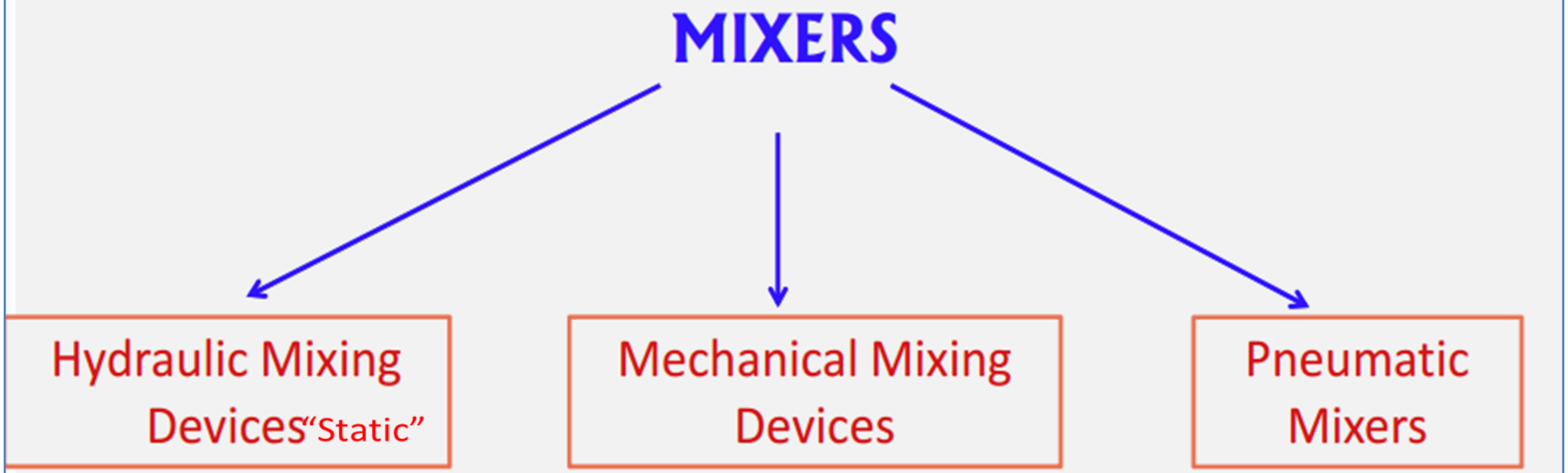
Two water particles moving 1m/sec relative to each other at a distance 0,1 m we would have

$$G=\frac{1m/\sec}{0.1m}=10\sec^{-1}$$

Velocity gradient measure of the relative velocity of two particles of fluid and distance between.

Variation in velocity gradient G_c





MIXERS

Hydraulic Mixing Devices“Static”

- → Venturi sections
- → Hydraulic jumps
- → Parshall flume
- → Weirs
- → Baffled mixing chambers

Mechanical Mixing Devices

- → Propeller mixer
- → Turbine mixer
- → Paddle mixer

Pneumatic Mixers

- → Air diffusers

Hydraulic Mixers

→ The degree of turbulence is measured by the loss in head.

→Dependent on flow

→Power dissipation in a hydraulic device

$$p = \rho\, gQ \Delta h_L$$

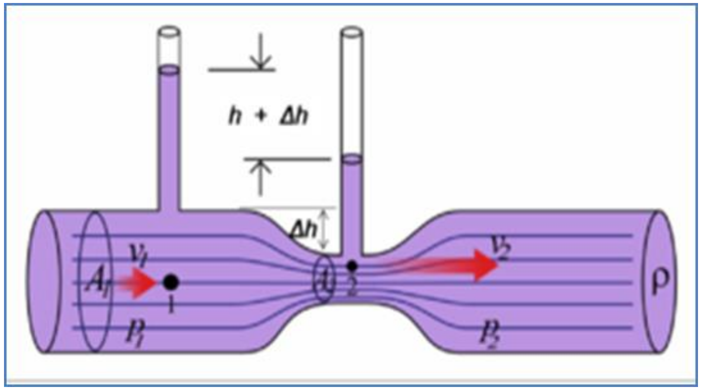
Venturi sections

The reduced pressure in the throat of the section aspirates the chemical feed solution into flow.

→ Turbulence generated in the throat.

$$h_L = C_d \frac{V_2^{\,2}}{2g}$$

C_d = constant ≈ 1.50 (-)

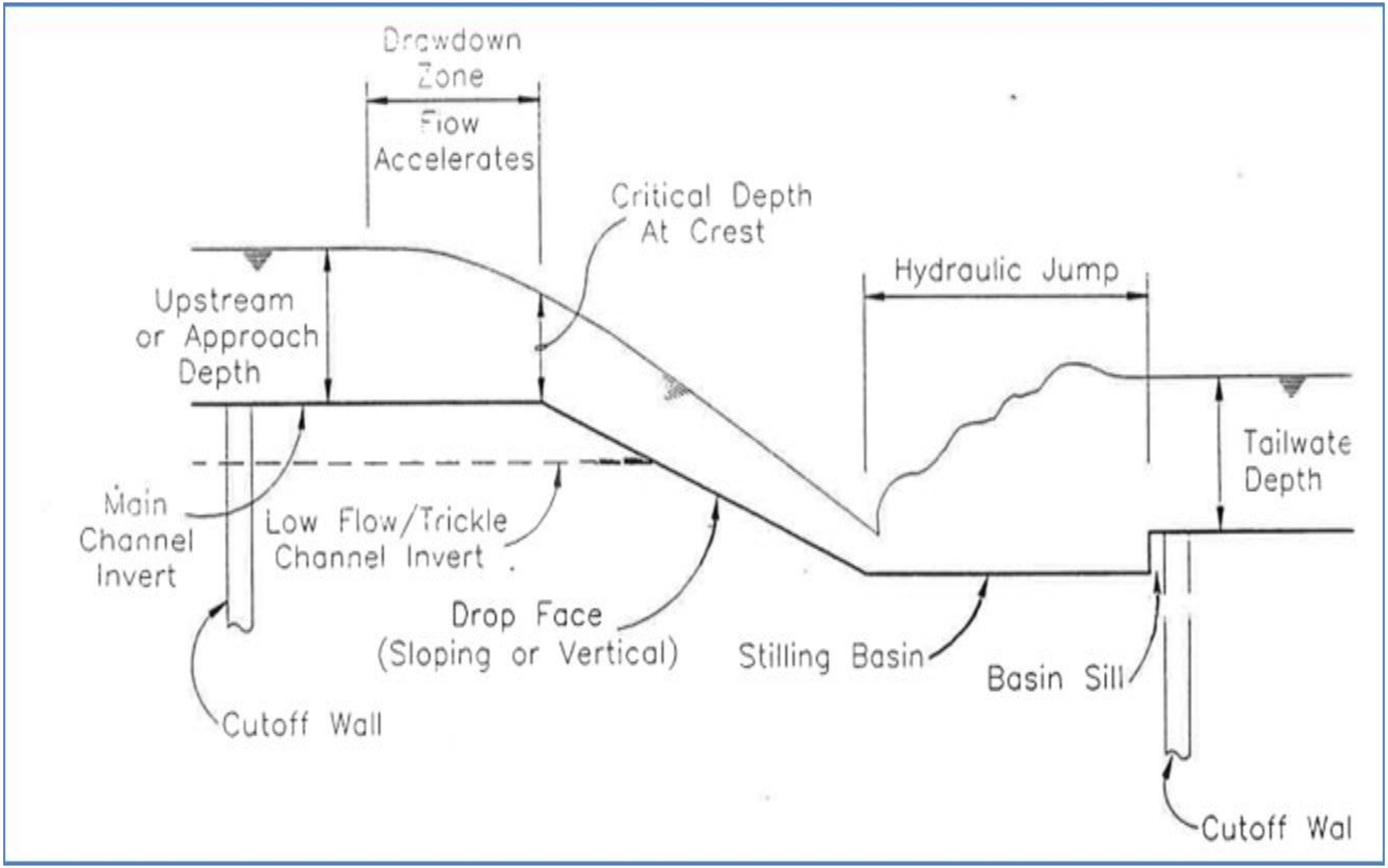


Hydraulic Jumps

A chute followed by a channel, with or without a drop in the elevation of channel floor.

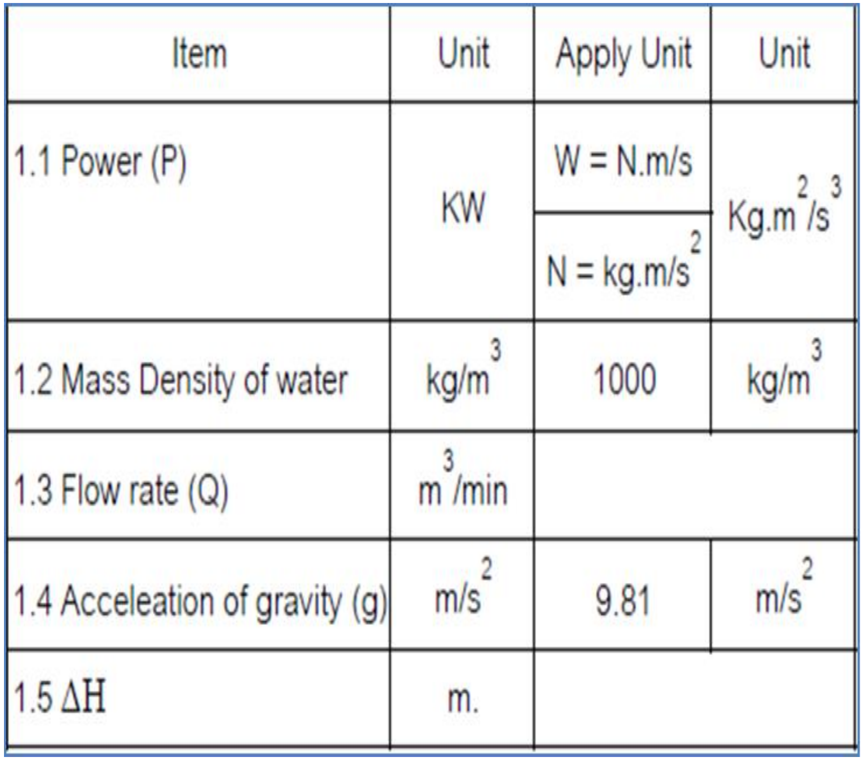
Chute → Creates supercritical flow.

Turbulence generated in the jump Provide suitable → mixing.

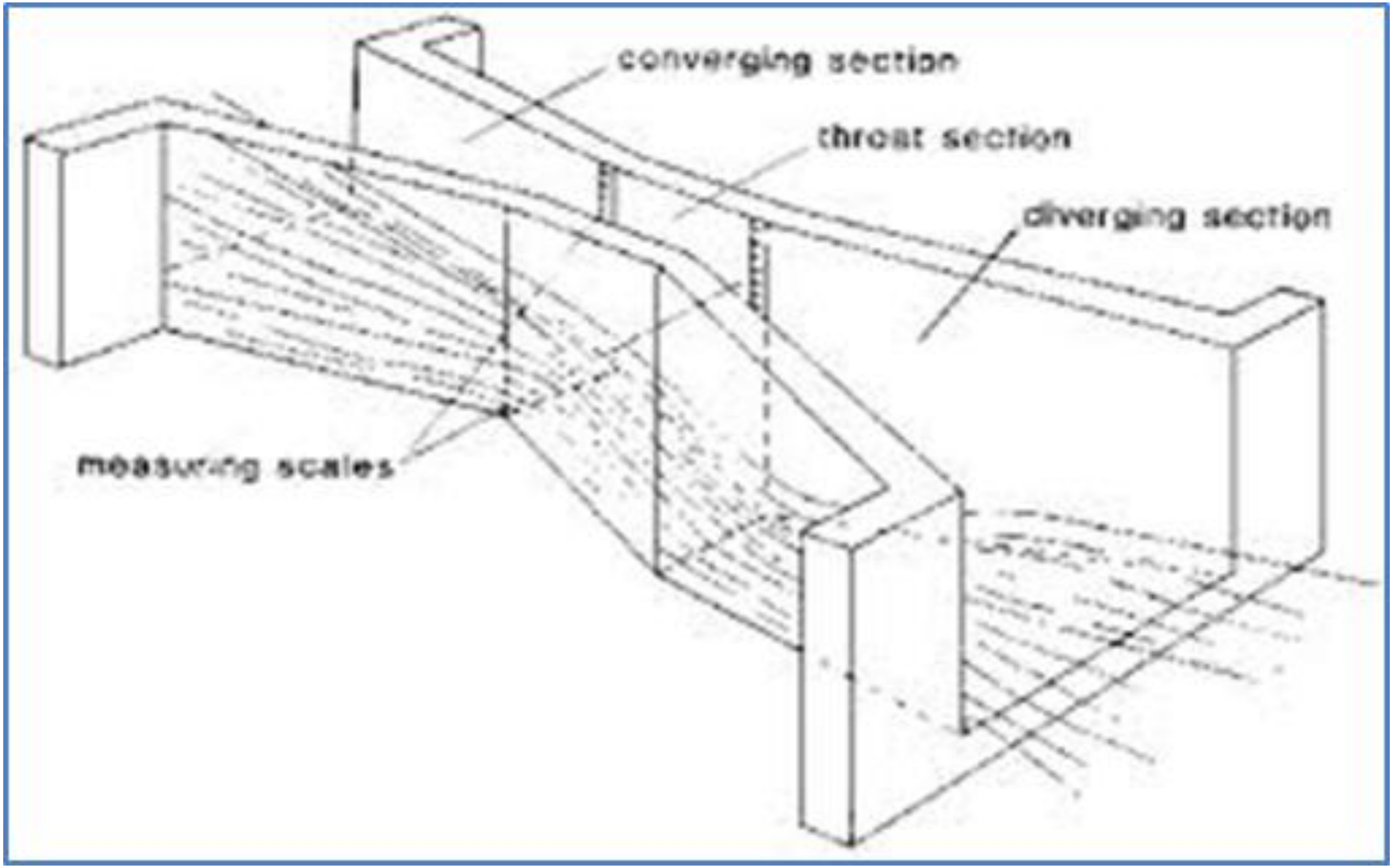

Drawdown Zone
Flow Accelerates
Critical Depth At Crest
Hydraulic Jump
Upstream or Approach Depth
Tailwate Depth
Main Channel Invert
Low Flow/Trickle Channel Invert
Drop Face (Sloping or Vertical)
Stilling Basin
Basin Sill
Cutoff Wall
Cutoff Wal

Parshall Flume

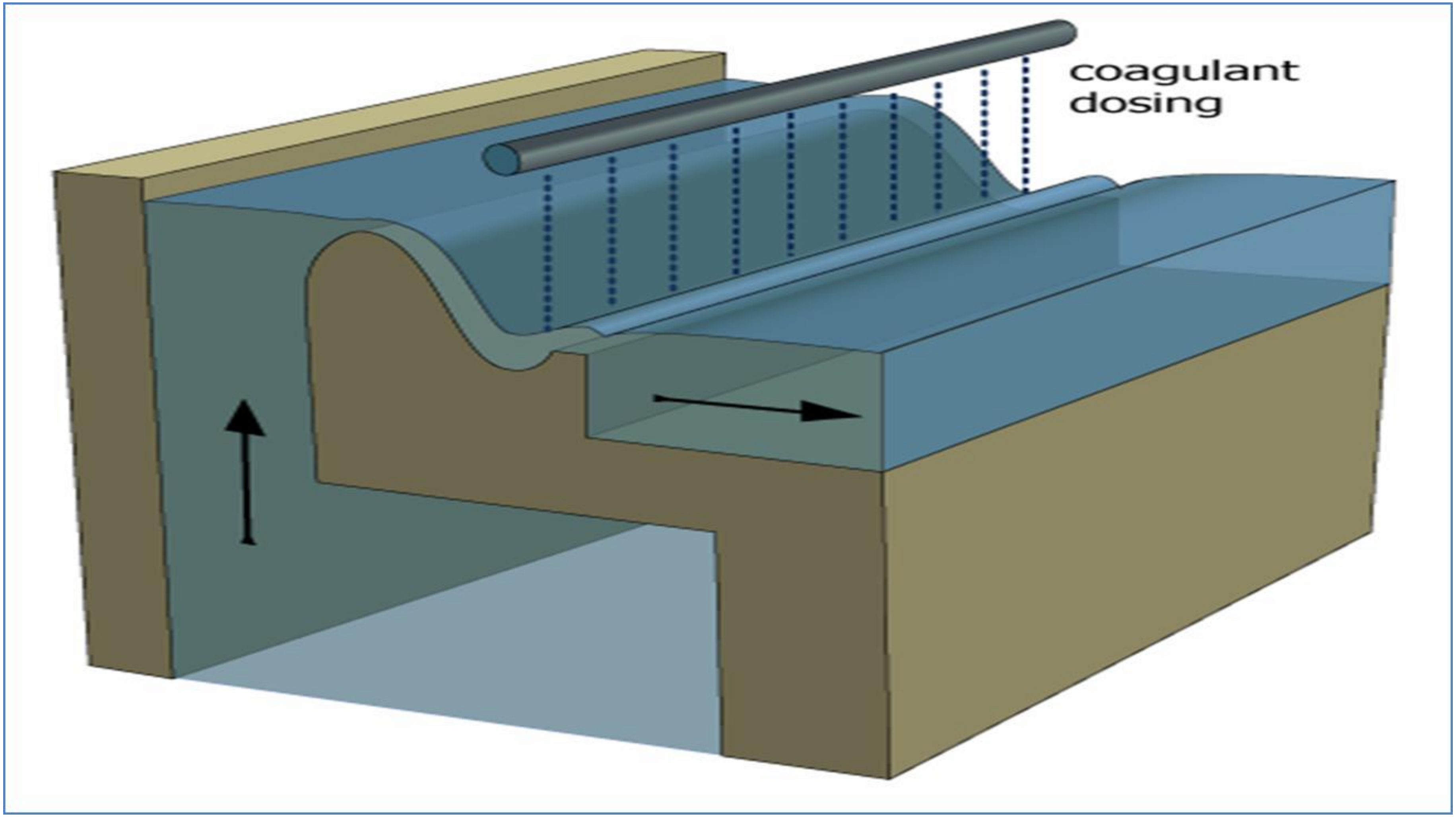
Effective rapid mixer when a hydraulic jump is incorporated immediately downstream of flume.



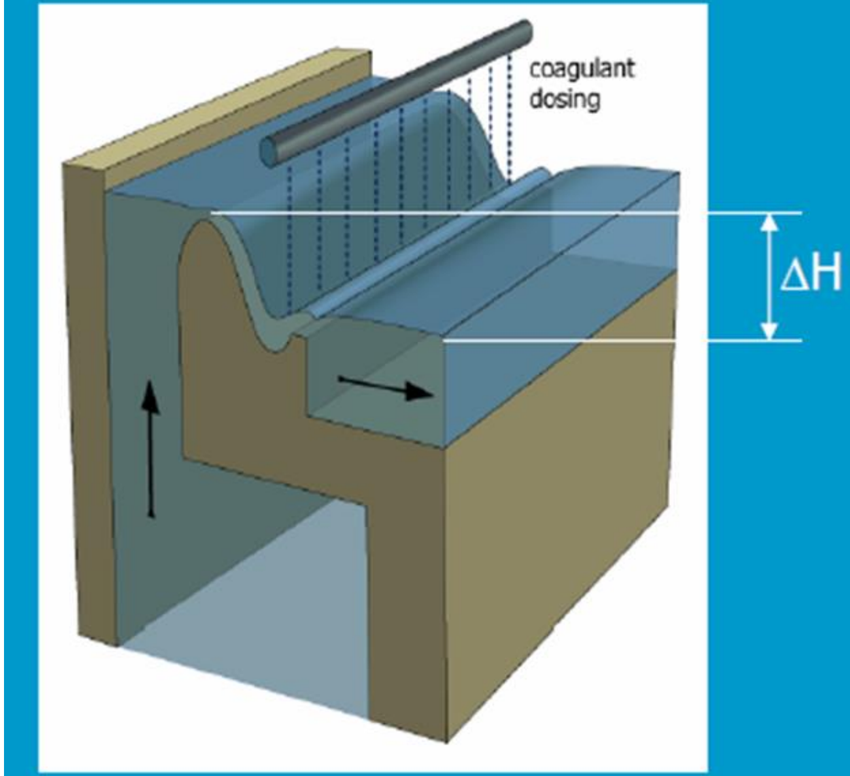
Item	Unit	Apply Unit	Unit
1.1 Power (P)	KW	W = N.m/s N = kg.m/s^2	Kg.m^2/s^3
1.2 Mass Density of water	kg/m^3	1000	kg/m^3
1.3 Flow rate (Q)	m^3/min		
1.4 Acceleation of gravity (g)	m/s^2	9.81	m/s^2
1.5 ΔH	m.		


converging section
throat section
diverging section
measuring scales

Weir mixer:



Example weir mixing:



static mixer $$G_c = \sqrt{\frac{\rho_w \cdot g \cdot \Delta H}{\tau_c \cdot \mu}}$$

Example:

$\Delta H = 0.75$ m; $Q = 4500$ m³/h; $V = 2$ m³

$T = 20°C \rightarrow \mu = 1.01 \cdot 10^{-3}$ N·s/m²

$Q = 4500$ m³/h $= 1.25$ m³/s

$\tau_c = 2/1.25 = 1.60$ sec

$$G_c = \sqrt{\frac{1000 \cdot 9.81 \cdot 0.75}{1.01 \cdot 10^{-3} \cdot 1.6}} = 2134 s^{-1}$$

Where:

ρ = density of water (kg/m^3)

g = gravity constant (m/s^2)

Q = flow (m^3/s)

ΔH = head loss over mixing tank (m)

μ = dynamic water viscosity (N·s/m^2)

τc = residence time in the mixing zone (s)

Baffled Mixing Chambers

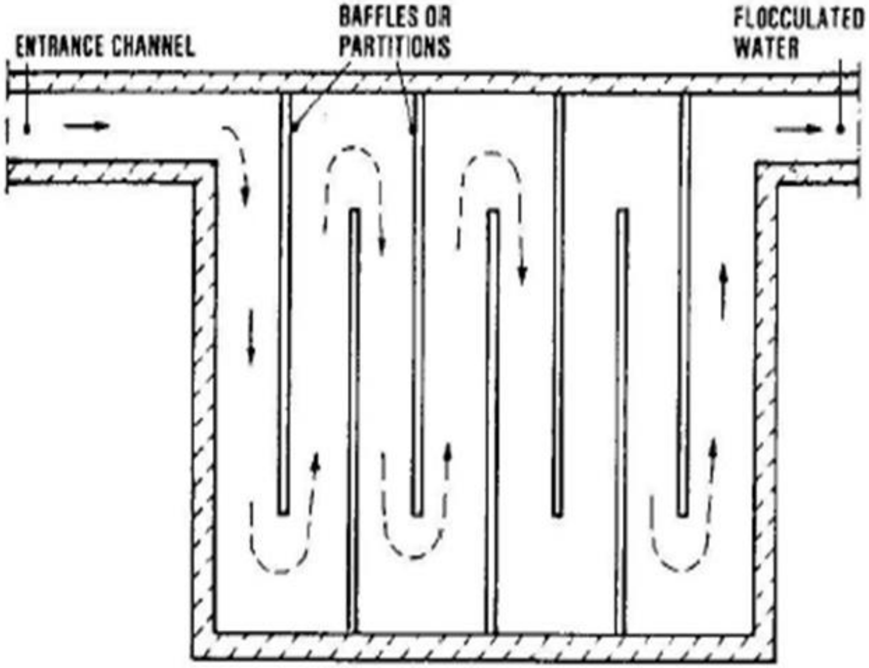


Figure 6.2. Horizontal-flow baffled channel flocculator (plan). *Source:* IRC, 1981b.

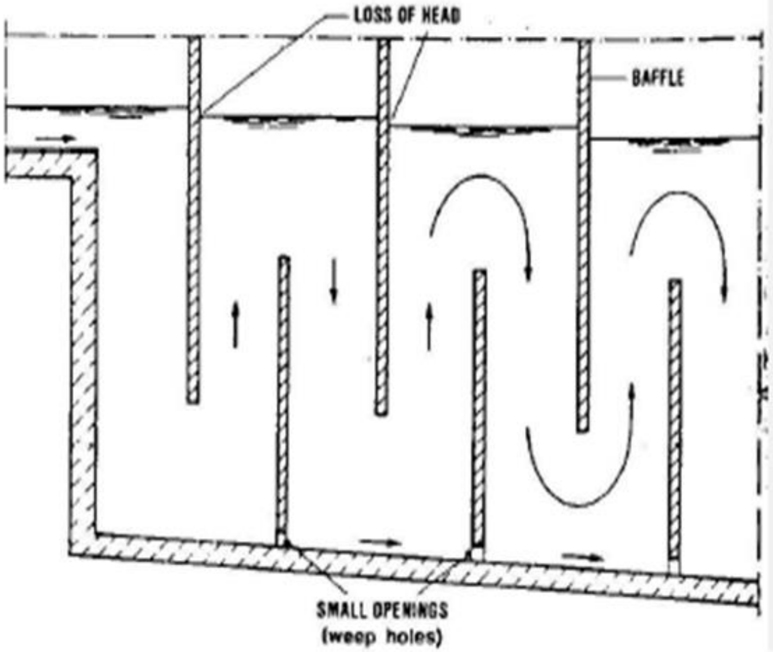


Figure 6.3. Vertical-flow baffled channel flocculator (cross-section). *Source:* IRC, 1981b.

ical flow baffled channel flocculator

Ref: Schulz & Okun, 1984, John Wiley & Sons

Mixing is accomplished by reversing the flow of water through channels formed.

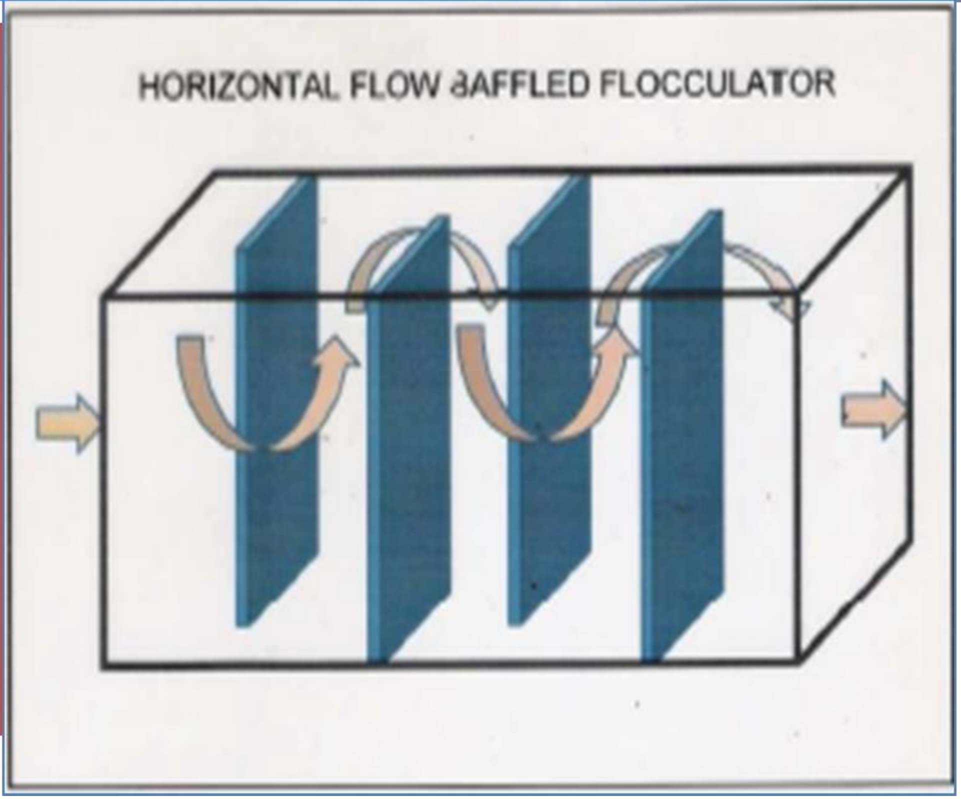
FOR HORIZONTAL FLOW

$$n = \left\{ \left[\frac{2\mu t}{\rho(1.44 + f)} \right] \left[\frac{HLG}{Q} \right]^{2} \right\}^{1/3}$$

HEADLOSS AROUND THE BAFFLE IN A CHANNEL can be computed by assuming 180° turn in the direction of flow in a square pipe

$h=3.2\,(v^2/2g)$

n = number of baffles in the basin
H = depth of water in the basin (m)
L = length of the basin (m)
G = velocity gradient (sec^{-1})
Q = flowrate (m^3/sec)
t = time of flocculation (sec)
μ = dynamic viscosity (kg/m.sec)
ρ =density of water (kg/m^3)
f = coefficient of friction of the baffles
w = width of the basin (m)



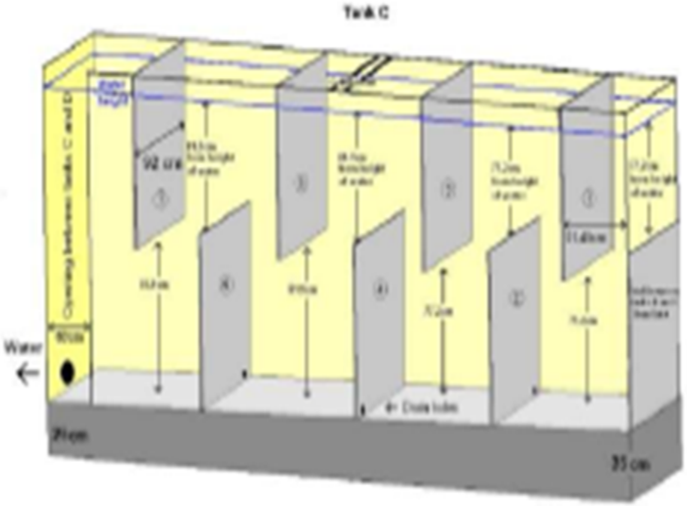
FOR VERTICAL FLOW

$$n = \left\{ \left[\frac{2\mu t}{\rho(1.44 + f)} \right] \left[\frac{WLG}{Q} \right]^2 \right\}^{1/3}$$

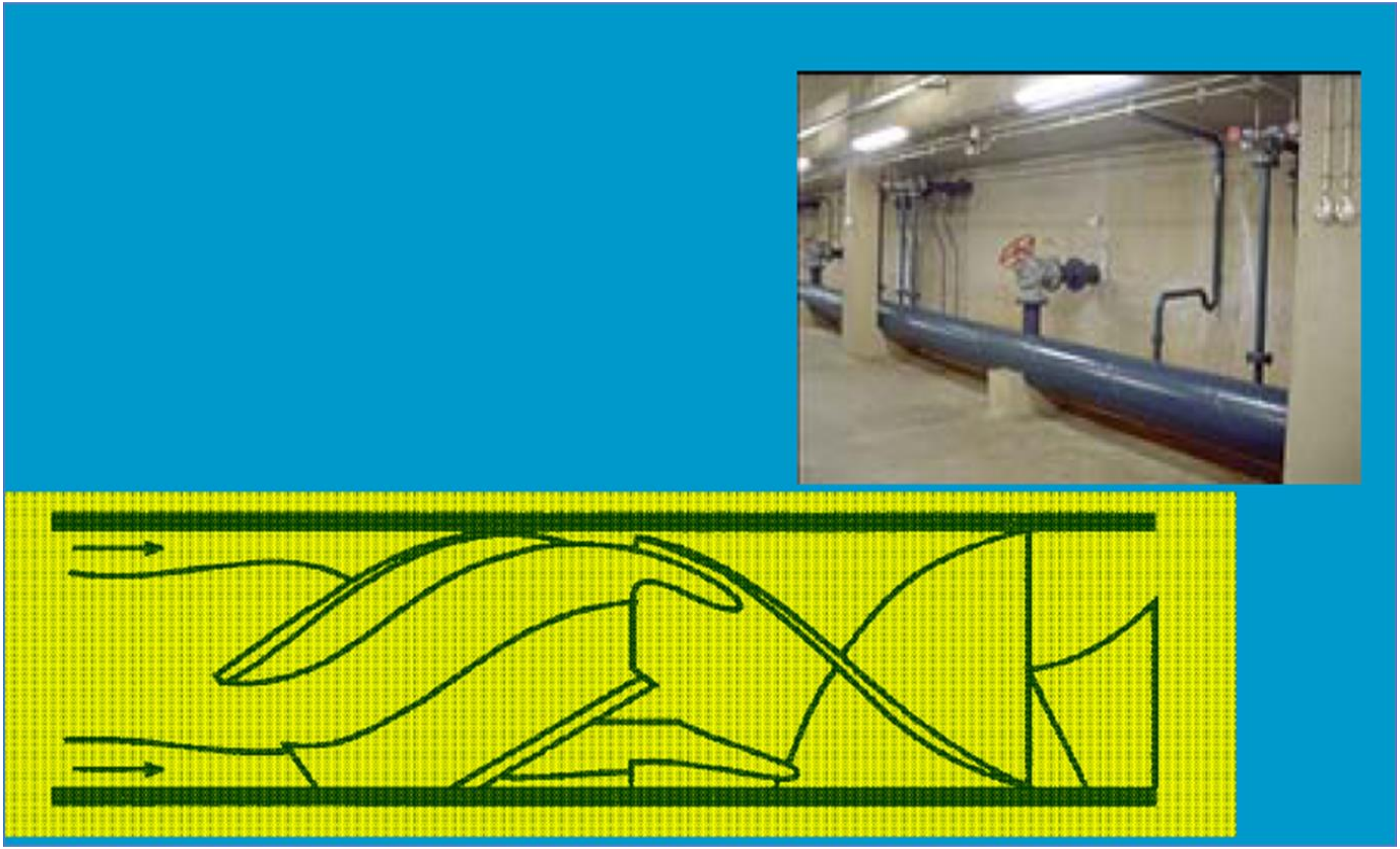
HEADLOSS AROUND THE BAFFLE IN A CHANNEL can be computed by assuming 180° turn in the direction of flow in a square pipe

$h=3.2\,(v^2/2g)$

n = number of baffles in the basin
H = depth of water in the basin (m)
L = length of the basin (m)
G = velocity gradient (sec^{-1})
Q = flowrate (m^3/sec)
t = time of flocculation (sec)
μ = dynamic viscosity (kg/m.sec)
ρ =density of water (kg/m^3)
f = coefficient of friction of the baffles
w = width of the basin (m)



static mixers



G-value for static mixer:

For static mixer, the degree of mixing is directly related to the headloss (i.e. pressure drop) through the mixer, and the velocity gradient is calculated from Equation:

$$G = \sqrt{\frac{P}{\mu V}} = \sqrt{\frac{Q\Delta p}{\mu V}}$$

Where:

G=average velocity gradient (s-1)

P=power input(W)

μ=dynamic viscosity (N.s/m^2) and

V is volume(m3)

Q is the flowrate (m^3/s)

ΔP is the pressure drop (bar). The headloss or pressure drop through the mixer measured by a differential electronic manometer meter

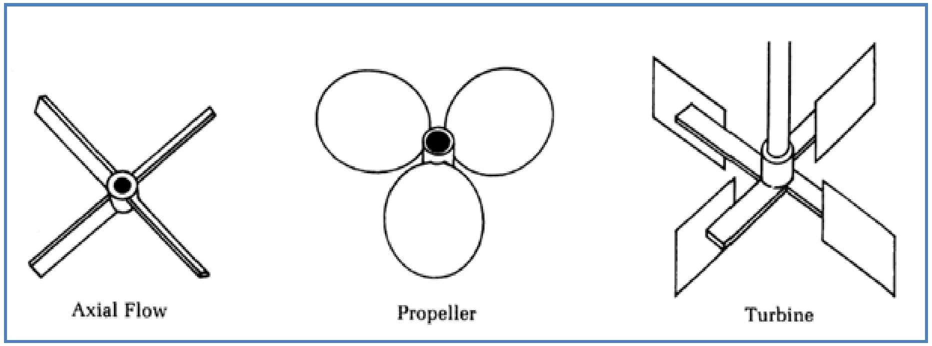
Mechanical Mixing Devices

Mixing impeller types used in water treatment

Turbine and Propeller Mixers

Reynolds number for impellers

$$R_e = \frac{D^2 n \rho}{\mu}$$



D = diameter of impeller, m
n = rev/sec
ρ = density of liquid, kg/m^3
μ = dynamic viscosity Ns/m^2
R = reynolds number (unitless)

Reynolds number : R_e <10 laminar
R_e>1000 turbulent

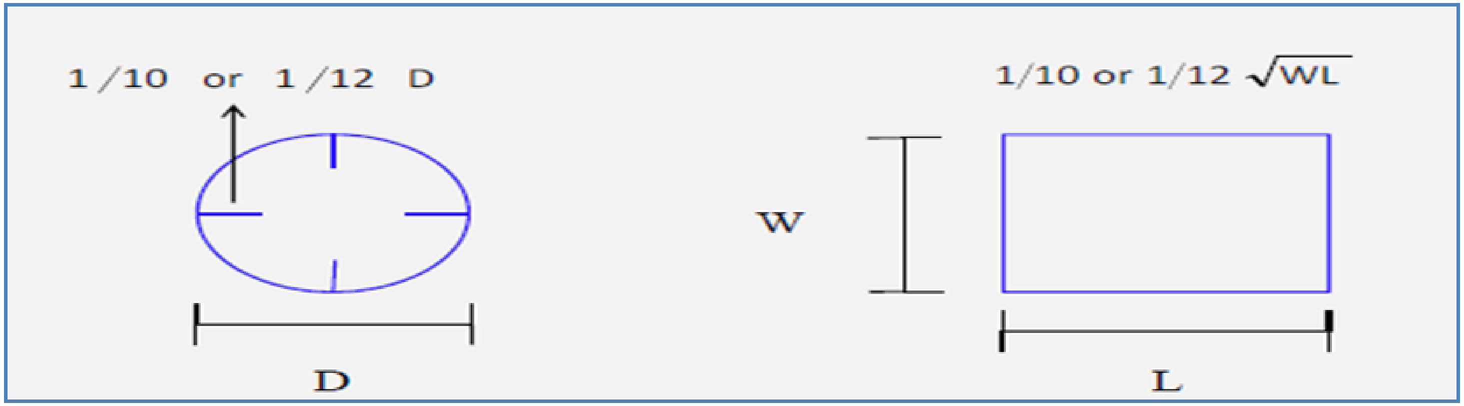
Vortexing :

→Liquid to be mixed rotates with the impeller

→Reduction in the difference between the fluid velocity and the impeller velocity (effectiveness of mixing decreases)

In circular or rectangular tanks the usual method used to limit vortexing.

To install 4 or more vertical baffles extending approximately 1/10th the diameter out from the wall.



Power in baffled tank

Power imparted in an unbaffled tank = 1/6 of the power imparted in the same tank with baffles

In small tanks (to prevent vortexing):

→Mounting the impeller off-center

→Mounting the impeller at angle with verticle

→Mounting the impeller to the side of basins at angle

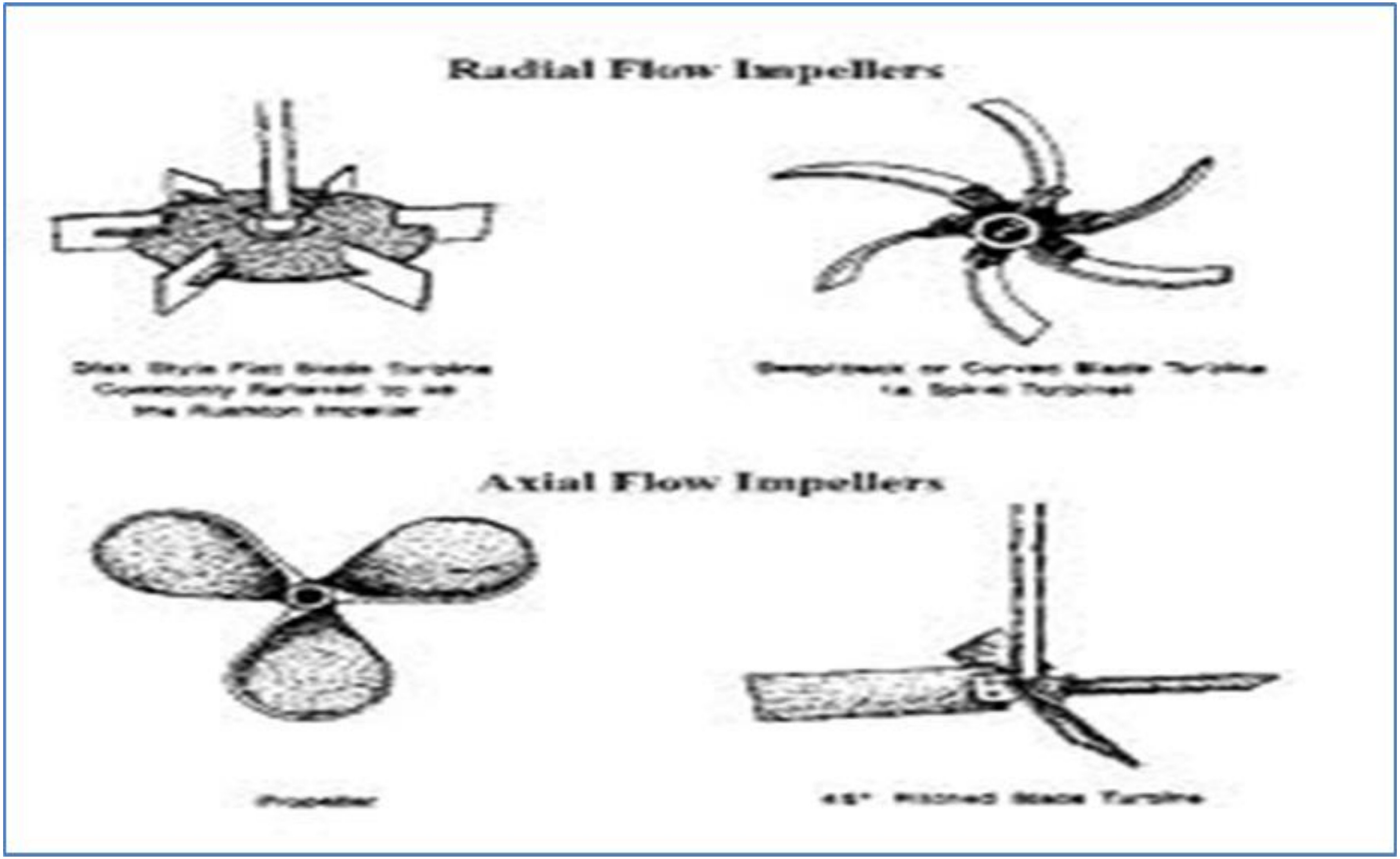
Types of Impellers :

1. Radial flow impellers

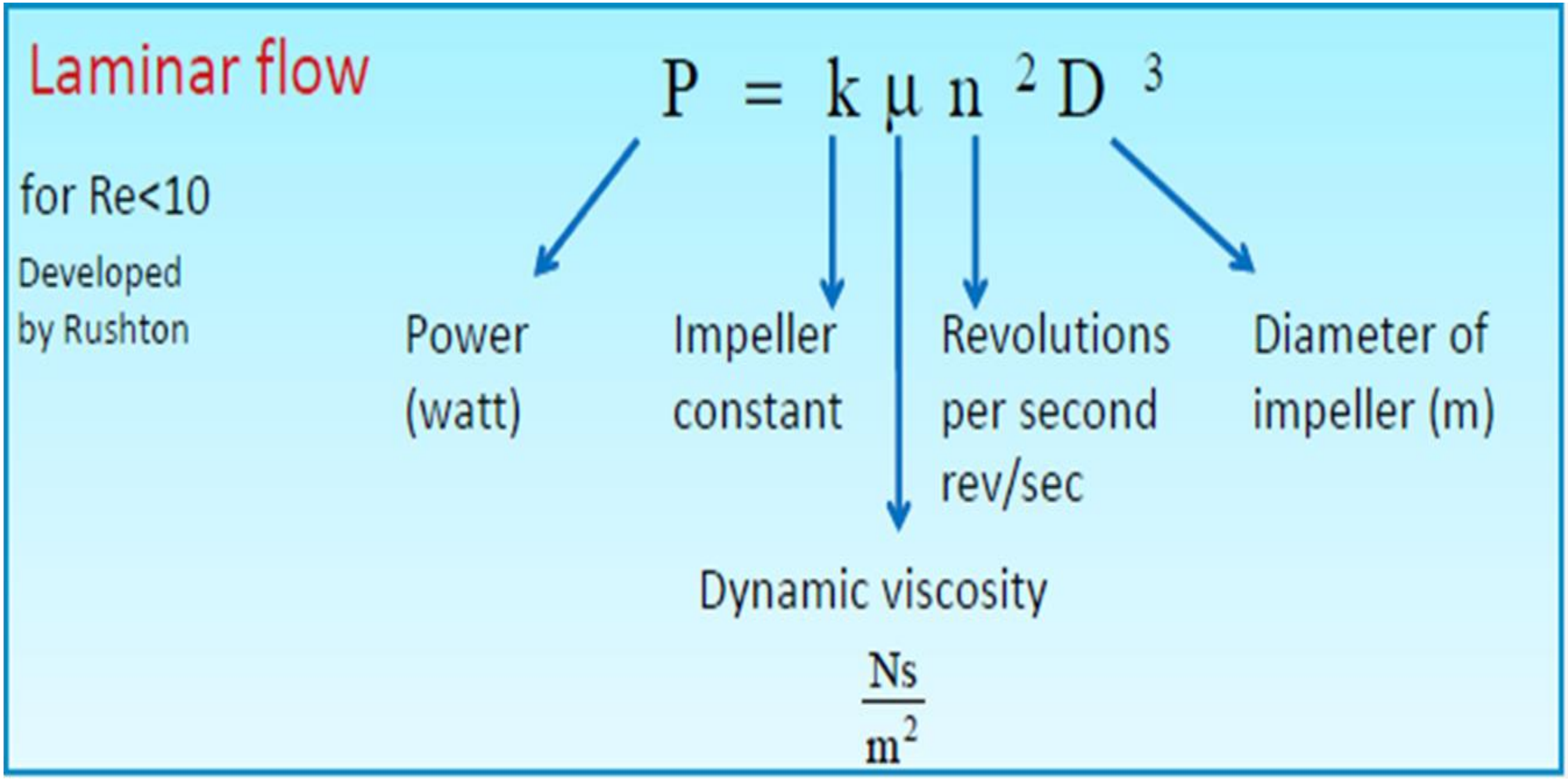
Generally have flat or curved blades located parallel to the axis of shaft.

2. Axial flow impellers

Make an angle of less than 90^{o} with drive shaft.


Radial Flow Impellers
Disk Style Flat Blade Turbine Commonly Referred to as the Rushton Impeller
Sweptback or Curved Blade Turbine (a Spiral Turbine)
Axial Flow Impellers
Propeller
45° Pitched Blade Turbine

Turbine and Propeller Mixers (continue)



Laminar flow

for Re<10

Developed by Rushton

$$P = k \mu n^2 D^3$$

Power (watt)

Impeller constant

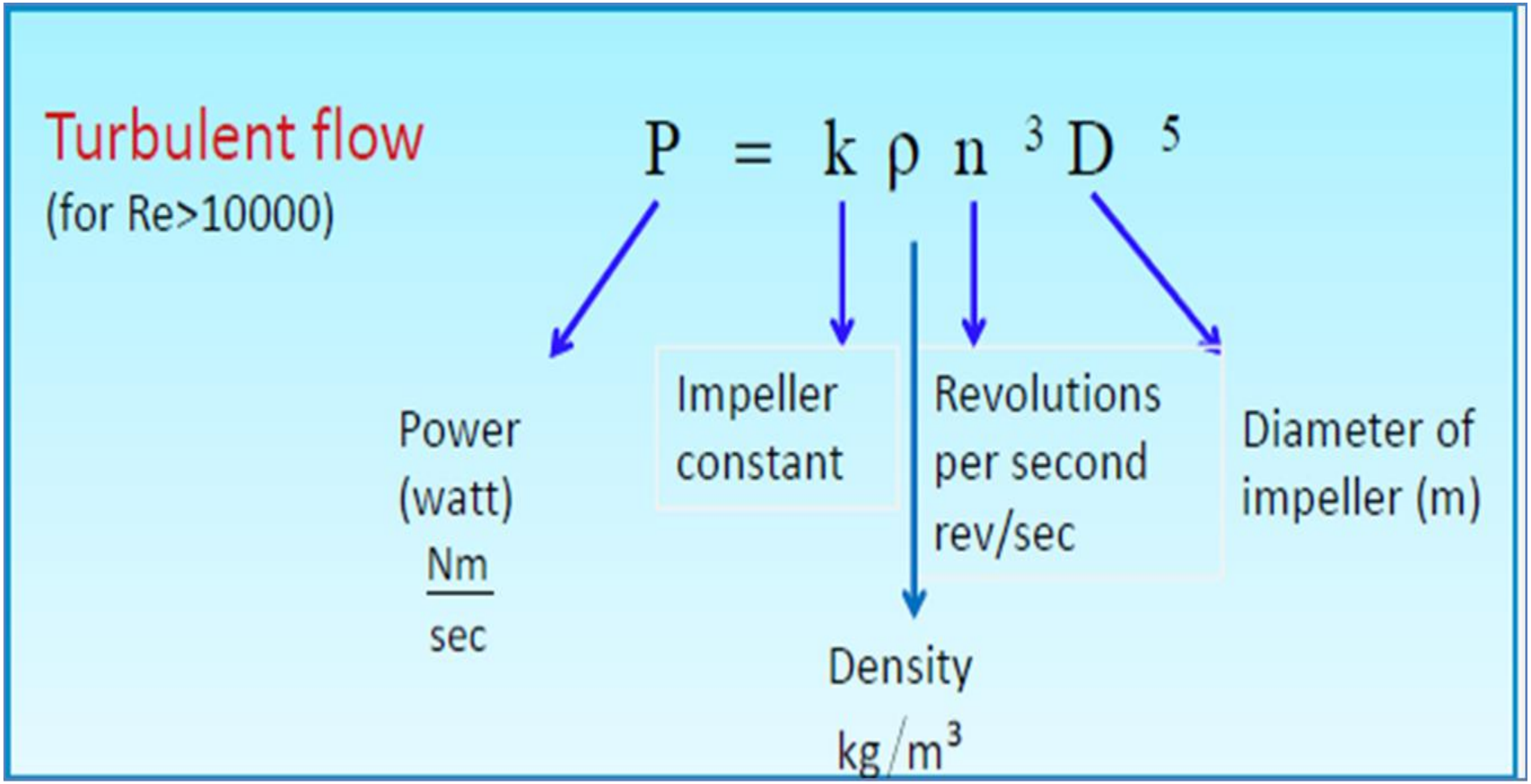
Dynamic viscosity $\frac{Ns}{m^2}$

Revolutions per second rev/sec

Diameter of impeller (m)

Power imparted in either **baffled** or **unbaffled tank**

Turbine and Propeller Mixers (continue)



Turbulent flow

(for Re>10000)

$$P = k \rho n^3 D^5$$

Power (watt) $\frac{\text{Nm}}{\text{sec}}$

Impeller constant

Density kg/m^3

Revolutions per second rev/sec

Diameter of impeller (m)

Power imparted in a baffled tank

Turbine and Propeller Mixers (continue)

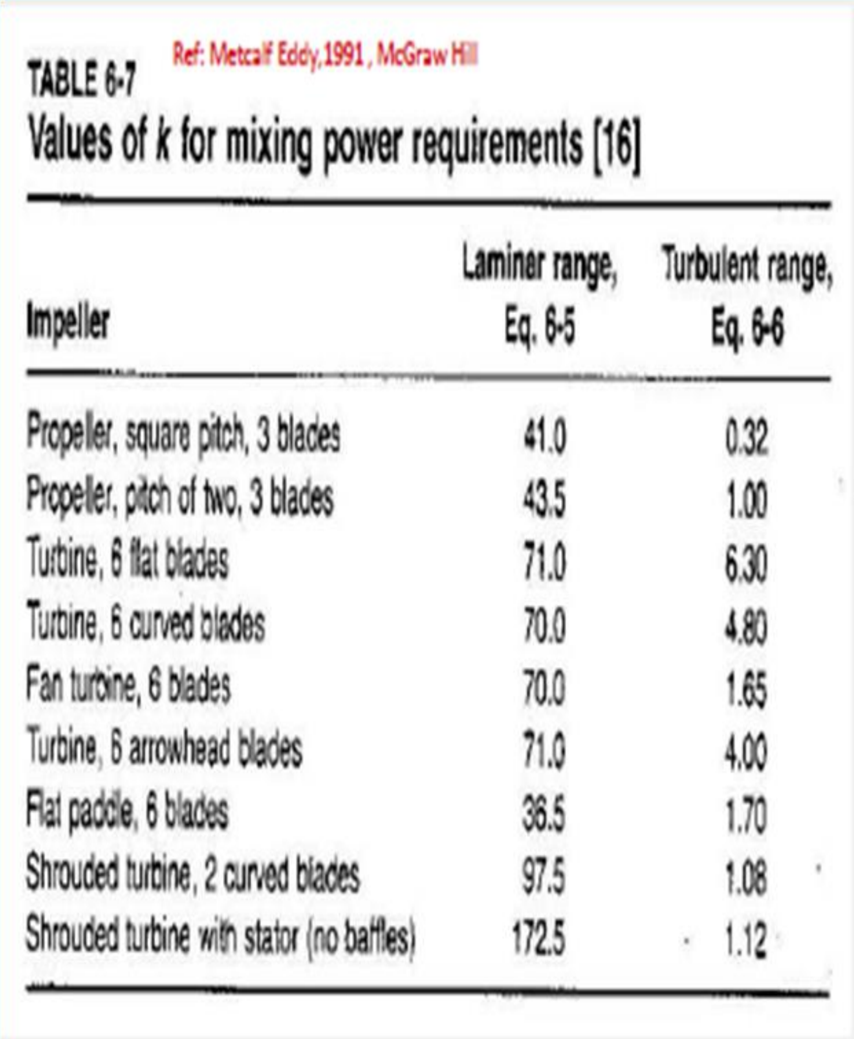


TABLE 6-7 Ref: Metcalf Eddy,1991 , McGraw Hill

Values of k for mixing power requirements [16]

Impeller	Laminer range, Eq. 6-5	Turbulent range, Eq. 6-6
Propeller, square pitch, 3 blades	41.0	0.32
Propeller, pitch of two, 3 blades	43.5	1.00
Turbine, 6 flat blades	71.0	6.30
Turbine, 6 curved blades	70.0	4.80
Fan turbine, 6 blades	70.0	1.65
Turbine, 6 arrowhead blades	71.0	4.00
Flat paddle, 6 blades	36.5	1.70
Shrouded turbine, 2 curved blades	97.5	1.08
Shrouded turbine with stator (no baffles)	172.5	1.12

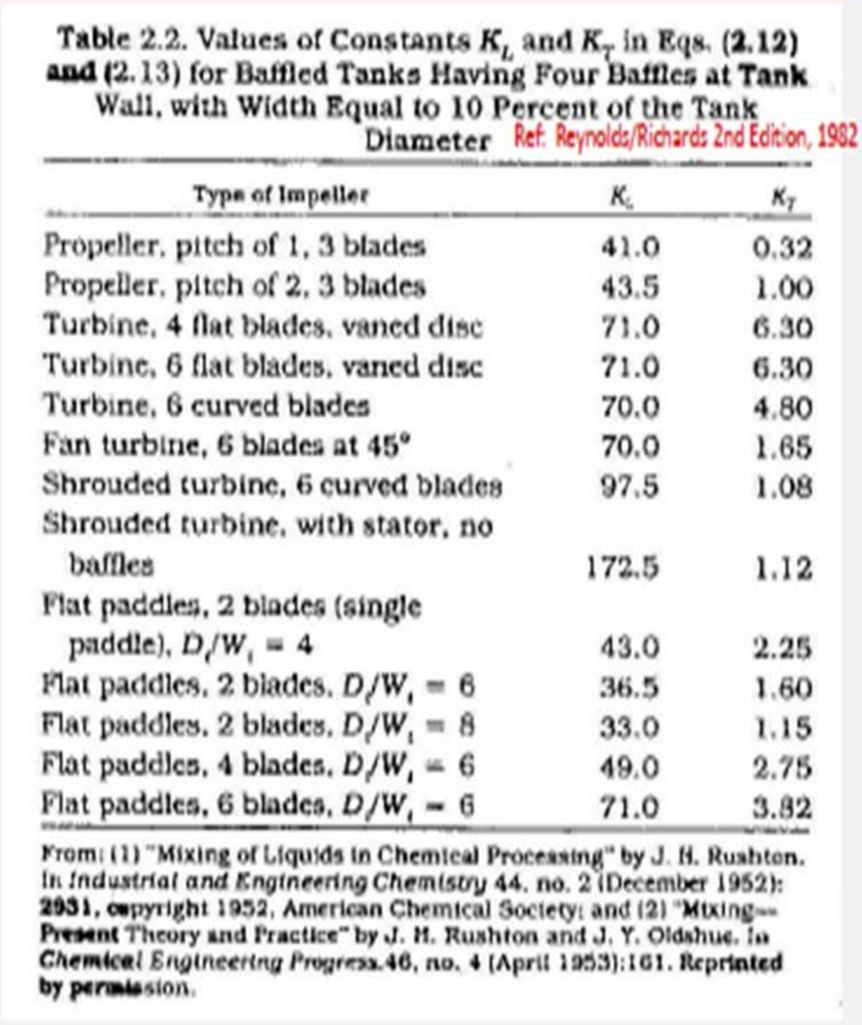


Table 2.2. Values of Constants K_L and K_T in Eqs. (2.12) and (2.13) for Baffled Tanks Having Four Baffles at Tank Wall, with Width Equal to 10 Percent of the Tank Diameter Ref: Reynolds/Richards 2nd Edition, 1982

Type of Impeller	K_L	K_T
Propeller, pitch of 1, 3 blades	41.0	0.32
Propeller, pitch of 2, 3 blades	43.5	1.00
Turbine, 4 flat blades, vaned disc	71.0	6.30
Turbine, 6 flat blades, vaned disc	71.0	6.30
Turbine, 6 curved blades	70.0	4.80
Fan turbine, 6 blades at 45°	70.0	1.65
Shrouded turbine, 6 curved blades	97.5	1.08
Shrouded turbine, with stator, no baffles	172.5	1.12
Flat paddles, 2 blades (single paddle), $D_t/W_i = 4$	43.0	2.25
Flat paddles, 2 blades, $D_t/W_i = 6$	36.5	1.60
Flat paddles, 2 blades, $D_t/W_i = 8$	33.0	1.15
Flat paddles, 4 blades, $D_t/W_i = 6$	49.0	2.75
Flat paddles, 6 blades, $D_t/W_i = 6$	71.0	3.82

From: (1) "Mixing of Liquids in Chemical Processing" by J. H. Rushton, In *Industrial and Engineering Chemistry* 44, no. 2 (December 1952): 2931, copyright 1952, American Chemical Society; and (2) "Mixing—Present Theory and Practice" by J. H. Rushton and J. Y. Oldshue. In *Chemical Engineering Progress* 46, no. 4 (April 1953):161. Reprinted by permission.

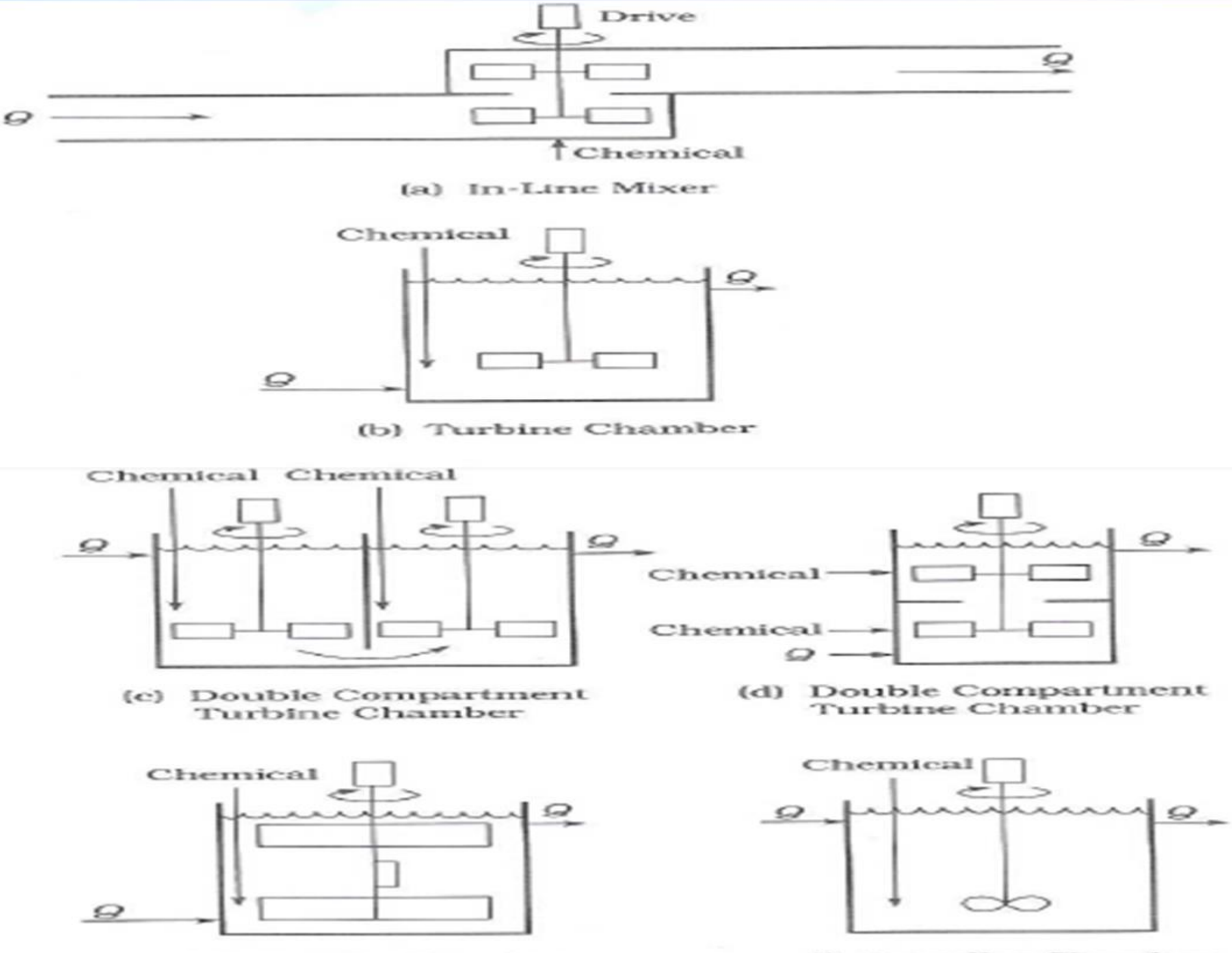


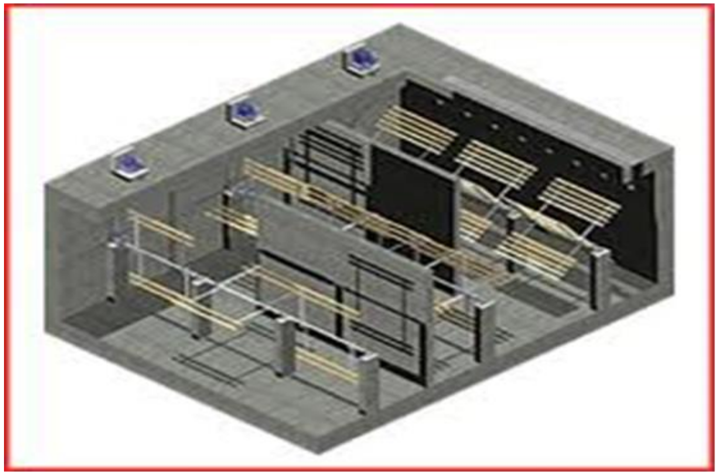
FIGURE 8.9

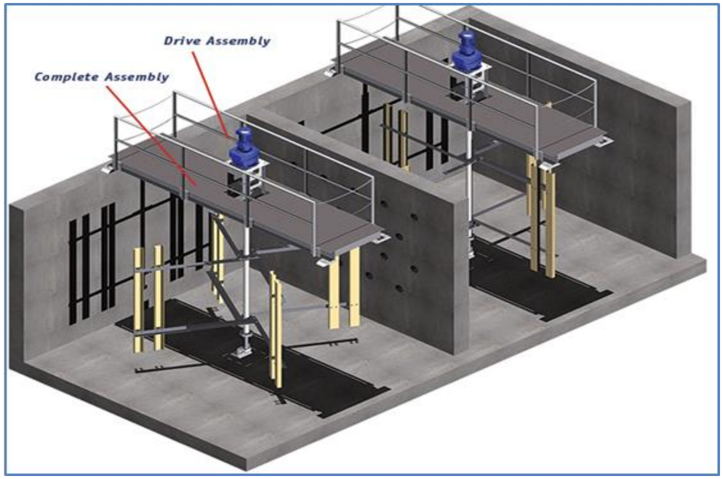
Devices

Ref: Reynolds/Richards 2nd Edition

Padddle Mixers

consists of a series of appropriately spaced paddles mounted on either a horizontal or vertical shaft generally rotate slowly are commonly used as flocculation devices





POWER IMPARTED TO THE WATER BY PADDLE

Newton’s Law for the drag force exerted by a submerged object moving in a liquid.

$$F_D = \frac{C_D A \rho V_p^2}{2} \longrightarrow P = F_D V_p = \frac{C_D A \rho V_p^3}{2}$$

F_D = Drag force N)

C_D = Drag coefficient

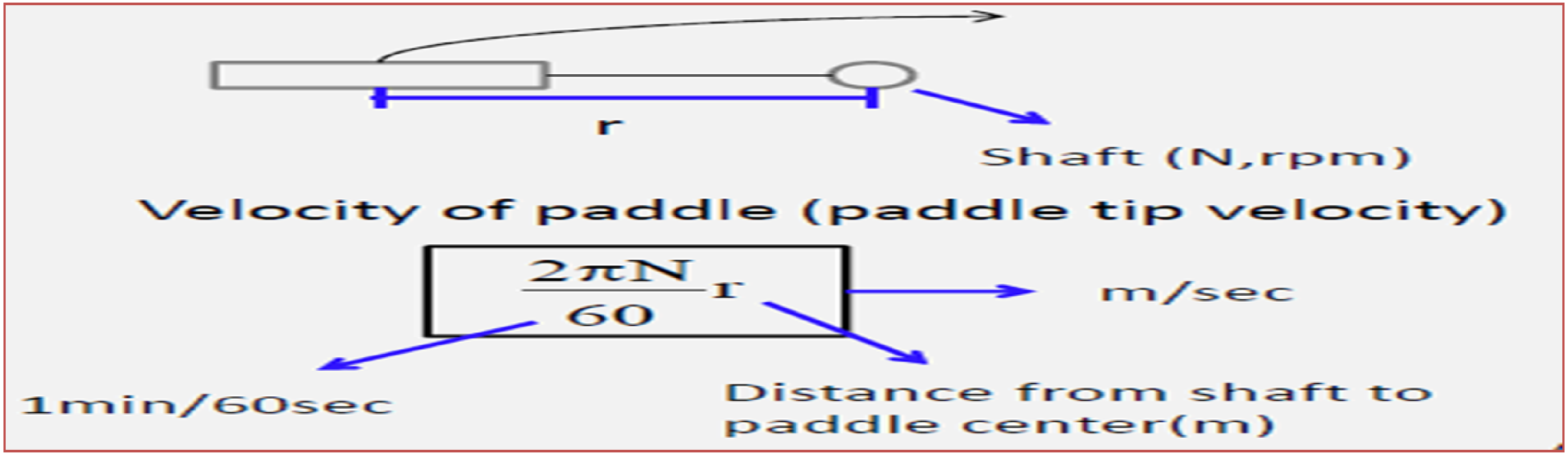
A = Cross-sectional area of paddle (ft^2 or m^2)
(paddle-blade area at right angle to the direction of movement)

ρ = Density of fluid ($\frac{slug}{ft^3}$ or $\frac{kg}{m^3}$)

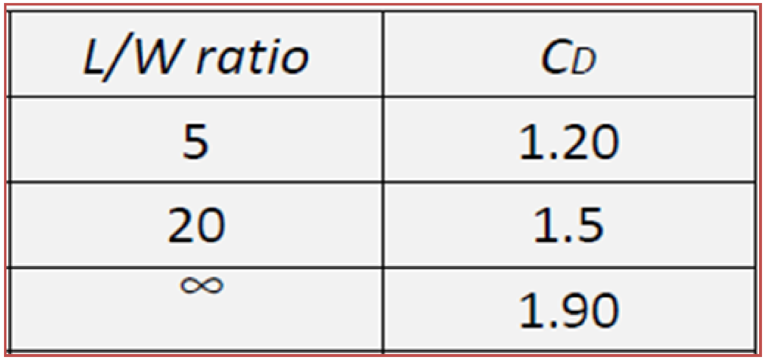
Vp = Relative velocity of paddles with respect to water.

$$\left\{ \begin{array}{l} 0.6 - 0.75\ V_{paddle\ tip} \\ V_{paddle\ tip} = v_{tip} = 2 \cdot \pi \cdot r \cdot N \end{array} \right\}$$

Relative velocity of paddles



THE DRAG COEFFICIENT (Cd) depends basically on the geometry of the paddle



L/W ratio	C_D
5	1.20
20	1.5
∞	1.90

The higher the rotation speed, the higher the tip velocity. When the tip velocity is higher than 1 m/s, formed flocs are broken up.

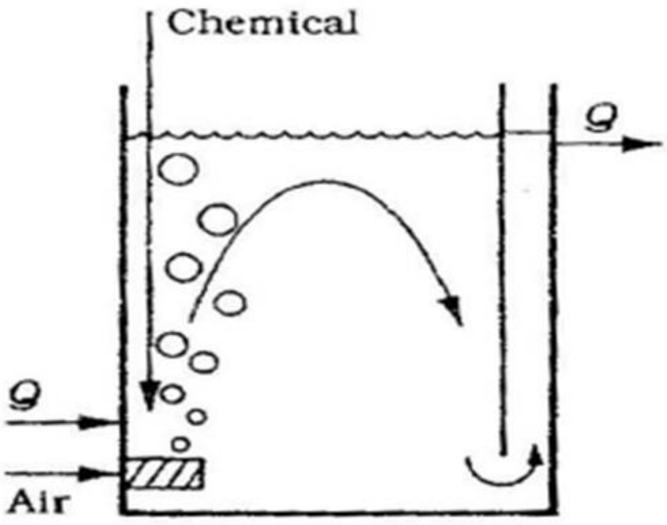
Pneumatic Mixers

When air is injected in mixing tank, power dissipated by the rising air bubbles can be estimated as:

$$P = 1.689\, Q_a \mathrm{Ln}\left(\frac{h + 10.33}{10.33}\right)$$

P=power dissipated (kW)
Q_a=air flow rate at operating temperature and pressure (m3/min)
H=depth to the diffusers in meters of water (air pressure at the point of discharge) (m)

Figure 2.13. Ref: Reynolds/Richards 2nd Edition
Pneumatic Rapid Mixing



Rapid Mix Tank Design

Maximum Tank Volume= 8 m^3

Mixing Equipment:Electric Motor, gear-type speed reducer, turbine of axial shaft impeller.

Usually the turbine impeller provides more turbulence and is preferred in rapid mix tanks.

The tanks are usually, baffled horizontally into two or three compartments in-order to provide sufficient residence time.

Tanks should also be vertically baffled to minimize vortexing.

Chemicals should be added below the impeller, point of most mixing.

Rapid Mix Tank Design

Design Liquid depth = 0.5 to 1.1 times the basin diameter or width of mixing champer.

Impeller diameter is between 0.3 and 0.50 times the tank diameter or width.

Vertical baffles extend into the tank about 10 % of the tank diameter or width.

Impellers typically do not exceed 1.0 meter in diameter.

Liquid depth may be increased to between 1.1 and 1.6 times the tank diameter if dual impellers on the shaft are employed. When dual impellers are employed, they are spaced about two impeller diameters apart.

Transfer efficiency of motor power to water power is about 0.8 for a single impeller.

Design Criteria:

G for rapid mix 700-1000 sec^{-1}

t (detention time) for rapid mixing 20-60 sec

Slow Mix Tank Design

Paddle tip speed = 0.1 to 1.0 m/s

Drag coefficient vary with length to width ratio.

Total paddle-blade area on a horizontal shaft not to exceed 15 to 20 percent of the total basin cross sectional area to avoid excessive rotational flow.

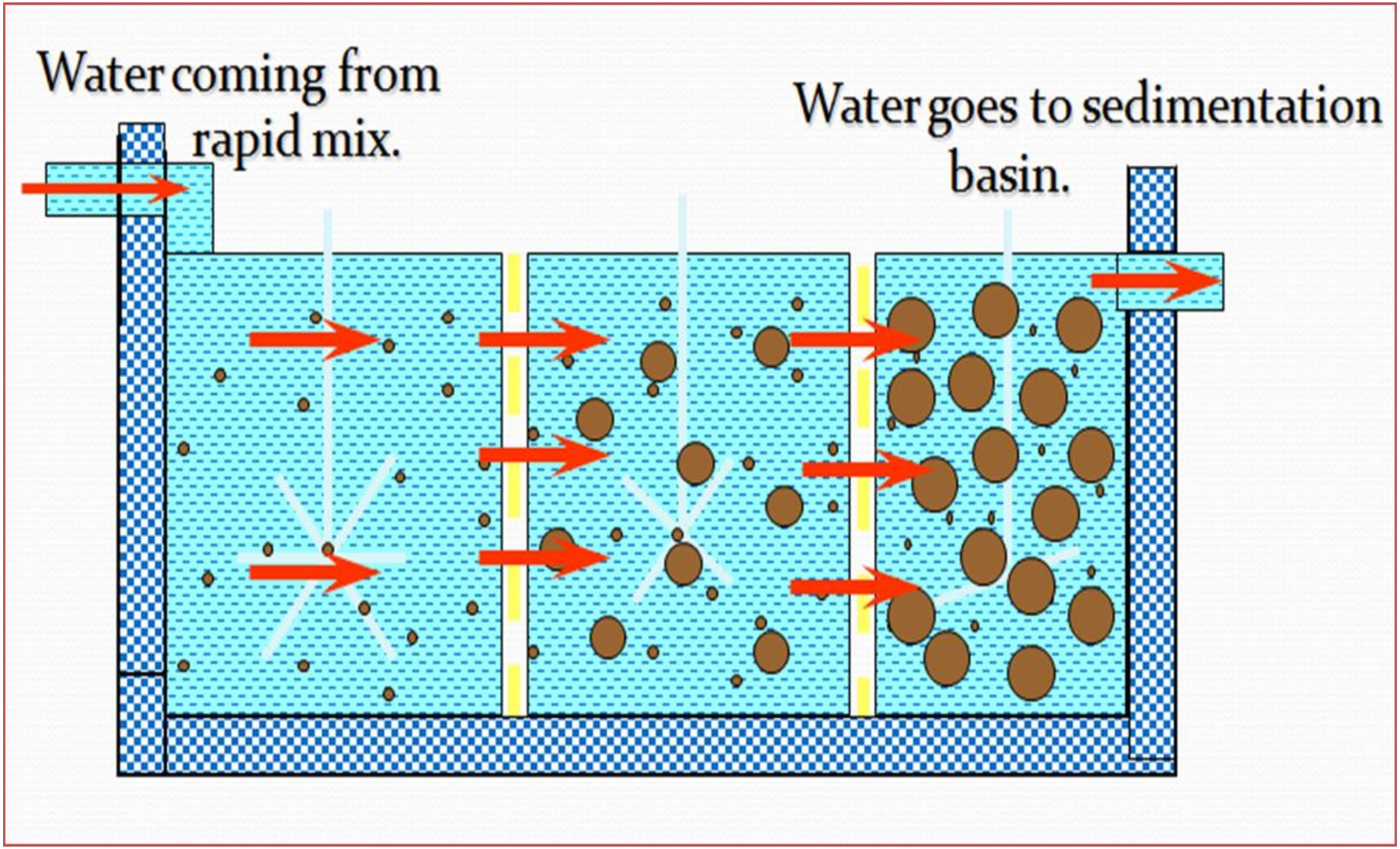
Design Criteria:

Gt 10 ——— 10^5

G → 10 - 75 sec $^{-1}$ (light / dense floc)

t = 10 - 30 min (small / large floc)

Flocculation process



Flocculation:

After coagulation and the resulting destabilization of particles, the particles must collide. The collision of particles can take place under natural circumstances (perikinetic floc formation) or by dissipation of mixing energy (orthokinetic floc formation).

Perikinetic floc formation:

During perikinetic floc formation, particles collide as a result of Brownian motion. Von Smoluchowski described the decrease in the total number of spherical particles as a function of time with the following equation:

$$-\frac{dn}{dt} = \alpha \cdot \frac{4 \cdot k \cdot T}{3 \cdot \mu} \cdot n^2$$

Where:

in which:

n = total number of particles per unit water volume (m^{-3})

α = collision efficiency (-)

K = Boltzmann constant ($J \cdot K^{-1}$)

T = absolute temperature (K)

Not every collision will result in attachment and therefore the collision efficiency is incorporated into the equation.

Orthokinetic floc formation:

By mixing, the collision frequency of the particles is artificially increased. The decrease in the total number of particles as a function of time is described by the following equation:

$$-\frac{dn}{dt} = \frac{4}{3} \cdot \alpha \cdot n_1 \cdot n_2 \cdot R^3 \cdot G_v$$

Where:

G_v = velocity gradient for floc formation (s-1)

R = collision radius (m)

n1 = number of particles with diameter d1 (-)

n2 = number of particles with diameter d2 (-)

For completely mixed systems:

With these equations it can be calculated that orthokinetic floc formation of particles with a diameter of 1 µm only takes place when velocity gradients higher than 10 s^{-1} are applied. Otherwise, perikinetic floc formation is predominant.

$$\frac{n}{n_o} = \frac{1}{1 + k_a \cdot c_v \cdot G_v \cdot t}$$

Flocculation important parameters

- residence time T

- residence time distribution

- velocity gradient for floc formation G_v

- floc volume concentration c_v.

Residence time T

Time is needed for the formation of removable flocs. The applied residence time varies between 500 and 3600 sec. On average the residence time for floc formation is about 30 minutes. To determine the required residence time, jar-test experiments are carried out.

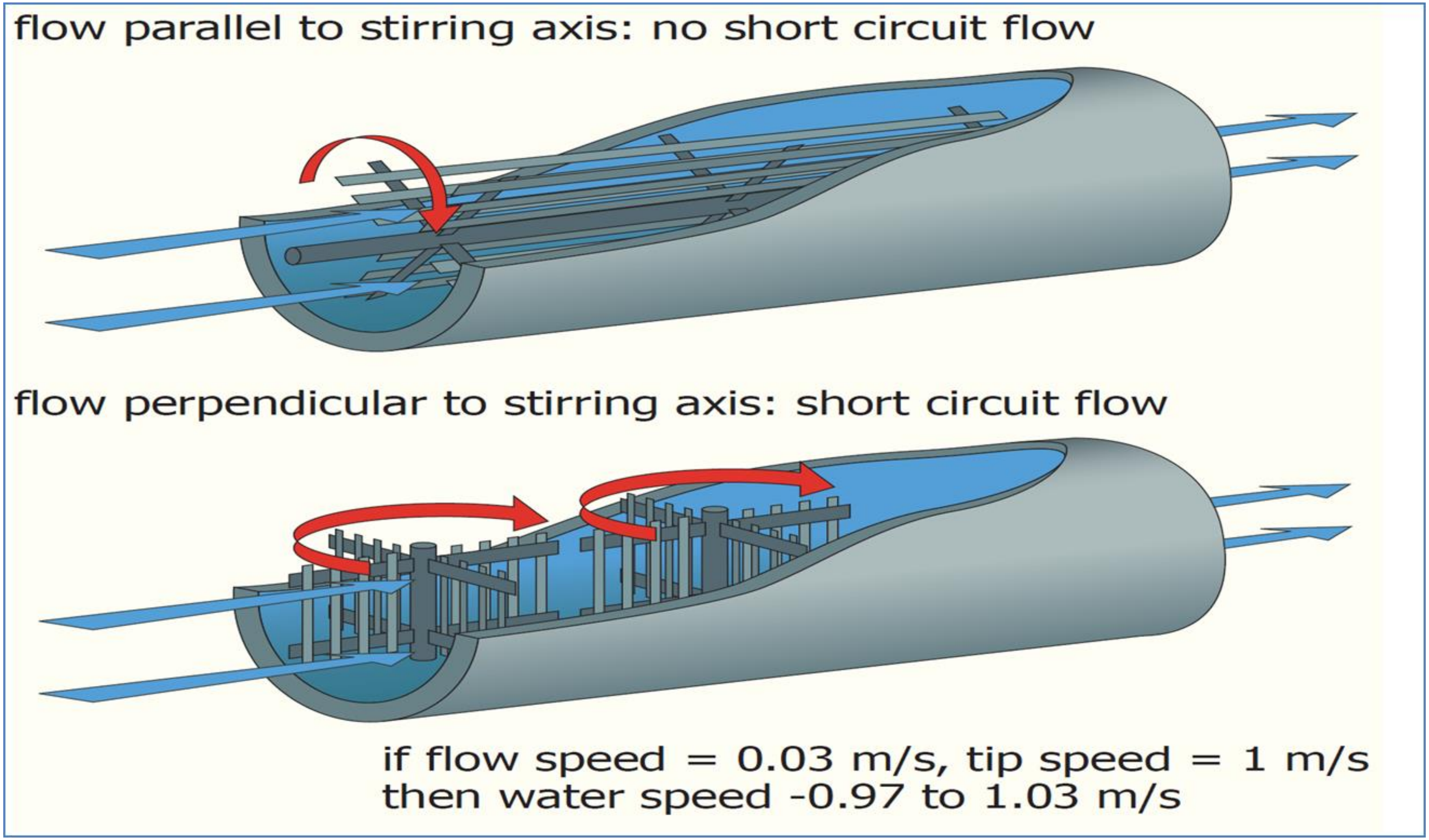
Residence time distribution

When water flows through a tank, the residence time of every droplet is different.

In order to approach the perfect plug flow where every droplet has the same residence time, criteria are developed for the design of a floc formation chamber.

A plug flow can be approached when the ratio between the length and width of a tank is at least equal to 3.

Energy dispersion:



flow parallel to stirring axis: no short circuit flow

flow perpendicular to stirring axis: short circuit flow

if flow speed = 0.03 m/s, tip speed = 1 m/s
then water speed -0.97 to 1.03 m/s

Sedimentation

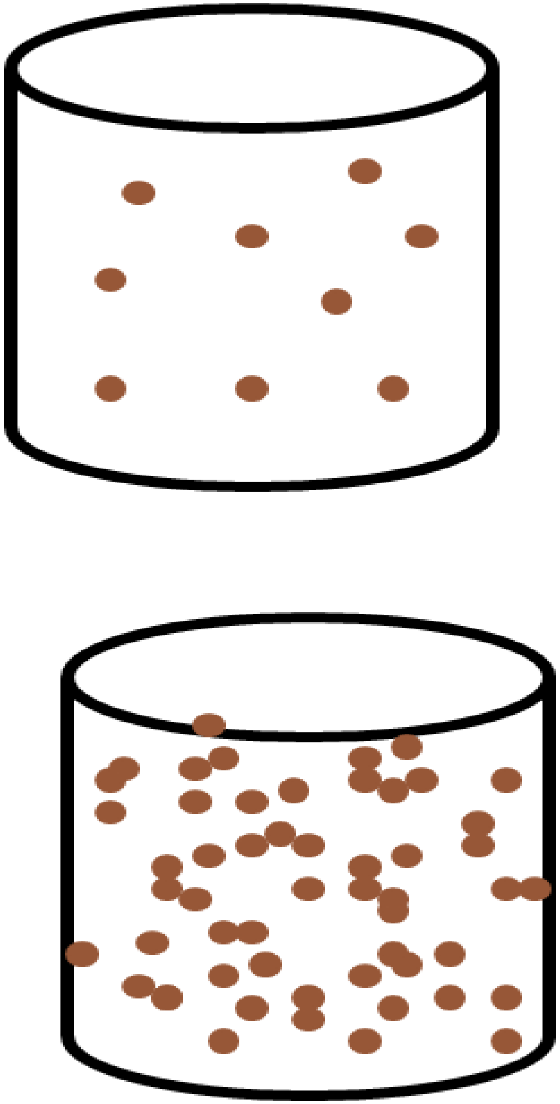
the oldest form of water treatment uses gravity to separate particles from water often follows coagulation and flocculation

occurs in _reservoirs_

Sedimentation: Effect of the particle concentration

Dilute suspensions

- Particles act independently



Concentrated suspensions

- Particle-particle interactions are significant
- Particles may collide and stick together (form flocs)
- Particle flocs may settle more quickly
- Particle-particle forces may prevent further consolidation

Oxidation

To remove inorganics (Fe^{++}, Mn^{++}) and some synthetic organics

- Cause unaesthetic conditions (brown color)
- Promote the growth of autotrophic bacteria (iron bacteria): taste and order problem

Free chlorine, chlorine dioxide, ozone, potassium permanganate

- $Fe^{++} + Mn^{++} + \text{oxygen} + \text{free chlorine} \rightarrow$ $FeO_x \downarrow$ (ferric oxides) + $MnO_2 \downarrow$ (manganese dioxide)

- $Fe(HCO_3)_2$ (Ferrous bicarbonate) + $KMnO_4$ (Potassium permanganase) → $Fe(OH)_3\downarrow$ (Ferric hydroxide) + $MnO_2\downarrow$ (manganese dioxide)
- $Mn(HCO_3)_2$ (Manganese bicarbonate) + $KMnO_4$ (Potassuim permanganase) → $MnO_2\downarrow$ (manganese dioxide)

Filtration

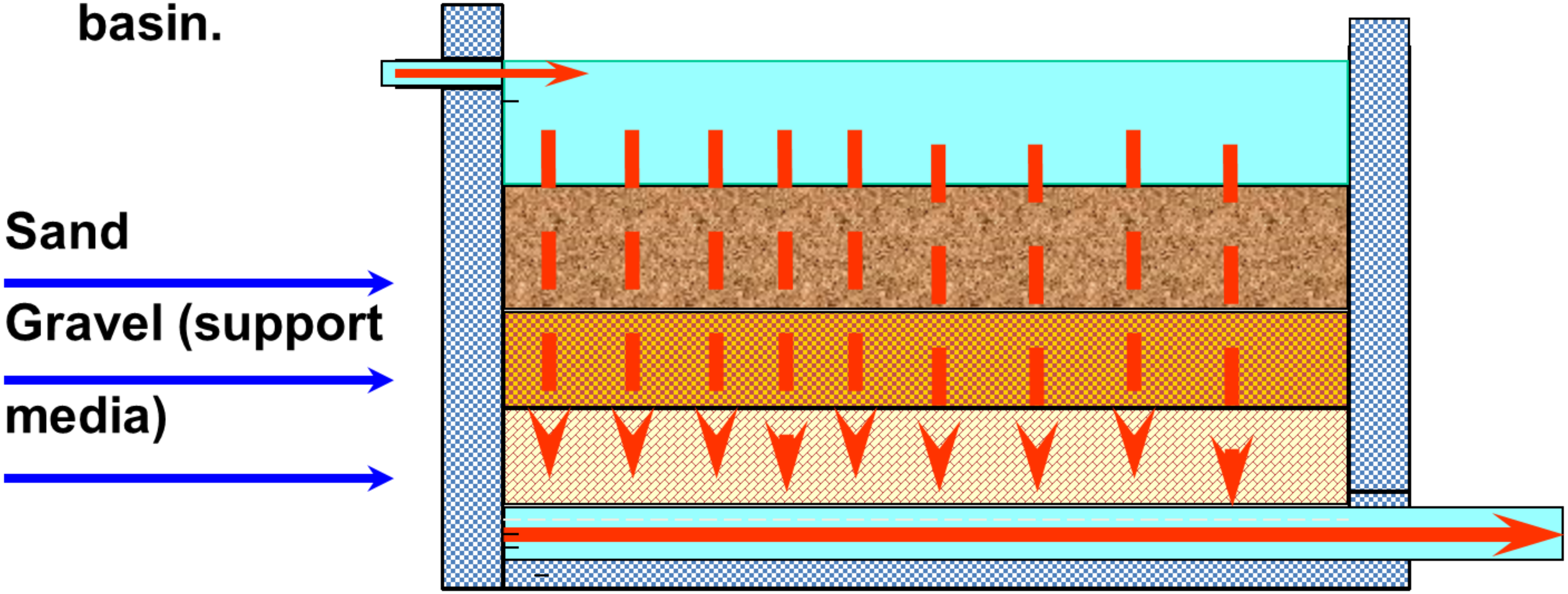
To remove particles and floc that do not settle by gravity in sedimentation process

Types of granular media

- Sand
- Sand + anthracite
- Granular activated carbon

Media depth ranges from 24 to 72 inches

Filter Example



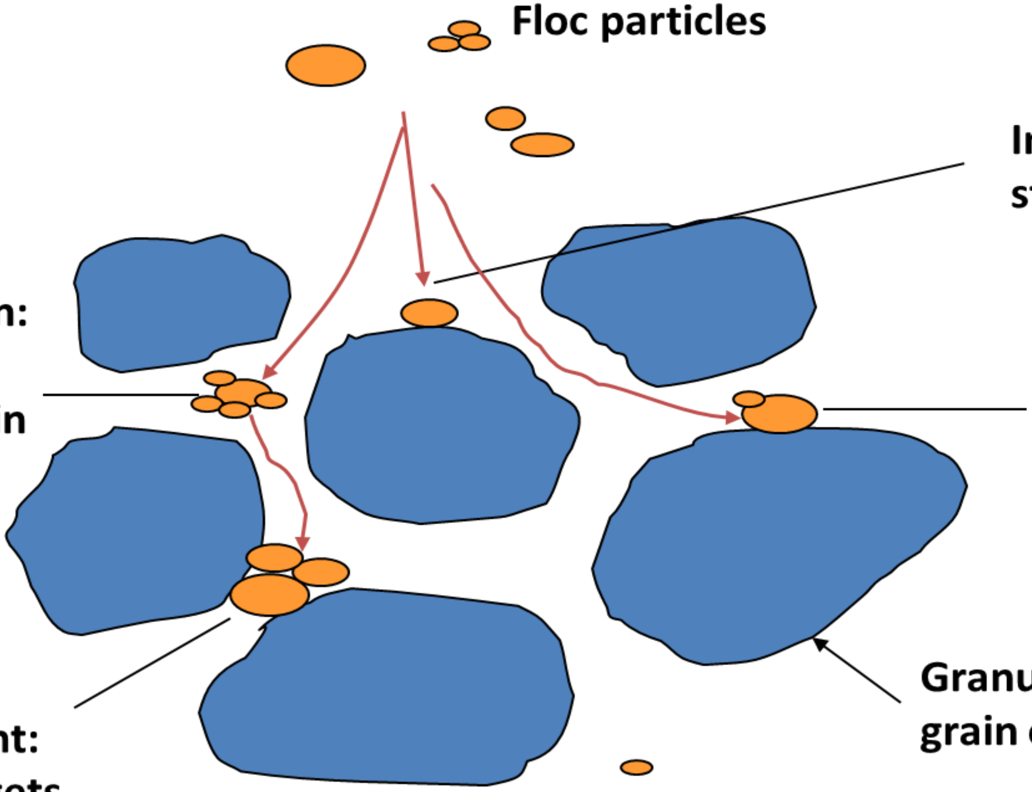
Water coming from sedimentation basin.

Sand

Gravel (support media)

Water going to disinfection

Mechanisms Involved in Filtration



Floc particles

Interception: hits & sticks

Flocculation: Floc gets larger within filter

Sedimentation: quiescent, settles, & attaches

Granular media, e.g., grain of sand

Entrapment: large floc gets trapped in space between particles

Removal of bacteria, viruses and protozoa by a granular media filter requires water to be coagulated

Disinfection in water

To inactivate pathogens in water

Various types

- Free chlorine
- Chloramines
- Chlorine dioxide
- Ozone
- UV

Free chlorine

(1) $Cl2 + H2O \rightarrow HOCl + HCl$

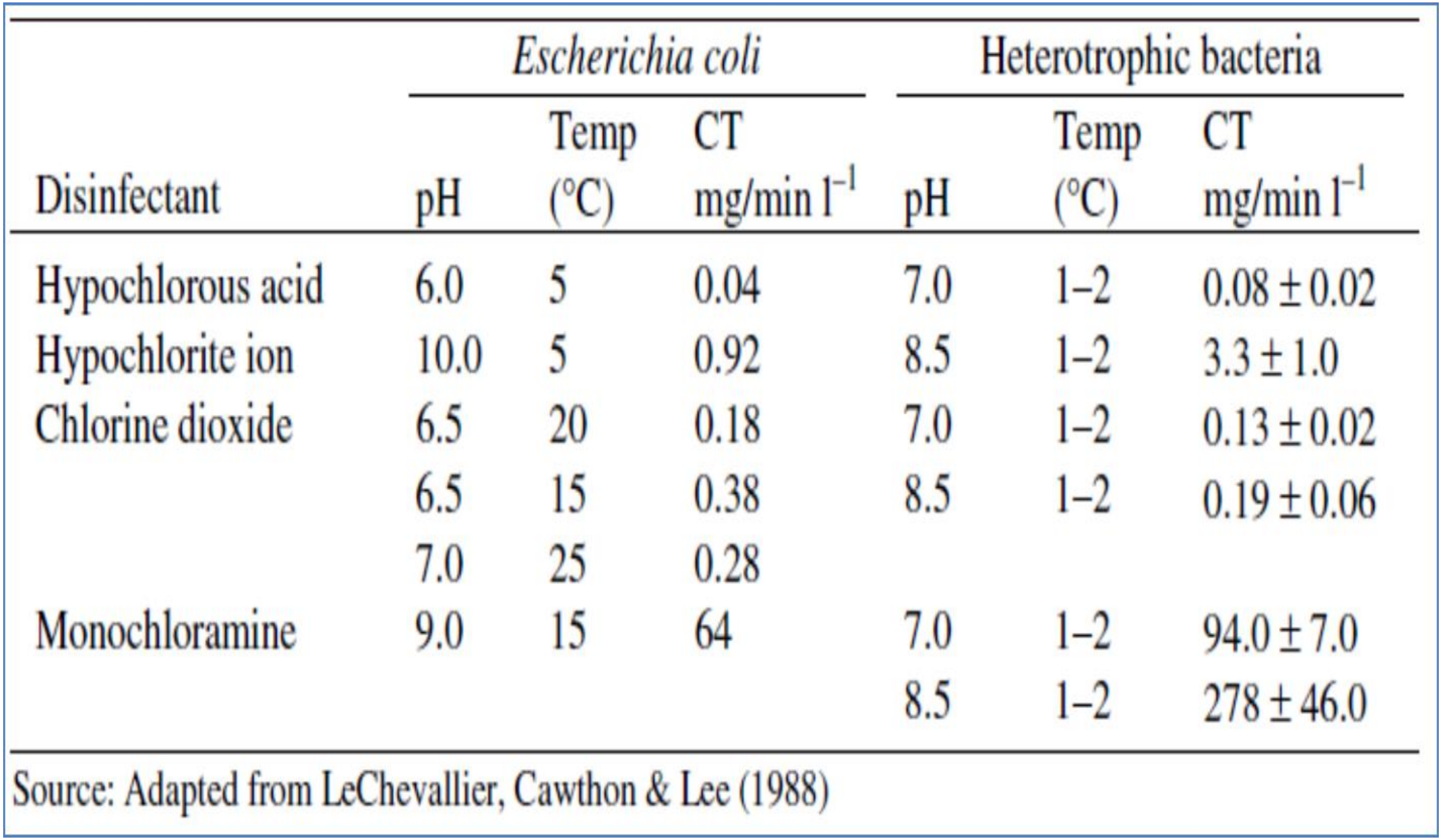
(2) $HOCl \rightarrow H^+ + OCl^-$

- between pH 3.5 and 5.5, HOCl is the predominant species
- between about pH 5.5 and 9.5, both HOCl and OCl^- species exist in various proportions

- **above pH 8, OCl^- predominates.**

Baker (1926) theorized that chlorine destroys microorganisms by combining with proteins to form N-chloro compounds.

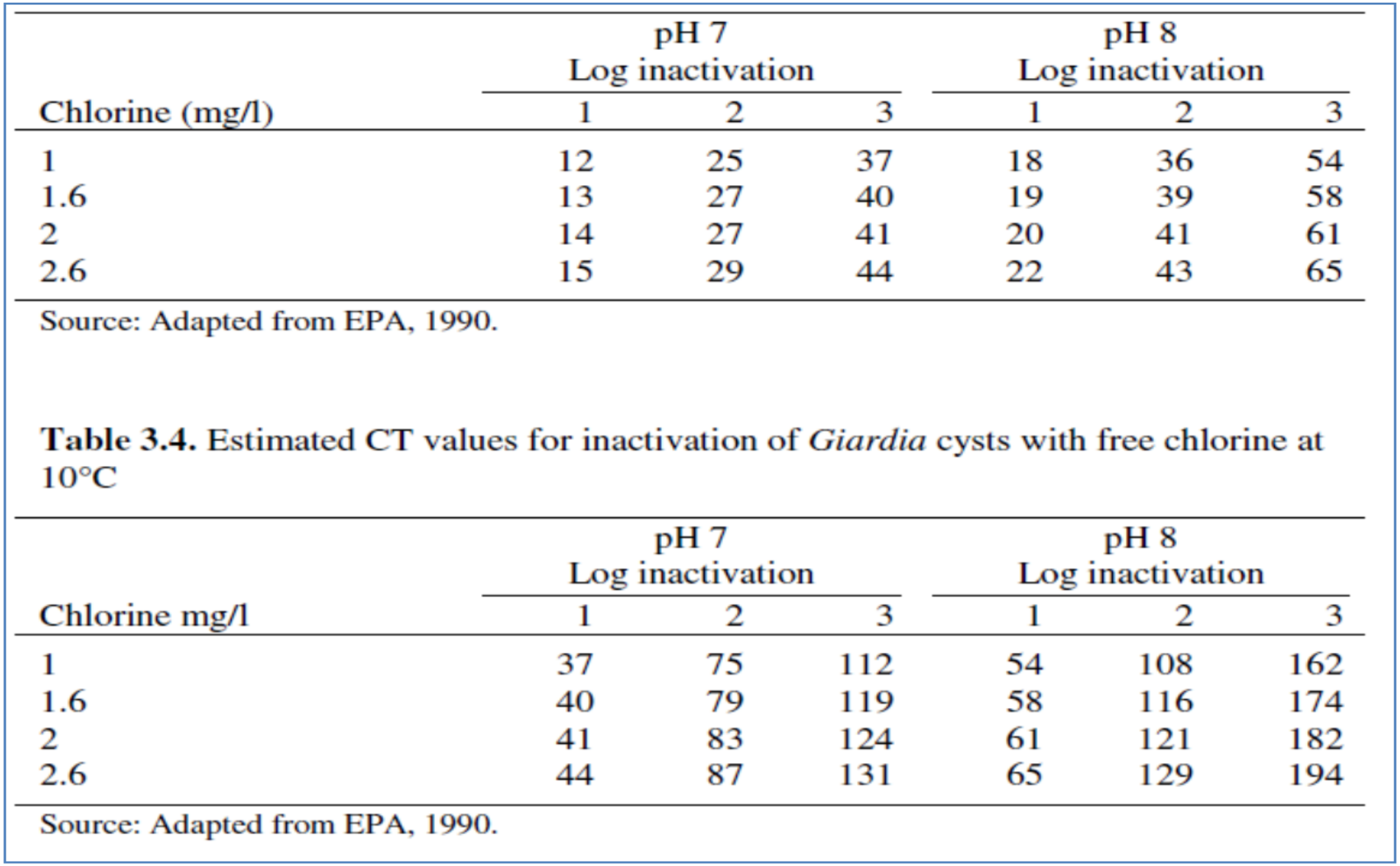
Effectiveness of chlorine against bacteria and viruses



	Escherichia coli			Heterotrophic bacteria		
Disinfectant	pH	Temp (°C)	CT mg/min l^{-1}	pH	Temp (°C)	CT mg/min l^{-1}
Hypochlorous acid	6.0	5	0.04	7.0	1–2	0.08 ± 0.02
Hypochlorite ion	10.0	5	0.92	8.5	1–2	3.3 ± 1.0
Chlorine dioxide	6.5	20	0.18	7.0	1–2	0.13 ± 0.02
	6.5	15	0.38	8.5	1–2	0.19 ± 0.06
	7.0	25	0.28			
Monochloramine	9.0	15	64	7.0	1–2	94.0 ± 7.0
				8.5	1–2	278 ± 46.0

Source: Adapted from LeChevallier, Cawthon & Lee (1988)

Effectiveness of chlorine against protozoa



Chlorine (mg/l)	pH 7 Log inactivation 1	2	3	pH 8 Log inactivation 1	2	3
1	12	25	37	18	36	54
1.6	13	27	40	19	39	58
2	14	27	41	20	41	61
2.6	15	29	44	22	43	65

Source: Adapted from EPA, 1990.

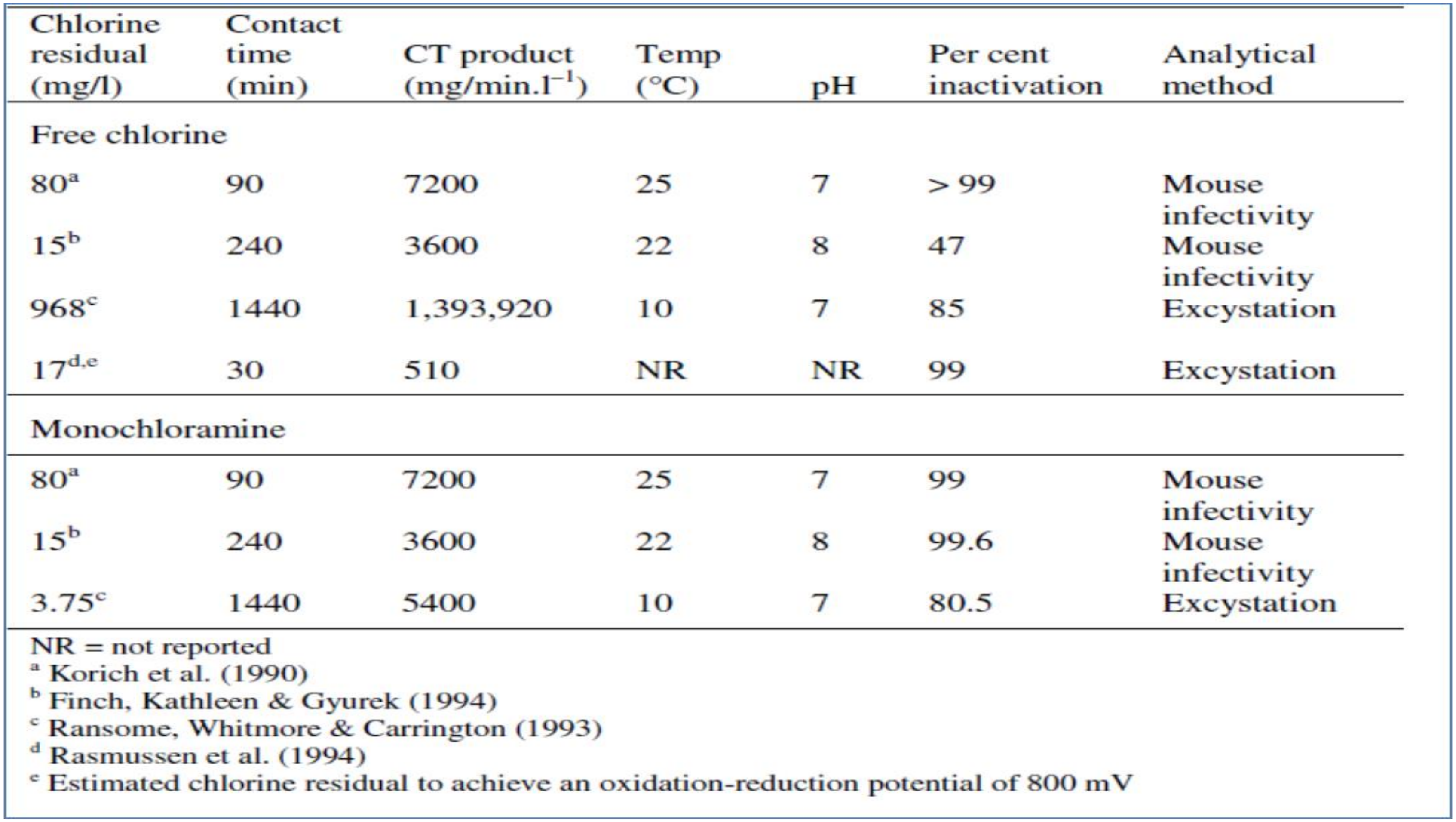
Table 3.4. Estimated CT values for inactivation of *Giardia* cysts with free chlorine at 10°C

Chlorine mg/l	pH 7 Log inactivation 1	2	3	pH 8 Log inactivation 1	2	3
1	37	75	112	54	108	162
1.6	40	79	119	58	116	174
2	41	83	124	61	121	182
2.6	44	87	131	65	129	194

Source: Adapted from EPA, 1990.

Estimated CT values for inactivation of Giardia cysts with free chlorine at 25°C

Effectiveness of chlorine against protozoa



Chlorine residual (mg/l)	Contact time (min)	CT product (mg/min.l^{-1})	Temp (°C)	pH	Per cent inactivation	Analytical method
Free chlorine						
80[a]	90	7200	25	7	> 99	Mouse infectivity
15[b]	240	3600	22	8	47	Mouse infectivity
968[c]	1440	1,393,920	10	7	85	Excystation
17[d,e]	30	510	NR	NR	99	Excystation
Monochloramine						
80[a]	90	7200	25	7	99	Mouse infectivity
15[b]	240	3600	22	8	99.6	Mouse infectivity
3.75[c]	1440	5400	10	7	80.5	Excystation

NR = not reported

[a] Korich et al. (1990)

[b] Finch, Kathleen & Gyurek (1994)

[c] Ransome, Whitmore & Carrington (1993)

[d] Rasmussen et al. (1994)

[e] Estimated chlorine residual to achieve an oxidation-reduction potential of 800 mV

Summary of free chlorine and monochloramine disinfection results for Cryptosporidium

Chloramination

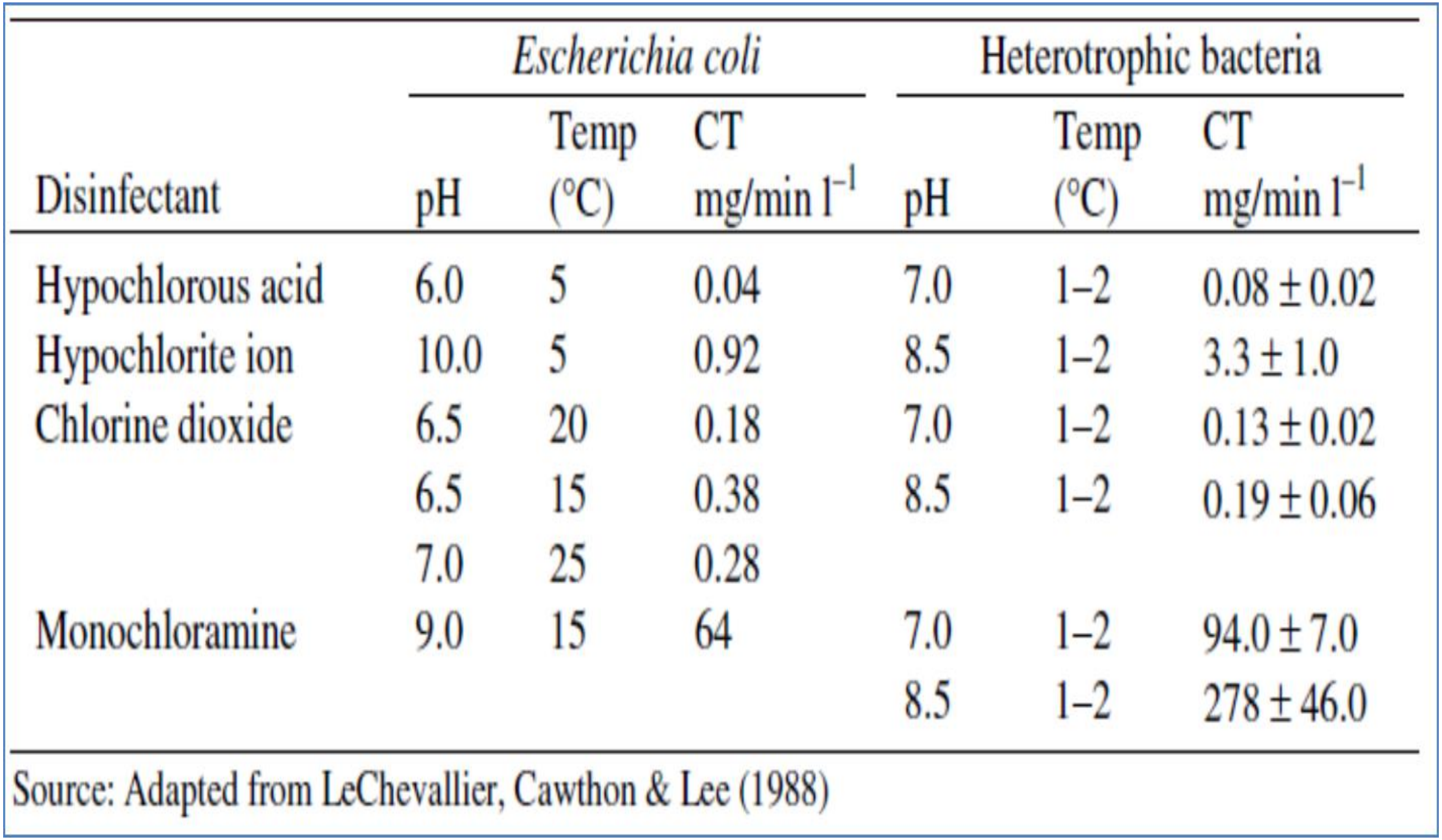
HOCl + NH3→ NH2Cl (monochloramine) + H_2O

HOCl + NH2Cl → NHCl2 (dichloramine) + H_2O

HOCl + NHCl2 → NCl3 (trichloramine) + H_2O

Effectiveness of Monochloramine is not recommended as a primary disinfectant because of its weak disinfecting power

Effectiveness of monochloramine



	Escherichia coli			Heterotrophic bacteria		
Disinfectant	pH	Temp (°C)	CT mg/min l^{-1}	pH	Temp (°C)	CT mg/min l^{-1}
Hypochlorous acid	6.0	5	0.04	7.0	1–2	0.08 ± 0.02
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Chlorine dioxide	6.5	20	0.18	7.0	1–2	0.13 ± 0.02
	6.5	15	0.38	8.5	1–2	0.19 ± 0.06
	7.0	25	0.28			
Monochloramine	9.0	15	64	7.0	1–2	94.0 ± 7.0
				8.5	1–2	278 ± 46.0

Source: Adapted from LeChevallier, Cawthon & Lee (1988)

Chlorine dioxide

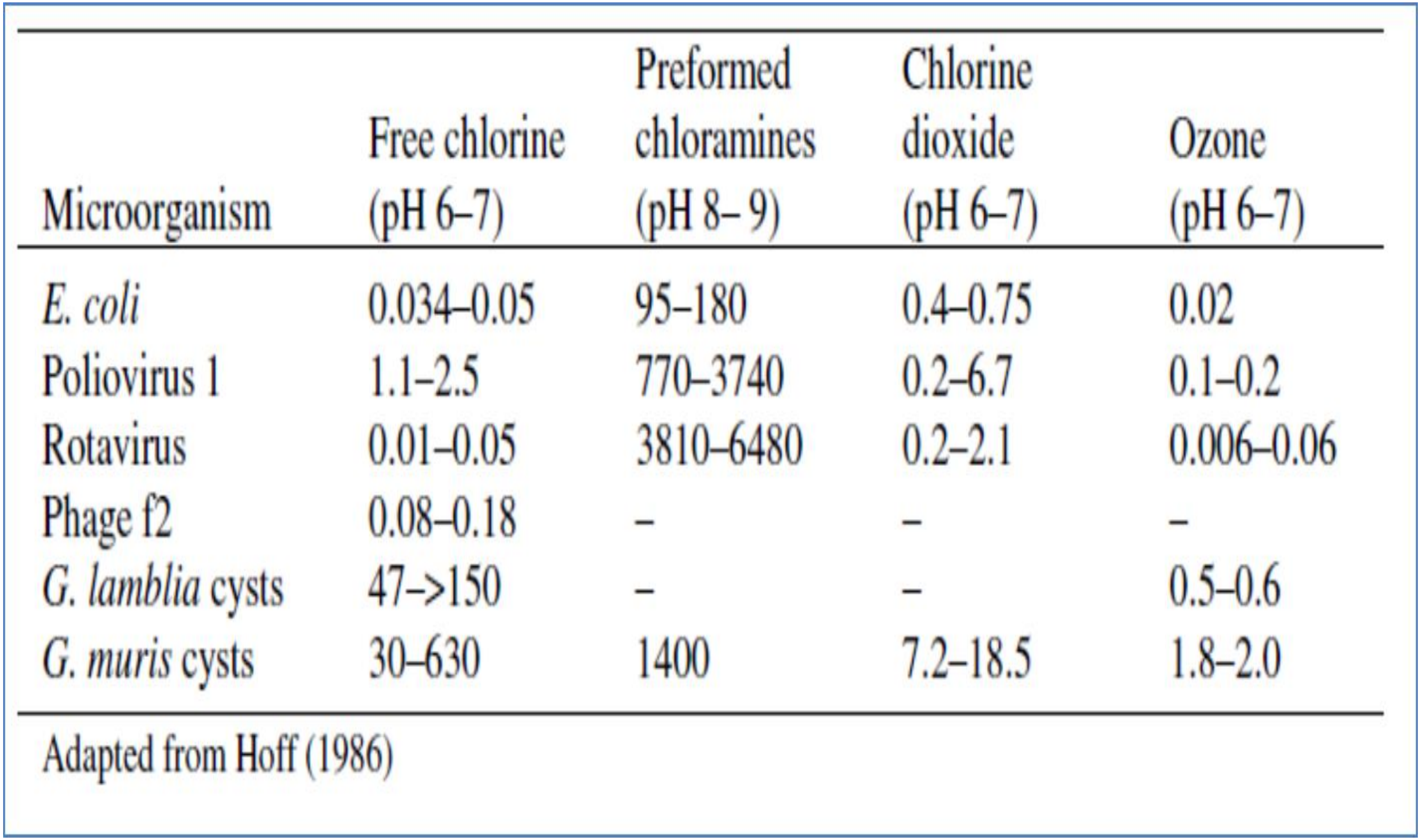
$ClO2 + 5e^{-} \longrightarrow Cl^{-} + 2O^{2-}$

However, in practice, chlorine dioxide is rarely reduced completely to chloride ion (White 1999). Chlorine dioxide is thought to inactivate microorganisms through direct oxidation of tyrosine, methionyl, or cysteinecontaining proteins

Ozone

The mechanism by which ozone inactivates microbes is not well understood. Ozone in aqueous solution may react with microbes either by direct reaction with molecular ozone or by indirect reaction with the radical species formed when ozone decomposes.

Effectiveness of ozone against bacteria and viruses

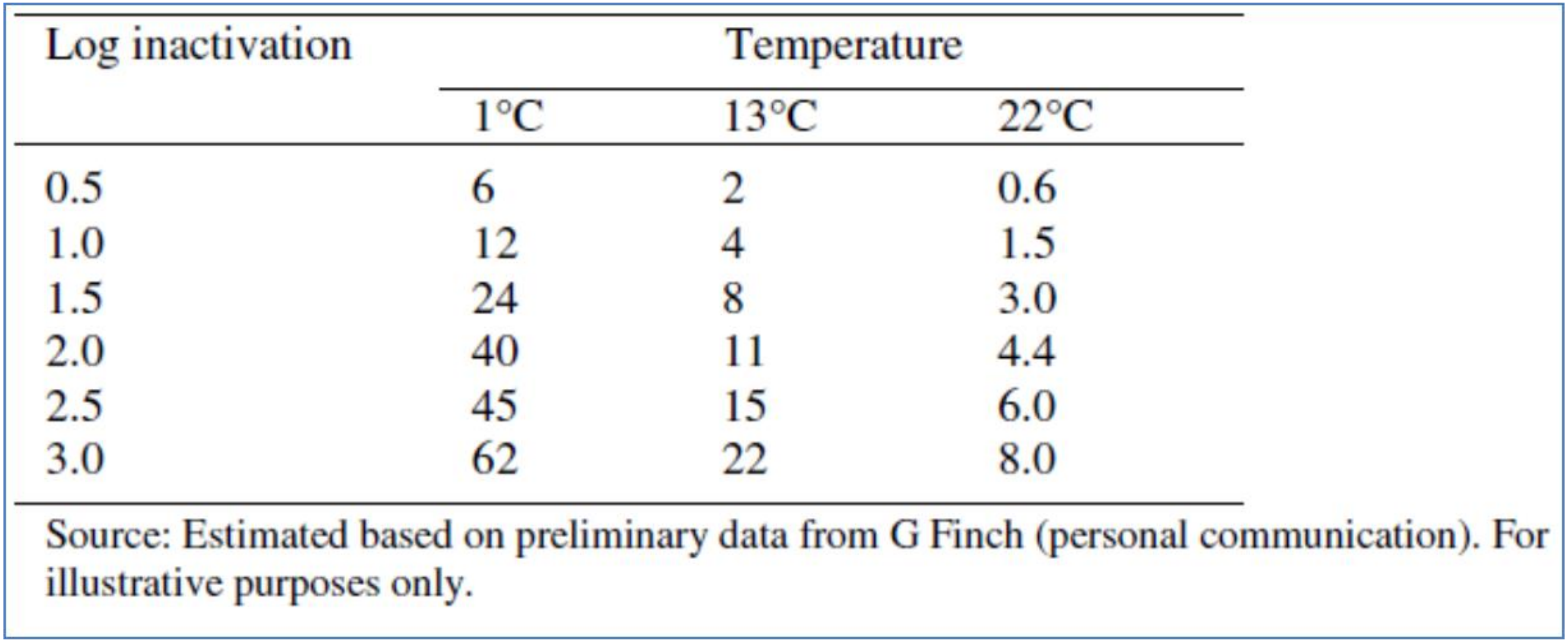


Microorganism	Free chlorine (pH 6–7)	Preformed chloramines (pH 8– 9)	Chlorine dioxide (pH 6–7)	Ozone (pH 6–7)
E. coli	0.034–0.05	95–180	0.4–0.75	0.02
Poliovirus 1	1.1–2.5	770–3740	0.2–6.7	0.1–0.2
Rotavirus	0.01–0.05	3810–6480	0.2–2.1	0.006–0.06
Phage f2	0.08–0.18	–	–	–
G. lamblia cysts	47–>150	–	–	0.5–0.6
G. muris cysts	30–630	1400	7.2–18.5	1.8–2.0

Adapted from Hoff (1986)

Effectiveness of ozone against protozoa

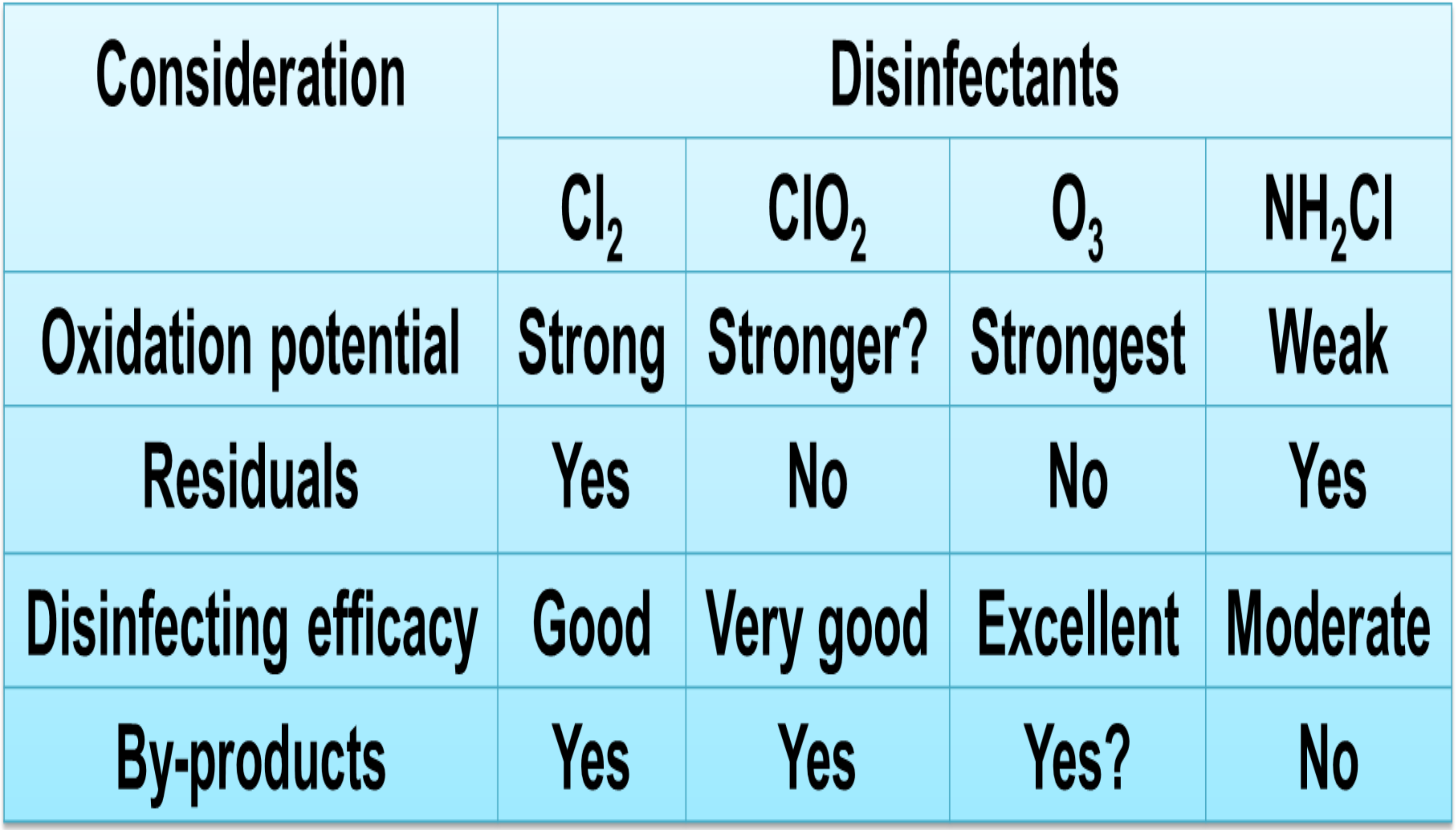
CT (mg/min l^{-1}) for Cryptosporidium inactivation by ozone



Log inactivation	Temperature		
	1°C	13°C	22°C
0.5	6	2	0.6
1.0	12	4	1.5
1.5	24	8	3.0
2.0	40	11	4.4
2.5	45	15	6.0
3.0	62	22	8.0

Source: Estimated based on preliminary data from G Finch (personal communication). For illustrative purposes only.

Comparison between major disinfectants



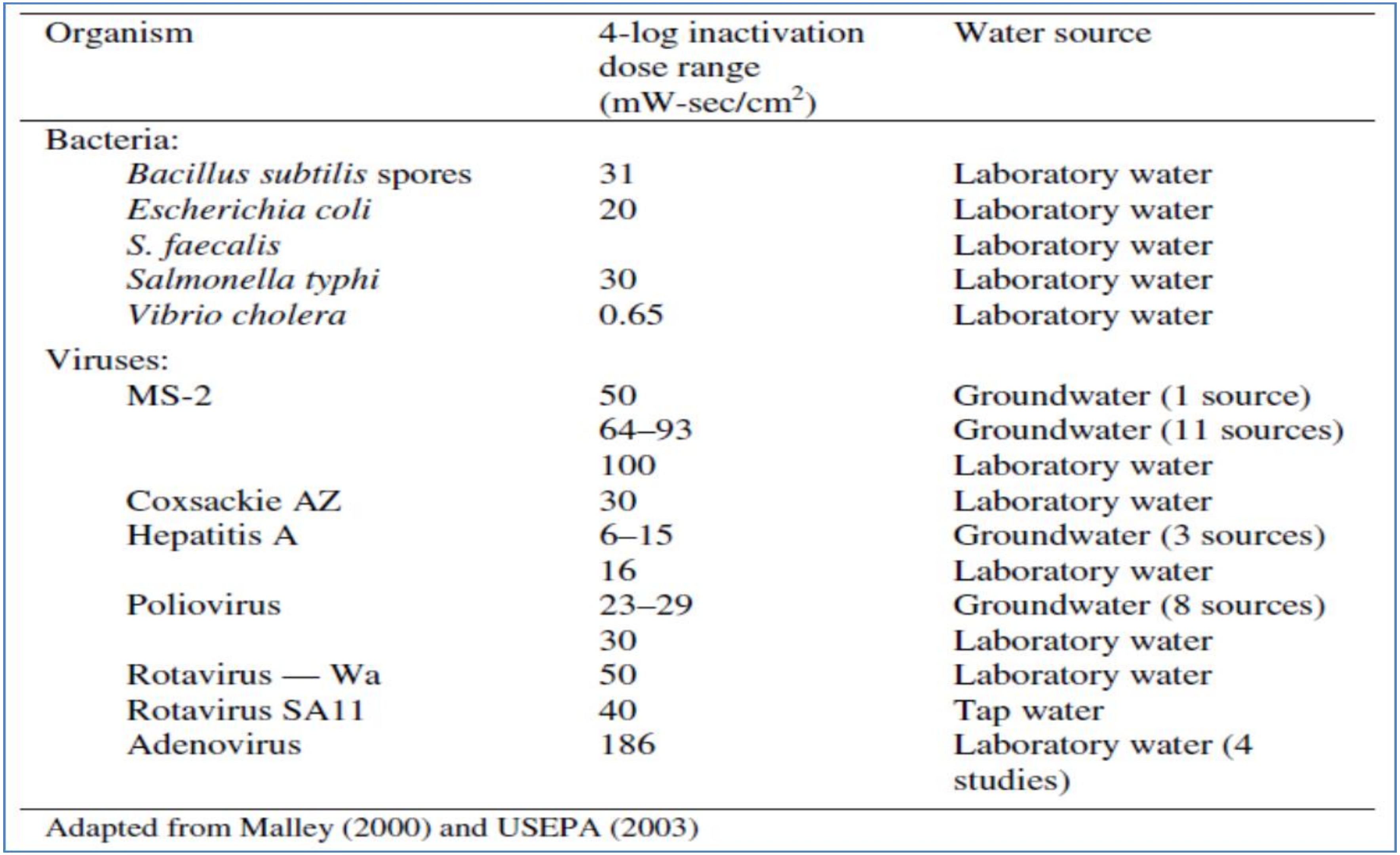
Consideration	Disinfectants			
	Cl_2	ClO_2	O_3	NH_2Cl
Oxidation potential	Strong	Stronger?	Strongest	Weak
Residuals	Yes	No	No	Yes
Disinfecting efficacy	Good	Very good	Excellent	Moderate
By-products	Yes	Yes	Yes?	No

Ultraviolet light

The UV light effective for inactivating microorganisms is in the UV-B and UV-C ranges of the spectrum (200–310 nm)

Thymine bases on DNA and ribonucleic acid (RNA) are particularly reactive to UV light and form dimers (thymine–thymine double bonds) that inhibit transcription and replication of nucleic acids, thus rendering the organism sterile.

Effectiveness of UV against bacteria and viruses



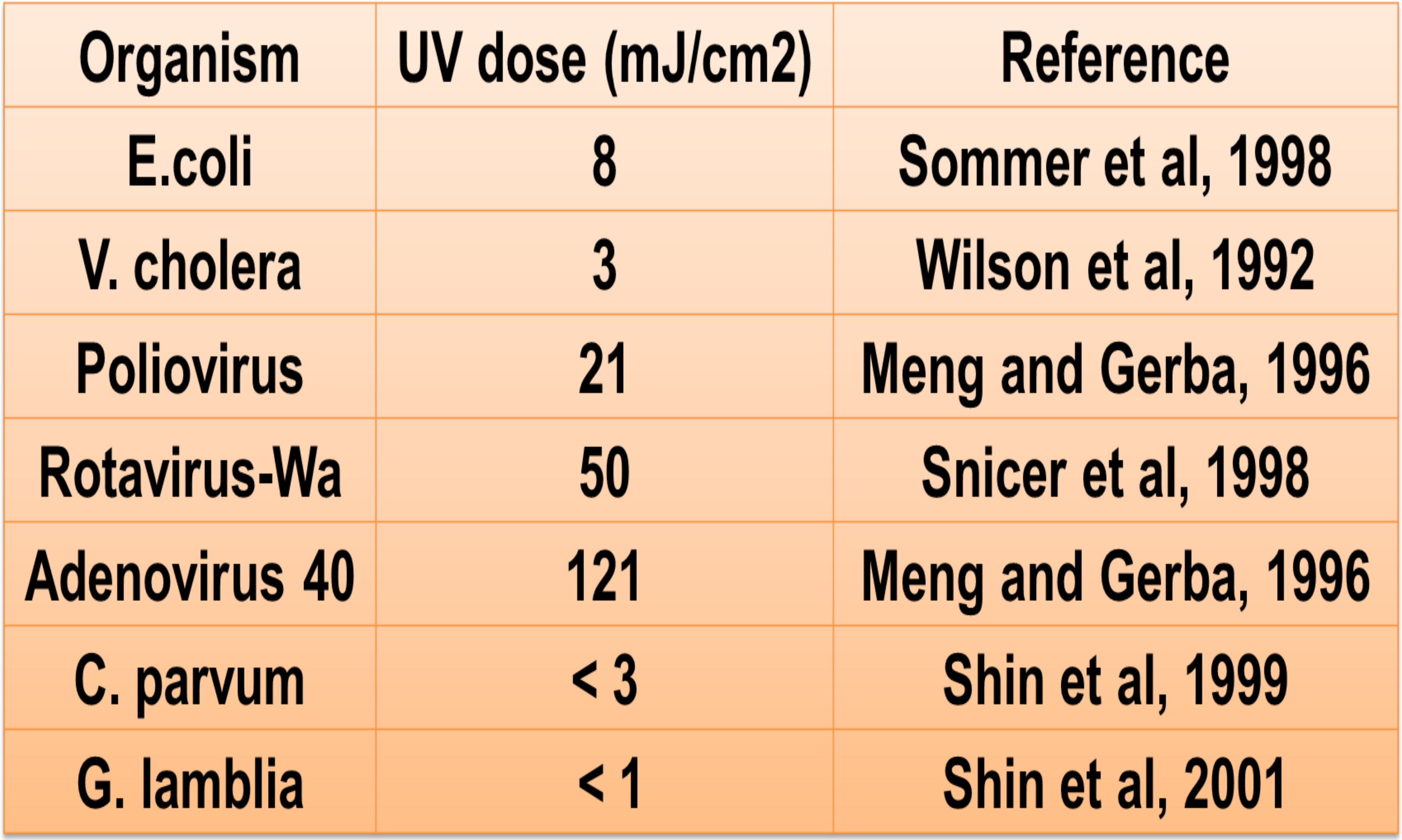
Organism	4-log inactivation dose range (mW-sec/cm^2)	Water source
Bacteria:		
Bacillus subtilis spores	31	Laboratory water
Escherichia coli	20	Laboratory water
S. faecalis		Laboratory water
Salmonella typhi	30	Laboratory water
Vibrio cholera	0.65	Laboratory water
Viruses:		
MS-2	50	Groundwater (1 source)
	64–93	Groundwater (11 sources)
	100	Laboratory water
Coxsackie AZ	30	Laboratory water
Hepatitis A	6–15	Groundwater (3 sources)
	16	Laboratory water
Poliovirus	23–29	Groundwater (8 sources)
	30	Laboratory water
Rotavirus — Wa	50	Laboratory water
Rotavirus SA11	40	Tap water
Adenovirus	186	Laboratory water (4 studies)

Adapted from Malley (2000) and USEPA (2003)

Effectiveness of UV against protozoa

UV inactivation was not effective for Giardia cysts or Cryptosporidium oocysts. However, more recent work showed that low or medium-pressure mercury vapour UV lamps, or pulsed UV technology can achieve 3-log inactivation of Cryptosporidium oocysts at UV doses less than 10 mW-sec/cm^2.)

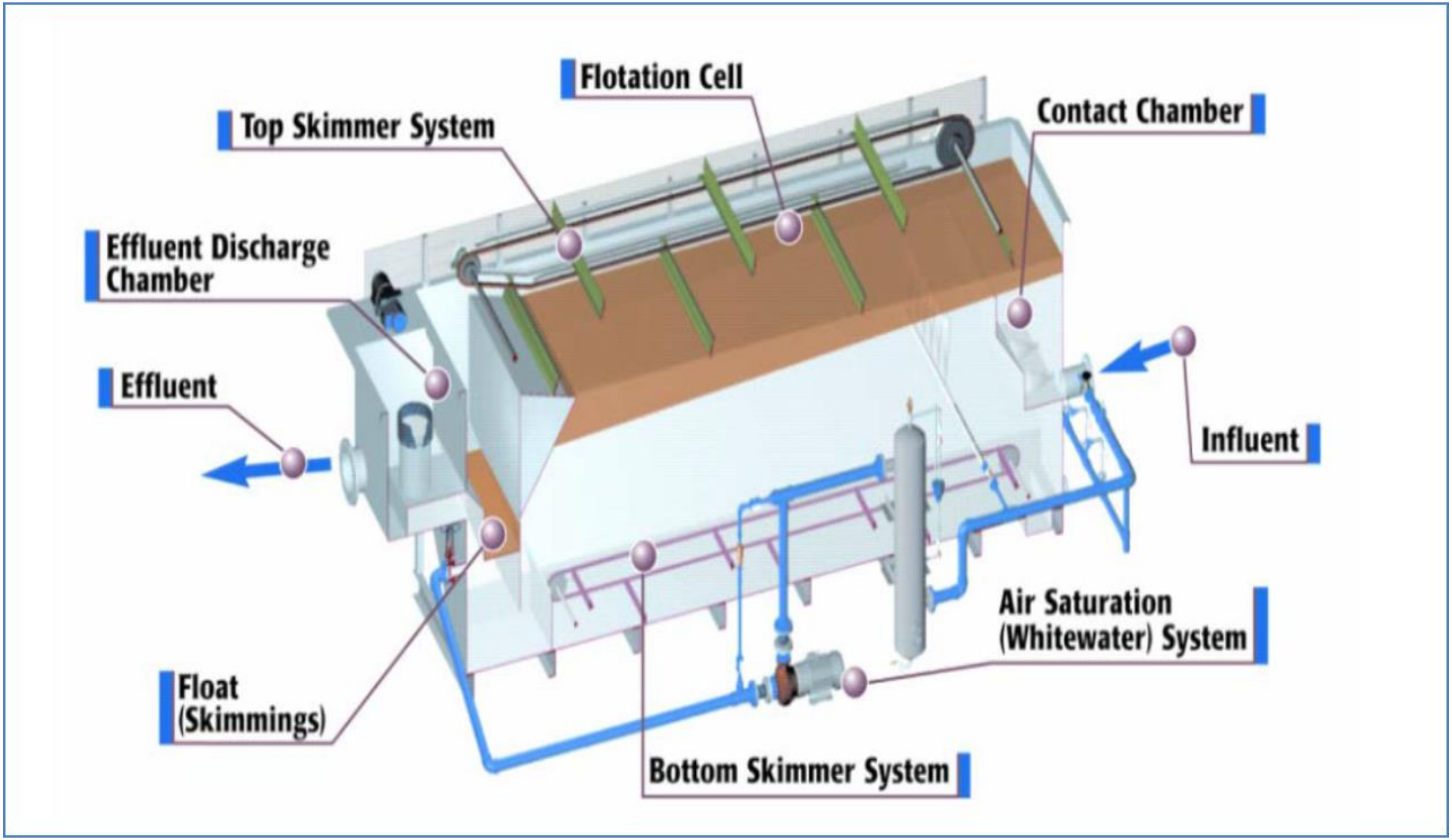
$I^*t_{99.99}$ Values for Some Health-Related Microorganisms



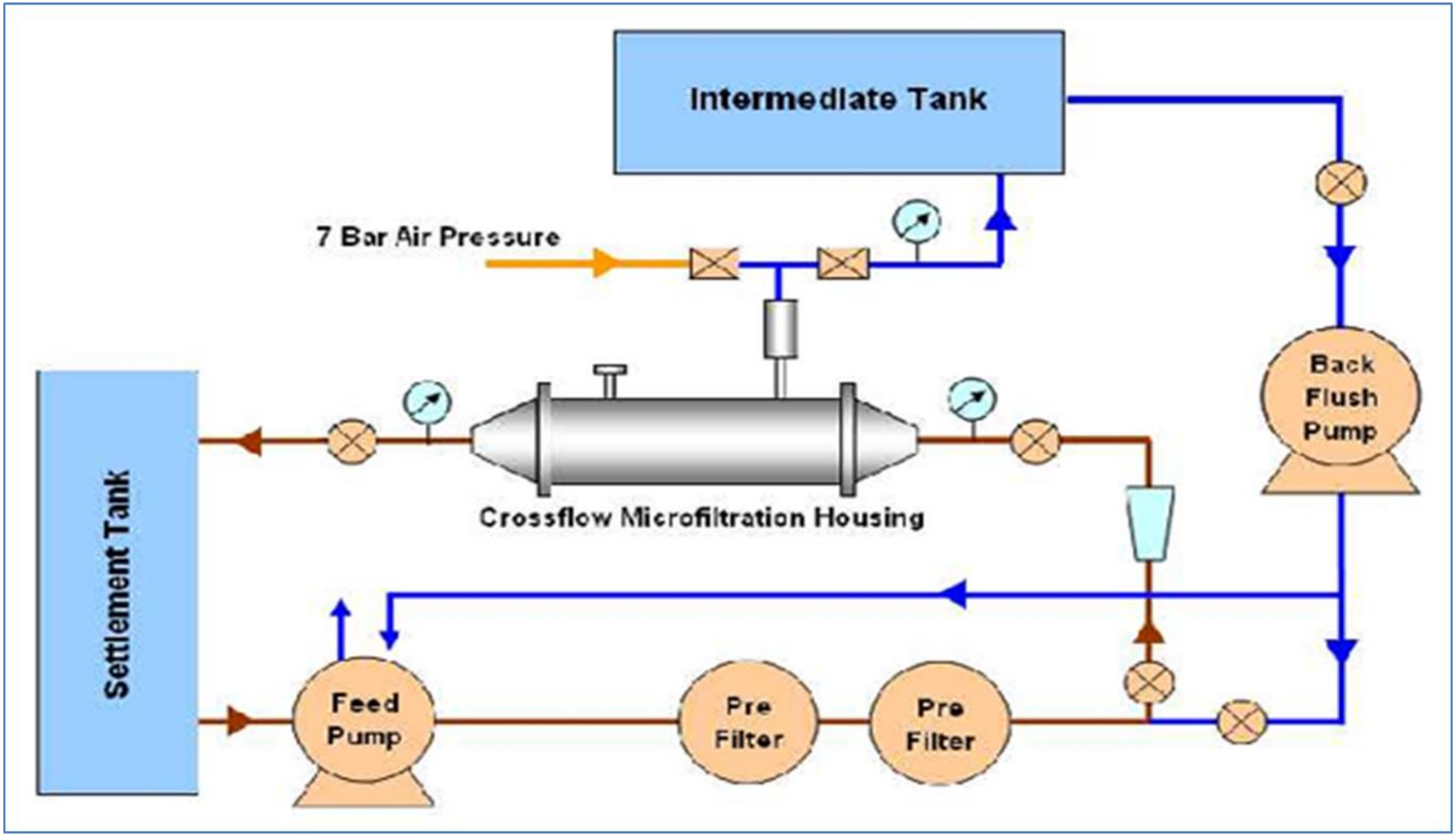
Organism	UV dose (mJ/cm2)	Reference
E.coli	8	Sommer et al, 1998
V. cholera	3	Wilson et al, 1992
Poliovirus	21	Meng and Gerba, 1996
Rotavirus-Wa	50	Snicer et al, 1998
Adenovirus 40	121	Meng and Gerba, 1996
C. parvum	< 3	Shin et al, 1999
G. lamblia	< 1	Shin et al, 2001

Other treatment process

Dissolved air flotation



Membrane filtration



Ground Water Treatment

Major contaminants in groundwater

Natural sources

- Iron and manganese
- Calcium and magnesium (Hardness)
- Arsenic
- Radionuclide

Artificial sources

- Nitrate (from infiltration of fertilizer and surface application of pesticides)
- Synthetic and volatile organic compounds (from improper disposal of industrial wastewater)

Flow diagram of typical groundwater treatment systems

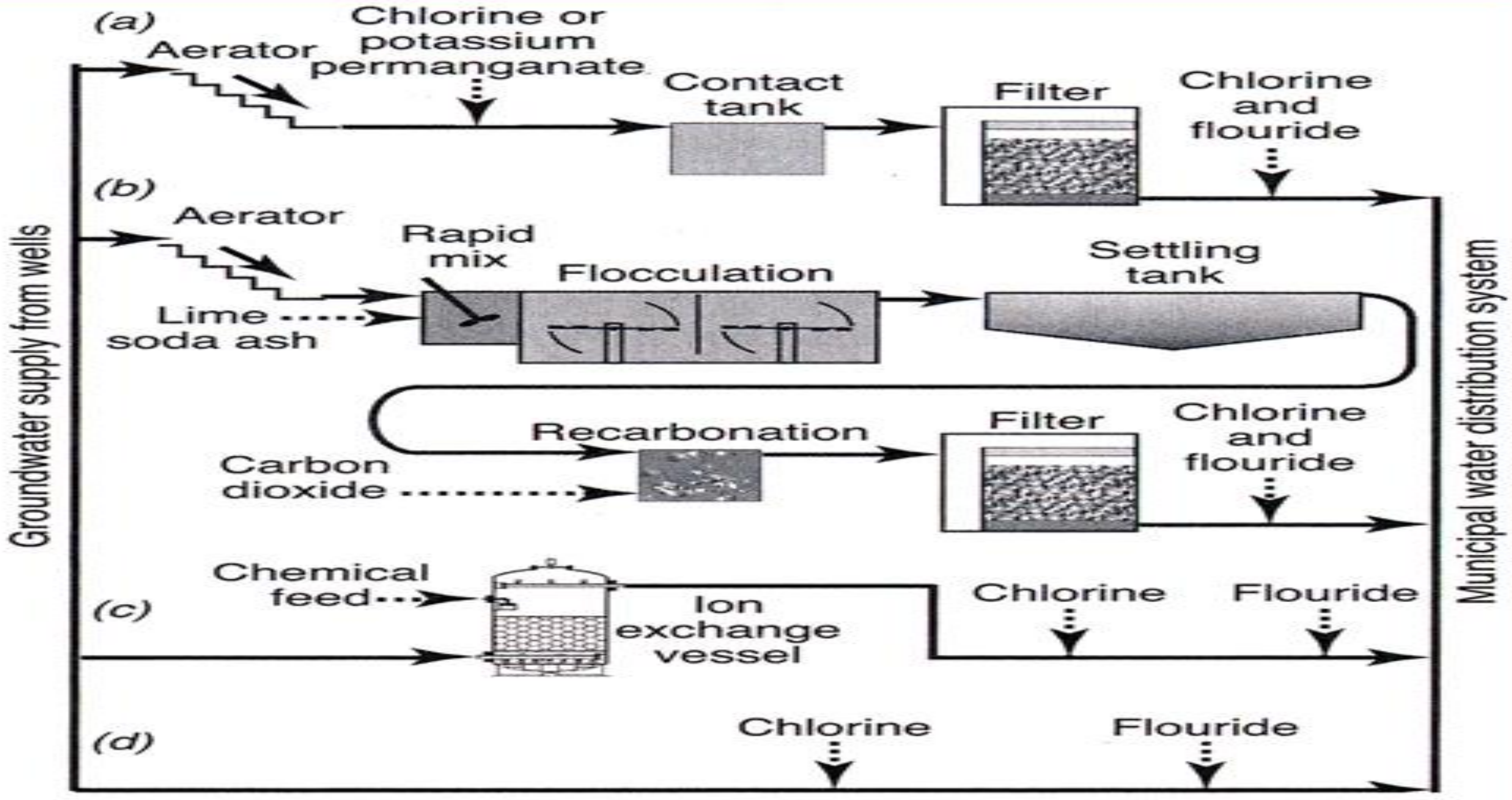


Figure 7–25
Flow diagrams of typical groundwater treatment systems. *(a)* Iron and manganese removal. *(b)* Precipitation softening. *(c)* Ion exchange. *(d)* Disinfection and fluoridation.

Iron and Manganese removal

To remove Ferrous iron (Fe^{++}) and manganous manganese ion (Mn^{++})

Aeration, sedimentation, and filtration

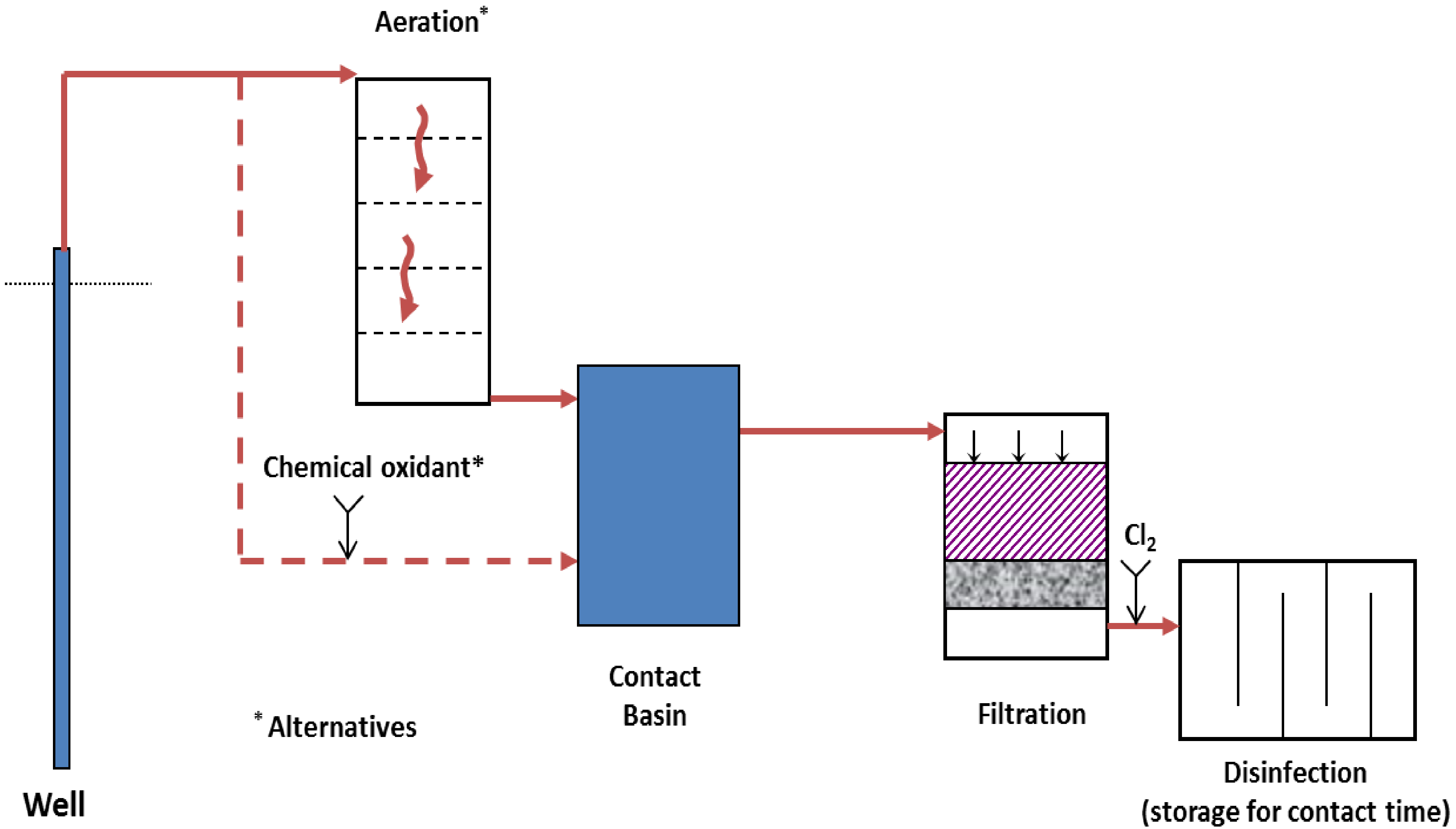
- Fe^{++} + oxygen → $FeO_x \downarrow$ (ferric oxides)

Aeration, chemical oxidation, sedimentation and filtration

- Fe^{++} + Mn^{++} + oxygen + free chlorine → FeO_x ↓ (ferric oxides) + MnO2 ↓

- $Fe(HCO_3)_2$ (Ferrous bicarbonate) + $KMnO_4$ (Potassium permanganase) → $Fe(OH)_3 \downarrow$ (Ferric hydroxide) + $MnO_2 \downarrow$ (manganese hydroxide)
- $Mn(HCO_3)_2$ (Manganese bicarbonate) + $KMnO_4$ (Potassuim permanganase) → $MnO_2 \downarrow$ (manganese hydroxide)

Flow diagram of typical groundwater treatment plant for Fe & Mn removal



Hardness removal

To remove Calcium (Ca^{++}) and Magnesium (Mg^{++}) ions

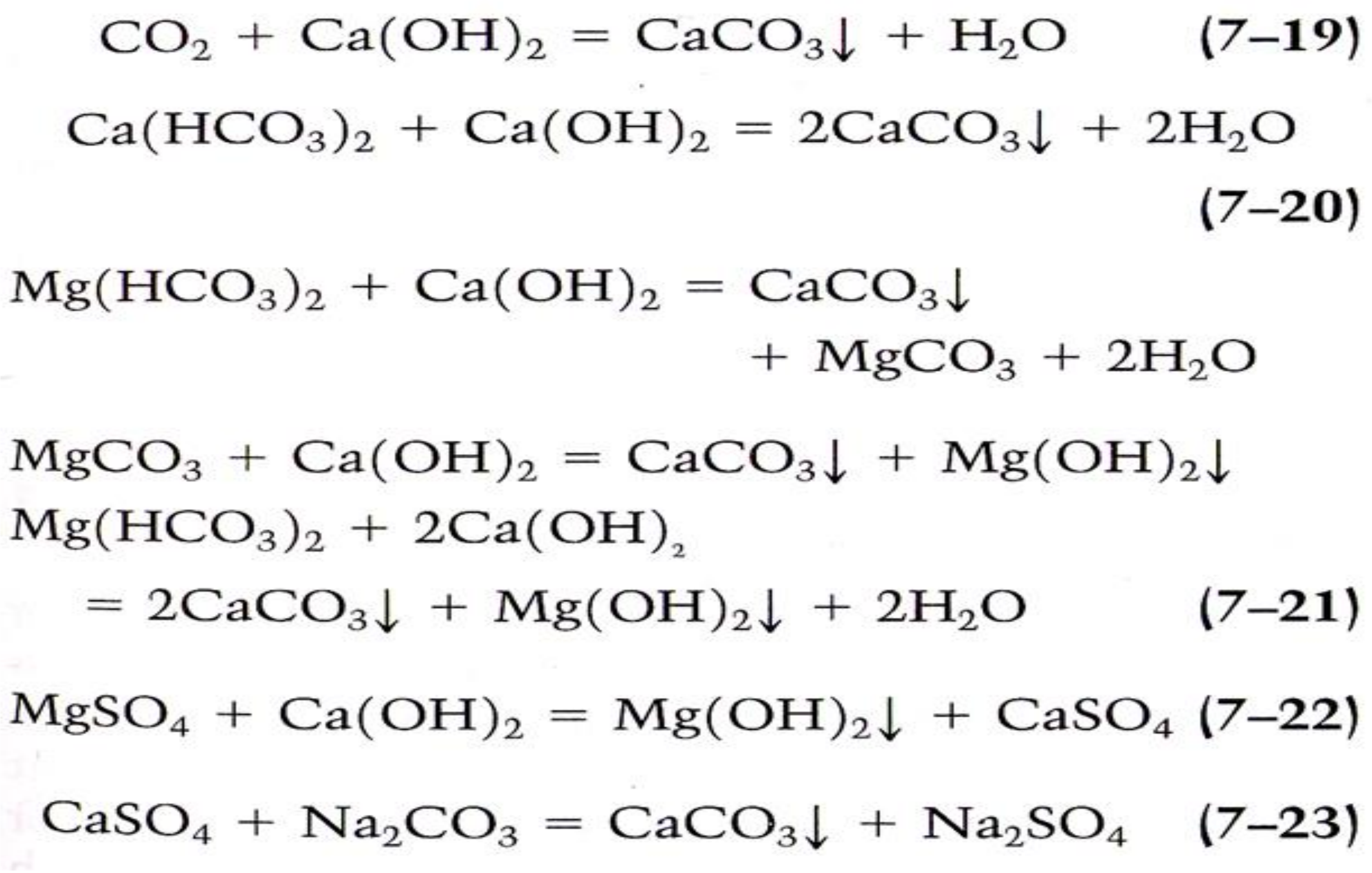
- Interfere with laundering by causing excessive soap consumption
- May produce scale in hot-water heaters and pipes

Lime (CaO) and soda ash (Na_2CO_3)

- Lime for carbonate hardness
- Soda ash for noncarbonate hardness

Equations in next slide

Hardness removal (equations)



$$CO_2 + Ca(OH)_2 = CaCO_3\downarrow + H_2O \tag{7–19}$$

$$Ca(HCO_3)_2 + Ca(OH)_2 = 2CaCO_3\downarrow + 2H_2O \tag{7–20}$$

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

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

$$Mg(HCO_3)_2 + 2Ca(OH)_2 = 2CaCO_3\downarrow + Mg(OH)_2\downarrow + 2H_2O \tag{7–21}$$

$$MgSO_4 + Ca(OH)_2 = Mg(OH)_2\downarrow + CaSO_4 \tag{7–22}$$

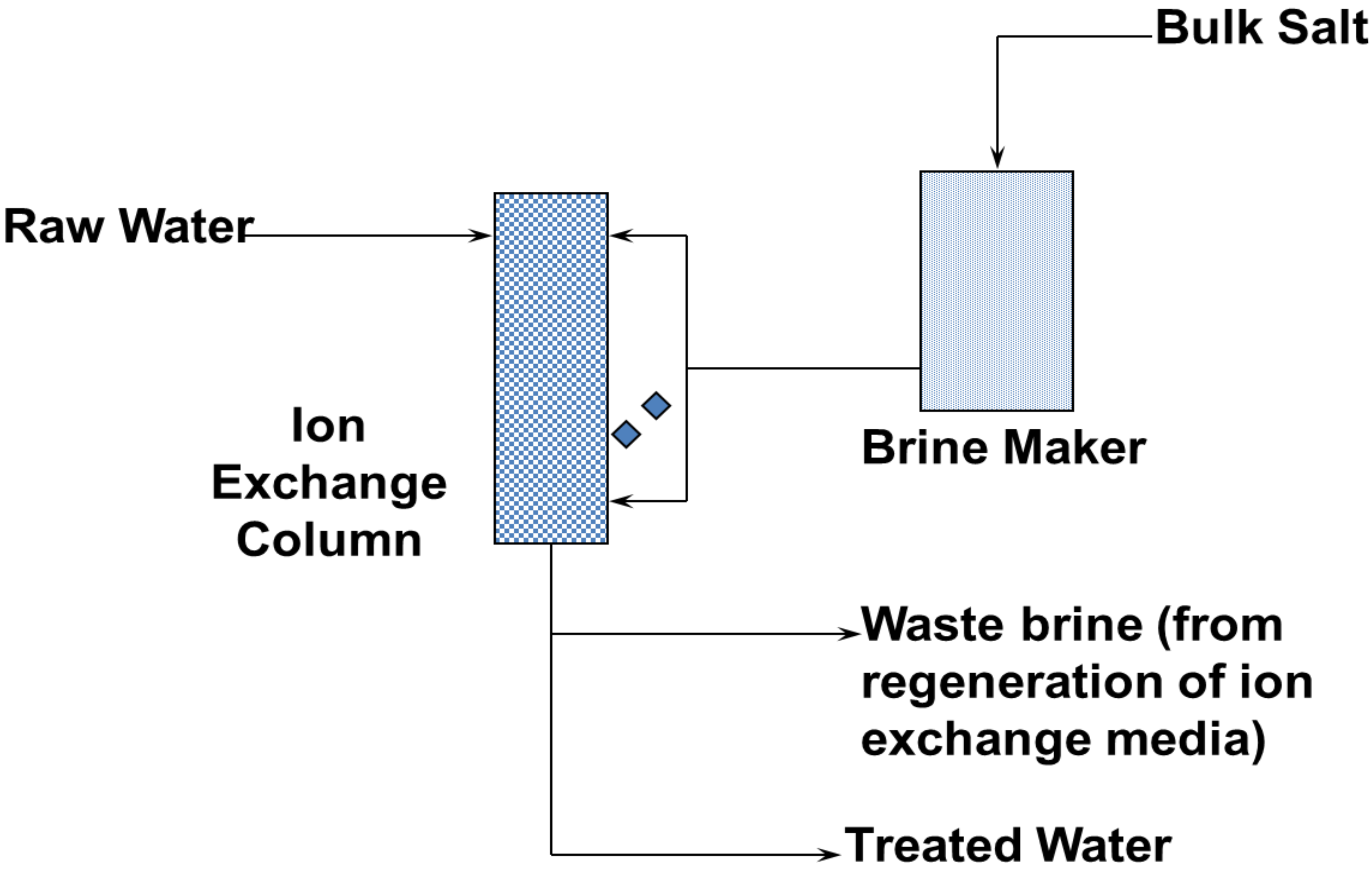
$$CaSO_4 + Na_2CO_3 = CaCO_3\downarrow + Na_2SO_4 \tag{7–23}$$

Ion exchange

To remove anions such as nitrate, fluoride, arsenic, and other contaminants or cations such as calcium and magnesium

Ion exchange vessel, a brine tank for regeneration, a storage tank for spent brine and backwash water, and piping for filtration and backwashing

Ion Exchange Process



Bulk Salt

Raw Water

Brine Maker

Ion Exchange Column

Waste brine (from regeneration of ion exchange media)

Treated Water

Advanced Treatment Processes

Activated Carbon

Activated carbon

Manufacture

- Usually made from either coal product (bituminous coal, lignite, or peat) or wood product (sawdust, coconut shells, or wood)
- Converted to activated carbon by heating the materials to between 300° and 1000°C.

The resulting activated carbon

- Are approximately 1 millimeter sized carbon grains
- Has large surface area (Handful of GAC has a larger surface area than ten football fields)

Adsorb particles and molecules to surface, usually due to molecular-level electrical forces.

Application of activated carbon (I)

Taste and odor control

Natural organic matters (NOM’s)

Disinfection-by-products (DBP’s)

Other artificial compounds

- **Volatile organic compounds (TCE, PCE, etc.)**
- **MTBE**
- **Metals**

ADSORPTION

Adsorption is a natural process by which molecules of a dissolved compound collect on and adhere to the surface of an adsorbent solid. Adsorption occurs when the attractive forces at the carbon surface overcome the attractive forces of the liquid.

Granular activated carbon is a particularly good adsorbent medium due to its high surface area to volume ratio. One gram of a typical commercial activated carbon will have a surface area equivalent to 1,000 square meters. This high surface area permits the accumulation of a large number of contaminant molecules.

ADSORPTION CAPACITY

The specific capacity of a granular activated carbon to adsorb organic compounds is related to:

✓molecular surface attraction,

✓the total surface area available per unit weight of carbon,

✓the concentration of contaminants in the wastewater stream.

This relationship can be expressed in the form:

$$X/M = KC * 1/n$$

where:

X/M = Amount of contaminant adsorbed per unit weight of carbon

C = Concentration of contaminant in the water stream

K,n - Empirical constants particular to the contaminant

Types of manufactured activated carbon

there are three major product groups:

❑Powdered activated carbon; particle size 1-150 µm

❑Granular activated carbon, particle size 0.5-4 mm

❑Extruded activated carbon, partilce size 0.8-4 mm

Application of activated carbon (II)

- Pressure filters

- Gravity filters

Membrane Filtration

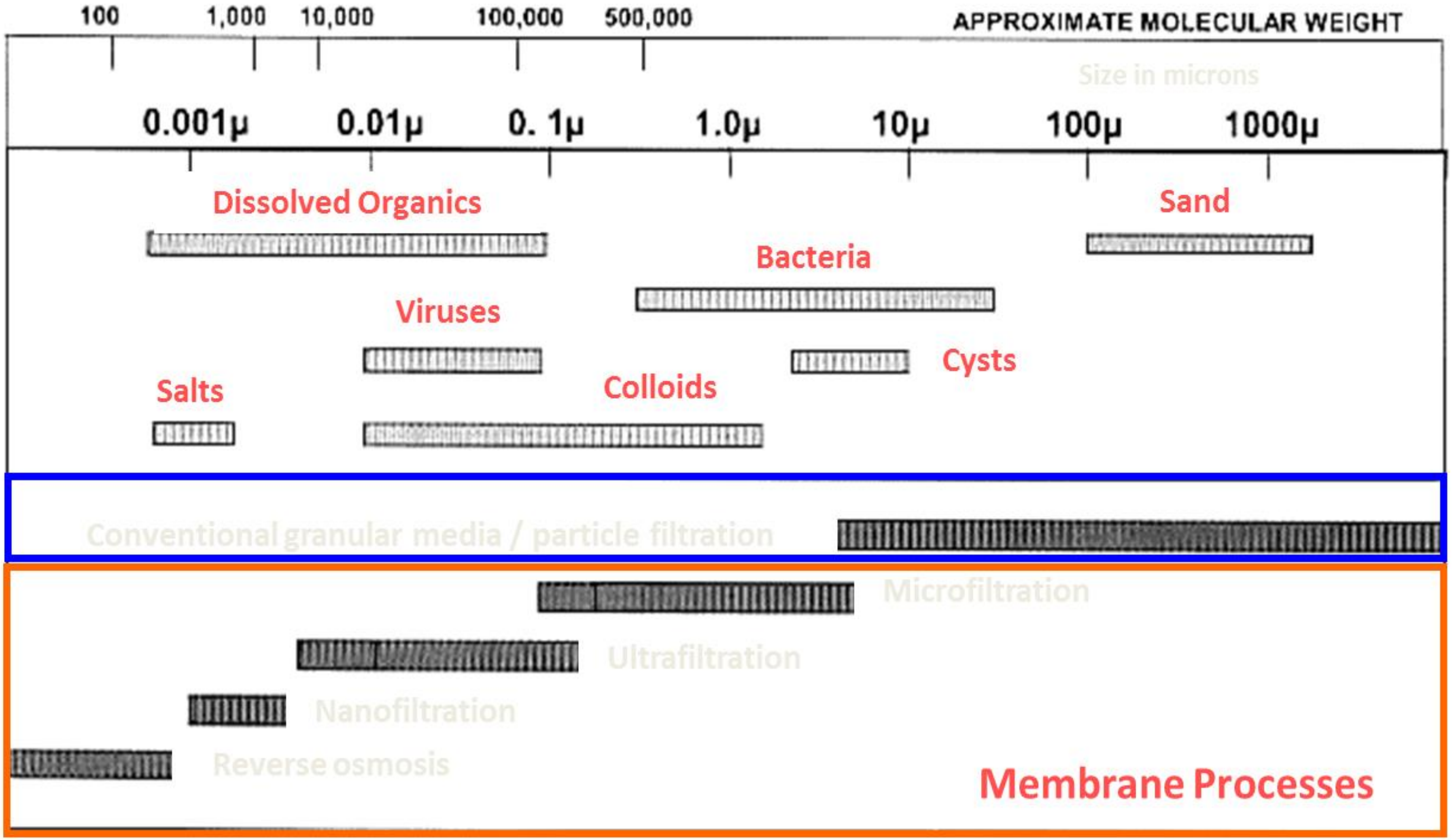
Membrane filtration

To remove colloidal and particulate contaminants including microorganisms (microfiltration and ultrafiltration) or to separate dissolved salts, organic molecules, and metal ions (nanofiltration and reverse osmosis)

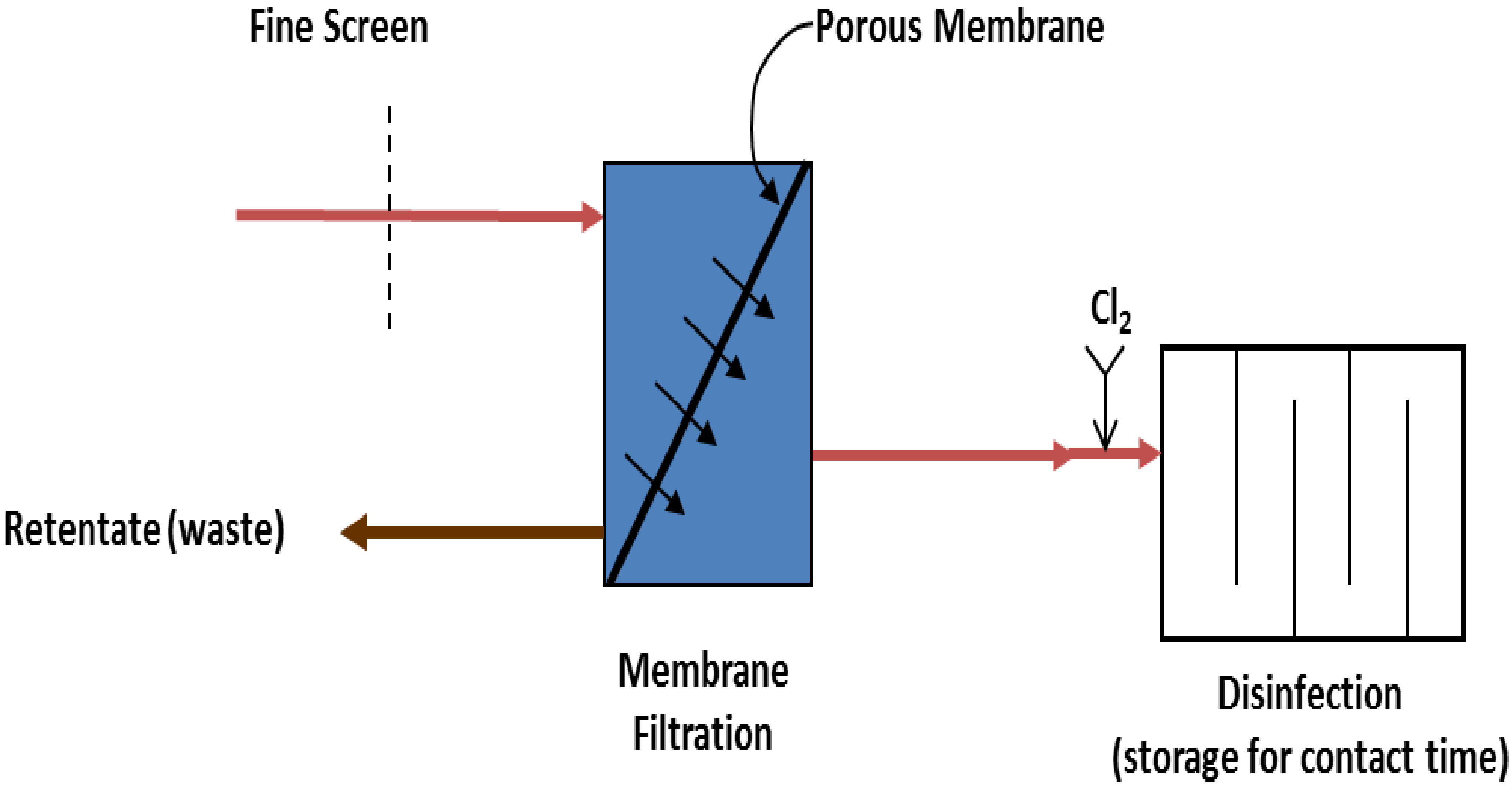
Pore size

- Microfiltration (0.7 – 7 µm)
- Ultrafiltration (0.008 – 0.8 µm)
- Nanofiltration (0.005 – 0.008 µm)
- Reverse osmosis (0.0001 – 0.007 µm)

Membrane Filtration Processes



Flow diagram of Membrane Filtration Treatment Plant



Typical modules of membrane filtration

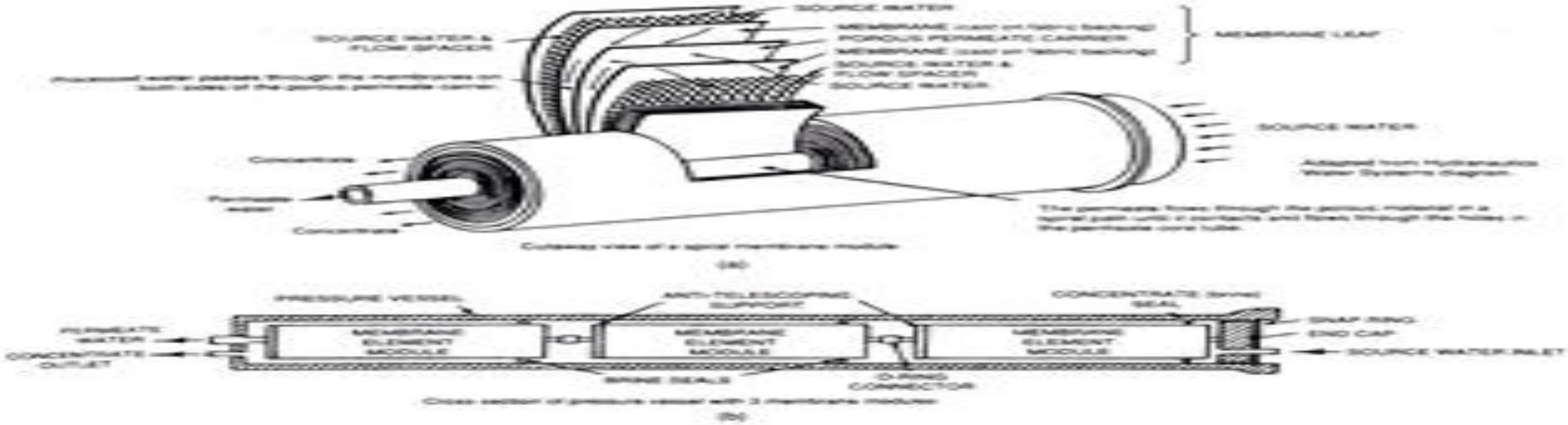


FIGURE 13.4 Typical spiral-wound RO membrane module for pressure-driven processes. Vessels with side ports near the end caps for feed and concentrate connections are also available. [*Adapted from* The U.S.A.I.D. Desalination Manual *(Buros et al., 1980) and is used courtesy of the U.S. Agency for International Development.*]

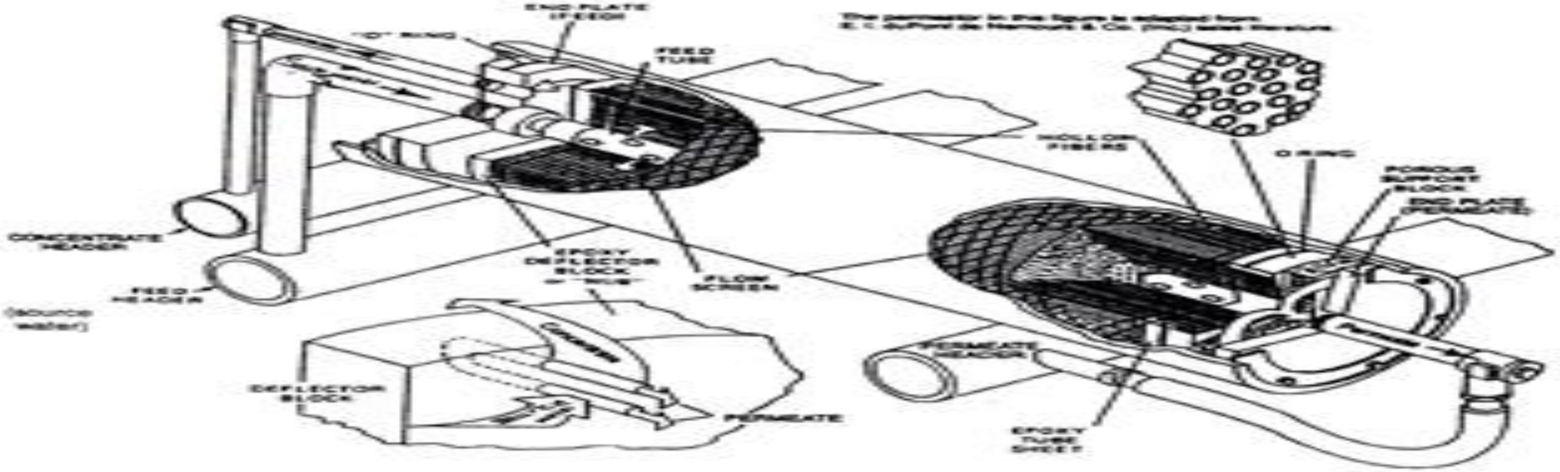


FIGURE 13.5 Typical hollow fine-fiber RO membrane module. [*Adapted from* The U.S.A.I.D. Desalination Manual *(Buros et al., 1980) and is used courtesy of the U.S. Agency for International Development.*]

Outside-in (vacuum) hollow fiber microfiltration module (install submerged in water)

Skid-mounted membrane unit

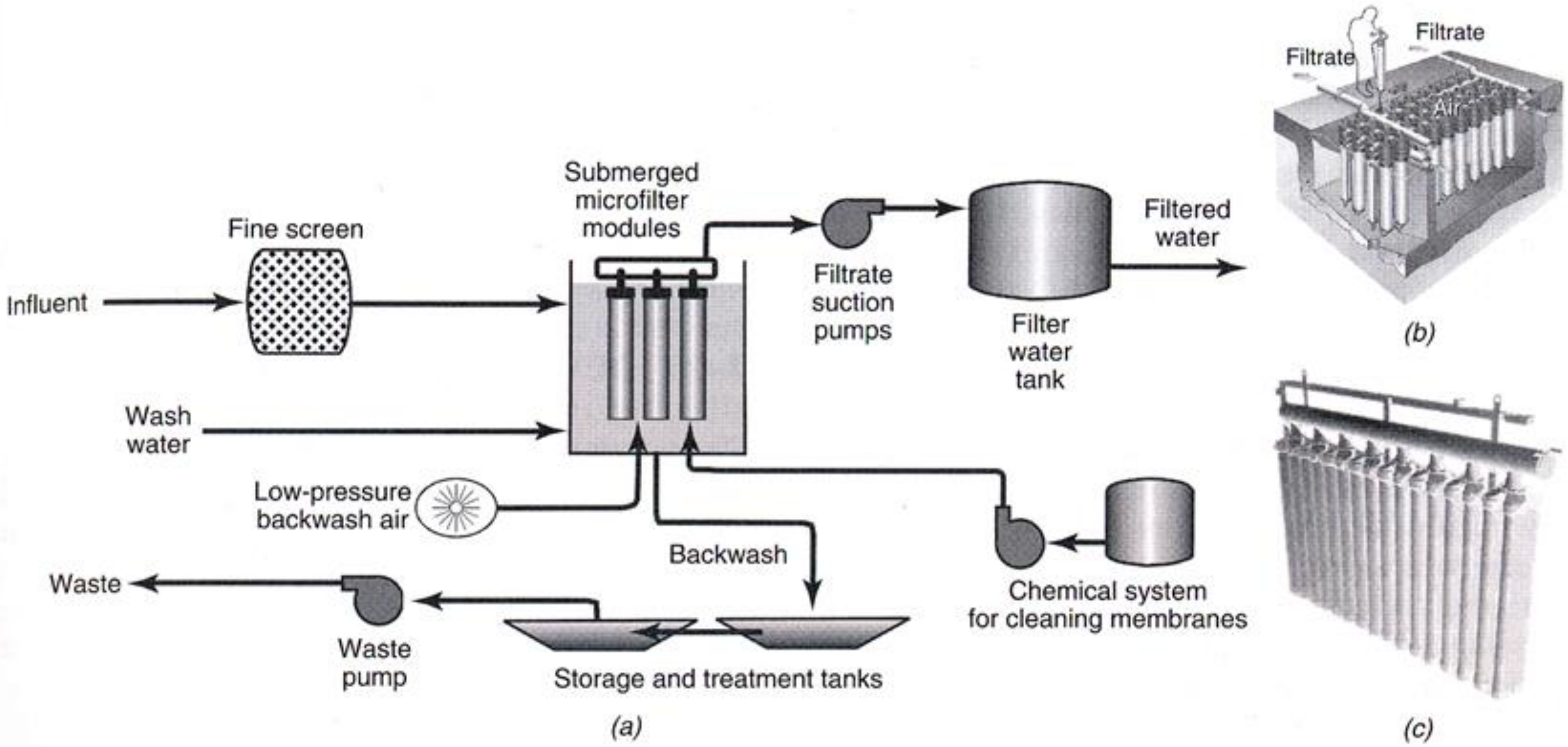


Figure 7–37

Memcor® continuous microfiltration-submerged (CMF-S) process. *(a)* Cell containing membrane modules and peripheral equipment including influent screen, filtration suction pumps, blowers for air scour, wash-water tank, chemical membrane cleaning system, and backwash processing. *(b)* Modules in a cell are grouped together in several manifolded assembles. *(c)* A manifold with suspended microfiltration modules.

(Courtesy of US Filter/Memcor.)

Multiple Membrane Units