Water Reuse and Disinfection

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2007 Idaho Wastewater Reuse Conference
June 26 - 27, 2007
DoubleTree Riverside
Boise, Idaho

Presentation Overview

- Water Reuse
- Indicator Organisms
- Bacterial Interpretations
- Disinfectants
- Treatment Process Impacts

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Water Reuse Categories

- *Unrestricted urban use* - irrigation of areas in which public access is not restricted, such as parks, playgrounds, school yards, and residences; toilet flushing, air conditioning, fire protection, construction, ornamental fountains, and aesthetic impoundments.
- *Restricted urban use* - irrigation of areas in which public access can be controlled, such as golf courses, cemeteries, and highway medians.
- *Agricultural use (food crops)* - irrigation of food crops which are intended for human consumption, often further classified as to whether the food crop is to be processed or consumed raw.
- *Agricultural use (non-food crops)* - irrigation of fodder, fiber and seed crops, pasture land, commercial nurseries, and sod farms.

Water Reuse Categories

- *Unrestricted recreational use* - an impoundment of water in which no limitations are imposed on body-contact water recreation activities.
- *Restricted recreational use* - an impoundment of water in which limited fishing, boating, and other non-contact recreational activities.
- *Environmental use* - recycled water used to create artificial wetlands, enhance natural wetlands, and to sustain stream flows.
- *Industrial use* - recycled water used in industrial facilities primarily for power plant cooling system make-up water, boiler-feed water, process water and general wash down.

Water Reuse Categories

- *Groundwater recharge* - using either infiltration basins, percolation ponds, or injection wells to recharge aquifers.
- *Indirect potable reuse* - the intentional discharge of highly treated reclaimed water into surface water or groundwater that are or will be used as a source of potable water.

Water Reuse Criteria

- Regulations adopted - 26 states
- Guidelines or design standards adopted - 15 states
- No regulations or guidelines adopted - 9 states

Water Reuse Regulations and Guidelines

Table 4-1. Summary of State Reuse Regulations and Guidelines

State	Regulations	Guidelines	No Regulations or Guidelines (1)	Change from 1992 Guidelines for Water Reuse (2)	Unrestricted Urban Reuse	Restricted Urban Reuse	Agricultural Reuse Food Crops	Agricultural Reuse Non-Food Crops	Unrestricted Recreational Reuse	Restricted Recreational Reuse	Environmental Reuse	Industrial Reuse	Groundwater Recharge	Indirect Potable Reuse
Alabama		•		N		•		•						
Alaska	•			NR				•						
Arizona	•			U	•	•	•	•		•				
Arkansas		•		N	•	•	•	•						
California (3)	•			U	•	•	•	•	•	•		•	•	•
Colorado	• (4)			GR	•	•	•	•	•	•				
Connecticut			•	N										
Delaware	•			GR	•	•		•						
Florida	•			U	•	•	•	•			•	•	•	•
Georgia		•		U	•	•		•						
Hawaii		•		U	•	•	•	•		•		•	•	•
Idaho	•			N	•	•	•	•						
Illinois	•			U	•	•		•						
Indiana	•			U	•	•	•	•						
Iowa	•			NR		•		•						
Kansas		•		N	•	•	•	•						
Kentucky			•	N										
Louisiana			•	N										
Maine			•	N										
Maryland		•		N		•		•						
Massachusetts		•		NG	•	•		•					•	•
Michigan	•			N			•	•						
Minnesota			•	N										
Mississippi			•	N										
Missouri	•			N		•		•						
Montana	•			GR	•	•	•	•						
Nebraska	•			GR		•		•						
Nevada	•			GR	•	•	•	•	•	•				
New Hampshire			•	N										
New Jersey		•		RG	•	•	•	•				•		
New Mexico		•		N	•	•	•	•						
New York		•		N				•						
North Carolina	•			U	•	•						•		
North Dakota		•		U	•	•		•						
Ohio		•		NG	•	•		•						
Oklahoma	•			GR		•	•	•						
Oregon	•			N	•	•	•	•	•	•		•		
Pennsylvania		•		NG				•						
Rhode Island			•	N										
South Carolina	•			GR	•	•		•						
South Dakota		•		N	•	•		•			•			
Tennessee	•			N	•	•		•						
Texas	•			U	•	•	•	•	•	•		•		
Utah	•			U	•	•	•	•	•	•		•		
Vermont	•			N				•						
Virginia			•	N										
Washington		•		U	•	•	•	•	•	•	•	•	•	•
West Virginia	•			N			•	•						
Wisconsin	•			N				•						
Wyoming	•			U	•	•	•	•						

(1) Specific regulations on reuse not adopted: however, reclamation may be approved on a case-by-case basis

(2) N - no change
NR - no guidelines or regulations to regulations
U - updated guidelines or regulations
NG - no guidelines or regulations to guidelines
GR - guidelines to regulations
RG - regulations to guidelines

(3) Has regulations for landscape irrigation excluding residential irrigation; guidelines cover all other uses

Water Reuse Regulations and Guidelines

Table 4-2. Number of States with Regulations or Guidelines for Each Type of Reuse Application

Type of Reuse	Number of States
Unrestricted Urban	28
Irrigation	28
Toilet Flushing	10
Fire Protection	9
Construction	9
Landscape Impoundment	11
Street Cleaning	6
Restricted Urban	34
Agricultural (Food Crops)	21
Agricultural (Non-food Crops)	40
Unrestricted Recreational	7
Restricted Recreational	9
Environmental (Wetlands)	3
Industrial	9
Groundwater Recharge (Nonpotable Aquifer)	5
Indirect Potable Reuse	5

Water Reuse Regulations and Guidelines

Table 4-3. Unrestricted Urban Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS [1]	Oxidized, coagulated, filtered, and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5.0 mg/l	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	2 NTU (Avg)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
	5 NTU (Max)	5 NTU (Max)					5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	None detectable (Avg)	2.2/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	2.2/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (Max in 30 days)	23/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

[1] NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

Table 4-4. Restricted Urban Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment and disinfection	Secondary – 23, oxidized, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized and disinfected	Secondary treatment and disinfection	NS [1]	Oxidized and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	20 mg/l	30 mg/l
TSS	NS	NS	5 mg/l	NS	NS	NS	30 mg/l
Turbidity	NS	NS	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg) 5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	200/100 ml (Avg)	23/100 ml (Avg)	75% of samples below detection	23/100 ml (Avg)	23/100 ml (Avg)	200/100 ml (Avg)	23/100 ml (Avg)
	800/100 ml (Max)	240/100 ml (Max in 30 days)	25/100 ml (Max)	200/100 ml (Max)	240/100 ml (Max)	800/100 ml (Max)	240/100 ml (Max)

[1] NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

Table 4-5. Agricultural Reuse - Food Crops

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and high-level disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized, coagulated, filtered, and disinfected
BOD5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5 mg/l	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	2 NTU (Avg)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
	5 NTU (Max)	5 NTU (Max)					5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	None detectable (Avg)	2.2/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	200/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (Max in 30 days)	400/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

(1) NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

Table 4-6. Agricultural Reuse - Non-Food Crops

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment and disinfection	Secondary-23, Oxidized, and disinfected	Secondary treatment, basic disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS [1]	Oxidized and disinfected
BOD_5	NS	NS	20 mg/l $CBOD_5$	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	20 mg/l	NS	NS	NS	30 mg/l
Turbidity	NS	NS	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg) 5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	200/100 ml (Avg)	23/100 ml (Avg)	200/100 ml (Avg)	2.2/100 ml (Avg)	200/100 ml (Avg)	20/100 ml (Avg)	23/100 ml (Avg)
	800/100 ml (Max)	240/100 ml (Max in 30 days)	800/100 ml (Max)	23/100 ml (Max)	400/100 ml (Max)	75/100 ml (Max)	240/100 ml (Max)

[1] NS - Not specified by state regulations

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Table 4-7. Unrestricted Recreational Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR [1]	Oxidized, coagulated, clarified, filtered, and disinfected	NR	NR	Secondary treatment and disinfection	NS	Oxidized, coagulated, filtered, and disinfected
BOD_5	NR	NS[2]	NR	NR	30 mg/l	5 mg/l	30 mg/l
TSS	NR	NS	NR	NR	NS	NS	30 mg/l
Turbidity	NR	2 NTU (Avg)	NR	NR	NS	3 NTU	2 NTU (Avg)
		5 NTU (Max)					5 NTU (Max)
Coliform	NR	Total	NR	NR	Fecal	Fecal	Fecal
		2.2/100 ml (Avg)			2.2/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
		23/100 ml (Max in 30 days)			23/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)

(1) NR - Not regulated by the state
(2) NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

Table 4-8. Restricted Recreational Reuse

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Secondary treatment, filtration, and disinfection	Secondary-23, oxidized, and disinfected	NR (1)	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS	Oxidized and disinfected
BOD_5	NS(2)	NS	NR	NS	30 mg/l	20 mg/l	30 mg/l
TSS	NS	NS	NR	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	NS	NR	2 NTU (Max)	NS	NS	2 NTU (Avg)
	5 NTU (Max)						5 NTU (Max)
Coliform	Fecal	Total	NR	Fecal	Fecal	Fecal	Total
	None detectable (Avg)	2.2/100 ml (Avg)		2.2/100 ml (Avg)	200/100 ml (Avg)	200/100 ml (Avg)	2.2/100 ml (Avg)
	23/100 ml (Max)	23/100 ml (Max in 30 days)		23/100 ml (Max)	23/100 ml (Max)	800/100 ml (Max)	23/100 ml (Max)

(1) NR - Not regulated by the state
(2) NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

Table 4-9. Environmental Reuse - Wetlands

	Arizona	California	Florida[1]	Hawaii	Nevada	Texas	Washington
Treatment	NR [2]	NR	Advanced treatment	NR	NR	NR	Oxidized, coagulated, and disinfected
BOD_5	NR	NR	5 mg/l $CBOD_5$	NR	NR	NR	20 mg/l
TSS	NR	NR	5 mg/l	NR	NR	NR	20 mg/l
Coliform	NR	NR	NS [3]	NR	NR	NR	Fecal 2.2/100 ml (Avg) 23/100 ml (Max)
Total Ammonia	NR	NR	2 mg/l	NR	NR	NR	Not to exceed chronic standards for freshwater
Total Phosphorus	NR	NR	1 mg/l	NR	NR	NR	1 mg/l

(1) Florida requirements are for discharge of reclaimed water to receiving wetlands
(2) NR - Not regulated by the state
(3) NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

Table 4-10. Industrial Reuse[1]

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR [2]	Oxidized and disinfected	Secondary treatment and basic disinfection	Oxidized and disinfected	NR	NS	Oxidized and disinfected
BOD_5	NR	NS [3]	20 mg/l	NS	NR	20 mg/l	NS
TSS	NR	NS	20 mg/l	NS	NR	---	NS
Turbidity	NR	NS	NS	NS	NR	3 NTU	NS
Coliform	NR	Total	Fecal	Fecal	NR	Fecal	Total
		23/100 ml (Avg)	200/100 ml (Avg)	23/100 ml (Avg)		200/100 ml (Avg)	23/100 ml (Avg)
		240/100 ml (Max in 30 days)	800/100 ml (Max)	200/100 ml (Max)		800/100 ml (Avg)	240/100 ml (Avg)

(1) All state requirements are minimum values. Additional treatment may be required depending on expected public exposure. Additional regulations for industrial systems are contained in Appendix A.
(2) NR - Not regulated by the state
(3) NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

Table 4-11. Groundwater Recharge [1]

	Arizona	California[2]	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR [3]	Case-by-case basis	Secondary treatment and basic disinfection	Case-by-case basis	NR	NR	Oxidized, coagulated, filtered, and disinfected
BOD_6	NR		NS[4]		NR	NR	5 mg/l
TSS	NR		10.0 mg/l		NR	NR	5 mg/l
Turbidity	NR		NS		NR	NR	2 NTU (Avg) 5 NTU (Max)
Coliform	NR		NS		NR	NR	Total 2.2/100 ml (Avg) 23/100 ml (Max)
Total Nitrogen	NR		12 mg/l		NR	NR	NS

(1) All state requirements are for groundwater recharge via rapid-rate application systems. Additional regulations for recharge of potable aquifers are contained in Section 4.1.1.10 and Appendix A.
(2) Groundwater recharge in California and Hawaii is determined on a case-by-case basis
(3) NR - Not regulated by the state
(4) NS - Not specified by state regulations

Water Reuse Regulations and Guidelines

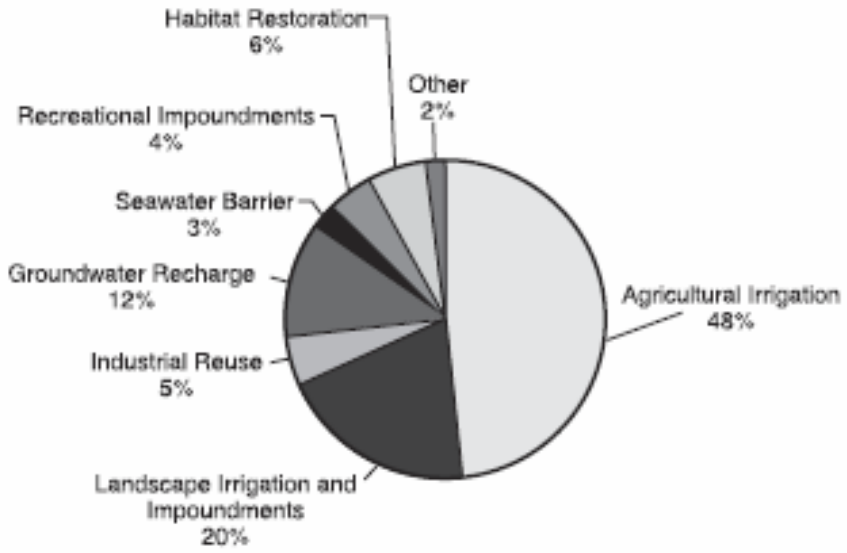
Table 4-12. Indirect Potable Reuse [1]

	Arizona	California[2]	Florida	Hawaii	Nevada	Texas	Washington
Treatment	NR [3]	Case-by-case basis	Advanced treatment, filtration, and high-level disinfection	Case-by-case basis	NR	NR	Oxidized, coagulated, filtered, reverse-osmosis treated, and disinfected
BOD_5	NR		20 mg/l		NR	NR	5 mg/l
TSS	NR		5.0 mg/l		NR	NR	5 mg/l
Turbidity	NR		NS [4]		NR	NR	0.1 NTU (Avg) 0.5 NTU (Max)
Coliform	NR		Total All samples less than detection		NR	NR	Total 1/100 ml (Avg) 5/100 ml (Max)
Total Nitrogen	NR		10 mg/l		NR	NR	10 mg/l
TOC	NR		3 mg/l (Avg) 5 mg/l (Max)		NR	NR	1.0 mg/l
Primary and Secondary Standards	NR		Compliance with most primary and secondary		NR	NR	Compliance with most primary and secondary

(1) Florida requirements are for the planned use of reclaimed water to augment surface water sources that will be used as a source of domestic water supply
(2) Indirect potable reuse in California and Hawaii is determined on a case-by-case basis
(3) NR - Not regulated by the state
(4) NS - Not specified by state regulations

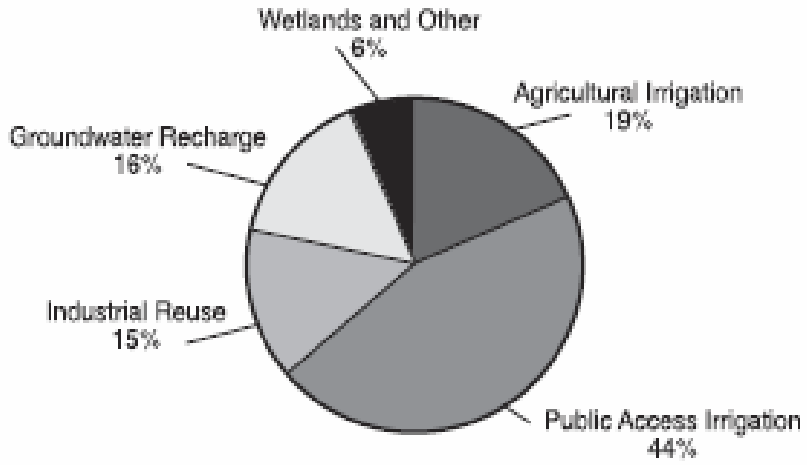
Water Reuse By Type

Figure 4-1. California Water Reuse by Type (Total 358 mgd)



Source: Adapted from California Environmental Protection Agency

Figure 4-2. Florida Water Reuse by Type (Total 584 mgd)



Source: 2001 Florida Water Reuse Inventory

Water Reuse Drivers

- Increasing water demands
- Water scarcity and droughts
- Environmental protection and enhancement
- Socio-economic factors
- Public health protection

Indicator Organisms

Ideal Indicator Organism

- a member of warm-blooded animal's intestinal microflora,
- present when pathogens are present and absent in uncontaminated samples,
- not multiply in the environment,
- at least equally resistant as the pathogen to environmental stress and to disinfection in water and wastewater treatment plants,
- present in greater numbers than the pathogen,
- detectable by means of easy, rapid, and inexpensive methods.

Human Fecal Flora

Strict anaerobes

Bacteroides (10^{11}/g)

Eubacterium (10^{11}/g)

Peptostreptococcus (10^{9}/g)

Bifidobacterium (10^{9}/g)

Endosporus (10^{10}/g)

Plectridium (10^{9}/g)

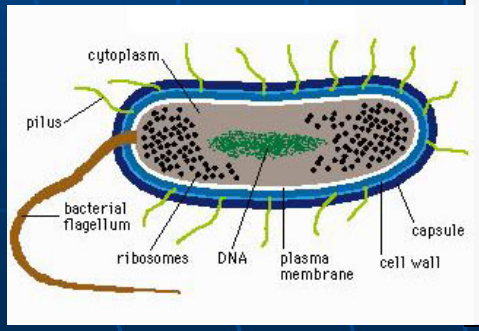
Clostridium (10^{9}/g)

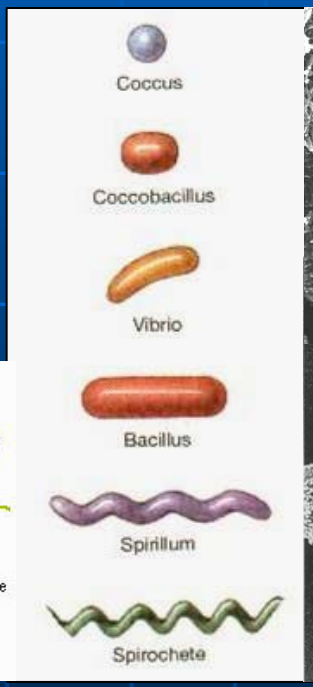
Aerobic and facultative anaerobes

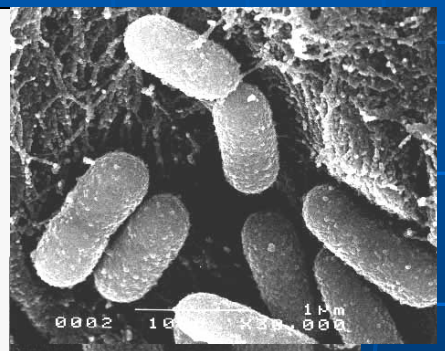
Enterobacteria (10^{7}/g)

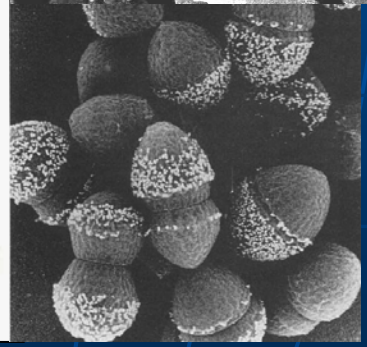
Streptococcus (10^{6}/g)

Lactobacillus (10^{6}/g)

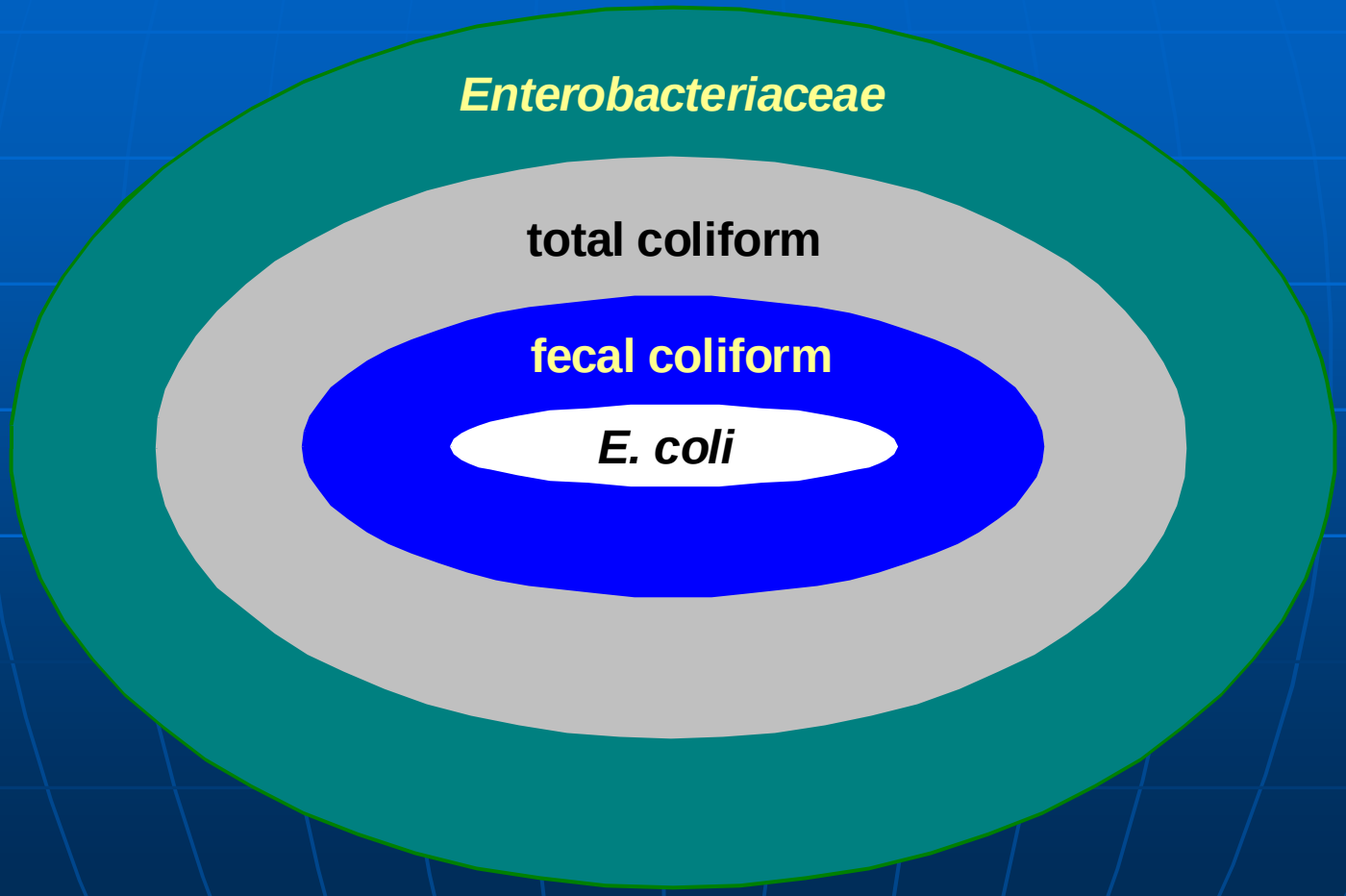








Enterobacteriaceae Family Relationships



Total coliform (TC)

They are aerobic and facultative anaerobes, gram-negative, non spore-forming, rod-shaped bacteria.

They ferment lactose with gas and acid production within 48 hours at 35 °C.

Include many enteric and non-enteric bacteria - Escherichia, Enterobacter, Klebsiella, and *Citrobacter*.

Fecal coliform (FC)

They are a subgroup of total coliform, which is characterized by coliform that can grow at an elevated temperature of 45°C.

This coliform group (*Escherichia coli, Citrobacter freundii,* and *Klebsiella pneumoniae*) are more likely to be from human and animal feces.

FC have long been used as an environmental indicator of fecal contamination.

Escherichia coli (EC)

An identified specie of both total and fecal coliform groups.

Is considered the most specific indicator for contamination from warm-blooded mammal feces.

Enterococci (EN)

They are aerobic and facultative anaerobes, gram- positive, non spore-forming, spherical-shaped bacteria.

A subgroup of fecal streptococci, *S. faecalis* and *S. faecium*, found in human and animal feces.

Clostridium perfringens (CP)

They are an obligate-anaerobe, gram-positive, spore-forming, rod-shaped bacteria.

They form spores which are very resistant to environmental stress and to disinfection.

Therefore, they are good indicators of current and past fecal contamination is soil, fresh water, and marine water environments.

Can be used as a bio-tracer to follow the fate (movement) of pathogen contaminated fecal pollution.

FRNA Bacteriophage

They are a polyhedral (cubic) shaped, single- stranded RNA virus with a proteinaceous coating.

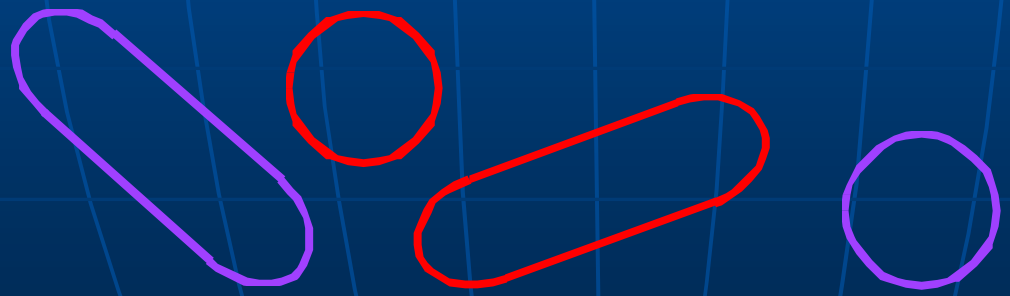
They are a group of viruses capable of infecting coliform bacteria cells which contain F (sex) pili.

They are found in sewage but not generally recovered from human feces.

Total Heterotrophic Bacteria

They are aerobic and facultative anaerobes, either gram-positive or negative, either non spore-forming or spore-forming, and either rod-shaped or spherical- shaped bacteria.

They obtain their carbon and energy sources from organic compounds and are everywhere in our environment.



Culture Methods

Most probable number (MPN)

Membrane filtration (MF)

Agar overlay technique (FRNA bacteriophage)

MPN and MF Differences

Characteristic	MPN	MF
Data obtained	statistical (estimated)	quantitative (actual)
Test length (time)	long (multi-step)	short (single step)
Procedure style	tedious	simple
Confirmation	indirect	direct/speciate
Delivery (container)	pipettes	graduated cylinder
Container rinsing	no	yes
Growth media	LTB, BGB, and EC	mFC
Total cost	high (high labor)	moderate (low labor)
Particle content	acceptable	unacceptable
Sample volume	small/limited	large
Stressed bacteria	no additional step	resuscitation needed
Viable/not culturable	insensitive	insensitive

Standard Culture Media

Organism	MF Media
Clostridium perfringens	mCP
enterococci	mE + EIA
total coliform	mENDO
fecal coliform	mFC
Escherichia coli	mTEC

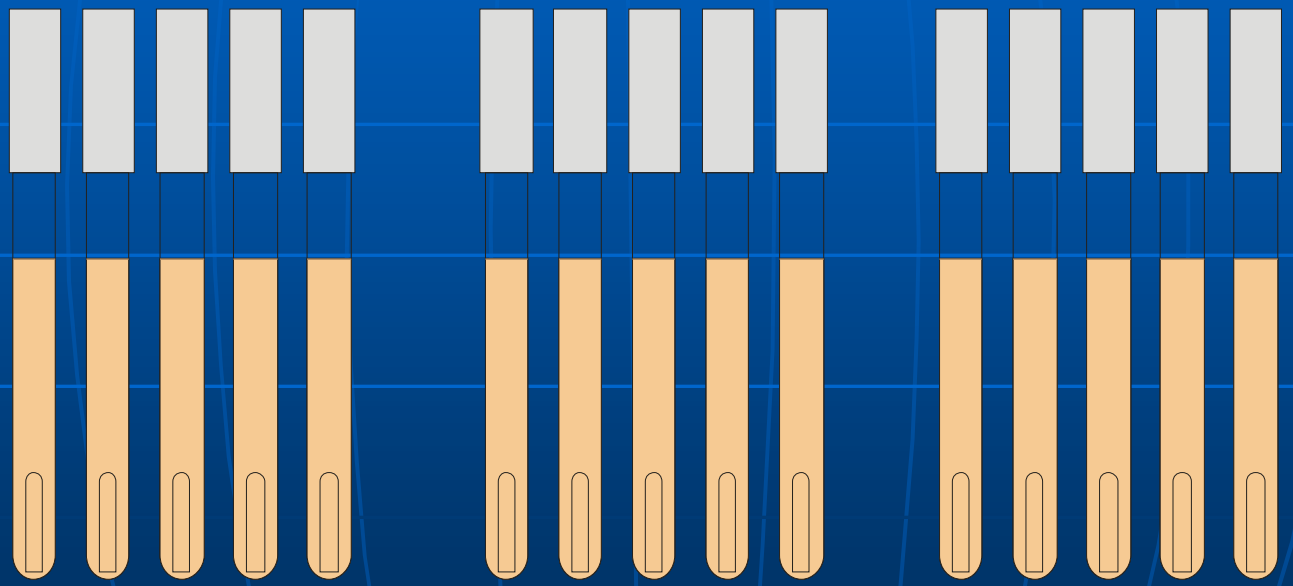
Alternative Culture Media

Organism	MF Media
enterococci	mEI
total coliform and *E. coli*	mI

Multi-tube Fermentation (MPN)

Presumptive Phase - Lauryl Tryptose Broth (LTB)

35°C, 24 hr re-check at 48 hr



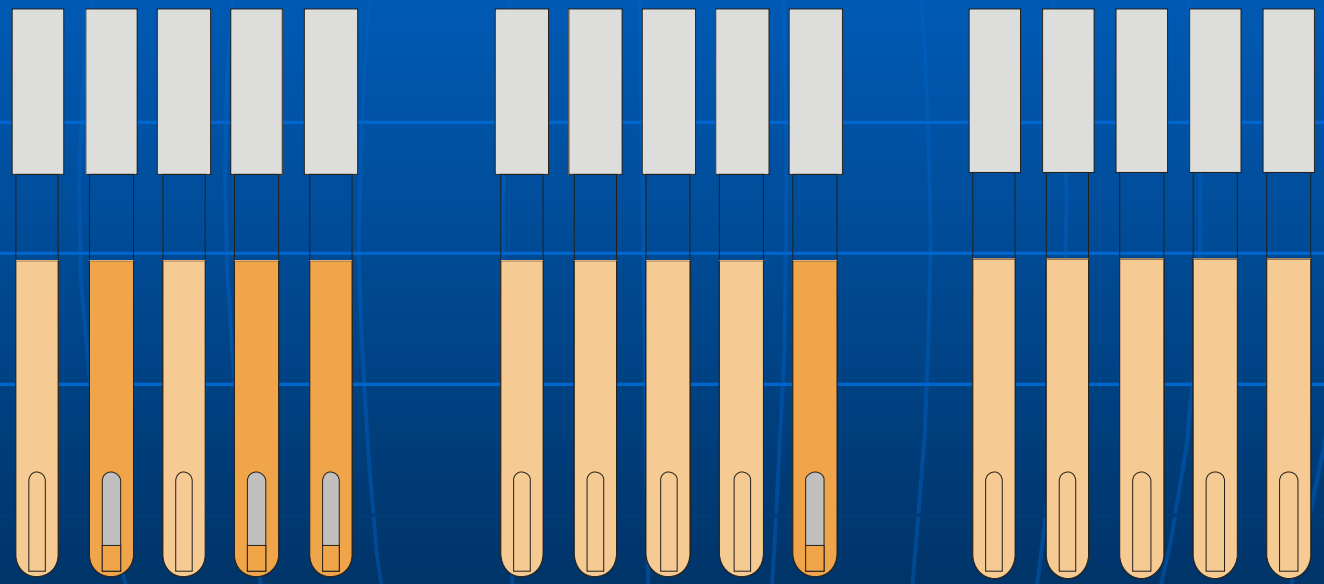
10 mL 1.0 mL 0.1 mL

Serial Dilution

Multi-tube Fermentation (MPN)

Presumptive Phase - Lauryl Tryptose Broth (LTB)

35°C, 24 hr re-check at 48 hr



10 mL 1.0 mL 0.1 mL

Serial Dilution

Multi-tube Fermentation (MPN)

Presumptive Phase - LTB Results

Combination of positives	MPN index/ 100 mL	95 % confidence limits lower	upper
3-0-0	8	3.0	24
3-0-1	11	4.0	29
3-1-0	11	4.0	29
3-1-1	14	6.0	35
3-2-0	14	6.0	35
3-2-1	17	7.0	40
MF	11	5.4	19.7

Multi-tube Fermentation (MPN)

Confirmed Phase -

Brilliant Green Lactose Bile Broth (BGB)

35°C, 48 hr

Multi-tube Fermentation (MPN)

Confirmed Phase -

Brilliant Green Lactose Bile Broth (BGB)

35°C, 48 hr

10 mL

1.0 mL

Multi-tube Fermentation (MPN)

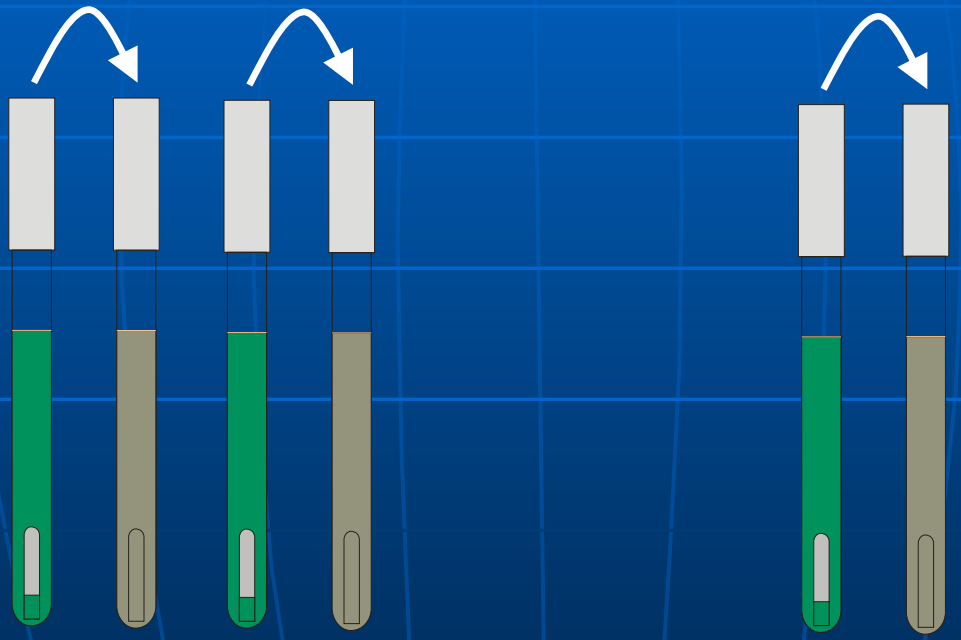
Confirmed Phase - BGB Results

Combination of positives	MPN index/ 100 mL	95 % confidence limits lower	upper
2-0-0	4	1.0	17
2-0-1	7	2.0	20
2-1-0	7	2.0	21
2-1-1	9	3.0	24
2-2-0	9	3.0	25
2-3-0	12	5.0	29
MF	7	2.8	14.4

Multi-tube Fermentation (MPN)

Completed Phase - EC MUG

44.5°C, 24 hr



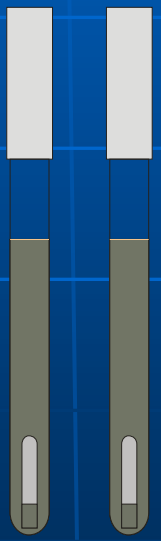
10 mL

1.0 mL

Multi-tube Fermentation (MPN)

Completed Phase - EC MUG

44.5°C, 24 hr



10 mL

Multi-tube Fermentation (MPN)

Completed Phase - BGB Results

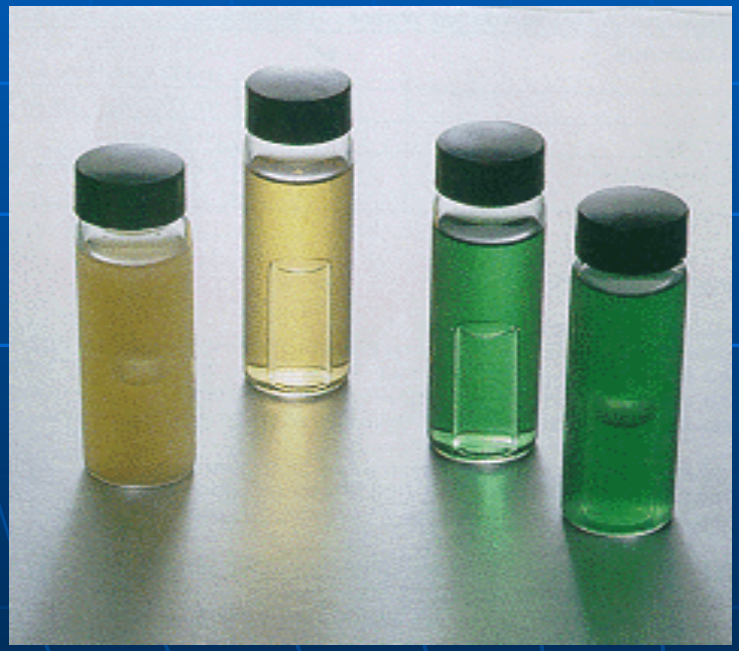
Combination of positives	MPN index/ 100 mL	95 % confidence limits lower	upper
2-0-0	4	1.0	17
2-0-1	7	2.0	20
2-1-0	7	2.0	21
2-1-1	9	3.0	24
2-2-0	9	3.0	25
2-3-0	12	5.0	29
MF	4	1.0	10.2

Multi-tube Fermentation (MPN)

Presumptive Phase - LTB

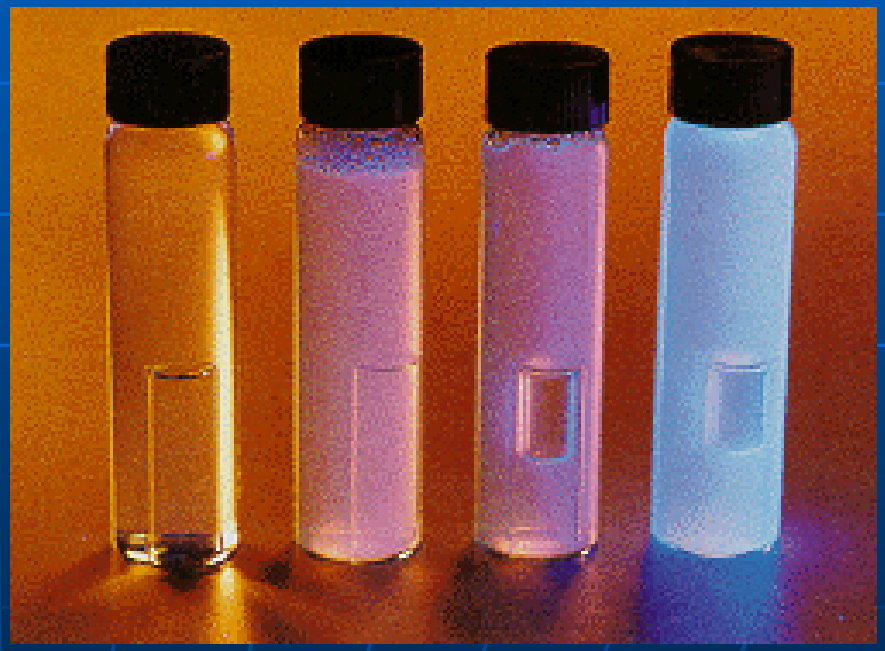
Confirmed Phase - BGB

35°C

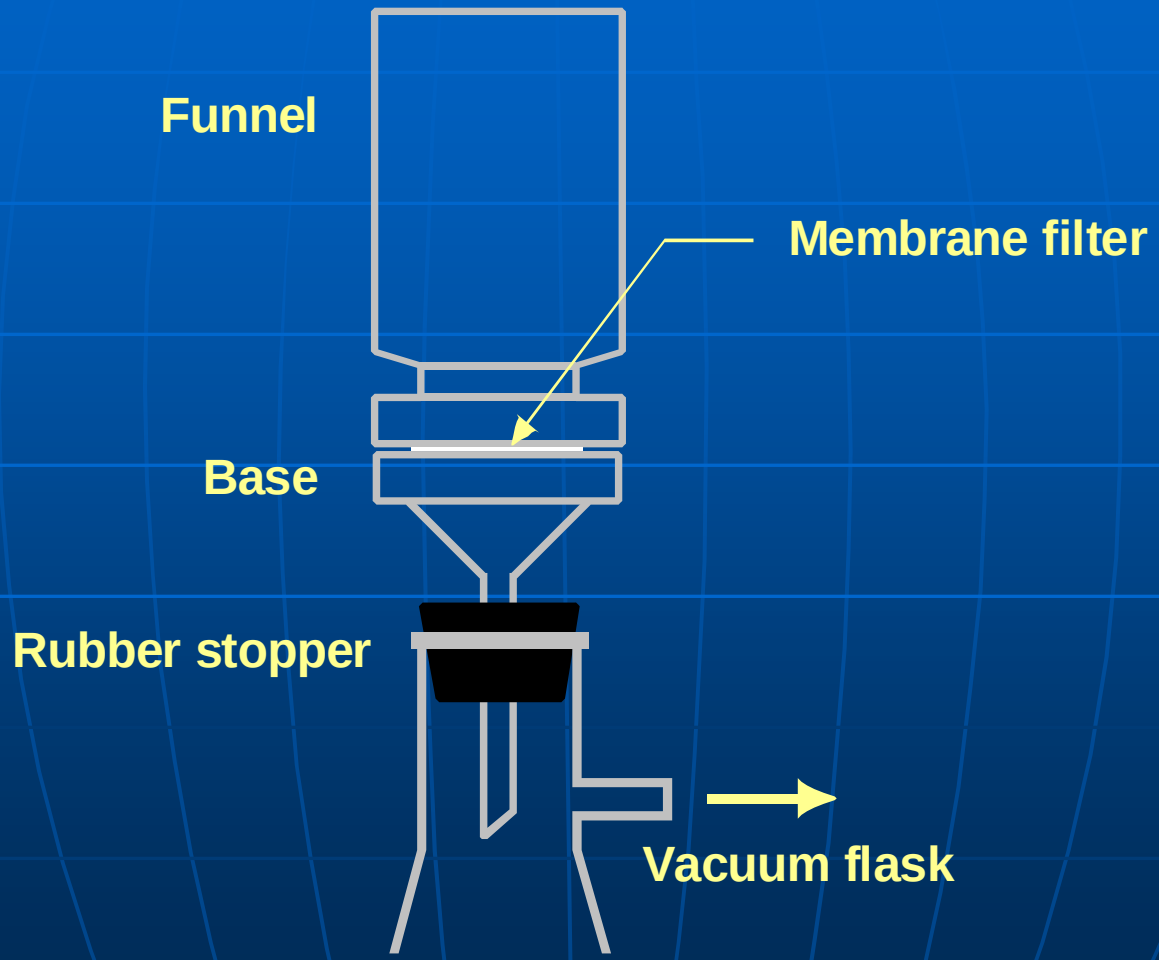


Completed Phase - EC MUG

44.5°C

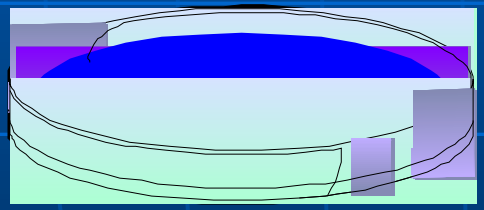


Membrane Filtration (MF)



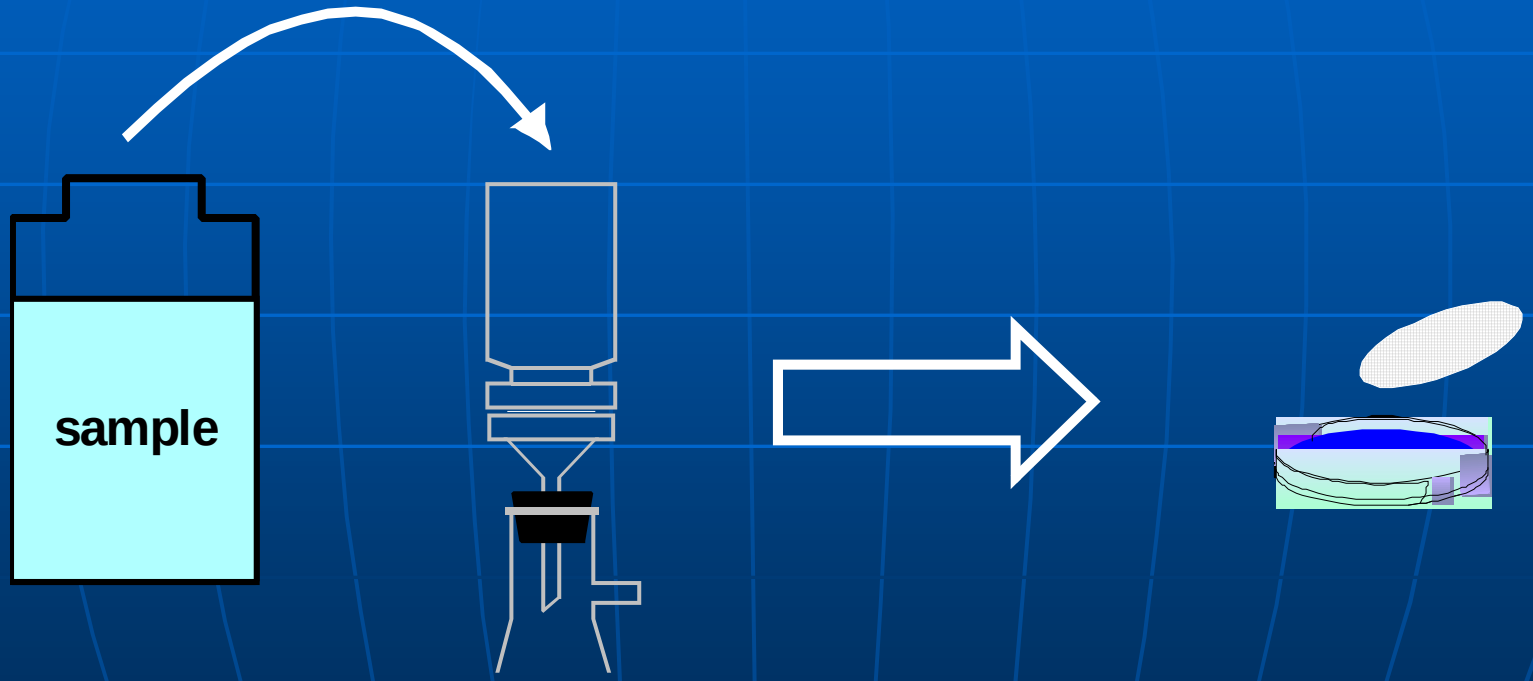
Membrane Filtration (MF)

Membrane filter



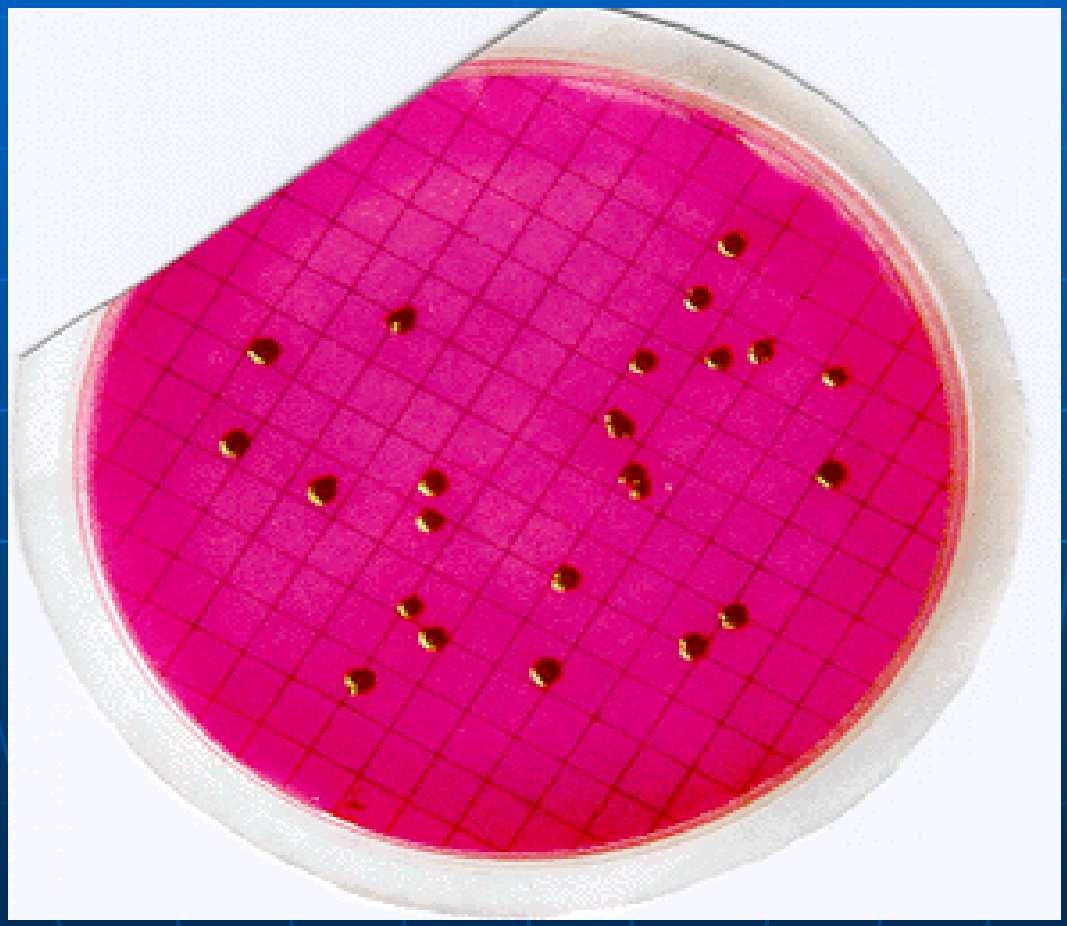
Petri dish

Membrane Filtration (MF)

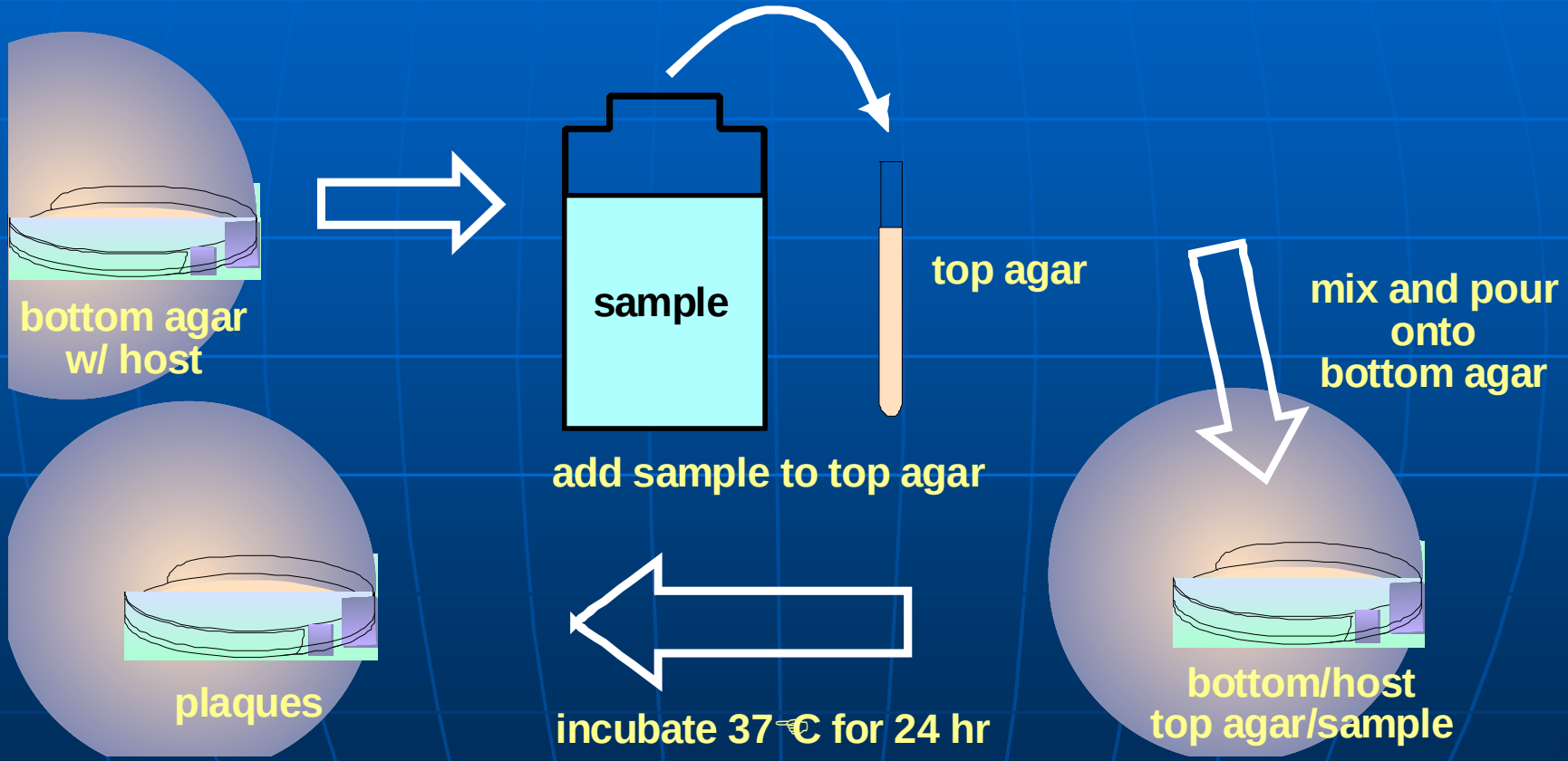


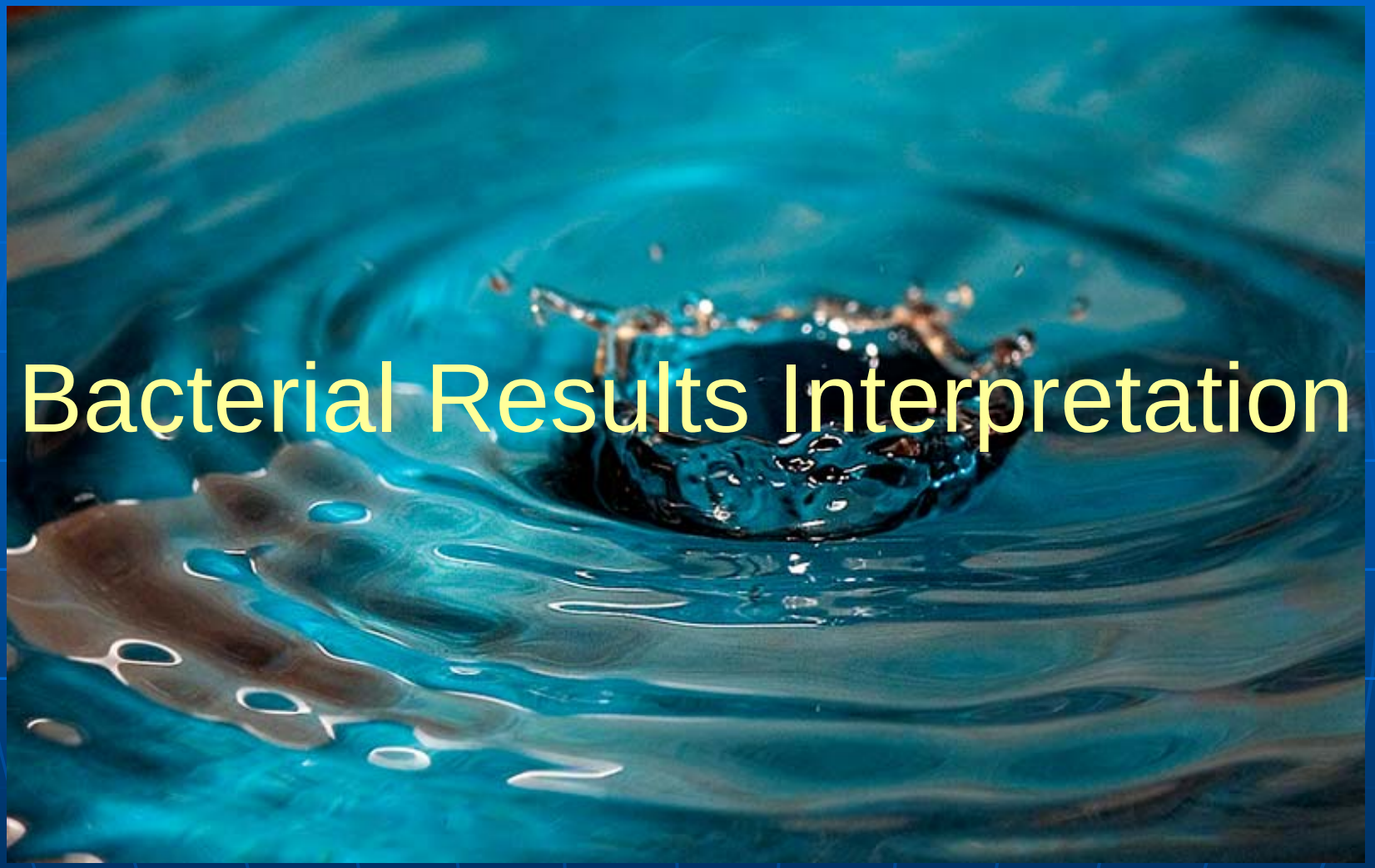
Membrane Filtration (MF)

mENDO Media (Total Coliform)



Bacteriophage Flow Sheet





Bacterial Results Interpretation

Bacterial Results

- Water quality standards
  - geometric mean
  - single sample maximum
  - not more than percent
- Water reuse criteria
  - none detectable in 4 of last 7 daily samples
  - 7-day median
  - geometric mean
  - Not to exceed in more than one sample in any 30-day period
  - single sample maximum


Disinfection

Chlorine

- oxidation,
- chlorine reactions,
- protein precipitation,
- cell wall permeability modifications, and
- hydrolysis and mechanical disruption.

UV Radiation

- pyrimidine dimers,
- DNA synthesis interference,
- RNA synthesis interference,
- protein synthesis interference,
- cell division delay,
- permeability changes, and
- motility changes.

Dose Relationships

Chlorine

$$D = Ct$$

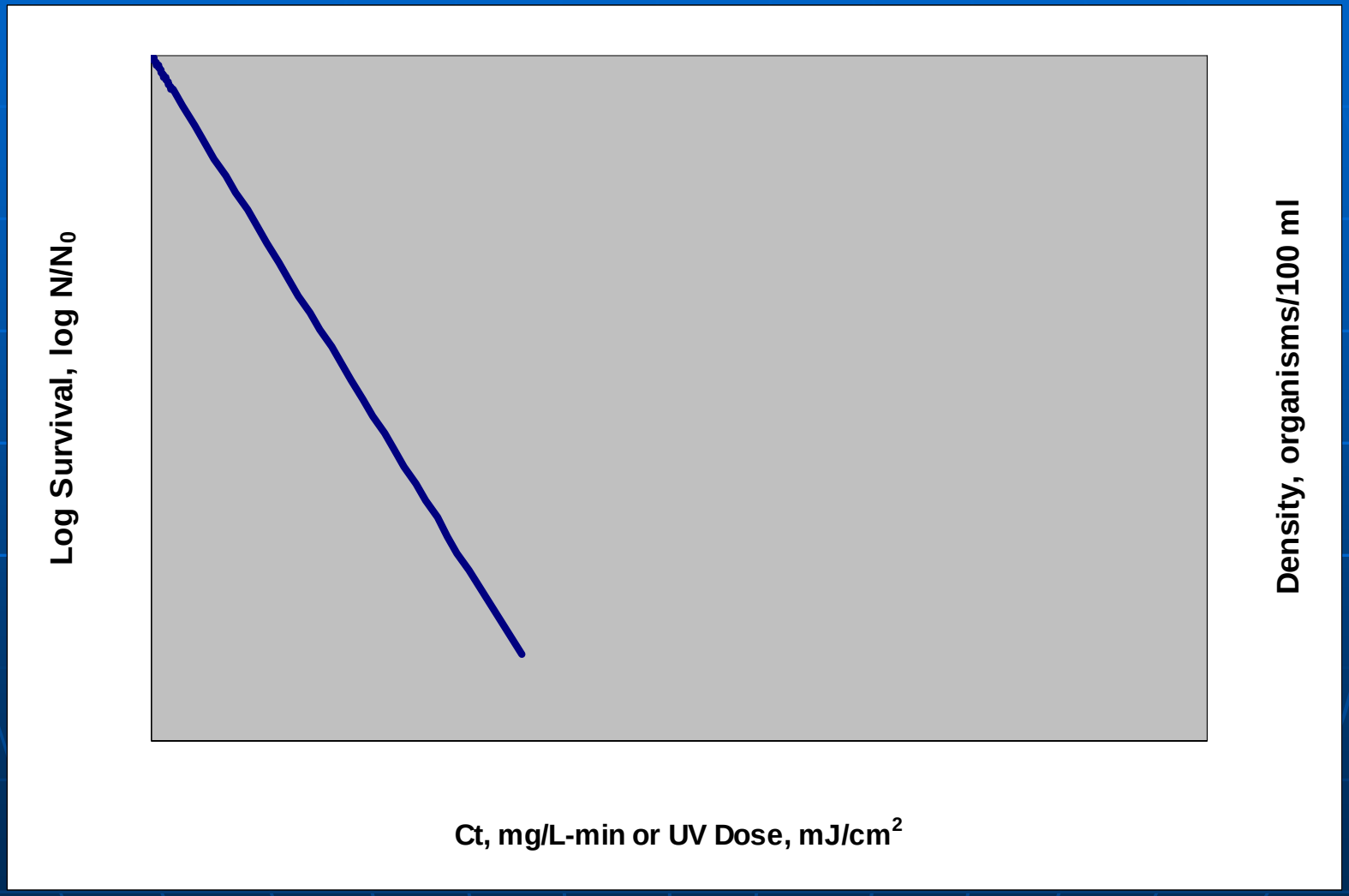
D = chlorine dose, mg/L - min
C = chlorine residual, mg/L
t = contact time, min

UV

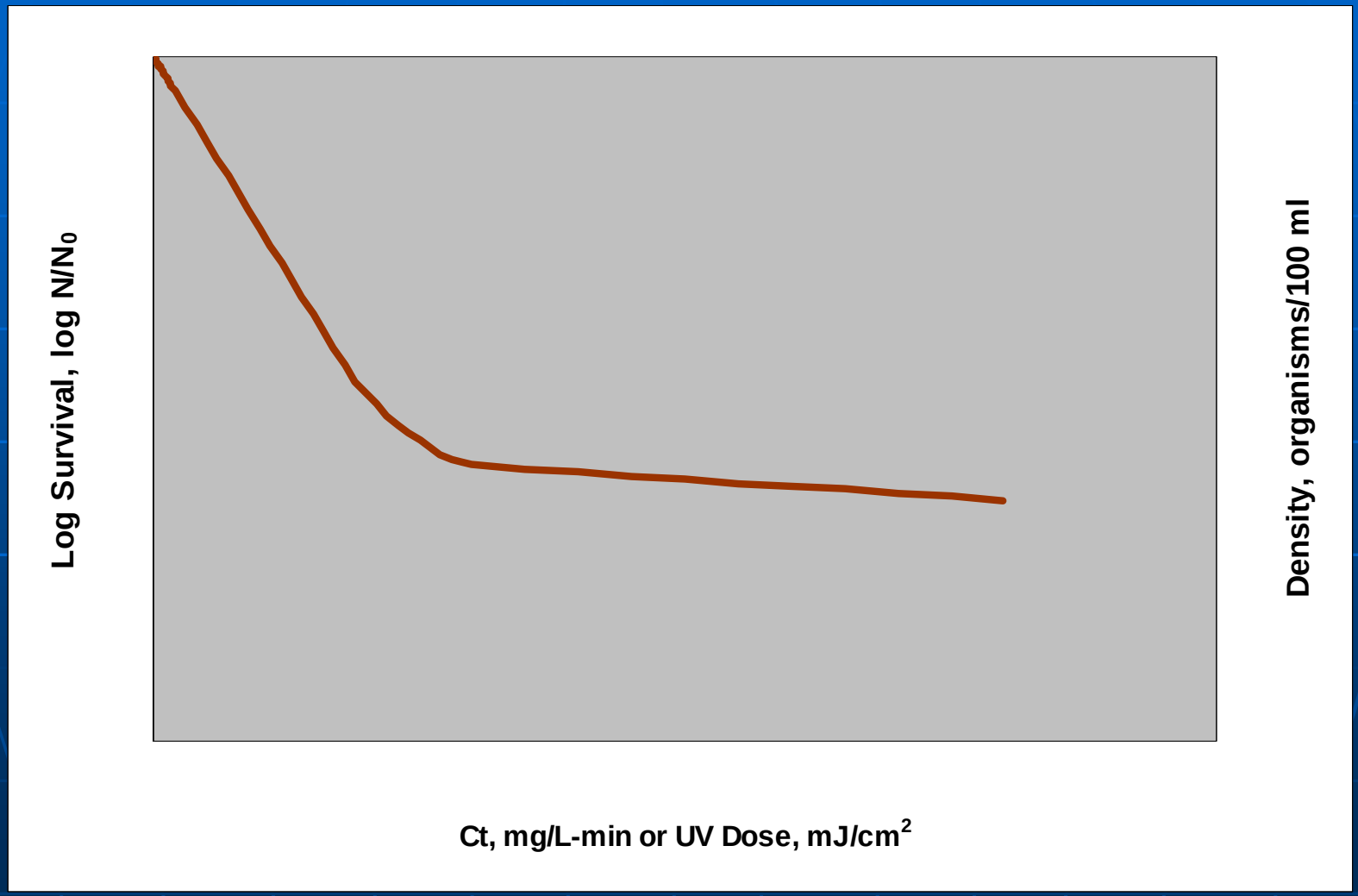
$$D = It$$

D = UV dose, mJ/sq cm
I = average UV intensity, mW/sq cm
t = exposure time, sec

Ideal Dose-Response Curve



Wastewater Dose-Response Curve



Dose-Response Curve Data Interpretation

$$\frac{N}{N_0} = e^{-kCt} \text{ or } e^{-kIt}$$

N = bacterial density after exposure, organisms/100 ml

N_0 = bacterial density before exposure, organisms/100 ml

k = inactivation rate, 1/mg/l-min or cm^2/mJ

C = chlorine residual, mg/l

I = average UV intensity, mW/cm^2

t = chlorine contact time, min or UV exposure time, sec

Dose-Response Curve Data Interpretation

First-order equation to determine k :

$$k = \frac{-\ln \frac{N}{N_0}}{Ct} \quad \text{or} \quad \frac{-\ln \frac{N}{N_0}}{It}$$

Dose-Response Curve Data Interpretation

First-order equation to determine D_{99} :

$$D_{99} = \frac{-\ln (0.01)}{k} \quad \text{or} \quad D_{99} = \frac{-\ln (0.01)}{k}$$

Relative Disinfection Effectiveness for Various Wastewater Microbes

Organism	Relative to TC Dose	
	Chlorine	UV Radiation
Bacteria		
fecal coliform	1.0	1.0
Salmonella typhi	1.0	0.9
Staphlylococcus aureus	2.5	1.0 - 1.5
total coliform	1.0	1.0
enterococci	NA	1.2
Clostridium perfringens	NA	5
Virus		
Coxsackie A-2	6 - 7	0.8 - 1.0
F specific bacteriophage (MS2)	5 - 6	1.8 - 2.0
Polio 1	6 - 7	2.0 - 3.0
FRNA phage	NA	0.9

NA = not available

Chlorine Compounds Effectiveness for 99 Percent *E. coli* Destruction

	Time equal[1], min		Dose equal[2], mg/L	
Compound	Dose, mg/L	RE	Time, min	RE
HOCl	0.1	1	2.1	1
OCl^-	11	110	125	60
NH_2Cl	55	550	500	240

1 - time = 2.1 min, 2 - dose = 0.10 mg/l, RE = relative effectiveness

Wastewater Disinfection Typical Doses

Effluent	Chlorine			UV radiation		
	Conc, mg/L	time, min	Ct, mg/L	Intensity, mW/cm^2	time, sec	Dose, mJ/cm^2
Trickling filter	5 - 20	60 - 90	300 - 1,800	2.2 - 9.3	7 - 14	15 - 130
Activated sludge	2 - 15	60 - 90	120 - 1,350	2.2 - 9.3	7 - 14	15 - 130
Filtered activated sludge	1 - 5	60 - 90	60 - 450	2.9 - 9.5	14 - 21	40 - 200
Primary effluent	25	30	65			25

USEPA Statement

- disinfection should not be required in those instances where significant benefits are not demonstrated,
- prospective disinfection benefits must be weighed against the environmental risks and costs,
- chlorine should be considered only when there are public health hazards to control, and
- alternative disinfection methods and/or dechlorination must be considered when and where public and aquatic health life impacts co- exist.

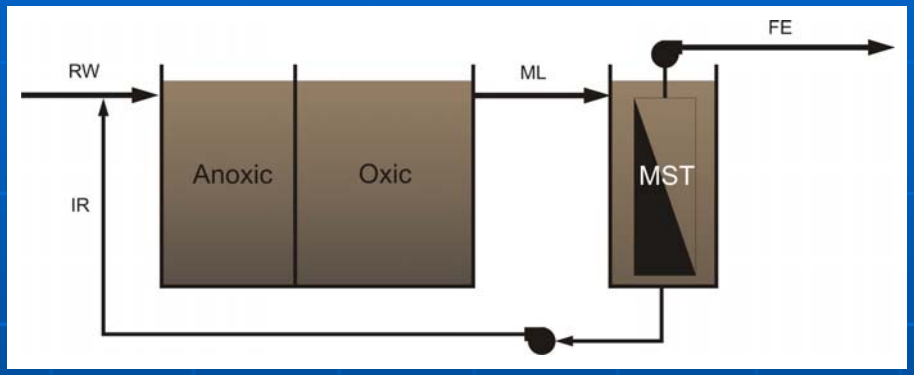
Treatment Process Impact

Wastewater Treatment Processes

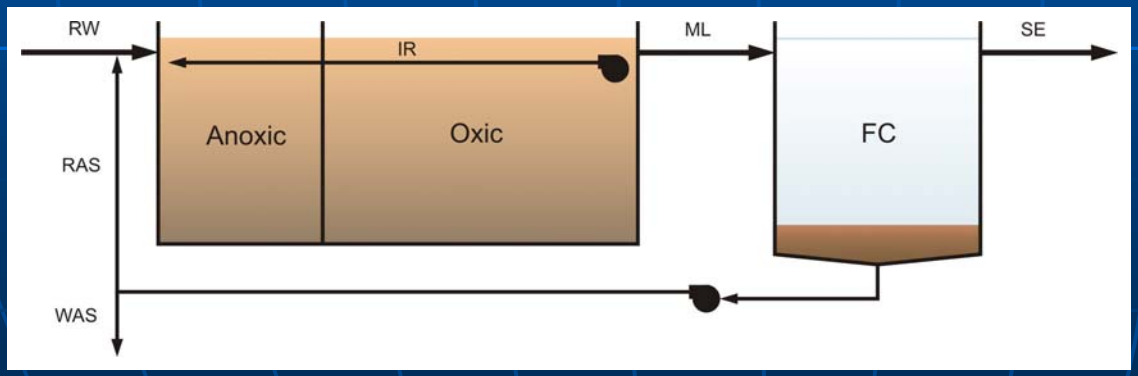
- Physical - screening, mixing, flocculation, sedimentation, flotation, filtration, adsorption, flow equalization, and disinfection
- Chemical - precipitation and disinfection
- Biological - aerobic suspended-growth, aerobic attached-growth, anoxic suspended-growth, anaerobic suspended-growth, anaerobic attached-growth, and various combinations

Treatment Processes

- MBR (membrane bioreactor)

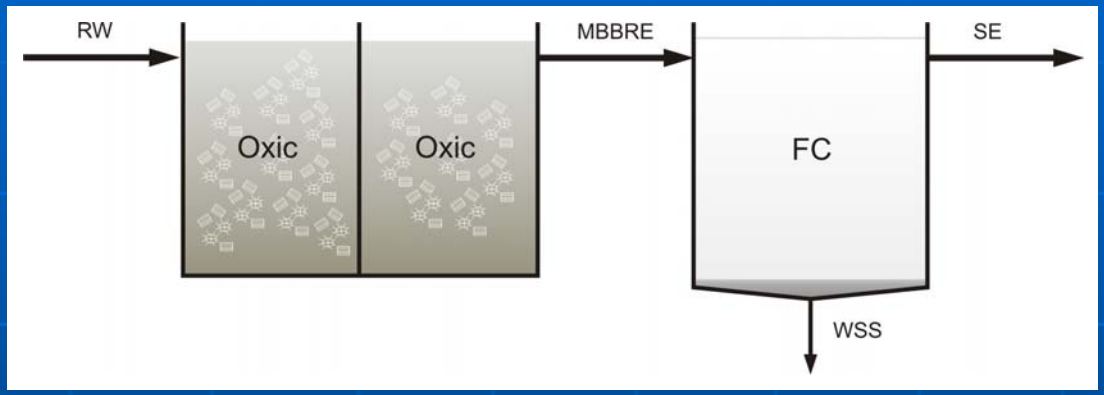


- CAS (conventional anoxic activated sludge)

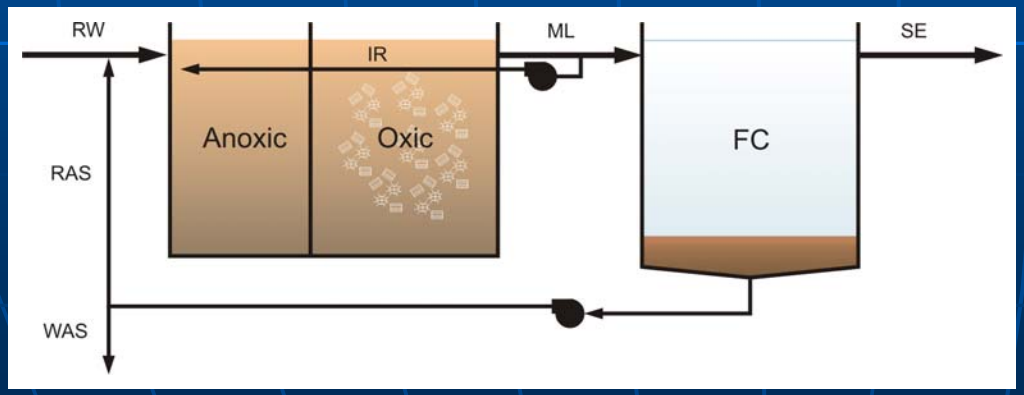


Treatment Processes

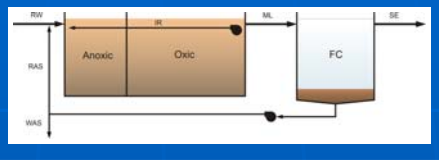
- MBBR (moving bed bioreactor)

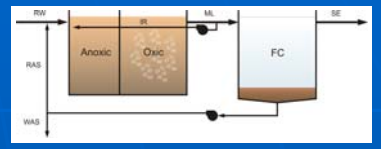


- IFAS (integrated fixed-film activated sludge)

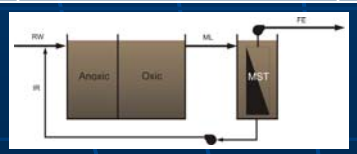


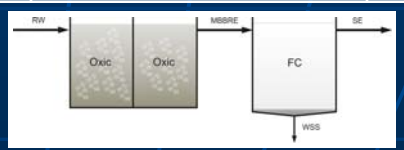
Effluent Quality



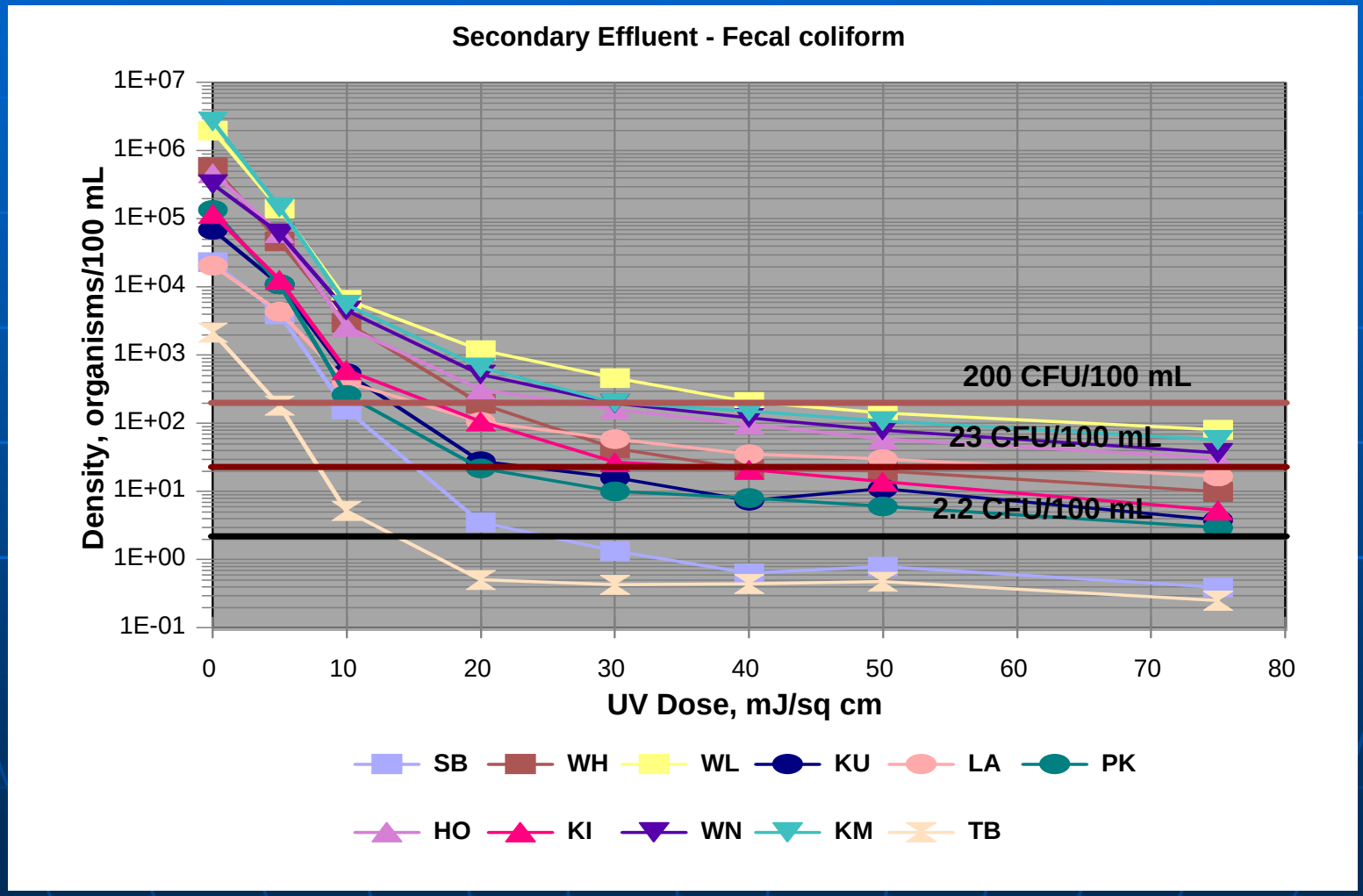


Description	MBR	CAS	MBBR	IFAS
TSS, mg/L	≤ 1	≤ 5 (≤ 2)	< 30 (≤ 5)	≤ 5 (≤ 2)
$TBOD_5$, mg/L	≤ 2	≤ 5 (≤ 2)	< 30 (≤ 10)	≤ 5 (≤ 2)
$SBOD_5$, mg/L	≤ 2	≤ 2	< 10	≤ 2
Turbidity, NTU	0.02	≤ 2 (≤ 1.5)	< 15 (< 2)	≤ 2 (≤ 1.5)
UVT, percent	85	83	< 65	75

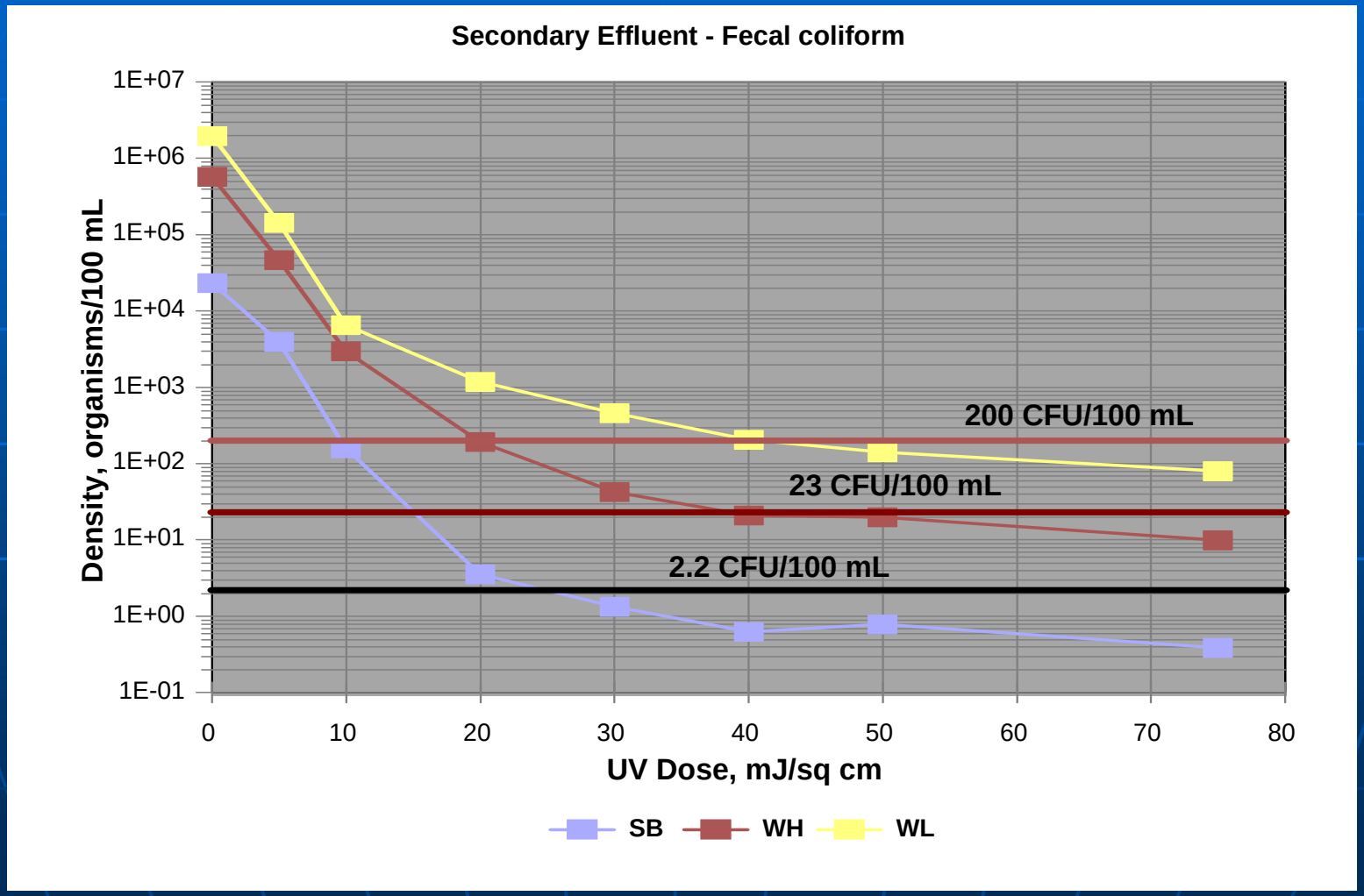




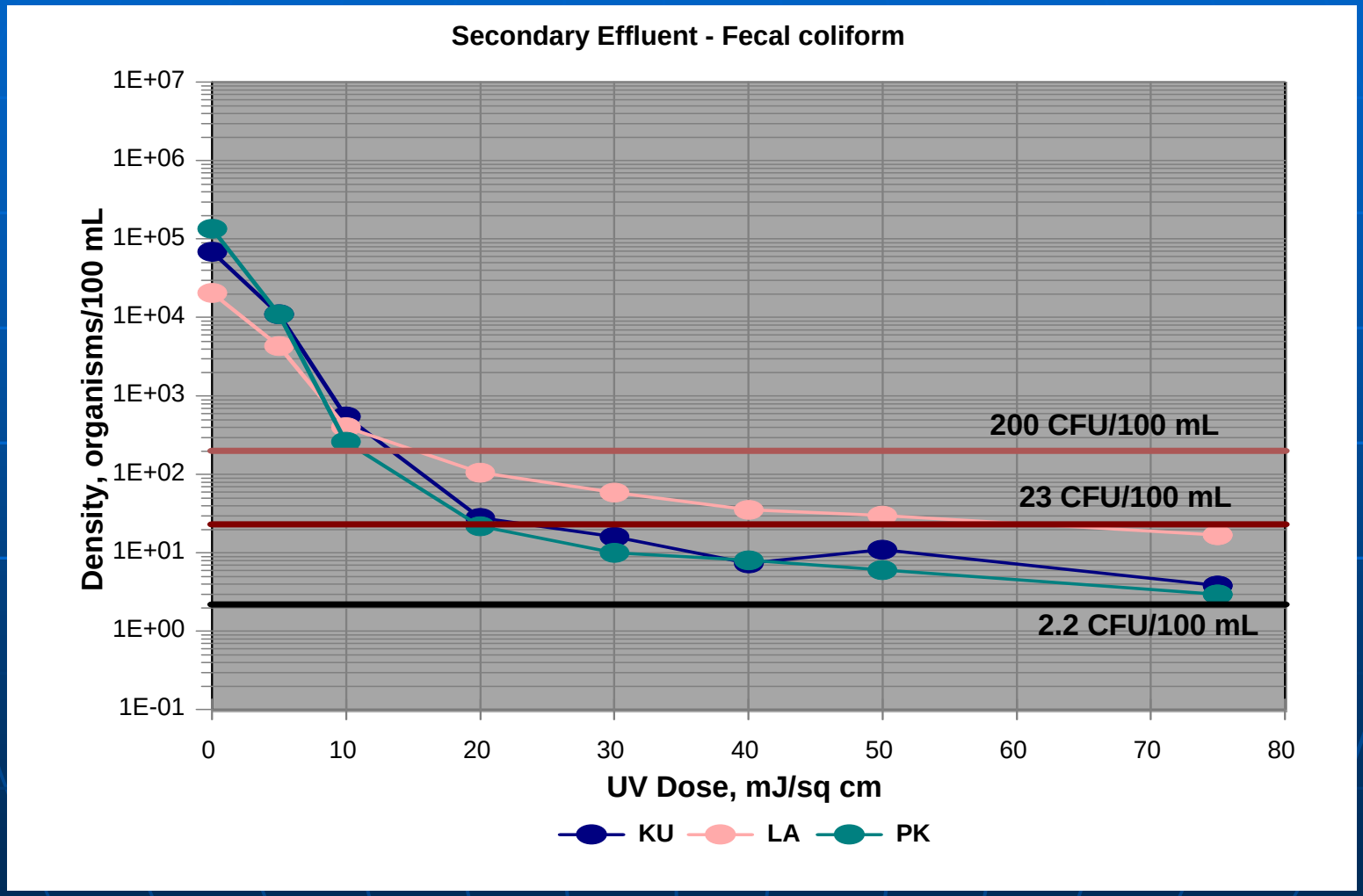
All Processes



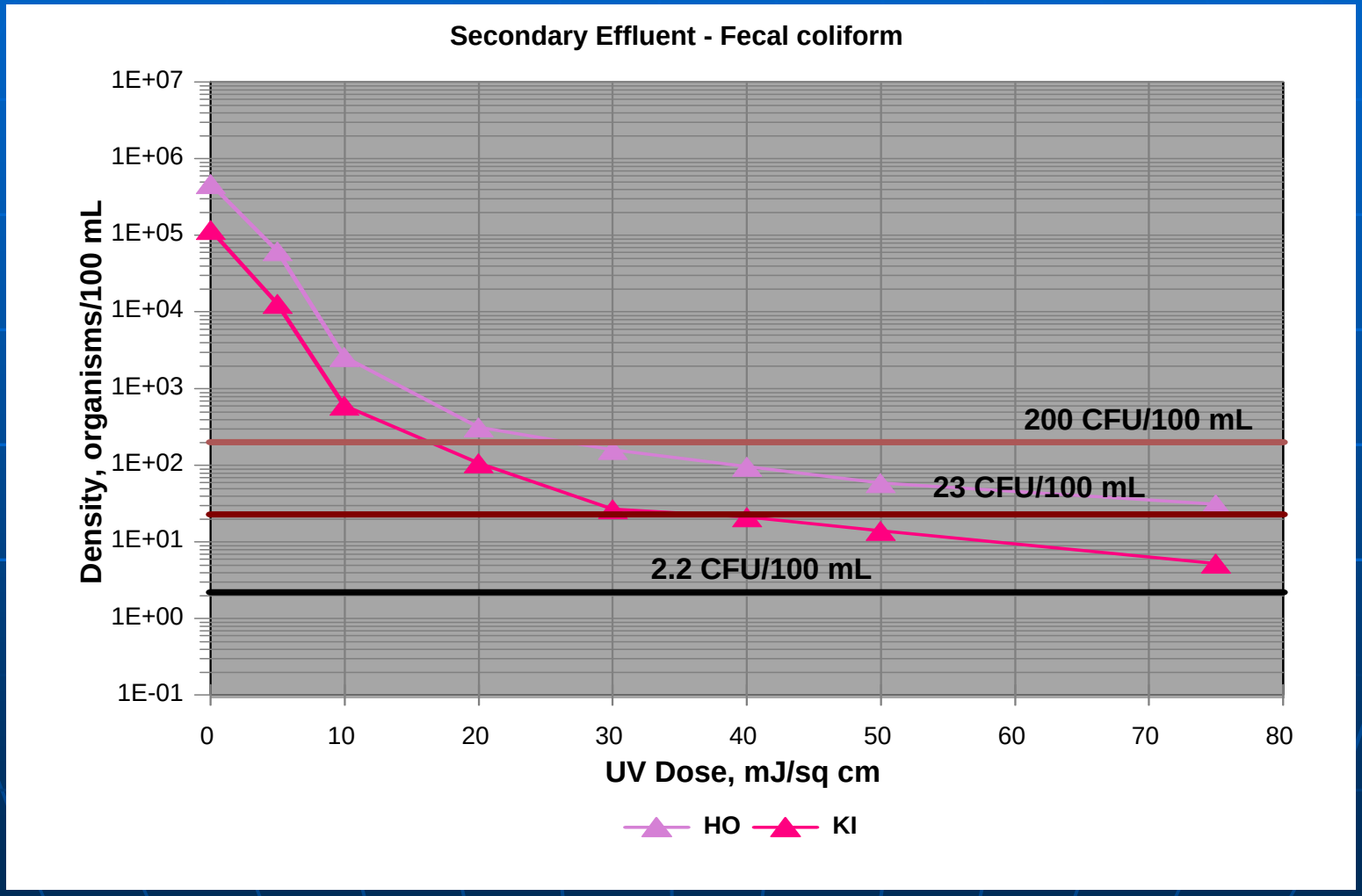
Conventional Activated Sludge



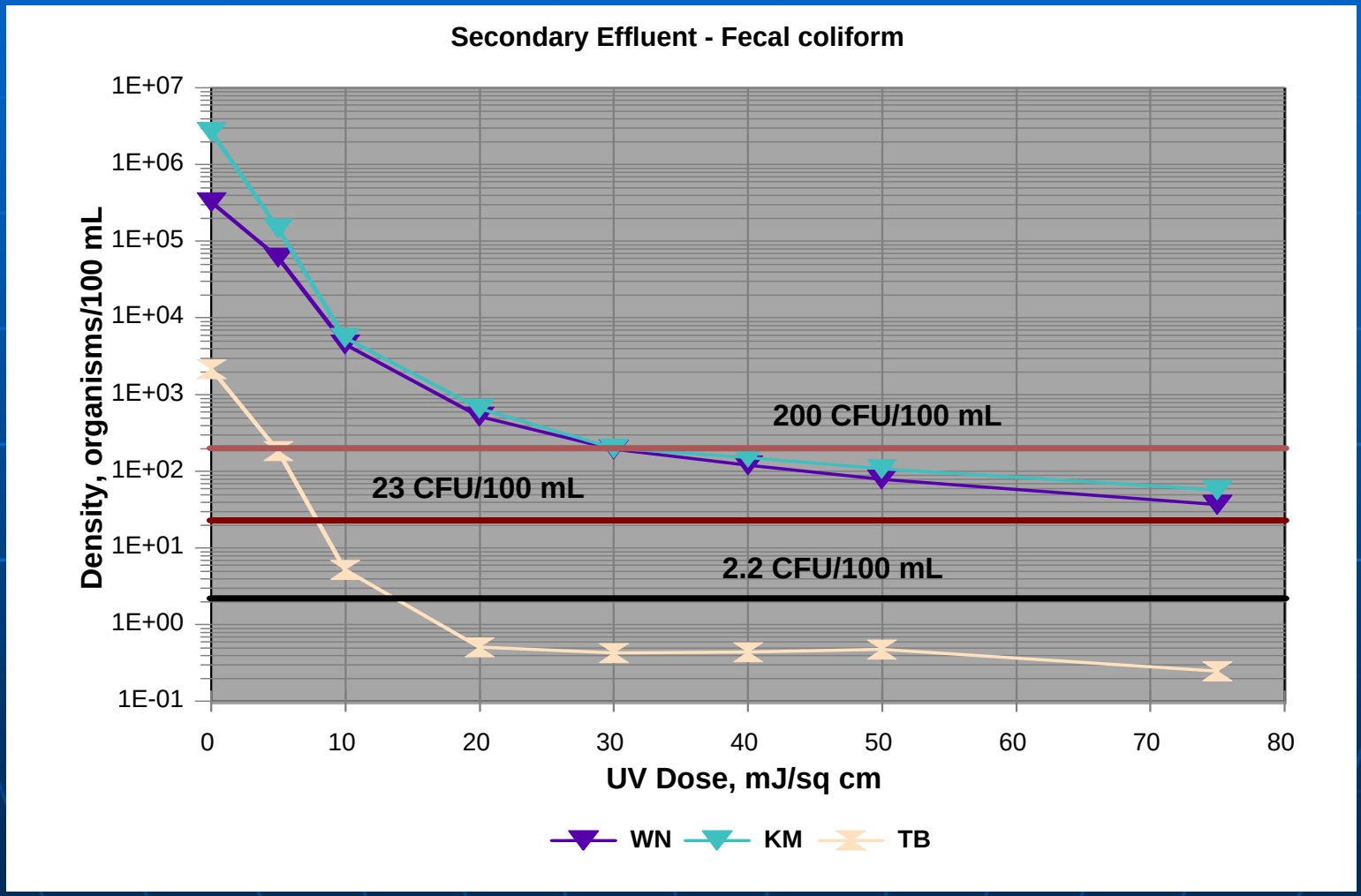
Extended Activated Sludge



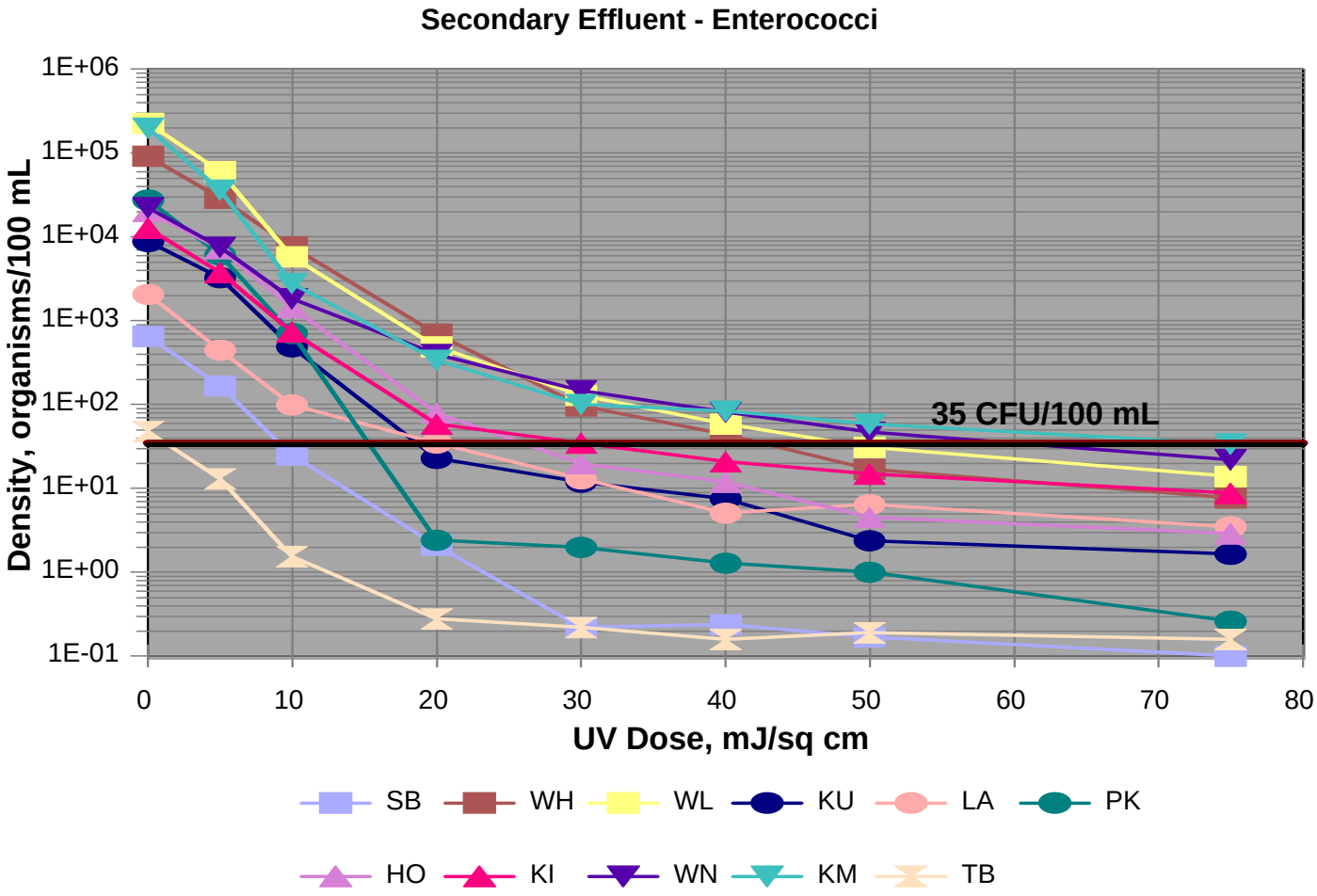
Trickling Filter/Solids Contact



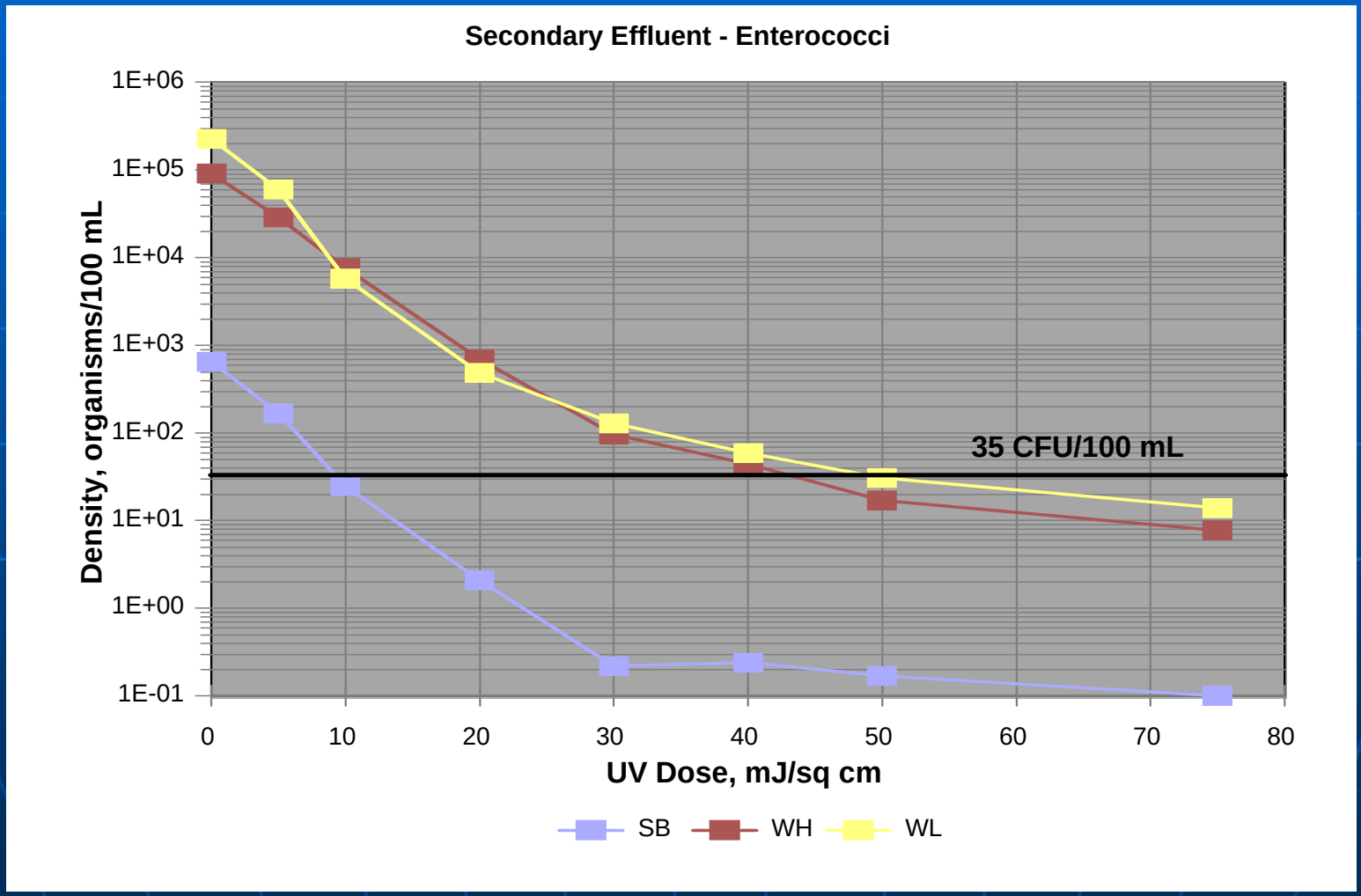
Other Processes



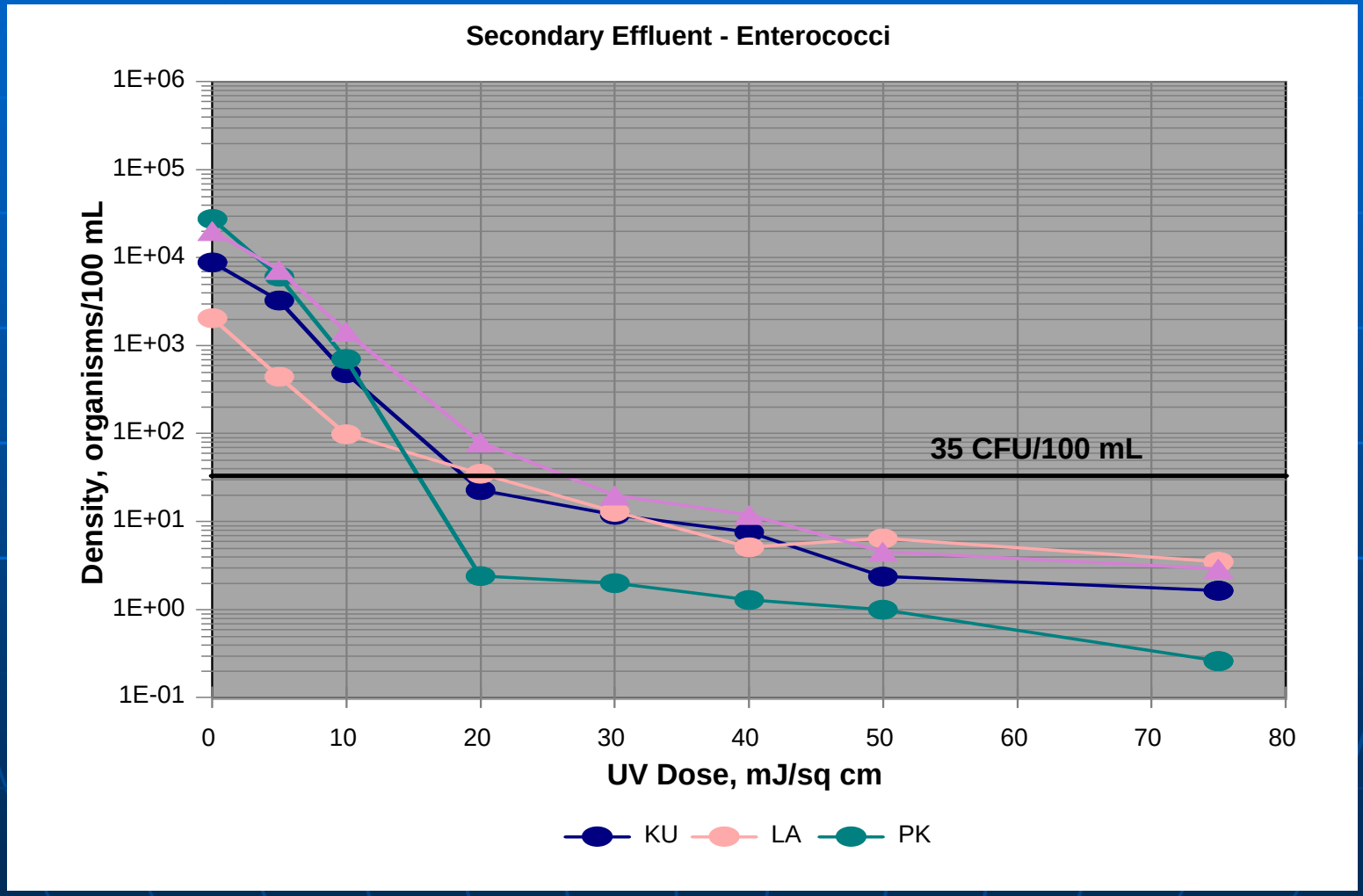
All Processes



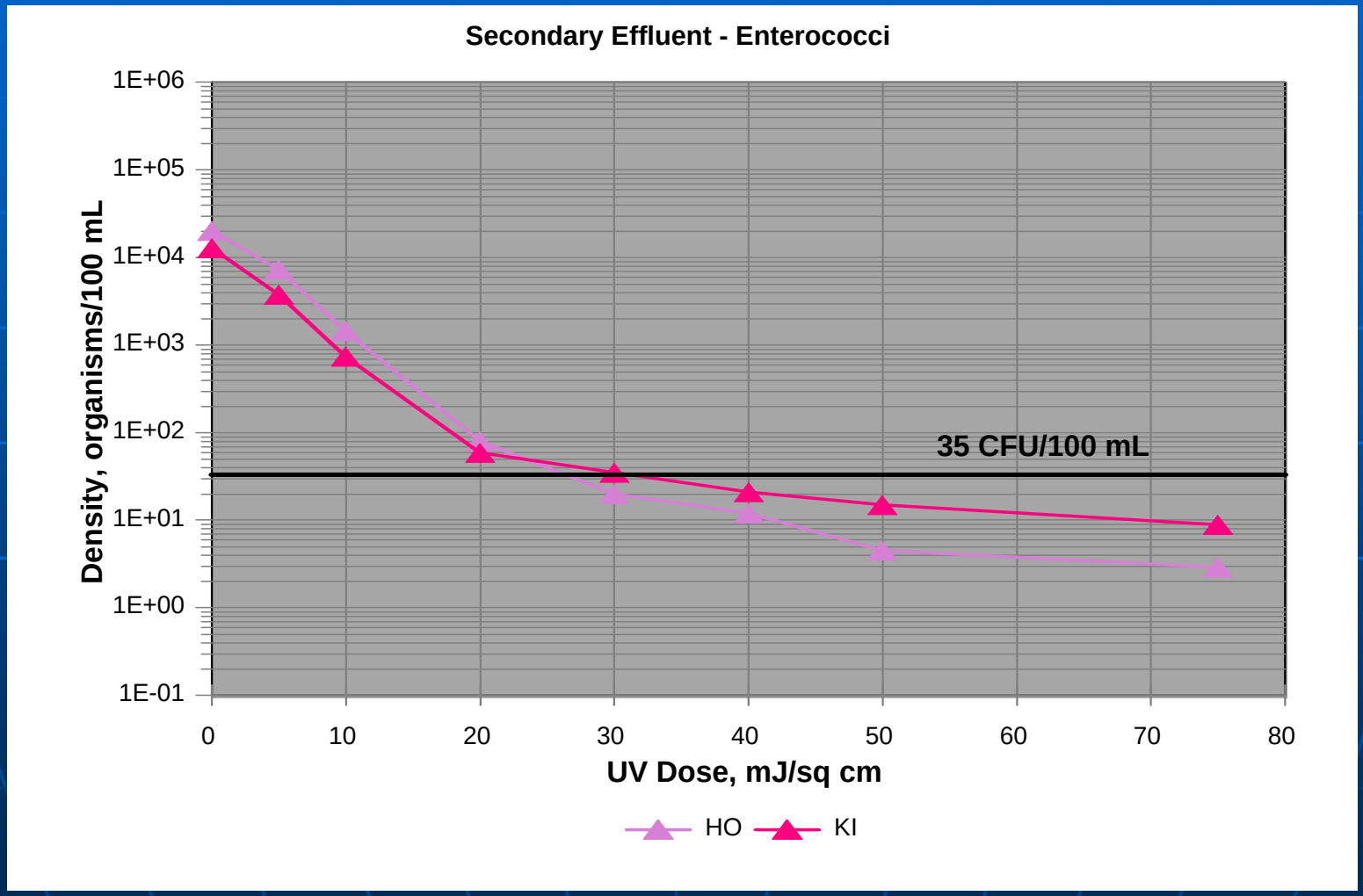
Conventional Activated Sludge



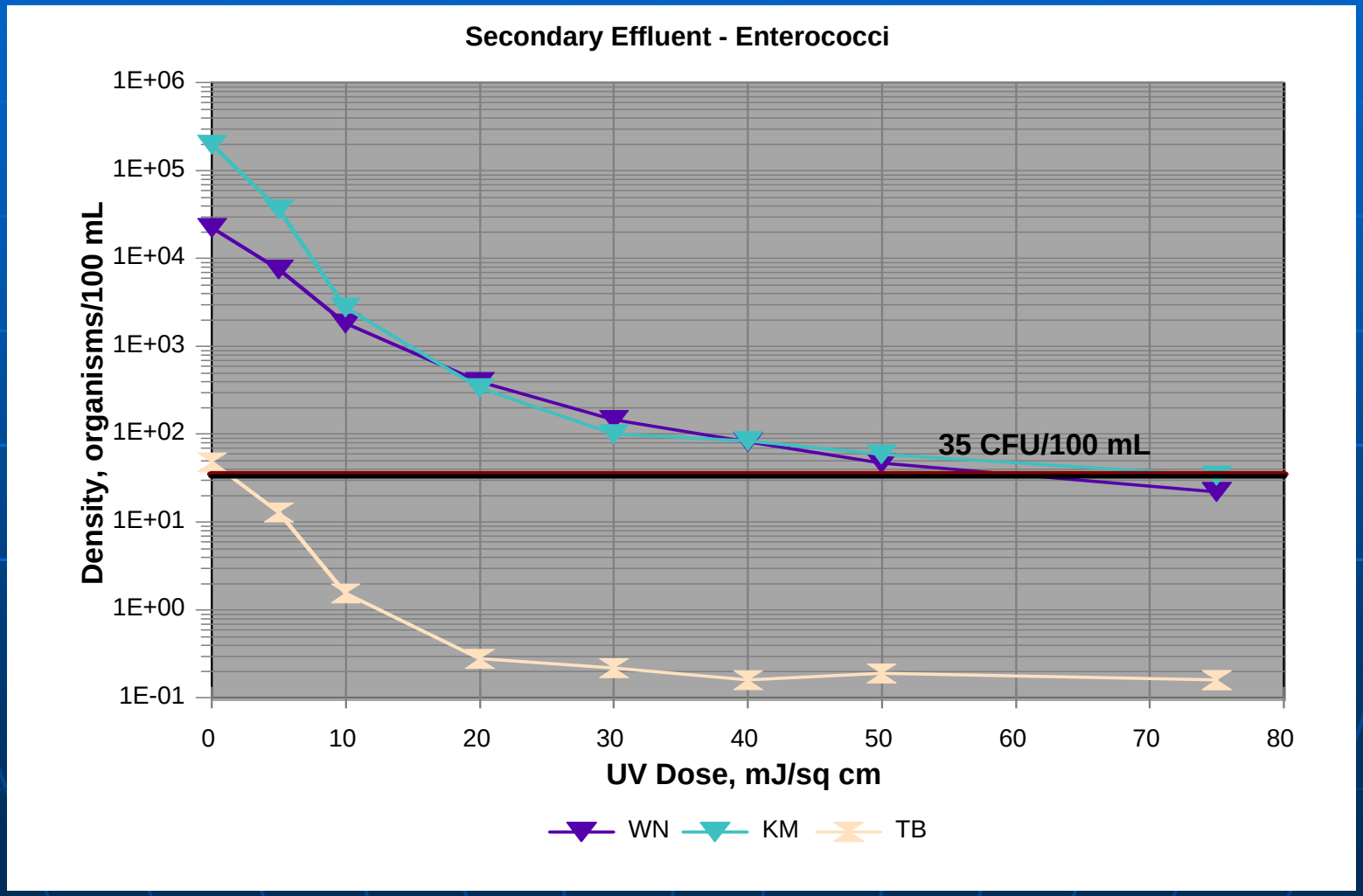
Extended Activated Sludge



Trickling Filter/Solids Contact



Other Processes




Questions


Thank you for not sleeping and making me feel
BAD!