ISPE® | Boston Area Chapter

Serving All of New England

Introduction to Water Purification

What's all the fuss about, anyway?

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Answer 4 Simple Questions

1. What is the incoming water quality?
2. What is the water quality that we need?
3. What treatment processes are available and what does each process do?
4. How do I get the water from the point where it is produced to the points where it is used (without picking up contamination along the way) ?

Question #1: What is our starting water quality?

What public information is available from the local municipality?

Contaminant Detected	Unit	MCL	MCLG	Level Detected	Range of Detection	Major Sources	Violation
Regulated Contaminants							
Nitrate	ppm	10	10	0.34	N/A	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion from natural deposits.	NO
Flouride *(see below)				1.17	0.88 to 1.17	Water additive that promotes strong teeth.	NO
* State (MCL)	ppm	2	none				
* EPA (MCL)	ppm	4	none				
Sodium	ppm	none	none	34.3	N/A	Erosion of natural deposits; road salt, and water treatment chemicals.	NO
Chlorite	ppm	1.0	0.8	0.50	0.21 to 0.50	By-product of drinking water disinfection.	NO
Turbity (see note)	NTU	1.0	TT=100%	0.17	0.06 to 0.17	Soil runoff.	NO
TT= Lowest percentage of monthly samples <0.3 NTU **Note:** Turbidity is a measure of the cloudiness of the water. We monitor it because it is a good indicator of the effectiveness of our filtration system.							
Disinfectant residual	ppm	(MRDL) 4	(MRDLG) 4	.97	0.42 to .97	By-product of drinking water disinfection.	NO
Perchlorate	ppb	2.0	none	0.33	N/A	Rocket propellants, fireworks, munitions, flares, blasting agents. Aged water treatment disinfection chemicals	NO

What public information is available from the local municipality?

Contaminant Detected	Unit	MCL	MCLG	Level Detected	Range of Detection	Major Sources	Violation
Volatile Organic Contaminants							
(TTHM)	ppb	80	0	(50)	0.5 to 50.0	By-product of drinking water chlorination.	NO
[Total Trihalomethanes]				(Highest Runing Annual Average)			
Disinfection By-Product Contaminants							
(HAA)	ppb	60	0	(20.7)	0 to 20.7	By-product of drinking water chlorination.	NO
[Halo-acetic Acids]				(Highest Runing Annual Average)			
Unregulated Contaminants							
MTBE	ppb	none	none	N/D	N/D<0.05	Gasoline Additive.	NO
Chloroform	ppb	none	none	15.1	3.9 to 15.1	By-product of drinking water chlorination.	NO
Bromodichloromethane	ppb	none	none	7.3	2.2 to 7.3	By-product of drinking water chlorination.	NO
Chlorodibromomethane	ppb	none	none	2.5	N/D<0.6 to 2.5	By-product of drinking water chlorination.	NO
Sulfate	ppm	none	none	5.0	5.0	Mineral and nutrient	NO
Unregulated contaminants are those for which EPA has not established drinking water standards. The purpose of un-regulated contaminant monitoring is to assist EPA in determining their occurrence in drinking water and whether future regulation is warranted.							

What public information is available from the local municipality?

Contaminant Detected	Unit	MCL	MCLG	Level Detected	Range of Detection	Major Sources	Violation
Radionuclides							
Gross Alpha	pCi/l	15	0	0.5 (+-1.1)	N/A	Erosion of natural deposits	NO
Radium 228	pCi/l	5	0	0.1 (+-0.6)	N/A	Erosion of natural deposits	NO
Contaminant	Unit	MCL	MCLG	Level Detected	Range of Detection	Major Sources	Violation
Lead	ppb	15	0	.001	0 of 50	Corrosion of household plumbing systems. Erosion of natural deposits.	NO
Copper	ppm	1.3	1.3	0.04	0 of 50	Corrosion of household plumbing systems. Erosion of natural deposits; Leaching from wood preservatives.	NO

Finished water pH ranged from 7.5 to 8.3

What we really need to know

Barium, MG/L

Boron, MG/L

Calcium, MG/L

Magnesium, MG/L

Potassium, MG/L

Silica as SiO2, MG/L

Sodium, MG/L

Strontium, MG/L

Ammonia, MG/L

Bicarbonate, MG/L

Carbonate, MG/L

Chloride, MG/L

Fluoride, MG/L

Nitrate as N, MG/L

Sulfate, MG/L

Silt Density Index

Organics Content (as TOC, MG/L)

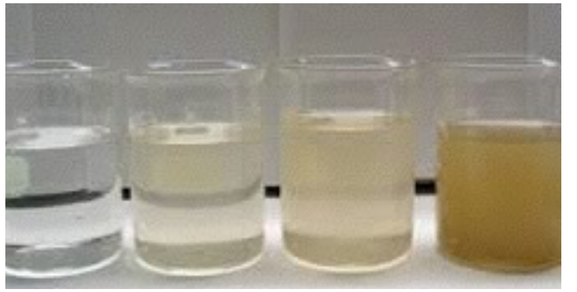
Let’s understand what’s in the water to start with

Classify the various contaminants

- Particles or Suspended Solids
- Dissolved Solids
  - Ionized
  - Non-ionized
- Colloidal Materials
- Dissolved Gases
- Bacteria and other living organisms

All Contaminants have the potential to introduce variability !!

Particles or Suspended Solids



- Materials that do not dissolve in water
- Can be any shape
- Mostly considered as hard, spherical particles
- Moving water holds more particles
- Larger and more dense particles will settle out by themselves
- Smaller particles may never settle

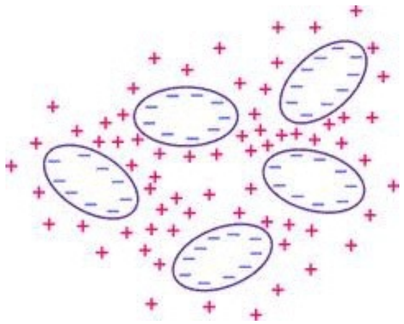
Dissolved solids, Ionized

- Materials that dissolve in water
- Form free floating ions in solution
  - Adds positive and negative charges to a solution
  - Solution remains electrically neutral
- The ionized solids content changes how much electricity the water can conduct
- Direct relationship between the abundance of ions and the conductivity of the water

Dissolved solids, Non-Ionized

- Materials that dissolve in water
- Do not form free floating ions in solution
  - No charge is added to the solution
- No change in the conductivity of the solution
- Cannot measure abundance by measuring conductivity
- Presence is more difficult to detect

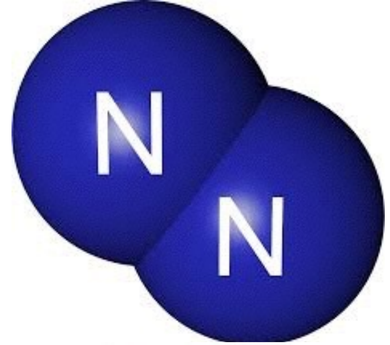
Colloidal Materials or Suspensions

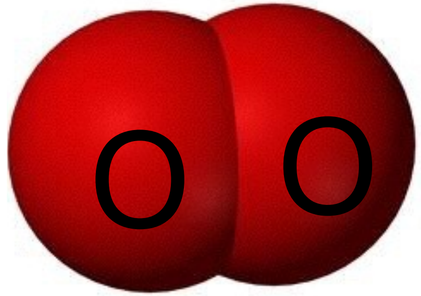


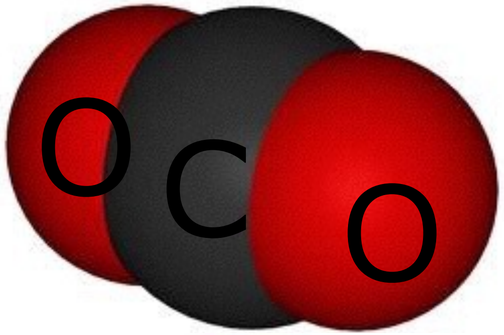
- Contain carbon
- Large in molecular size (10,000-5,000,000 MW)
- Slightly negative charge
- Somewhere between suspended and dissolved
  - Too small to settle by themselves
  - Held in solution by size and charge repulsion
- Undetectable change in the conductivity
- Measure abundance by silt density index
- Can quickly clog purification processes

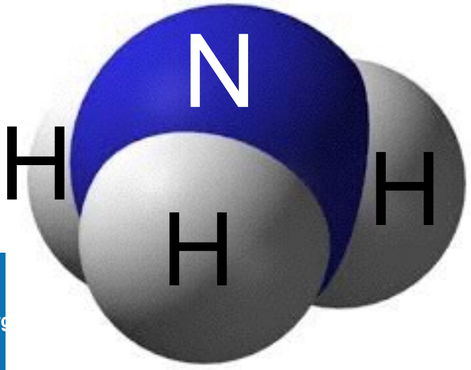
Dissolved Gases

- Nitrogen, oxygen, carbon dioxide, ammonia
  - Not removed by most purification processes
  - More dissolved gases in solution at lower temperatures (opposite of dissolved solids)
  - Least understood and least studied contaminant
  - Carbon dioxide is troublesome because it adds conductivity when it dissolves into solution
  - Ammonia can be troublesome to some purification processes in waters treated with chloramine
  - Measured in clean steam as non condensible gases

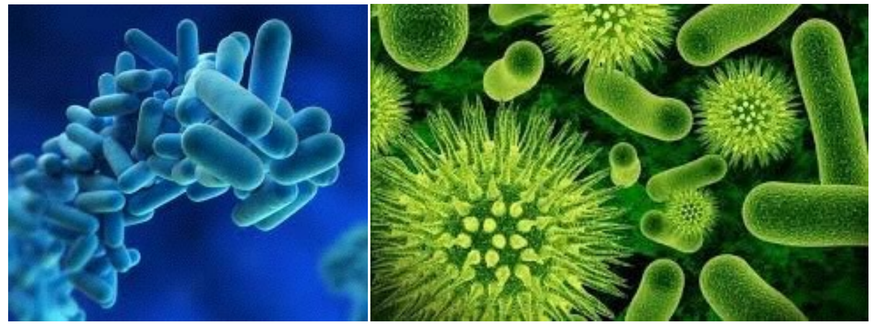








Bacteria and other living organisms

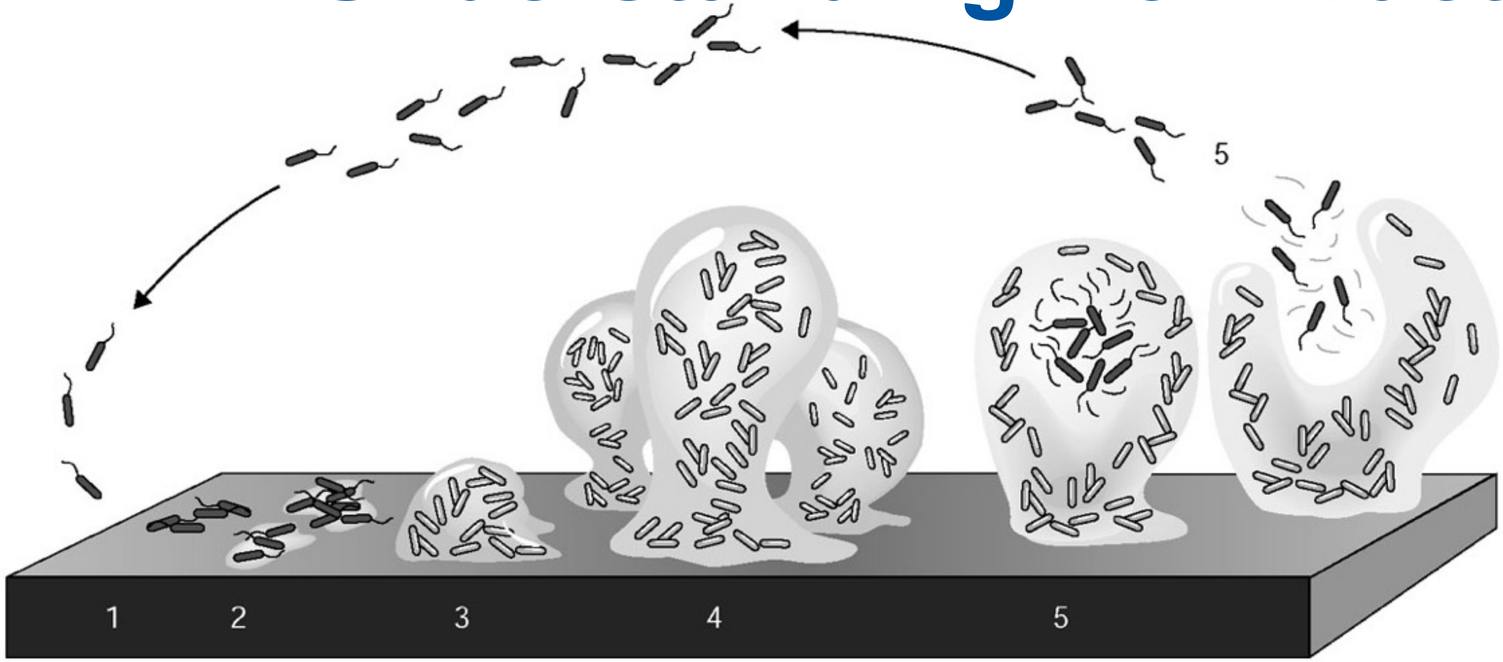


Not uniformly distributed in a water system

- Exist in equilibrium with their environment
- More food = more bacteria
- Less than 1% is free floating (detectable)
- Bacteria competes for nutrients with cells we're growing
- Bacteria can replicate every 30 minutes
  - Mammalian cells replicate every 24 hours
  - That's a ratio of 2800 trillion to 1

YIKES!!!!!!!!!!!!

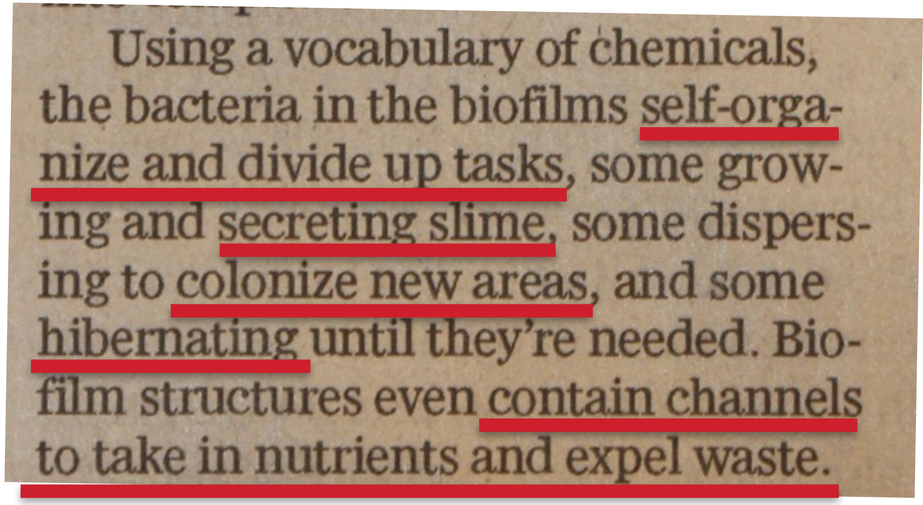
Understanding How Bacteria Work



Attach **Colonize** **Biofilm Development and Growth** **Send out scouts**

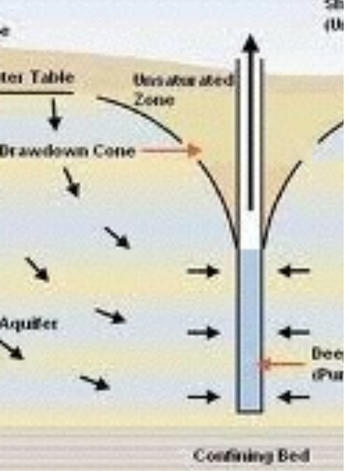
Not uniformly distributed like other contaminants

Regular sterilizations or nutrient deprivation for best control

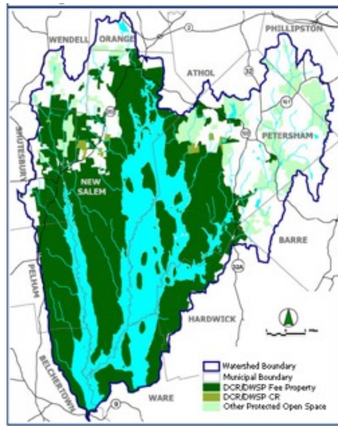


Using a vocabulary of chemicals, the bacteria in the biofilms self-organize and divide up tasks, some growing and secreting slime, some dispersing to colonize new areas, and some hibernating until they're needed. Biofilm structures even contain channels to take in nutrients and expel waste.

Boston Globe, June 29, 2016



Where does our water come from?
How do it properties vary?



Well Water

Low Suspended Solids

High Dissolved Salts

Low Colloidal Content

Some Dissolved Gases

Surface Water

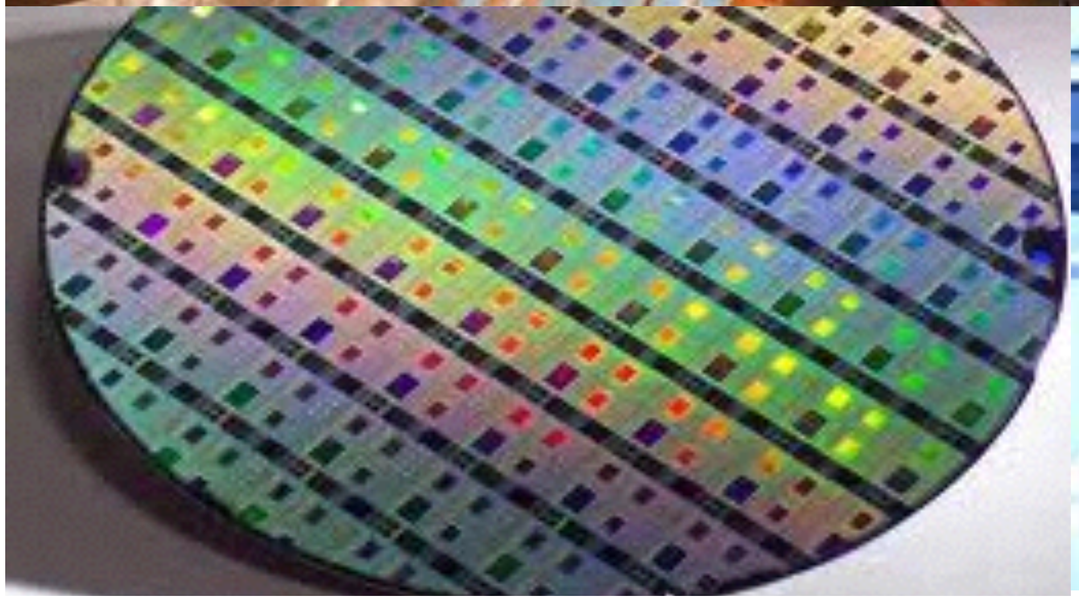
High Suspended Solids

Low Dissolved Salts

High Colloidal Content

High Dissolved Gases

Question #2 What is the end use of the water ??



What water quality do we really need ?

It depends !

Where are we in the product's life cycle ?

Research

Clinical Trials

Pilot Scale

Drug Discovery

Full Scale Manufacturing

Labs use CLSI/NCCLS or ASTM specifications for purity

PARAMETER	CLSI/NCCLS			ASTM			
	TYPE 1	TYPE 2	TYPE 3	TYPE 1	TYPE 2	TYPE 3	TYPE 4
Conductivity (max)	<0.1	<0.2	<0.5	0.056	1.0	0.25	5.0
Resistivity (min)	>10.0	>2.0	>1.0	18.0	1.0	4.0	0.2
pH	---	---	---	---	---	---	5.8-8.0
Silica (ppb)	<500	<100	<1000	3	3	500	----
Sodium (ppb)	---	---	---	1	5	10	50
Chlorides	---	---	---	1	5	10	50
Total Organic Carbon (ppb)	---	---	---	100	50	200	---
Bacteria (cfu/ml)	<10	10	---	Separate specification, only where bacteria control is required Type 1 : 10/1,000 ml Type 2 : 100/1,000 ml Type 3 : 10,000/1,000 ml			

Dialysis has their own requirements

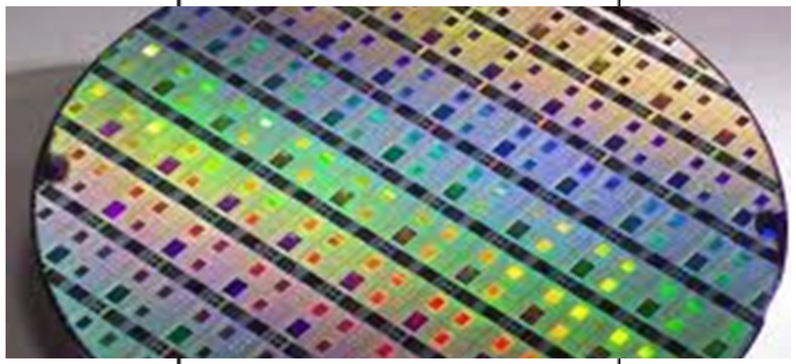
CHEMICAL CONTAMINANTS & MAXIMUM ALLOWED (MG/L

Aluminum	0.01	Lead	0.005
Antimony	0.006	Magnesium	4 (0.3mEQ/L)
Arsenic	0.005	Mercury	0.0002
Barium	0.10	Nitrate	2.0
Beryllium	0.0004	Potassium	8 (0.2 mEq/L)
Cadmium	0.001	Selenium	0.09
Calcium	2 (0.1mEQ/L)	Silver	0.005
Chloramines	0.10	Sodium	70 (3.0 mEq/L)
Chromium	0.014	Sulfate	100.0
Copper	0.10	Thallium	0.002
Fluoride	0.20	Zinc	0.10
Free Chlorine	0.50		

BACTERIA	MAXIMUM ALLOWED
Water used for dialysate → *(RD52,4.1.2)*	<200 CFU/ml Endotoxin level <2 EU/ml
Dialysate → → → *(RD52, 4.3.2.1)*	<200CFU/ml Endotoxin level <2 EU/ml

Microelectronics requirements are unbelievable !

PARAMETER	ATTAINABLE	ACCEPTABLE	ALERT	CRITICAL
Resistivity	18.2	18.2	17.9	17.5
TOC (online, ppb)	<1	<2	5	10
THM (ppb)	<2	<5	---	---
Particles by laser 0.05 to 0.1 micron 0.1 to 0.2 micron 0.2-0.3 micron 0.3-0.5 micron >0.5 micron	<100/1000 ml <50/1000 ml <20/1000 ml <10/1000 ml <1/1000 ml	<500/1000 ml <300/1000 ml <50/1000 ml <20/1000 ml <4/1000 ml		
Bacteria (cfu/1000 ml)	<1	<6	25	>25
Silica (total, ppb)	<0.5	<3	>5	>10



PARAMETER	ATTAINABLE	ACCEPTABLE	ALERT	CRITICAL
Phosphate (ppb)	<0.02	<0.1	>0.01	>0.5
Silicate (ppb)	<0.05	0.1	<0.02	>0.5
Sodium (ppb)	<0.01	0.05	>0.02	>0.5
Potassium (ppb)	<0.02	<0.1	>0.02	>0.5
Ammonium (ppb)	<0.06	0.1	<0.02	>0.5
Calcium (ppb)	<0.02	<0.1	>0.01	>0.2
Magnesium (ppb)	<0.02	<0.1	<0.01	>0.2
Fluoride (ppb)	<0.1	<0.1	>0.02	>0.5
Chloride (ppb)	<0.02	0.1	<0.02	>0.5
Bromide (ppb)	<0.02	<0.1	>0.01	>0.5
Nitrate (ppb)	<0.02	<0.1	<0.01	>0.5

METAL ION CONTAMINANTS, ALL ARE MEASURED IN PARTS PER TRILLION				
Aluminum (ppt)*	7	50	>0.0	200
Barium (ppt)*	2	10	>50	100
Boron (ppt)*	300	<2000		
Chromium (ppt)*	8	30	>30	50
Copper (ppt)*	5	50	>50	>200
Iron (ppt)*	10	100	200	>200
Lithium (ppt)*	4	30	100	>100
Magnesium (ppt)*	2	20	100	>200
Manganese (ppt)*	4	30	>30	100
Nickel (ppt)*	5	50	>50	100
Sodium (ppt)*	10	60	>200	>500
Strontium (ppt)*	2	10	>10	>10
Zinc (ppt)*	8	60	>50	>100

Pharmaceutical Water Quality

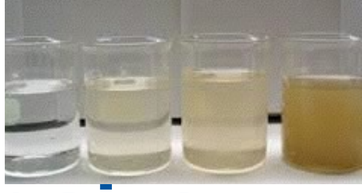
PARAMETER	USP PURIFIED	USP WFI
Total Organic Carbon (ppb)	500	500
Conductivity	<1.3 @ 25°C	<1.3@25°C
Bacteria	None given, but recommended to be 100/ml	None given, but recommended to be 10/100 ml
Endotoxins	----	<0.25 EU/ml

Hey, Why Is Injectable Grade Water Allowed To Have Bacteria ??

Question #3
What water purification processes are available?

What does each one actually DO?

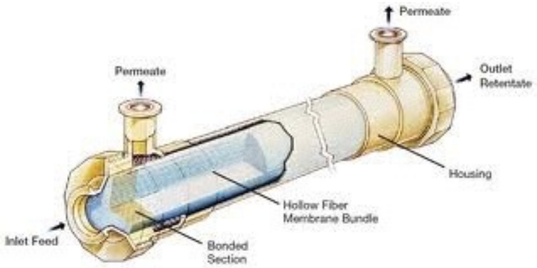
Suspended Solids Removal



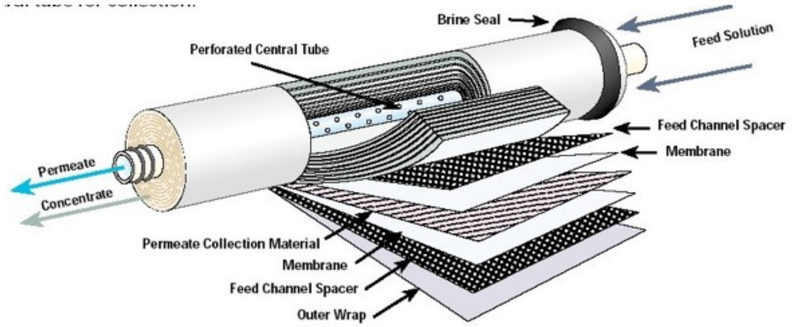
Particle filters remove contaminants based on their size

Nominally rated filters
80-95% removal efficiency
Sizes down to ~ 1 micron

Most are absolute rated filters
95-99.9999% removal efficiency
Sterile filtration
0.1 to 0.8 micron size

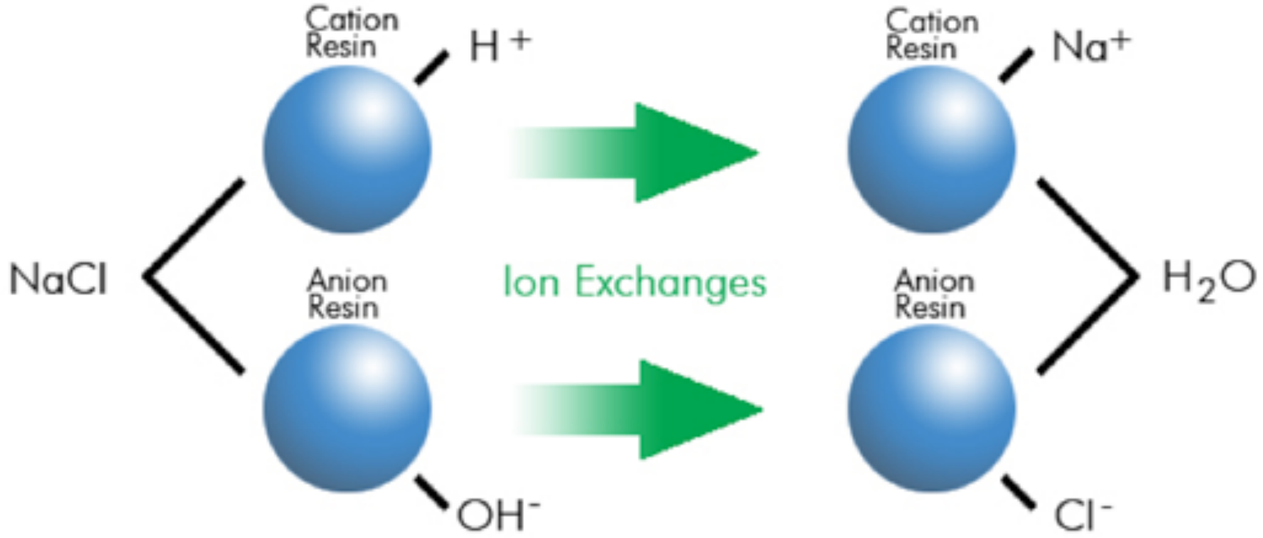


Ultrafiltration
~99% removal efficiency
5,000-500,000 MWCO



Reverse Osmosis
90-99%% removal efficiency
200-500 MWCO

Ion exchange removes contaminants based on their electric charge in solution

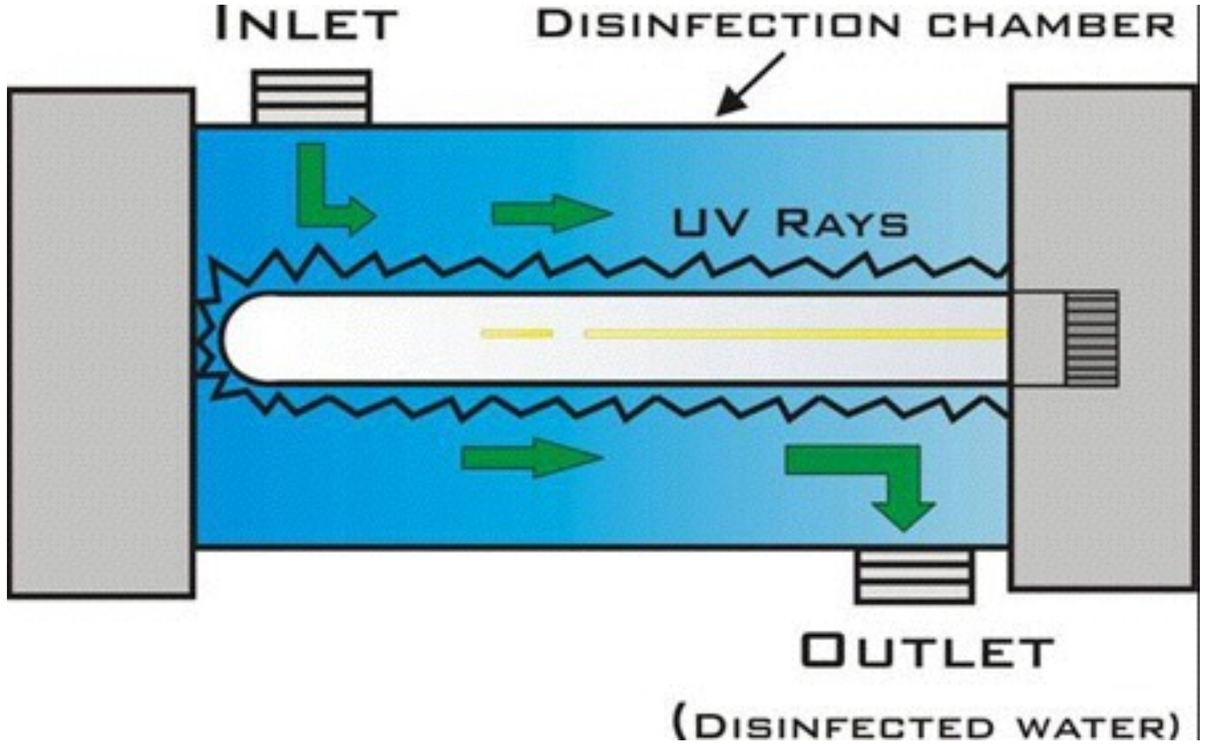


Carbon filters remove small (below 1,000 MW) non polar molecules

Remove disinfectants from drinking water

Protects chlorine sensitive reverse osmosis membranes

Ultraviolet units come in two basic flavors

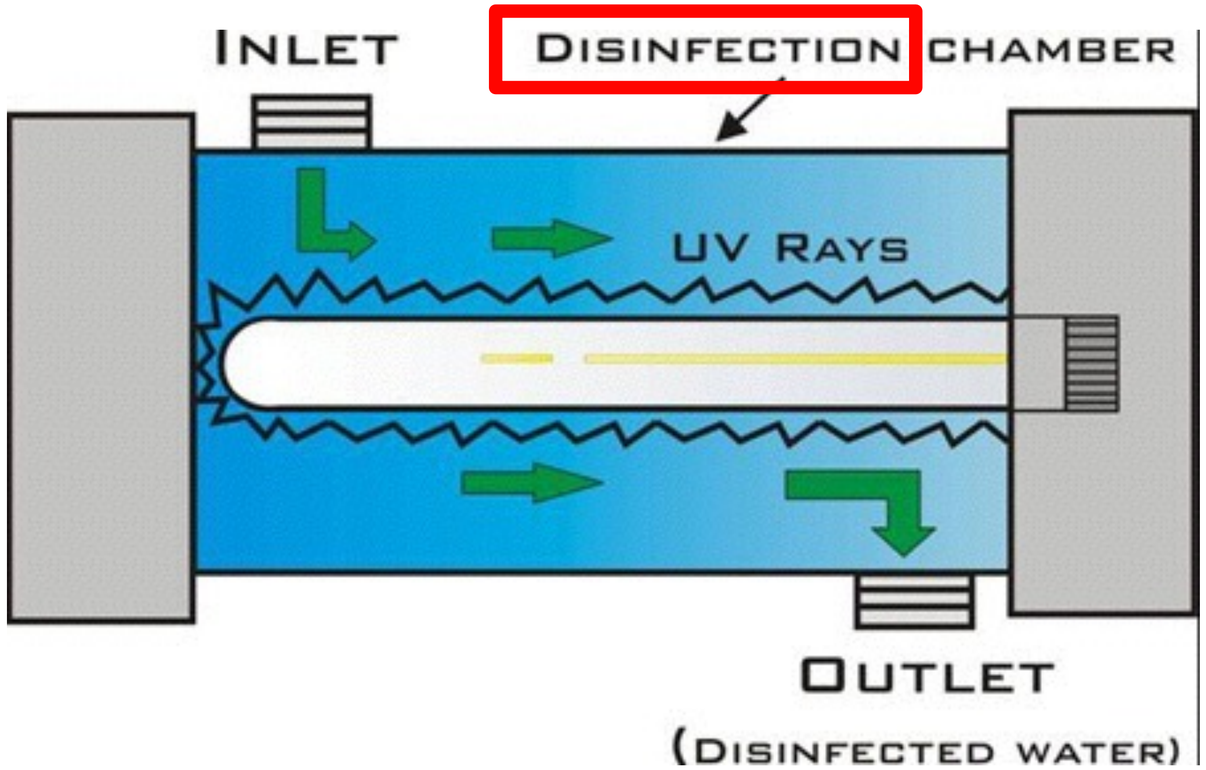


Single wavelength units (254 nm) for bacterial control

Dual wavelength units (185 & 254 nm) for organics (TOC) and bacteria control

Dual wavelength units (185 & 254 nm) increase the conductivity of the water, so location is extremely important

Commonly Misused Words



Sanitize
10^3 reduction

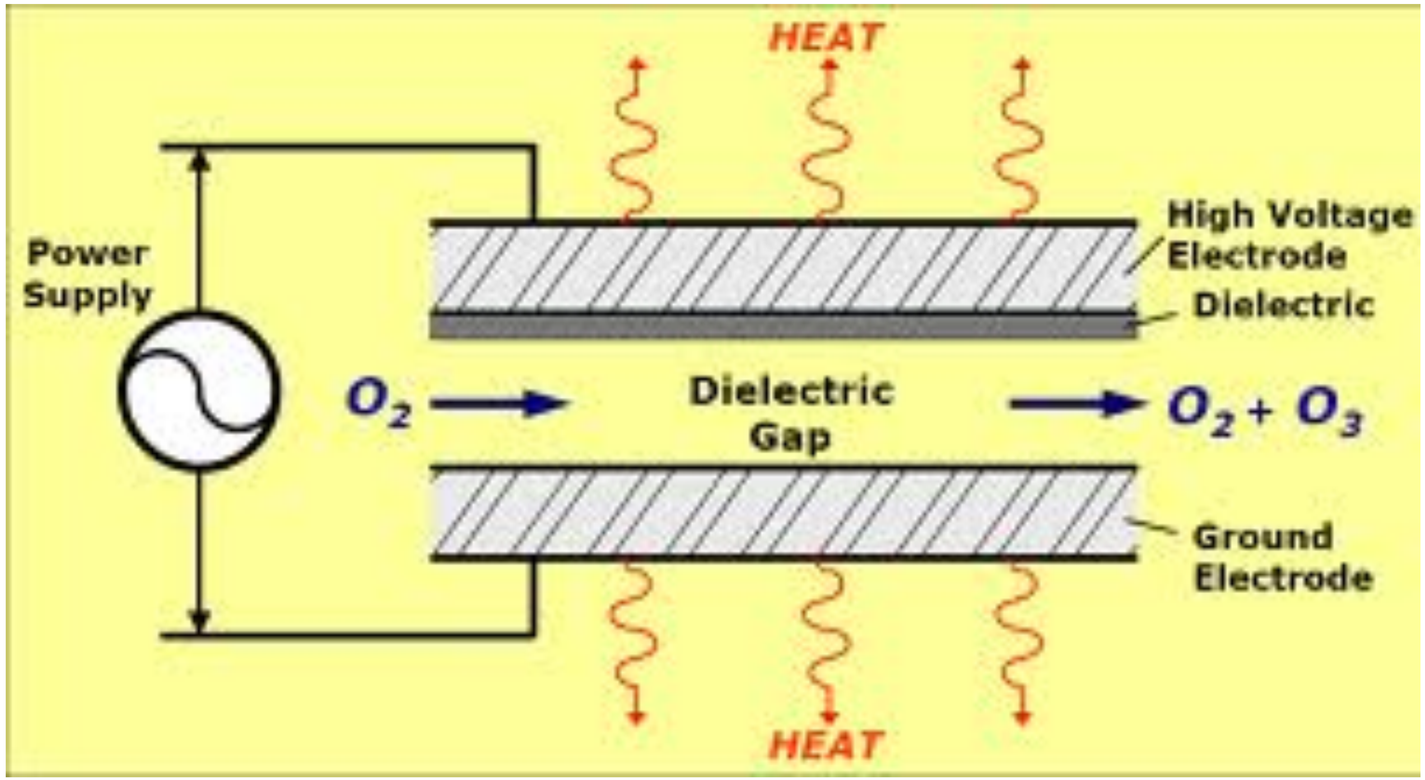
Disinfect
10^5 reduction

Sterilize
10^6 reduction

These words are used almost interchangeably by equipment manufacturers

But these words mean very different things

Ozone Generators are becoming more popular



Oxidizes organics

Kills bacteria

Consumes biofilm

Ozone is NOT considered an added substance

Mis-application and misuse of ozone technology has led to compatibility and other under and over dosing problems, making many users reluctant

Distillation is the only water treatment process that removes the water from the contaminants

Considered the gold standard for producing Water-For-Injection (WFI) grade water

Dissolved gases and some chemicals can carry over into distillate (product water)

Summary of Unit Operations

Table 1 - Removal Capabilities of Various Water Purification Processes

	Coarse Particle Filters	Absolute Membrane Filters	Ultrafilters	Reverse Osmosis	Carbon Filtration	Ultraviolet Disinfection	Deionization
Particles	F	G-E	E	E	N	N	N
Dissolved Ions	N	N	N	G-E	N	N	E
Small Organics	N	N	N	F-G	G-E	N	P
Colloids	N	F-P	G-E	E	P-F	N	P
Bacteria	P	E	E	E	A	G	A-P

N = None P = Poor F = Fair G = Good E = Excellent A = Adds contaminants to systems

THANK YOU

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