

Aeration, Iron Removal and Basic Stabilization

Purpose of Aeration

- Aeration removes dissolved gases and oxidizes dissolved metals by introducing air into water.
- Aeration works in two different ways to remove the undesirable compounds from the water, oxidation and volatilization (degasification.)
- Aeration also facilitates the oxidation reaction by removing CO_2 which raises pH.

Reductions Achieved by Aeration

- Taste and odors caused by H_2S , Iron, Manganese, and any volatile compounds
- Reductions in corrosive constituents, i.e. CO_2 (to 5 ppm) and H_2S
- Supersaturated water is corrosive and stability must be adjusted

Aeration Processes

- Removing undesirable gases such as Hydrogen Sulfide or Carbon Dioxide is accomplished by forcing them to escape into the air.
- Removal of iron and manganese is accomplished by chemical oxidation. Once oxidized, these new compounds can be removed by sedimentation or filtration.

Types of Aeration Systems

- Water into Air. This method produces small drops of water that fall through the air.
- Air into Water This method creates small bubbles of air that rise through the water being aerated. (less common in small systems).

Methods Used to Aerate

Aerators mix air and water using one, or a combination of both of the following methods.

Producing small water drops that fall through the air. (water into air)

Creating small air bubbles that rise through the water. (air into water)

Forcing air up through the water as it falls.
(forced draft)

The most commonly used types of aerators for small systems are the cascade and spray.

Cascade Tray Aerator



- Even distribution of water over top tray
- Loading Rates of 1 to 5 GPM for each sqft. of Tray area.
- Trays 1/2" openings perforated bottoms
- Protection from insects with 24 mesh screen

Forced Draft Aeration System



Blower

- Includes weatherproof blower in housing
- Counter air through aerator column
- Includes 24 mesh screened downturned inlet/outlet
- Discharges over 5 or more trays

Packed Tower Odor Removal System



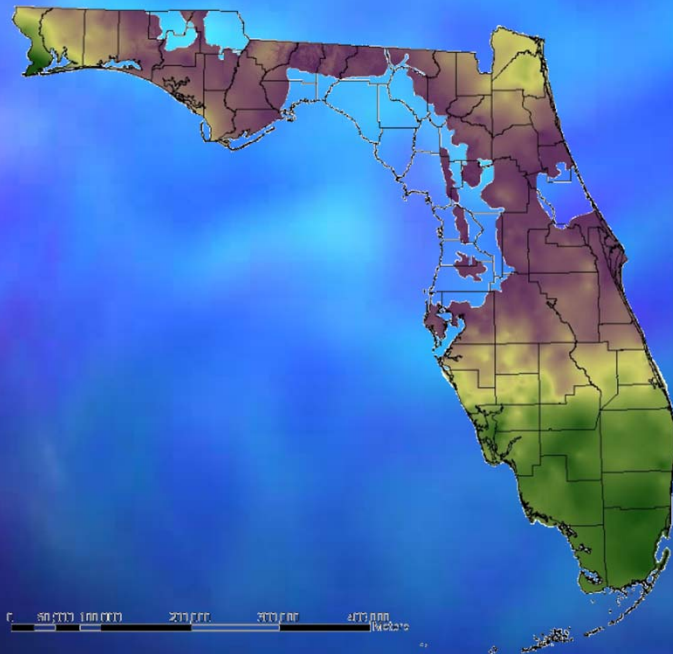
- Uses Henry's Law constants for mass transfer
- Usually requires pilot testing
- Used to Remove VOCs below MCL
- Col to Packing $>7:1$ ratio
- Air to water at pk $>25:1$ with max $80:1$
- Susceptible to Fouling from $\text{CaCO}_3 > 40 \text{ PPM}$

Protection of Aerations Systems from Insect, Vermin and Slime

- Growth of Insects
- Contamination from Bird Droppings
- Contamination from Animals
- Growth of Slime

Iron and Manganese Problems

Iron Problems - Most Prevalent in Unconfined, Surficial, and Biscayne Aquifers



- Iron dissolved by reaction with CO_2
- Iron from well sources will be in a dissolved state
- When exposed to O_2 precipitants form
- Visible as red and brown color
- Will stain fixtures and clothes
- Imparts taste and odor

Iron Concentrations in Florida Aquifer Systems

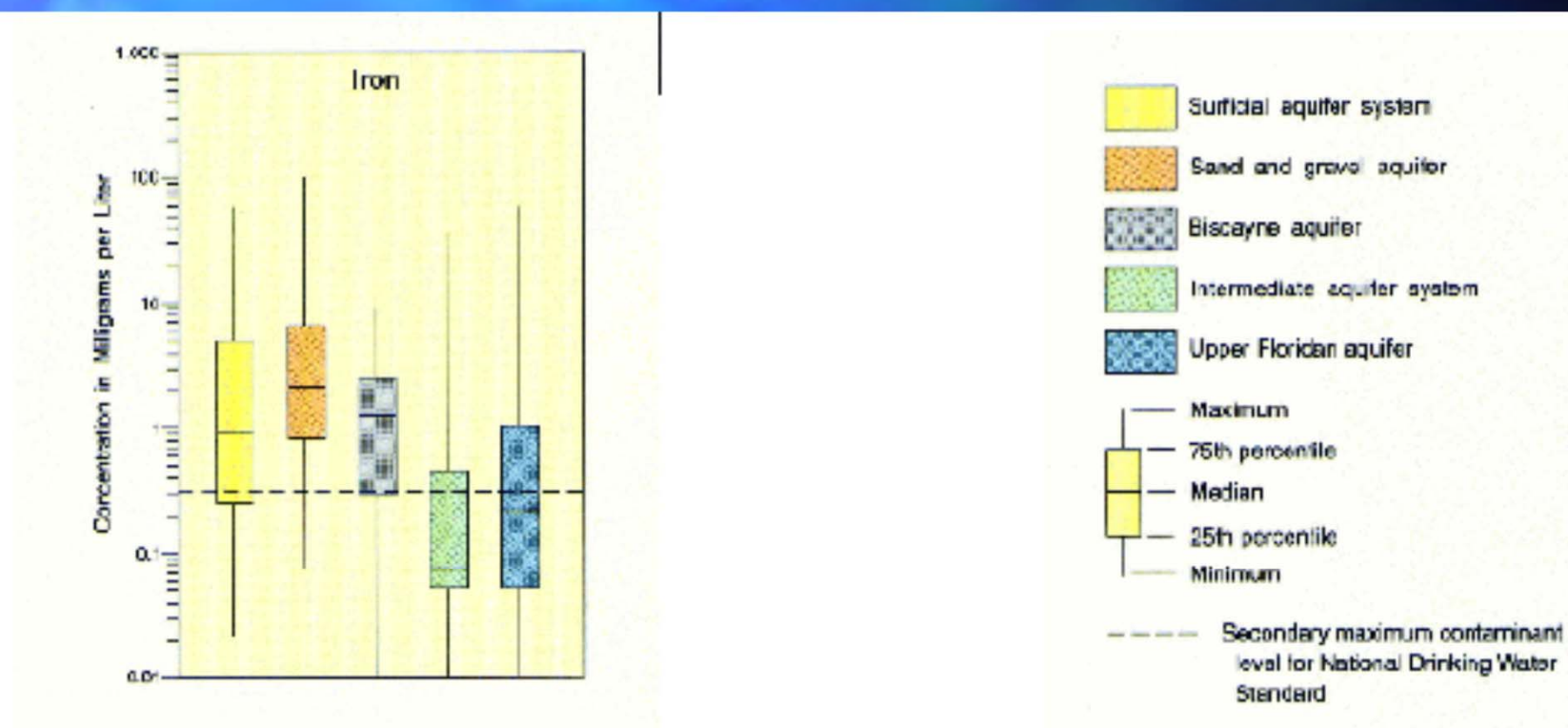


Figure 3. Iron in Florida aquifer systems (from Fernald and Purdum, 1998, page 54).

Iron and Manganese Facts

Regulated SMCL

- Iron < 0.30 mg/l
- Manganese < 0.05 mg/l

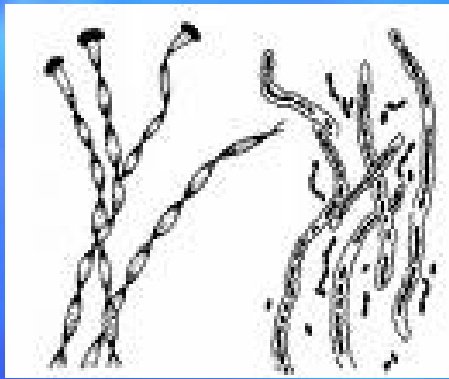
Problem Types

Red Water

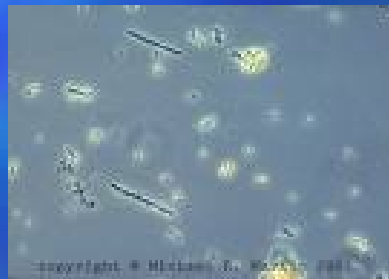
Black Particles

- Ground waters that contain Iron and Manganese are devoid of Oxygen.
- Presence of Carbon Dioxide reduces insoluble Fe^{+++} & Mn^{+++} to soluble Fe^{++} & Mn^{++} only under anaerobic conditions

Iron Bacteria in Water Supply System



Bacterial
Growth



Iron
Bacteria
Cells



Iron
Problem ¹⁵

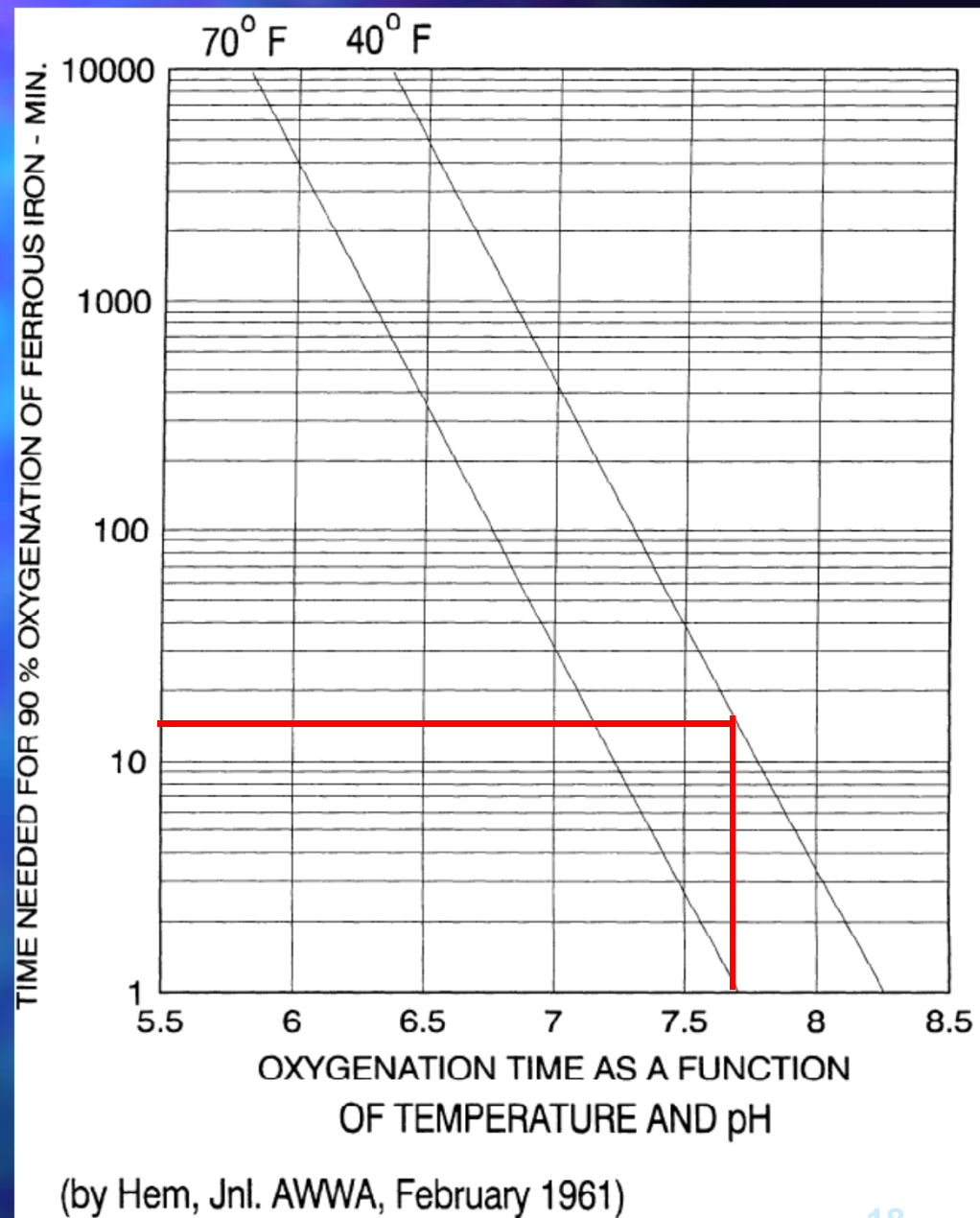
Forms of Iron Found in Water Treatment

- Soluble Iron or Clear Water Iron (Fe^{++})
- Precipitant Iron or Red Water Iron (Rust, Fe^{+++} , settles out)
- Organically Bound Iron Soluble Iron
- Bacterial Iron (Slim or biogrowth)
 FeCO_2 (siderite) + $\text{CO}_2 \rightarrow \text{Fe}^{++} 2\text{HCO}_3^-$

Soluble Iron (Fe^{+3}) and Manganese (Mn^{+3}) Can be Removed by Aeration

- Water with $\text{Fe} + \text{Mn} > 0.3$ PPM will have disagreeable taste and odor.
- Removal of Fe/Mn by aeration is dependent on pH, contact time, temperature and presence of organic material.
- By maintaining pH above 7, contact time can be significantly reduced.
- pH can be adjusted by adding lime (increases pH and speeds oxidation).
- Air requirement is 0.15 PPM air to 1 PPM Fe
- It will be necessary to periodically chlorinate the aeration system to control slime growths.

Plot of
pH vs. Time for
Iron Removal at
90%
Efficiency
(min 30 minutes
detention)



Treatment Methods to Remove Iron

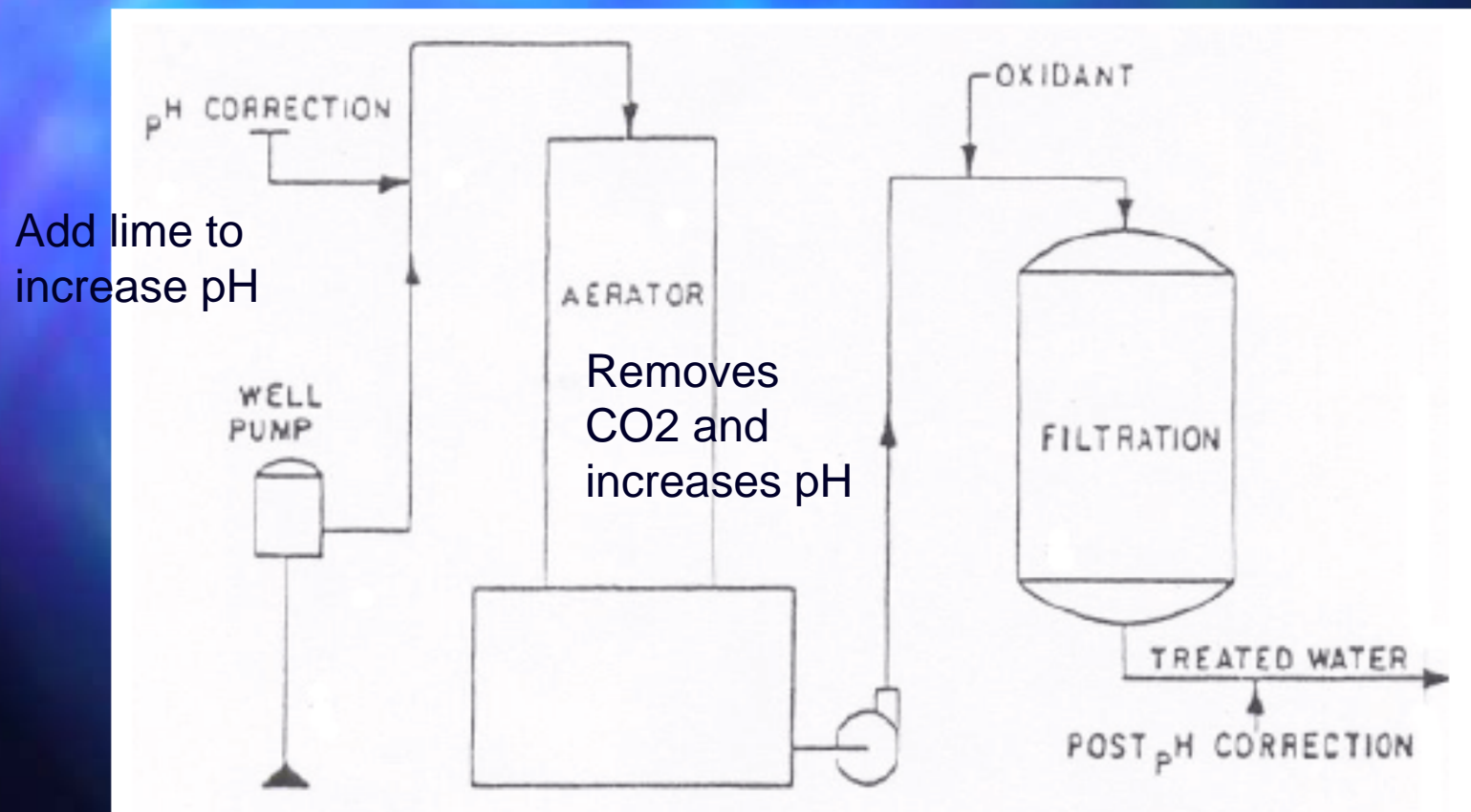
Comparison of Oxidants Required to Oxidize 1mg/l of Ferrous Iron or Manganous Manganese

Oxidant	Iron	Manganese
Oxygen	0.14	0.29
Chlorine	0.62	1.30
Chlorine Dioxide	1.21	2.45
Ozone	0.86	0.87
Potassium Permanganate	0.91	1.92

Effects of pH on Fe and Mn Removal

- Chemical pH adjustment will also remove CO_2 . CO_2 impedes reactions by lowering pH
- The most Effective iron removal occurs between a pH of 7 and 9.
- Iron removal by aeration will operate best at a pH of 8.0 and should never be operated lower than 7.5.
- If organic iron presents a problem, hydroxide alkalinity must be provided and upward pH adjustment needed.
- If Manganese is a problem pH will need to be raised to 9.5; Manganese oxidation can take as long as 60 minutes

Schematic of Typical Fe Removal Aeration System



Determining if Dissolved Iron is Present

- Draw a sample from the well and allow it to stand for 30 minutes
- Water should be clear and colorless turning to a slight yellow haze color after contact with air
- If allowed to stand it will finally form a yellowish brown color
- If aerated and allowed to stand it will form reddish brown deposits in bottom of container

Chemical Oxidation of Fe Using Chlorine

- The main advantage of chlorine over aeration is the requirement for much shorter reaction times
- Chlorine is frequently used instead of aeration when iron concentrations exceed 5 PPM
- When levels of iron and manganese exceed 5 PPM, sedimentation may also be necessary prior to filtration
- Chlorine residual concentration of 1 to 4 PPM is needed to force the reaction to completion
- Chlorine residual concentration after a contact tank should never be allowed to drop below 0.5 PPM
- The Chlorine concentration that is most effective is determined by the use of a jar test

Dissolved Iron Problems

- Soluble iron passing into the water distribution system will encourage the growth of iron bacteria
- Precipitates will form in the distribution system
- Iron particles will stain clothes and fixtures (Red Water Complaints)

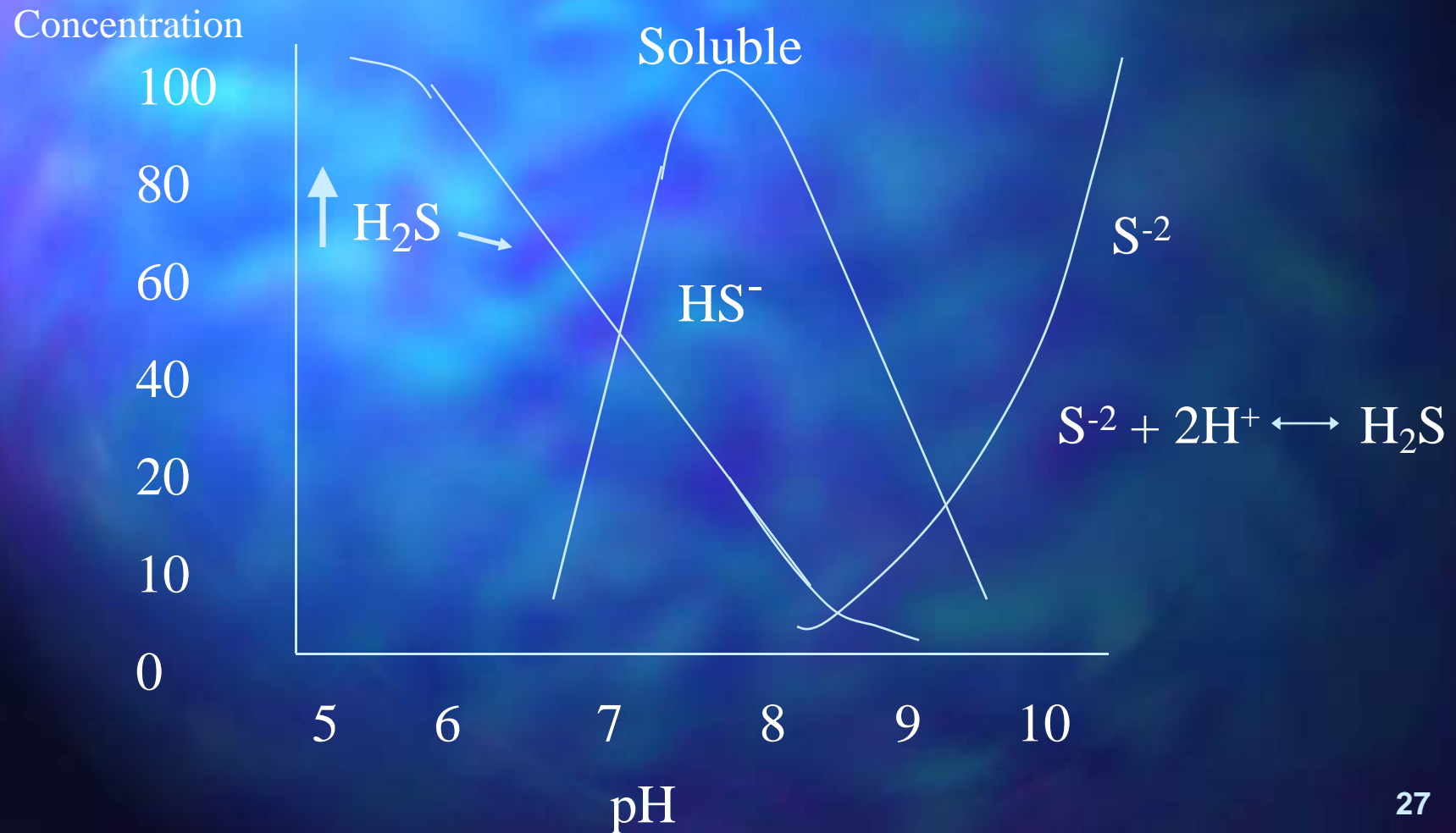
Use of Potassium Permanganate

- High Levels of chlorine can cause DBP Problems
- Some systems have moved to the use of Potassium Permanganate
- Besides controlling iron & manganese, sulfides and color are also removed.

Clarification Requirements for Iron and Manganese

- Oxidized particles must be removed
- Anthracite filters are frequently employed
- With high Fe/Mn concentrations in source water (> 6 PPM) a clarifier may be necessary

Hydrogen Sulfide Solubility



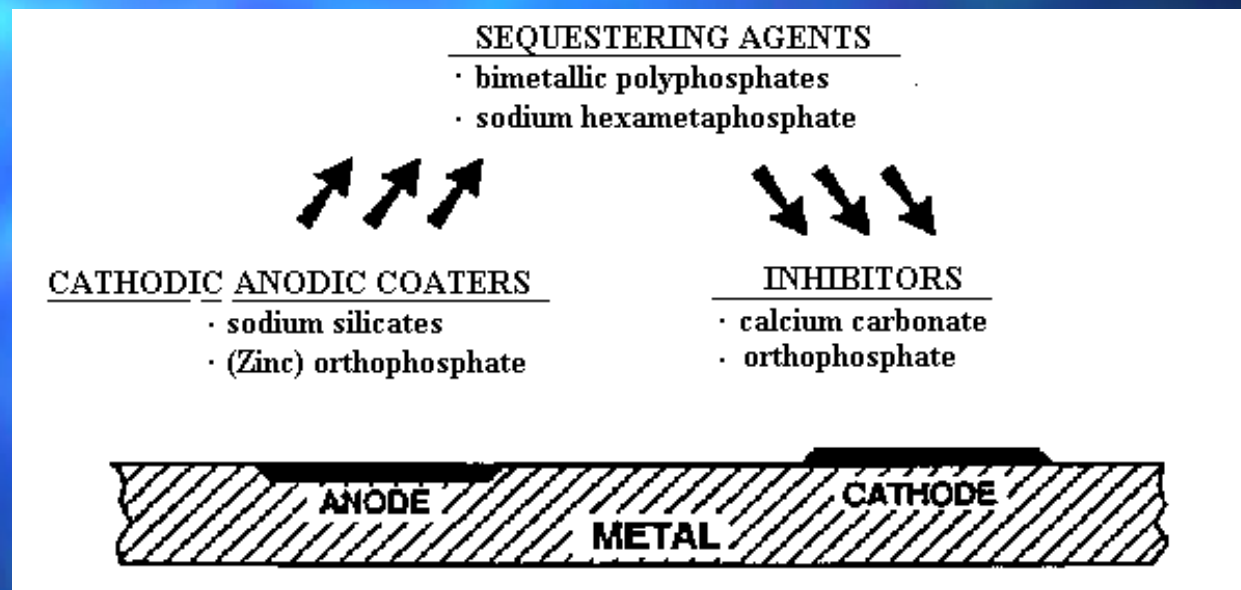
Hydrogen Sulfide Removal Techniques (DEP)

Sulfide (mg/l)	Recommended Treatment Process	Achievable Range of Removal	
< 0.3	Direct Chlorination	↓	100%
> 0.3	Direct Chlorination (requires filtration)	↓	100%
0.3 to 0.6	Conventional Aeration	↑	50%
0.6 to 3.0	Forced Draft Aeration	↑	90%
> 3.0	Packed Tower Aeration	↑	> 90%

Stabilization of Iron and Manganese in Drinking Water by Sequestering

- What does sequester mean?
 - To set aside; to separate and reject; to eliminate
 - In chemistry as in sequester metal: remove it from solution or combine it with something else to prevent it from coming out of solution

Sequestering Action of Poly and Ortho Phosphates



Some Benefits Attributed to Phosphate Addition

- Control of Iron and Manganese Color and Staining
- Scale Reduction
- Corrosion Inhibition
- Hydrogen Sulfide Oxidation
- Chlorine Demand Reduction
- Bacterial (MPN) Reduction
- Disinfectant By-Product Reduction
- Increased Life of Iron Pipelines
- Increased Life of Water Heating Elements
- Improved Taste of Water
- Water Color Enhancement

Sequestering of Dissolved Iron to Prevent Iron Precipitation

- The purpose of the sequestering agent is to combine with the Iron in the ferrous state before it has had time to react
- Sequestering may be used for iron control instead of primary treatment.
- For Soluble Iron, Sequestering agents must be added at bottom of well to prevent air contact
- Sequestering of Soluble iron is also commonly used as a post treatment strategy to prevent any soluble iron from entering the distribution system

Considerations in the Use of Polyphosphates for Sequestering

- Polyphosphates are effective for low concentrations of iron and manganese
- Polyphosphate sequestering agents can start to degrade to orthophosphate after about 3 days
- Polyphosphate sequestering does not work under stagnant conditions (slow moving water or dead end conditions)
- Over feeding Polyphosphate can contribute phosphorus as a nutrient that favors the growth of slime bacteria

Polyphosphates for Sequestering Soluble Iron and Manganese after Treatment

- The Polyphosphate, Hexametaphosphate is commonly used for Sequestering Soluble Iron and Manganese
- Sequestering is used when soluble Iron and Manganese exists after treatment; The Agent is added after sedimentation
- Large doses (>5 mg/l) will soften rust deposits in pipelines which are transported into homes
- Proper dose is to keep soluble iron and/or manganese tied up for 4 days

Use of Polyphosphates

- The polyphosphate form is the active sequestering agent
- Sequestering agents are added far from disinfectant as possible
- The polyphosphate concentration is the difference between total phosphate and orthophosphate present
- Polyphosphate sequestering requires a initial shock dose for about 30 days to complete demands
- After the demands are met, a minimum of 4 ppm polyphosphate is fed into the water to treat 2 ppm of iron or less

Use of Orthophosphates for Sequestering

- Orthophosphate is used to sequester iron ions at pipe surfaces
- The Sequestering forms a protective coating that prevents further iron migration
- Ortho/Poly Blends provide both sequestering of soluble iron and iron movement from pipelines under corrosive conditions

DEP Limitations in Sequestering Iron and Manganese

- Sequestering with polyphosphates may be used when the combination of $(\text{Fe} + \text{Mn}) < 1 \text{ mg/l}$
- Polyphosphate may not exceed 10 mg/l
- Sequestering with sodium silicates may be used when combination of $(\text{Fe} + \text{Mn}) < 2 \text{ mg/l}$
- Sodium Silicate can not exceed 20 mg/l
- Sodium Silicate is applicable prior to air contact only!



Polyphosphate Dosing System₃₇

Troubleshooting Customer Complaints caused by Corrosion

<u>Water Characteristic</u>	<u>Likely Cause</u>
-----------------------------	---------------------

Red/reddish-brown Water	Distribution Pipe Corrosion
Bluish Stains on fixtures	Copper Line Corrosion
Black Water	Sulfide Corrosion of Iron
Foul Tastes and Odors	By-Products of Bacteria
Loss of Pressure	Tuberculation
Lack of Hot Water	Scaling
Reduced Life of Plumbing	Pitting from Corrosion



Basic Chemistry for Water Plant Operators

Matter

- Solids
- Liquids
- Gases

Periodic Table of Elements

1 IA 1A	2											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 <u>H</u> 1.008	2 <u>He</u> 4.003											5 <u>B</u> 10.81	6 <u>C</u> 12.01	7 <u>N</u> 14.01	8 <u>O</u> 16.00	9 <u>F</u> 19.00	10 <u>Ne</u> 20.18
3 <u>Li</u> 6.941	4 <u>Be</u> 9.012											13 <u>Al</u> 26.98	14 <u>Si</u> 28.09	15 <u>P</u> 30.97	16 <u>S</u> 32.07	17 <u>Cl</u> 35.45	18 <u>Ar</u> 39.95
11 <u>Na</u> 22.99	12 <u>Mg</u> 24.31	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 ← ←	9 VIII 8	10 → →	11 IB 1B	12 IIB 2B						
19 <u>K</u> 39.10	20 <u>Ca</u> 40.08	21 <u>Sc</u> 44.96	22 <u>Ti</u> 47.88	23 <u>V</u> 50.94	24 <u>Cr</u> 52.00	25 <u>Mn</u> 54.94	26 <u>Fe</u> 55.85	27 <u>Co</u> 58.47	28 <u>Ni</u> 58.69	29 <u>Cu</u> 63.55	30 <u>Zn</u> 65.39	31 <u>Ga</u> 69.72	32 <u>Ge</u> 72.59	33 <u>As</u> 74.92	34 <u>Se</u> 78.96	35 <u>Br</u> 79.90	36 <u>Kr</u> 83.80
37 <u>Rb</u> 85.47	38 <u>Sr</u> 87.62	39 <u>Y</u> 88.91	40 <u>Zr</u> 91.22	41 <u>Nb</u> 92.91	42 <u>Mo</u> 95.94	43 <u>Tc</u> (98)	44 <u>Ru</u> 101.1	45 <u>Rh</u> 102.9	46 <u>Pd</u> 106.4	47 <u>Ag</u> 107.9	48 <u>Cd</u> 112.4	49 <u>In</u> 114.8	50 <u>Sn</u> 118.7	51 <u>Sb</u> 121.8	52 <u>Te</u> 127.6	53 <u>I</u> 126.9	54 <u>Xe</u> 131.3
55 <u>Cs</u> 132.9	56 <u>Ba</u> 137.3	*	72 <u>Hf</u> 178.5	73 <u>Ta</u> 180.9	74 <u>W</u> 183.9	75 <u>Re</u> 186.2	76 <u>Os</u> 190.2	77 <u>Ir</u> 190.2	78 <u>Pt</u> 195.1	79 <u>Au</u> 197.0	80 <u>Hg</u> 200.5	81 <u>Tl</u> 204.4	82 <u>Pb</u> 207.2	83 <u>Bi</u> 209.0	84 <u>Po</u> (210)	85 <u>At</u> (210)	86 <u>Rn</u> (222)
87 <u>Fr</u> (223)	88 <u>Ra</u> (226)	**	104 <u>Rf</u> (257)	105 <u>Db</u> (260)	106 <u>Sg</u> (263)	107 <u>Bh</u> (265)	108 <u>Hs</u> (265)	109 <u>Mt</u> (266)	110 <u>Ds</u> (271)	111 <u>Rg</u> (272)	112 <u>Cn</u> (277)	113 <u>Uut</u> --	114 <u>Fl</u> (296)	115 <u>Uup</u> --	116 <u>Lv</u> (298)	117 <u>Uus</u> --	118 <u>Uuo</u> --

* Lanthe nide Series	57 <u>La</u> 138.9	58 <u>Ce</u> 140.1	59 <u>Pr</u> 140.9	60 <u>Nd</u> 144.2	61 <u>Pm</u> (147)	62 <u>Sm</u> 150.4	63 <u>Eu</u> 152.0	64 <u>Gd</u> 157.3	65 <u>Tb</u> 158.9	66 <u>Dy</u> 162.5	67 <u>Ho</u> 164.9	68 <u>Er</u> 167.3	69 <u>Tm</u> 168.9	70 <u>Yb</u> 173.0	71 <u>Lu</u> 175.0
** Actinid e Series	89 <u>Ac</u> (227)	90 <u>Th</u> 232.0	91 <u>Pa</u> (231)	92 <u>U</u> (238)	93 <u>Np</u> (237)	94 <u>Pu</u> (242)	95 <u>Am</u> (243)	96 <u>Cm</u> (247)	97 <u>Bk</u> (247)	98 <u>Cf</u> (249)	99 <u>Es</u> (254)	100 <u>Fm</u> (253)	101 <u>Md</u> (256)	102 <u>No</u> (254)	103 <u>Lr</u> (257)

<u>Alkali Metal</u>	<u>Alkaline Earth</u>	<u>Semi-Metal</u>	<u>Halogen</u>	<u>Noble Gas</u>
<u>Non Metal</u>	<u>Basic Metal</u>	<u>Transition Metal</u>	<u>Lanthanide</u>	<u>Actinide</u>

The Periodic Chart

Use of Atomic Weight

Includes
Isotopes

Use 16

8
O
Oxygen
15.99

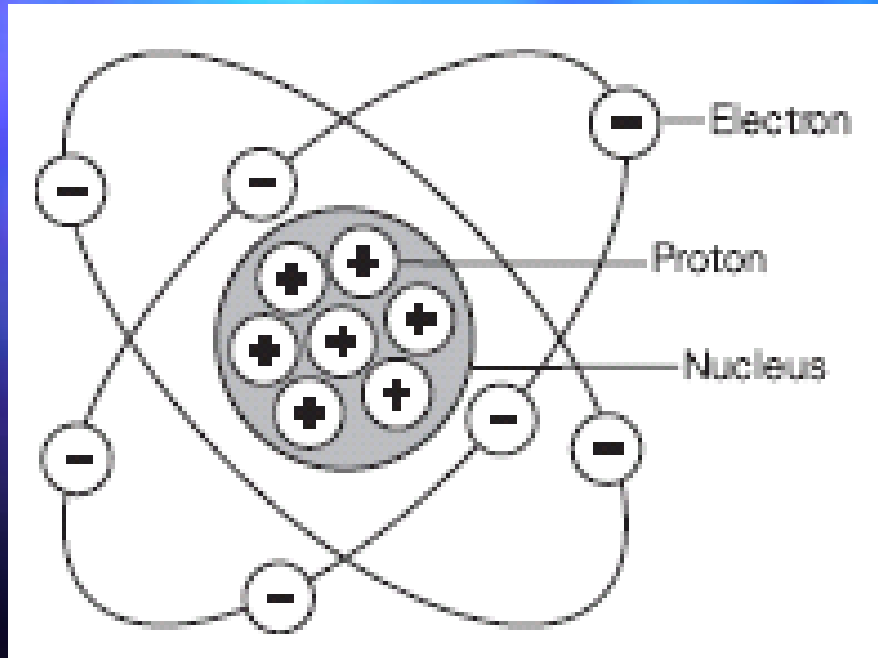
Atomic Number

Symbol

Name

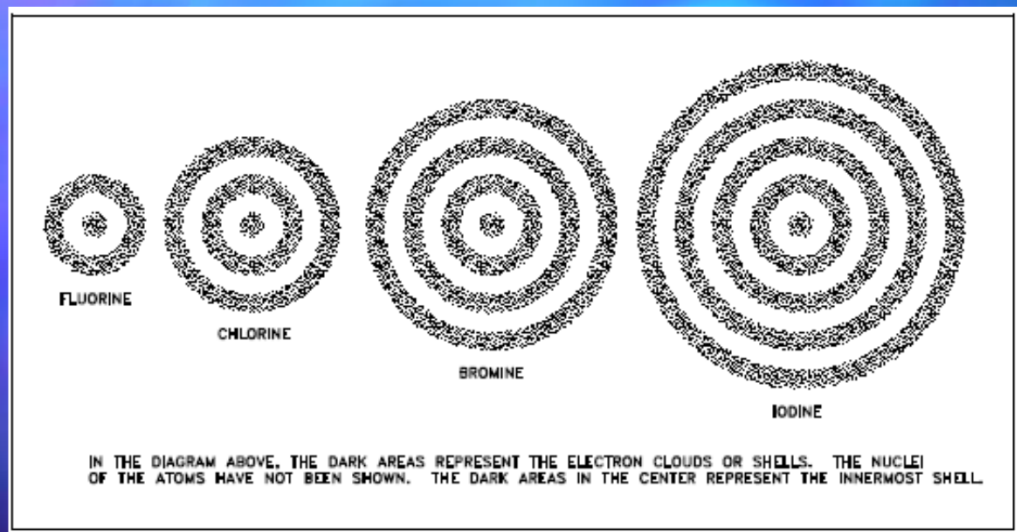
Atomic Weight

Atoms are classified by the # of Protons in the Nucleus called the Atomic Number



- Atoms are made up of protons, electrons and neutrons.
- Atoms are classified by the number of protons in the nucleus and is its atomic number.
- Nucleus is made up of protons and neutrons which give the atom its atomic mass. Electrons do not have mass. Mass of each is 1.
- Electrons orbit the nucleus and have a negative charge. Protons have a positive charge and neutrons have no charge.
- Atoms have the same number of electrons as protons unless acted upon by an external force.

Shells and Valances in Chemical Reactions



Electrons exist in Orbits called Shells and combine according to Valence or the number of electrons gained or lost.

- Chemical reactions involve primarily the electrons in the outermost shell of an atom.
- The outermost shell is called the valence shell
- The electrons in that shell are called valence electrons.

Electron Configuration Table

1s² **Gold**
2s² 2p⁶
3s² 3p⁶ 3d¹⁰
4s² 4p⁶ 4d¹⁰ 4f¹⁴
5s² 5p⁶ 5d¹⁰
6s¹

An electron configuration table is a type of code that describes how many electrons are in each energy level of an atom and how the electrons are arranged within each energy level. What is the element shown?

What do all those numbers and letters mean?

- The first number is the **energy level**. We can tell right away that an atom of gold contains 6 energy levels.
- The lowercase letter is the **sub-shell**. The sub-shells are named s, p, d and f. The number of available sub-shells increases as the energy level increases.
- The number in superscript is the **number of electrons in a sub-shell**. Each sub-shell can hold only a certain number of electrons. The s sub-shell can hold no more than 2 electrons, the p sub-shell can hold 6, the d sub-shell can hold 10 and the f sub-shell can hold as many as 14.

Element Name	Atomic Number	Electron Configuration	Valence Shell	Common Oxidation Numbers
Hydrogen	1	1 s ¹	1 s ¹	+1, -1
Helium	2	1 s ²	1 s ²	0
Lithium	3	1 s ² 2 s ¹	2 s ¹	1
Beryllium	4	1 s ² 2 s ²	2 s ²	2
Boron	5	1 s ² 2 s ² 2 p ¹	2 s ² 2 p ¹	3
Carbon	6	1 s ² 2 s ² 2 p ²	2 s ² 2 p ²	+4, +2, -4
Nitrogen	7	1 s ² 2 s ² 2 p ³	2 s ² 2 p ³	+5, +3, -3
Oxygen	8	1 s ² 2 s ² 2 p ⁴	2 s ² 2 p ⁴	-2
Fluorine	9	1 s ² 2 s ² 2 p ⁵	2 s ² 2 p ⁵	-1
Neon	10	1 s ² 2 s ² 2 p ⁶	2 s ² 2 p ⁶	0
Sodium	11	1 s ² 2 s ² 2 p ⁶ 3 s ¹	3 s ¹	1
Magnesium	12	1 s ² 2 s ² 2 p ⁶ 3 s ²	3 s ²	2
Aluminum	13	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ¹	3 s ² 3 p ¹	3
Silicon	14	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ²	3 s ² 3 p ²	4
Phosphorus	15	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ³	3 s ² 3 p ³	+5, +3, -3
Sulfur	16	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ⁴	3 s ² 3 p ⁴	+6, +4, +2, -2
Chlorine	17	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ⁵	3 s ² 3 p ⁵	-1
Argon	18	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ⁶	3 s ² 3 p ⁶	0
Potassium	19	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ⁶ 4 s ¹	4 s ¹	1
Calcium	20	1 s ² 2 s ² 2 p ⁶ 3 s ² 3 p ⁶ 4 s ²	4 s ²	2

Anions and Cations

- **Electron Configurations of Anions**

Electrons are added to the next highest partially filled shell.



- **Electron Configurations of Cations**

Electrons from the highest occupied energy shell are removed



Properties of the Elements

Metals

- Metals constitute the largest class of Elements.
- Metals tend to lose electrons to form positive ions.

Nonmetals

- Nonmetals are often gases at room temperature
- As solids they are not lustrous, malleable or ductile, and are poor conductors of heat and electricity.
- Nonmetals gain electrons to form negative ions .

Semi-Metals

- Semi-metals may exhibit properties of either.

Calculating Molecular Weight of a Compound

The Molecular Weight of a Compound is the sum of the Atomic Weights of all of the atoms in a compound. For example take sodium silicofluoride (Na_2SiF_6). What is its molecular weight?

Symbol	No. of Atoms	Atomic Weight	Molecular Weight
Na	2	22.99	45.98
Si	1	28.09	28.09
F	6	19.00	114.00
Molecular Weight of Chemical			188.07

Based on this information what is the Fluoride ion purity, % in the compound?

$$\text{Fluoride ion purity, \%} = \frac{\text{molecular wt. of F in compound}}{\text{molecular wt. of the compound}} = \frac{114}{188} = .606 \text{ or } 60.6\%$$

What is the molecular weight of calcium hydroxide (lime)?


- Chemical formula is Ca(OH)_2
- How many atoms are there of each element and what are the atomic weights?

Element	Atoms	Atomic Wt
Ca	= <u>1</u> ;	<u>40</u>
Oxygen	= <u>2</u> ;	<u>16</u>
Hydrogen	= <u>2</u> ;	<u>1</u>

$$\text{Molecular Weight} = (1 \times 40) + (2 \times 16) + (2 \times 1) = 74$$

Mole Equivalency in Water Treatment



- A mole is the weight in grams of the molecular weight of a substance.
 - From our last example: One mole of $\text{Ca}(\text{OH})_2$ is equal to 74 grams, which is the sum of the substance's molecular or atomic weight.
- How many grams in 2  of lime?
 - 2 moles would equal 148 grams

Concentration: How does ppm and mg/l relate to each other?

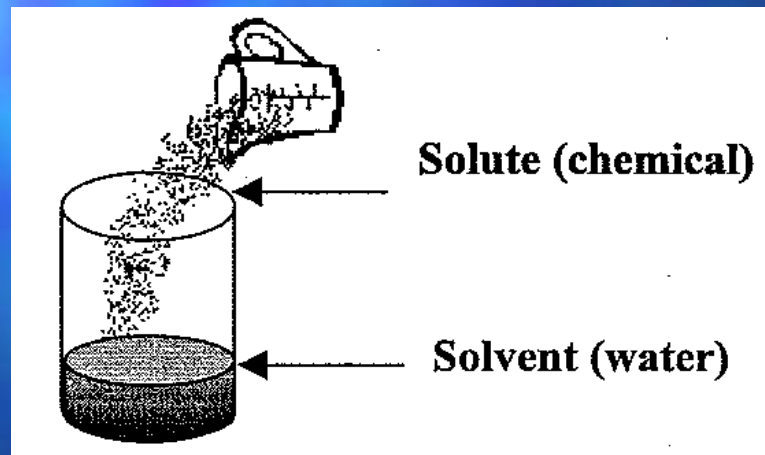
Metric System			
1000	kilogram	kg	10^3
100.0	hectogram	hg	10^2
10.0	dekagram	dag	10^1
1.0	gram	g	10^0
0.1	decigram	dg	10^{-1}
.01	centigram	cg	10^{-2}
.001	milligram	mg	10^{-3}
.0000001	microgram	μg	10^{-6}

$$\frac{1\text{mg}}{\text{L}} = \frac{1\text{mg}}{1\text{ kg}} = \frac{1\text{mg}}{\text{million mg}} = \frac{1\text{ part}}{\text{million}}$$

- Metric system units go in steps of 10, 100, and 1,000.
- One milligram in a kg is 1 ppm (by mass).
- One liter (L) of pure water at 4°C and 1 standard atmosphere pressure weighs exactly 1 kg
- So 1 mg/L is 1 ppm. Another way to say it is a liter of water weighs 1,000 grams or 1 million milligrams.
- Therefore, 1 mg in 1 liter is 1 mg in 1 million milligrams or 1 part per million.

Concentration

- The concentration of a solution is a measure of the amount of solute dissolved in a given amount of solvent.
- A solution consists of two parts: a solvent and a solute.
- When working in water treatment, the solvent is usually water.



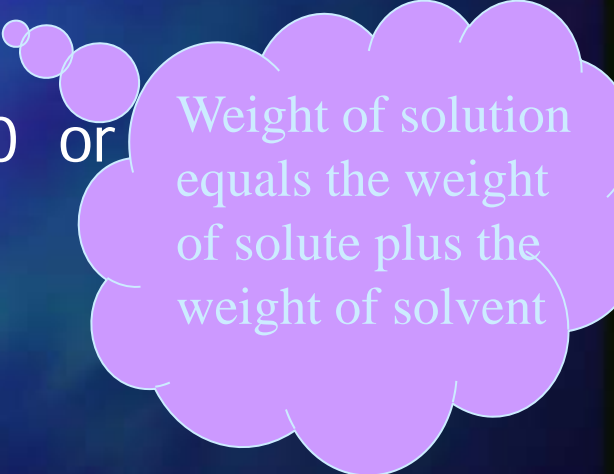
- Commonly expressed as mg/l (same as ppm) but can be expressed as percent strength and grains per gallon GPG.

Concentration

- For the extremely dilute solutions, concentration is often expressed in parts per million (ppm).
- The amount of solute and solution present can be stated in terms of either mass or volume.
- Therefore, different types of percent (weight or strength) and ppm exist:
 - mass-mass;
 - volume-volume;
 - mass-volume

Percent Strength

- Percent strength of a solution can be expressed as percent-by-weight or percent-by-volume.
- To calculate percent strength by weight , the following formulas are used:
- Percent strength = $\frac{\text{Weight of Solute}}{\text{Weight of Solution}} \times 100$ or
- Percent strength = $\frac{\text{Weight (dry)}}{\text{Weight (prod)}} \times 100$ or
- Percent strength = $\frac{\text{part}}{\text{whole}} \times 100$



Weight of solution equals the weight of solute plus the weight of solvent

If 10lbs of chemical are added to 100 lbs of water, what is the percent strength (by weight) of the solution?

- Percent strength = $\frac{\text{Weight of Solute}}{\text{Weight of Solution}} \times 100$
- Weight of Solute = 10lbs
- Weight of Solution = 110lbs
- Percent strength = $\frac{10}{110} \times 100 = 9\%$

Example: A lab procedure requires you to add 10 lbs of sodium hydroxide to water. How many lbs of sodium are required for this reaction?

Weight percent = $\frac{\text{atomic weight of element}}{\text{molecular weight of compound}} \times 100$

- Step 1. Determine the molecular weight of sodium hydroxide (NaOH).
- Atomic weight
 - Sodium = 23
 - Oxygen = 16
 - Hydrogen = 1
- Molecular weight of NaOH = 40

Example: A lab procedure requires you to add 10 lbs of sodium hydroxide to water. How many lbs of sodium are required for this reaction?

- Step 2: Determine the percent of sodium in sodium hydroxide.

- Percent strength = $\frac{\text{Weight (dry)}}{\text{Weight (prod)}} \times 100$
(of Sodium)

- Percent strength = $\frac{23}{40} \times 100 = 57.5\%$
(of Sodium)

- Step 3: Calculate the amount of sodium.

- Percent strength = $\frac{\text{part}}{\text{whole}} \times 100$

- $\frac{\text{Whole} \times \text{Percent strength}}{100} = \text{Part}$

- Part = $\frac{10\text{lbs} \times 57.5}{100} = 5.75 \text{ lbs of Sodium}$

In 50 gallons of solution, there is 50 lbs of chlorine. What is the strength of the solution? Assume the solution has the same density as water.

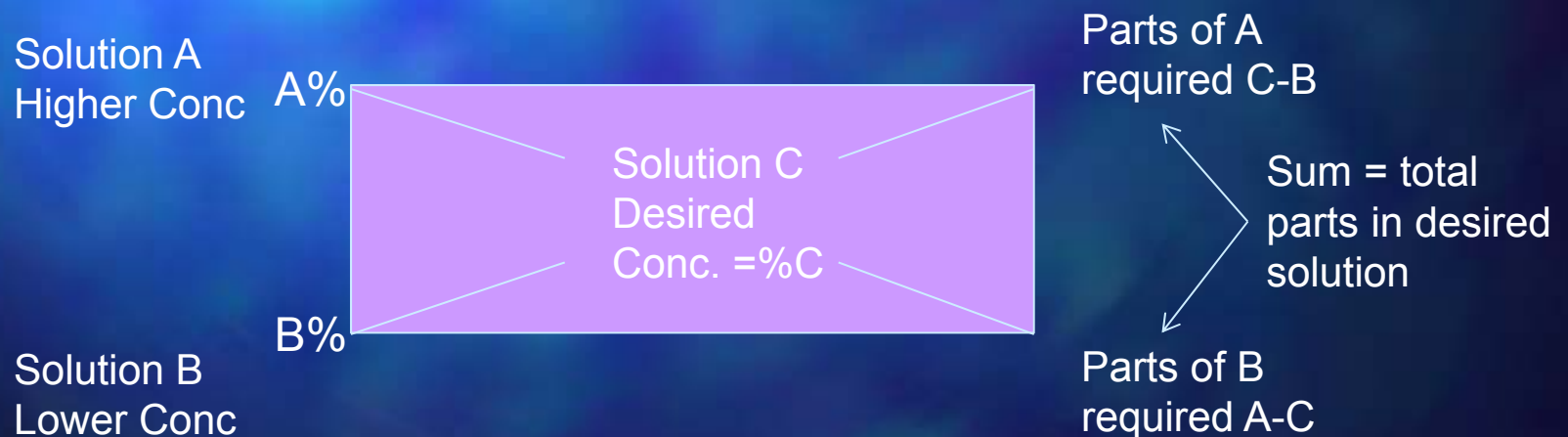
- Step 1: Determine the weight of the solution. Since there are 8.34 lbs/gal we know that the 50 gals of solution weighs:

$$\frac{8.34 \text{ lbs}}{\text{gal}} \times 50 \text{ gals} = 417 \text{ lbs of solution}$$

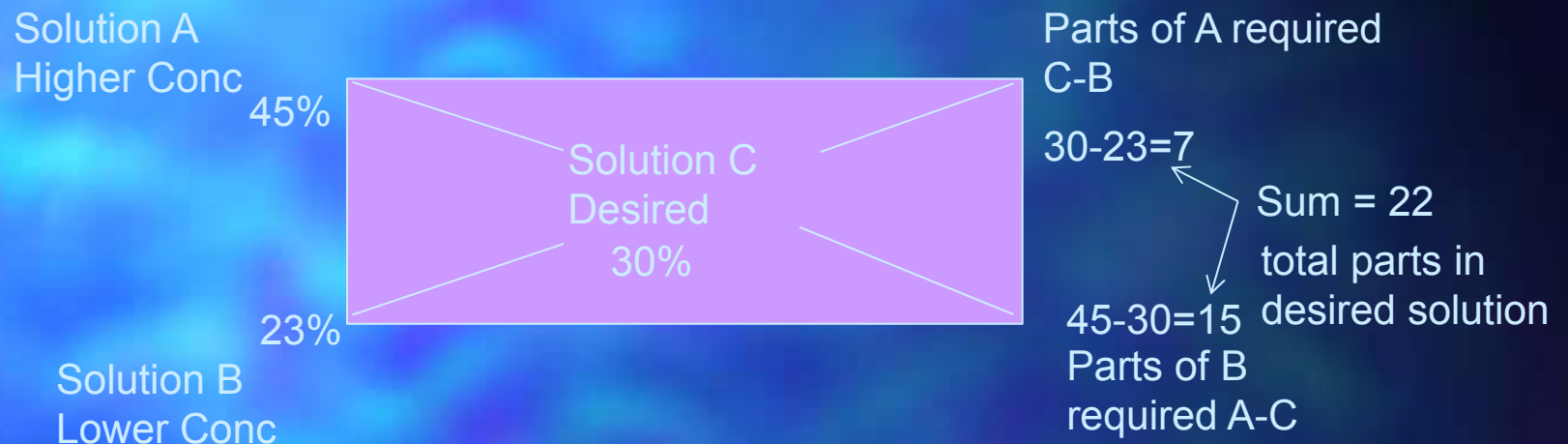
- Step 2: Determine the percent strength.
- Percent strength = $\frac{\text{Weight of Solute}}{\text{Weight of Solution}} \times 100$ or
- Percent strength = $\frac{50 \text{ lbs of Cl}}{417 \text{ lbs of Solution}} \times 100 = 12\%$

Dilution Calculations

- In some cases a particular strength of solution will be required. Usually this solution is created by diluting a stronger strength of that same solution with water or with a weaker solution of the same chemical.
- The best method to determine quantities of weak and strong solutions by percent is the "Rectangular diagram"



Example: A plant has a 45% and 23% solution of ferric chloride. The operator must create 150 gallons of a 30% solution. How much of each solution should be used to create a 30% strength?



Percentage of Solution A Required = $7/22 = 32\%$

Percentage of Solution B Required = $15/22 = 68\%$

Using $\text{Percent} = \frac{\text{Part}}{\text{Whole}}$ or $\text{Part} = \text{Percent} \times \text{Whole}$

Solution A = $32\% \times 150 \text{ gals} = 48 \text{ gals}$

Solution B = $68\% \times 150 \text{ gals} = 102 \text{ gals}$

Molarity

- Another way of expressing concentration.
- Molarity is the number of moles of solute dissolved in one liter of solution.
- The units, therefore are **moles per liter**, specifically it's **moles of solute per liter of solution**.

Example: What is the molarity of a solution prepared by dissolving 15.0 g of sodium hydroxide in enough water to make a total of 225 mL of solution?

$$\text{■ Molarity (M)} = \frac{\text{Moles of Solute}}{\text{Liters of Solution}}$$

$$M = \frac{15.0 \text{ g NaOH}}{225 \text{ ml solution}} \times \frac{1 \text{ mole NaOH}}{40 \text{ g NaOH}} \times \frac{1000 \text{ ml}}{1 \text{ liter}}$$

1 Mole = Molecular weight of NaOH

Atomic Wts: Na = 23; O = 16; H = 1

Molecular weight is 40

$$M = \frac{1.67 \text{ mole NaOH}}{\text{liter}} = 1.67 \text{ M NaOH}$$

Solutions and Standards

Aqueous Solution	Mixture completely dissolved in water
Standard Solution	A solution in which the exact concentration (molecular weight is known)
Standardize	Determining the exact strength of solution by comparison with standard of known strength
Titration	Process of adding chemical of known strength to determine concentration of unknown compounds

Alkalinity/Acidity

Alkali	Soluble Salts that neutralize Acids
Alkaline	Sufficient amount of alkali to raise pH above 7
Alkalinity	Capacity of Water to neutralize acids
	Does not exist below pH 4.5
Acidic	Condition of Water to lower pH below 7

Acids

- An acid is any substance that releases hydrogen ions when mixed with water.
- For example: Hydrochloric acid (HCl) dissociates or breaks apart in water, forming H^+ and Cl^- ions.
- In general, acids contain an "H" in the chemical formula.
 - Sulfuric acid: H_2SO_4 ; Nitric acid: HNO_3 ;
Carbonic acid: H_2CO_3

Bases

- A base is any substance that produces hydroxyl ions (OH^-) when dissociated in water.
- For example, caustic soda (NaOH) releases sodium (Na^+) ion and a hydroxyl ion (OH^-) in water.
- Examples of bases: Caustic soda - NaOH ;
Lime – CaO ; Potassium hydroxide – KOH ;
Ammonia – NH_3

Salts

- Salts are compounds resulting from an acid-base mixture.
- These compounds do not contain either a hydrogen or hydroxide ion.
- Mixing hydrochloric acid and caustic soda forms basic table salt (sodium chloride)



- Mixing lime and carbonic acid form calcium carbonate.



pH

- pH is most important parameter in our drinking water.
- pH of a solution is a measurement of how acidic or basic a solution is.
- pH is measured on a scale of 0 to 14.
- Pure water is considered neutral and has a pH of 7.0.
- Solutions that contain a greater number of hydrogen ions than hydroxide ions are considered acidic and has a pH below 7.0.
- Solutions that contain a greater number of hydroxide ions compared to hydrogen ions is considered basic and has a pH above 7.0.

pH (continued)

- pH is a major constituent in corrosion control.
 - Increasing pH above 7.0 in the distribution system reduces lead and copper.
 - In most cases, pH levels above 9.0 can induce scaling or precipitation of calcium carbonate.
- pH is also a major factor in floc formation for filtration.
 - Alum works best at pH's at or below 7.0.
 - Ferric products work best at pH's above 8.0.
- pH has an effect on chlorine disinfection and formations of trihalomethanes (THM's).

Alkalinity

- Alkalinity is the measurement of the water's capacity to neutralize an acid.
- There are three types of alkalinity: bicarbonate (HCO_3^-), Carbonate (CO_3^{2-}), and hydroxide (OH^-).
- Many of the chemicals used in water treatment, such as alum, chlorine, or lime, cause changes in alkalinity.
- Alkalinity of water is needed to:
 - Calculate the chemical dosages in coagulation and water softening
 - Calculate corrosivity
 - Estimate carbonate hardness of water
- Type of alkalinity and quantities determined from acid titrations.



Ions in Water Treatment

- All acids, bases and salts disassociate or ionize in water. These are known as electrolytes.
- Electrolytes normally have the same number of protons as electrons that neutralize one another. When dissolved in water they split into their respective elements or compounds and lose or gain electrons. This results in the elements or compounds becoming positively or negatively charged.
- Sodium and Calcium give up electrons and become positively charged. Positively charged ions are called "cations."
- Chlorine is negatively charged because it gains electrons. Negatively charged ions are called "anions."

Important Ions in Water Chemistry and Common Valences

Cations

- H^+
- Na^+
- Ca^{++}
- Mg^{++}
- Mn^{++} or $^{+++}$
- Fe^{++} or $^{+++}$
- S^{++}
- NH_4^+
- Al^{+++}

Anions

- Cl^-
- O^{--}
- OH^-
- HCO_3^-
- CO_3^{--}
- NO_3^-
- SO_4^-
- OCl^-

Oxidation Reduction Reactions

- Oxidation or Reduction is a method of forcing reactions to completion by the reaction of an ion with an oxidant or reducing agent.
- Oxidation refers to the loss of electrons, while reduction refers to the gain of electrons.
- Each reaction by itself is called a "half-reaction", simply because we need two (2) half-reactions to form a whole reaction.
- For example
 - $\text{Cu (s)} \rightarrow \text{Cu}^{2+} + 2 \text{e}^{-}$
 - $2 \text{Ag}^{+} (\text{aq}) + 2 \text{e}^{-} \rightarrow 2 \text{Ag (s)}$
- Oxidation/reduction reactions will proceed to completion.

Oxidation in Water Treatment

- Oxidize Inorganic Elements such as Iron and Manganese
- Destruction of Taste and Odor Compounds
- Destruction of Synthetic Organic Chemicals
- Assist in the Coagulation Process by Destabilization of Particles
- Control of Biological Growth

Chlorination and Disinfection

Disinfection and Sterilization



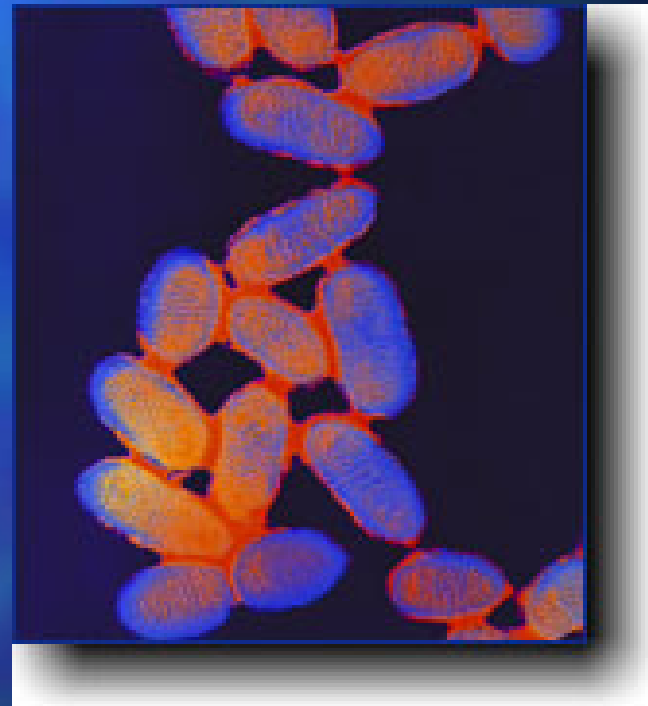
- Disinfection – inactivates pathogenic organisms
- Sterilization - destroys all organisms

“To all Citizens: boil and strain the water before drinking to prevent hoarseness.”

Hippocrates, 350 B.C.

Purpose of Disinfection

- Protect the public from disease-causing pathogens
- By inactivating pathogens to ensure that they are reduced to non-harmful levels



Considerations for Choosing a Disinfectant

- Effective for the Conditions Encountered
- Economical
- Operationally practical
- Reliable
- Safe for public consumption with no unintended consequences

Disinfection Agents

- Heat energy
- Radiant energy – UV
- Chemical Agents

Disinfection by Heat

- Expensive to operate on large scale
- Used for emergency situations in distribution systems
- Precautionary Boil Water Notices are issued when the distribution system is compromised
- Clearance requires two consecutive days of negative coliform samples

Disinfection by Radiant Energy (Ultraviolet Radiation)

- Ultraviolet Radiation (UV) used selectively in surface water treatment plant applications
- No residual activity so chlorine is used as secondary disinfectant
- Inactivation of cysts (Giardia) and oocysts (Crypto) difficult to measure
- Very Susceptible to turbidity

Disinfection by Chemical Agents in the U.S.

- Chlorine and Monochloramine 93%
- Potassium Permanganate 5%
(Used as alternate oxidant w/ Cl₂ secondary)
- Ozone (O₃) 1%
(requires secondary disinfectant)
- Chlorine Dioxide 1%
(requires secondary disinfectant)
- Hydrogen Peroxide < 1%
(requires secondary disinfectant)

Reasons for the Selection of Chlorine as a Disinfectant

- Readily available and economical
- Low cost compared to other substances
- Proven effectiveness in relatively low dosages
- Simple feed and control procedures
- Requires safe storage and handling

Disadvantages in the Use of Chlorine

- Highly toxic
- Regulatory agencies placing tightening restrictions on storage and use
- Must have Emergency Response Plan
- Produces Disinfection Byproducts

Other Uses of Chlorine at a Water Treatment Plant

- Control Aquatic Life
- Oxidize Iron, Manganese and Sulfides
- Remove Tastes and Odors
- Maintain a Microbial Residual in Water Distribution System
- Prevent Algal Growth in Basins and Plant Process Facilities
- Improve Coagulation and Filtration

Use of Chlorine for Removing Taste and Odors

- Most widely used chemical for color removal
- Effective for use for organic odors such as fishy, grassy or flowery
- Very effective for removing (oxidizing) inorganics such as iron or hydrogen sulfide
- Will intensify phenolic (solvent) odors
- Will increase THM's and HAA5's
- Alternatives include Potassium Permanganate, Ozone and Chlorine Dioxide

Use of Potassium or Sodium Permanganate as Disinfectant

- Powerful Oxidizing Agent
- Used to Remove Fe/Mn and TOC
- Does not produce DBPs
- Shipped as a Solid (KMnO_4) or Liquid (NaMnO_4)
- Two to three times as expensive as Cl
- Corrosive, stains purple and can color water pink (removed with chlorine).
- Requires Secondary Disinfectant

Use of Ozone (O_3) as a Disinfectant

- Effective in taste in odor removal. Does not produce TTHMs or DBP
- Bromate, MCL must be controlled
- No residual, so secondary disinfectant required
- Requires on-site generation
- Unstable - not stored
- Utilizes sensitive equipment which requires careful monitoring

On-site Ozone Generation



Ozone is always generated on-site. Dosing is accomplished in chamber, any residual Ozone is purged and secondary disinfectant is added.

Chlorine Dioxide

- long been used for taste and odor and for iron and manganese control
- will not produce THMs and HAA5s
- can produce chlorite and chlorate residuals in drinking water. Chlorate has an established MCL.
- must be prepared on-site and uses gas chlorination system to produce feed product

The background of the slide is a dark, abstract image with swirling blue and purple hues. A faint, glowing pattern resembling a globe or a molecular structure is visible in the center, with bright blue and cyan highlights. The overall effect is ethereal and scientific.

Use of Chlorine

Forms of Chlorine

- Gas Chlorine (Cl_2) - 100% available as chlorine
- Liquid Chlorine or Bleach (NaOCl) - Sodium hypochlorite (5% - 15% active chlorine) is a pale yellow liquid
- Solid Chlorine [Ca(OCl)_2] - Calcium hypochlorite comes in a granular, powdered or tablet form. It is a white solid that contains 65% to 75% available chlorine.

Gas Chlorine

- Lowers the pH of the water
- Produced from liquid chlorine shipped in pressurized cylinders
- 100% available as chlorine
- Moisture in a chlorination system will combine with the chlorine gas and cause corrosion

Liquid Chlorine

(Sodium Hypochlorite)

- Solid chlorine raises the pH of the water
- Arrives in a plastic container
- 5 -15% chlorine by weight
- More expensive than converting chlorine in liquid form to gas
- Safe and easy to handle and dose
- Very corrosive
- Toxic - apply in vented area
- Weakens over time

Solid Chlorine

(Calcium hypochlorite)

- Solid chlorine raises the pH of the water
- 65% to 75% available chlorine
- Easily dissolves in water
- Easy to store; longer shelf life than liquid
- Very corrosive
- Highly reactive
- Toxic - apply in vented area
- Undissolved solids can foul check valves and plug injection fittings



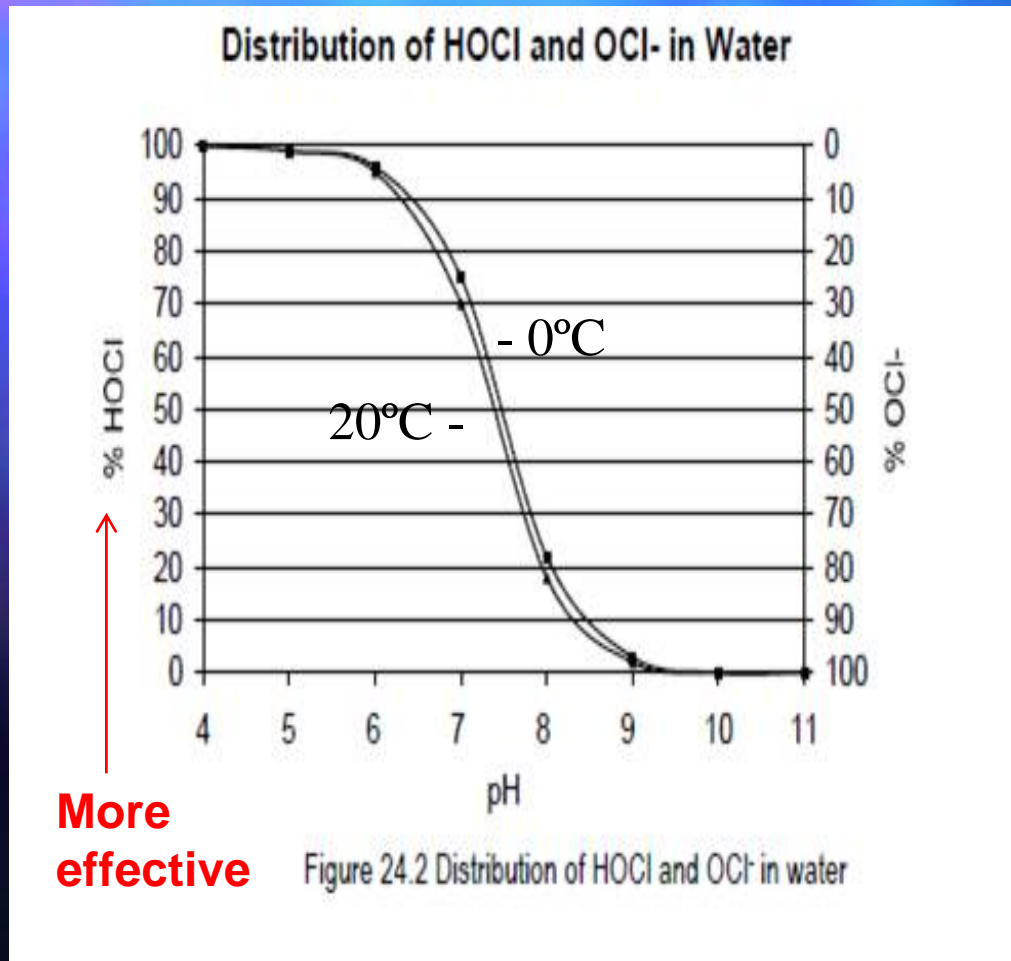
Factors Affecting Chlorination Effectiveness

- Chlorine concentration and form
- Effluent pH (lower increases effectiveness)
- Effluent temperature (higher increases effectiveness)
- Contact time (generally, longer increases effectiveness)
- Effluent suspended solids (turbidity reduces effectiveness)

Chlorine Residual Requirements in Distribution System

A free chlorine residual of 0.20 mg/l or a combined chlorine residual of 0.60 mg/l
or an equivalent chlorine dioxide residual, must be maintained in the water distribution system at all times.

Relationship between HOCl, OCl⁻ and pH



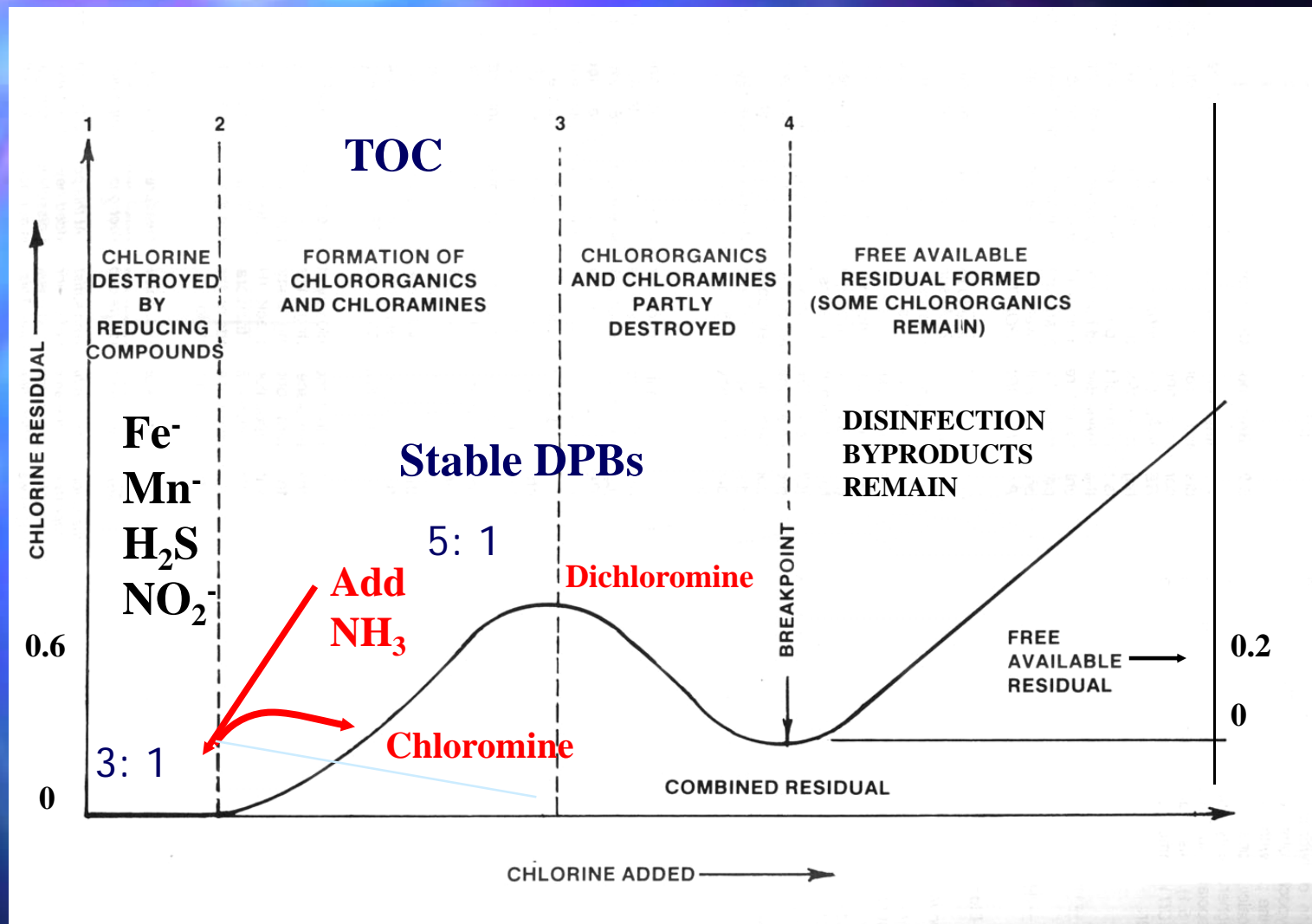
- Chlorine reacts with water
- Producing hypochlorous acid (HOCl) and the hypochlorite ion (OCl⁻)
- These provide the disinfection ability of chlorine

Reactions of Chlorine with Water Constituents



**Order of
Reaction**

1. Reducing Compound (inorganics)
2. Production of Chloramines
3. Production Chlororganics (organics)
4. Combined Chlorine
5. Breakpoint Chlorination
6. Free Chlorine Residual



Breakpoint Chlorination Curve



Chlorine Relationships

$\text{CL Dose} = \text{Chlorine Residual} + \text{CL Demand}$

$\text{Chlorine Residual} = \text{CL Dose} - \text{CL Demand}$

$\text{CL Demand} = \text{CL Dose} - \text{Chlorine Residual}$

Inactivation of Bacteria and Virus with Chlorine

- Inactivation of Pathogens is accomplished by meeting CT limits (Time that Pathogen is in contact with concentration of residual chlorine)
- 3-Log Giardia Inactivation for SW — **99.9%**
- 4-Log Virus Inactivation for GW — **99.99%**
- Tables of acceptable Inactivation (mg-min/l) are published by DEP

Substances that Cause Chlorine Demand (mg/l to mg/l basis)

- Hydrogen Sulfide (H_2S) (8:1 ratio)
- Inorganic metals - Fe and Mn (0.67:1 ratio)
- Nitrite (5:1 ratio, 3:1 ratio with NH_3)
- Organic materials (TOC and NOM), (0.1:1 ratio)
- All react with chlorine and reduce it to the chloride ion which has no disinfectant power
- $\text{H}_2\text{S} > 0.3 \text{ mg/l}$ and $\text{Fe} > 0.1 \text{ mg/l}$ must be filtered to remove colloidal solids

Chlorine Residual

- Free Chlorine - aqueous chlorine, hypochlorite ion and hypochlorous acid
- Combined Chlorine Residual - compounds formed by reactions of hypochlorous acid and ammonia (chloramines)
- Total Chlorine Residual - sum of free and combined chlorine

Minimum Chlorine Residual

- DEP requirements are 0.20 PPM Free Chlorine Residual or 0.60 PPM Chloramine Residual at all points in Distribution System

Question?

- Why is turbidity of importance to public health?
 1. Causes bad tastes
 2. Interferes with disinfection
 3. Looks undesirable
 4. Requires filtration



Considerations for Hypochlorination Systems

Difference between Gas and Hypochlorination

- Gas chlorine lowers the pH (increases the hydrogen concentration) favoring the formation of Hypochlorous acid (more effective)
- Hypochlorination (both Sodium and Calcium) raises the pH favoring the formation of the Hypochlorite ion. (less effective)

Parts of a Hypochlorinator

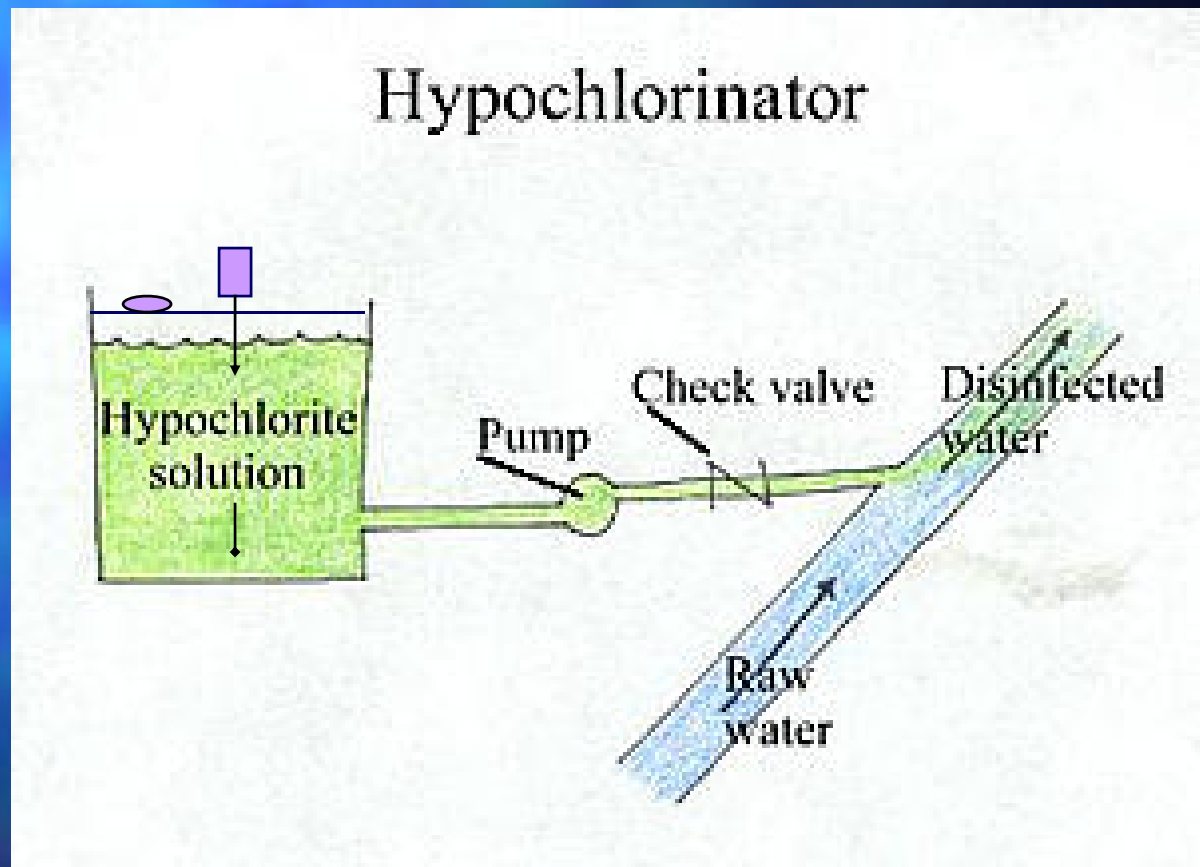
Parts:

Mixing Tank

Metering
Pump

Check Valve

Well Pump



Hypochlorination Chemical Feed Pumps

Peristaltic

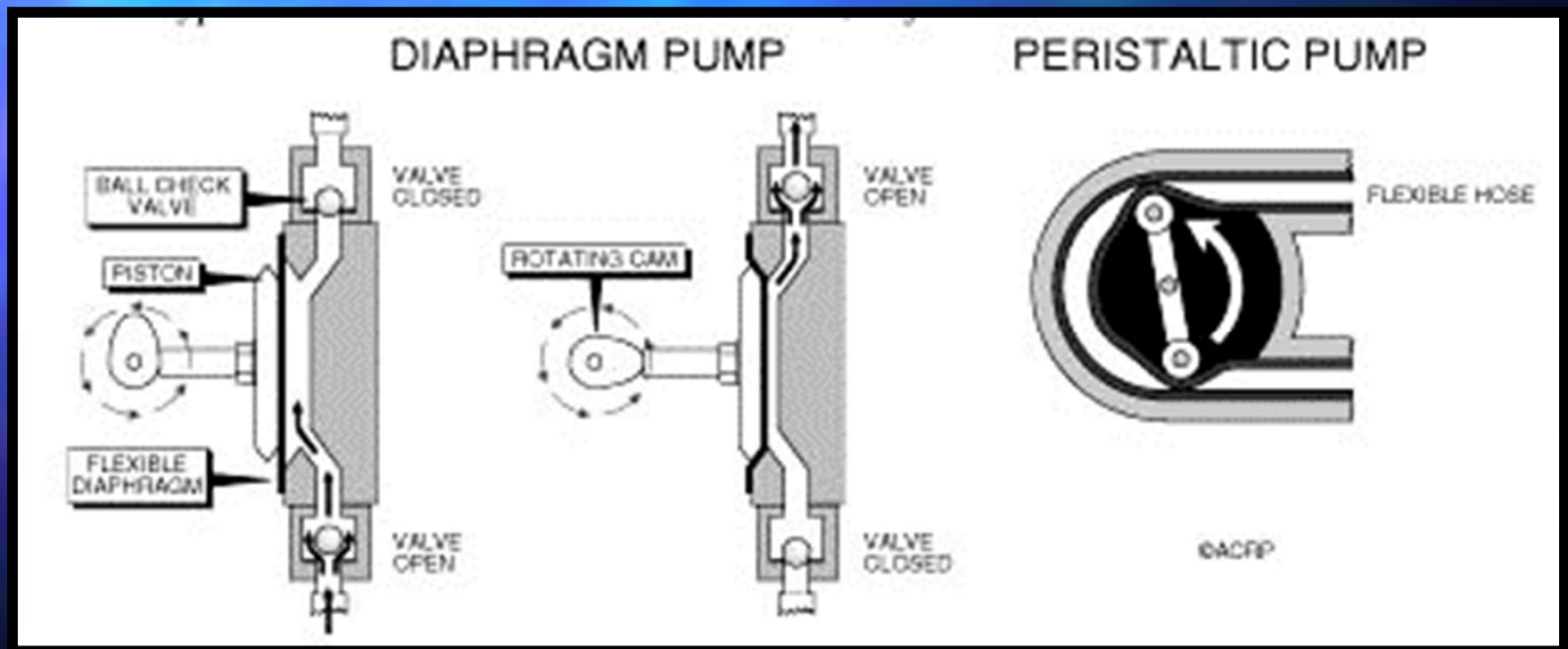


Diaphragm



Parameter	Peristaltic Pump	Diaphragm Pump
<u>Fluid</u>		
Chemical resistance	- Fewer components to be attacked. Few pump tube material options.	- Many components to be attacked. Many component material options.
Un-dissolved solids	- Excellent: no valves to clog.	- Poor: valves can clog causing failures.
Outgassing	- Excellent: automatically primes	- Poor: difficult to prime
Shear stress	- Excellent: will not damage fluid	- Poor: can damage delicate fluid
Temperature	- Limited range: pump tubing is affected by high and low temperatures.	- Extended range: effect of temperature on the diaphragm is minimal.
<u>Pressure</u>		
Injection Pressure	- Limited discharge range - <125psi typical. No change in output due to changes in system pressures.	- Extended discharge range - >125psi typical. Large change in output due to changes in system pressure.
<u>Control</u>		
Remote Adjustment	- Excellent: steady dispersion of chemical at very low output with speed adjustment.	- Good: intermittent dispersion of chemical at low outputs.
External communications	- Excellent	- Excellent
Diagnostics	- Excellent: tube failure and flow verification alarm systems available.	- Excellent: diaphragm failure and flow verification alarm systems available.
<u>Maintenance</u>		
Service interval	- Service required at regular intervals.	- Service recommended at regular intervals.
Life expectancy	- Excellent	- Excellent

Chemical Feed Pumps



Hypochlorination System Maintenance Considerations

- Pumps, feed lines, and injection points should be regularly inspected and cleaned
- Clean using mild acid solution
- Pump should be properly lubricated and free of corrosion
- Adjust feed rate only when running
- Do not store chemical for long periods
@ Date of Manf. 12.5% after 30 days 11.5%

Cl lines are
what color?
YELLOW

Considerations for Hypochlorite Storage

- Protect skin, eyes, and respiratory tract
- Wear protective gloves Hypochlorite will burn skin
- Cover all containers
- Keep chemical dry, covered and stored away from direct sunlight.
- Add water to container before the hypochlorite powder is added.
- Flush all spills with large amounts of water
- Keep the chlorine room well ventilated.
- Store Calcium hypochlorite away from contact with organic matter to prevent fire.



Considerations for Gas Chlorination Systems

Physical and Chemical Properties of Chlorine as a Gas

- Pressurized liquid expands 450 times in atmosphere
- Under normal atmospheric pressure at room temperature, chlorine is a yellow-green gas
- 2.5 times heavier than air

Exhaust fans
should be located
where?

Floor level.

Maximum Draw-Off Rates

150 lb cylinders - approximately 40 lbs/day

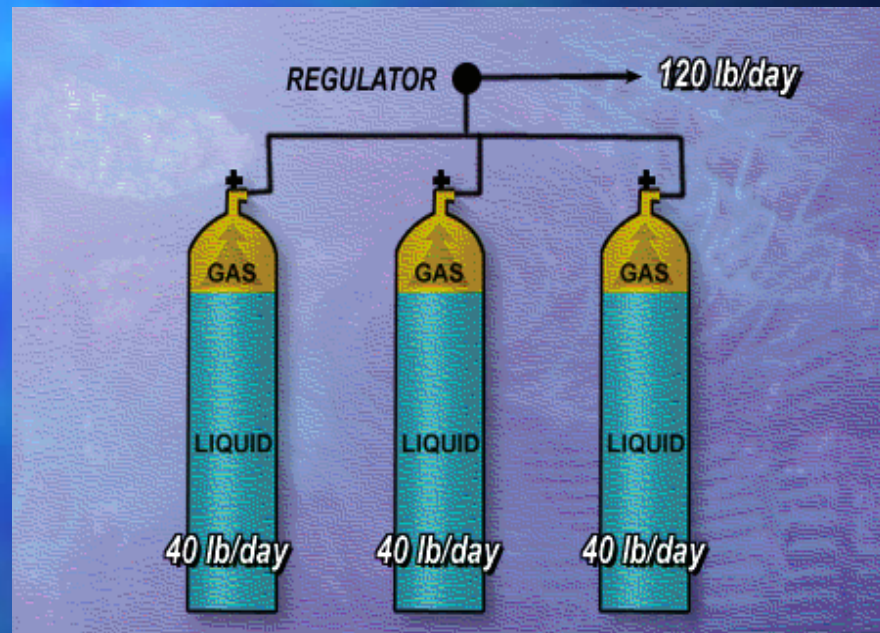
1-ton containers - approximately 400 lbs/day

Computed as 8 pounds / F° drop

- Temperature of remaining chlorine decreases as the rate of withdrawal increases
- When temperature of chlorine is low enough it will not evaporate

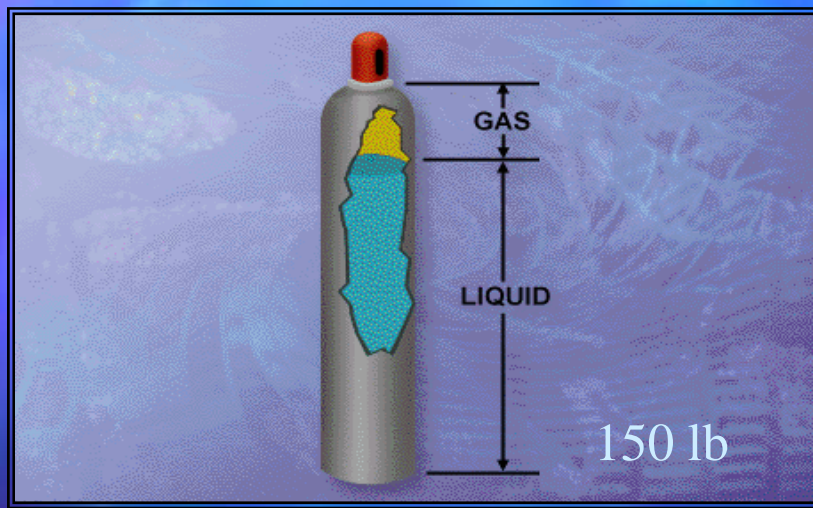
Preventing Chlorine Icing

- When attempting to feed more than the allowable amount from any container, manifolding is required



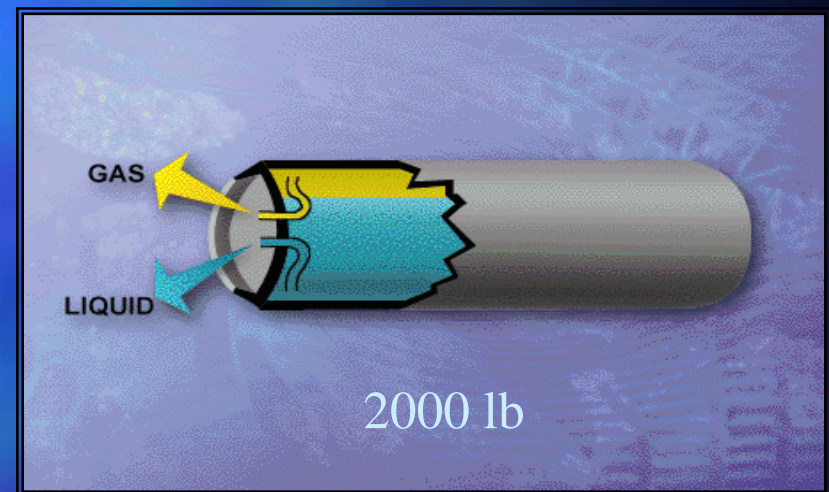
Computed as 8 pounds / F° drop

Dosing Configurations of Chlorine Cylinders



150 lbs Cl - 92 lbs Tare

Total Weight ~ 242 lbs



2000 lbs Cl - 1550 lbs Tare

Total Weight ~ 3,600 lbs

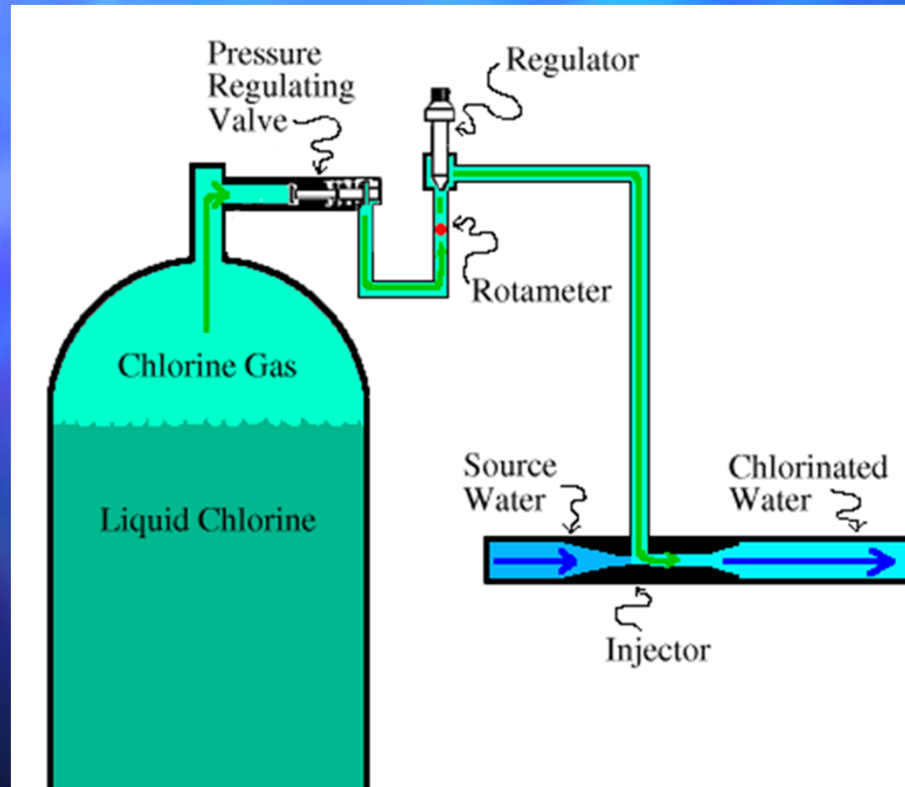
Storage of Chlorine Cylinders

- Keep away from heat or direct sunlight
- Provide separate room with ventilation.
- Maintain 55°F
- Temperature
- Protect from Fire
- Chlorine tanks are provided with fusible plugs that melt between 158 to 165 degrees F.
- Ton cylinders will have 6 to 8 of these plugs, 3 or 4 on each end; 150 lb, one.

Safe Handling of 1-Ton Cylinder

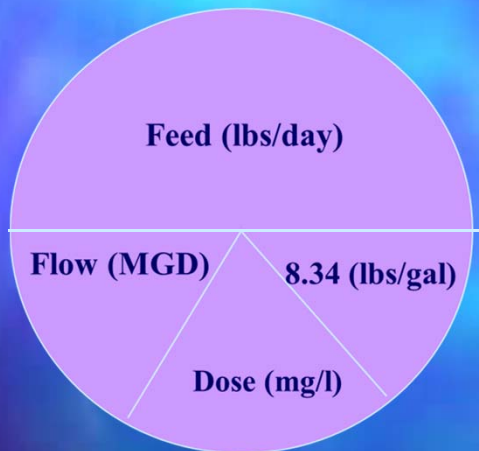


Principles of Gas Chlorination



- Injector
- Pressure Regulating Valve
- Rotameter
- Rate Valve

Find the Chlorine Dose



A chlorinator is set to feed 20lbs of chlorine in 24 hrs to a flow of 0.85 MGD. Find the chlorine dose in mg/l.

$$\text{Dose} = \text{Feed} / (\text{flow} \times 8.34)$$

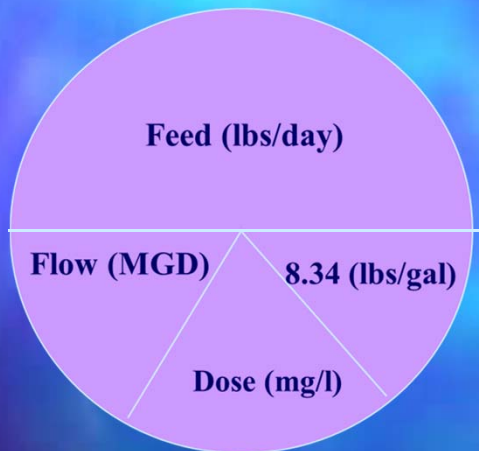
Check units

$$\text{Feed} = \frac{20\text{lbs}}{24\text{hrs}} \times \frac{24\text{hrs}}{1 \text{ day}} = \frac{20\text{lbs}}{\text{day}}$$

$$\text{Dose} = \frac{20\text{lbs}}{\text{day}} \times \frac{\text{day}}{0.85 \text{ MGD}} \times \frac{\text{gal}}{8.34\text{lbs}}$$

$$\text{Dose} = 2.8 \text{ ppm or } 2.8\text{mg/l}$$

Find the Chlorine Dose



A chlorinator is set to feed 20lbs of chlorine in 12 hrs to a flow of 0.85 MGD. Find the chlorine dose in mg/l.

$$\text{Dose} = \text{Feed} / (\text{flow} \times 8.34)$$

Check units

$$\text{Feed} = \frac{20\text{lbs}}{12\text{hrs}} \times \frac{24\text{hrs}}{1\text{ day}} = \frac{40\text{lbs}}{\text{day}}$$

$$\text{Dose} = \frac{40\text{lbs}}{\text{day}} \times \frac{\text{day}}{0.85\text{ MGal}} \times \frac{\text{gal}}{8.34\text{lbs}}$$

$$\text{Dose} = 5.6 \text{ ppm or } 5.6 \text{ mg/l}$$

Chlorine Safety

All Forms of Chlorine are Hazardous

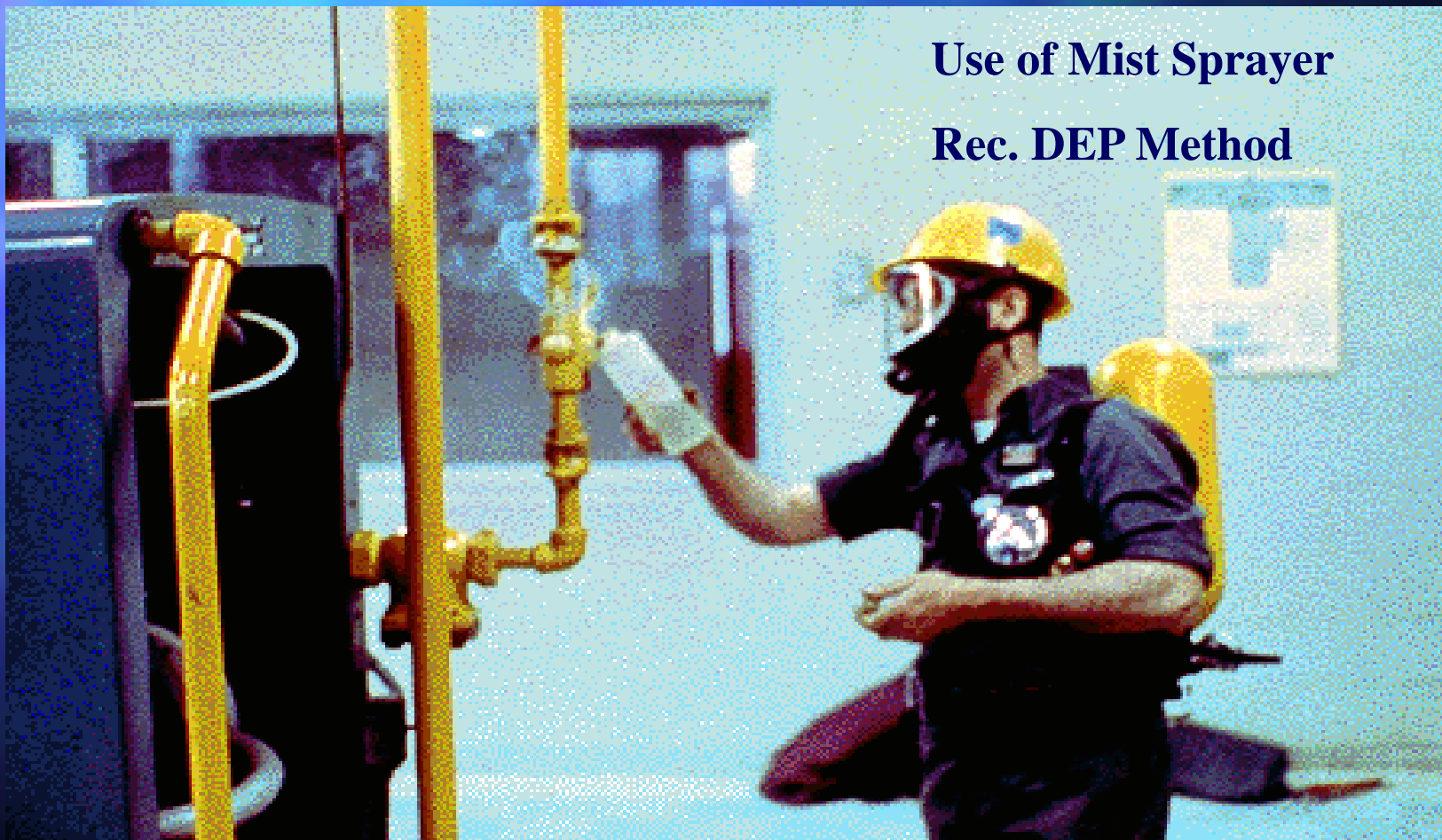


- Chlorine gas/liquid - extremely hazardous substance
- Calcium hypochlorite and sodium hypochlorite - hazardous substance
- Disinfection agents kill living organisms and tissue

Chlorinator Start Up

- Use Self Contained Breathing Apparatus, Protective Clothing and work in pairs
- Inspect cylinder before connecting
- Check fittings
- Use new lead gasket
- Connect yoke with $\frac{3}{4}$ turn
- Open cylinder valve one turn
- Check for leaks with ammonia (rag preferable)
- Have emergency repair equipment on-hand (A-kit 150, B-kit 2000, C-kit tank car)

Chlorine Leaks



Use of Mist Sprayer

Rec. DEP Method

Emergency Eyewash Shower at Small Plant



Required for
Gas Chlorine

Effects of Chlorine on Humans

Chlorine Conc

Physiological Response

.3-3.5 mg/L

detectable by smell

30 mg/L

causes coughing

40-60 mg/L

damage to tissue

1000 mg/L

death after a few breaths

- Permissible Exposure Level (PEL) is 0.5 ppm (8-hour weighted average)

- Immediately Dangerous to Life or Health (IDLH) concentration is 10 ppm

Contents of a Chlorine Emergency Preparedness Program

- Chlorine Safety Program
- Written Rules and Safety Procedures
- Periodic hand-on training
- Establishment of Emergency Procedures
- Establishment of Maintenance and Calibration Program
- Fire, Police, Emergency Agency Coordination and (Chemtrec 800-424-9300.)

Fluoridation

Fluoridation Considerations

- Added as Supplement to Natural Occurring Concentrations
- Typically 1 to 1.2 mg/l as Fluoride
- Regulated MCL at 4 mg/l SDA and 2 mg/l DEP
- Halogen and as Oxidant very Active!
- Overdosing causes mottling of teeth and bone deterioration

Fluoride Compounds

Compound Name	Formula	Purity	pH
Sodium Fluoride	NaF	97%	7.6
Sodium Fluorosilicate	Na ₂ SiF ₆	98%	3.6
Hydrofluoro-silicic Acid	H ₂ SiF ₆	23%	1.2

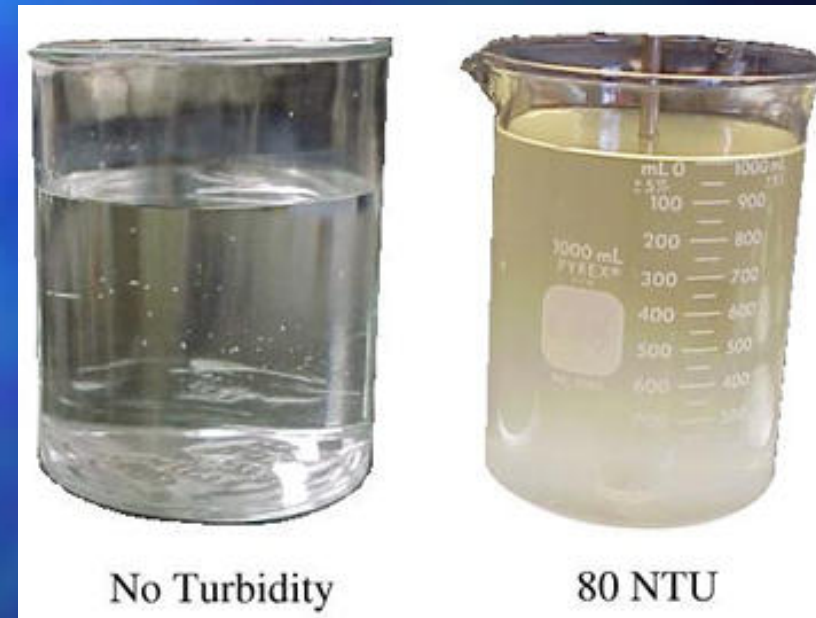
Coagulation and Flocculation

Coagulation is a physical and chemical reaction occurring between the “ALKALINITY” of the water and the coagulant added to the water which results in the formation of insoluble flocs (floc that will not dissolve).

Purpose of Coagulation and Flocculation

Remove turbidity from the water

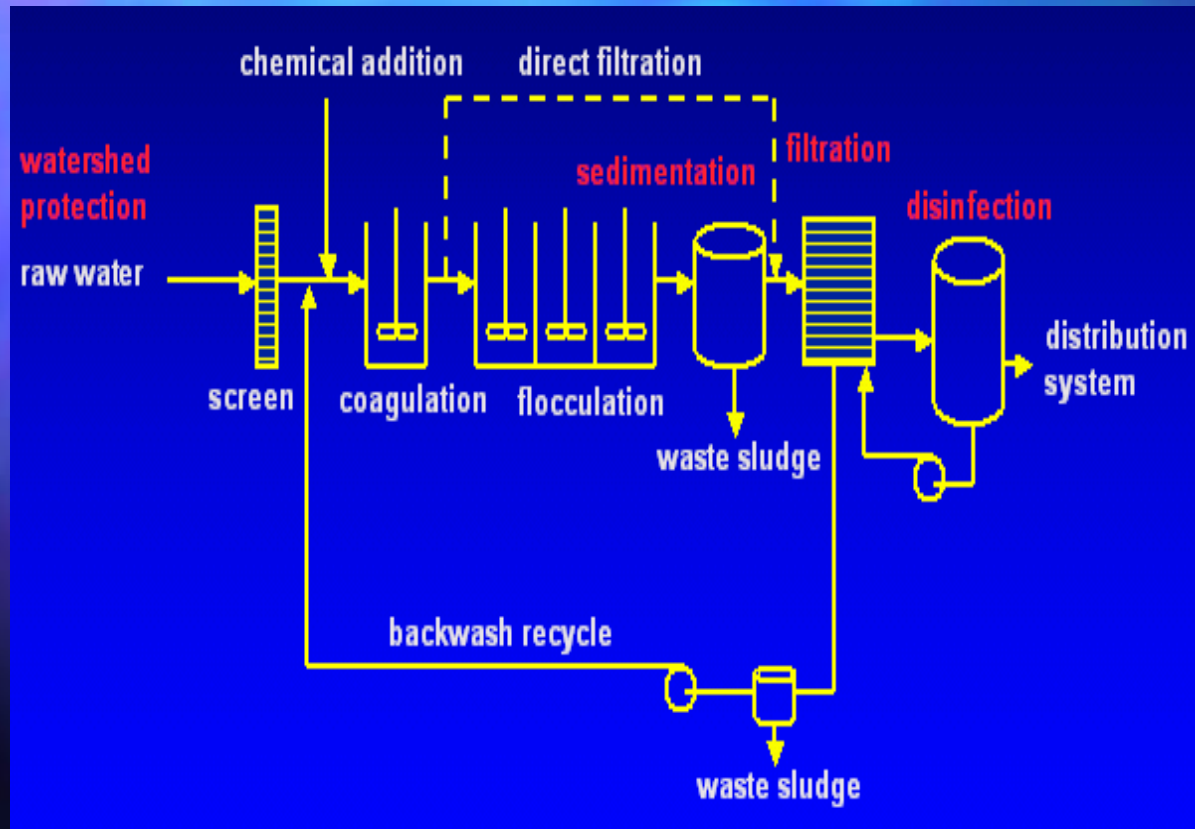
- Turbidity is the cloudy appearance of water caused by small suspended particles
- Commonly referred to as non-settleable or colloidal solids



Particles in Water

- Chemicals in solution (have been completely dissolved in the water).
- Colloidal solids, also known as nonsettleable solids (do not dissolve in water although they are electrically charged).
- Suspended, or settleable solids (will settle out of water over time).

Conventional Coagulation/Flocculation Process



- Pretreatment
- Chemical Feed
- Flash Mixing
- Coagulation & Flocculation
- Sedimentation
- Filtration
- Disinfection

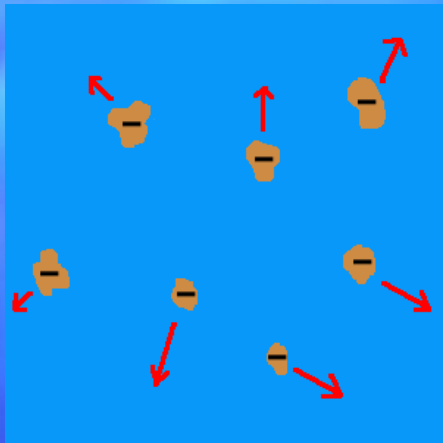
Pretreatment Considerations in the Coagulation/Flocculation Process



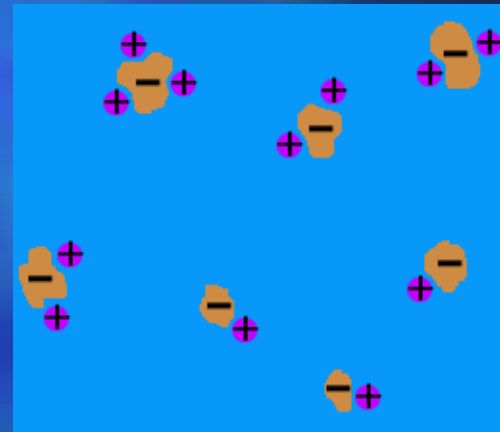
Factors that May Dictate Pretreatment

- Leaves, plant material and silt
- Seasonal raw water quality changes caused by drought, high water or temperature changes
- Potential upstream pollution
- Wind conditions
- Algae blooms
- Bacterial problems

Particle Removal by Coagulation



Negatively charged particles repel each other due to electricity.



Positively charged coagulants attract to negatively charged particles due to electricity.

- Coagulants neutralize negative charged particles
- Allows particles to come closer and form larger clumps
- Provides "agglomeration sites" for larger floc

Factors Affecting the Effectiveness of the Coagulation Process

- Best pH (pH Range: Al, 5 – 7 ; Fe, 5 – 8)
- Alkalinity of water (> 30 PPM residual)
- Concentration of Salts (affect efficiency)
- Turbidity (constituents and concentration)
- Type of Coagulant used (Al and Fe salts)
- Temperature (colder requires more mixing)
- Adequacy of mixing (dispersion of chemical)

Chemical Coagulants used in Water Treatment

Chemical Name	Chemical Formula	Primary Coagulant	Coagulant Aid
Aluminum Sulfate	$\text{Al}_2(\text{SO}_4)_3$	X	
Ferrous Sulfate	FeSO_4	X	
Ferric Sulfate	$\text{Fe}(\text{SO}_4)_3$	X	
Ferric Chloride	FeCl_3	X	
Cationic Polymer	Various	X	X
Calcium Hydroxide	$\text{Ca}(\text{OH})_2$	X ^a	X
Calcium Oxide	CaO	X ^a	X
Sodium Aluminate	$\text{Na}_2\text{Al}_2\text{O}_4$	X ^a	X
Bentonite	Clay		X
Calcium Carbonate	CaCO_3		X
Sodium Silicate	NaSiO_3		X
Anionic Polymer	Various		X
Nonionic Polymer	Various		X


^a - Used as primary coagulant in water softening processes.

Primary Coagulants

- Primary coagulants are always used in the coagulation/flocculation process. Alum and ferric sulfate are most commonly used.
- Different sources of water need different coagulants to react over a wider pH range.
- Primary coagulants have multivalent charges (+2, +3, +4) which allow them to react with the negatively charged colloidal materials in the water.
- All of the coagulant chemicals will remove alkalinity from the water.

Coagulant Aids

- Add density to slow-settling floc and add toughness to the flocs so that they will not break up during mixing and settling processes.
- Not always required and are generally used to reduce flocculation time.
- Effective at extending pH ranges for primary coagulant performance.
- Most are expensive.

Raw Water Parameter	Chemical Consideration
<p>Alkalinity</p> <p><i>Alkalinity is a measure of the ability to neutralize acid.</i></p> <p><i>Alkalinity levels are typically expressed as calcium carbonate (CaCO_3) in mg/L.</i></p> 	<p>Alkalinity influences how chemicals react with raw water. Too little alkalinity will result in poor floc formation, so the system may want to consider adding a supplemental source of alkalinity (such as lime, soda ash, or caustic soda). Beware that these supplemental sources of alkalinity may raise the pH of the water, and further pH adjustment may be needed to obtain proper floc formation. Systems should discuss this issue with a technical assistance provider or a chemical supplier. One rule of thumb is that alum consumes half as much alkalinity as ferric chloride.¹</p>
Alkalinity < 50 mg/L	<p>This concentration of alkalinity is considered low, and acidic metallic salts, such as ferric chloride or alum, may not provide proper floc formation. Systems may want to consider a high basicity polymer, such as polyaluminum hydroxychloride (PACl), or an alum/polymer blend.¹</p>
Increase in total organic carbon	<p>More coagulant is typically needed. Remember, organics influence the formation of disinfection byproducts and systems will need to comply with the Stage 1 Disinfection Byproduct Rule. A good resource is the EPA guidance manual <i>Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual</i> (May 1999).</p>
pH between 5.5 and 7.5	Optimum pH range for alum. ²
pH between 5.0 and 8.5	Optimum pH range for ferric salts. ²
pH > 8.5	Ferric salts might work or other high acidic coagulants ³ .
Temperature < 5°C	<p>Alum and ferric salts may not provide proper floc formation. May want to consider using PACl¹ or non-sulphated polyhydroxy aluminum chloride.³</p>

Use of Alum as a Coagulant

- Earliest and Most Widely Used Coagulant
- Effective Range pH 5.0 to 7.0; (6.5 optimal)
- Effective Range for Color is ~ 5.5
- Reacts with Alkalinity - results in drop in pH
- For every 2 mg/l Alum; 1 mg/l Lime is added to replace alkalinity

Use of Ferrous Sulfate (Copperas) and Lime for Coagulation

- Combination produces Ferric Hydroxide
- pH 8.4 range to 9.0
- Oxygen must added by aeration or chemically such as chlorine
- Very Effective for turbid water
- Care must be taken because color not removed at high pH

Use of Ferric Chloride as a Coagulant

- Has wider pH range than Ferrous Sulfate
- Typically used where color removal is also desirable.
- Does not require oxygen supplement

Use of Ferric Sulfate as a Coagulant

- Does not require oxygen supplement
- Effective over wider pH ranges
- Effective within all temperature ranges
- Eliminates odors from existing Hydrogen Sulfide
- Lower doses required than Ferrous Sulfate

Use of Coagulant Aids

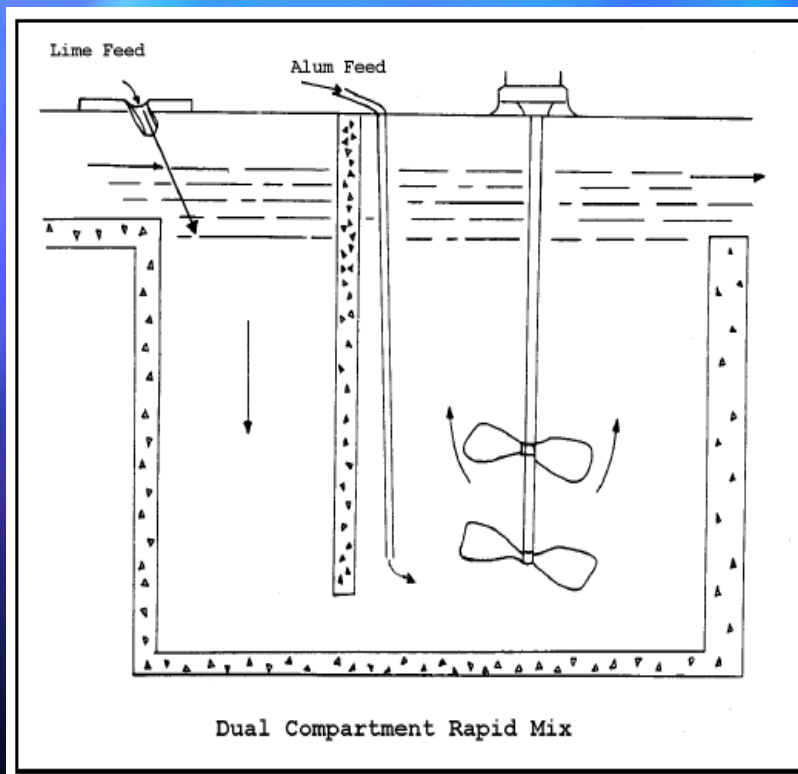
- Lime
- Weighting Agents
- Polymers
 - Cationic +
 - Anionic -
 - Nonionic

Coagulant Mixing and Flash Mixers

Purpose of the flash mix process is to rapidly mix and equally distribute the coagulant chemical throughout the water.

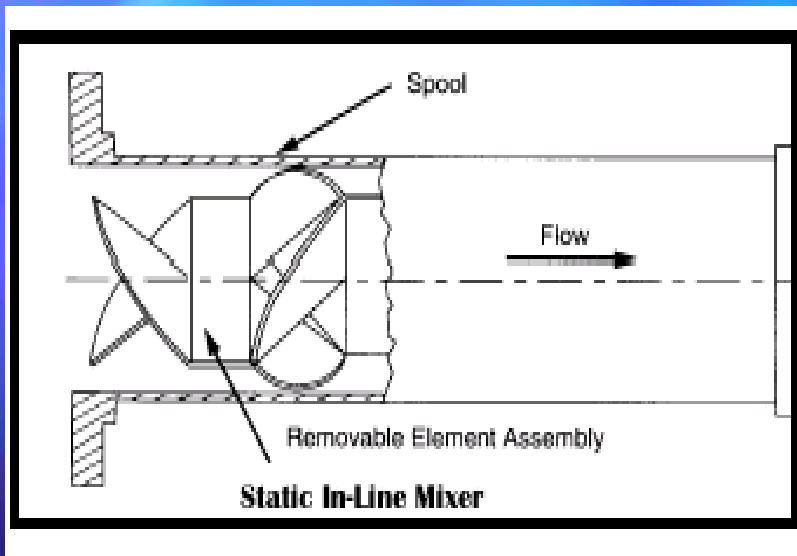
- Coagulant must make contact with all of the suspended particles.
- Process occurs in seconds.
- First results are formation of very small particles.
- Detention time and the speed of the mixer should be sufficient to thoroughly mix all the chemical with no breakup of floc particles.

Mixing Coagulants and Coagulant Aids



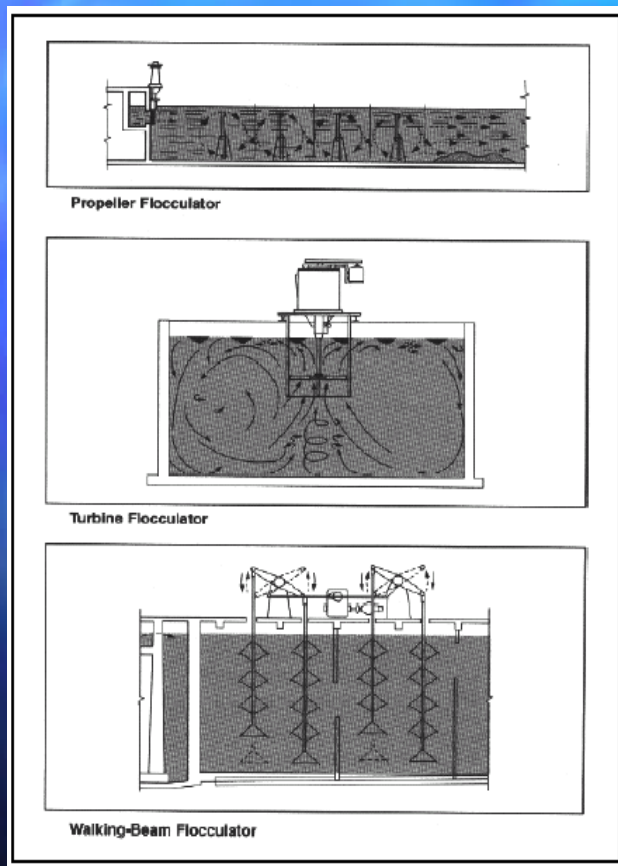
- Rapid/Flash Mix typically occurs in a tank
- Mixing velocity 5 – 7 fps
- Coagulant and coagulant aids added in first chamber

Static Mixer for Polymers



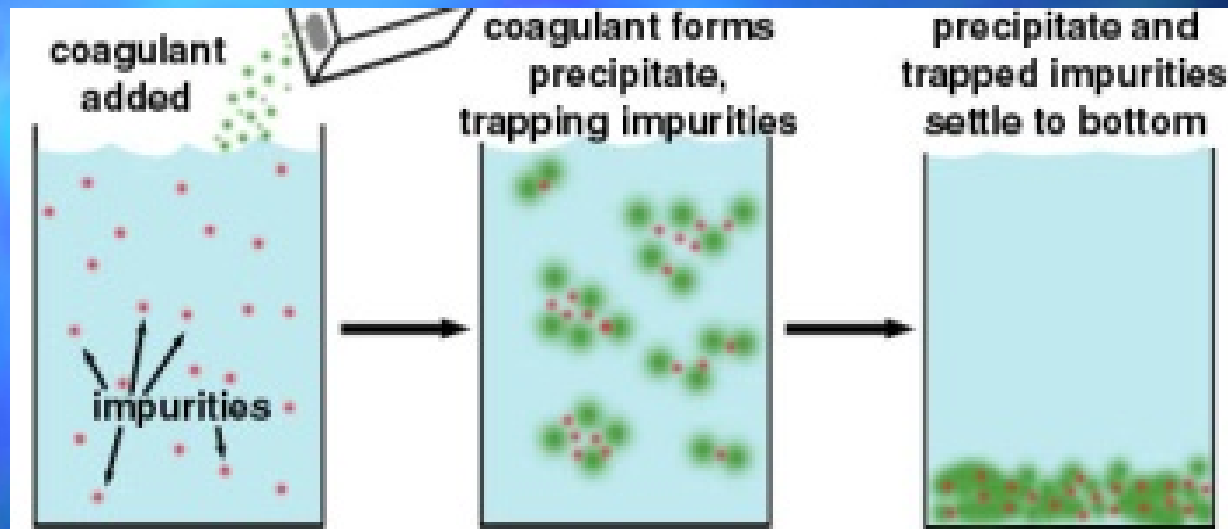
- Used prior to Coagulation
- Addition of oxidizing agents, GAC and polymers
- Used as far as possible upstream to maximize contact time

Flocculation Process



- Flocculation is a slow stirring process that causes the gathering together of small, coagulated particles into larger, settleable particles.
- Controlled by the rate of collisions between particles and the effectiveness promoting attachment.
- Changes in temperature can necessitate longer detention times.

Flocculation Followed by Sedimentation



- Instantaneous mix of coagulants
- Neutralizes the negative charges on colloids
- During the gentle mixing of flocculation, allows particles to agglomerate into larger particles
- Heavier particles are removed by settling

Importance of Flocculator Speed

- If the speed of the stirring process is too great then the floc particles will be “sheared” or broken apart causing an increase in turbidity.
- If flocculator speed is too slow then “short-circuiting” may occur.
- Purpose is to create a floc of good size (0.1 to 3mm), density, and toughness for later removal in the sedimentation and filtration processes.

What is Short-Circuiting?

"A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water."

May result in shorter contact, reaction, or settling times.

Desirable Floc Quality



- A popcorn flake is a desirable floc appearance.
- Smooth circular particles tend to settle quicker while irregular shaped particles settle slower.
- Tiny alum floc may be an indication that the chemical dosage is too low.
- If the water has a milky appearance or a bluish tint, the alum dose is probably too high.
- Should be increasing in size as it moves through the basins

Performance Monitoring

- Mixing needs to be adequate
- Monitor pH for optimum conditions
- Flow measurement is important to accurately establish chemical feed rates, wash water rates, and unit loadings
- Chemical feed systems need dosage control
- Jar Test at the Start of Every Shift or more!

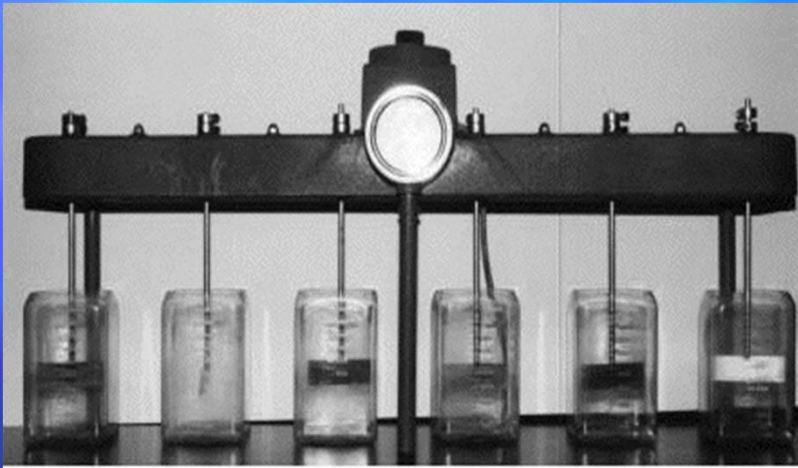
What adjustment should be made in the speed of flocculators when the water temperature drops?

Increase Speed

Performance Measurement Using the Jar Test

- A jar test is a laboratory procedure where varying dosages of coagulant are tested in a series of glass or plastic jars under identical conditions.
- The jars are injected with coagulant dosages and gently paddled or flocculated to match field conditions as closely as possible.
- After a set of time to simulate field conditions the jars are observed to determine which dosage produces the largest, strongest floc or which dosage produces the floc that settles the fastest.
- Other laboratory tests sometimes include a jar test to determine the optimal pH or determine the turbidity of the settled water and its filterability.

Jar Test Apparatus and Procedures



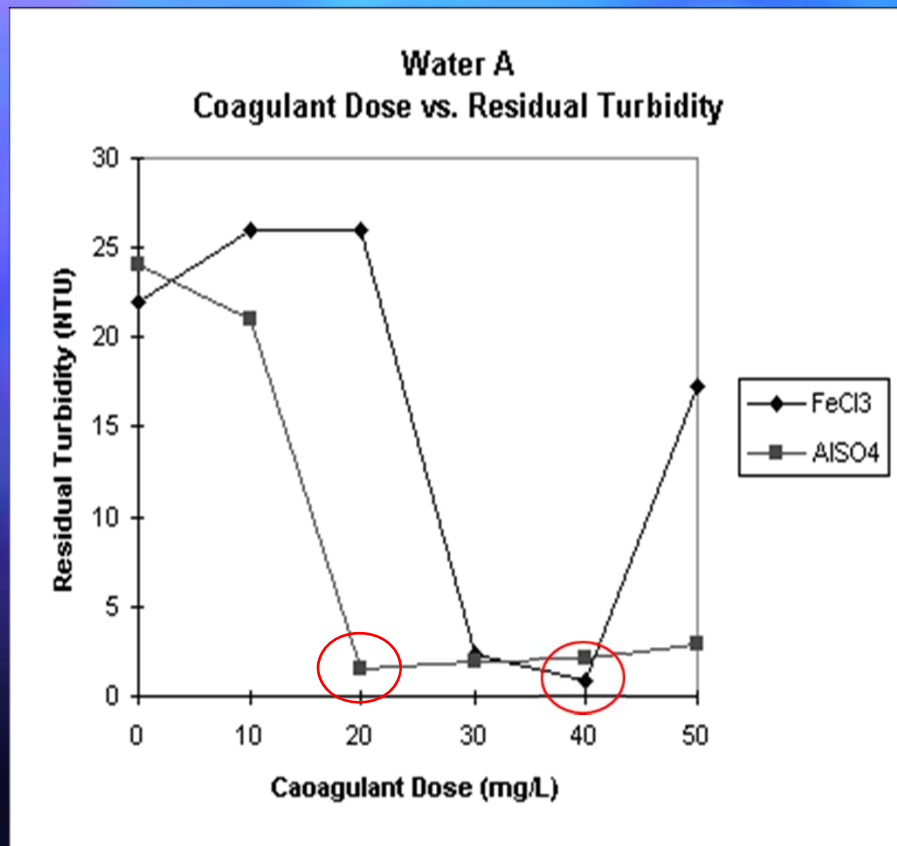
- Six paddles
- One container is control
- RPM gauge allows for mixing speed to match plant conditions

Flash Mix: 1 Minute at 80 RPM

Flocculation: 30 Minutes at 20 RPM

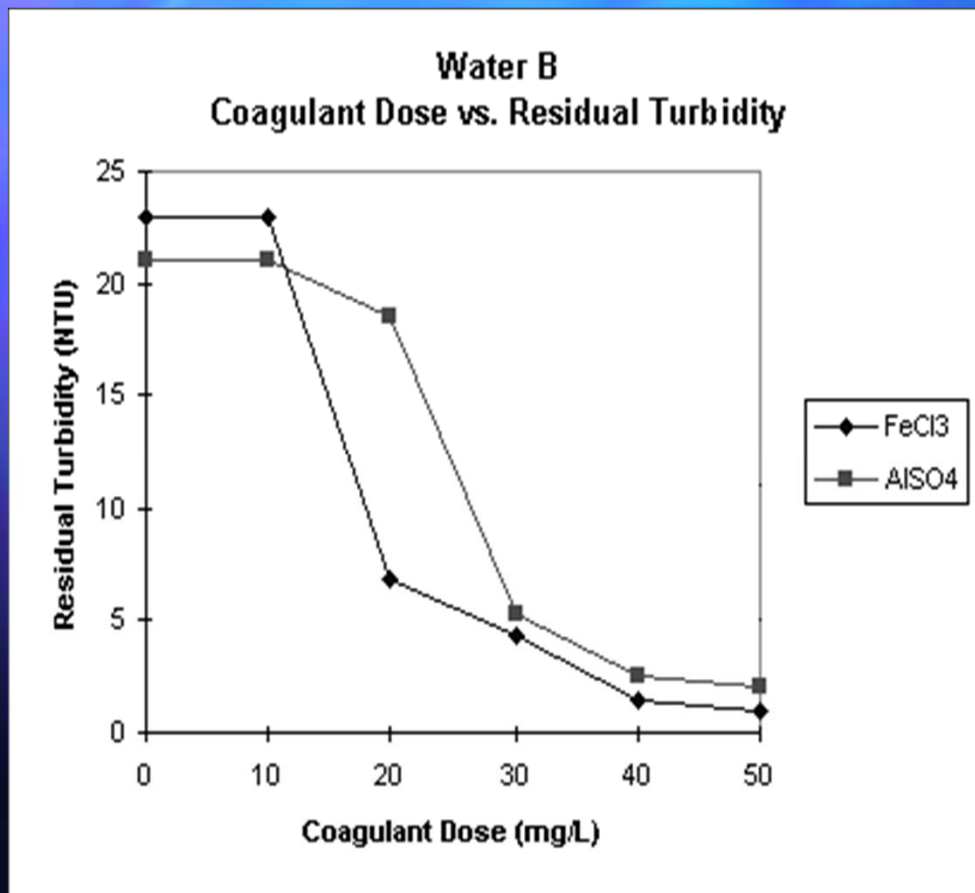
Settling: 30 Minutes

Jar Test Plot for Low Alkalinity Water



- Alum initially reacts with low alkalinity
- With Ferric Chloride requires chemical to reach optimal pH before reacting
- Adding too much coagulant increases turbidity

Jar Test Plot for Higher Alkalinity Water

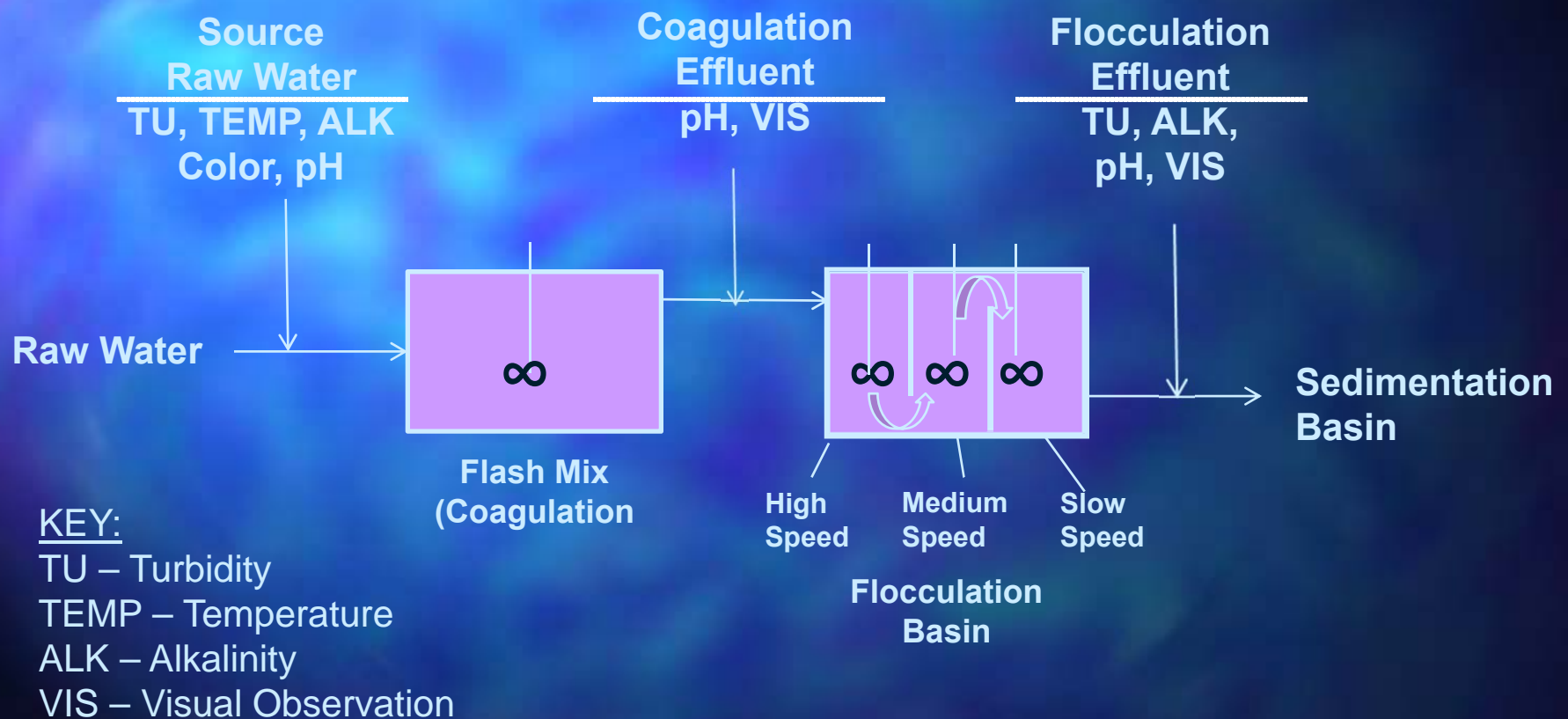


- Higher Coagulant doses are needed for high alkalinity waters
- Ferric Chloride required more chemical but reached lower turbidity
- Since Alum did not produce water < 1 NTU a coagulant aid is necessary

Evaluation of Jar Test Results

- Rate of Floc Formation (15 min.)
- Type of Floc Particles (circular or popcorn)
- Clarity of the Water between the Floc
- Size of the Floc (.1 to 3 mm)
- Amount of Floc (too little may need agent)
- Clarity of Water above Settled Floc (clear)
- Volume of Floc

Coagulation-Flocculation Process Monitoring and Sampling Points





Corrosion and Corrosion Control

What is Corrosion?

Corrosion is the gradual decomposition or destruction of a material (such as metal or cement lining) as it reacts with water.



Corrosive Water

- Weakens pipes and equipment, including residential plumbing.
- Dissolves toxic metals such as lead and copper from the distribution system or house plumbing into the drinking water.
- Causes color, taste, and odor problems when metals such as iron and copper are dissolved into the water.
- Causes TUBERCULATION which can reduce capacity of system, increase pump energy costs, and reduce system pressures.

Types of Electrochemical Corrosion

- Metallic corrosion
- Galvanic corrosion

Conditions for Corrosion to Occur

Corrosion is a chemical reaction and requires three things:

1. Anode – Point from which metal is lost and electric current begins.
2. Cathode – Point where electric current leaves the metal and flows to the anode through the electrolyte.
3. Electrolyte – Conducting solution (usually water with dissolved salts)

Galvanic Series

ANODE

(Most Active)



CATHODE

(Least Active)

Magnesium
Zinc
Aluminum (2S)
Cadmium
Aluminum (175T)
Steel or Iron
Cast Iron
Lead – Tin Solder
Lead
Nickel
Brasses
Copper
Bronzes
Stainless Steel (304)
Monel Metal
Stainless Steel (316)
Silver
Graphite
Gold

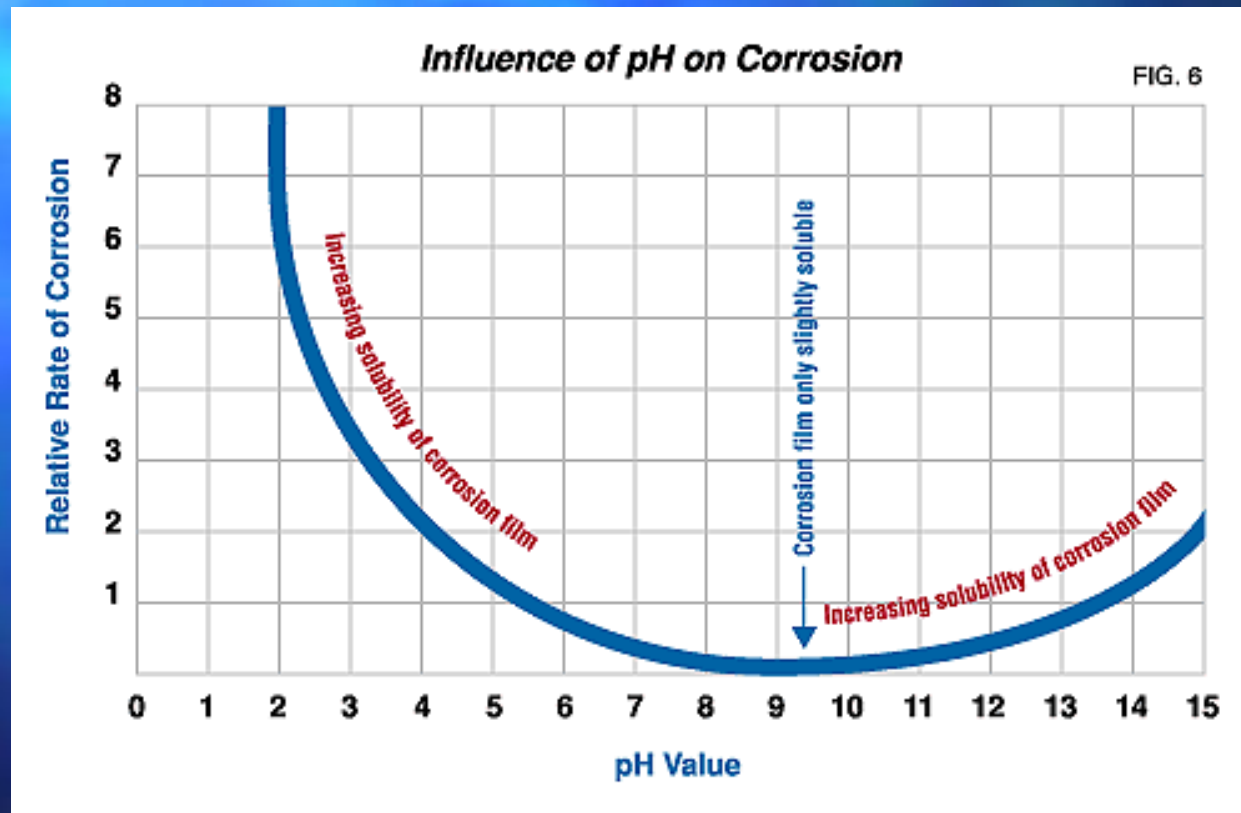
Physical Factors Influencing Corrosion

- Type and arrangement of materials
- System pressure
- Soil moisture
- Presence of stray electric currents
- Temperature
- Water flow velocity

Chemical Factors Influencing Corrosion

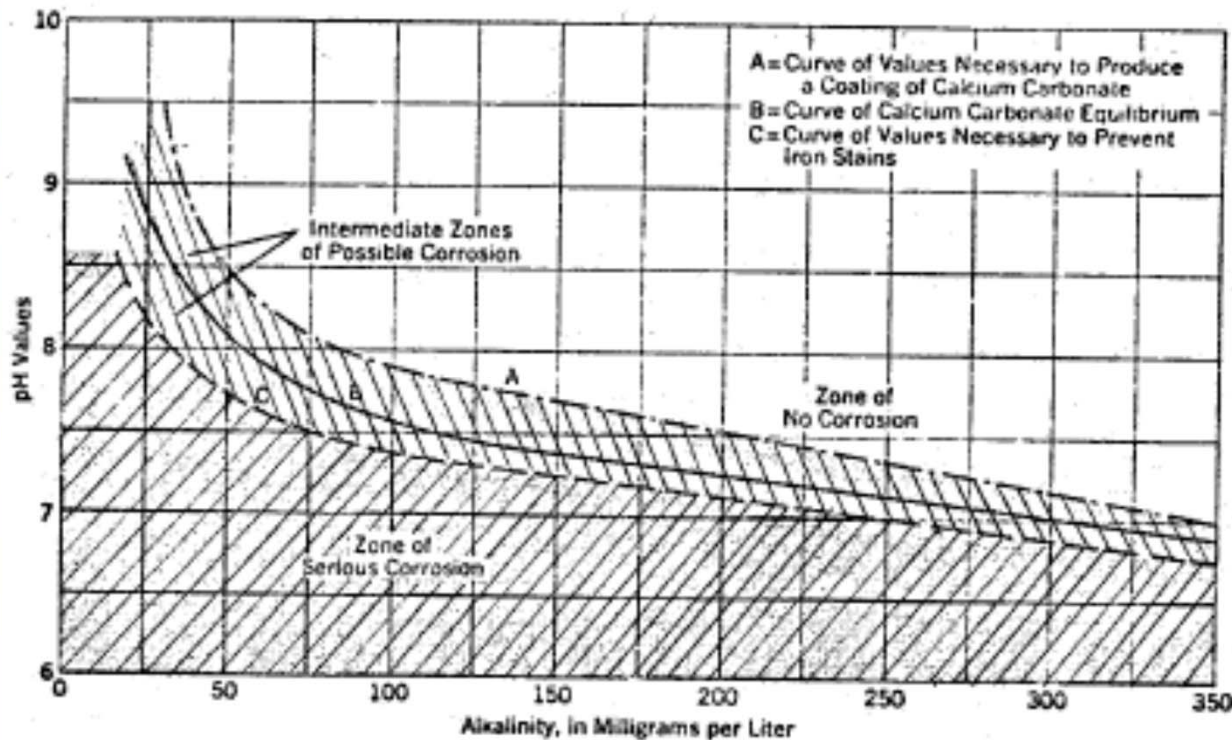
- Water's pHs
- Water alkalinity
- Chlorine residual
- Dissolved solids and gases in the water
- Types and concentrations of minerals present

Effects of pH on the Rate of Corrosion in Water Treatment



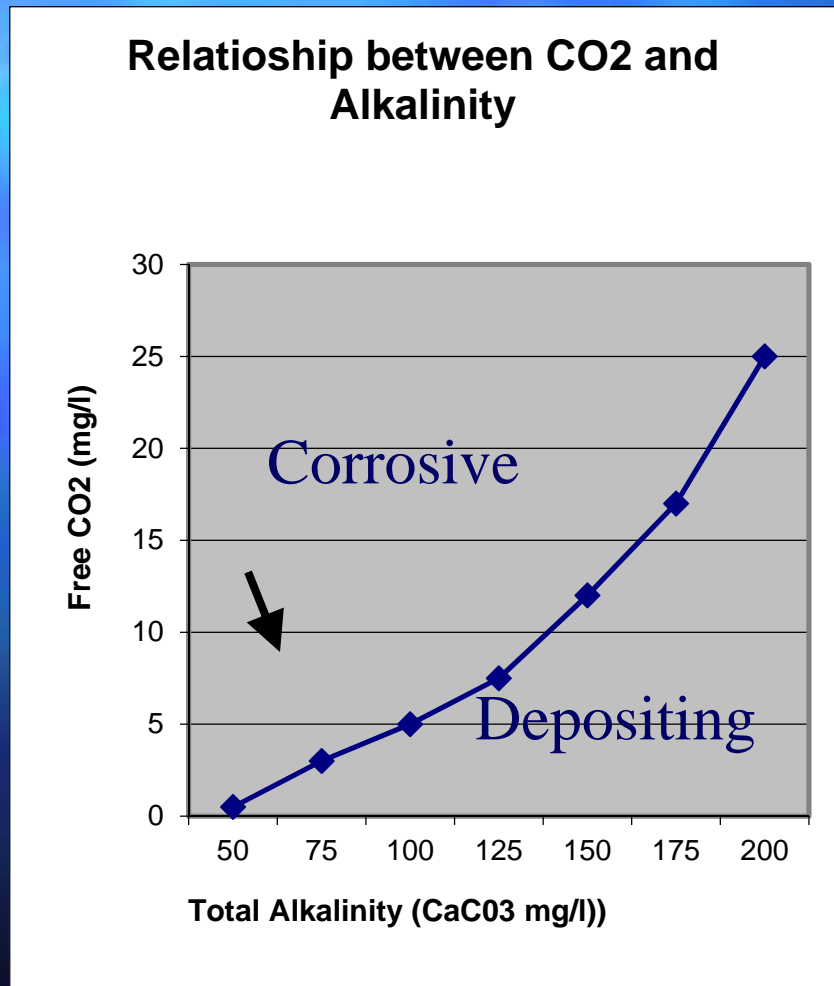
Relationships between Alkalinity, pH

FIGURE ALKALINITY VS PH



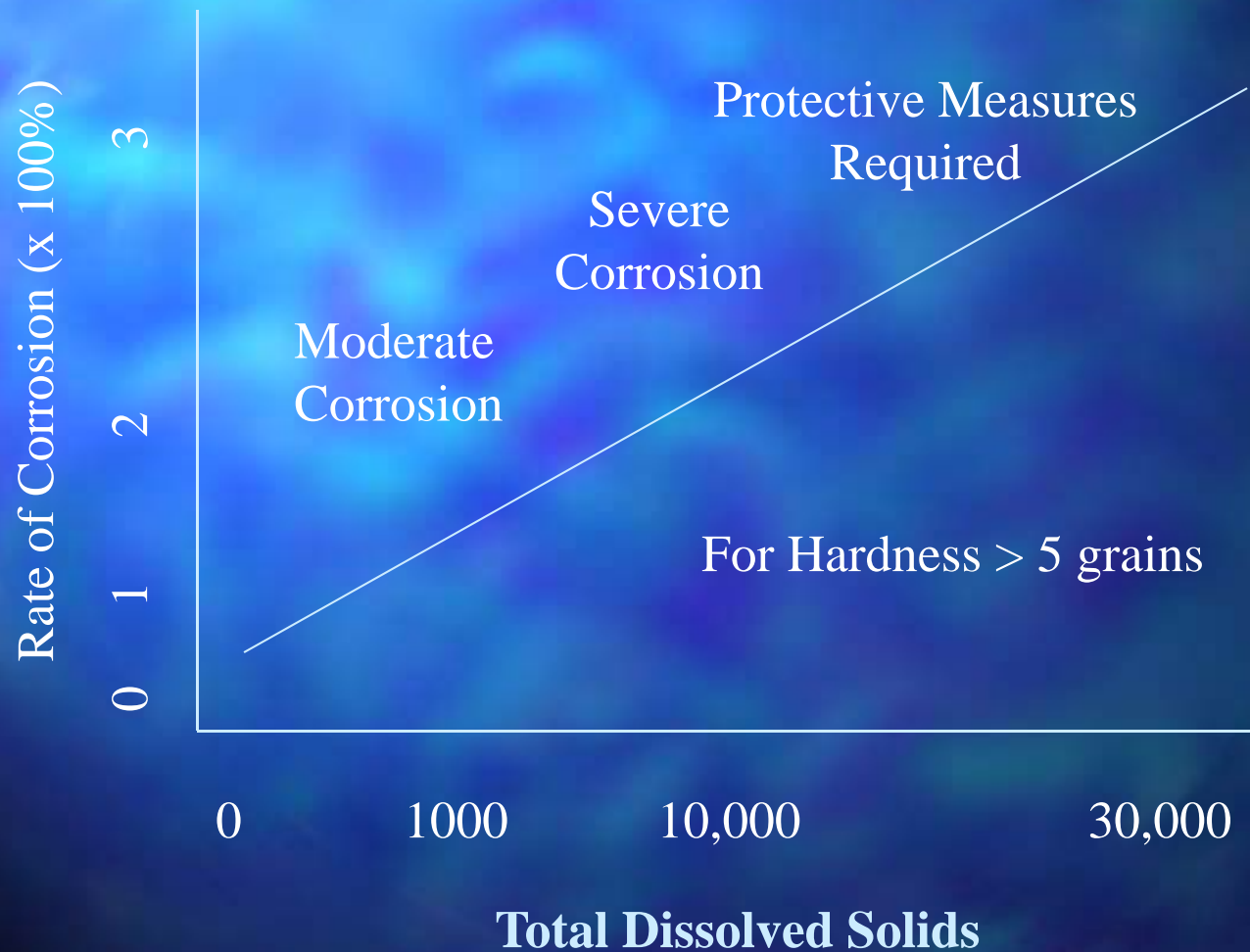
A Water can be Corrosive or Depositing based upon it's pH and Alkalinity.

Carbon Dioxide Content in Water Greatly Affects it's Corrosivity



A Water with High Concentration of CO₂ will be very Corrosive. CO₂ is often removed to it's ambient air concentration of 3.5 – 4 PPM by Aeration.

Effect of Dissolved Solids on Rate of Corrosion



Biological Factors Influencing Corrosion

- Iron bacteria
- Sulfate-reducing bacteria

Types of Chemical Corrosion in a Water System

- Galvanic Dissimilar metals in contact in water. Frequently occurs in service lines.
- Pitting Caused by scratches or imperfections in metal pipe. Can result in holes in pipe.
- Tuberculation Caused by metal ion transfer and development of electrolytic cell formation inside pipe. Can result in large deposits.
- Crevice Occurs at joints where there is little water movement.
- Biological Bacterial wastes contacting pipe materials. Cause of most taste and odor problems.
- Dealloying Preferential removal of one alloy from a metal. Can result in pipe failure.

Cathodic Protection by Direct Protection or Electrical Polarization

- Linings are provided that shield metal surfaces from contact with water
- Selecting dissimilar metals that result in flooding or Polarizing the cathode with electrons. Sacrificial (magnesium) anodes decay in the water slowly, providing protection
- Electronic cathodic protection system polarizes by supplying a continuous flow of electrons from the anode (metal surface) through the water carrier to the cathode

Other Chemical Corrosion Protection Mechanisms

- Removing Corrosive Agents - Treating the water that removes contaminants such as CO₂, or dissolved solids thus reducing rate of corrosion in the water.
- Chemical Addition - Adding chemicals that slow the chemical corrosion reaction rates by raising the pH and Alkalinity of the water
- Sequestering – Adding phosphates that tie up a particular metal in solution at the metal surface.

Corrosion Control by Adjusting pH or Alkalinity

- Adjustment of water chemistry
 - pH
 - Alkalinity
- Thin Coating is provide to protect water mains and plumbing



Chemical Stabilization

Recap

- For high pH waters, lower the pH by adding sulfuric acid or carbon dioxide
- For low pH waters, lime, soda ash, sodium bicarbonate, or caustic soda can be added to raise pH
- Sequestering agents or silicates can be added that chemically tie up the scale forming ions

Concepts of Alkalinity and Chemical Adjustment

- Alkalinity increases when an alkali is added to a water
- Carbon dioxide is produced in a water when alkalinity is consumed
- Carbon dioxide is destroyed when an alkali is added to a water.
- The pH of a water will decrease when carbon dioxide is formed and will increase when CO_2 is destroyed.
- Knowing the changes that various chemicals make to alkalinity and carbon dioxide levels allows prediction of the pH of the water as a result of different treatment regimes

Chemicals Used in Water Treatment that change Alkalinity and pH

Lower

- Gas Chlorine
- Sulfuric Acid (Muriatic)
- Carbon dioxide
- Alum
- Ferric Chloride
- Hydrofluosilicic Acid

Raise

- Sodium Hydroxide
- Calcium Hydroxide (Lime)
- Sodium bicarbonate (Soda)
- Sodium Carbonate (Soda Ash)
- Calcium Hypochlorite

All Acids and Bases Raise and Lower Alkalinity and CO₂ content when applied

CHEMICAL	Δ □mg ALKALINITY, CaCO ₃ per mg CHEMICAL	Δ□ mg CO ₂ , per mg CHEMICAL
Alum	-0.45	0.40
H ₂ SO ₄	-1.02	0.90
HCl	-1.37	1.20
Ca(OH) ₂	1.35	-1.19
Na ₂ CO ₃	0.94	-0.41
NaOH	1.25	-1.10
NaOCl	0.67	-0.59
Chlorine (gas)	-1.41	1.24

Determining pH of Water

$$\text{pH} = \log \left\{ 2.2 \times 10^6 \times \frac{(\text{Alkalinity in mg/l as CaCO}_3)}{(\text{CO}_2 \text{ in mg/l})} \right\}$$

Measured Alkalinity 60 mg/l as CaCO ₃	Measured CO ₂ = 7.4 mg/l
---	--

$$\text{pH} = \log \left\{ 2.2 \times 10^6 \times 60/7.4 \right\} = 7.25$$

Approximate pH between 7.0 to 8.0 at TDS ~ 100 ppm

Adjusting Alkalinity and pH

Measured Alkalinity - 60 mg/l (as CaCO_3); Desired 75 mg/l
 Measured CO_2 - 7.4 mg/l

Chemical	Alkalinity Value	CO_2 Value
Na_2CO_3	0.94/mg/l	- 0.41 mg/l
Amount Alkalinity Needed (75 - 60) = 15		$\frac{15}{0.94} = 16 \text{ mg/l Na}_2\text{CO}_3$
Alkalinity = 60 + 15 = 75 mg/l as CaCO_3		
$\text{CO}_2 = 7.4 \text{ mg/l} + (15 \times -0.41) = 1.25 \text{ mg/l}$		
New pH = $\log \{2.2 \times 10^6 \times 75/1.25\} = 8.12$		

Determining CaCO_3 Saturation Using the Marble Test

Sample Compares	Water Stability	Saturation CaCO_3
pH and Alkalinity Increases	Water is Corrosive	Water is Under Saturated
PH and Alkalinity Decrease	Water is Scale Forming	Water is Supersaturated
PH and Alkalinity the same	Water is Stable	Water is Saturated

CaCO_3



Acid

Use of the Langelier Index for Determining Water Stability

- Every water has a particular pH value where the water will neither deposit scale nor cause corrosion.
- A stable condition is termed saturation.
- Saturation (pH_s), varies depending on calcium hardness, alkalinity, TDS, and temperature.
- The Langelier Index = $\text{pH} - \text{pH}_s$
Corrosive $0 > \text{LI} > 0$ Scale Forming

Recommended Treatment for Corrosive and Scaling Water based on LI

Saturation Index	Description	General Recommendation
- 5	Severe Corrosion	Treatment Recommended
- 4	Severe Corrosion	Treatment Recommended
- 3	Moderate Corrosion	Treatment Recommended
- 2	Moderate Corrosion	Treatment May Be Needed
-1	Mild Corrosion	Treatment May Be Needed
-0.5	None- Mild Corrosion	Probably No Treatment
0	Near Balanced	No Treatment
0.5	Some Faint Coating	Probably No Treatment
1	Mild Scale Coating	Treatment May Be Needed
2	Mild to Moderate Coatings	Treatment May Be Needed
3	Moderate Scale Forming	Treatment Advisable
4	Severe Scale Forming	Treatment Advisable

Calculate LSI for Example

$$\text{pHs} = A + B - \log [\text{Ca Hardness}] - \log [\text{Alk}]$$

Temp. 23°C , TDS 158, Ca 20, Alkalinity 75 mg/l, pH 8.12

1. Convert Ca to CaCO_3 Equivalent

$$2.5 \times 20 \text{ mg/l} = 50 \text{ mg/l Ca as } \text{CaCO}_3 \text{ and}$$

$$\text{Alkalinity} = 75 \text{ mg/l as } \text{CaCO}_3$$

2. Compute A and B Values from Table

$$A = 2.01 \quad B = 9.78$$

3. Compute pHs

$$\text{pHs} = 11.8 - \log [\text{Calcium Hardness}] - \log [\text{Alkalinity}]$$

$$= 11.8 - 1.7 \text{ (from table)} - 1.9 \text{ (from table)}$$

$$= 8.2$$

4. Compute LSI

$$\text{LSI} = \text{pH} - \text{pHs.}$$

$$\text{LSI} = 8.1 - 8.2$$

$$\text{LSI} = -0.1 \text{ (slightly corrosive)}$$

Langelier Index Calculation

**Table of Values for Computing pHs
Used in Determination of Langlier Saturation Index (LSI)**

Temperature C	A Value		TDS mg/l	B Value		Ca or <u>Alk</u> as <u>CaCO₃</u> mg/l	<u>log</u> Ca or <u>Alk</u>
5	2.27		50	9.72		10	1.0
10	2.20		100	9.75		20	1.3
15	2.12		200	9.80		40	1.6
20	2.05		400	9.86	→	60	1.8
25 →	1.98		800	9.94	→	80	1.9
30	1.91		1600	10.04		100	2.0
						150	2.2
						200	2.3
						400	2.6

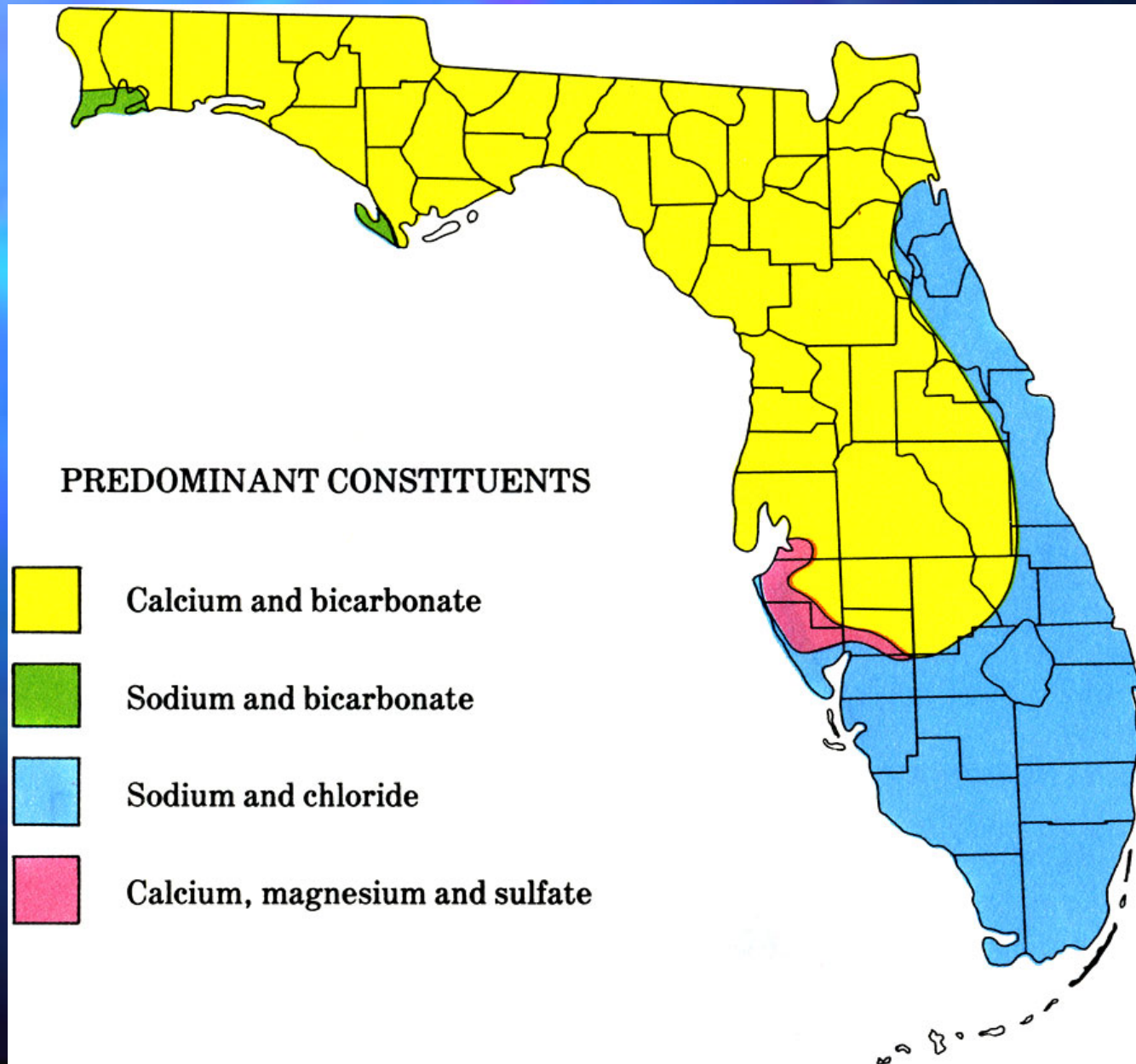
Ca to CaCO₃ Equivalent

ION	CHEMICAL FORMULA	FORMULA WEIGHT	FOR EQUIVALENT AS CaCO ₃ MULTIPLY BY
Aluminium	Al ⁺⁺⁺	27.0	5.56
Ammonium	NH ₄ ⁺	18.0	2.78
Calcium	Ca ⁺⁺	40.1	2.50
Ferric (Iron)	Fe ⁺⁺⁺	55.9	2.69
Ferrous (Iron)	Fe ⁺⁺	55.9	1.79
Magnesium	Mg ⁺⁺	24.3	4.12
Sodium	Na ⁺	23.0	2.18
Potassium	K ⁺	39.1	1.28
Bicarbonate	HCO ₃ ⁻	61.0	0.82
Carbonate	CO ₃ ⁻⁻	60.0	1.67
Chloride	Cl ⁻	35.5	1.41
Hydroxide	OH ⁻	17.0	2.94
Sulphate	SO ₄ ⁻⁻	96.1	1.04

Demineralization (RO, NF, UF, MF, ED, IE)

**"The Rime of the Ancient Mariner": "Water, water,
everywhere / nor any drop to drink."**

Predominant Constituents of Dissolved Solids



Water Supply Classification

- Fresh Water, less than 1,000 mg/l TDS
- Brackish Water, 1,000 – 10,000 mg/l TDS
- Seawater, 35,000 mg/l TDS

Types of Demineralization Processes



Phase Change

- Freezing
- Distillation

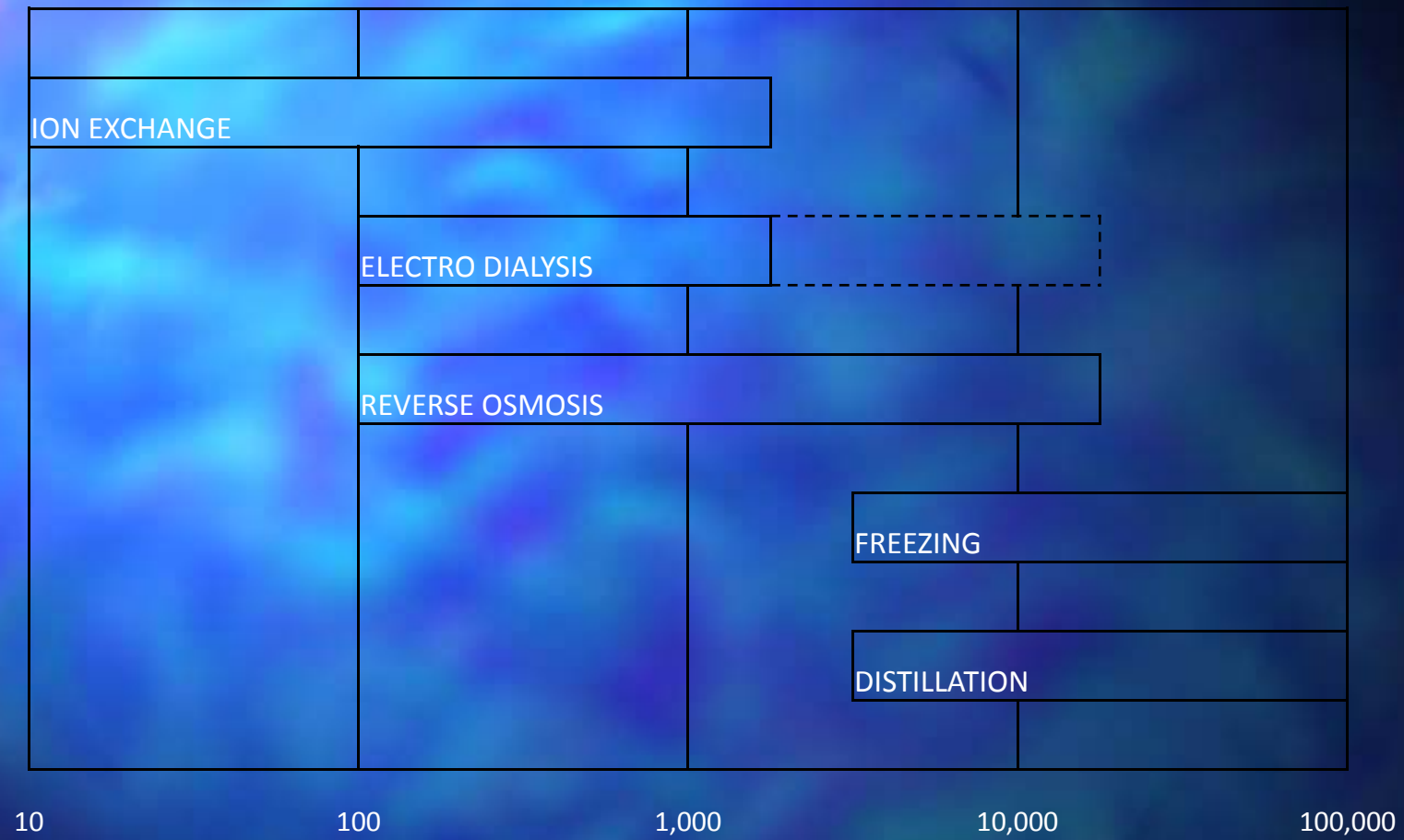
(Seawater)

Non-Phase Change

- Reverse Osmosis
(Membrane Filtration)
- Electro Dialysis
- Ion Exchange

(Fresh to Brackish)

TDS CONCENTRATION, mg/l

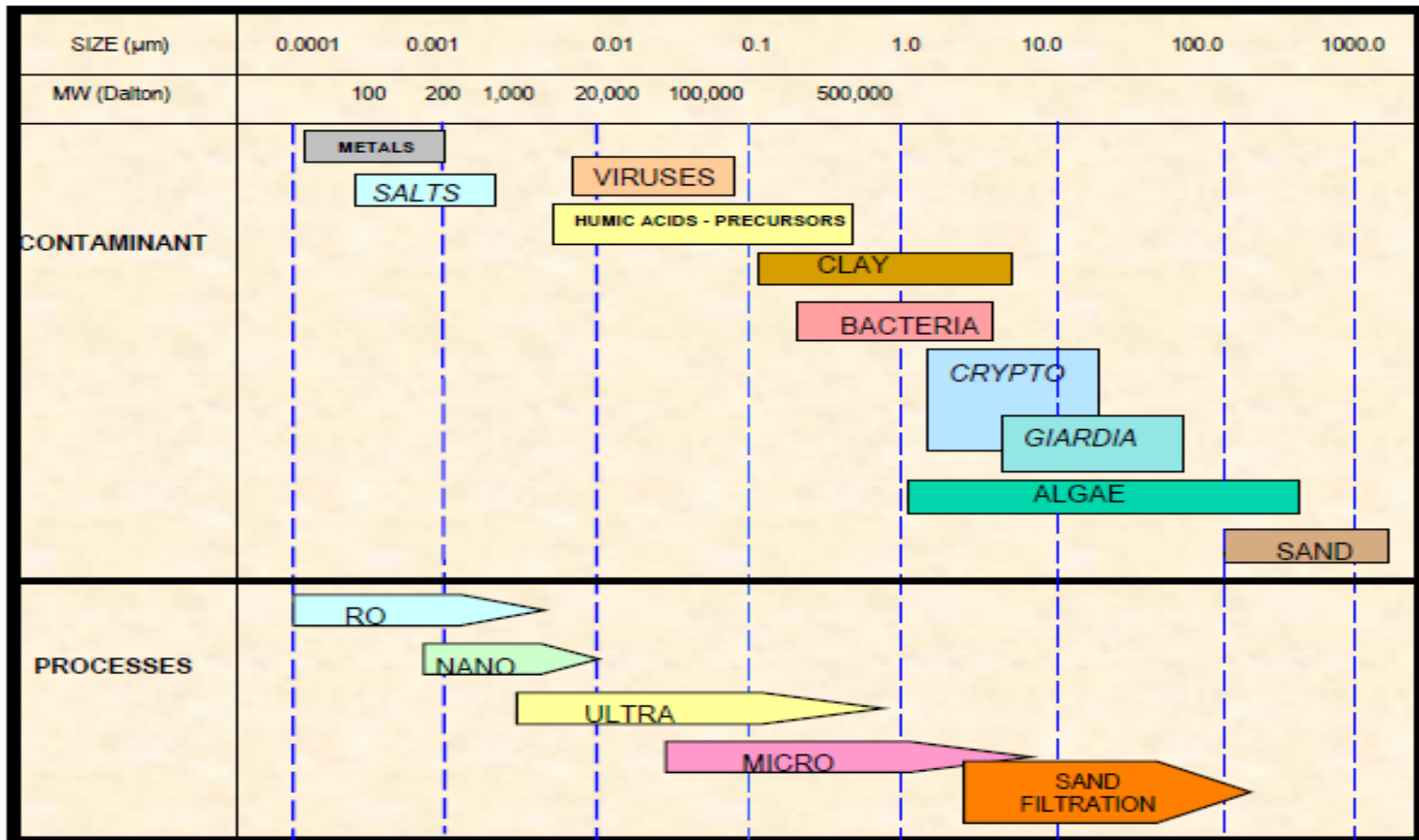


Note: The dashed lines indicate a feasible range of operation, but not typical range.

Selection of Demineralization Process

- Mineral Concentration in Source Water
- Product Water Quality Required
- Brine Disposal Alternatives
- Pretreatment Required
- Other Particle Removal Considerations
- Cost Effectiveness

Membrane Filtration



Graphic courtesy of Watek Engineering

Figure 1.6 Separation Chart

The nanofiltration typically has the highest operating pressures of the other membrane processes shown.


Pressure Filtration Membrane Treatment Systems

Higher Pressures
(150 to 1200 PSI)

- Desalination
 - Reverse Osmosis
 - Conventional Reverse Osmosis
 - Nanofiltration
 - Reverse Osmosis
- 1200
250
150

Lower Pressure
(20 to 70 PSI)

- Electrodialysis
 - Ultrafiltration
 - Microfiltration
 - (Conventional)
- 150
0

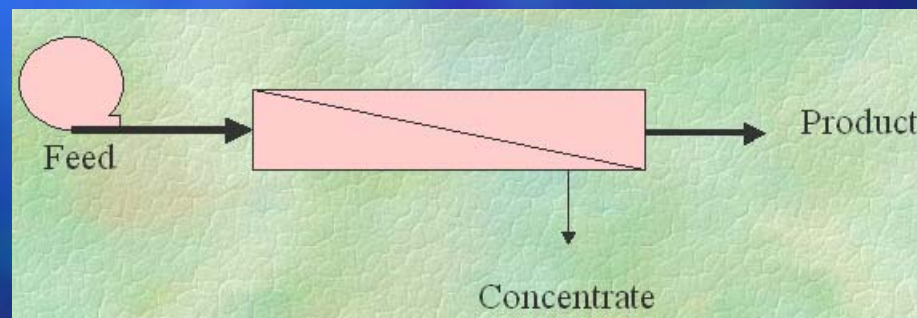


REVERSE OSMOSIS

(includes RO, NF, UF, MF)

Reverse Osmosis

- Reverse Osmosis (RO) systems are used for inorganic mineral removal and for saline water including desalination of sea water.
- RO excludes atoms and molecules < 0.001 microns; the ionic or mineral size range.



RO Treatment Element

Reverse Osmosis Treatment

- Two types of selective membranes are used for demineralization: Cellulose Acetate and Thin Film Composite
- Operated at 200 to 400 psi, @ 5.5 pH
- Salt Rejection above 95%*
- Quality and Quantity of Permeate increase with higher Pressure
- Flow (Flux) Rate depends on Mineral Concentration
- Subject to Fouling from biological contaminants

Components of a Reverse Osmosis System



Reverse Osmosis
System

Pressure Vessel Housing
*Concentrate Control Valve
Sample Valves
Flush Connection
Cleaning Connections
Permeate Rinse Valve
Permeate Drawback Tank
Membranes
Pumps
Piping

*** Never Left Fully Closed!**

Reverse Osmosis Treatment Operating Considerations

- Used for mineral removal only
- Turbidity <1 NTU
- Flux Range 15 – 20 GFD (gallons Flux per day per sq. ft. membrane surface)

Types of Semipermeable Membranes

Cellulose Acetate

- First commercially available membrane
- Operating pressure: 400 psi
- Operating pH: 4.0 – 6.0
- Flux rate: 25 GFD (gallons of flux per square foot per day)
- Subject to biological attack and hydrolysis

Thin Film Composites

- Operating pressure: 200 psi
- Operating pH: 3.0 – 10.0
- More expensive than cellulose acetate membrane
- Higher rejection (98%) and flux rates (25 – 30 GFD)
- Not subject to biological attack, hydrolysis, or compaction but is sensitive to oxidants in feedwater

As the membrane hydrolyzes, both the amount of water and the amount of solute which permeate the membrane increase and the quality of the product water deteriorates.

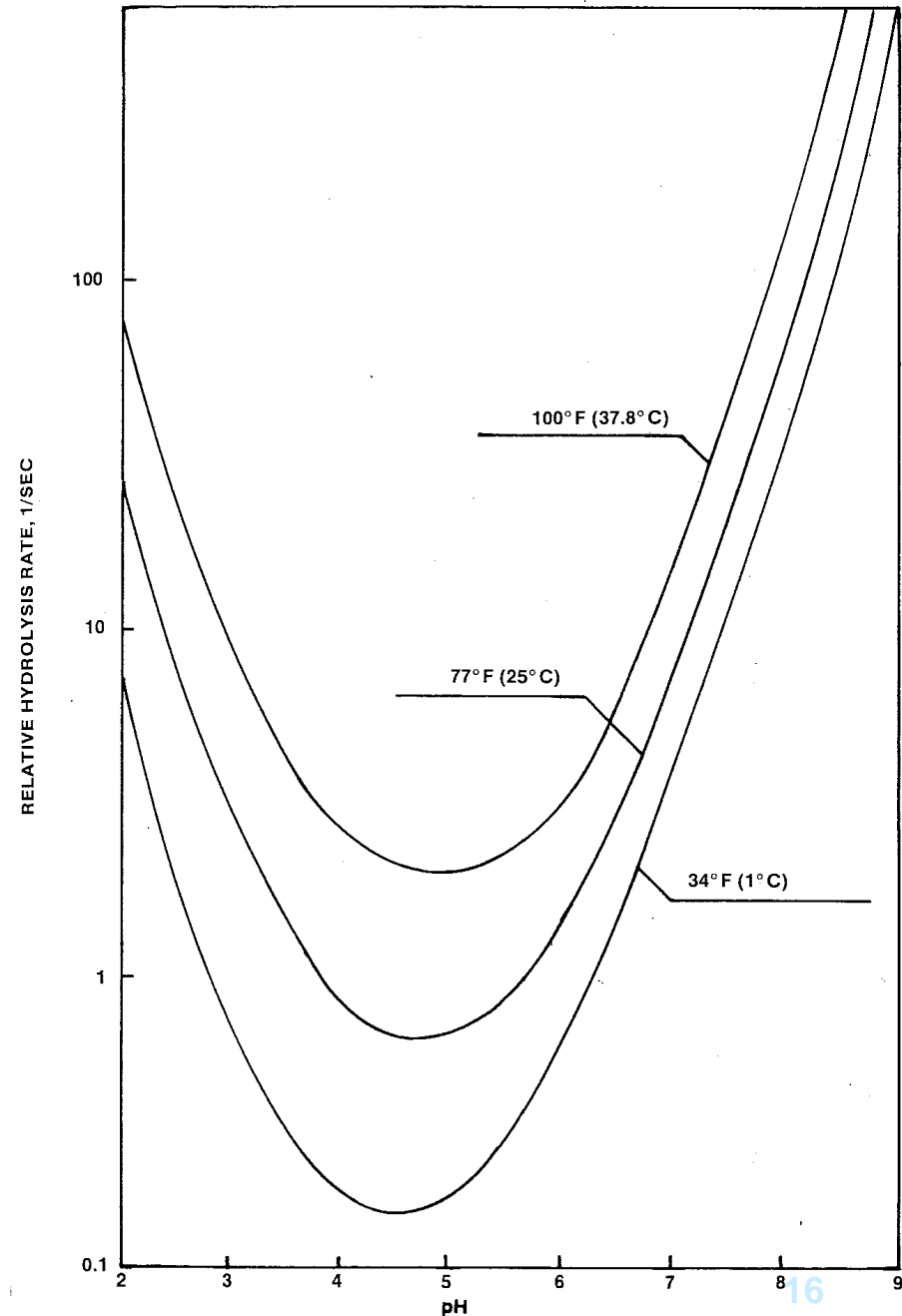
T or F

True

Effect of Temperature and pH on Hydrolysis Rate for Cellulose Acetate Membranes

Time required to achieve a 200% increase in mineral passage at 23°C

pH	Time
5.0	6 years
6.0	3.8 years
7.0	1 year
8.0	51 days
9.0	3.6 days



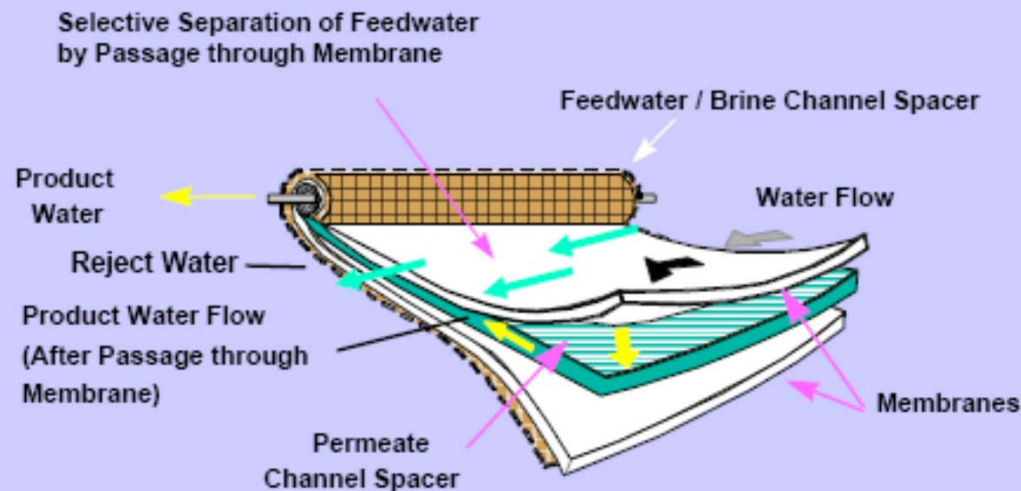
Effect of temperature and pH on hydrolysis rate for cellulose acetate membrane

Membrane Configurations

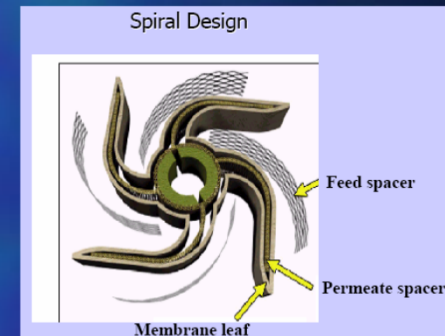
- Spiral Wound
- Hollow Fine Fiber
- Tubular

Spiral Wound Membrane Element Configuration

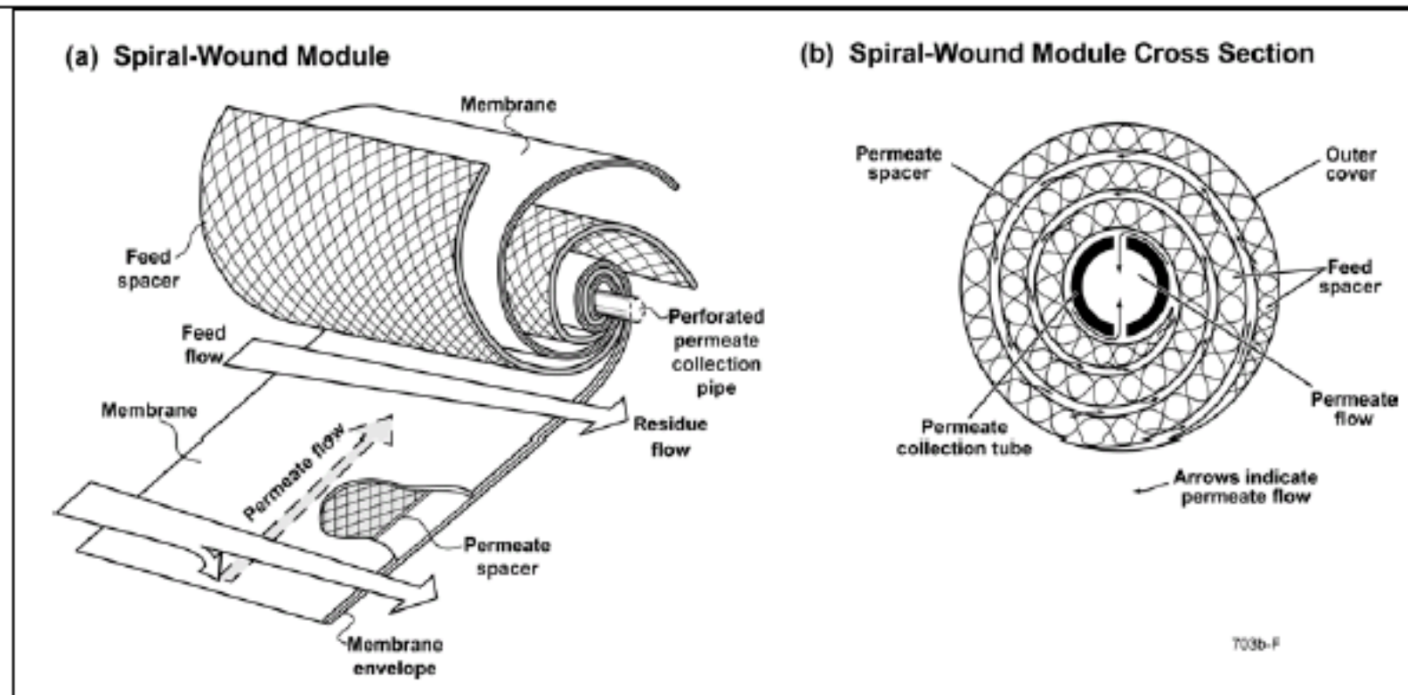
How a Spiral Wound Element Works



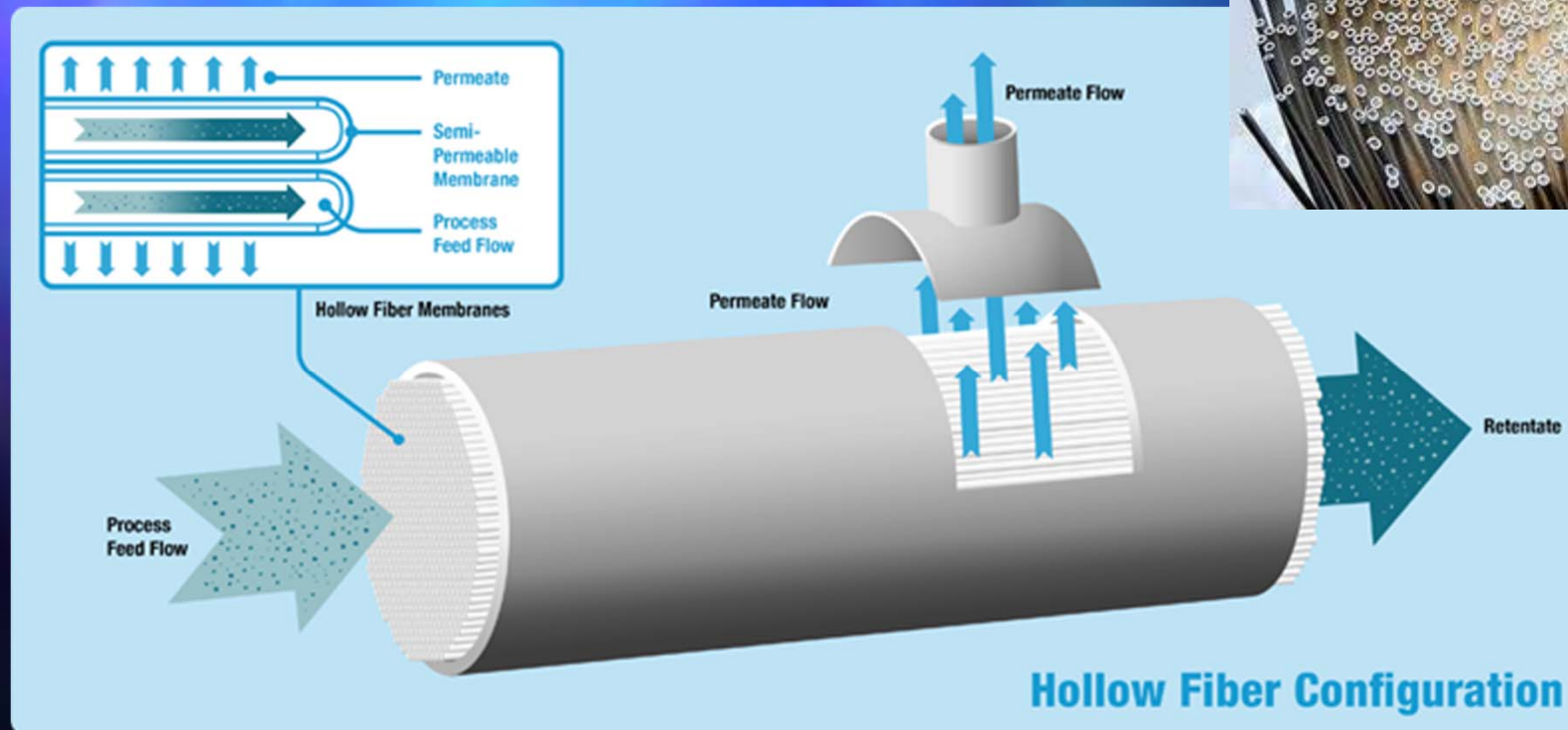
Dow Chemical Co



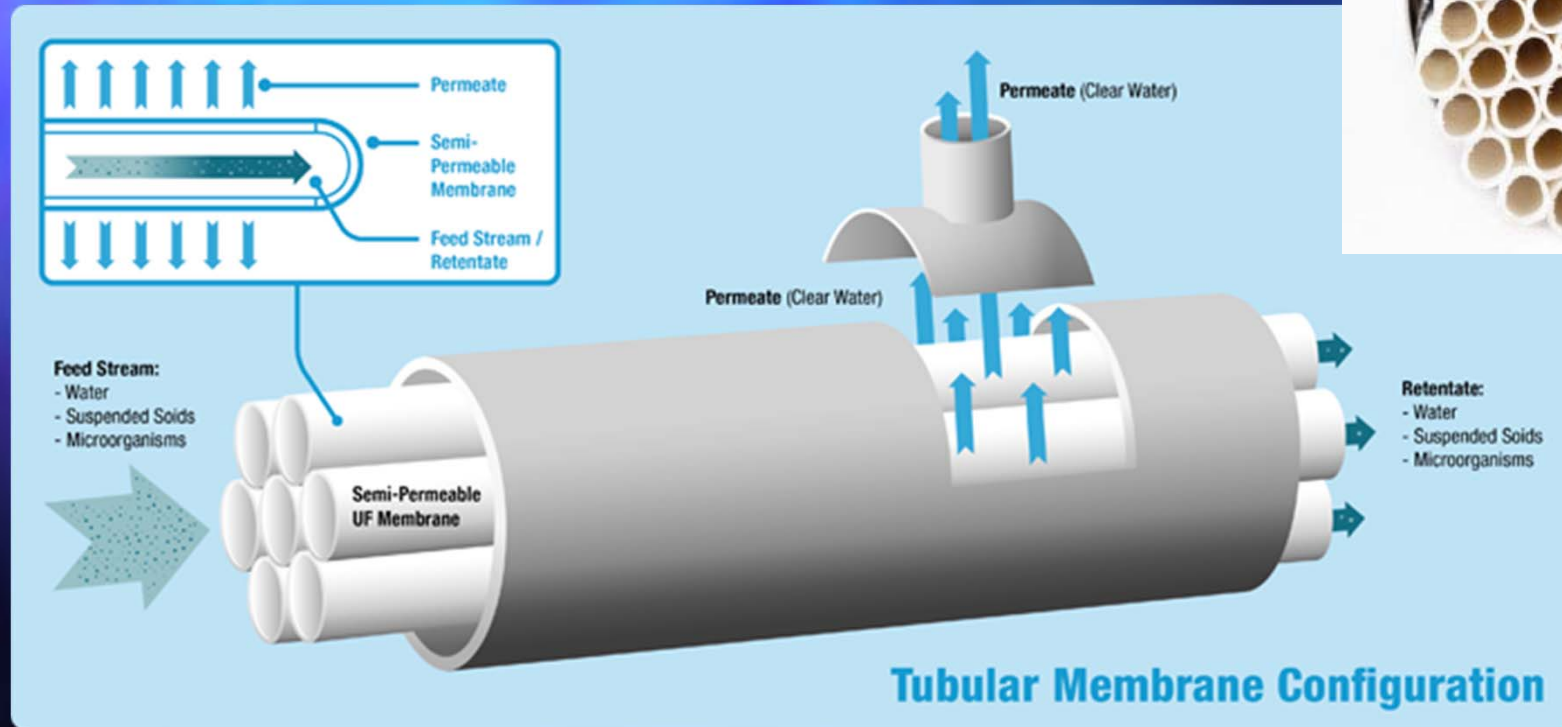
Spiral Wound Membrane



Hollow Fine Fiber Membrane Element Configuration



Tubular Membrane Element Configuration



Constituents Affecting the Reverse Osmosis Process

- pH – slows hydrolysis and extends life of cellulose acetate membranes
- Temperature – as the temperature of the feedwater increases, flux increases
- Suspended Solids & Turbidity
- Mineral Content (salts)
- Microbes

pH Adjustment with Reverse Osmosis

- pH is lowered with acid prior to treatment to prevent minerals from coming out of solution and clogging membranes
- A pH of 5.5 is standard for most feedwater
- If pH and temp. are allowed to increase, Hydrolysis (breakdown of the acetate membranes) will occur and mineral rejection will decrease

Pretreatment Requirements for Reverse Osmosis Systems

What is the most frequently used scale inhibitor?

Hexametaphosphate

<u>Constituent</u>	<u>Problem</u>	<u>Treatment</u>
Gross suspended particulates	Blockage	Media Filtration
Colloidal materials	Fouling	Coagulation/Filtration
Microbiological Matter	Fouling	Add oxidizing agent
Oxidizing agents (Cl)	Failure	GAC or Dechlorination
Carbonates (CO_3 , HCO_3)	Scaling	pH adjust or softening
Sulfate (SO_4)	Scaling	Inhibitor or Cation Rem.
Silica	Scaling	Lime Softening
Iron (Ferric, +3)	Scale/Foul	Greensand (no aeration)
Hydrogen Sulfide (H_2S)	Scale/Foul	Degasification

Removal of Microbial Contaminants with Reverse Osmosis

Why is chlorine added to the feedwater of an RO unit?

Prevent Biological Fouling

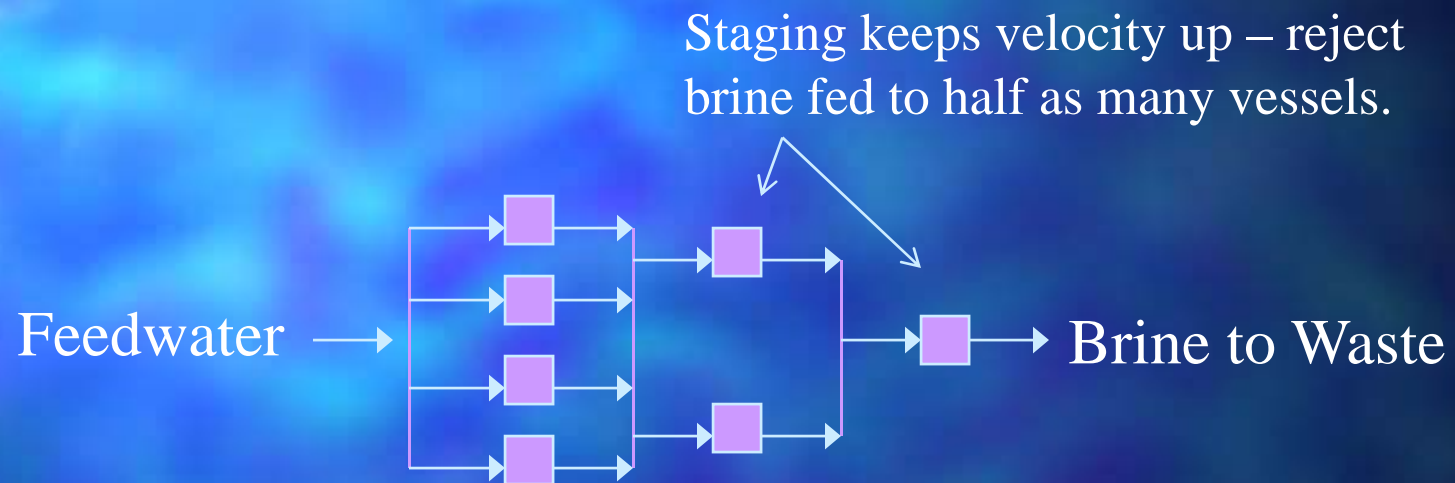
- Organisms removed to keep them from fouling or plugging membranes.
- Organisms can be removed by pre-chlorination and maintaining 1 to 2 mg/l chlorine residual through the RO process. Too much chlorine can impair membrane efficiency.
- If oxidant-intolerant (composite polyamide-type) membranes are used then chlorination must be followed by de-chlorination

Polarization in Reverse Osmosis Systems

- Polarization is the buildup of mineral deposits along the edges of the membrane.
- Polarization reduces both flux and reject
- Polarization is reduced by increasing flow velocity causing deposits to breakaway from the membrane walls.
- Brine flow rates can be kept high as product water is removed by staging.
- The most common and serious problem resulting from concentration polarization is the increasing tendency for precipitation of sparingly soluble salts and the deposition of particulate matter on the membrane surface.

Staging

Vessels in a 4-2-1 configuration yields an 85% recovery of feedwater as product water.



Product Water not Shown

NF and RO Comparison

Softening (Nanofiltration)

- Applied pressure: 150 psi
- Min Salt Rejection: 75-80%
- Hardness Rejection >95%
- Flux Range: 25 – 30 GFD
- Used for softening or special applications

Reverse Osmosis

- Applied Pressure: 225 psi
- Min Salt Rejection: 97-98%
- Hardness Rejection >99%
- Flux Range: 25-30 GFD
- Used for mineral removal

GFD – gallons of flux per sq. ft. per day

When Should RO Elements be Cleaned?

- Element cleaning should be performed at regular intervals to keep pressure as low as possible.
 - When pressure to maintain rated capacity increases by 15%.
 - When product water flow decreases by 15% at constant pressure.
 - When a rise of 15% in the system differential pressure has been observed.
- Symptoms of membrane fouling
 - Lower product water flow rate
 - Lower salt rejection
 - High ΔP

How to Clean RO Membranes

- To remove inorganic precipitates, use an acid flush of citric acid.
- For biological or organic fouling, use various solutions of detergents, sequestrants, chelating agents, bactericides, or enzymes.
- Clean at low pressure not to exceed 60 psi.
- Membranes are typically cleaned for approximately 45 minutes.

Ultrafiltration Membrane Systems

- Generally used for Pretreatment
- Can replace several treatment processes
- Extremely flexible for changed feed water conditions
- Operates at 50 psi

Ultrafiltration Operation

- Units are operated in parallel with some product recirculated to maintain high flow velocity
- Increase recirculation rates for higher TDS removal
- Units are backwashed to remove fouling with product water

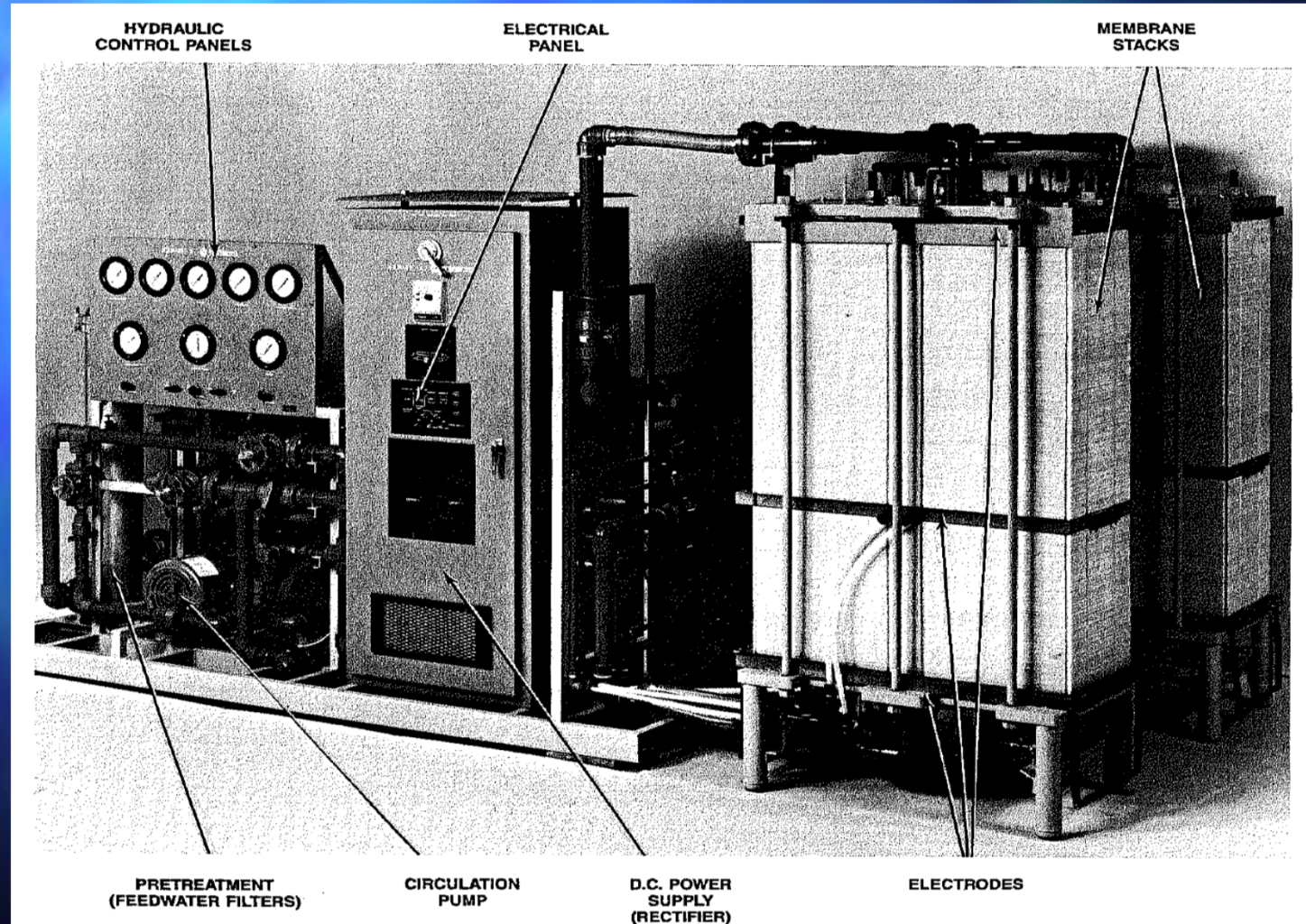
Microfiltration Membrane Filtration Treatment Process

- Microfiltration is used for removal of particles, suspended solids, bacteria and cysts in source water.
- Organics are not removed.
- Operates at 20 to 35 PSI.
- Typically used for Pretreatment in front of RO Systems

Advantages of Microfiltration

- Highly automated with little operator attention
- Water quality achieved regardless of source water changes
- Chlorine Demand Reduced
- Replaces conventional treatment processes
- Wide flow ranges (.6 to 22 MGD)

Electrodialysis

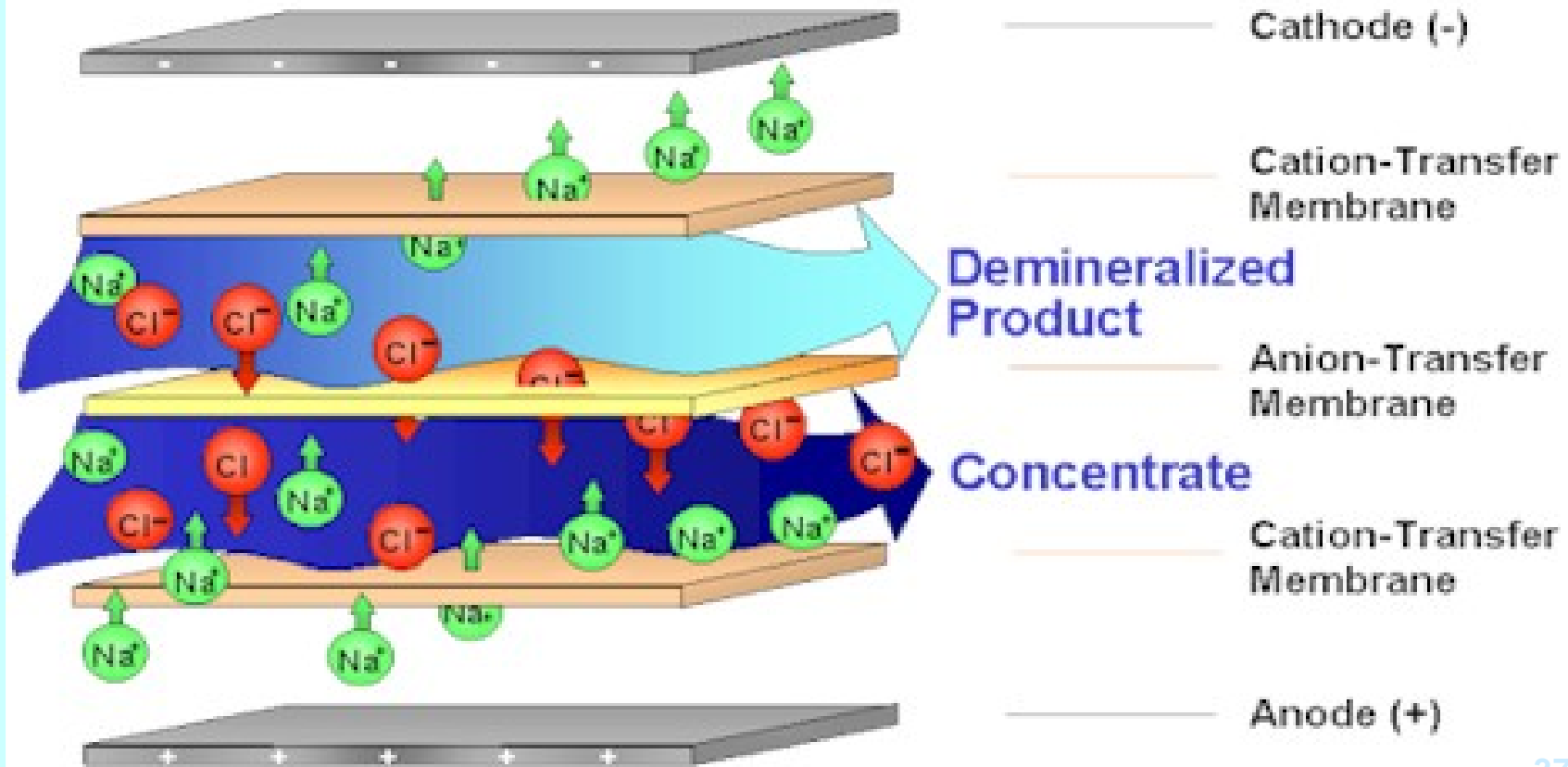


Electrodialysis Applications

- Selective membrane process for removing Minerals Only!
- Uses membrane filtration in combination with electricity.
- Electrodialysis can be less expensive to operate for low TDS waters or when a 50% mineral removal is adequate.
- Positive ions are attracted to a negatively charged cathode and negatively charged ions are attracted to a positively charged anode.

Electrodialysis

- Uses electrical power to draw ions from product water to the concentrate stream.



Cations

Sodium



Calcium



Magnesium



Anions

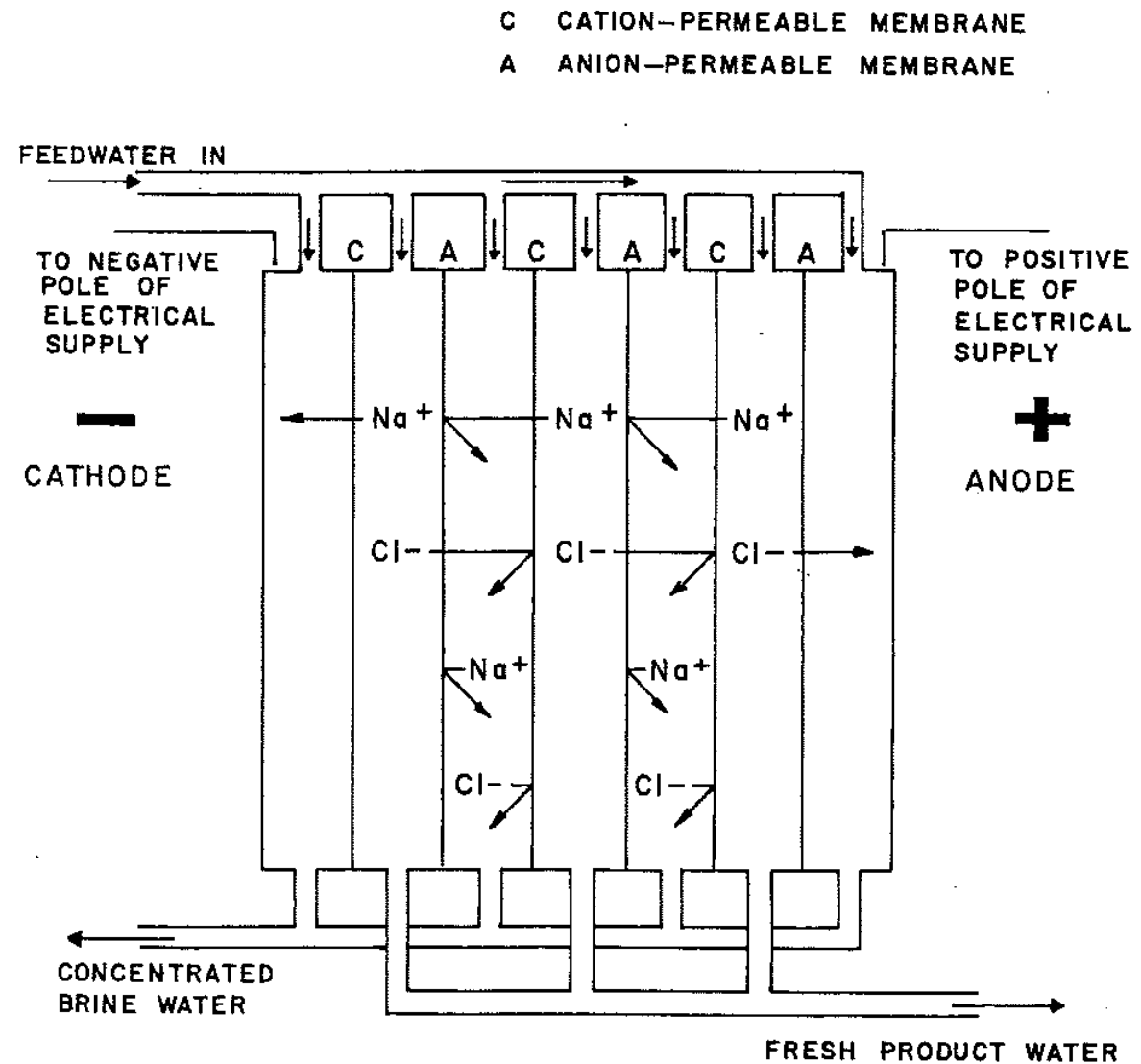
Chloride



Bicarbonate



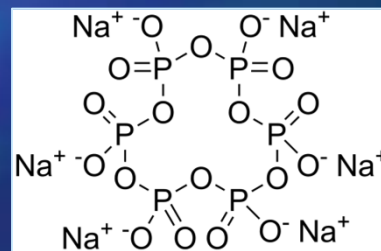
Sulfate



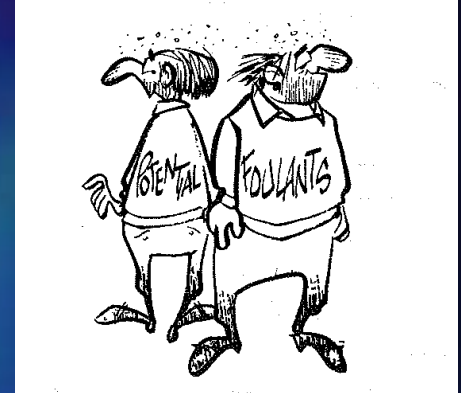
Electrodialysis demineralization process

Operating and Maintenance Considerations for ED Systems

- Fouling and Plugging of Membranes
- Water Temperature
- Alkaline Precipitation
- Pretreatment for Solids Removal
- Undesirable Minerals (Fe, Mn, H₂S & Cl)
- Hexametaphosphate



Do Not Operate if Feedwater has any of the following:



- Chlorine residual of any concentration
- Hydrogen sulfide of any concentration
- Calgon or other hexametaphosphates in excess of 10 mg/l
- Manganese in excess of 0.1 mg/l
- Iron in excess of 0.3 mg/l

Which of the following items is/are acceptable in the feedwater to an electrodialysis unit?

1. Chlorine residual
2. Hydrogen sulfide
3. Iron
4. Manganese
5. Sodium

Ion Exchange

Ion exchange can be defined as exchanging hardness causing ions (calcium and magnesium) for the sodium ions that are attached to the ion exchange resins to create a soft water. The term "ion exchange" is the same as the term "Zeolite".

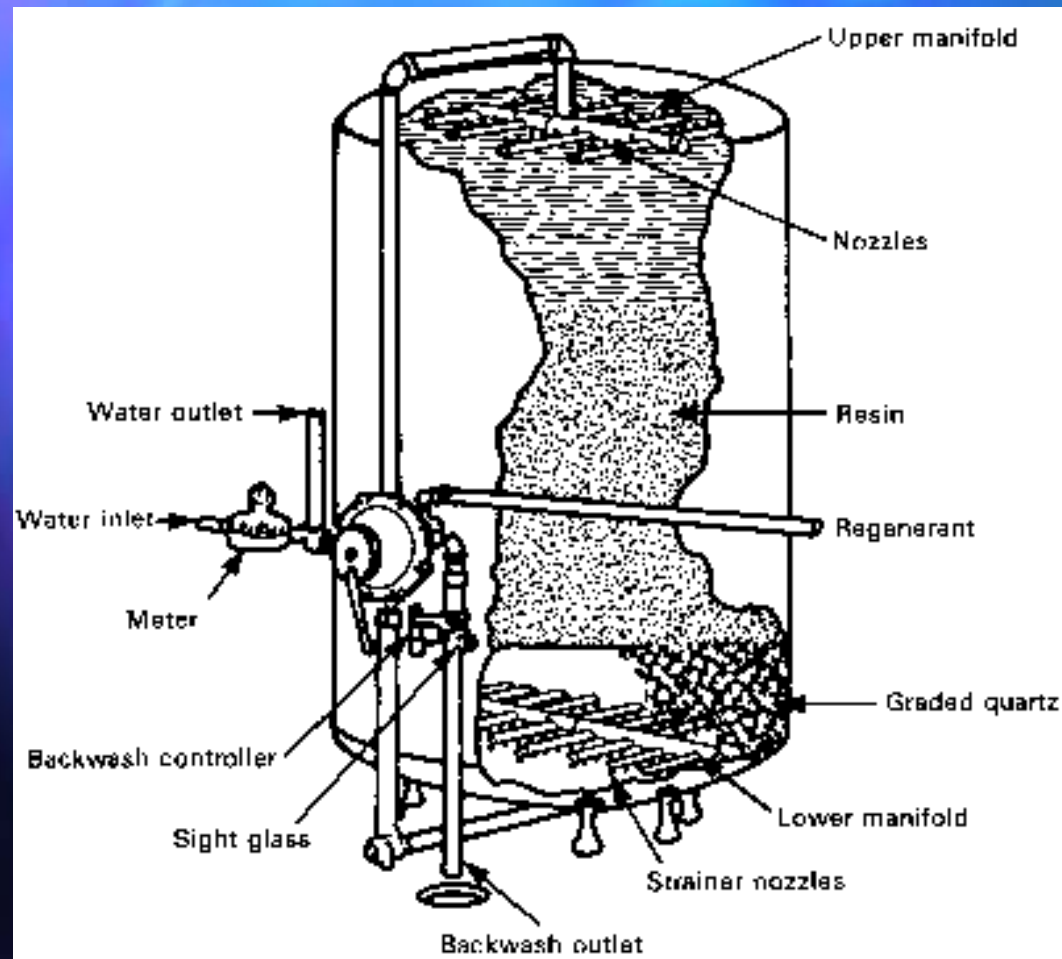
ION EXCHANGE

- The removing of non-desirable ions by replacing them with more desirable ions.
- Generally, the process is used for softening but can be used with any positively charged ion including Tannins.
- Can also be used with negative charged particles.

Ion Exchange Unit Types

- Upflow
- Gravity Sand Filter Type Unit
- Pressure Downflow

Parts of an Ion Exchanger



Vessel

Distributor

Backwash Space

Resin

Resin Support

Underdrain

Piping & Valves

Ion Exchange Resins

- Natural zeolites (crystalline aluminosilicates) no longer used
- These have been replaced by synthetic resins.
- Resins made of cross-linked polymer matrixes that attached to functional groups with covalent bonds
- Resins are manufactured as beads and typically screened to 0.3 to 1.3 mm dia.
- A typical resin used for softening is polystyrene attached to 6 to 8% divinylbenzene (DVB).
- Service life can be as much as 10 years with 3 to 5 typical. Generally resin replaced when capacity is reduced by 25%.

Flow Considerations for Ion Exchange Softening

- Limited by pressure loss and physical characteristics of the Cation resin
- Flows above 20 gpm/sf will break beads
- Pressure losses above 50 psi across bed will also break beads
- Pressure losses across beds < 20 psi
- Generally a flow rate of 10 gpm/sf and a bed depth of 3 feet is typical.
- Ion Exchange Design is based on empty bed contact time (EBCT), 1.5 - 7.5 min or its reciprocal service flow rate (SFR) 1 - 5 gpm/cf

Operating Considerations

Ion Exchange Softening

- Iron: Ferrous captured deep inside resin bead or Ferric (precipitation) causes beads to become clogged and can not be removed.
- Corrosiveness of Brine Solution on metallic parts
- Oxidation of polymer from high chlorine level
- Strainer blockage
- Fouling of Resin from oil, grease or organic matter (Resin cleaning takes about 8 hours)

Optimal Water Characteristics for Ion Exchange

pH	6.5 – 9.0
NO ₃	< 5 mg/l
SO ₄	< 50 mg/l
TDS	< 500 mg/l
Turbidity	< 0.3 NTU
Total Hardness	<350 mg/l

Selectivity Considerations



Stages of Ion Exchange

Stage 1. Service Stage

Stage 2. Backwash Stage

Stage 3. Brine or Regeneration Stage

Stage 4. Rinse Stage

Ion Exchange Service Stage 1

- Normal operating stage where actual softening takes place.
- Length of service is mainly dependent on source water hardness.
- High source water sodium and or TDS can hinder process.
- TDS, unit size, and removal capacity affect length of time between regeneration.
- Beware of iron and manganese. Insoluble particles will plug the filter media. Monitor source water on a routine basis.

Ion Exchange Backwash

Stage 2

- A reverse flow through the softening unit is used to expand and clean resin particles.
- Ideal bed expansion during backwash is 75 - 100 %
- Some resin could be lost during backwash. Should be monitored to minimize loss.
- Too much loss of resin may be caused by an improper freeboard on the tank or wash troughs.
- Backwash durations widely vary based on the manufacture, type and size of resin used and the water temperature.

Ion Exchange Regeneration Stage 3

- Sodium ion content is recharged by pumping concentrated brine solution onto the resin.
- Optimum brine solution is between 10 -14% sodium chloride solution.
- A 26% brine solution (fully concentrated or saturated) can cause resin to break up.
- The salt dosage used to prepare brine solution is one of the most important factors affecting ion exchange capacity. Ranges from 5 to 15 lbs/ft³.
- The lower the concentration, the longer will be the regeneration time.

Ion Exchange Rinse Stage 4

- Clean water is washed through the system to rinse the resin and to washout the excess brine solution.
- If rinse is not sufficient for removal of concentrate a salty taste will be noticed in the effluent. If a salty taste is noticed then rinse rate and time should be increased.

Question: An ion exchange softener contains 50 cubic feet of resin with a hardness removal capacity of 20 kilograms per cubic foot of resin. The water being treated has a hardness of 300 mg/l as CaCO_3 . How many gallons of water can be softened before the softener will require regeneration?

- First, calculate the exchange capacity:

Exchange capacity, grains = (removal capacity, gr/ft³) x (media vol, ft³)

Exchange capacity, grains = (20,000 gr/ft³) x (50 ft³) = 1,000,000 grains of removal cap.

- Water treated before regeneration

Water treated, gal = (exchange capacity, grains) / (hardness removed, grains/gal)

$$\text{Water treated, gal} = \frac{1,000,000 \text{ gr}}{1} \times \frac{1}{300 \text{ mg/L}} \times \frac{17.1 \text{ mg/L}}{1 \text{ gr/gal}} = 57,000 \text{ gal}$$

Corrosion Concerns in Ion Softening

- Ion Exchange produces a water with zero hardness.
- Water with zero hardness is very corrosive creating red water problems.
- "Ideal" water hardness for drinking water ranges between approximately 50 to 100 mg/L.
 - Above this level, hardness can contribute to scaling of water heaters and boilers.
 - Water with hardness below this level tends to be more aggressive and can cause deterioration of the inner surface of pipes, eventually leading to pinholes or leaks.
- Water is adjusted by blending to achieve 86 mg/l or 5 gpg Hardness

Blending or Bypass Flow

- If a softener plant treats 120,000 gal/day determine the Blending Volume or Bypass Flow

$$\text{Bypass flow, gal/day} = \frac{(\text{total flow, gal/day}) \times (\text{finished water hardness, gr/gal})}{\text{Raw water hardness, gr/gal}}$$

$$\text{Bypass flow, gal/day} = \frac{(120,000 \text{ gal/day}) \times (5 \text{ gr/gal})}{17.5 \text{ gr/gal}} = 34,286 \text{ gal/day}$$

Concentrate Disposal

- Combine with reclaimed water and release to surface water. (CWA & NPDES)
- POTW (TBLL; Effluent & Biosolids)
- Deep Well injection – (UIC)
- Evaporation/Crystallization - Capacity limited (RCRA)
- Landfill (PELT (paint test), TCLP (leaching))

Disinfection and Disinfection Byproducts (DBP)



Regulatory Requirements for Disinfection By-Product Management & Disinfection By-Product Monitoring for Water Treatment Plants

DPB Rule Requirements

Rule/Requirement	Applicability/ Rule or Change	Key Dates
Stage 1 D & DBPs- Compliance with D/DBPs	Monitor Mo'ly/ Qtr'ly	1/01/04
Stage 2 D & DBPs- Compliance with D/DBPs	Ave. D-DBPs All SWTP & UDI Individual D-DBPs	mid.-2005
Interim Enhanced Surface Water Treatment- Disinfection Profiles (DP)	All SWTP & UDI DP at Dosing Points	1/14/06
Filter Backwash Recycle- Monitoring & Construction	All SWTP & UDI New Facilities on-line	6/08/06
Stage 2 D & DBPs- Compliance with IDSE	All CWS	10/01/06 Varies ³

Disinfection By-Product (DBP) Formation

- Disinfection Byproducts (DBP) are produced by the reaction of free chlorine with organic material found in natural waters.
- The amount of organic materials in a natural water called NOM can be approximated by the amount of Total Organic Carbon (TOC) present in the water source.
- NOM consists of various chemical compounds containing carbon, originating from decayed natural vegetative matter found in water.

Raw Water Considerations

- Generally surface waters or ground waters under the direct influence of surface water will have higher levels of organic materials (TOC.)
- Surface waters have higher organic content than Ground Water
- If surface water mixes with ground water, each well may experience different levels of TOCs.

DBP Health Impacts

- Can be carcinogenic (cancer causing)
- Can cause reproduction problems
- Can damage blood or kidneys
- For these reasons, EPA has set DBP limits in the drinking water

Production of Trihalomethanes

- Trihalomethanes (THMS) are produced by the reaction of chlorine with organic constituents found in natural waters.
- The 4 compounds of concern are:
 - Chloroform (typically 70%)
 - Bromoform
 - Bromodichloromethane
 - Dibromochloromethane
- The sum of the concentrations of these four compounds are Total Trihalomethanes (TTHMs)

Production of Haloacetic Acids

- Haloacetic Acids (HAA5) are produced by the addition of chlorine with organic constituent found in natural waters
- The 5 compounds of concern are:
 - Monochloroacetic Acid
 - Dichloroacetic Acid
 - Trichloroacetic Acid
 - Monobromoacetic Acid
 - Dibromoacetic Acid
- The total concentrations of these five compounds are known as HAA5s

Disinfection Byproducts (DBP) and Chlorination Considerations

- DBP's are produced by the reaction of free chlorine with organic material called "precursors"
- Precursors" are best reduced prior to chlorination for minimizing DBP production

Factors Affecting Disinfection By-Product Production

- Turbidity and the type of NOM present
- Concentration of Chlorine added
- pH of water
- Bromide Ion Concentration
- Temperature
- Contact Time

Locating TTHM Areas

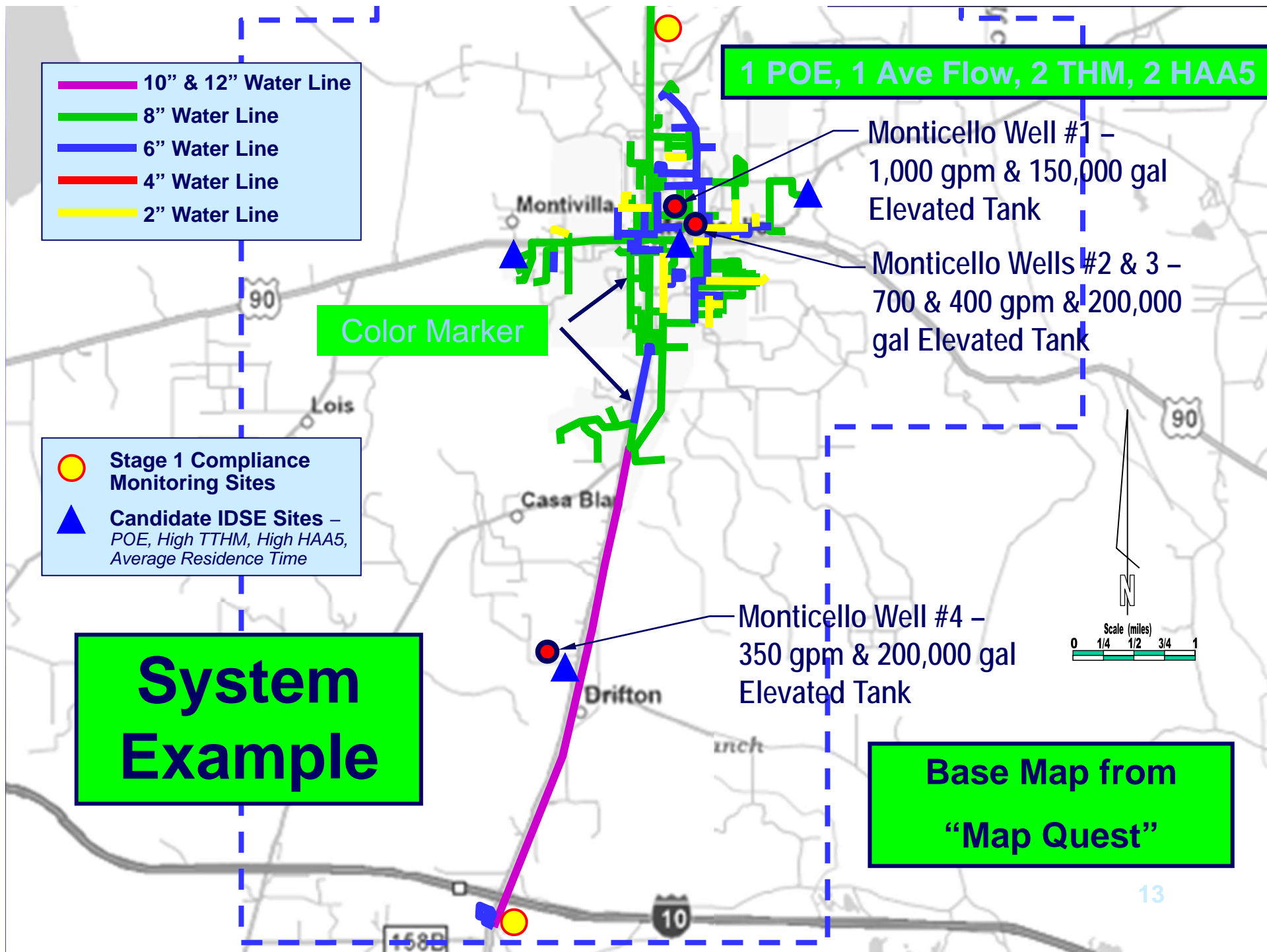
- High Water Age
- Storage Tanks do not fluctuate
- No / Few Customer Areas
- Stagnant Areas
- Dead Ends
- Bad Pipe
- Regrowth Areas



Pipe Tuberculation
with Bacterial
Growth producing
Organic Precursors

Locating HAA5 Areas

- Low Demand Areas
- Toward Middle System Areas w/ Stagnant / Low Water Age
- Areas with No / Little Regrowth
 - Eliminate Biodegradation Locations
 - Free Chlorine Residuals < 0.2 mg/L
 - HPC Data
- No Dead Ends



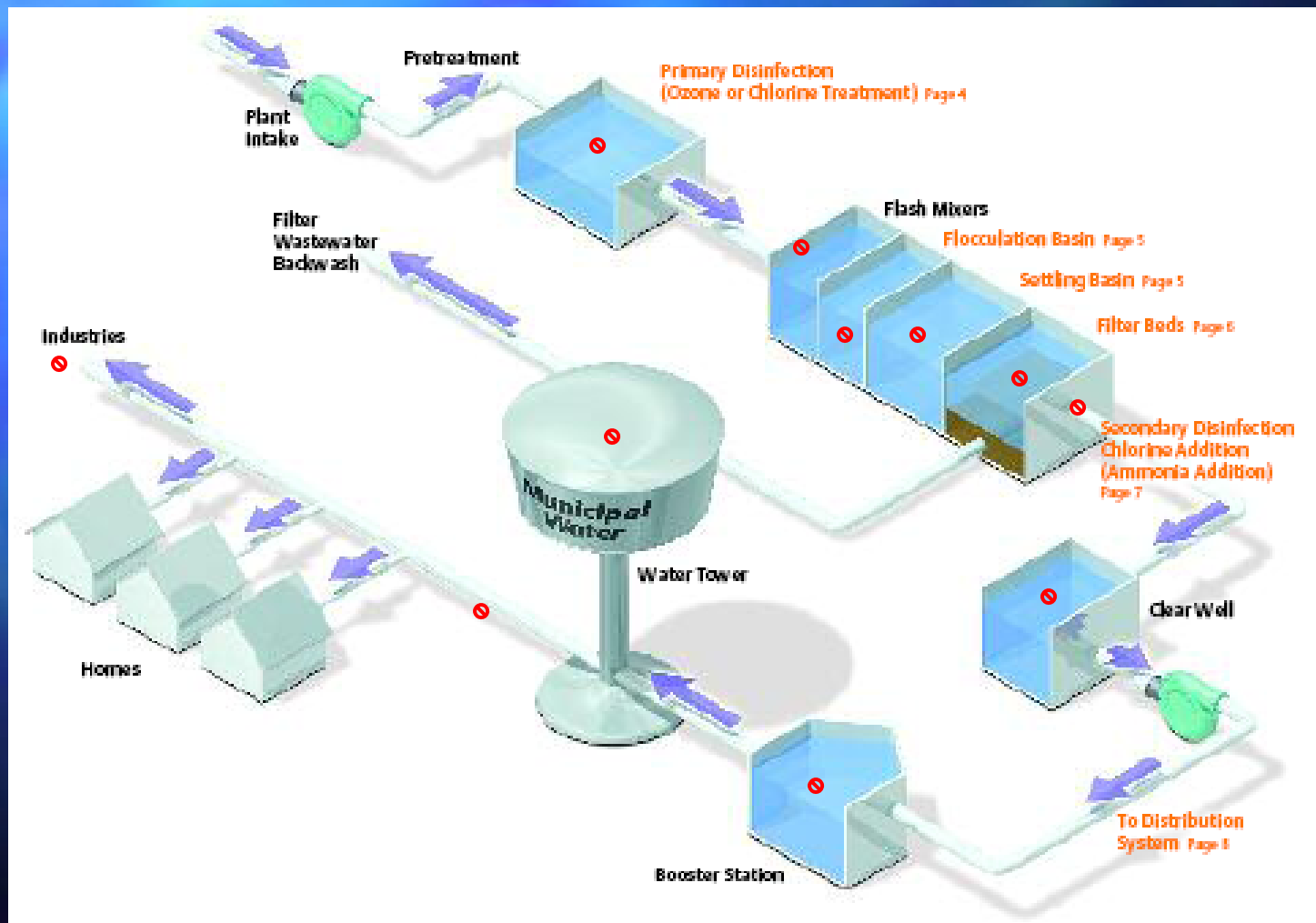


Treatment Techniques for Controlling DBPs

Strategies for Reducing DBPs in Order of Cost Effectiveness

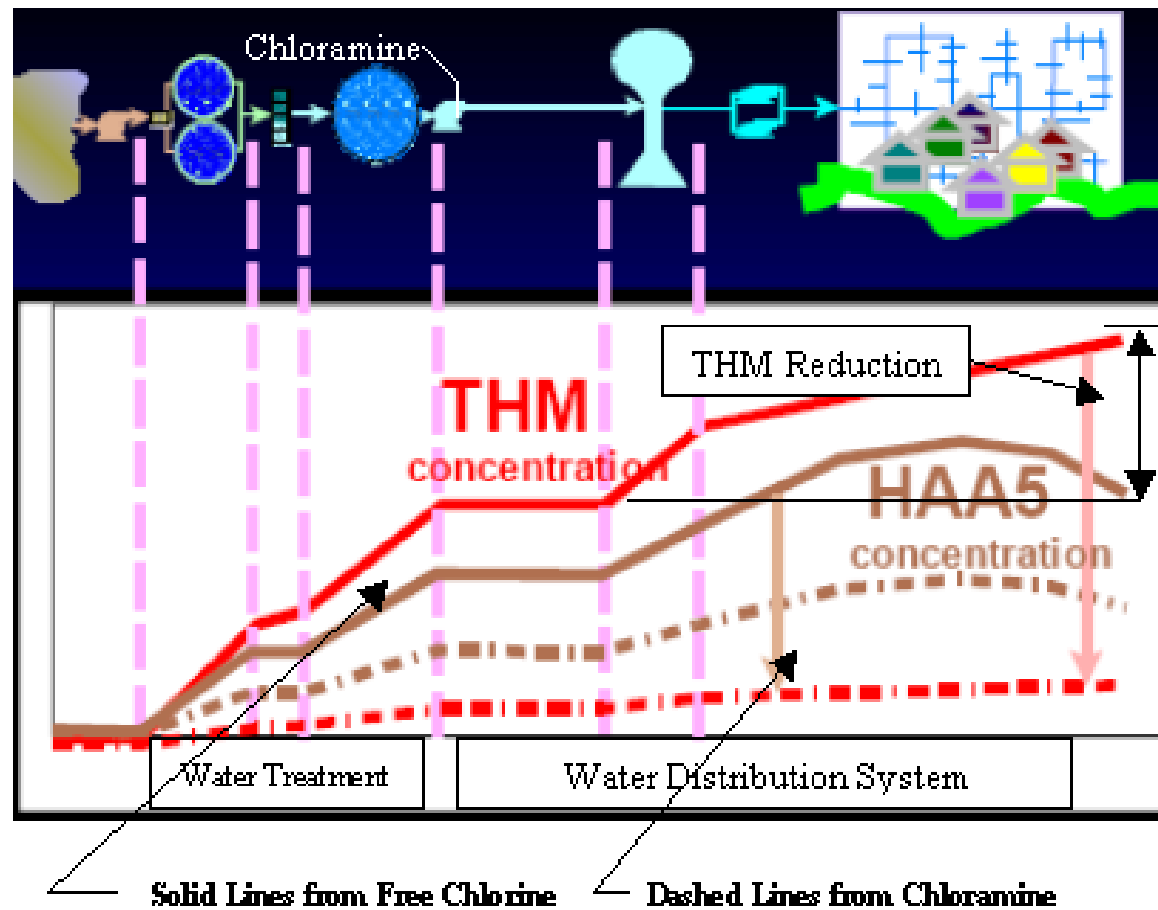
- Precursor Removal
- Disinfection By-Product Management using System Flushing and Storage Tank Management
- Use of Alternative Disinfection Strategies
- Disinfection By-Product Removal

Formation of DBP in a Water System



Disinfectant and DBP Production in a Typical Water System

Comparison of the Production of THM's and HAA5's
For Free Chlorine and Chloramine for a Typical Water System



DBP Precursor Reduction Strategies

Methods for Reducing Precursors

- Disinfection By-Product Management
i.e. Nutrient and biota control in source and finished water.
- Solids removal systems including:
pre-sedimentation, infiltration galleries,
filtration, coagulation and membrane filtration.
- Addition of powdered or granular activated carbon to remove organics.



DBP Management in a Water Distribution System

DBP Reduction Techniques in a Water Distribution System

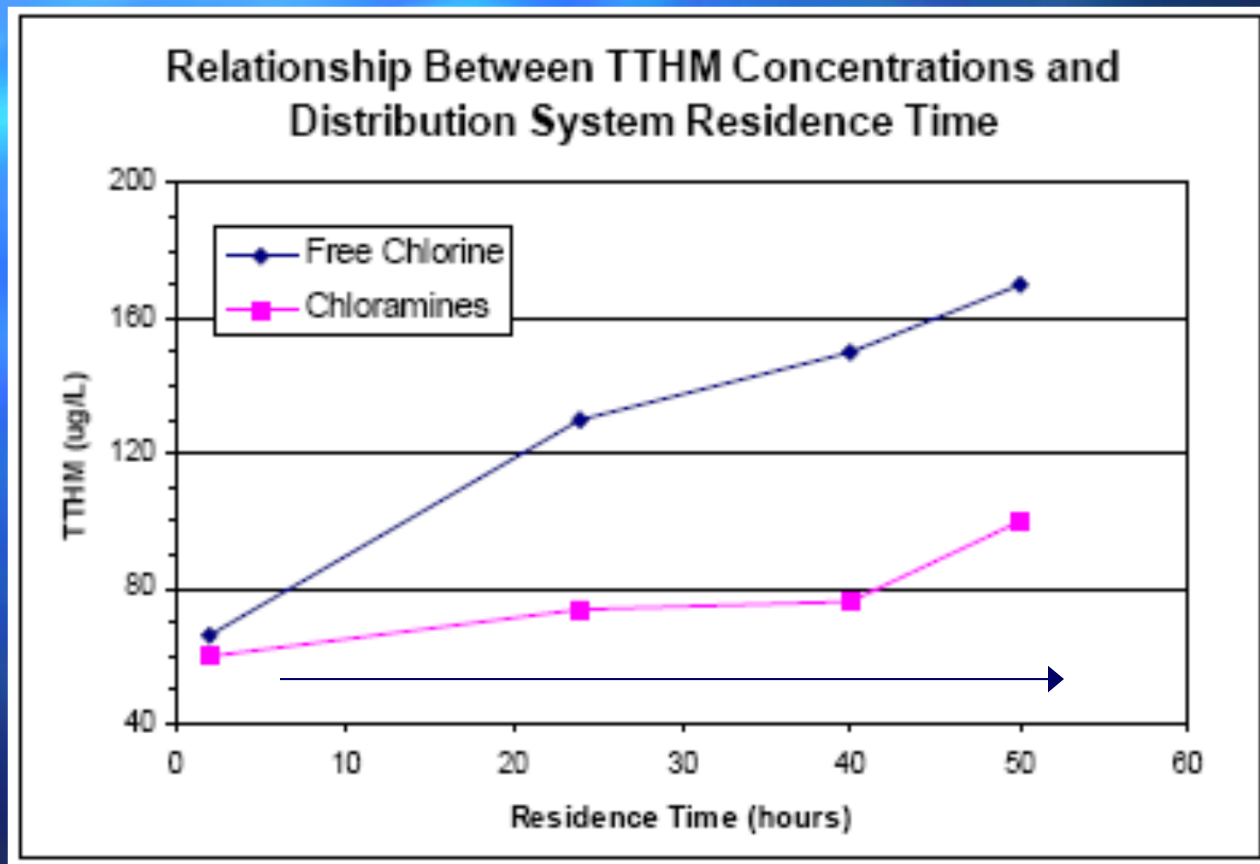
- Reducing detention time in storage tanks,
- Ensuring turnover in distribution system
- Flushing dead-end lines.

Typical Distribution System Water Age (Days)

Population	Miles of WM	Water Age
> 750,000	> 1,000	1 – 7 days
< 100,000	< 400	> 16 days
< 25,000	< 100	12 – 24 days

AWWA: Water Age for Ave and Dead End Conditions

Effects of Water Age on DBP Production



Problems with Water Turnover and Sediments in Storage Tanks

- Sediments contain significant concentrations of organic nutrients
- Sediments exert a disinfectant demand
- Sediments provide protective layers for biofilms which allow pathogens to repair
- Sediments encourage the growth of slow growing nitrifying bacteria that lower residual
- Can contribute toward the formation of DBPs
- Can cause turbidity, taste and odor problems

Turnover Guidelines for Water Storage Tanks

Georgia - Daily Goal: 50% of storage volume
- Minimum: 30% of storage volume

Virginia - Complete turnover every 72 hrs

Ohio - *Required* Daily: 20% of storage volume
- Recommended 25% of volume

DBP Reduction by Establishment of a Flushing Program

Flushing Program	Suggested Actions/DEP Rule	Benefits to Treatment System
Written Flushing Procedures	Submit a Written Water Main Flushing Program. DEP Rule 62-555.350	Sampling is during normal operating conditions, and is not valid if you ONLY flush the day you are collecting samples
Treatment Components in Contact With Water	Clean & remove biogrowths, calcium or iron / manganese deposits, & sludge DEP Rule 62-555.350(2)	Improves water quality, reduces chlorine demand & regrowth in the water system.
Reservoirs and Storage Tanks	Clean & remove biogrowths, Ca or Fe / Mn deposits, & sludge from storage tanks. DEP Rule 62-555.350(2) FAC	Improves water quality, reduces chlorine demand & biological regrowth in the water system.
Water Distribution Mains	Begin systematic flushing of water system from treatment plant to system extremities.	Improves water quality, reduces chlorine demand & biological regrowth in the water system.
Dead-End Water Mains	Flushing (every other day) or Automatic Flushing. DEP Rule 62-555.350(2)	Improves water quality, & reduces biological regrowth.

In-Plant DBP Management Disinfectant Strategies

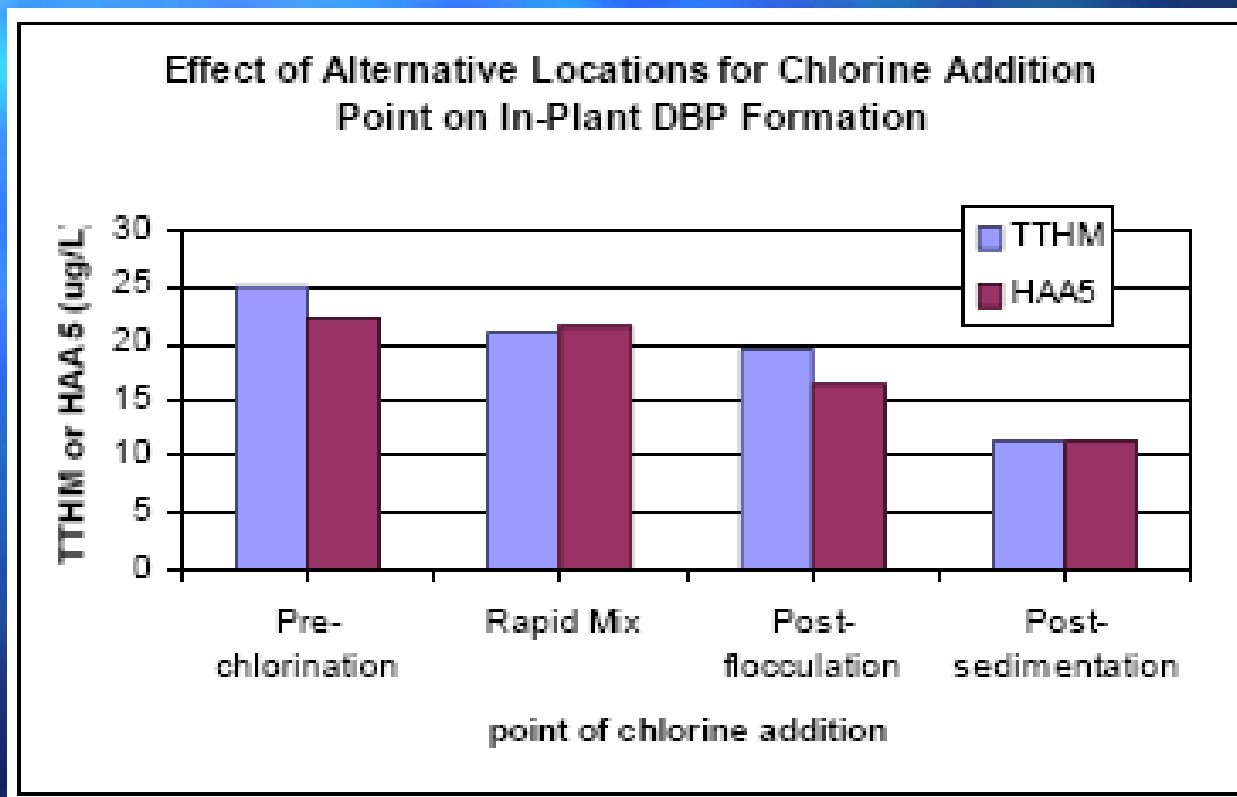
Use of Disinfectant Strategies

- Reduce Dosing Concentration of Disinfectant
- Change Points of Application
- Change forms of Disinfectant
- Use of Multiple Disinfectants
- Change Disinfectant

Effective Chlorination System Modification Strategies

Disinfection Location	Action	Benefit
Chlorine Feed	Reduce chlorine feed rates while maintaining proper chlorine residuals	Fewer DBPs formed in the water system. No / little cost for this option.
Chlorine Injection Point	Change point of chlorine injection to reduce the age of chlorinated water	Fewer DBPs formed in the water system. Small cost for this option.
Chlorine Injection Boosters	Add chlorine injection point(s) to boost Chlorine residuals in the distribution system instead of at the plant	Lower total chlorine added at the plant site. Fewer DBPs formed in the distribution system.
Alternate Disinfection / Application	Use of chloramines in distribution systems with long detention times with ozone or chlorine dioxide as a primary disinfectant	Fewer DBPs formed in the water system. Costs for this option could be significant.

Effects of Moving the Point of Disinfection



Strategies for the use of Primary and Secondary Disinfectants

- Includes a consideration for change of application points
- Includes of changes in the types of disinfectant to reduce DBP formation
- Use of Chloramines, Ozone or Chlorine Dioxide can be used separately (Primary Disinfectant) or in combination (Secondary Disinfectant, used in Distribution System) with Free Chlorine reduce DBP formation



Changing the Disinfectant to the Use of Chloramines

Chloramines are Formed by adding Ammonia to Chlorine

- Ammonia Gas is fed like Chlorine Gas
- Anhydrous Ammonia as a Liquid
- Chlorine Fed First
- Quenched or Reacted by Ammonia
- Taste & Odor Problems when Free Chlorinated Water Interfaces with Chloraminated Water
- Chloramine formed will have less disinfection (inactivation) power

Chloramine Advantages

- Chloramines Not As Reactive With Organic Compounds
- Chloramine Residual are More Stable & Longer Lasting
- Chloramines Provides Better Protection Against Bacterial Regrowth in Systems with Large Storage Tanks & Dead End Water Mains when Residuals are Maintained
- Since Chloramines Do Not React With Organic Compounds; Less Taste & Odor Complaints
- Chloramines Are Inexpensive
- Chloramines Easy to Make

Chloramine Disadvantages

- Not As Strong As Other Disinfectants
eg. Chlorine, Ozone, & Chlorine Dioxide
- Cannot Oxidize Iron, Manganese, & Sulfides.
- Necessary to Periodically Convert to Free Chlorine for Biofilm Control in the Water Distribution System
- Chloramine Less Effective at High pH
- Forms of Chloramine such as Dichloramine cause Treatment & Operating Problems
- Excess Ammonia Leads to Nitrification
- Problems in Maintaining Residual in Dead Ends & Other Locations

Nitrification Concerns in Water Storage Tanks with the Use of Chloramine

- Nitrification is the conversion of ammonia to nitrate
- Occurs in dark areas, at $\text{pH} > 7$, with at warm temperatures and long detention
- Typically these problems are associated with systems that use chloramine which contains ammonia and can support the nitrification process
- Nitrite (intermediate product) will consume free chlorine and chloramine disinfectants
- Must ensure that disinfectant residual levels are adequate (> 1.5 ppm chloramine with 2.5 mg/l recommended)

Nitrification Monitoring Indicators

- Depressed Disinfectant Levels
- Elevated DBPs
- Elevated Bacterial Counts (HPC)*
- Elevated Nitrate/Nitrite Levels for Chloramination Systems
- High Corrosion Potential
- Note: Direct Monitoring ineffective

* HPC use organic carbon as food, include total coliform;
Not to exceed 500/ml in 95% of samples


Proactive Biofilm Control Considerations

- Microbial Repair Mechanism Increased
- Some Microbes can develop chloramine resistance
- Free chlorine is absorbed by biofilm surface (4 ppm free chlorine ineffective in controlling biofilm on pipe surface)
- Chloramines at 2 mg/l continuous dose was found effective for control

Direct Removal of DBP

Disinfection By-Product Removal Systems

- Oxidation: Ozone, Chlorine Dioxide, and UV.
- Aeration: Open Storage, Diffused Air and Packed Towers.
- Adsorption: Powdered Activated Carbon and Synthetic Resins



DEP Water Quality and Treatment Process Requirements for D - DBP

Safe Drinking Water Act

MCL's for TTHM, HAA5, Chlorite and Bromate

- TTHM .080 mg/l
- HAA5 .060 mg/l
- Chlorite 1.0 mg/l*
- Bromate 0.010 mg/l **

* associated with the use of Chlorine Dioxide

** naturally occurring precursor in systems near saltwater, associated with use of Ozone

Also Maximum Residual Disinfectant Limit

Chlorine	4 mg/l
Chloramine	4 mg/l
Chlorine Dioxide	0.8 mg/l

These concentrations have been found to
have adverse health effects

Inactivation Reductions for Pathogens required for Surface Water/UDI Systems

- Giardia lamblia 99.9% or 3 log
 - Viruses 99.99% or 4 log
 - Cryptosporidium 99% or 2 log *
- Water Systems are assumed to be in compliance if they use conventional or direct filtration and meet turbidity requirements

Simultaneous Compliance

Balancing Disinfection Protection with DBP Removal

- Deactivation is proportional to concentration of chlorine and contact time ($C \times T$).
- Reducing free chlorine (C) will reduce disinfection inactivation potential but reduce DBP formation potential.
- Reducing contact time (T) will reduce disinfection potential and reduce DBP formation potential.

General Guidelines for Surface Water Treatment

Turbidity Standards

Alternative filtration technology in combination with disinfection consistently achieves removal and/or inactivation of:

- 99.9% of *Giardia lamblia* cysts (filtration + disinfection)
- 99.99% of viruses (filtration + disinfection)
- 99% of *Cryptosporidium* (filtration alone)
(Interim Enhanced SWTR 12/16/98)

Turbidity Reductions for Subpart H Treatment Plants Using Conventional or Direct Filtration

- 95% of samples taken each month must be less than 0.3 NTUs
- no one sample can exceed 1 NTU

Plants meeting these criteria are assumed to meet the 2 log removal for *Cryptosporidium*

Subpart H System requirements for Conventional Filtration

- Must use enhanced coagulation or enhanced softening
- may be exempted if source water are consistently below 2.0 mg/l TOC and 2.0 L/mg-m SUVA
- can achieve .040 mg/l TTHM and .030 mg/l HAA5

Considerations for Required TOC Reductions for Subpart H Plants for Enhanced Coagulation and Softening

- High TOC source water concentrations require greater removal rates
- Higher Alkalinity source water concentrations the lower the removal rate



Disinfection Profiling and Benchmarking (not on C/D Exam)

Water Treatment Facilities Required to Perform Disinfection Profiling and Benchmarking

- Surface Water Plants
- Ground Water Plants Under the Direct Influence of Surface Water
- Ground Water Plants Utilizing Treatment Processes with Tanks Open to the Atmosphere

Requirements for Subpart H for Disinfection Profiling and Benchmarking

- Systems that have annual average of
TTHM > 0.064 mg/l
or
- Systems that have annual average of
HAA5 > 0.048 mg/l

**Must Develop System Disinfection Profiles and Benchmarks for their
Water Treatment Plant**

Disinfection Profile

(definition)

A compilation of the daily inactivation of Giardia or Viruses based on the measured disinfection residual, pH, temperature and peak flow that affects the efficiency of the disinfection process (microbial inactivation potential) collected over a period of one year.

Baffling Considerations for Contact Basins

- Actual detention time in a basin is dependent on its shape, inlet, outlet and baffling
- a tracer test (plug or continuous) may be used to identify the actual detention time in a basin
- actual detention time (T_{10}) is the time which 90% of all the water passing through the basin is retained
- baffling factors can be used to estimate T_{10}

Microbial Inactivation

Microbial Inactivation is derived from a table based on the disinfection concentration and the actual contact time in a plant process segment.

The sum of these microbial inactivation values are used to determine the log reduction for Giardia and viruses for the Plant.

Disinfection Profile Development

- Measure disinfectant residual concentration, pH and temperature, daily at each disinfection sampling point, i.e. if there are four disinfection feed points there will be four disinfection sampling points
- The measurements must be taken at peak hourly flow
- Must be retained by PWS for review at 3 year Sanitary Survey interval

Summary

Determining Disinfection Profiles

- Collect the disinfection residual concentration, peak hourly flow data for each segment
- Calculate the CT_{10} value each segment
- Determine the log inactivation for Giardia and log inactivation for Viruses for each segment
- Add the Giardia and Viruses segments to determine the log inactivation for the Plant

Disinfection Benchmark

The calculated average microbial inactivation for each month developed from the disinfection profile for the lowest monthly average for the year or for multi-year if more than one year is used.

Benchmark Comparison to Identify Proposed Modification Impact

- Proposed modifications are evaluated based on current operating conditions
- These evaluations are made using the temperature, pH, and contact times from the original “Disinfection Profile”
- From these the average log Giardia and virus inactivation's are determined.
- If the modification results in a log inactivation that is lower than the original benchmark, it must result in adequate disinfection

EPA Guidance Documents for Disinfection Profiling

- *Disinfection Profiling and Benchmarking Guidance Manual*

EPA 815-R-99-013

- *LT1ESWTR Disinfection Profiling and Benchmarking Technical Guidance Manual*

EPA 816-R-03-004

These Documents can be obtained at:

<http://yosemite.epa.gov/water/owrccatalog.nsf/>

Methods for Reducing DBPs and meeting Pathogen Inactivation Requirements

- Using chemical or physical processes to remove precursors from source waters
- Moving the point of disinfection after clarification
- Using enhanced coagulation before disinfection
- Developing a system to provide adequate contact time to achieve sufficient disinfection
- Developing seasonal modifications in disinfection to reduce summer high DBP levels
- Changing the primary or secondary disinfectant
- Changing the contact basin geometry and/or baffling
- Increasing the pH during disinfection > 1 unit



State of Florida Drinking Water Rules

Florida Drinking Water Rules are found in Florida Administrative Code (FAC)

- Updated each Year by DEP in "*Florida Drinking Water Rules*."
- Also DEP updates each Year "*Book of Forms*."
- Can be obtained from DEP or at FRWA, annual Focus on Change presentation hosted around the state beginning in February each year.

Florida Administrative Code and adoption of CFR 40

Federal Regulations

Rule Coverage and Requirements

- 62-550 **FAC** — Florida Administrative Code – Only in FL
- Drinking Water Standards, Monitoring and Reporting
- 40 CFR 141, Subpart H, 7/1/03,
■ Filtration and Disinfection
- 40 **CFR** 141, Subpart I, 7/1/02,
■ Control of Lead and Copper in Drinking Water
- 40 CFR 141, Subpart L, 1/16/01
- Disinfection Residuals, Byproducts and Precursors

SDWA

Florida Administrative Code and adoption of CFR 40 Federal Regulations Rule Coverage and Requirements

- 40 CFR 141, Subpart O, 12/09/02
Consumer Confidence Reports
- 40 CFR 141, Subpart P, 7/1/03,
Enhanced Filtration and Disinfection serving 10,000 people or more
- 40 CFR 141, Subpart T, 7/1/03,
Enhanced Filtration and Disinfection serving less than 10,000 people
- 62-555 FAC
Permitting, Construction, Operation and Maintenance of Public Water Systems

Florida Administrative Code and adoption of CFR 40

Federal Regulations

Rule Coverage and Requirements

- 62-560 FAC
- Requirements of Public Water systems that are out of Compliance
- 62-699 FAC
- Treatment Plant Classification and Staffing
- 62-602 FAC
- Drinking Water and Domestic Wastewater Treatment Plant Operators
- 62-532 FAC
- Well Permitting and Construction Requirements

Monitoring and Reporting Excerpts from 62-550 FAC

Purpose of Monitoring


- Detect potential problems
- Inform the public of dangerous conditions
- Verify compliance
- Collect data on emerging contaminants of concern
- Determine program effectiveness

Monitoring Points

- Beginning of Process
(Ambient monitoring)
- Within treatment
processes
- End of treatment
processes and
distribution system

Parameters Monitored

- Chemical
 - Mostly numeric standards for contaminants or other parameters
- Physical
 - Numeric (flow, temperature, turbidity or narrative (objectionable color, taste)
- Biological
 - Presence (total coliform, fecal coliform)
- Radiological
 - Presence (gross alpha monitoring)



Florida Primary and Secondary Drinking Water Standards and Other Regulated Parameters

Florida Regulated Contaminants

Florida Rule CH 62-550	Coverage Area
Table 1	MCLs for Inorganic Compounds
Table 2	Maximum Residual Disinfectant Levels
Table 4	MCLs for Volatile Organic Contaminants
Table 5	MCLs for Synthetic Organic Contaminants
Table 6	Secondary Drinking Water Standards
Table 7	Monitoring Frequencies and Locations
Table 8	Initial and Routine Monitoring Schedule

SDWA

Current Number of Regulated Contaminants by Category

Number of Regulated Contaminants

Inorganic (IOC's)	15
-------------------	----

Synthetics and Volatiles	
--------------------------	--

(SOC's and VOC's)	51
-------------------	----

Radionuclides (RAD's)	4
-----------------------	---

Some Common Inorganic Contaminants and their Maximum Contaminant Levels (MCLs)

<u>Contaminant</u>	<u>MCL (mg/l)</u>
--------------------	-------------------

Arsenic	0.010
---------	-------

Asbestos	7 (MFL)
----------	---------

Million fibers per liter

Fluoride	4.0
----------	----------------

2.0 in FL

Mercury	0.002
---------	-------

Nickel	0.1
--------	-----

Nitrate	10
---------	----

Nitrite	1
---------	---

Total Nitrate+Nitrite	10
-----------------------	----

Sodium	160
--------	-----

Discovered
by Dr Black
at UF

Some Regulated Volatile and Synthetic Compounds

Select Volatile	MCL	Select Synthetic	MCL
Trichloroethylene (TCE)	.003	Alachlor	.002
Vinyl Chloride	.001	Diquat	.002
Trichloroethane	.2	EDB	.00002
Benzene	.001	Heptachlor	.0004

Removed by aeration

Chlorine Residuals

<u>Contaminant</u>	<u>MCL in FL MRDL (mg/l)</u>
Chlorine	4.0 (as Cl ₂)
Chloramines	4.0 (as Cl ₂)
Chlorine Dioxide	0.80 (as ClO ₂)

$\text{NH}_2\text{CL} + \text{TOC} = \text{no DBPs}$

Secondary Regulated Contaminants (applies to CWS)

<u>Contaminant</u>	<u>MCL (mg/l)</u>	
Chloride	250	
Sulfate	250	
TDS	500	
Copper	1.0	
Fluoride	2.0	
Iron	0.30	> .30 causes red water
Manganese	0.05	
Silver	0.1	
pH	6.5 to 8.5	
Color	15 cu	

Corrosive

Scale

Maximum Contaminant Levels for Disinfection Byproducts

<u>Contaminant</u>	<u>MCL (mg/l)</u>
Total Trihalomethanes	0.08
Haloacetic Acids (Five)	0.06
Bromate	0.010
Chlorite	1.0



Monitoring and Reporting

SWDA Rule Applicability to PWS Systems

Total Coliform	PWS
SWTR	Subpart H
Phase I*	CWS/NTNC
Phase II	CWS/NTNC
Phase IIB	CWS/NTNC
Phase V	CWS/NTNC
Lead/Cu	CWS/NTNC
S1 DBPR	CWS/NTNC
Filter BRR	Subpart H & filter plants

CC Reports	CWS
P Notification	PWS
Arsenic	CWS/NTNC
Radionuclides	CWS
LT1ESWR	Subpart H < 10 ⁴ pop
GWR**	PWS (gw)
Radon**	CWS (gw)
S2 DBPR**	PWS (gw)

* PWS for Nitrate & Nitrite

** Upcoming rules

Initial and Routine Monitoring for CWS & NTNCWS

<u>Parameter</u>	<u>Frequency/Application</u>
■ Asbestos	Every 9 Yrs
■ Nitrate/Nitrite	Yearly GW Quarterly Subpart H
■ Microbiological	Monthly Multiple Locations
■ CL and NH ₂ Cl	Monthly at Coliform Location
■ THMs and HAA5s	<500 Yrly; Warm Mo >500 Yrly GW, QTR Sub H >10K 1/QTR GW, 4/QTR Sub H

Initial and Routine Monitoring for CWS & NTNCWS

<u>Parameter</u>	<u>Frequency/Application</u>
■ Inorganic	Every 3 Years GW Yearly Subpart H
■ Volatile Org.	Every 3 Yrs, 4 Quarterly
■ Synthetic Org.	Every 3 Yrs, 4 Quarterly
■ Secondary	Every 3 Years
■ Radiological	Every 3 Years

Compliance Cycles

- Nine year cycle - Three year compliance periods
- Large systems 3,300 population and above sample first year of compliance period.
- Population $< 3,300$ sample in second year of compliance period.
- Non-Transient Non-Community sample in third year of compliance period.

Specific State Requirements that Water Treatment Plant Operators Must Know

Specific Rules and Regulations that Water Plant Operators Must Know

- Chapter 62-550
Standards, Monitoring, and Reporting
- Chapter 62-555
Permitting, Construction and Operation and Maintenance of Public Water Systems
- Chapter 62-560
Requirements of Public Water Systems that are out of Compliance
- Chapter 62-602
Operator Certification Rule
- Chapter 62-699
Plant Classification and Staffing Requirements

Bacteriological Monitoring

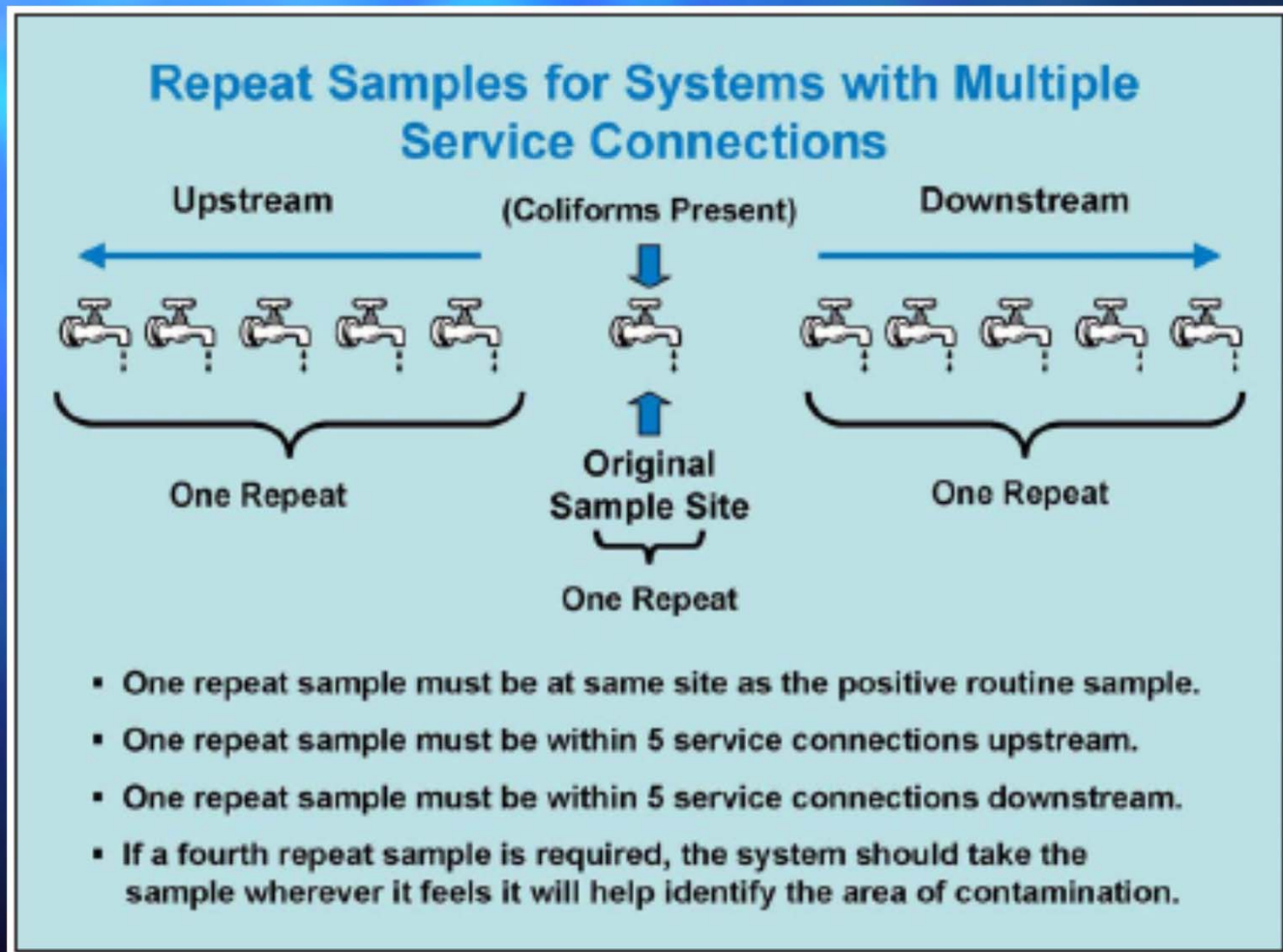
Four Principle DEP Requirements

1. All PWS Systems must test for coliform bacteria to determine compliance.
2. All PWS Systems must provide raw sample from each source or each well.
3. The number of distribution samples is dependent on the population served.
4. Provide bacteriological and chemical analysis results to FDEP postmarked by the 10th of following month.

Bacteriological Monitoring Failure to Meet Standards

- Repeat samples must be taken upon failure in the same month.
- Repeat samples must be taken at site of failure and at location within 5 service connections upstream and downstream.
- Systems collecting fewer than five samples a month that has one or more total coliform-positive samples shall collect at least five routine samples the next month.
- If fecal coliform is detected DEP must be notified by the end of the day that the system is notified of the test result.

Requirements for Repeat Samples



Chemical Constituents

Nitrate/Nitrite Testing

- Transient Non-Community Water Systems (TNCWS) must test for Nitrate/Nitrite yearly, along with quarterly bacteriological samples.
- All PWS's must test for Nitrate/Nitrite yearly, with Community (CWS) and Non-Transient Non-Community (NTNCWS) monitoring for bacteriological samples monthly.
- Nitrate MCL - 10 mg/l
- Nitrite MCL - 1 mg/l
- Combination – 10 mg/l

Chemical Constituents

Lead and Copper Action Levels

Chemical Constituent	Action Level
Lead action level	0.015 mg/l
Copper action level	1.3 mg/l

- All CWS and NTNCWS are covered.
- Action levels are exceeded if 10% of the samples exceed the above.
- Samples are based on population served.

Chemical Constituents

Secondary Contaminants

- Non-Transient Non-Community Systems must test for chemical analyses excluding secondary contaminants in their three year compliance cycle.
- Community Systems must test for chemical analyses and secondary contaminants in their three year compliance cycle.
- Secondary physical contaminants are non-health related (pH, color, odor)

Minimum Reporting Requirements for CWS

- MORs postmarked by the 10th of the month following the reporting period;
- Submit chemical analysis results for Pesticides & PCBs, Volatile Organics, Radionuclides, Primary Inorganics, TTHMs, Asbestos, Nitrate and Nitrite, Secondary Contaminants.

Water System Record Keeping Requirements

- Copies of written reports, cross connection control programs, sanitary surveys, shall be kept at least 10 years.
- Chemical analyses shall be kept for 10 years.
- Records of action to correct a violation shall be kept for 3 years.
- Water plant operation reports (MORS) shall be kept for not less than 10 years.
- Records concerning a variance or exemption granted shall be kept for at least 5 years.
- Records of bacteriological analyses shall be kept for not less than 5 years.

Water Treatment Plant Operating Requirements

- Must provide the required DEP certified water plant operator.
- Plant shall be maintained in good condition
- A hard bound Operation and Maintenance logbook shall be on site and available for inspection; all maintenance and daily testing records shall be recorded.
- Can not modify treatment or source without DEP approval
- Monthly Operating Reports (MOR's) are to be kept and submitted to DEP each month by the 10th.
- Can not operate plant greater than capacity without DEP approval

Water Treatment Plant Category Designations for C and D WTPs

Category	Description
I	Chemical Preparation
II	Demineralization
III	Filtration w/ Primary Treatment or Ion Exchange
IV	Primary Treatment, Aeration and Stabilization
V	Disinfection Only

DEP WTP License Requirements

Water Treatment Process	Class A	Class B	Class C	Class D
Category 1: Chemical preparation with filtration including lime softening, coagulation, direct filtration.	5.0 MGD and above	1.0 MGD up to 5.0 MGD	up to 1.0 MGD	None at this level
Category II: Demineralization including reverse osmosis desalinization, electrodialysis, and ultra filtration.	6.5 MGD and above	1.0 MGD up to 6.5 MGD	up to 1.0 MGD	None at this level
Category III: Filtration (other than category II) including primary treatment or ion exchange.	8.0 MGD and above	2.0 MGD up to 8.0 MGD	up to 2.0 MGD	None at this level
Category IV: Primary Treatment (includes aeration, stabilization, and disinfection).	None at this level	10 MGD and above	0.1 MGD up to 10 MGD	Up to 0.1 MGD
Category V: Disinfection only	None at this level	None at this level	.25 MGD and above	Up to .25 MGD

Lead Operator Must have License shown:

Class C Staffing Requirements

NEW as of 3/6/13!

Category		I	II	III	IV	V
5 visits/week and 1 visit/weekend			Below 0.1 MGD	Below 0.25 MGD	0.1 to 1.0 MGD	0.25 to 3.0 MGD
	Total hours/week		2.4	1.8	1.2	0.6
1 hr. ea. Day and weekend		Less than 0.1 MGD	0.1 to 0.25 MGD	0.25 to 0.5 MGD	1.0 to 3.0 MGD	3.0 to 5.0 MGD
3 hr. ea. Day and weekend		0.1 to 0.3 MGD	0.25 to 0.5 MGD	0.5 to 1.0 MGD	3.0 to 5.0 MGD	
6 hr. ea. Day and weekend		0.3 to 1.0 MGD	0.5 to 1.0 MGD	1.0 to 2.0 MGD	5.0 to 10 MGD	5.0 & Above

Class D Staffing Requirements

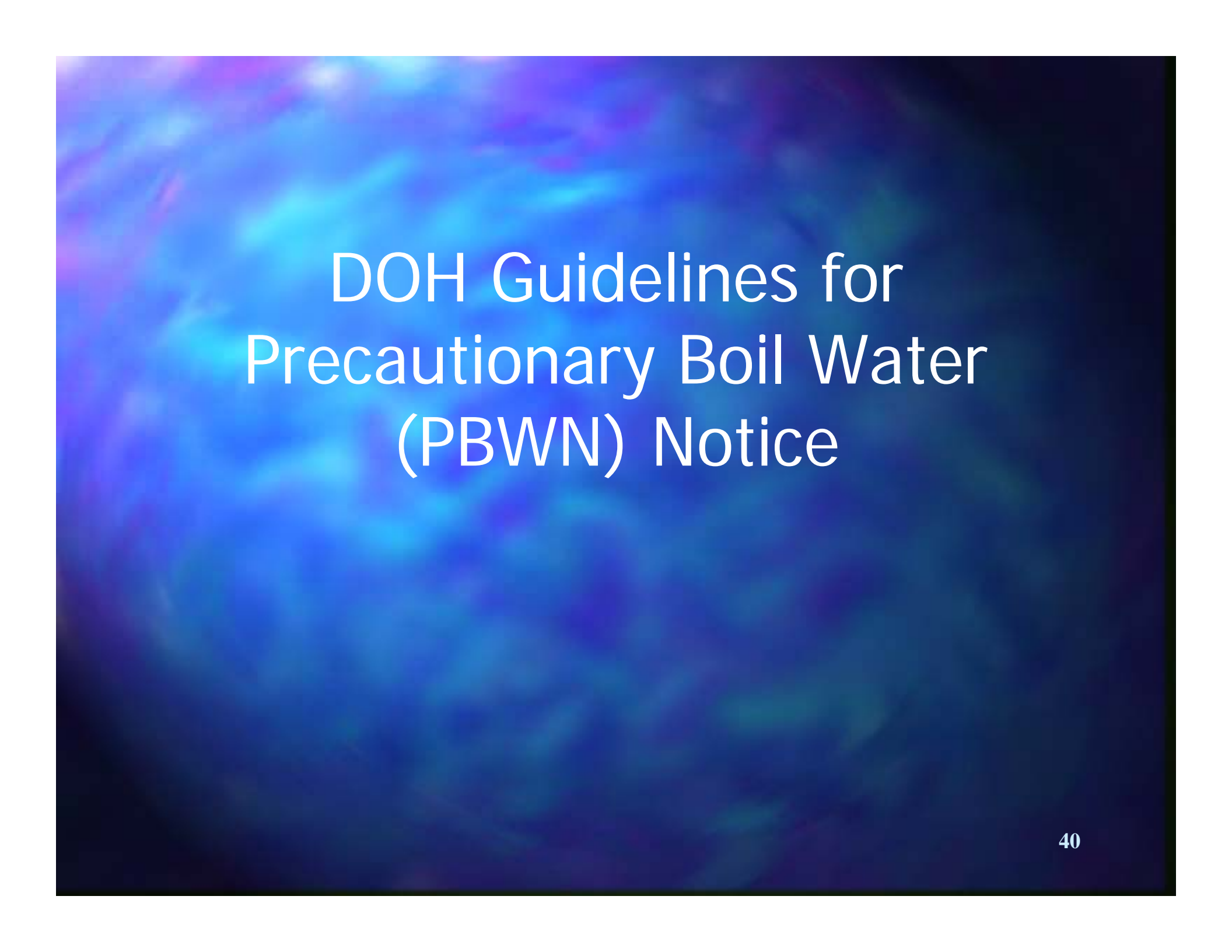
Category	IV	V
3 visits/week on nonconsecutive days for total of 0.6 hours/week	Less than 0.1 MGD	
3 visits/week on nonconsecutive days for total of 0.3 hours/week		0.05 to 0.25 MGD
2 visits/week on nonconsecutive days for total of 0.2 hours/week with no more than 5 days between visits		Less than 0.05 MGD

Water System Capacity Requirements

- For new community water systems (CWS), or for CWS and NTNCWS that grew to CWS status through facility expansion.
- Construction Permit from FDEP and demonstrate financial, managerial and technical capacity.
- Have required operator license
- Have capability to conduct monitoring and reporting

Water Distribution System Requirements

- Maintain 20 psi in distribution system at service connection except for break or extraordinary conditions.
- Document program for exercising all system valves
- Must have quarterly dead-end system flushing program and as necessary from complaints
- > 350 people or 150 connections
 - must map locations of valves, fire hydrants and facilities
 - must have Emergency Preparedness Plan for system,
 - and have minimum of two wells and backup generator



DOH Guidelines for Precautionary Boil Water (PBWN) Notice

Types of Problems Resulting in PBWN

- Microbiological
- Zero or Negative Pressure
- Low Water Pressure (maintain pressure during repair, maintain > 0.2 CI residual and limit affected area.)
- Water Main Breaks or Interruptions
- Flooding of Wells

Confirmed Microbiological Problems

- The Presumptive test is that Total Coliform has been detected.
- The Confirmation test is the confirmed presence of fecal indicator such as E coli or other fecal bacteria such as coliphage;
- Boil water notices must be issued ASAP but no later than 24 hours after results;
- DEP must be contacted by end of day;
- To lift notice repeat samples must be clear of TC, FC and EC and residual >0.20 mg/l Cl.

Main Break Clearance Samples

- Require two satisfactory days of sample results (PBWN may be lifted after first set contingent on second set)
- Two consecutive sets of repeat if second set is positive;
- Main clearance samples should be clearly marked and submitted with MORs.

Water Pipeline Additions to Distribution Systems

- Must have DEP permit
- Must provide a horizontal separation of 10' from sanitary sewer pipe
- Must maintain 12" vertical separation between sanitary, storm and reclaimed pipelines
- Must maintain 1 full length centered of water pipe to ensure joints are farthest away from intrusion points.



Minimum Disinfection Requirements

- Maintain a free chlorine residual of 0.2 or combined chlorine residual of 0.6 mg/l throughout the distribution system.
- Provide an approved DPD “free chlorine” test kit and daily checks 5 days per week
Chlorination facilities with a daily demand of 10 lbs./day or more must provide gas chlorination with automatic switchover.

Water Treatment System Facility Maintenance Requirements

- Must inspect storage tanks with access every 5 years
- Must rehabilitate tanks as needed using approved coatings
- Must clean sludge accumulations yearly
- Must exercise isolation valves at water storage tanks and in-plant facility

Sanitary Surveys Requirements

- Currently cover Subpart H Systems and are performed every 3 years for CWS and 5 years for NCWS by DEP
- On-site evaluation
 - Source
 - Treatment
 - Distribution system
 - Finished water storage
 - Pumps, pump facilities, and controls
 - Monitoring and reporting and data verification
 - System management and operation
 - Operator compliance with State requirements

Filtration

Filtration

- The process of passing water through material such as a bed of sand, coal, or other granular substance to remove floc and particulate impurities. Impurities include:
 - Suspended particles (fine silts and clays)
 - COLLOIDS
 - Biological forms (bacteria and plankton)
 - Floc

Filtering Mechanisms

- Sedimentation
- Adsorption
- Biological Action
- Absorption
- Straining
- Sedimentation on media
- Gathering of particles on the surface of the media or interfaces
- Break down of organic material by bacteria that cause a mat to develop that stains particles
- Soaking particles into the body of the media by molecular or chemical action
- Capturing particles in media pore spaces

Filtration Types

1. Gravity Filtration
 - Sand
 - Dual Media (sand and anthracite coal)
 - Multi or Mixed Media (sand, anthracite coal, and GARNET)
2. Pressure Filtration
 - Mixed Media
3. Diatomaceous Earth Filtration
 - Precoat Filtration
4. Slow Sand

Range	Ionic	Molecular		Macro Molecular	Micro Particle		Macro Particle
Microns	0.001	0.01	0.1	1.0	10	100	
~ Molecular Weight	100	10,000	100,000	500,000			
Size Range Of Selected Water Constituents	Dissolved Organics				Giardia		
			Viruses	Bacteria			
			Colloids				Sand
	Salts				Cryptosporidium		
Filtration or Membrane Process				Particle Filtration			
		Micro Filtration					
	Ultra Filtration						
			<u>Nonfiltration</u>				
		Reverse Osmosis					

Filter Applications

Solids Removal by Gravity and Pressure Filtration:

- Particulate Matter
- Flocs formed by Coagulation
- Calcium Carbonate and Magnesium Hydroxide Flocs formed in Lime Treatment
- Precipitates such as Iron and Manganese
- Some Microorganisms (effective removal depends upon effective chemical disinfection)

Gravity and Pressure Filtration Processes

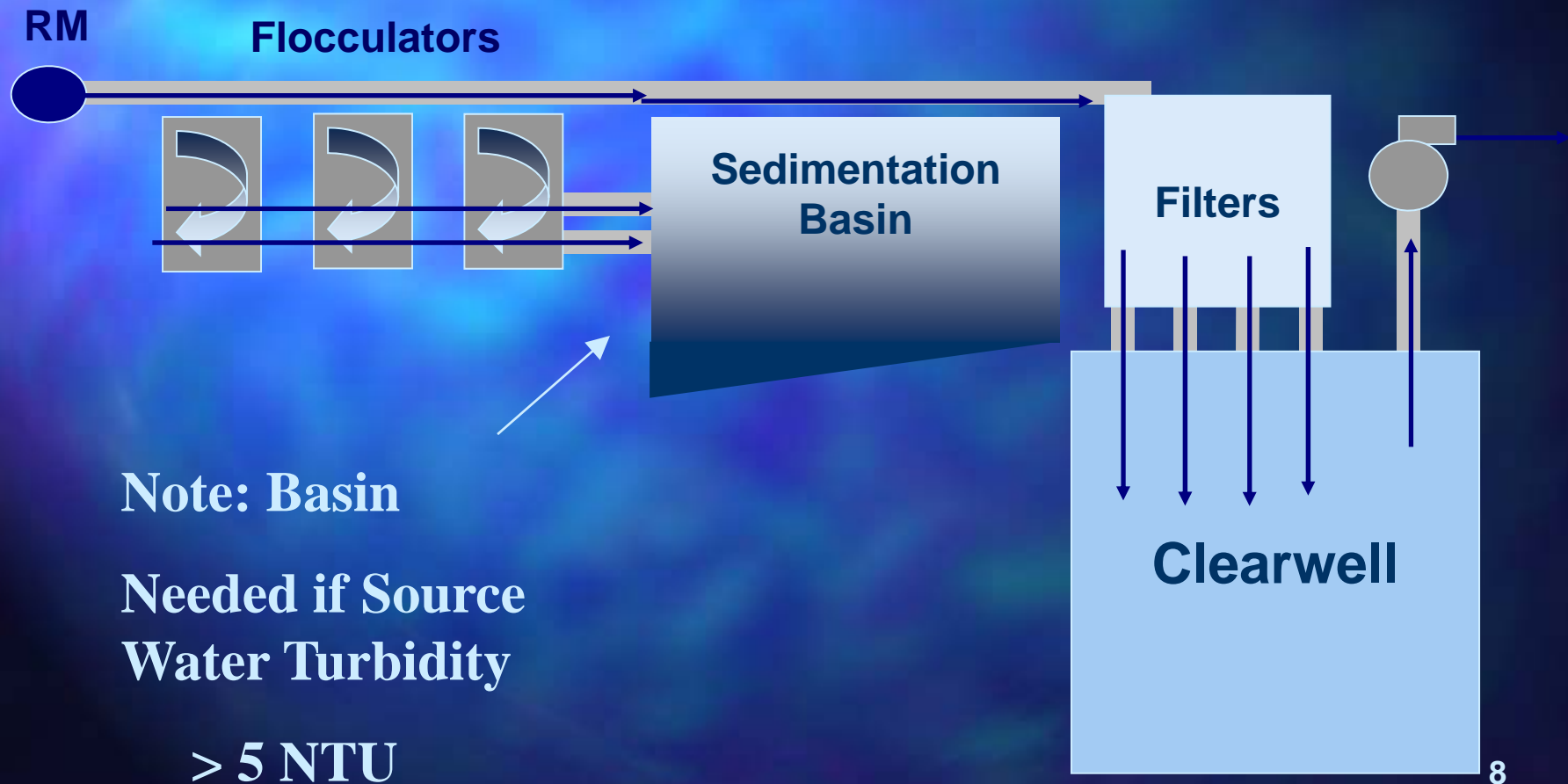
Conventional Filtration

- Filtration is preceded by coagulation, flocculation and sedimentation

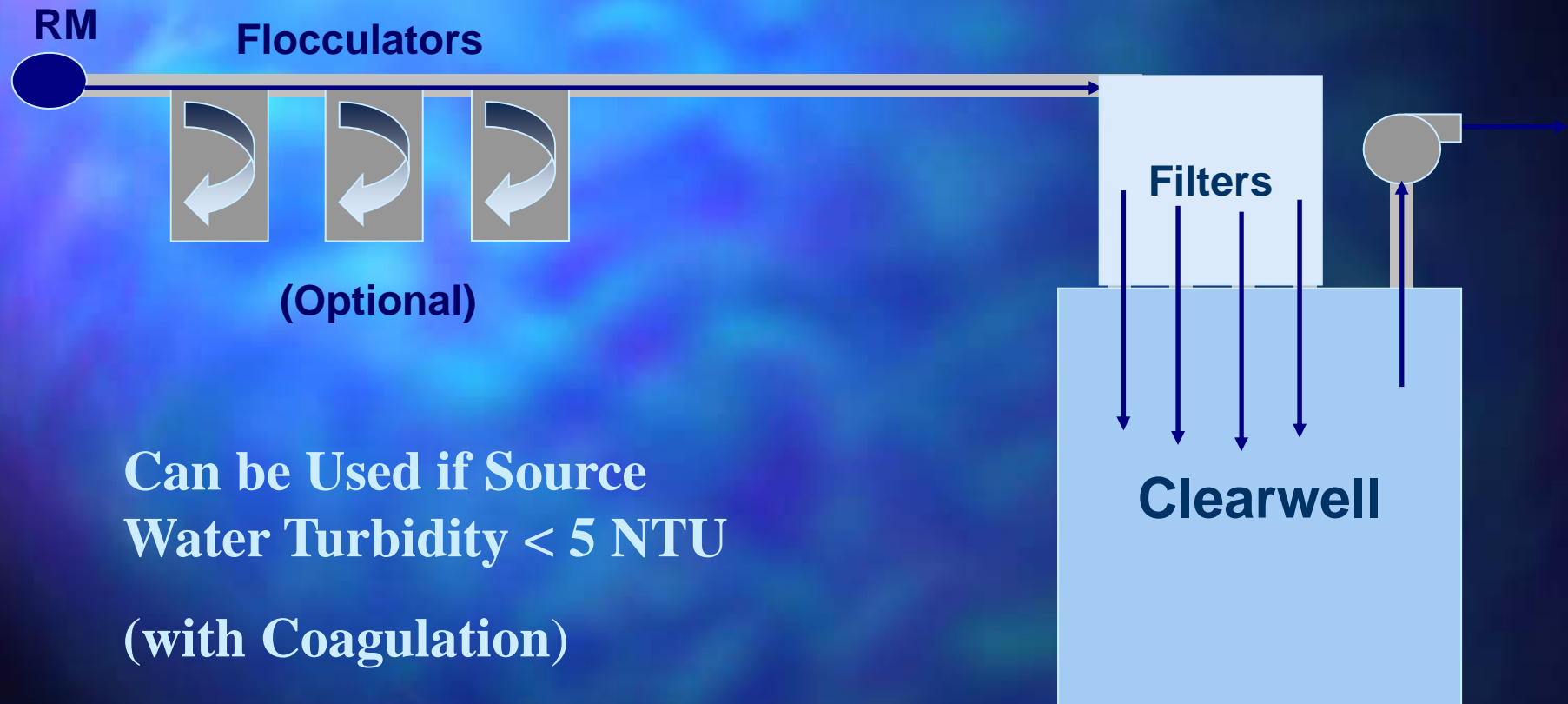
Direct Filtration

- Same as conventional filtration without sedimentation

Conventional Filtration



Direct Filtration



Can be Used if Source
Water Turbidity < 5 NTU
(with Coagulation)

Methods of Classifying Gravity and Pressure Filters

by

Loading Rates

Media

Depth

Stratification

and

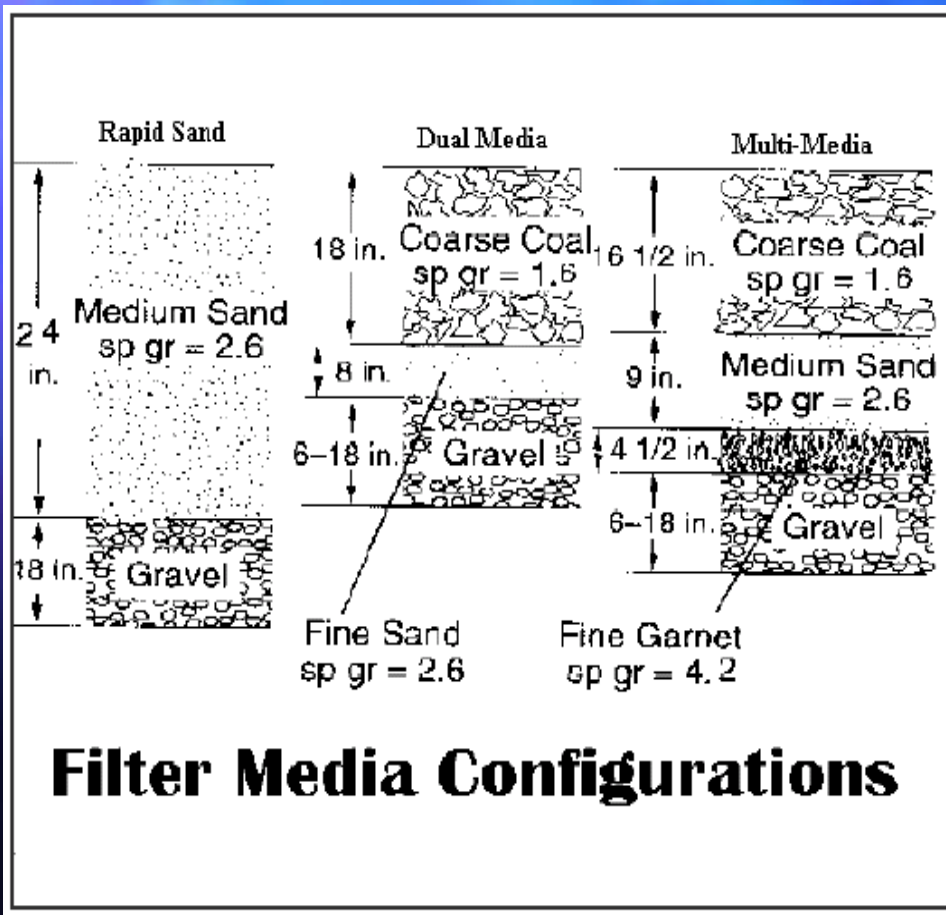
Head Pressures

(1 MGD WTP Comparison)

General Properties Filtration Media

- Coarse enough to retain large quantities of floc
- Sufficiently fine to prevent passage of suspended solids
- Deep enough to allow relatively long filter runs
- Graded to permit backwash cleaning

Media Configurations for Gravity Filters



- Single media (sand)
- Dual Media (sand and anthracite)
- Mixed or multi-media (sand, anthracite and garnet)

Filter Media Characteristics

Filter	Media	Size (mm)	Spec Grav	Depth (in)	Flow Type	Flow gpm/sf
Slow Sand	Fine Sand	0.2	2.6	36 – 48	Gravity	.05 - .03
Rapid Sand	Course Sand	0.35 – 1.0	2.6	24 – 36	Gravity	2 – 4
Dual Media	Anthracite Sand	0.9 – 1.2 0,4 – 0,55	1.4 – 1.6 2.6	18 – 24 6 – 10	Gravity	4 – 5
Mixed Media	Anthracite Sand Garnet	0.9 – 1.2 0,4 – 0,55 0.2	1.4 – 1.6 2.6 4.2	16.5 9 4.5	Gravity	5
Diatom. Earth	Diatomaceous	0.005 to 0,125		1/16 to 1/8	Pressure or Vacuum	0.5 – 5
Pressure	All Media	Application			Pressure	2 ₁₃ 4

<u>Characteristic</u>	<u>Rapid Sand</u>	<u>Slow Sand</u>	<u>Diatomaceous Earth or Pressure Filter</u>
Filtration Rate	2 gpm/sft.	.06 gpm/sft.	1 gpm/sf
Filtration Area	350 sft.	11,000 sft.	700 sft.
Depth of Media	18" gravel 30" sand Permanent	12" gravel 42" sand to 12" after ultimate use	1/16 to 1/8" surface
Size of Sand (Uniformity Coef .)	.35 to .80 mm U.C.<1.7.	.20 to .40 mm U.C.<2.5	Recoating Required .01 to .20 mm
Media Distribution	Stratified	Unstratified	Unstratified
Loss of Head	< 1 ft. initial 9 ft. final	0.2 ft. initial 4 ft. final	2 psi (5 ft.) initial 30 psi (70 ft.) final
Cycle Time	To 200 hrs.	60 days	To 40 hrs
Penetration of Matter	Deep Vertical	Shallow	Surface
Cleaning Method	Backwash/expansion	Surface Scraping of Schmutzdecke	Air Bump/Backwash
Wash Water Used	> 1%	< 0.6 %	< 1%
Pretreatment	Coagulation Flocculation Sedimentation	None Sometimes Aeration And/or Presettling	None, sometimes Aeration, Presettling or micro screening
Chlorination	Always	Always	Always
Raw Water Quality	High Turbidity High Color Moderate Algae	Moderate Turbidity Low Color Moderate Algae	Low Turbidity Low Color Low Algae
Hydraulic Type	Gravity Flow	Gravity Flow	Vacuum or Pressure

Media Type, Backwashing Frequency and Maximum Loading Rate

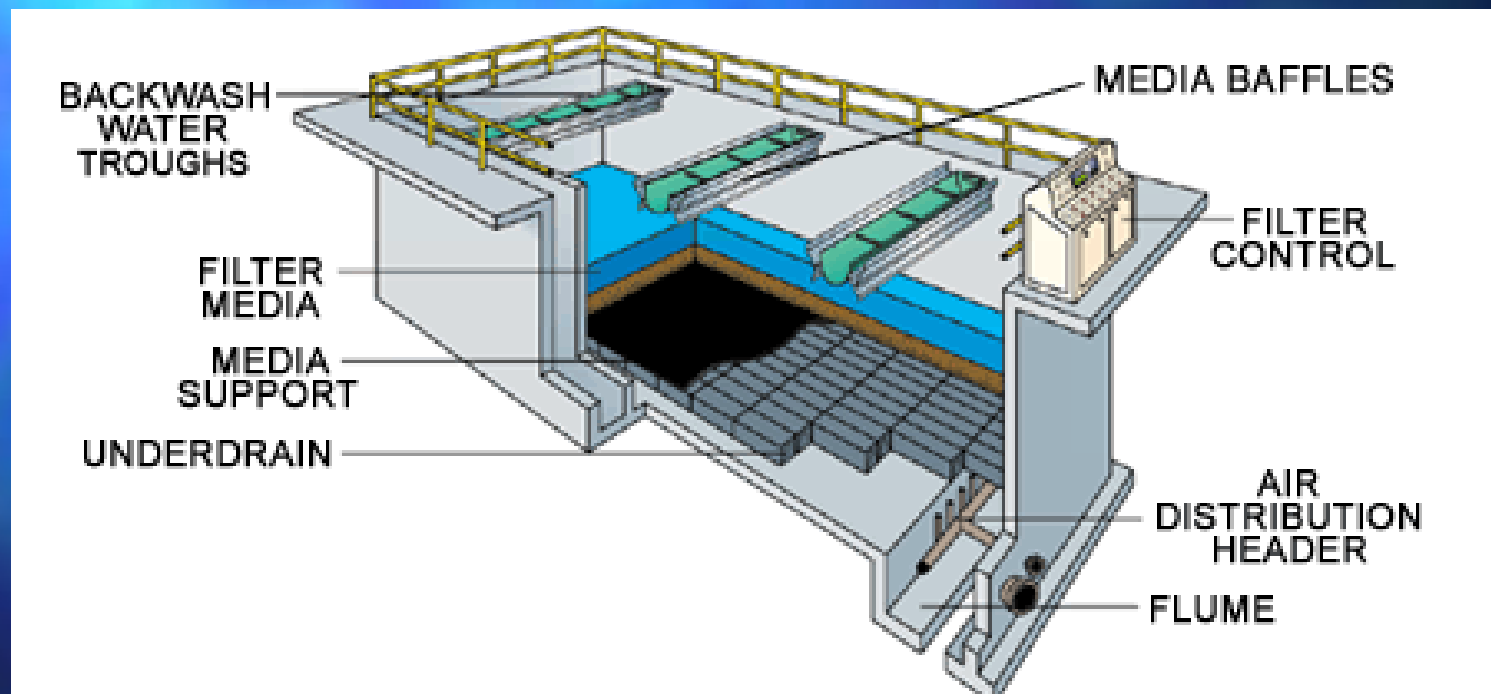
Dual and Multimedia Filters allow more time between Backwashing and can handle higher flow rates through the filter with the same removal efficiency.

- Sand Only 2 GPM/sf.
- Dual or Multi-Media 4 GPM/sf.
- Deep Bed (depth > 60") 6 GPM/sf.

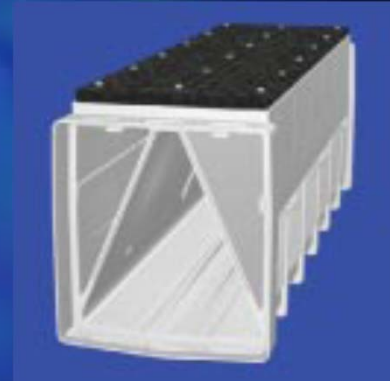
Filter Components

- Inlet chamber
- Filter media
- Underdrain
- Washwater trough/ Backwash trough
- Effluent Chamber
- Scouring Mechanism

Standard Filter Configuration

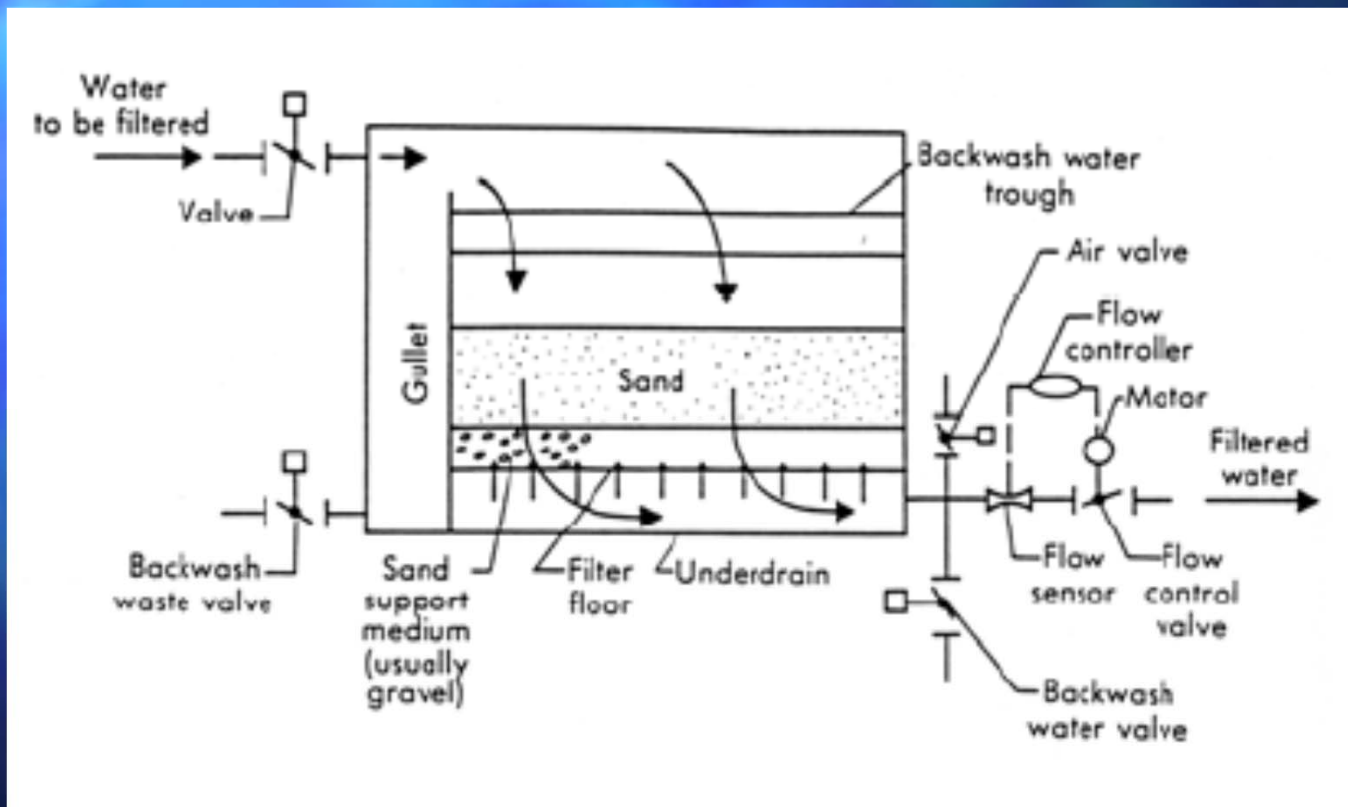


Purpose and Types of Underdrains

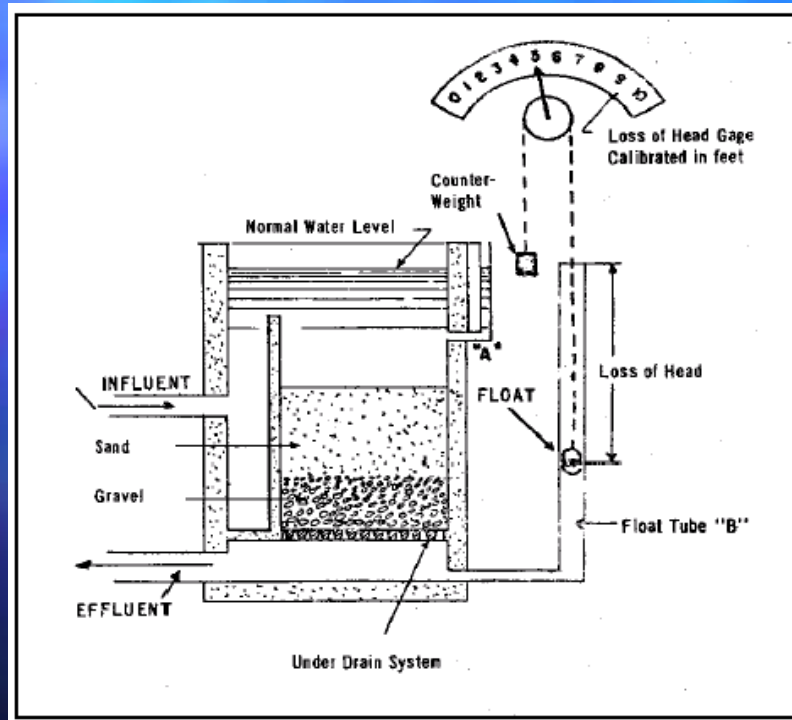


- Support the filter media
- Collect the filtered water
- Distribute the water for backwashing and air scouring
- Common types of underdrains include:
 - High-density polyethylene underdrain block
 - Plastic nozzle underdrain systems

Filter Operation



Head Loss Control



- Materials collect on surface raising head pressure and filter must be backwashed
- Generally 8 ft head max. allowable loss
- Some Systems also use Turbidity Meter

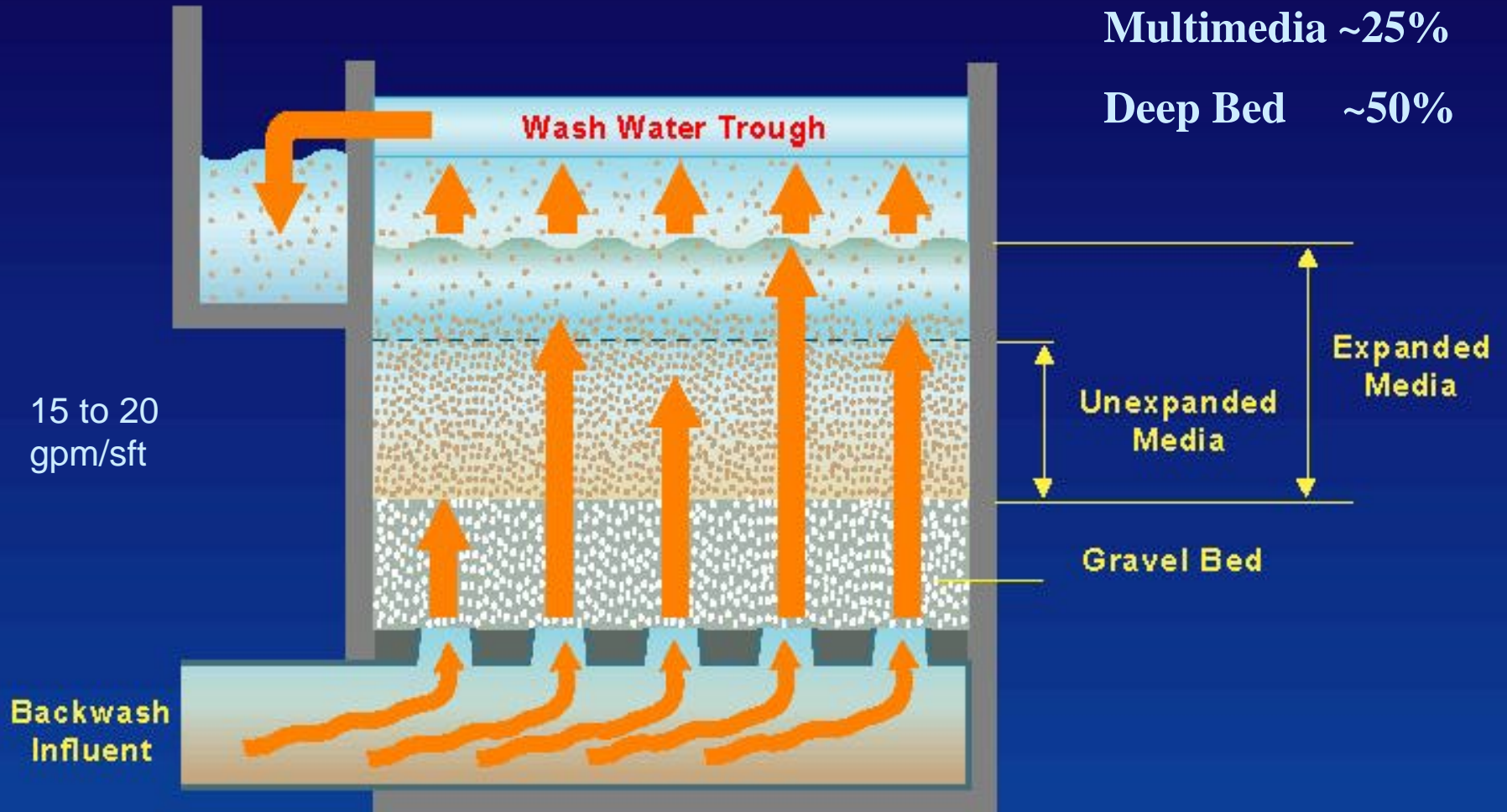
Gravity Filter Backwashing

Filter Bed Expansion

Sand Filter ~40%

Multimedia ~25%

Deep Bed ~50%



Filter Scouring Considerations

Purpose is to dislodge deposits
from media surfaces

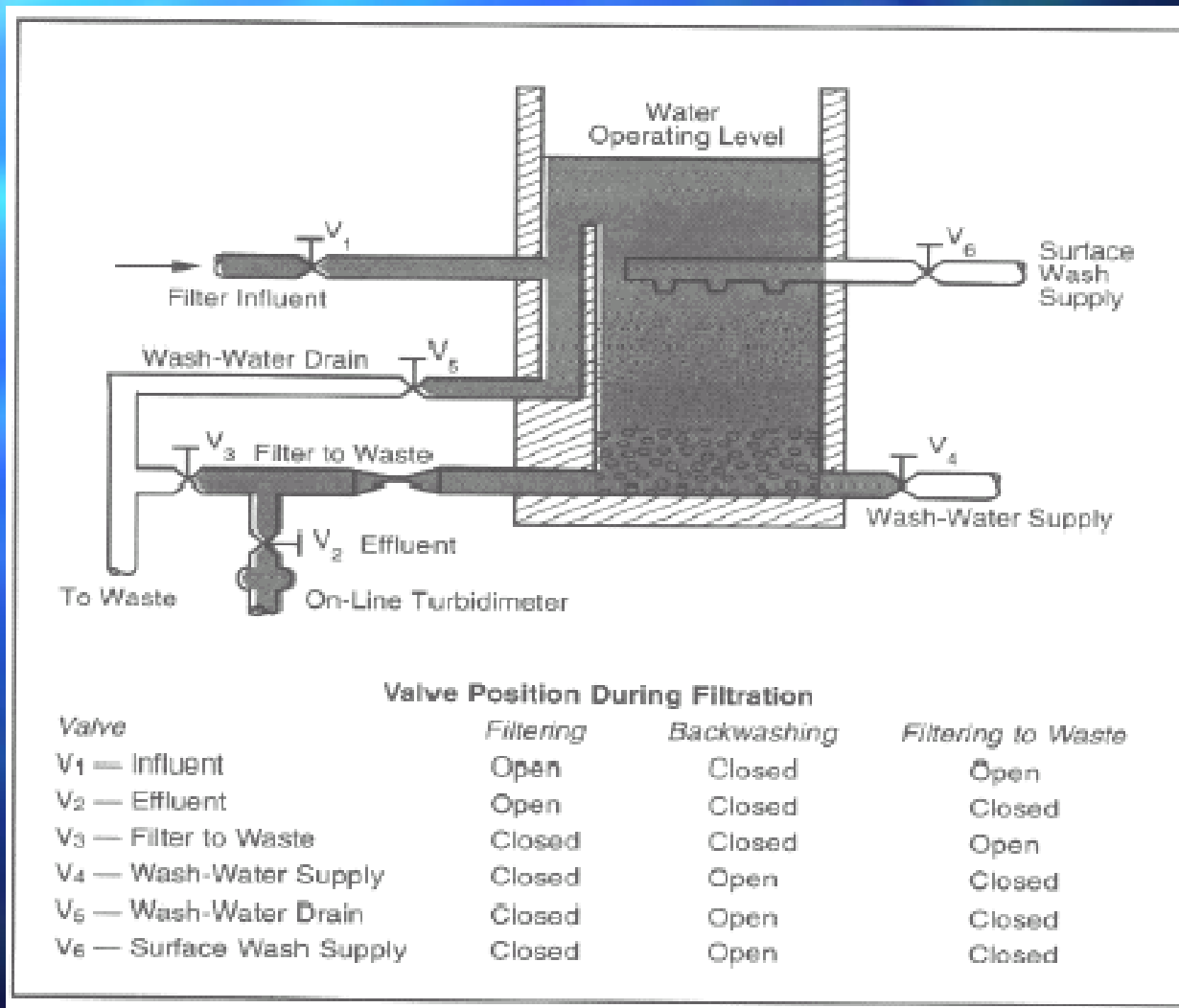
Air Scour

- Run during backwash
- Stops before bed is fully expanded to prevent media loss
- Stop and run Backwash 2 min to restratify bed

Surface Water Scour

- Fixed or Rotating Arm
- Break up Surface Mats
- Also used during backwash to clean media

Filter Backwashing Procedures



Backwash Parameters

- Typically at about 24 hour intervals
- Rate: 15 gpm/ft²
- Backwashing Duration: 5 - 10 min.
- Filter to waste for 3 - 5 min.
- Water used for backwashing: 2% - 4% of filtered water

Question:

Opening the backwash water valve to fast will surge the filters and cause...

- a. Damage to the underdrain
- b. Damage the media
- c. Media to be displaced
- d. All of the above

Recognizing and Correcting Filter Problems

Causes of Poor Filter Performance

- Filter Problems: operational, mechanical equipment failure, media failure
- Turbidity Errors: calibration, air bubbles, debris
- Chemical Feed Failures: coagulant, coagulant aid, filter aid
- Poor Water Quality: increased turbidity, algae

Visual Identification of Filter Problems

- Mudballs – Formed by chemical deposits of solids during backwashing (leads to coating of media surfaces)
- Surface Cracking – Caused by compressible matter around media at surface
- Media Boils – Caused by too rapid of backwash and displaces gravel support below
- Air Binding – Caused by excessive headloss (infrequent backwashing) allowing air to enter media from below

Large Mudball

Typical Size ¼" to 2+" dia.



How can mudball
formation be prevented?

Proper surface washing

Gravity Filter Troubleshooting

Problem

Mud ball formation in the filter bed.

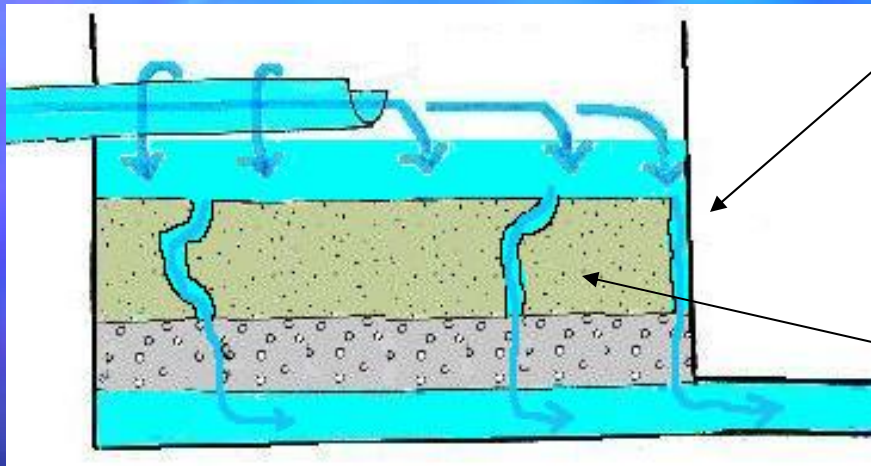
Cause/Check

- Poor coagulation
- Poor Sedimentation
- Improper Backwashing

■ Solution

- Correct coagulation and sedimentation problems
- Adjust backwash cycle

Surface Cracking in a Filter



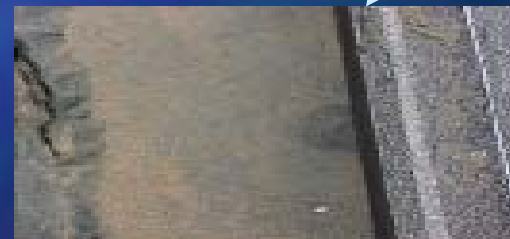
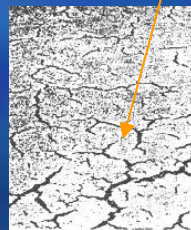
Retraction:

Filter Media Separation
along wall.

Filter Cracking:

Cracks on the Filter
Surface.

- 12 inches long or
- 1/4-inch wide or
- 1/2-inch deep.

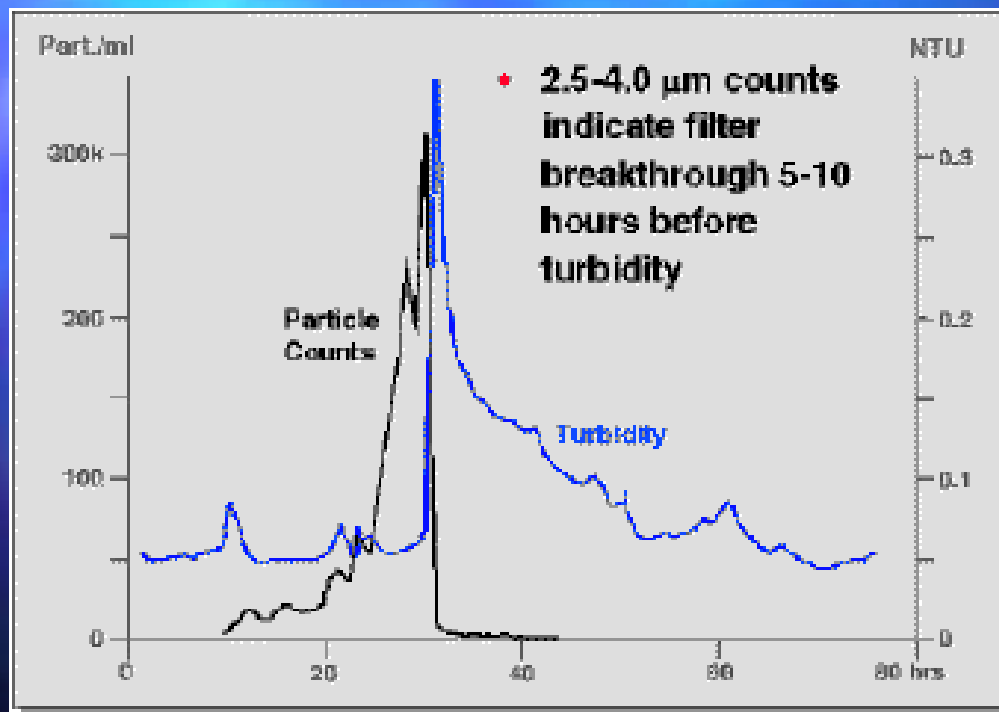


Media Boils in a Filtration System



Gravel Movement in
Media Bed

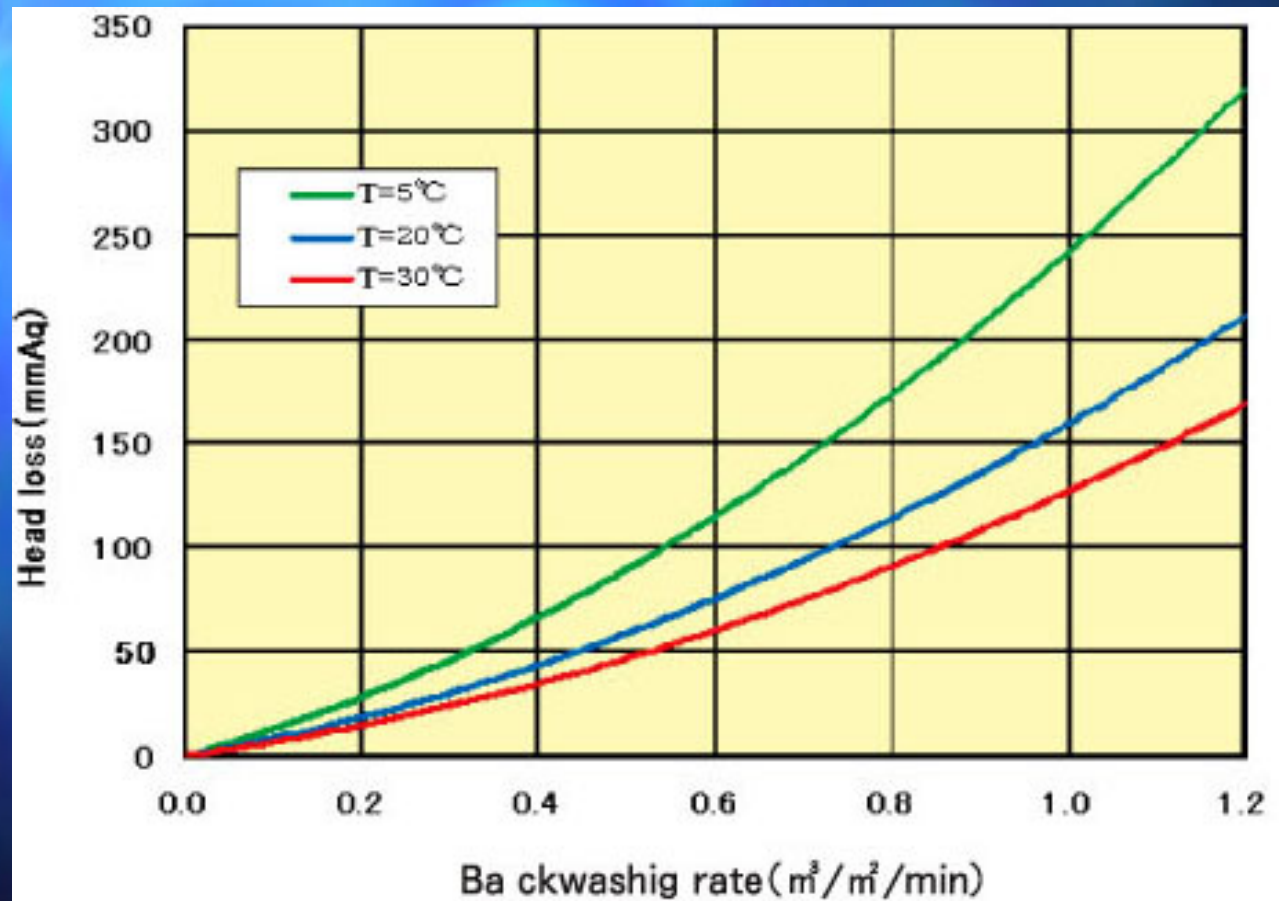
Anticipating Filter Breakthrough



Filter Process Control

- Head Pressure
- Increase in Turbidity

Effects of Temperature on Backwashing



Gravity Filter Backwashing Troubleshooting

Problem

Media Boils, Media Loss, Surface Cracking, Air Binding or failure of the filter to come clean during backwash.

Cause/Check

Improper backwash flow rates, surface scour rates or duration.

Solution

- Backwash flow rates
- Adjust surface scour rates
- Change duration of backwash cycle.

Special Application Filters

Greensand for Iron Removal
Activated Carbon for Organic Removal

Greensand Media for Iron and Manganese Removal

- Greensand added to filter media
- Greensand is a Natural Resin specific to Iron and Manganese
- Regenerated by adding potassium permanganate until pink color is achieved

Powdered Activated Carbon Filtration for Taste and Odor Removal

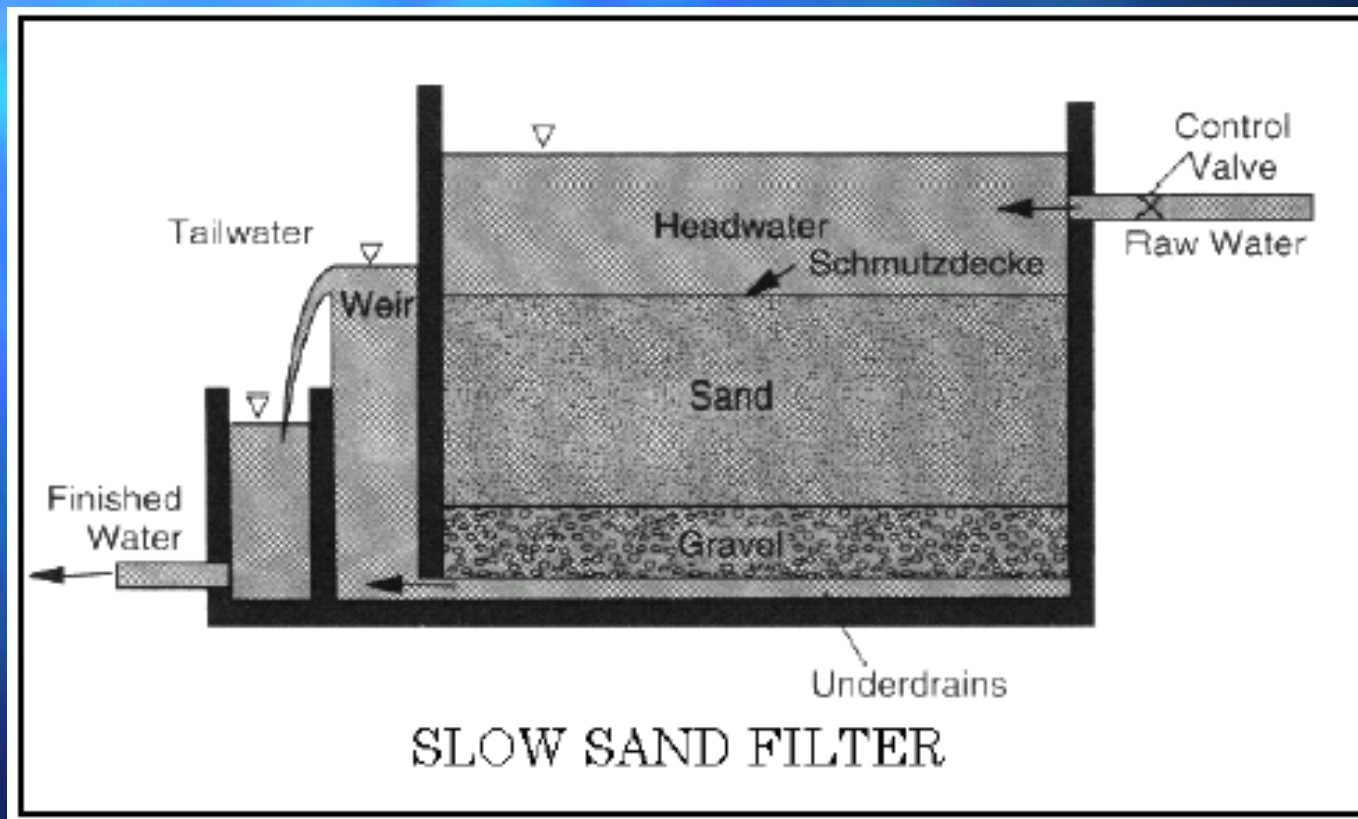
- Added at flash mixer in coagulation process or ahead of conventional filter using a dry or wet slurry
- Dry Feeders used for batches and Slurry feeders used for continuous feeds.
- Effective at doses from 1 to 15 mg/l for taste and odors but > 100 mg/l for THM or precursor removal

Granular Activated Carbon Filter for Taste and Odor

- Used as a separate media layer or as a “contactor” following filtration
- Requires 10 minutes of contact time with filter media
- Process control checks include check for microbes, head loss, turbidity and taste/odor removal.

Slow Sand Filtration

Slow Sand Filter Configuration



Benefits of Slow Sand Filtration

- Effective in reducing disinfection by-product precursors
- Effective at removing Giardia
- Require very little operator attention
- Very Reliable

Slow Sand Filtration Operating Parameters

- Turbidity of less than 10 NTU.
- Color of less than 30 units.
- Algae of less than 5 mg per cubic meter of chlorophyll A.

Slow Sand Filtration Considerations

- 50 to 100 times slower than conventional filtration.
- Requires smaller sand particles (smaller pore spaces), effective size 0.25 to 0.35 mm, with a uniformity coefficient of 2 to 3.

Slow Sand Filtration Start-up and Cleaning Considerations

- Start-up may take as long as 6 months to develop the initial biological mat (Schmutzdecke).
- May perform poorly for 1 to 2 days after filter cleaning, called the "ripening period."
- Because of the length of time required for cleaning and ripening, redundant filters are needed.
- Filter must always be submerged to maintain biological mat

Slow Sand Filtration Head Loss Considerations

- Initial headloss is about 0.2 feet, maximum
- Head loss should be no more than 5 feet to avoid air binding and uneven flow of water through the filter medium.

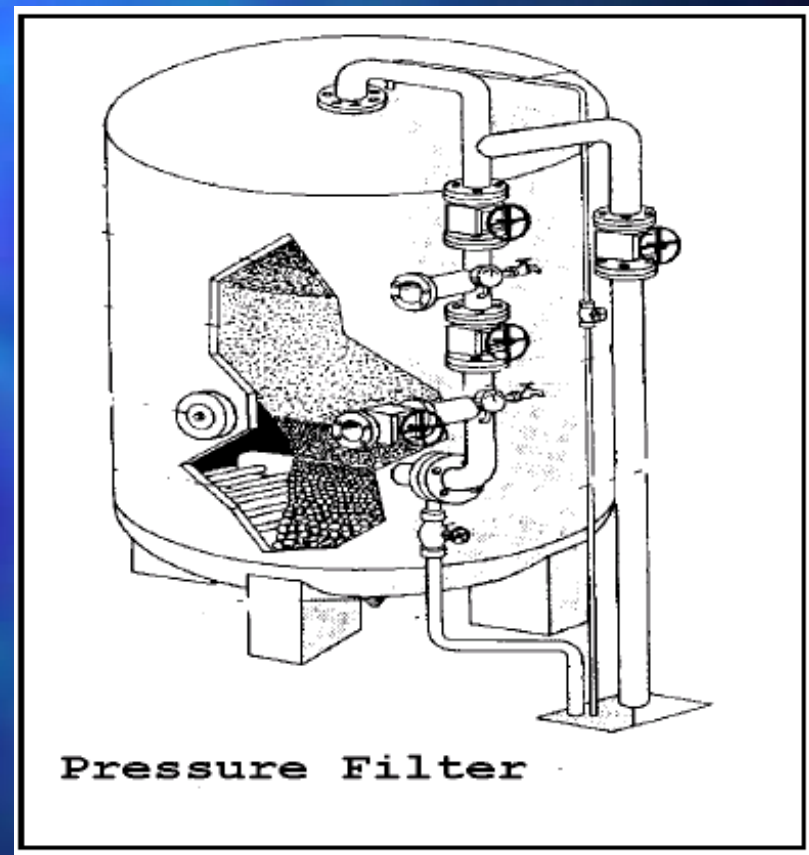
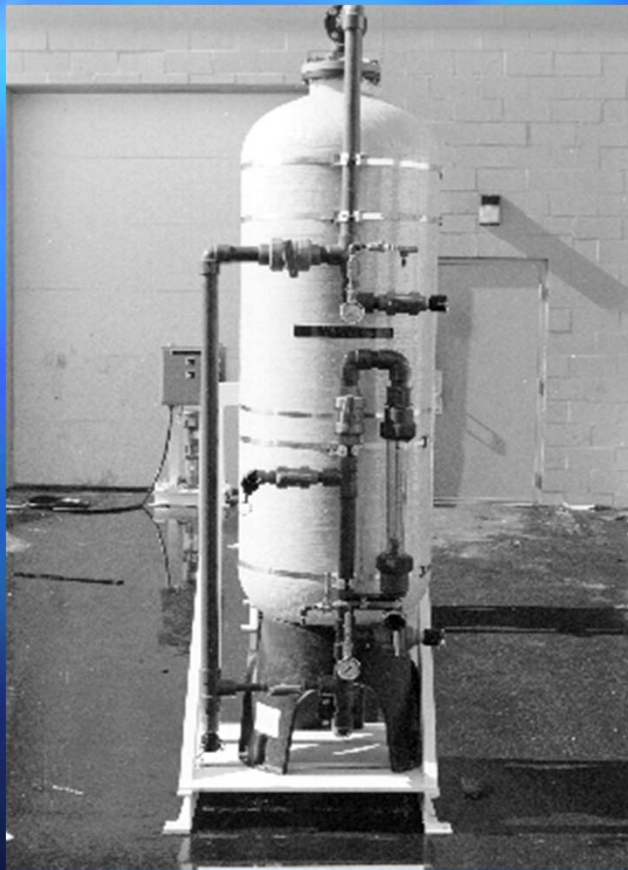
Cleaning Slow Sand Filters



- The normal length of time between cleanings is 20 to 90 days.
- Cleaning involves scraping manually 1 to 2 inches and discarding the sand.
- New sand should be added when sand depth approaches 24 inches, approximately every 10 years.

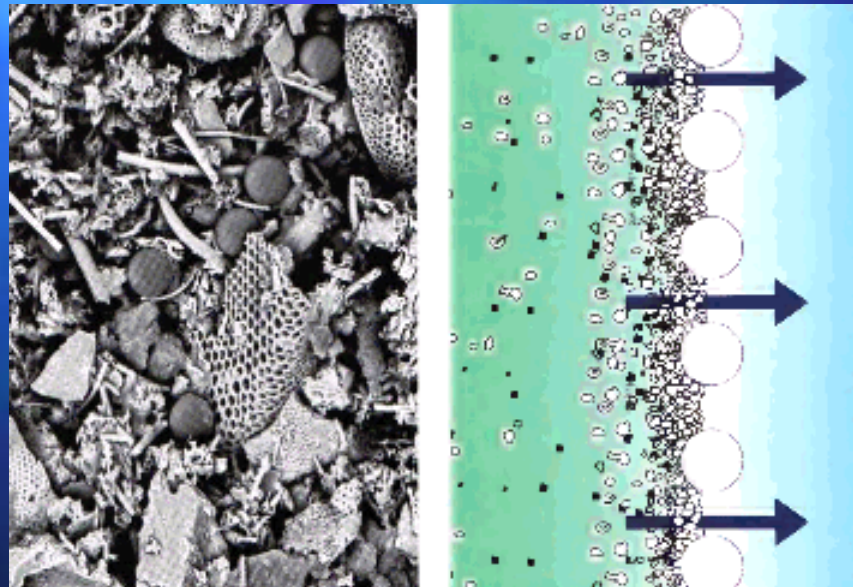
Pressure Filters

Pressure Filter & Schematic



Diatomaceous Earth Filtration

- Filter is composed of siliceous skeletons of microscopic plants called diatoms.
- Skeletons are irregular in shape therefore particles interlace and overlay in a random strawpile pattern which makes it very effective for Giardia and crypto removal.



Diatomaceous Earth Filtration Precoat Considerations

- Difficulty in maintaining a perfect film of DE of at least 0.3 cm (1/8 in) thick has discouraged widespread use except in waters with low turbidity and low bacteria counts.
- The minimum amount of filter precoat should be 0.2 lb/sft and the minimum thickness of precoat should be 0.5 to enhance cyst removal.

Diatomaceous Earth Filtration Coagulant Enhancement

- The use of a alum (1 to 2% by weight) or cationic polymer (1 mg per gram of earth) to the body feed improves removal of viruses, bacteria and turbidity removal

Diatomaceous Earth Filtration

Body Feed Considerations

- Continuous body feed is required because the filter cake is subject to cracking.
- Lack of body feed increases headloss due to buildup on the surface.
- Body feed rates must be adjusted for effective turbidity removal.
- Filter runs range from 2 to 4 days depending on the rate of body feed and media size.

Diatomaceous Earth Filtration

Body Feed Considerations

- Interruptions of flow cause the filter cake to fall off the septum.
- Precoating should be done any time there are operating interruptions to reduce the potential for passage of pathogens.
- The use of the finest grades of diatomaceous earth coating will increase the effectiveness of the process to 3 logs bacteria removal and 98 percent removal for turbidity.

Bag and Cartridge Filter Technologies

Bag and Cartridge Filter Loading Rates

- Used generally for polishing flow into RO unit
- Filter can accommodate flows up to 50 gpm.
- As the turbidity increases the life of the filters decreases; bags will last only a few hours with turbidity > 1 NTU.
- Operate by physically straining the water
- Can operate down to ~ 1.0 micron

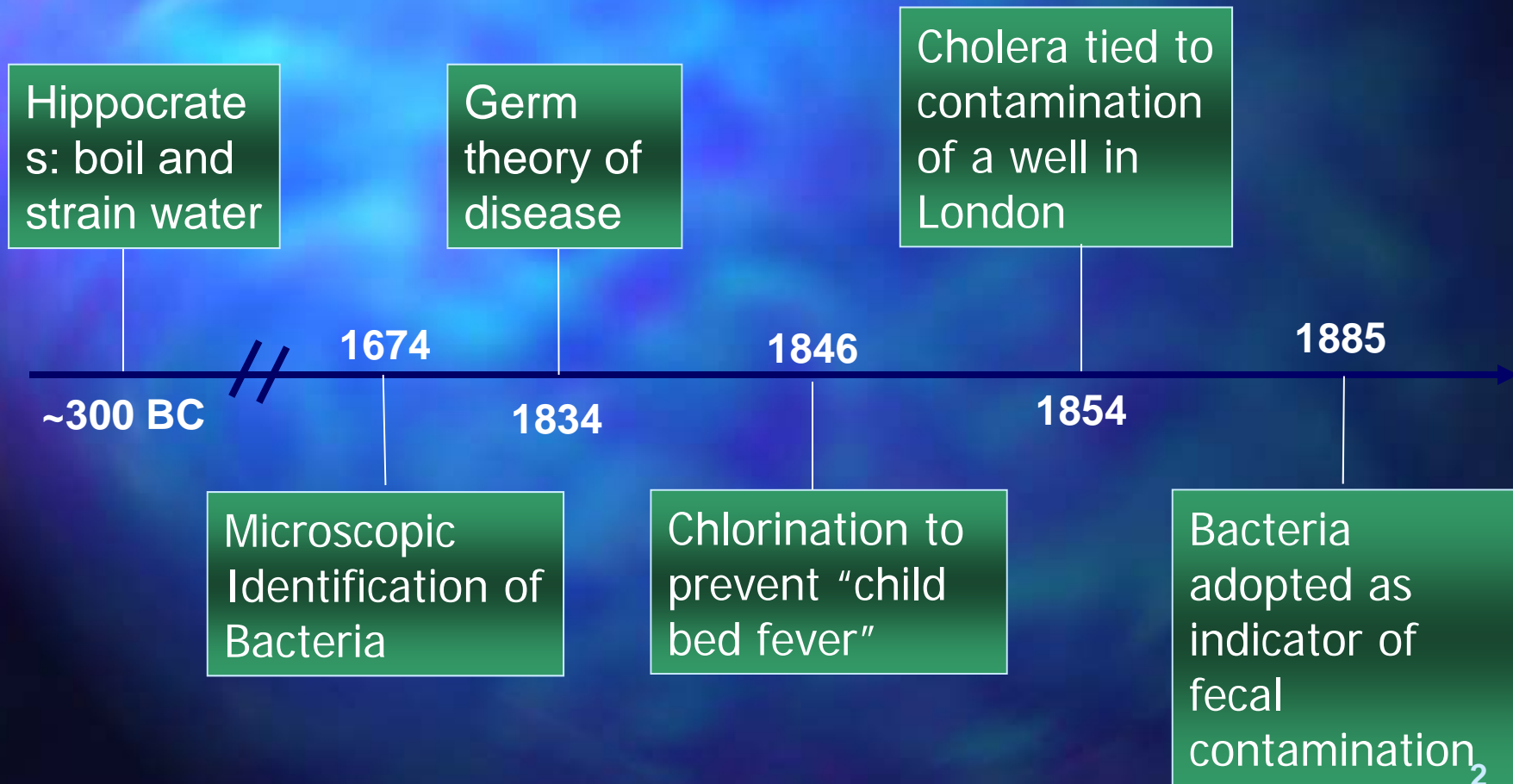
Application of Bag and Cartridge Filters as Finishing Filters

- For a conventional or direct filtration plant that is on the borderline of compliance installing bag/cart filtration takes the pressure off by increasing the turbidity level to 1 NTU
- Increases public health protection by applying two physical removal technologies in series

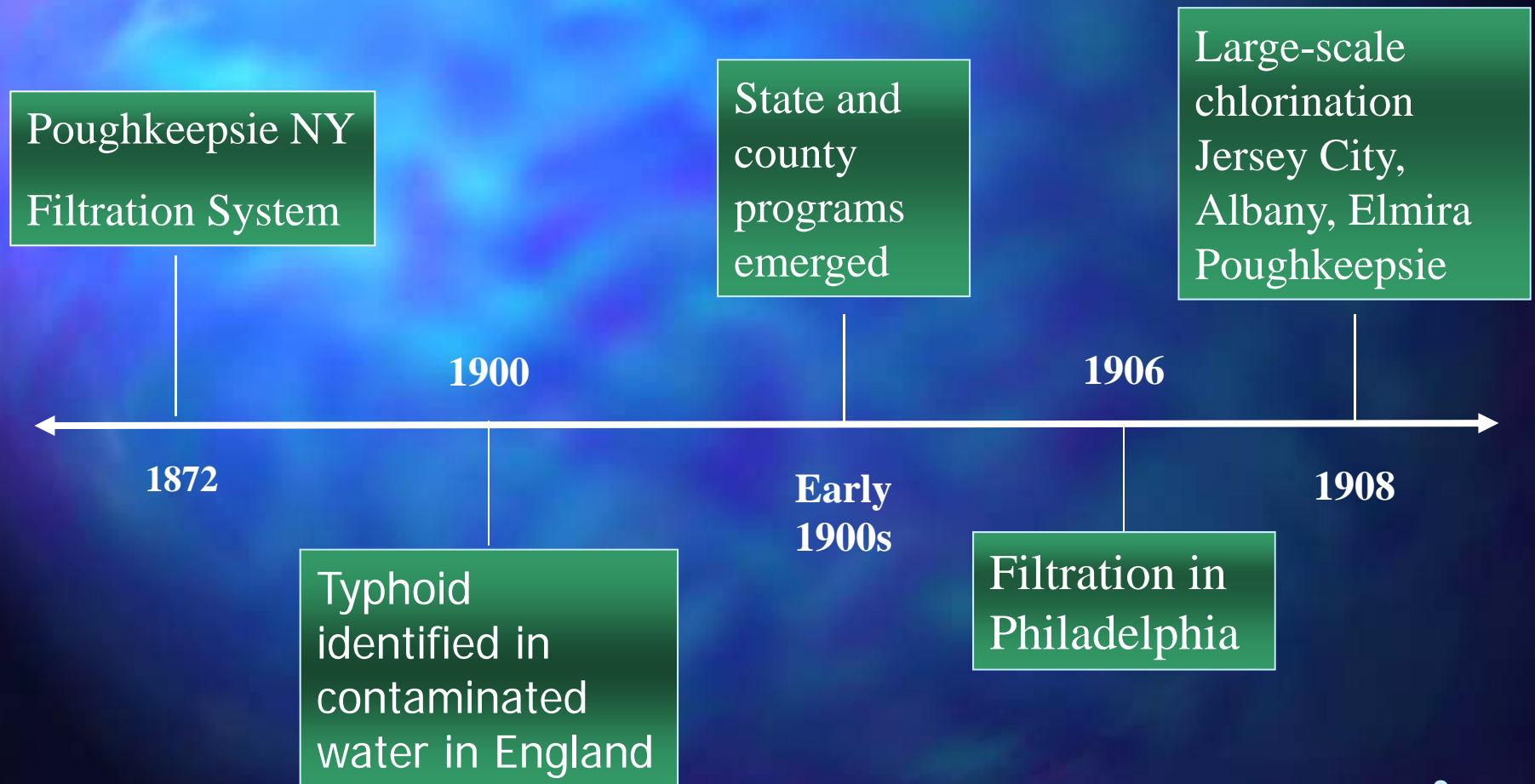


Introduction to Water Treatment

Early Filtration & Disinfection of Water Supplies



Development of Filtration & Disinfection in US Water Treatment

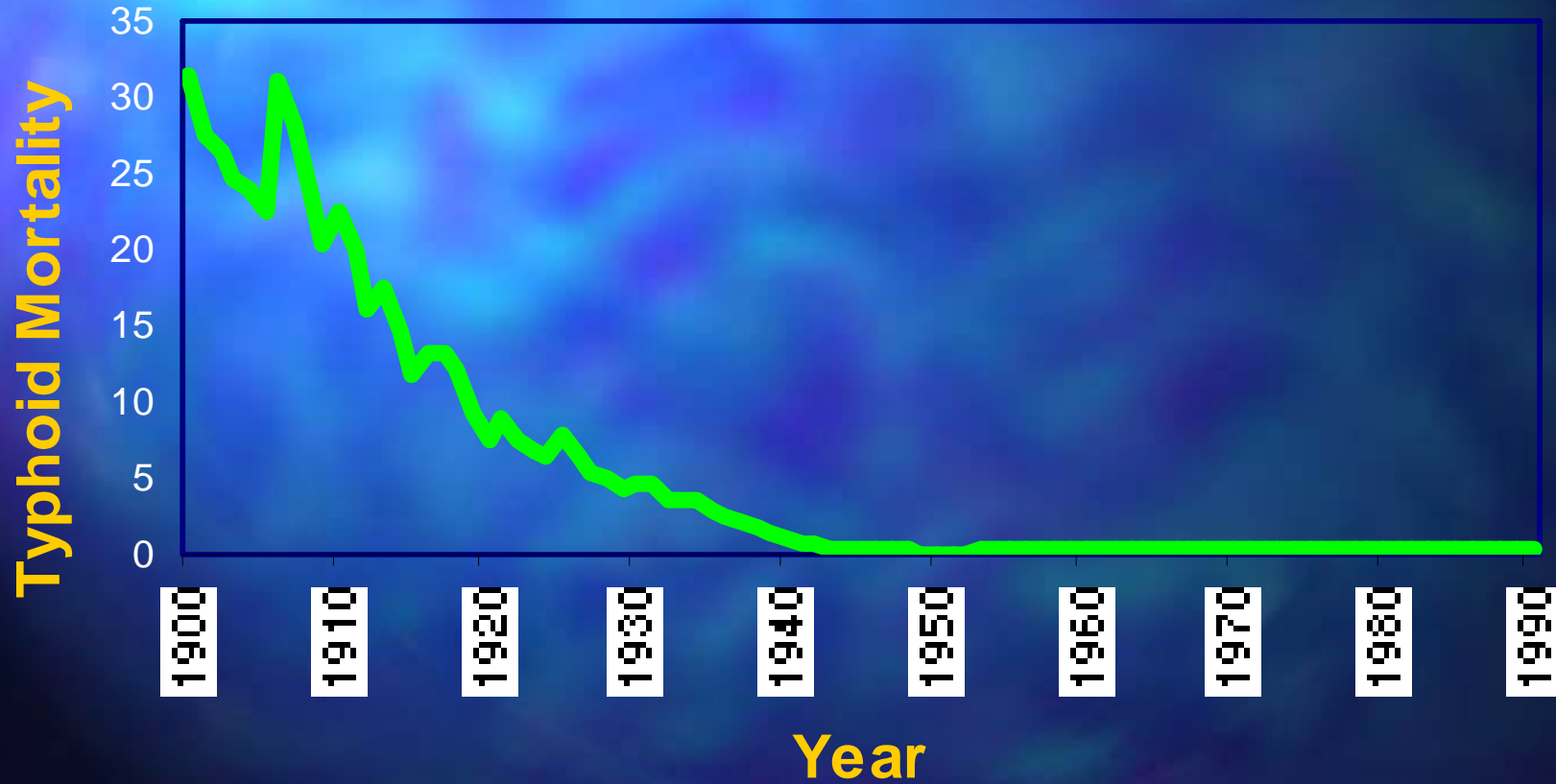


Early US Treatment Techniques for Bacterial Inactivation

- Slow Sand Filtration (no backwash)
 - Large filter beds with relatively slow filtration rates that strain out particles
 - Particles are removed by sieving and organic action
- Disinfection
 - Chlorine added to drinking water in very small concentrations

Early Success in Drinking Water Protection with Typhoid

Typhoid Deaths Per 100,000 People

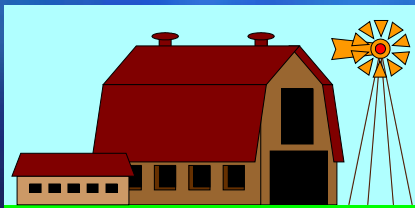




Water Borne Illnesses of Concern

- Cholera
- Dysentery
- Gastroenteritis
- Giardiasis
- Hepatitis
- Typhoid

Drinking Water Health Concerns Resulting from Cultural Changes in US



- Urbanization
 - Discharge from septic tanks, storm and sanitary sewers
- Industrialization
 - Discharges of metals and chemicals
 - Production of nuclear material
- Intensive Farming and Agriculture
 - Pesticide and fertilizer use
 - Feedlots and meat production

Types of Contaminants, Some Examples and Sources

Contaminant	Examples	Source
Microbial Contaminants	<i>Cryptosporidium</i> , <i>E. coli</i> , Norovirus	Sewage treatment plants, septic systems, agricultural livestock operations, and wildlife
Inorganic Chemical Contaminants	Arsenic, Copper, Fluoride, Lead	Naturally occurring or result from urban stormwater runoff, industrial or domestic wastewater discharges, soil and gas production and mining or farming
Disinfectants	Chlorine, Chloramine	Water additive for inactivating microbial contaminants
Disinfection Byproducts	Trihalomethane, Haloacetic acid	Byproduct of drinking water chlorination
Organic Chemical Contaminants	Pesticides and Herbicides, Benzene, Toluene	Agriculture, stormwater runoff, byproducts of industrial processes and petroleum production, gas stations, urban stormwater runoff, and septic systems
Radioactive Contaminants	Radium, Uranium	Naturally occurring or result from oil and gas production and mining activities

Modern Water Treatment

Filtration

- Surface Water contains organisms
- Turbidity is representative of quality
- Graded sand provides effective removal

Chlorination

- Cl is a very strong Oxidant that destroys integrity of Bacterial Cell Wall
- Highly effective for low turbidity water
- Residual provides evidence for continued effectiveness

Multiple Barrier Approach



Risk Prevention:
Source Selection
and Protection



Risk Management:
Treatment Methods
and Efficiencies



Monitoring and
Compliance:
Detecting and
Fixing Problems



Individual Action:
Consumer
Awareness and
Participation

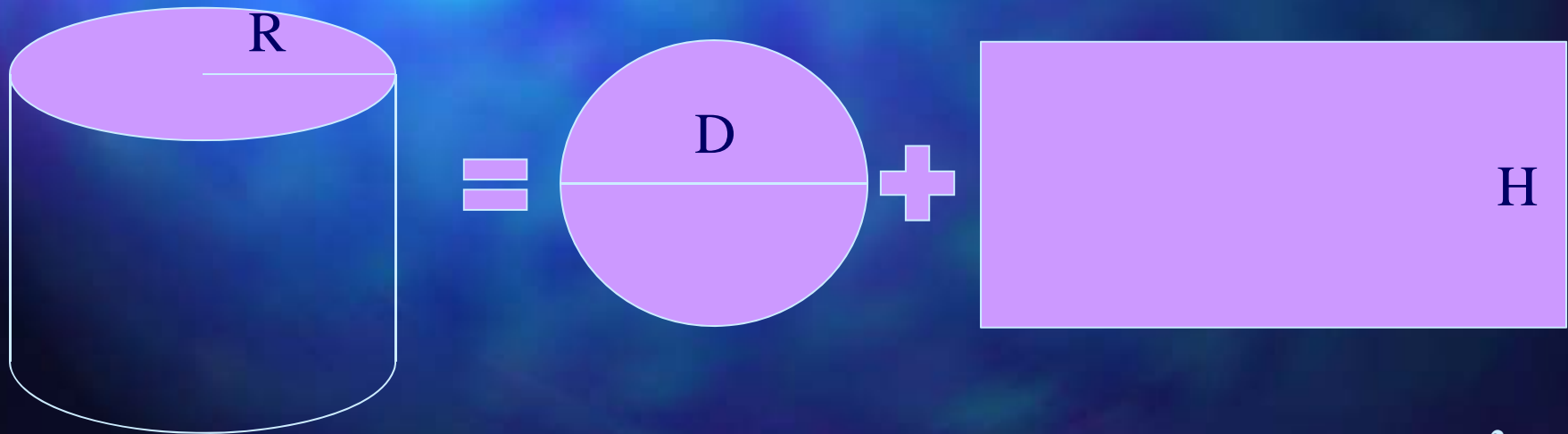
Your Role as an Operator

- Responsible for the operation of the water system
- Correction of any problems that make the water unsafe
- Monitoring the water for contamination
- Adherence to state and federal rules and regulations that apply to the water treatment aspect of providing water to the public

Math for Water Operators

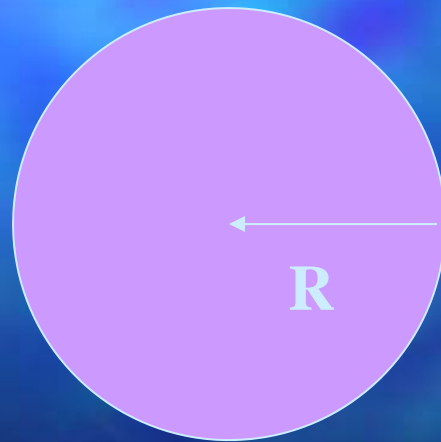
Calculate Surface Area of a Tank

- Top area = $\pi * R^2$
- Side = Circumference * height
 $= \pi * D * H$



Determine Area of the Top of the Tank

CALCULATE THE SURFACE AREA OF THE CIRCLE

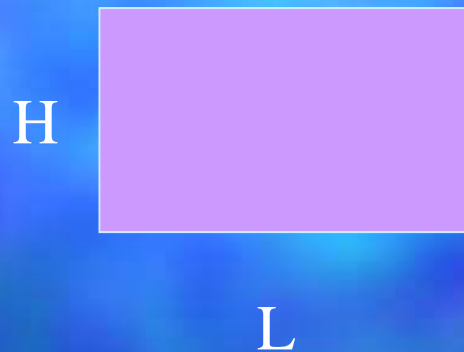


$$\text{RADIUS} = 20 \text{ FT}$$

$$\begin{aligned}\text{Area} &= \pi * R^2 \\ &= 3.14 * 20 * 20 \\ &= 1,256 \text{ SQ FT}\end{aligned}$$

Determine Area of the Sides of the Tank

- **CALCULATE THE SURFACE AREA OF THE SIDE**



AREA OF A RECTANGLE:

$$\text{AREA} = L * W \text{ (or H)}$$

In this case $L = \text{circumference}$

$$\text{AREA} = \pi * D * H$$

$$\text{AREA} = 3.14 * 40 * 20 = 2,512 \text{ ft}^2$$

What is the Area to be Painted for a Circular Tank?

- Assume the tank has a radius of 20 ft and a height of 20 ft and both sides are to be painted.
- From previous:

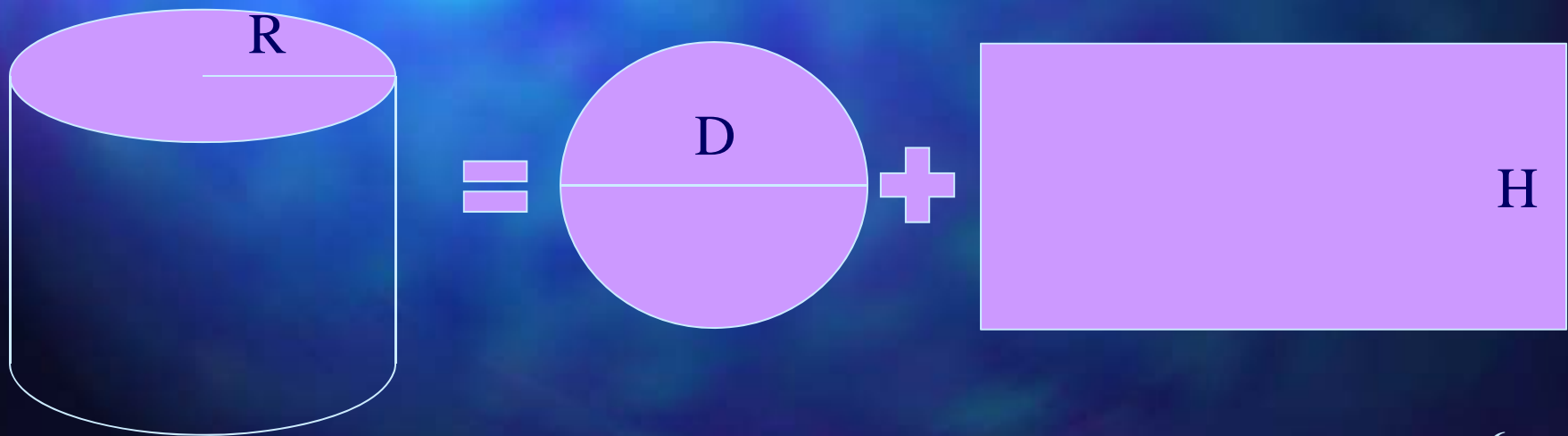
Area of Top = $1,256 * 3$ (both sides of top and bottom inside) = $3,768 \text{ ft}^2$

Area of Sides = $2,512 * 2$ (inside and outside)

Total area to be painted = $6,280 \text{ ft}^2$

What is the Volume of our Tank?

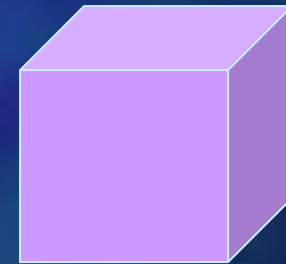
- Top area = $\pi * R^2 = 1,256 \text{ ft}^2$
- Height = 20 ft
- Volume = $\pi * R^2 * H = 25,120 \text{ ft}^3$



Volume of Water

- VOLUME:

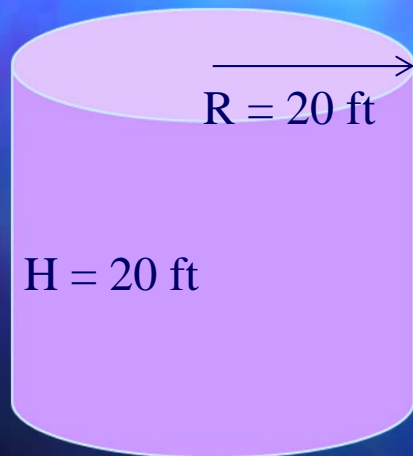
$$7.48 \text{ gal} = 1 \text{ cu ft}$$



How Many Gallons of Water will our Tank Hold?

From formula sheet
 $1 \text{ cft} = 7.48 \text{ gal}$

$$\text{Area} = \pi \times R^2$$



$$\text{Vol} = \text{Area} \times \text{Height}$$

Determine # Gallons in a 25,120 ft³ Tank

$$\begin{aligned} \text{Gallons in Tank} &= 25,210 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{\text{ft}^3} \\ &= 187,898 \text{ Gallons} \end{aligned}$$

Density of Water

- DENSITY:

8.34 LBS = 1 GAL

Gallons to Pounds Example

8.34 LBS / GAL

Determine Pounds of Water in a 187,898 Gallon Tank

Gal of Water x lbs/gal = Pounds of Water

187,898 gal x 8.34 lbs/gal = 1,567,066 Pounds

Weir Overflow Rate

Weir Loading Rate = Filter GPD/Foot of Weir

- Load = 150,000 gpd
- Diameter = 40 ft

Circumference = $\pi * D = 3.14 * 40 = 125.6$ ft

Weir Overflow Rate = $150,000\text{gpd}/125.6$ ft
= 1,194 gpd/ft.

Concentration of Chemicals

- Concentration of Chemical PPM = mg/l:

1 Pound of Chemical Added to 1,000,000 lbs of Water

10 Pounds of chemical are added to 1,567,066 pounds of water. What is Concentration in PPM and mg/l?

$$\frac{10 \text{ lbs chemical}}{1,567,066 \text{ lbs water}} \quad \text{or} \quad \frac{10 \text{ lbs}}{1.6 \text{ M lbs}} \quad \text{or} \quad 6.25 \text{ PPM}$$

Determining Height of Water in Tank with Pressure Gauge

- 1 psi = 2.31 feet

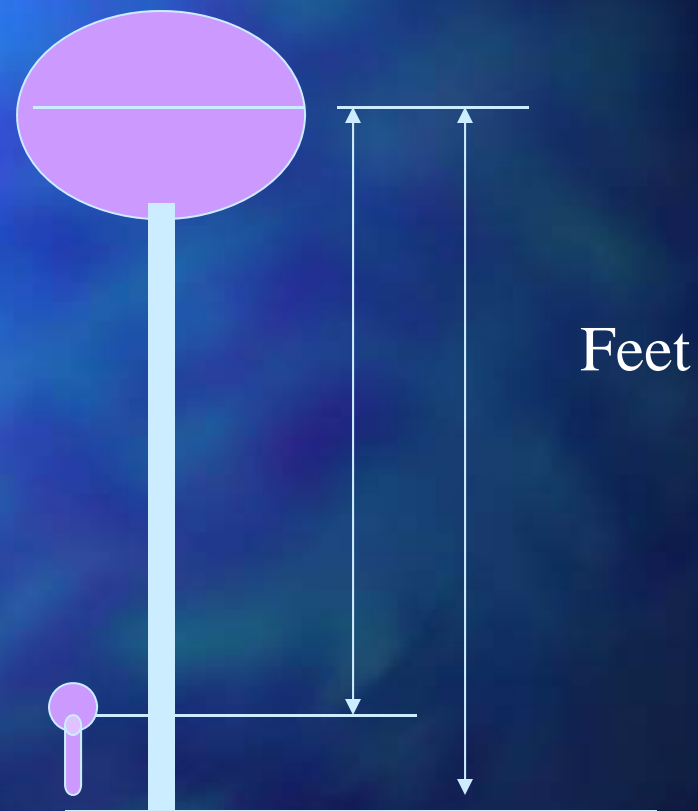
Given: 20 psi

Need: feet of water

20 psi X 2.31 = 46.2 feet of head

And about 48 ft from the ground

PSI



Converting Percent to mg/l

■ CONCENTRATION

CONCENTRATION MAY ALSO BE REFERED TO AS
DOSAGE.

$$1 \text{ ppm} = 1 \text{ mg/l}$$

$$1\% = 10,000 \text{ ppm}$$

Given: 1.4% Solution

Need: Parts per Million

$$1.4 \times 10,000 = \underline{14,000 \text{ PPM}}$$

Calculate Hydraulic Loading of Tank

$$\text{Hydraulic Loading Rate, gpd/ft}^2 = \frac{\text{Total Flow Applied, gpd}}{\text{Area, ft}^2}$$

Given: Load of 1MGD and a tank 50 ft in diameter = $\pi \times R^2$ find the HLR in ft/min.


$$\text{HLR} = \frac{1,000,000 \text{ gal}}{\text{day}} \times \frac{1}{3.14 \times 25 \text{ ft} \times 25 \text{ ft}} = 510 \text{ gpd/ft}^2$$

$$= \frac{510 \text{ gal}}{\text{day} \times \text{ft}^2} \times \frac{\text{ft}^3}{7.48 \text{ gal}} \times \frac{1 \text{ day}}{24 \text{ hours}} \times \frac{1 \text{ hour}}{60 \text{ min}} = .047 \text{ ft/min}$$

Pipe Flow Problems

CALCULATE FLOW IN A PIPELINE

$$Q \text{ (cfs)} = \text{Velocity (fps)} \times \text{Pipe Area (ft}^2\text{)} = VA$$



The diagram shows a horizontal purple rectangle representing a pipe. To the left of the pipe, a horizontal arrow points to the right, labeled with the letter 'Q'. Above the pipe, a vertical arrow points down to the top edge, labeled '24"'. Below the pipe, a vertical arrow points up to the bottom edge, labeled '1 ft'.

$Q = 2 \text{ ft/s} \times 3.14 \times 1 \text{ ft} \times 1 \text{ ft}$

$Q = 6.28 \text{ ft}^3/\text{sec}$

$V = 2 \text{ fps}$
Pipe = 24" DIA
Find Q

Detention Time Calculation

$$\text{DETENTION TIME} = \frac{\text{TANK CAP. (GAL.)}}{\text{RATE OF FLOW (GAL/TIME)}}$$



$$\frac{300,000 \text{ GAL}}{100,000 \text{ GAL/HR}} = 3 \text{ HOURS}$$

Detention Time Calculation

Estimate the detention time in hours for a 30-foot diameter circular clarifier when the flow is 0.5 MGD. The clarifier is 8 feet deep.

$$\text{Detention Time (hrs)} = \frac{\text{Volume}}{\text{Flow}}$$

$$\begin{aligned}\text{Volume} &= .785 \times \text{Diameter}^2 \times \text{Height} \\ &= .785 \times 30^2 \times 8 \\ &= 5,652 \text{ ft}^3\end{aligned}$$

$$\text{DT} = \frac{5,652 \text{ ft}^3}{1} \times \frac{\text{day}}{500,000 \text{ gal}} \times \frac{24 \text{ hrs}}{1 \text{ day}} \times \frac{7.48 \text{ gal}}{1 \text{ ft}^3}$$

$$\text{DT} = 2.0 \text{ hrs}$$

Determining Chemical Concentration

PARTS PER MILLION

Pounds of Chemical/Day per Million Pounds of Water/Day

$$\text{PPM} = \text{mg/L} = \frac{\text{POUNDS OF CHEMICAL/DAY}}{(8.34 \text{ LBS/GAL} * \text{MGD})}$$

$$\text{PPM} = \text{mg/L} = \frac{\text{lbs}}{\text{day}} \times \frac{\text{gal}}{8.34 \text{ lbs}} \times \frac{\text{day}}{\text{MG}}$$

Chemical Dose Calculation Example

PARTS PER MILLION = mg/l

$$\text{mg/l} = \frac{\text{POUNDS OF CHEMICAL PER DAY}}{(8.34 \text{ LBS/ GAL} * \text{MGD})}$$

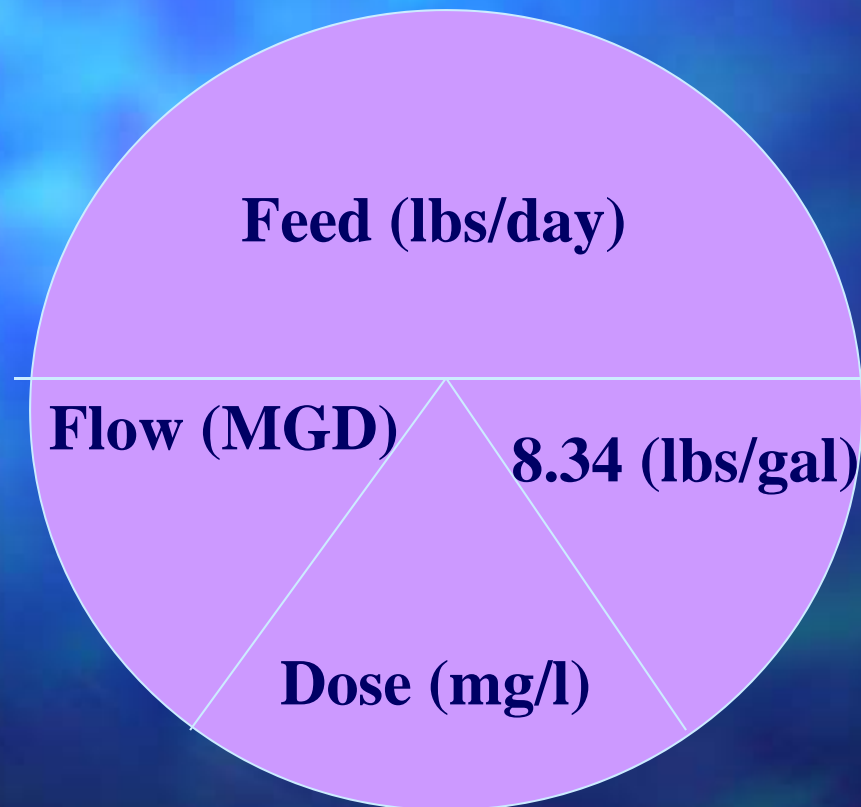


$$\text{Dose} = \frac{12 \text{ lbs}}{\text{day}} \times \frac{\text{gal}}{8.34 \text{ lbs}} \times \frac{\text{day}}{.75 \text{ MG}}$$

$$\text{Dose} = 1.9 \text{ PPM} = 1.9 \text{ mg/l}$$

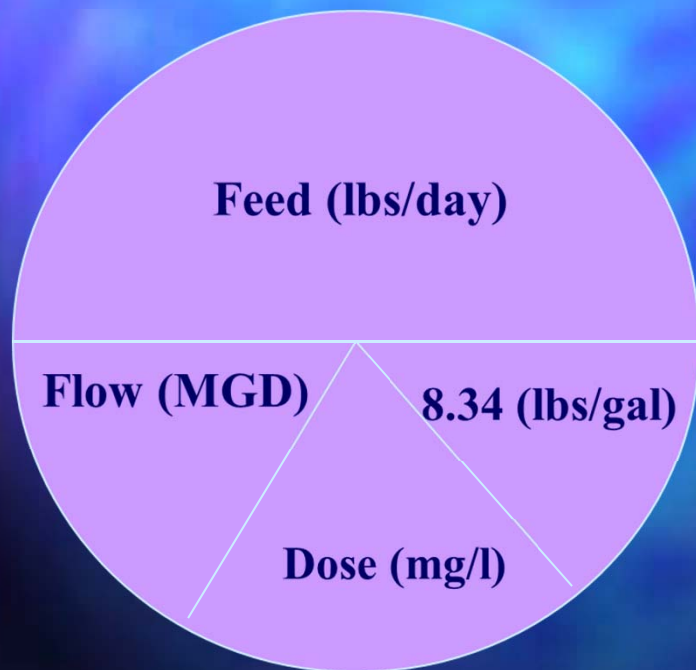
Chemical Dose Wheel

$$\text{Feed} = \text{Flow} \times \text{Dose} \times 8.34$$



Chemical Dosing Example

$$\text{Feed} = \text{Flow} \times \text{Dose} \times 8.34$$



Dry Alum dose from a Jar Test has been determined to be 10 mg/l. Determine the setting on the alum feeder in pounds per day for flow of 3 MGD.

Feeder Setting (lbs/day) = Flow (MGD) x Dose (mg/l) x 8.34 (lbs/gal)

Feeder Setting = 3 MGD x 10 mg/l x 8.34 lbs/gal

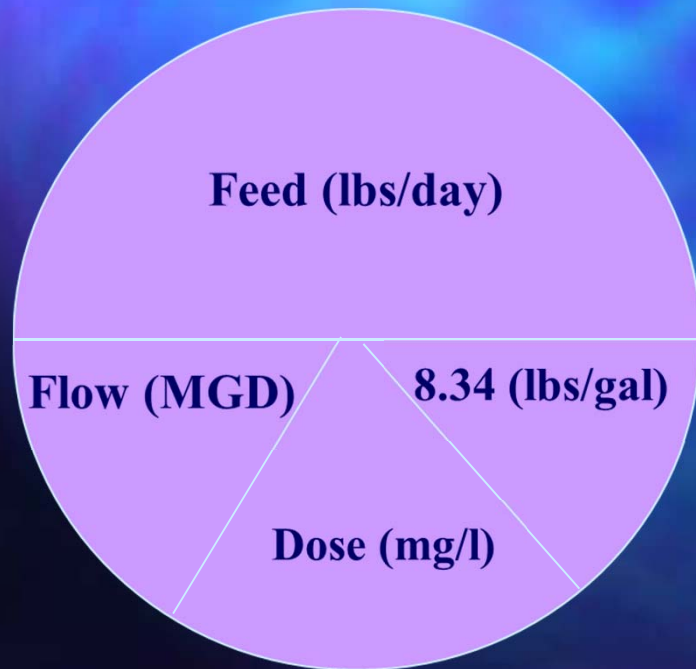
Feeder Setting = 250.2 lbs/day

Cover the Variable Desired

Divide Top by Bottom or Multiply

Fluoridation Example

- A flow of 4 MGD is to be treated with a 20% solution of hydrofluosilicic acid which contains a fluoride purity of 79.2%. The water to be treated contains no fluoride and the desired fluoride concentration is 1.8 mg/l. Assume the hydrofluosilicic acid weighs 9.8 lbs per gallon. What should be the feed rate of hydrofluosilicic acid? Calculate the feed rate in lbs/day and gal/day.



$$\text{Feed} = \text{Flow} \times \text{Dose} \times 3.785$$

Note: In this problem the dose quality has to be adjusted. It comes from a 20% solution and is only 79.2% pure.

Fluoridation Example

- A flow of 4 MGD is to be treated with a 20% solution of hydrofluosilicic acid which contains a fluoride purity of 79.2%. The water to be treated contains no fluoride and the desired fluoride concentration is 1.8 mg/l. Assume the hydrofluosilicic acid weighs 9.8 lbs per gallon. What should be the feed rate of hydrofluosilicic acid? Calculate the feed rate.

$$\text{Feed (lbs/day)} = \frac{\text{Flow} \times \text{Dose} \times 8.34}{(\text{Acid solution}) \times (\text{purity})}$$

$$\text{Feed Rate} = \frac{4.0 \text{ MG}}{\text{Day}} \times \frac{1.8 \text{ mg}}{\text{l}} \times \frac{8.34 \text{ lbs}}{\text{gal}} \times \frac{1}{.2} \times \frac{1}{.792}$$

$$\text{Feed Rate} = 379 \text{ lbs acid/day}$$

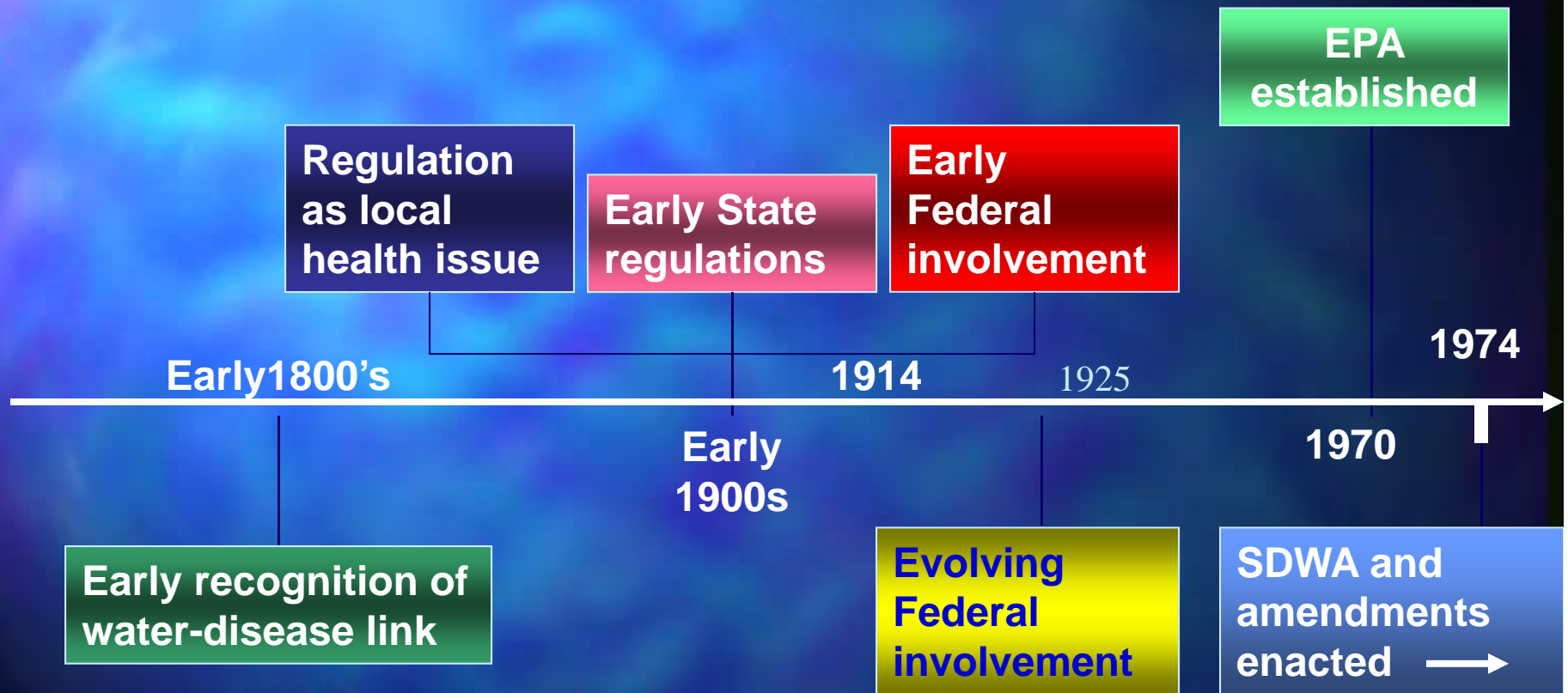
What is the feed rate in gallons/day?

$$\text{Feed rate, gal/day} = \frac{\text{feed rate, lbs/day}}{\text{chemical sol'n, lbs/gal}} = \frac{379 \text{ lbs/day}}{9.8 \text{ lbs/gal}} = 39 \text{ gal/day}$$



The Safe Drinking Water Act

Government Regulation of Drinking Water in US



Safe Drinking Water Act 1974

- Impetus for passage
 - Increased concern and awareness
 - Inconsistent State Requirements
- Development of Standards
 - Scientifically Based on Health Impacts
 - National Enforceable Standards
 - Required Water Systems to Monitor to Ensure Compliance

SDWA enacted

December 16, 1974

Safe Drinking Water Act Contents

- EPA established National Primary (Enforceable) and Secondary Drinking Water Standards (Recommended)
- Regulations use a multi-barrier approach.
- Establishes a public water system supervision program (PWSS), based on the level of risk posed to the public.
- Provide for State implementation and enforcement
- Requires Licensed Operators

Safe Drinking Water Act

- Gave EPA authority to set drinking water standards in Three Ways:
 - Maximum Contaminant Level Goal (MCLG) (**Secondary Standards**) Note: all are MCLs in Florida!
 - Maximum Contaminant Level (MCL) or numeric standards (**Primary Standards**)
 - Provided for Treatment Techniques (TT) for Surface Water Plants

SDWA Contaminant Monitoring

- Chemicals (Inorganic)
- Pesticides (Organic)
- Bacteria and Viruses (Micro-organisms)
- Radioactivity
- Turbidity
- Trihalomethanes (Disinfection By-products)

1986 SDWA Additions

- Creation of the NTNC category of water system
- Organic Chemical Monitoring and Detection Added
- Surface Water Treatment Rule provided for Higher Filtered Water Standards (NTU requirements)
- CT calculations for Giardia (Birds) and Viral Inactivation

State and Federal Regulations

- Multiple Barriers Regulated:
- Plans and Specifications for Water Systems after 350 customers
 - Plans and Specs
 - Facility Locations
 - EMP
 - Backup Generation
- Sanitary Surveys Required
- Training for Operators Required
- PWS Permit System Revised and Incorporated

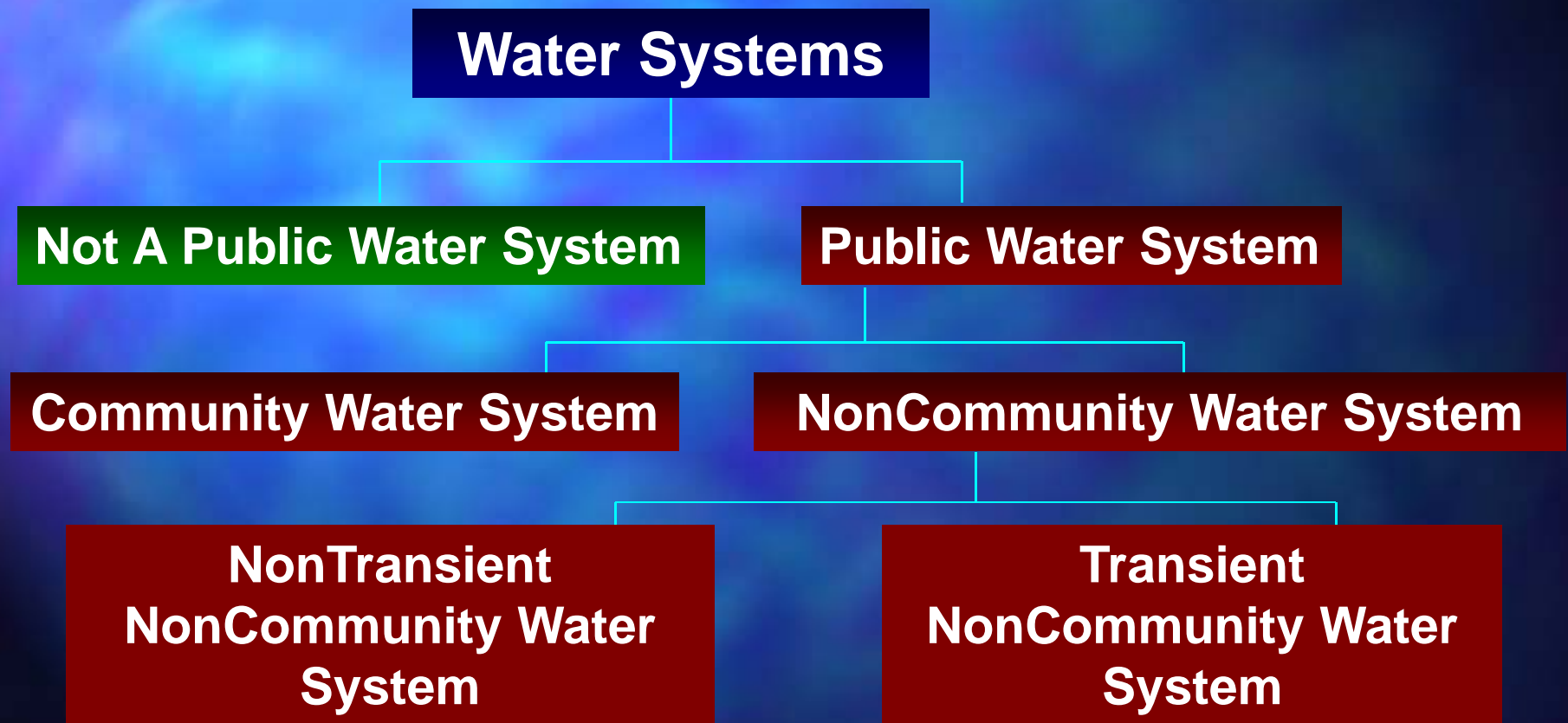
Effects of 1986 Amendments

(continued)

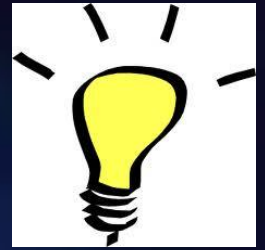
- Ground water under the direct influence (GWUDI) must meet Surface Water Standards (Microscopic Particle Analysis)
- Public Notification for CWS (Tier 1, 2 & 3)
- More stringent coliform monitoring requirements added for all PWS
- Lead/Copper and Corrosion Monitoring

Public Water System (PWS) Designations

Regulatory Distinctions Between Water Systems



Public Water System (PWS)



a system for the provision to the public of water that has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year

Community Water System (CWS)

- A public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.
- Serves people where they live.
- Exposure to contaminants could be lifetime.

Noncommunity Water System (NCWS)

- A public water system that is not a community water system.
- There are two types of non-community systems (based on the length of exposure of the consumers to the water): transient and non-transient.

Non-transient Non-community Water System (NTNCWS)

- A public water system that is not a community water system but that regularly serves at least 25 of the same persons over 6 months of the year.
- e.g., schools or businesses with their own water system
- Exposure to contaminants could be similar to that for community water systems.

Transient Non-community Water System (TNCWS)

- A noncommunity water system that does not regularly serve at least 25 of the same individuals at least 6 months per year.
- e.g., rest areas, campgrounds, truck stops, visitor centers with their own water system
- Individual exposure to the water is very short-term.



Specific Rules and Regulations of the Safe Drinking Water Act

Current SDWA Regulations

- Total Trihalomethanes (TTHMs and HAA5s)
- Chemical Rules (Phases I, II, IIb, and V)
- Surface Water Treatment Rule (Turbidity Control)
- Total Coliform Rule (Monitoring Based on Population)
- Lead and Copper Rule (Action Levels Established)
- Stage 1 D/DBP Rule (DBP Monitoring)
- Interim Enhanced SWTR (CT and Disinfection Profiles)
- Radionuclides
- Consumer Confidence Report Rule
- Arsenic
- Filter Backwash Recycling Rule
- Long Term 1 Enhanced Surface Water Treatment Rule

Total Trihalomethanes (TTHM) and Haloacetic Acids (HAA5s)

- Disinfection By-Products are Trihalomethanes and Haloacetic Acids. They are the by-products of disinfectants that combine with organic materials in the water
- Standard applies to CWS' and NTNCS' that use a disinfectant
- $\text{TTHM} < 80 \text{ PPB}$ and $\text{HAA5} < 60 \text{ PPB}$ based on RAA (Rolling Annual Average)

Chemical Contaminants

- Regulations cover 69 drinking water contaminants, most of which are carcinogens
- Applies to CWSs and NTNCWSs
- Contaminants cover three types:
 - Volatile organic chemicals (Solvents)
 - Synthetic organic chemicals (Chlorinated Hydrocarbons such as herbicides and pesticides)
 - Inorganic chemicals (metals)

Surface Water Treatment Rule

- Applies to systems that use surface water (including GWUDI)
- Establishes treatment techniques for *Giardia*, Viruses, Legionella, and Turbidity
- Requires Disinfection and usually Filtration
- Establishes monitoring requirements for turbidity and disinfectant residuals

Total Coliform Rule

- To control microbiological contaminants
- Applies to all PWSs
- Requires systems to sample for coliform in the distribution system based on Size
- Generally at least 4 samples or 1 per 1000 customers and representative of water system; Larger Systems >5%
- Presence of coliform can indicate treatment failures or deterioration of the distribution system
- Coliform presence indicate potential of pathogens

Lead and Copper Rule

- To control lead and copper leaching into drinking water
- Applies to all CWS & NTNCW
- Requires systems to sample water distribution system based on size
- Must meet Pb and Cu standards based on 90th percentile (< 10% failure)

Stage 1 D/DBP Rule

- Limits TTHMs and HAA5s in drinking water
- Establishes treatment performance standards for filtration, enhanced coagulation and softening
- Applies to all NTNCWS and CWS s
- Requires systems to sample for Disinfectant Residuals and Disinfection By-Products
- Number of Samples based on source and system size

Interim and Long Term Enhanced Surface Water Treatment Rule (IESWTR) and (LTESWTR)

- Optimize existing conventional treatment systems for pathogen removal
- Requires disinfection profiling and benchmarking
- Requires filter profiles, filter self-assessments and comprehensive performance evaluations
- Applies to all surface water and GWUDI source waters according to size

Filter Backwash Recycling Rule

- To control microbiological contaminants in plant recycling streams
- Applies to surface water and GWUDI plants
- Requires systems to monitoring filter backwash frequency and loading rates

Stage 2 D/DBP Rule

- Requires Monitoring Plan when Stage 1 > 60 PPM TTHM and/or > 40 PPM HAA5
- Must Submit Monitoring Plan or Apply for exemption
- Must submit beginning 4/1/2007 or later depending on size
- Multiple locations depending on source and size different than Stage 1 D/DBP Sites

Operator Certification Requirement

EPA Role

- Publish operator certification and recertification guidelines
 - Specify minimum standards for State programs
 - Apply to CWSs and NTNCWSs

State Role

- Determine appropriate experience, education and training requirements
- Certify operators

Requires Consumer Confidence Reports

- Required Annually all CWS
- Easy-to-understand explanations of drinking water standards and health effects
- Information on the quality of the water system's source and monitoring results
- Health effects information on any contaminant in violation of an EPA health standard

Bacteria that cause Disease (Human and Animal Feces)

Salmonella (Typhi, Paratyphi, other sp.)	Typhoid, Paratyphoid, Gastroenteritis
Shigella	Dysentery
Vibrio cholerae	Cholera
E. coli 0157:H7	Gastroenteritis
Yersinia enterocolitica	Gastroenteritis
Helicobacter Pylori	Peptic Ulcer

Inorganic Contaminants

<u>Chemical</u>	<u>Probable Source</u>	<u>Health Effect</u>
Aluminum	Coagulation	Dialysis Dementia
Arsenic	Dissolution of Rock	Gastrointestinal, Cardiac
Asbestos	Dissolution of Rock and As pipeline	Gastric, kidney, pancreatic cancer
Barium	Industrial Release	Hypertension
Cadmium	Industrial Release	Testicular, prostrate tumors
Chromium	Industrial Release	Liver and kidney damage

Inorganic Contaminants (cont.)

<u>Chemical</u>	<u>Probable Source</u>	<u>Health Effect</u>
Molybdenum	Industrial Discharge	Bone loss, infertility
Nickel	Industrial Discharge	Possible carcinogen
Nitrate/Nitrite	Agriculture and Urban septic tanks	Methemoglobin, possible carcinogen
Selenium	Industrial Discharge	Liver, fatigue, diarrhea
Sodium	Water Softeners	Hypertension
Sulfate	Natural Waters	Laxative Effects
Zinc	Corrosion	Muscular weakness, pain, nausea

Volatile (evaporative) Organic Compounds

#	Contaminant	Constituents	Probable Source
1.	Petroleum or Petroleum additives	Benzene, Toluene and Xylenes	Leaky fuel tanks (also MBTE)
2.	Halogenated VOCs	Dichlorobenzene, Dichloroethane, Dichloroethelyne, Tetrachloroethylene (PCE), Trichloroethylene (TCE)	Degreaser and solvent disposal, former use as Septic Tank cleaners (low odor thresholds)
3.	Chlorinated Disinfection by-products	Trihalomethanes	Industrial discharge

Synthetic Organic (Pesticides) Contaminants

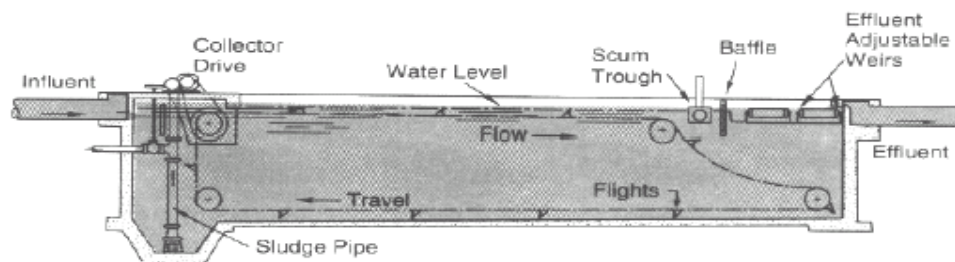
#	Contaminant	Constituents	Probable Source
1.	Insecticides	<ul style="list-style-type: none"> ■ DDT, DDE, DDE. ■ Carbamates, i.e. Aldicarb, Carbofuran, Oxamyl, Dieldrin. ■ Organophosphates, i.e. Diazinon 	Agricultural
2.	Herbicides	Alachlor, Atrazine, Cyanazine, Dachal, Dicamba, 2,4,D, Picloram, Microprop	Agriculture, Picloram is used in ROWs; Mecoprop is used on lawns
3.	Fungicides	1,2-Dichloropropane, Ethylene Thiourea (ETU)	Agriculture

Radiological Contaminants

Types of Radiation	Description
Alpha Radiation (massive ingestion can damage cells)	Large positively charged particles made up of two protons and two neutrons
Beta Radiation (smaller size with less damage to organs)	Electrons or positrons.
Gamma Radiation (min. effect at small levels)	Electromagnetic or wave energy such as X-rays

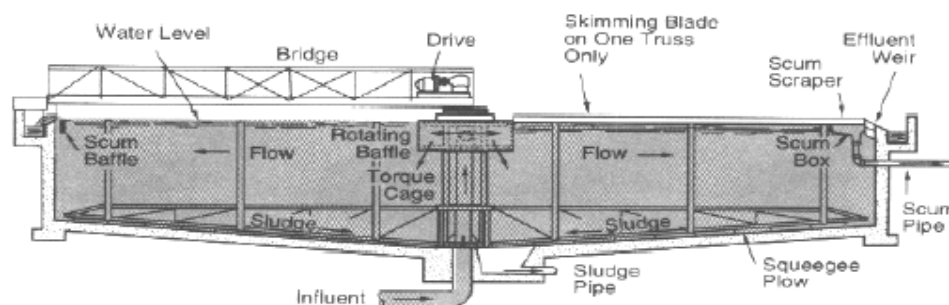
Sedimentation

Plain Sedimentation Water Treatment



Rectangular Sedimentation Basin

Courtesy of FMC Corporation, MHS Division



Circular Sedimentation Basin

Rectangular

Achieve Higher
Solids Removal

Less Sensitive to
Short Circuiting

Circular

More Compact
per Unit Space

High Rate Settling

Tube Settlers

- Increase area to allow more settling
- Tubes are placed at 60° angles to allow solids to be removed by gravity
- Currents and Wind are dampened by tubes
- Loading Rates 2 to 5X conventional

Plate Settlers

- Based on theory that shallow basins provide same settling as deep
- Area is increased proportional to the area of each plate
- Use much smaller footprint
- Loading rates 5 to 10X conventional

Types of Sedimentation Process and their Applications

Description

- Plain Sedimentation
- Coagulation Sedimentation
- Reactor Clarifier (Up flow Clarifier)

Application

Used to remove sand and coarse silt lowering turbidity

Follows the coagulation process to remove floc

Combines coagulation and sedimentation in one process in water softening plants

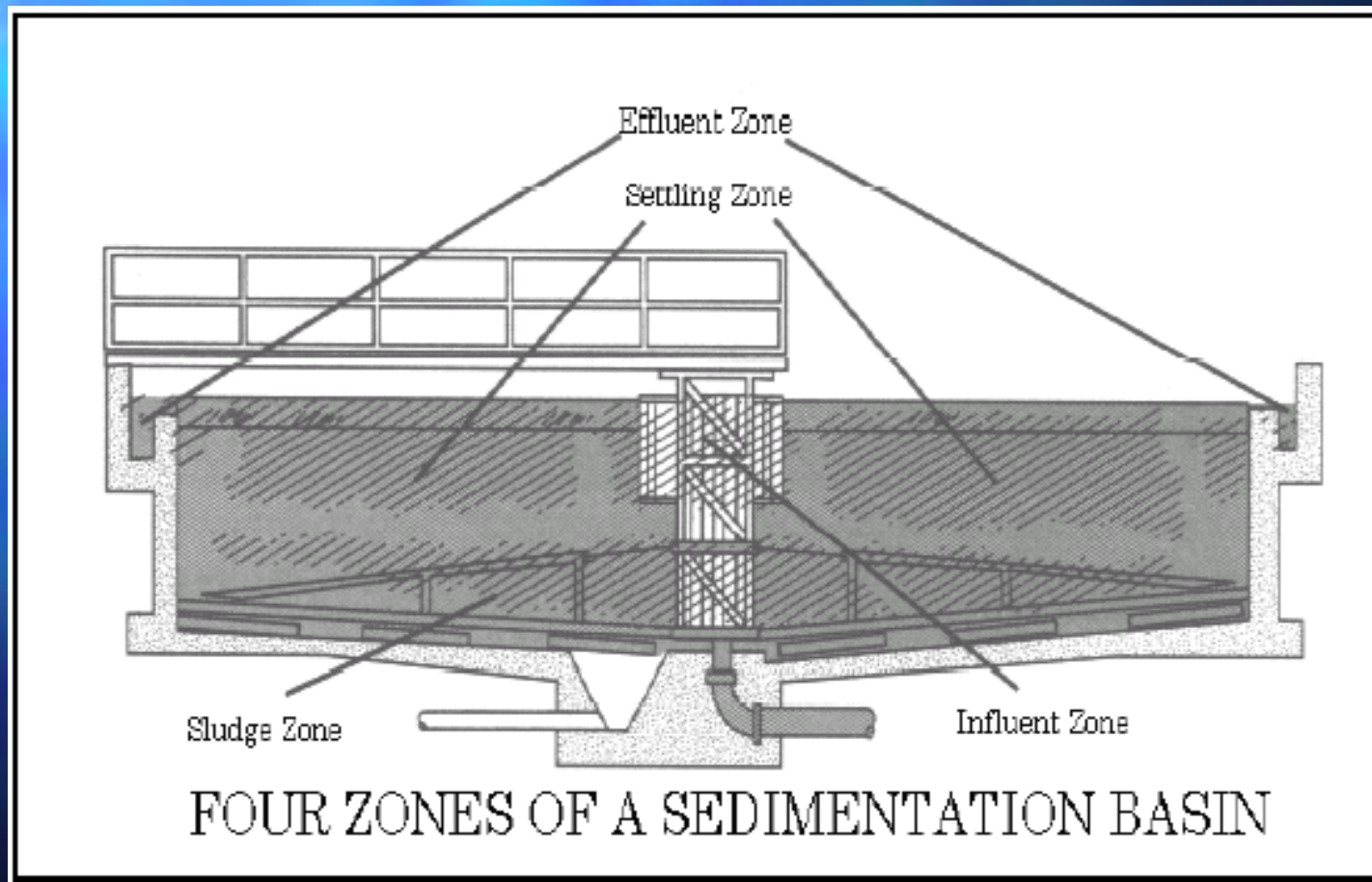
Theory of Sedimentation

- Slow velocity of water to provide sedimentation
- Two to four hours detention is usually provided
- Velocity through the basin should be from 1 to 3 feet per minute.

Factors That Affect Particle Settling

1. Particle size and distribution
2. Shape of the Particles
3. Density of Particles
4. Temperature (viscosity and density of water)
5. Electrical Charge on Particles
6. Dissolved Substances in the Water
7. Flocculation Characteristics of particles
8. Wind
9. Inlet and Outlet conditions and Shape of Basin

Schematic of a Sedimentation Tank



Influent Sedimentation Zone

- Inlet to the sedimentation basin
- End point in a rectangular tank and middle in a round tank
- Baffles direct flow ensuring lateral flow and prevent short circuiting and carryover.

Settling Sedimentation Zone

- Largest Portion of the Tank
- Velocity reduced to 1 to 3 ft/min
- Detention times ranges from 2 to 4 hours
- Overload Loading rates of
~800 gpd/sft.
- Tube settlers can greatly improve settling rates

Sedimentation Basin Loading Rates Using Alum

Application	gpd/sf
Turbidity Removal	800-1200
Color and Taste Removal	600-1000
High Algae Content	500-800

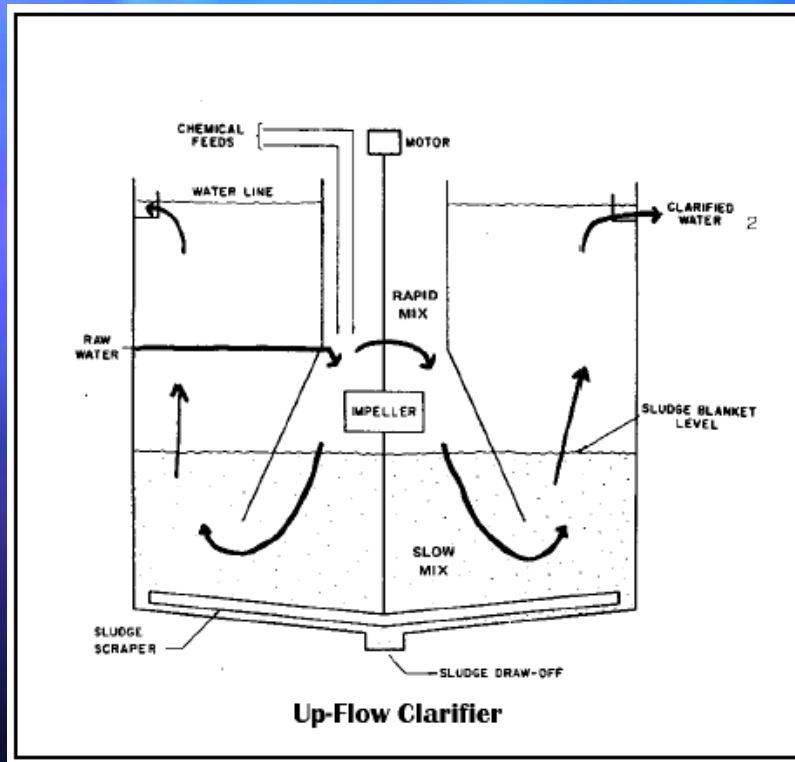
Effluent Sedimentation Zone

- Effluent Lander collects effluent flow
- Weirs along the edge skim water evenly
- Typically weirs have V notches every foot
- Weirs must be kept clean and level to ensure even flow and sludge blanket
- Baffle plate used to retain floating solids
- Weir Loading rates of 10,000 to 14,000 gpd/ft are used

Sludge Sedimentation Zone

- Collection zone at bottom of tank
- Sludge must be removed at min. once per day to prevent septicity and bulking
- Turbine or rake equipped with torque indicator: high torque will break shear pin (too much sludge); fluctuating torque (uneven sludge distribution)

Schematic and Operation of an Upflow Clarifier



- Upflow Clarifiers are also known as Solids-Contact Clarifiers, and Reactor Clarifiers (lime softening).
- The sludge produced is recycled to aid settling
- The process performs coagulation, flocculation and sedimentation in one Basin
- Slurry refers to the suspended clumps produced by the mixture of solids and floc.

Advantages of Solids Contact Units

- Ability to adjust the volume of Slurry
- Adjustment of Slurry Blanket allows the operator to cope with operating conditions that require more solids

Operating Considerations of Solids Contact Units

Advantages

- Ability to adjust the volume of Slurry
- Adjustment of Slurry Blanket allows the operator to cope with operating conditions that require more solids

Disadvantages

- Instability to rapid changes in flow, temperature or turbidity
- Rising flow rate increases the depth of slurry but not volume
- Falling flow rate decreases the depth of slurry by not volume

Performance Monitoring for Sedimentation Processes

- The performance of a Sedimentation Tank is measured by a comparison of the turbidity entering and leaving the basin measure several times per shift or when quality changes
- Observe clarity of settled water noting size and appearance of any suspended floc
- Ensure clean weirs at influent and effluent
- Observe sludge blanket depth; high blanket depths favor particles passing over weirs at higher flows.
- Remove sludge at min. daily
- Do not exceed loading rates

Record to be Maintained for Sedimentation Basin Performance

1. Process Water Quality (NTU) in and out of Basin
2. Process Water Production
3. Process Equipment Performance
4. Solids Removed from Basin

Short Circuiting in Sedimentation Tanks

- Short-circuiting occurs when the path of the flow passes directly through portions of the sedimentation tank; these can usually be observed as floc over the ends of basins
- These high velocities occur under high flow conditions.
- Short-circuiting causes particulate matter to be held in suspension and be transported through the tank.
- Baffling can help break up the flow paths and can help control short-circuiting.
- Sedimentation Tanks should not be loaded above tank design overflow rates.
- When dealing with chemical floc loading rates must be reduced

Question

Why may currents in sedimentation basins be beneficial?

1. Currents distribute suspended solids unevenly throughout the basin
2. Currents increase the expected performance of the basin
3. Currents promote flocculation in the basin
4. Currents reduce adverse effects caused by winds

Sludge Treatment and Disposal

Volumes of Waste Sludge Produced

- Raw Water Quality
- Facility Design
- Flow
- Treatment Process Employed

Constituents in Water Plant Sludge

- Excessively high or low pH;
- High total suspended solids (TSS);
- High total dissolved solids (TDS);
- High concentrations of heavy metals, including arsenic, lead, and aluminum;
- High concentrations of competing ions, including fluoride, sodium, sulfate, chloride, and other salts concentrations; and,
- High concentrations of radionuclides and daughter products

DISPOSAL ALTERNATIVES FOR WATER PLANT SLUDGE

- Land Disposal and Landfilling
- Deep Well Injection
- Discharge to POTW
- Surface Water Disposal
- Beneficial Reuse

PROCESSING OF LIQUID SLUDGE

- Mechanical Dewatering
- Filter Press
- Evaporation and Drying
- Thermal Processing

Effects of Concentrating Chemical Sludge

Concentration (% solids)	Volume Total (gallons)	Water Removed (gallons)
2%	10,000	0
4%	5,000	5,000
8%	2,500	7,500
16%	1,250	8,750
32%	625	9,375
64%	312	9,688

Off-site Disposal of Waste Sludge

- Monitoring Requirements
- Flow Equalization
- Brine Recycling
- pH Neutralization
- Settling and Gravity Thickening
- Evaporation
- Chemical Precipitation

Sludge Disposal

- Combine with reclaimed water and release to surface water. (CWA & NPDES)
- POTW (TBLL; Effluent & Biosolids)
- Deep Well injection – (UIC)
- Evaporation/Crystallization - Capacity limited (RCRA)
- Landfill (PELT (paint test), TCLP (leaching))

Question: Calculate the theoretical detention time for a rectangular sedimentation basin. The basin is 80 feet long, 30 feet wide, 10 feet deep, and treats a flow of 1.8 MGD.

Detention time = Volume / Flow

$$\text{Volume} = 80 \text{ ft} \times 30 \text{ ft} \times 10 \text{ ft} \\ 24,000 \text{ ft}^3$$

$$\text{Flow} = 1.8 \text{ MGD} = 1,800,000 \text{ gal/day}$$

$$\text{DT (hrs)} = 24,000 \text{ ft}^3 \times \frac{\text{day}}{1,800,000 \text{ gals}} \times \frac{7.48 \text{ gals}}{\text{ft}^3} \times \frac{24 \text{ hrs}}{\text{day}}$$

$$\text{DT (hrs)} = 2.4 \text{ hrs}$$

Water Softening for Hardness Removal



Important Definitions in Lime Softening Treatment

- HARDNESS is caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride, and nitrate.
- CALCIUM HARDNESS is caused by calcium ions (Ca^{2+}).
- MAGNESIUM HARDNESS is caused by magnesium ions (Mg^{2+}).
- TOTAL HARDNESS is the sum of the hardness caused by both calcium and magnesium ions.
- CARBONATE HARDNESS is caused by alkalinity present in the water up to the total hardness. This value is usually less than the total hardness.
- NONCARBONATE HARDNESS is that portion of the total hardness in excess of the alkalinity.

Hardness in Water

- High concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water cause hardness
- Generally, water containing more than 100 mg/l of hardness expressed as calcium carbonate (CaCO_3) is considered to be hard
- Excessive hardness is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, pipelines and home appliances, damage in industrial processes and can cause objectionable tastes.

Hardness Descriptions

Description	Hardness (mg/l of CaCO ₃)
Extremely soft to soft	0 – 45
Soft to moderately hard	46-90
Moderately hard to hard	91-130
Hard to very hard	131-170
Very hard to excessively hard	171-250
Too hard for ordinary domestic use	Over 250

What is Hardness?

- Hardness is due to the presence of divalent (having a valance of two) metallic cations (Ca^{2+} and Mg^{2+}) in water .
- Hardness is usually reported as Calcium Carbonate (CaCO_3) Equivalent
- Equivalent weight of an element is that weight which will combine with an equivalent weight of another element.
- Equivalent Weight of $\text{CaCO}_3 = \frac{\text{Molecular Weight}}{\text{Number of Equivalents}}$

How do we calculate hardness?

To calculate hardness we use the following expressions:

- Equivalent Weight = $\frac{\text{Molecular Weight}}{\text{Valence}}$
- Calcium Hardness = Calcium, mg/l $\frac{(\text{Equivalent Weight of CaCO}_3)}{\text{Equivalent Weight of Calcium}}$
(mg/l as CaCO₃)
- Magnesium Hardness = Magnesium, mg/l $\frac{(\text{Equivalent Weight of CaCO}_3)}{\text{Equivalent Weight of Calcium}}$
(mg/l as CaCO₃)

Total Hardness = Calcium Hardness + Magnesium Hardness

What is Hardness?

- Hardness is usually reported as CALCIUM CARBONATE EQUIVALENT. This allows us to add the hardness caused by calcium and magnesium and other ions and report the results as total hardness.

In calculating hardness we use the following expressions:

- $$\text{Chemical Hardness} = \text{Chemical, mg/l} \times \frac{\text{Equivalent Weight of CaCO}_3}{\text{Equivalent Weight of Chemical}}$$

(mg/l as CaCO₃)
- Exa:
$$\text{Calcium Hardness} = \text{Calcium, mg/l} \times \frac{50}{20} = (\text{calcium, mg/l}) \times 2.5$$

(mg/l as CaCO₃)
- $$\text{Equivalent Weight of Chemical} = \frac{\text{Atomic Weight}}{\text{Valence}}$$
- Exa:
$$\text{Equivalent Weight of Calcium} = \frac{40}{2} = 20$$

Calcium Carbonate Equivalents

Chemical	Molecular Weight	Valence	Equivalent Weight of Chemical	Calcium Carbonate Equivalent
Calcium Carbonate	100	2	50	NA
Calcium (Ca^{2+})	40	2	20	2.5
Magnesium (Mg^{2+})	24.3	2	12.15	4.12
Chloride (Cl^-)	35.45	1	35.45	1.41
Sulfate (SO_4^{2-})	96.07	2	48.03	1.04

- Equivalent Weight of Chemical = $\frac{\text{Molecular Weight}}{\text{Valence}}$
- Calcium Carbonate Equivalent = $\frac{(\text{Equivalent Weight of CaCO}_3)}{\text{Equivalent Weight of Chemical}}$
(mg/l as CaCO_3)

Example

Example: A sample of water contains 80 mg/L of Ca^{2+} (expressed as Ca^{2+}) and 20 mg/L of Mg^{2+} (expressed as Mg^{2+}). Determine the total hardness of the water in terms of mg/L as CaCO_3

- calcium hardness = $(80)(50/20) = 200$ mg/L as CaCO_3
- magnesium hardness = $(20)(50/12.2) = 82$ mg/L as CaCO_3
- total hardness = $200 + 82 = 282$ mg/L as CaCO_3

Methods of Removing Hardness

Treatment Method	Hardness Levels Retained
Lime Softening (Chemical Precipitation)	Solubility Level of about 35 mg/l (CaCO_3)
RO (Nanofiltration) (Membrane Filtration)	85 – 90% removal
Ion Exchange (Chemical Exchange)	Basically Zero Water must be blended

Benefits of Lime Softening

- Removal of Ca and Mg Hardness
- Removal of iron, manganese, arsenic and uranium.
- Reduction of solids, turbidity and TOC
- Inactivation of Bacteria and viral removal due to high pH.
- Raises pH and prevents Corrosion
- Removal of excess fluoride.

Generalizations

Removing TOC with Lime Softening

- Calcium Carbonate Precipitation removes from 10 to 30% of color, TOC and DBP precursors
- Magnesium Hydroxide Precipitation removes 30 to 60% of color, TOC and DBP precursors
- Iron or Alum augmentation can remove another 5 to 15% of color, TOC and DBP precursors

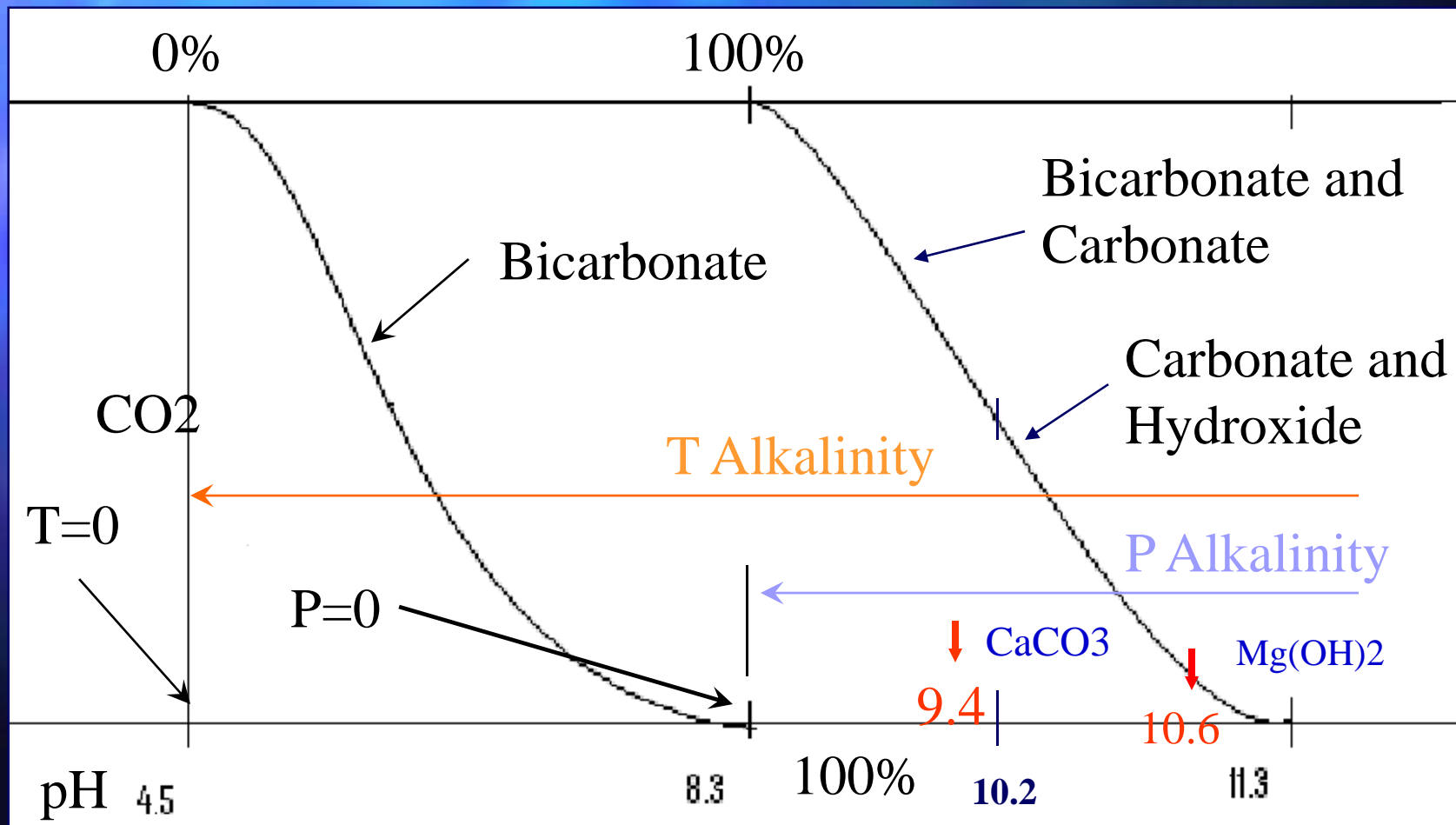
Alkalinity Definitions

- The capacity of water to neutralize acids.
- The measure of how much acid must be added to a liquid to lower the pH to 4.5
- It is caused by the water's content of bicarbonate, carbonate, hydroxide, and occasionally borate, silicate, and phosphate.
- Carbonate Hardness is the sum of the bicarbonate, carbonate, hydroxide hardness
- Alkalinity = Carbonate Hardness (all forms)

Important Terms in Lime Softening

- Hardness
- Calcium Hardness
- Magnesium Hardness
- Carbonate Hardness
- Non-carbonate Hardness
- Calcium Carbonate Equivalent
- Alkalinity (neutralize acids)
- Bicarbonate Alkalinity
- Carbonate Alkalinity
- Hydroxide Alkalinity
- Total Alkalinity (Bicarbonate, Carbonate, Hydroxide)
- Natural Alkalinity (Bicarbonate)

Relationships among pH, Alkalinity and Indicators



Types of Alkalinity that can be Present at pH Values

- Below 4.5 only CO_2 present, no Alkalinity
- Between 4.5 to 8.3 only Bicarbonate present
- Between 8.3 to 10.2 Bicarbonate & Carbonate.
- Between 10.2 to 11.3 Carbonate & Hydroxide
- At 9.4 Calcium Carbonate becomes insoluble and precipitates
- At 10.6 Magnesium Hydroxide becomes insoluble and precipitates

Lime Softening Chemical Removal Process

- Water having hardness caused by calcium and magnesium bicarbonate can be softened using only lime.
- Lime reacts with the bicarbonate to form calcium carbonate which will precipitate and settle out at a pH greater than 9.4.
- At a pH greater than 10.6 magnesium reacts to form magnesium hydroxide which will precipitate.

Chemical Titration with Methyl Orange (T) and Phenolphthalein (P)

- Methyl Orange is used to determine the combination of alkalinity provided by carbonate, bicarbonate and hydroxide or Total Alkalinity.
- A sample of the water is titrated by adding the Methyl Orange color indicator and adding measured amount of acid until the color is absent.
- The Total Alkalinity (T) is then computed
- Phenolphthalein is used to determine the carbonate and hydroxide alkalinity present.
- A sample of the water is titrated by adding the Phenolphthalein color indicator and adding measured amount of acid until the color is absent.
- The Hydroxide and Carbonate Alkalinity (P) is then computed

Hardness Relationships

- $TH = CH + NCH$ (each expressed as mg/l as $CaCO_3$)
- The amount of carbonate and noncarbonate hardness depends on the alkalinity of the water
 - Alkalinity $>$ Total Hardness (all hardness is in carbonate form)
$$TH = CH$$
 - Alkalinity $<$ Total Hardness (both Carbonate Hardness and Noncarbonate Hardness are present)
$$CH = \text{Alkalinity}$$
$$NCH = TH - CH = TH - \text{Alkalinity}$$

Calculation of Alkalinity Constituents in Drinking Water based on Methyl Orange and Phenolphthalein Titrations



Equation #	Titration Result	Bicarbonate ph 4.5 to 8.3	Carbonate >PH 8.3	Hydroxide >11.3
1	$P = 0$	T	0	0
2	$P < \frac{1}{2} T$	$T - 2P$	$2P$	0
3	$P = \frac{1}{2} T$	0	$2P$	0
4	$P > \frac{1}{2} T$	0	$2T - 2P$	$2P - T$
5	$P = T$	0	0	T

Key: P – phenolphthalein alkalinity; T – total alkalinity

Determination of Alkalinity

Example

1.) Given: $T = 180 \text{ mg/l}$

$P = 34 \text{ mg/l}$

2.) Compute Values for T , $\frac{1}{2} T$ and P

$T = 180$, $\frac{1}{2} T = 90 \text{ mg/l}$, $P = 34 \text{ mg/l}$

3.) Enter Table and use Equation #2

4.) Compute Values: Bicarbonate = 112

Carbonate = 68 mg/l

Types of Lime Used in WTP

- Quick Lime (CaO) (molecular wt. 56)
 - 75 % - 99% purity (typically 85%)
 - Dry powder and must be slaked for 15 - 30 minutes at cold temperature
 - Slaking (agitating) produces CaOH_2
 - Used at Large WTP because lower cost
- Hydrated Lime (CaOH_2) (molecular wt. 74)
 - Made when Quick Lime is slaked
 - Very stable
 - Small WTPs use directly due to convenience
 - Hydrated Lime shipped 80% - 99% purity (typically 95%)

Lime Softening Process Limitations

- Unable to remove all carbonate (~ 30 mg/l) and no Non-Carbonate hardness.
- High degree of operator control.
- Color removal for highly colored waters may be hindered due to high pH.
- Sludge handling and disposal are costly (~ 2.5 mg/l per mg/l lime added)



Primary Coagulants Sometimes Used in Lime Softening

- Primary coagulants are aluminum sulfate (alum), ferrous sulfate, ferric sulfate and ferric chloride.
- These inorganic salts will react with the alkalinity in the water to form insoluble flocs which will trap the suspended matter in them.

Secondary Coagulant Aids

Sometimes Used in Lime Softening

- Coagulant aids often added to help stimulate the production of floc.
- They include sodium aluminate, bentonite or clay, sodium silicate and various synthetic cationic and non-ionic polymers.
- Bentonite is often used in waters with high color and low turbidity to bind with small floc

Removal of Organics by Lime Softening Precipitation

Calcium Carbonate	10% to 30% of Color, TOC & DBP
Magnesium Hydroxide	30% to 60% of TOC & DBP and 80% of Color
Addition of Alum/Ferric	+5% to +15% of Color, TOC & DBP
Sequential Treatment	Additional Removal Color, TOC and DBP

Color removal often requires pretreatment with Alum

Types of Lime Treatment

- Excess Lime Treatment
 - Removes Ca & Mg
 - Excessive amt. of Sludge
- Selective calcium Removal
 - Used for Low Mg FL waters
 - Sludge amounts reduced
- Split Treatment
 - Split Treatment is sometimes used when non-carbonate hardness is low and Mg concentration are high
 - CO₂ requirements are reduced by unsoftened flow stream
 - Generally 80% treated/20% raw



Typical Recarbonation

Chemistry of Lime Softening and Softening Equation

Carbonic Acid + Lime > Calcium Carbonate

Calcium Bicarbonate + Lime > Calcium Carbonate pH ~9.4

Magnesium Bicarbonate + (2) Lime > Magnesium Hydroxide pH ~10.6

Lime Needed = $\frac{(A + B + C + D) 1.15}{\text{Purity of the Lime}}$

A = CO₂ (source) B = Bicarbonate (removed as CaCO₃), C = Hydroxide (effluent as CaCO₃), D = Magnesium (removed)
(all in mg/l)

Adjusting Lime for Purity and to Aid Reaction

Purity at 85%

- Lime Needed = Amt. Calculated in mg/l divided by Purity

- i.e., $\frac{100 \text{ mg/l}}{0.85} = 118$

Excess Lime at 15%

- Excess Lime Needed to aid reaction = Amt Calculated in mg/l multiplied by excess

- i.e., $118 \times 1.15 = 136$

Lime Dosing Calculation Methods

$$\text{Amount Needed} = \frac{\text{Compound Removed} \times \text{Lime Molecular Weight}}{\text{Compound Molecular Weight}}$$

■ Approximate

Amount of Lime needed to:

- a. Neutralize CO_2
- b. Remove all Alkalinity
- c. Provide Excess CaCO_4
- d. Remove all Mg

■ Exact

Amount of Lime needed to:

- a. Neutralize CO_2
- b. Remove Alkalinity to Min. Possible
- c. Provide Excess CaCO_4
- d. Remove a portion of the Mg

Calculating a Lime Dose Using the Exact Method

$$\text{Lime Needed} = \frac{\text{Compound Removed} \times \text{Lime Molecular Weight}}{\text{Compound Molecular Weight}}$$

Component	Mole Wt	Chemical Analysis of Source Water (mg/l as CaCO ₃)	Desired Softened Water Quality (mg/l as CaCO ₃)	Amt. Re-moved	Compound Removed/Compound Mole Weight	* Multiply by Lime Type (Mole Wt)	Lime Needed (mg/l)
CO ₂ (A)	44	6	0	6	Amt/44	x 74	10
Alkalinity (B)	100	170	30	140	Amt/100	x 74	104
Hydroxide (C)	100	0	0	0	Amt/100	x 74	0
Magnesium (D)	24.3	21	3	18	Amt/24.3	x 74	55
Total							169
With 15% Excess Lime and 90% Purity, Hydrated Lime Needed = Total x 1.15/.90							216

CaO = 56 (Quick Lime) Ca(OH)₂ = 74 (Hydrated Lime)

Factors for Converting to Lime and Soda Ash Using the Approximate Method

Component	Factor for Converting to Quick Lime - CaO (Mole Wt-56 / Mole Wt - Component)		Factor for Converting Hydrated Lime - Ca(OH) ₂ (Mole Wt-74 / Mole Wt – Component)		Factor for Converting Soda Ash - Na ₂ CO ₃ (Mole Wt-106 / (Mole Wt – Component)	
CO ₂	1.27 mg/l	10.63#s/MG	1.68 mg/l	14.06#s/MG		
Alkalinity	0.56 mg/l	4.67#s/MG	0.74 mg/l	6.17#s/MG		
Excess CaCO ₃	0.56 mg/l	4.67#s/MG	0.74 mg/l	6.17#s/MG		
Magnesium	2.31 mg/l	19.24#s/MG	3.05 mg/l	25.4#s/MG		
Excess Soda Ash					1.06 mg/l	8.84#s/MG
Non-carbonate Hardness					1.06 mg/l	8.84#s/MG

Conversion mg/l to #s/MG

$$1.27\text{mg/l} = 1.27\text{ppm or } 1.27\text{\#s/M} \times 62.4\text{\#s/ft}^3 / 7.48\text{gal/ft}^3 = 10.63 \text{ \#s/MG}$$

Note: Lime Dose adjustments are made using a “Jar Test”

Example: Assuming no excess lime is added, find the correct dosages in milligrams per liter for lime (containing 90% pure CaO) and soda ash (containing 99% pure Na₂CO₃) required to remove all hardness.

The following test results were provided by the laboratory:

CO₂ concentration 25 mg/l as CO₂

HCO₃ (bicarbonate) concentration 205 mg/l as CaCO₃

Mg (magnesium) concentration 9 mg/l as Mg

non-carbonate hardness concentration 95 mg/l as CaCO₃

-
- CO₂: 25 mg/l x 1.27 = 31.75 mg/l as CaO
 - HCO₃: 205 mg/l x 0.56 = 114.80 mg/l as CaO
 - Mg: 9 mg/l x 2.31 = 20.79 mg/l as CaO
 - TOTAL: = 167.34 mg/l as CaO
 - Adjust the lime dosage for purity: = $\frac{167.34 \text{ mg/l}}{0.90} = 185.93 \text{ mg/l}$
-
-
- Soda Ash: 95 mg/l x 1.06 = 100.7 mg/l as Na₂CO₃
 - Adjust the soda ash dosage for purity: = $\frac{100.7 \text{ mg/l}}{.99} = 101.72 \text{ mg/l}$

Non-Carbonate Removal

- First Identify the Amount of Non-Carbonate Hardness
- It is the Total Hardness – the Carbonate Hardness Removed + the Carbonate Hardness Remaining.
- The amount of Soda Ash Required is Equivalent to the Non-Carbonate Hardness Calculated above adjusted to its Calcium Carbonate Equivalent ($106/100$)

Soda Ash Needed

Constituent	Source Water	Softened Water Req.
CO2 mg/l	6	0
Total Alkalinity mg/l (Carbonate Hardness)	170	30
Total Hardness mg/l	280	70
Mg mg/l	21	3

$$\begin{aligned}\text{Total Hardness Removed} &= \text{Total Hardness} - \text{Total Hardness Remaining} \\ &= 280 - 70 = 210\end{aligned}$$

$$\text{NCH} = \text{Total Hardness Removed} - \text{Carbonate Hardness}$$

$$\text{NCH} = (210 - 170) \times 1.06 = \underline{42 \text{ mg/l of Soda Ash}}$$

Recarbonation in Lime Softening

- Because water has unused lime (calcium hydroxide) and magnesium hydroxide in solution at high pH (pH 11), these must be converted to a stable forms.
- CO_2 is added to reduce Ca(OH)_2 to CaCO_3 which precipitates at about pH 10; additional CO_2 is added to convert Mg(OH)_2 to soluble $\text{Mg(HCO}_3)_2$ which occurs at a pH of 8.4.
- Reaction must be completed before filtration so that calcium carbonate will not precipitate in the filters or carry into distribution system.

Recarbonation Converts Excess Lime and Mg Products to Stable Bicarbonate Compounds

CO₂
Needed is
Based on
Excess Ca
and
Mg(OH)₂
Left

Equiv. Wts.

CO₂ = 44


Mg = 24

Ca(OH)₂ = 74

Constituent		Ca & Mg OH
Ca(OH) ₂ or Lime	=	169 mg/l
Ca(OH) ₂ Excess	15%	25.4 mg/l
Mg (OH) ₂ mg/l	21	3

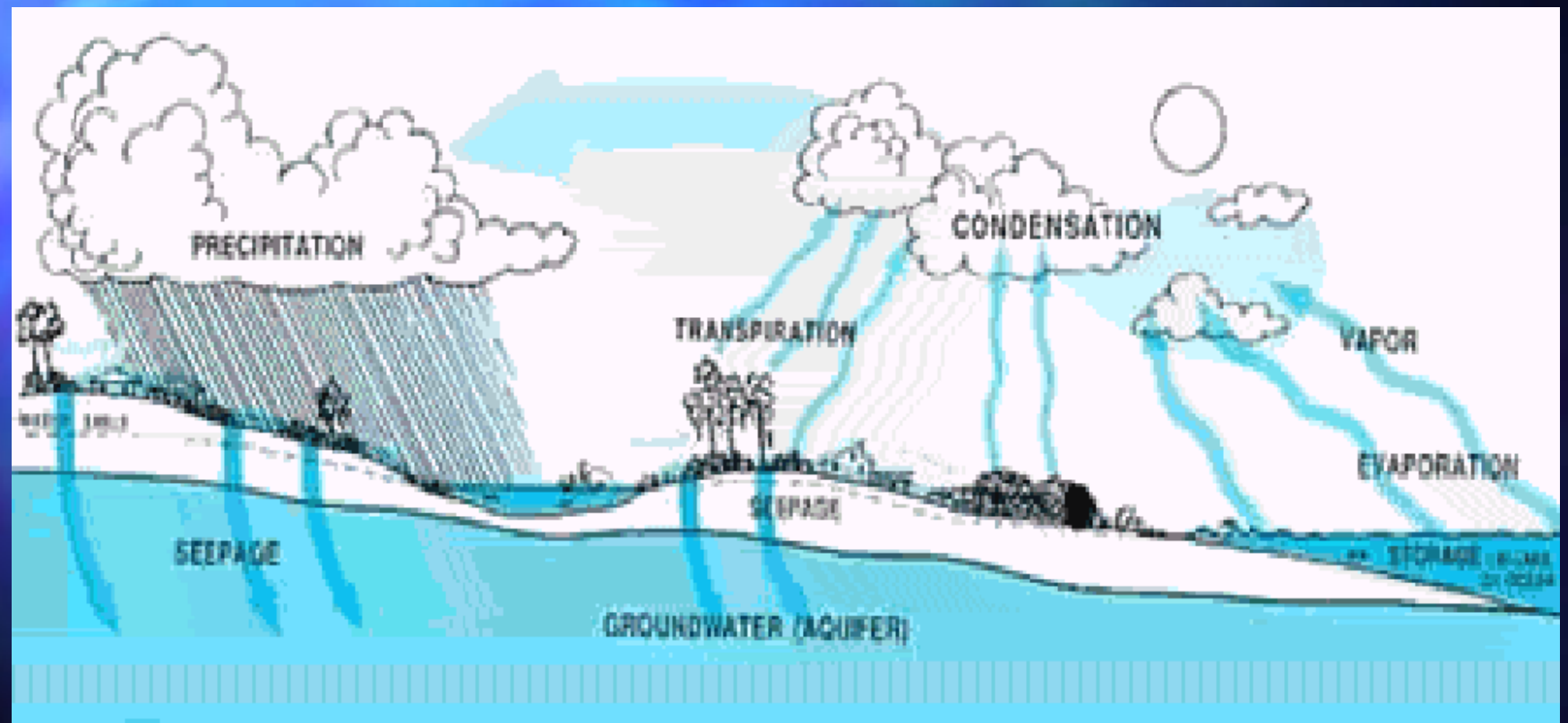
$$\text{Total CO}_2 \text{ feed} = 25.4 \times 44/74 + 3 \times 44/24$$

$$15 + 6 = 21 \text{ mg/l CO}_2$$

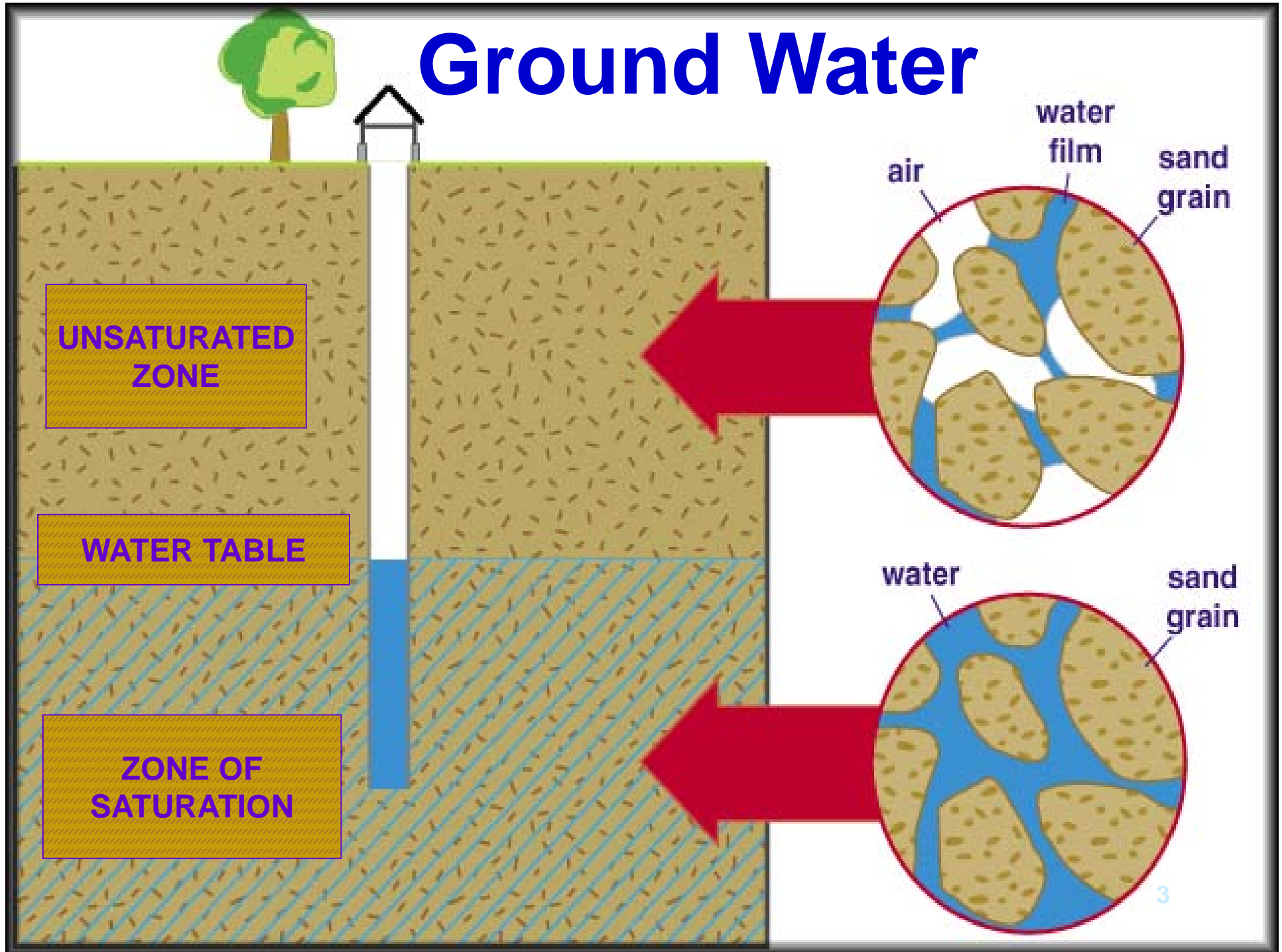


Water Sources for Drinking Water Supplies

Hydrologic Cycle

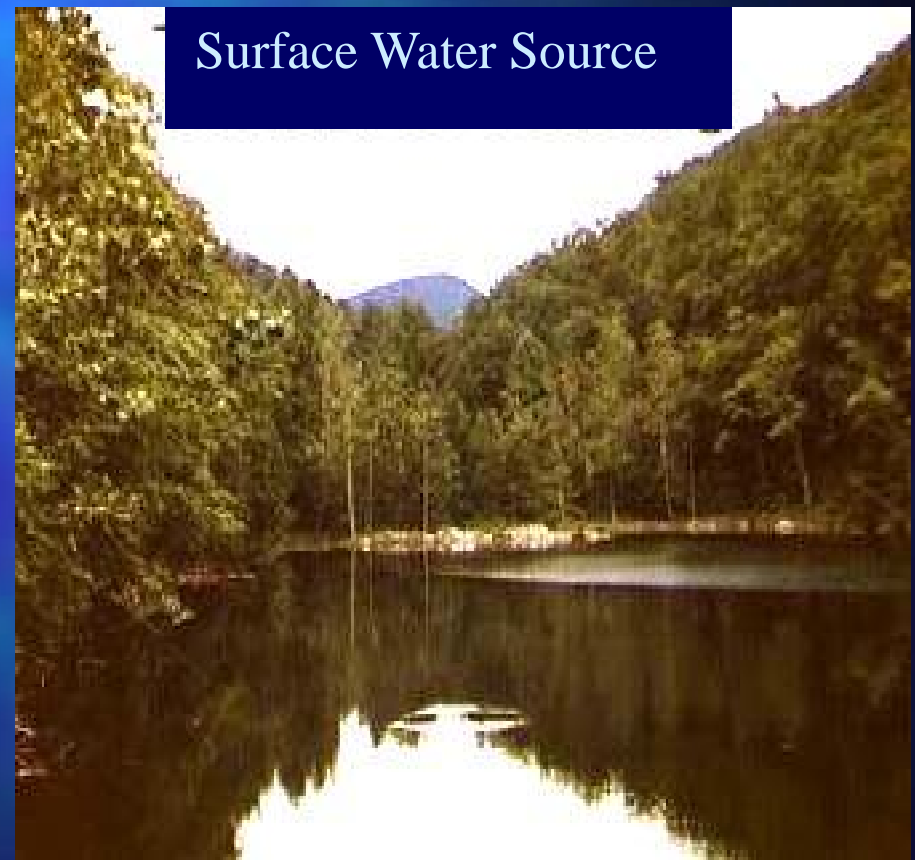


Ground Water



Sources of Drinking Water

- Surface water
- Ground water
- Ground water under the direct influence of surface water
- Desalinated sea water
- Rain water



Selecting A Source of Drinking Water

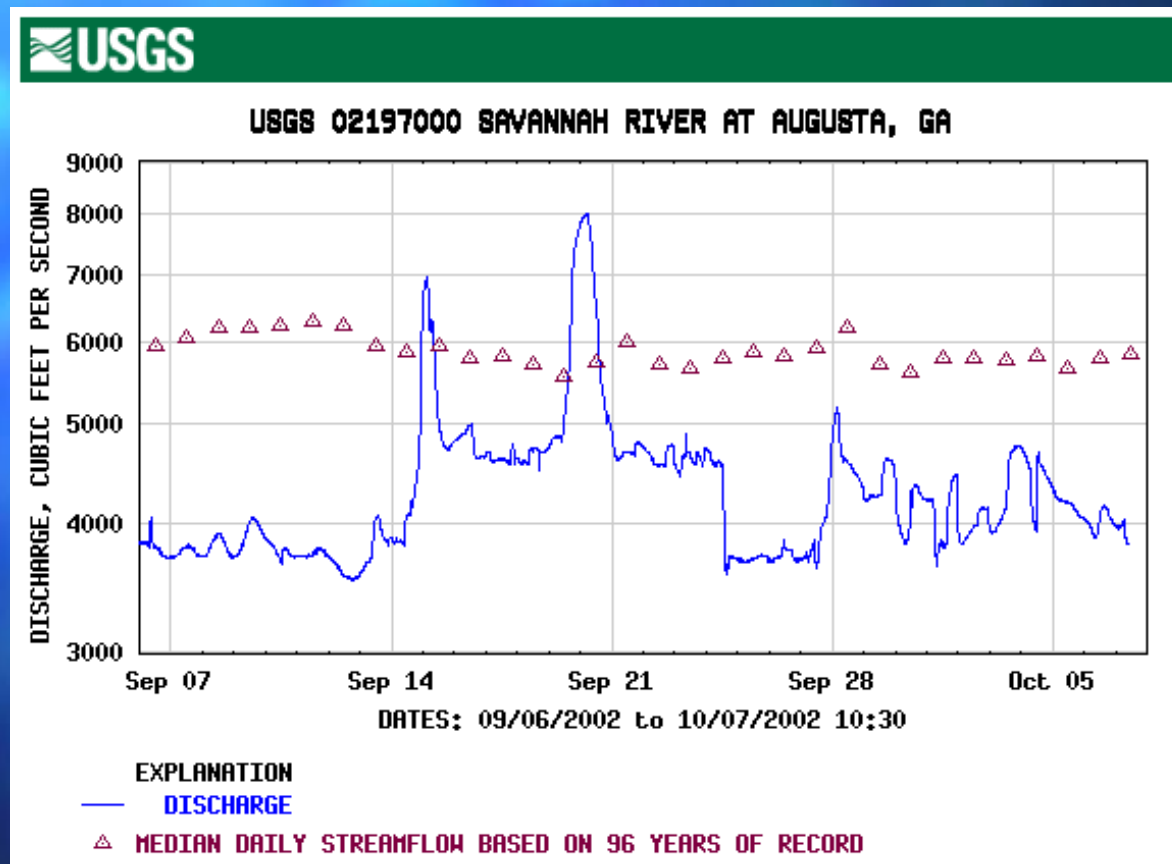
- Adequate quantity
- Meets requirements for microbiological, physical, chemical and radiological quality
- Best available source economically reasonable and technically possible



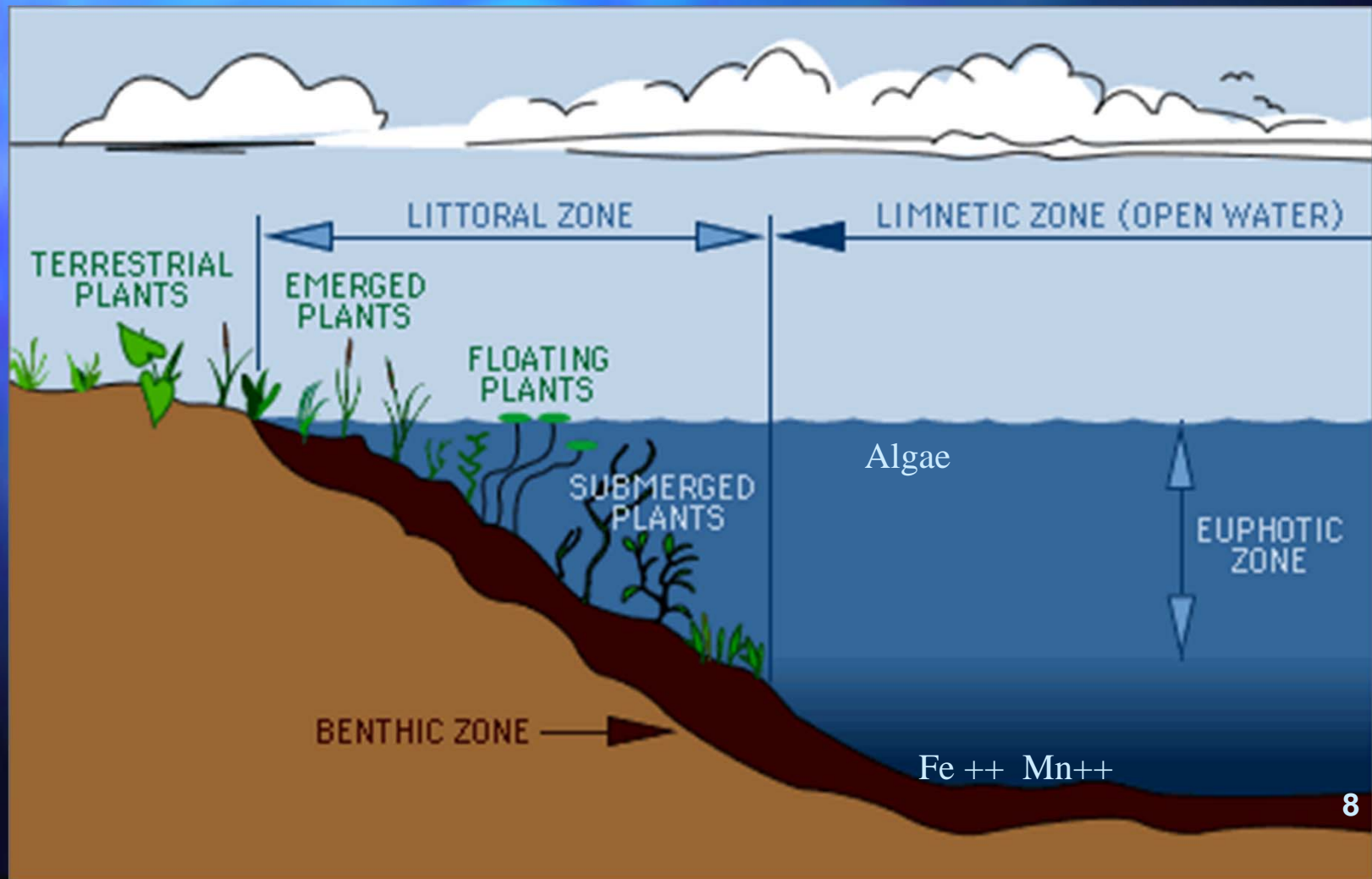
Characteristics of Surface Water Sources

- Quality of streams and rivers can change rapidly
- Subject to accidental spills
- Lakes and reservoirs have more gradual changes

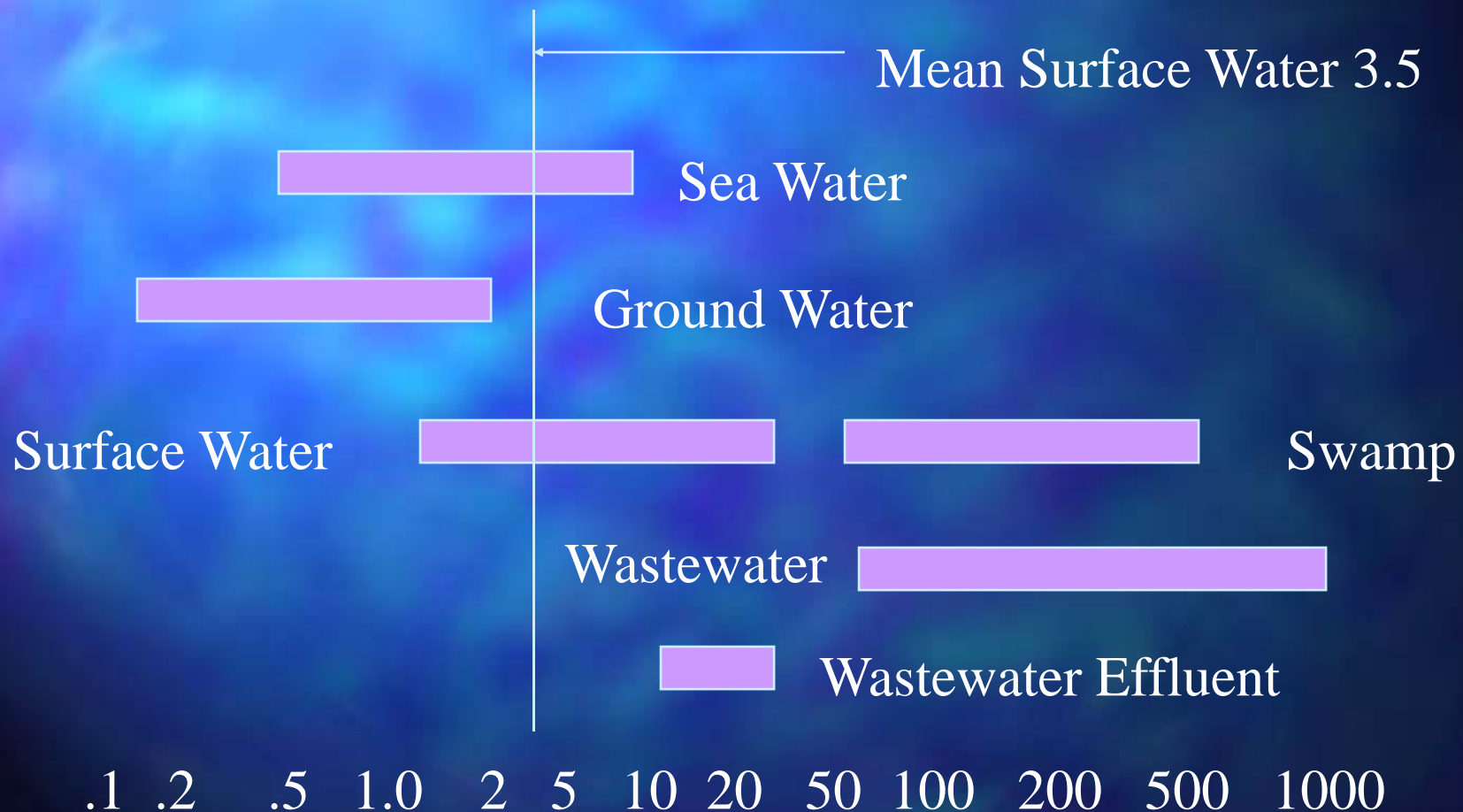
Dynamics of Moving Bodies of Water



Structure of Surface Water Systems



Organic Carbon (TOC) in Natural Waters mg/l

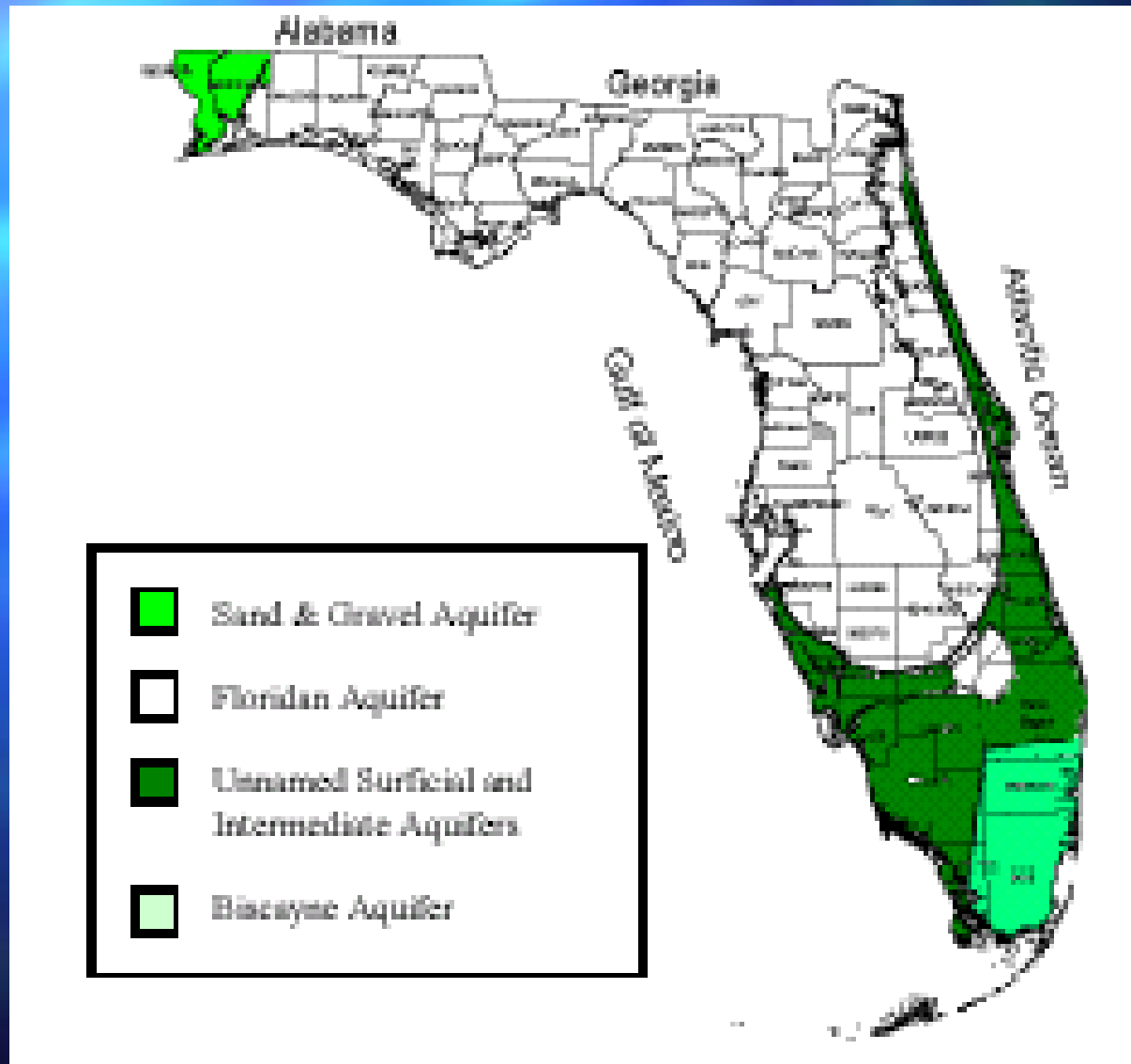


Algae Considerations



- Algae blooms in warm weather contribute to taste and odor
- Algae blooms increase pH during daylight hours (decrease CO₂ content)
- Algae blooms lower pH at night

Florida Groundwater Sources



Characteristics of Ground Water Sources

- Seasonal quality is relatively constant
- Quality may vary greatly from well to well
- Usually superior to surface water:
 - Bacteriological content
 - Turbidity
 - Total organic concentrations
- Mineral content may be inferior to surface water



Well being drilled

Ground Water Sources Must Provide Quantity and Quality

■ Quantity

- Equal or exceed design maximum and average day demands with largest producing well out of service
- Minimum of two sources
- Standby power supply

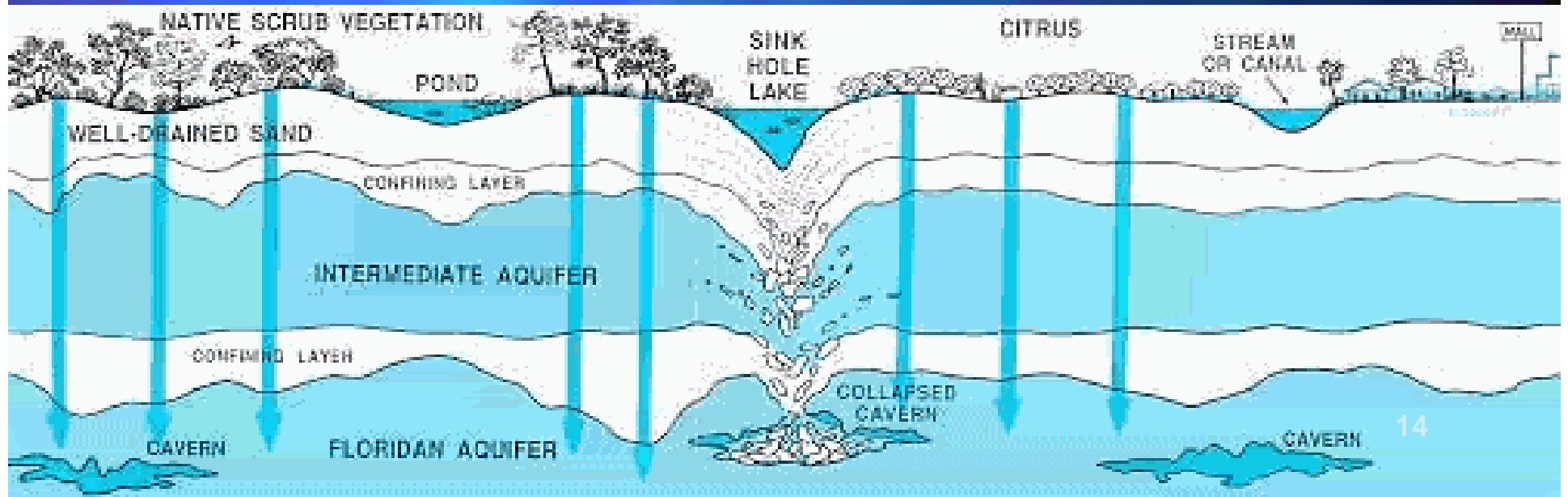
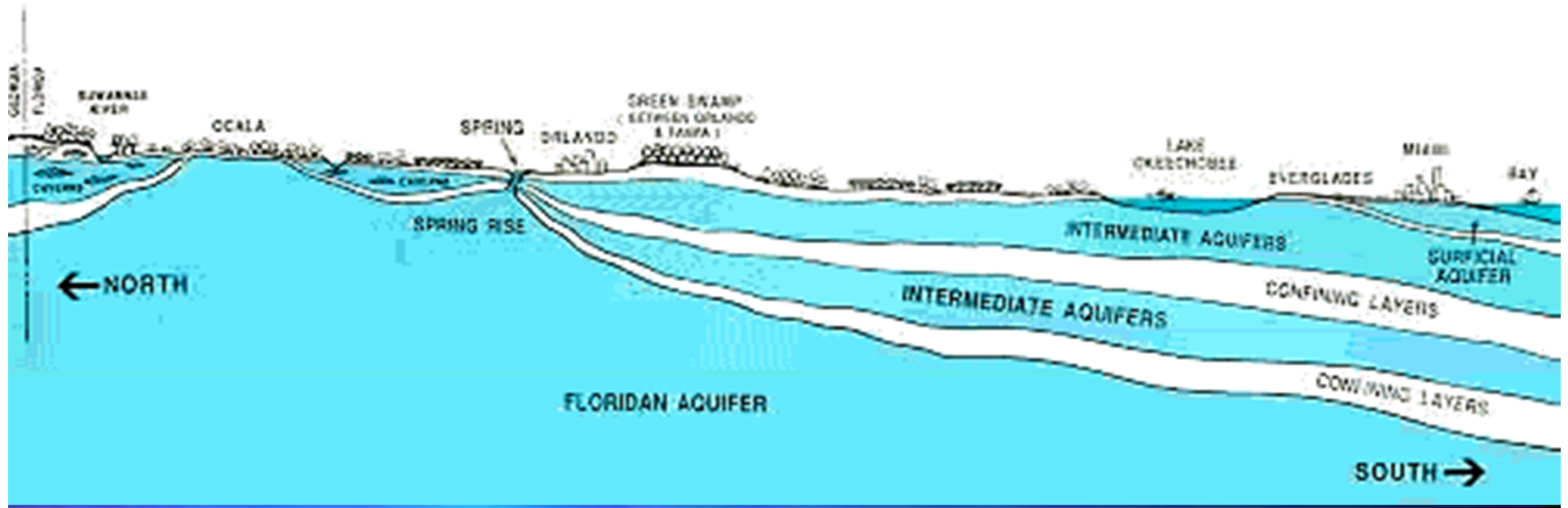
■ Quality

- Every new, modified or reconditioned ground water source must sample to demonstrate quality
- Adequate separation between well and potential sources of contamination and ground water development

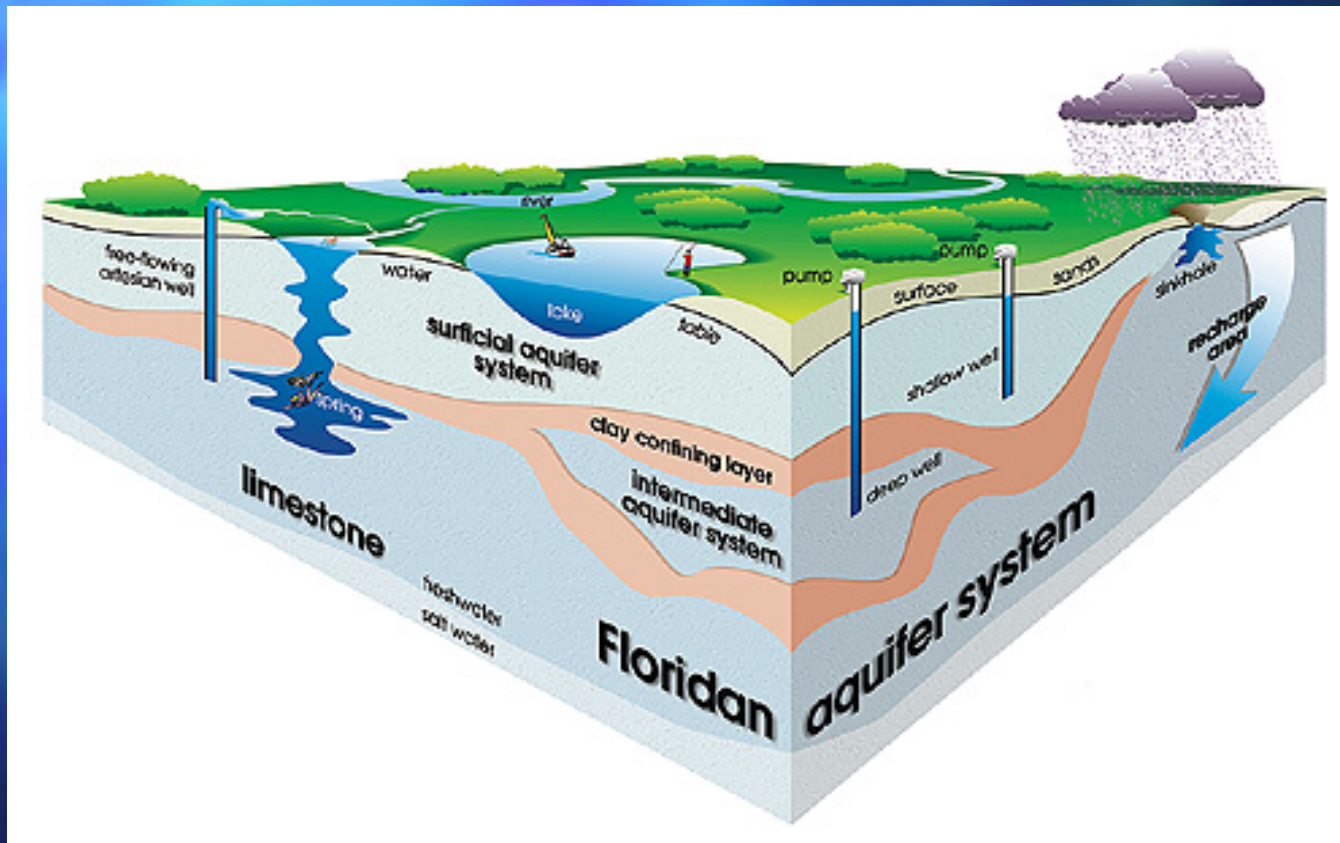


Artesian well ¹³

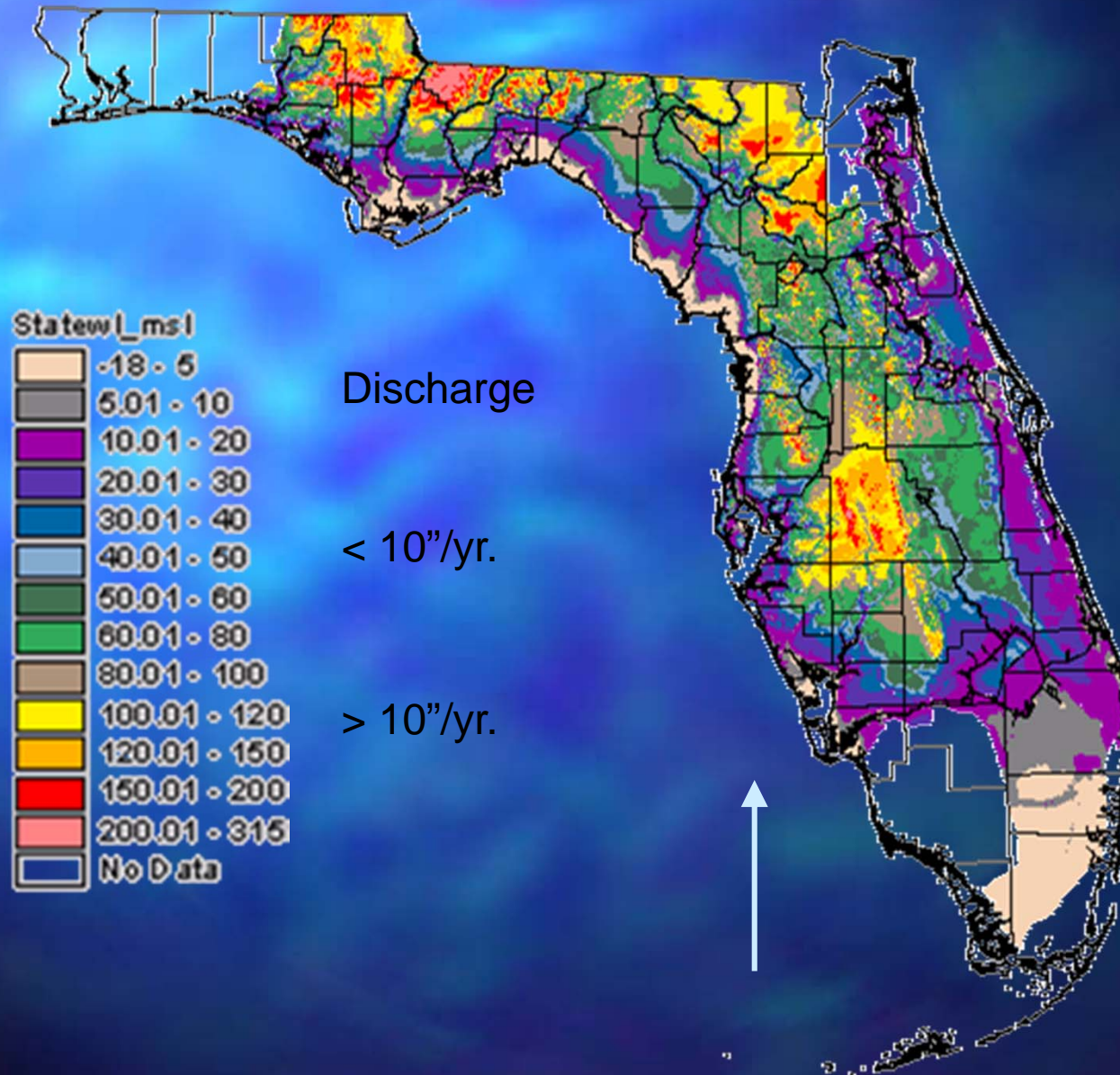
Floridian Aquifer Across Florida



Floridan Aquifer



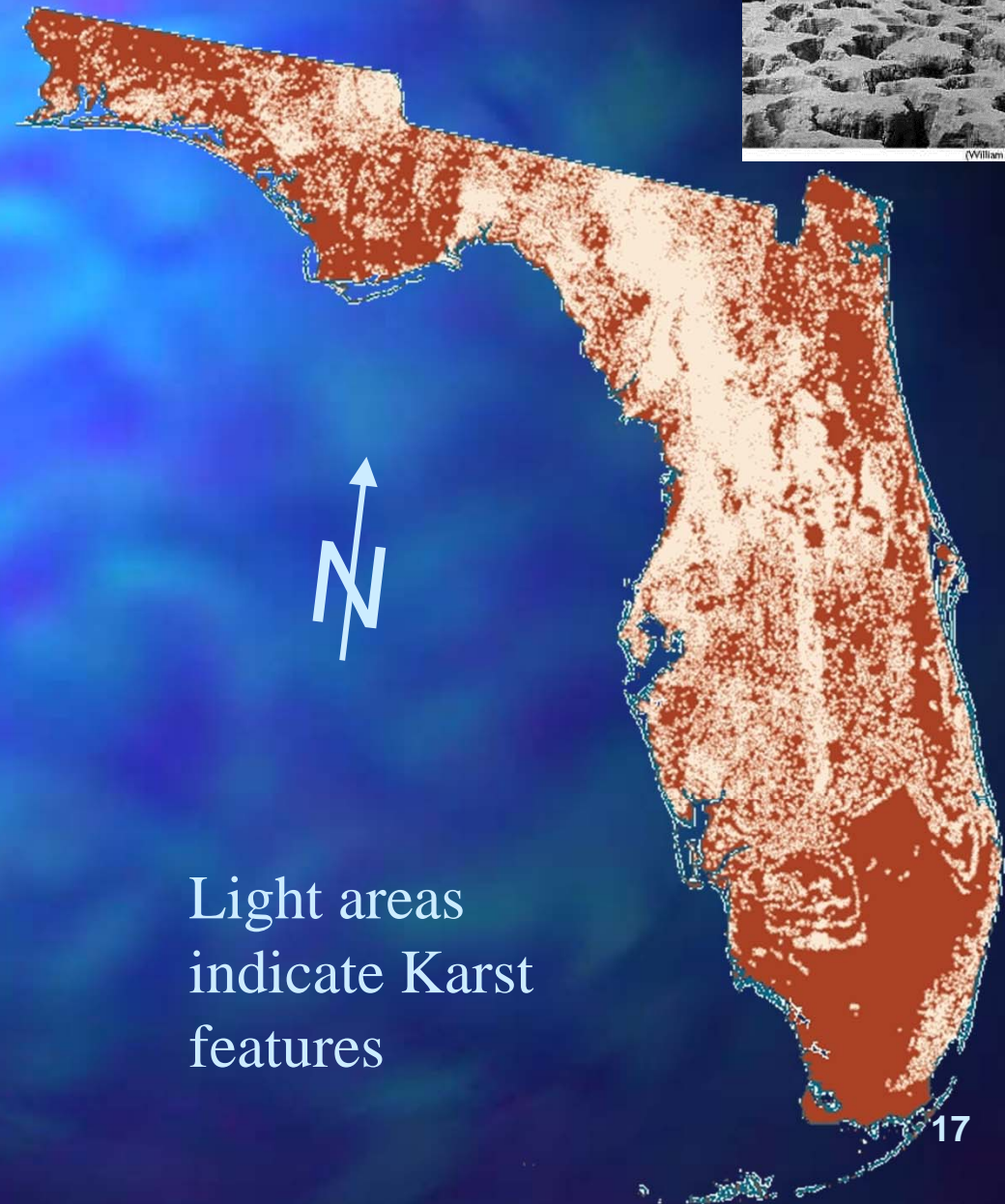
Potentiometric Surface of Upper Floridan



Karst Features



- Karst is a type of topography that is characterized by depressions caused by the dissolution of limestone.
- These features include caves, sinkholes, springs, and other openings.
- In karst areas, interactions between surface water and groundwater are extensive and groundwater quality can degrade quickly.



Light areas
indicate Karst
features

Karst Features and Solution Cavities



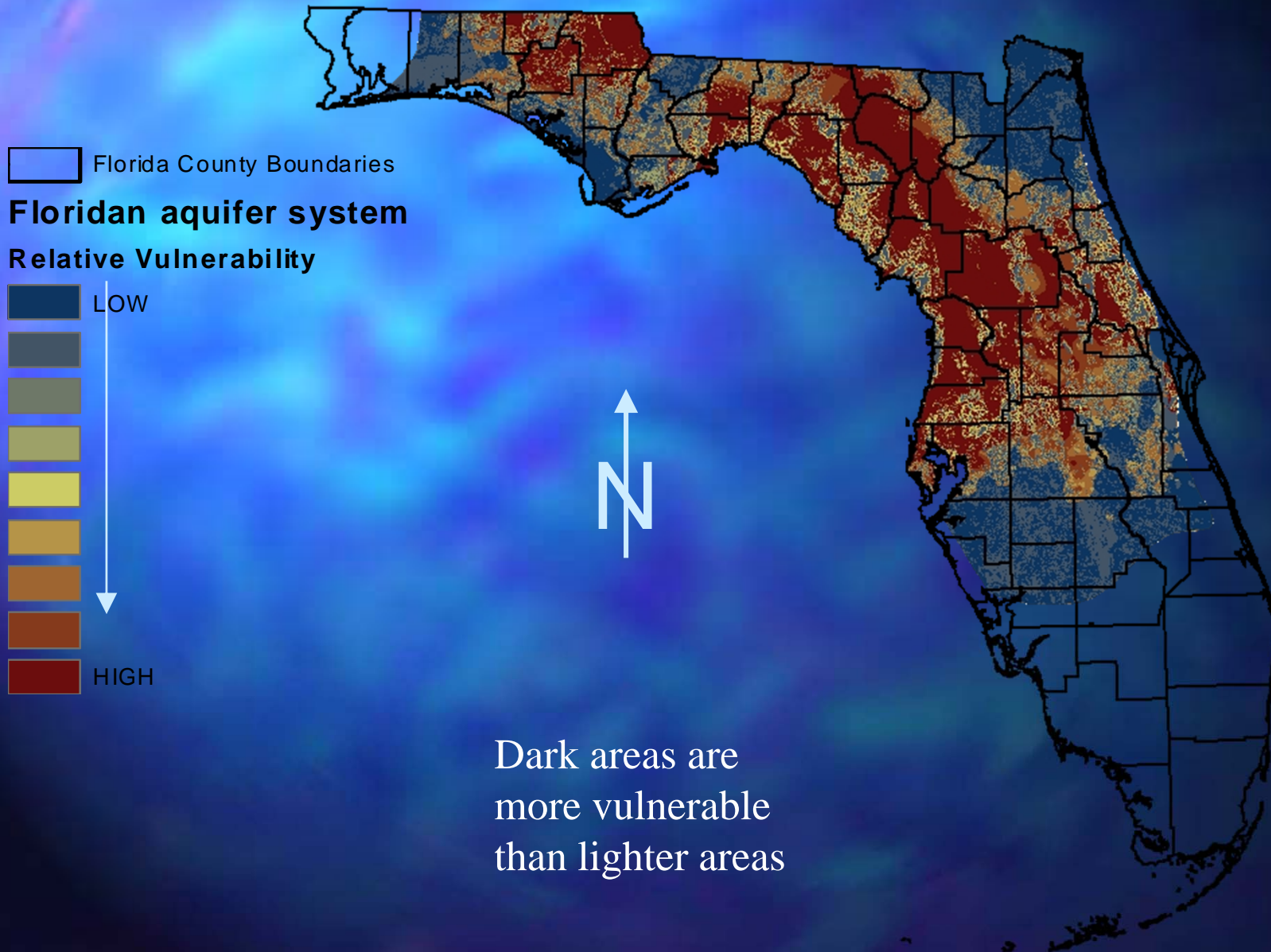
Karst Limestone Feature

Limestone is easily dissolved by Carbon Dioxide.

Carbon Dioxide is dissolved from the air and from decomposing matter.

Subsurface cavities, caves, drainage basins, sinkholes and other geologic features characterize Florida's karst conditions.

Florida Aquifer System Relative Vulnerability Map for Nitrate





Threats to Drinking Water

Contaminant Effects

- Acute Health Effects – Immediate
Tier 1 Health Risk Notification - 24 hrs
Fecal, Nitrate, Turbidity, or treatment technique
- Chronic Health Effects – Long Term
Tier 2 Health Risk Notification – 30 days
all other MCLs not listed above
- Aesthetic Concerns
Tier 3 Health Risk Notification – 1 Yr.
Secondary Standard

Pathogens Causing Acute Health Affects

- Viruses (e.g., Hepatitis A & E, Norwalk Virus, Enteroviruses, Adenoviruses, Rotaviruses)
- Bacteria (e.g., *Shigella*, *Legionella*, *Salmonella*, *E.coli*)
- Parasites, protozoa and cysts (e.g., *Giardia lamblia*, *Cryptosporidium*)

Viruses (Require Host)

Size	0.02 to 0.30 μm
Structure	Particles, Protein Coat and Nucleic Core
Enteric	Excreted in Feces
Number	>100 known

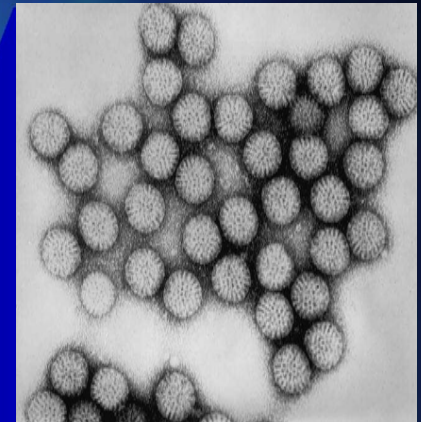
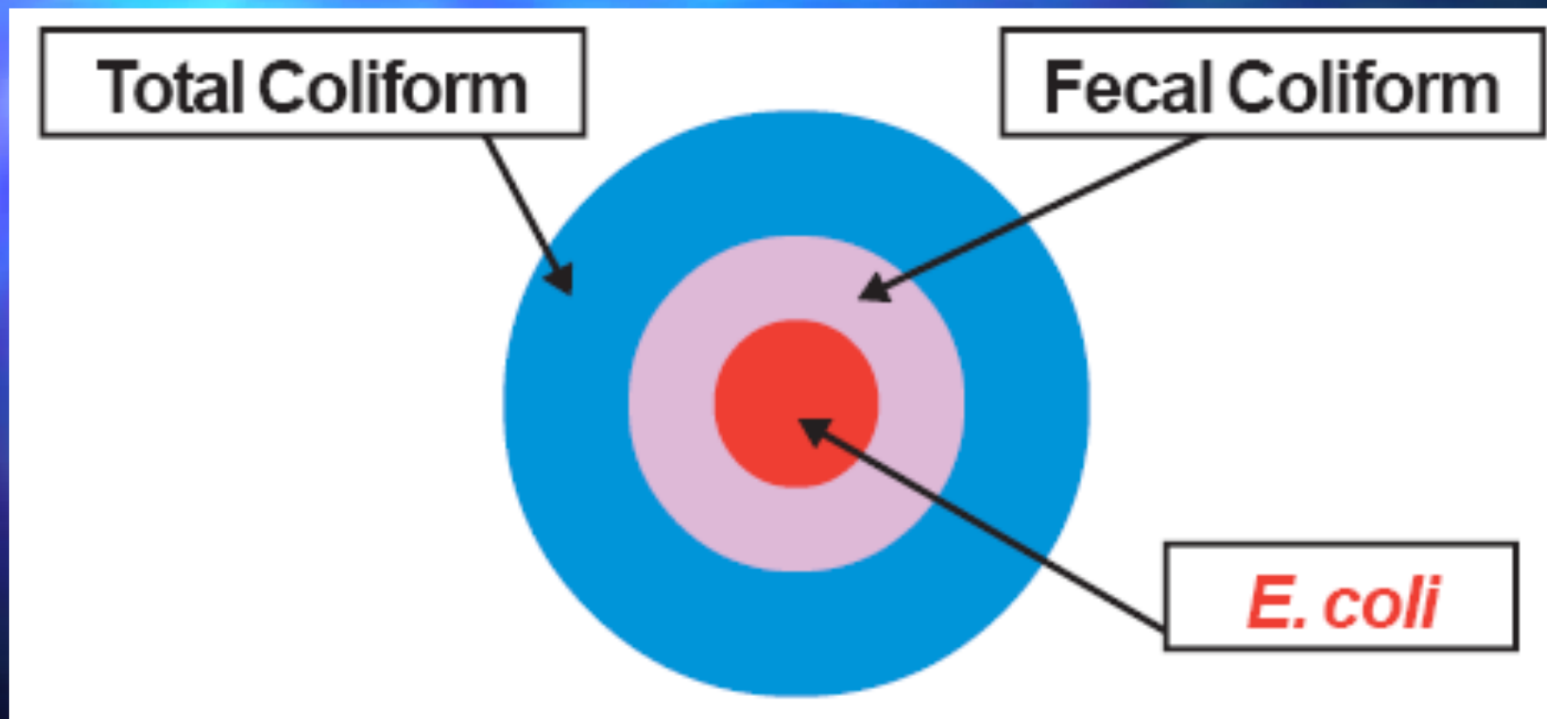


Photo: Rotavirus, ASM Digital Collection

Water Borne Diseases found in Virally Contaminated Water

Viral Group	Disease
Enterovirus	Meningitis, GB Spinal Syn., Respiratory, Hepatitis
Adenovirus	Respiratory, Conjunctivitis, Appendicitis
Hepatitis	Infectious Hepatitis, Downs Syndrome

Indicator Organisms and Pathogenic Contaminants



Gastroenteritis (Most Common Illness) from Fecal Contamination of Water

- Symptoms are nausea, vomiting and diarrhea; typically not reported
- Can be caused by viral or bacterial contamination
- Over 100 types of human enteric viruses have been identified in wastewater; some not yet identified may be virulent
- Viruses can survive outside host organism
- Viruses survive longer than indicator organisms in the presence of disinfectant

Some Facts About Bacteria

- Bacteria are widely distributed on earth
- They have been found 4 miles above earth and 3 miles below sea sediments.
- One gram of fertile soil contains up to 100,000,000 bacteria.
- Bacteria are inconceivably small and measured in microns. One micron is equal to $1/1,000,000$ of a meter.
- During the rapid growth phase bacteria undergo fission (cell division) about every 20 to 30 minutes.
- One bacterial cell after 36 hrs of uncontrolled growth, could fill approximately 200 dump trucks.

Types of Samples

Compliance Routine Samples

	Annual, Monthly, or Quarterly samples, collected from representative locations throughout your water system in 100mL or 125mL containers and submitted to a lab within 30 hours.
- Repeat Samples	collected within 24 hours after you receive notification of a positive coliform result.

Non-Compliance Samples

- Additional	samples required by DEP in order to help identify extent of the contamination or provide better info.
- Replacement	compliance sample that is collected but does not get analyzed, i.e., expired, broken, insufficient vol.
- Special Samples	collected due to repairs, complaints, or maintenance to ensure that coliform has not entered the water distribution system.

Sample Collection Procedures

- Accidental Contamination – Remove Obstruction (aerators, hoses, etc. that harbor bacteria)
- Sample Containers – Use Appropriate Type of Container (Sample Bottles or Whirl-Pac)
- Preservation- Use Specified Method; if refrigeration required use $\leq 4^{\circ}\text{C}$
- Label – Sample Container and Time
- Chain of Custody – Tracing and Handling

Bacteria and Pathogenic Indicators in Water Treatment

Total Coliform	Ferment Lactose @ 35°C
Include Species of Genera	Citrobacter Enterobacter Klebsiella E. Coli
Fecal Coliform	Grow at 44°C Produce Enzyme
E. Coli	More Specific Indicator of Contamination
HPC	< 500 colonies/ml

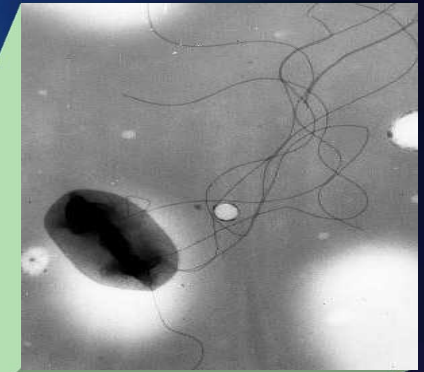
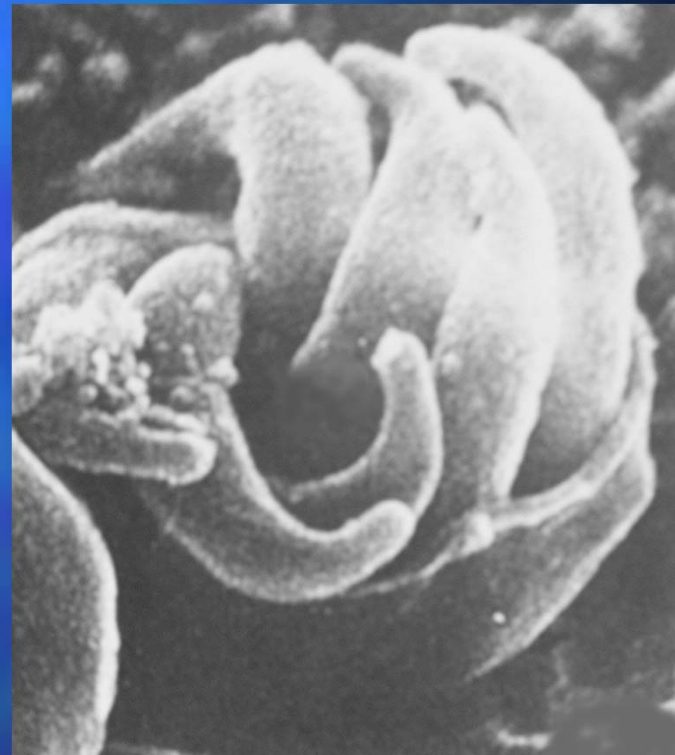


Photo: CDC. *E. coli* 0157:H7
11 of 140 cause gastrointestinal disease

Regulated Protozoa



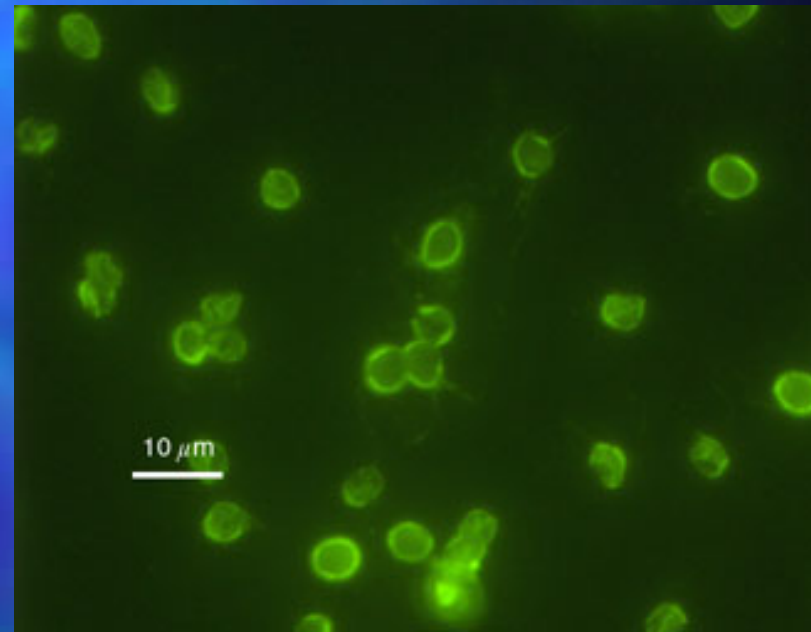
Giardia



Cryptosporidium

Cryptosporidium Oocysts and Giardia Ocysts

- Extremely Small
- Electron Microscope required
- Form protective layer
- Bunch in clusters
- Turbidity will protect from Cl and UV



Oocysts showing protective layer

Types of Contaminants Causing Chronic Health Effects

- Volatile organic chemicals (VOCs)
- Inorganic chemicals (IOCs)
- Synthetic organic chemicals (SOCs)
- Radionuclides

Contamination Sources

- Septic Tanks, storm and sanitary sewers
- Waste disposal activities
- Horticulture and animal pasturing
- Chemically treated lawns
- Subsurface liquid disposal
- Runoff from storm events
- Characteristics of soil above rock
- Decomposition of organic matter

Protecting the Water Source

- Security and Safety
- Contamination Prevention Programs

Security and Safety of the Water Sources

- Secure surface water sources
- Properly seal wellheads
- Screen and securely attach well vents and caps
- Properly secure observation, test and abandoned wells

Long-Term Groundwater or Wellhead Protection

- Protection of ground water sources
- Subdivision growth controls
- Zoning
- Land purchase
- Acquisition of development rights
- Land use restrictions





Water Storage Systems

Water Storage Tanks

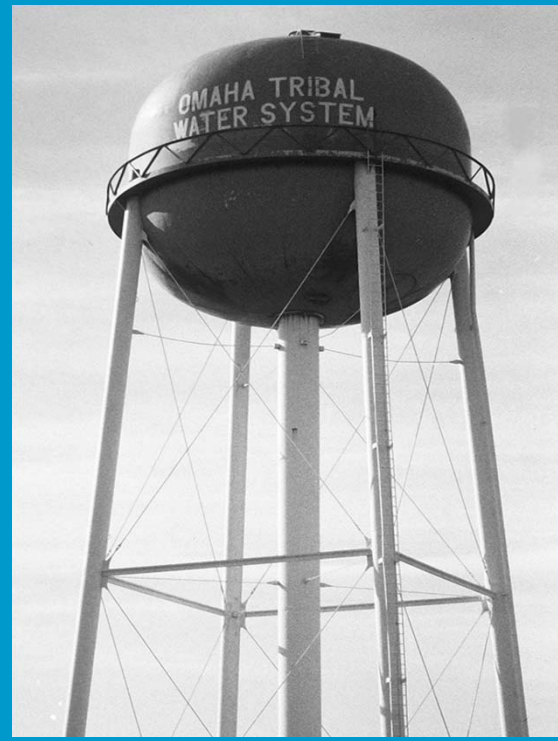
Types:

- Gravity or Elevated
- Ground Storage
- Hydropneumatic

Water Storage Tanks



Ground Storage



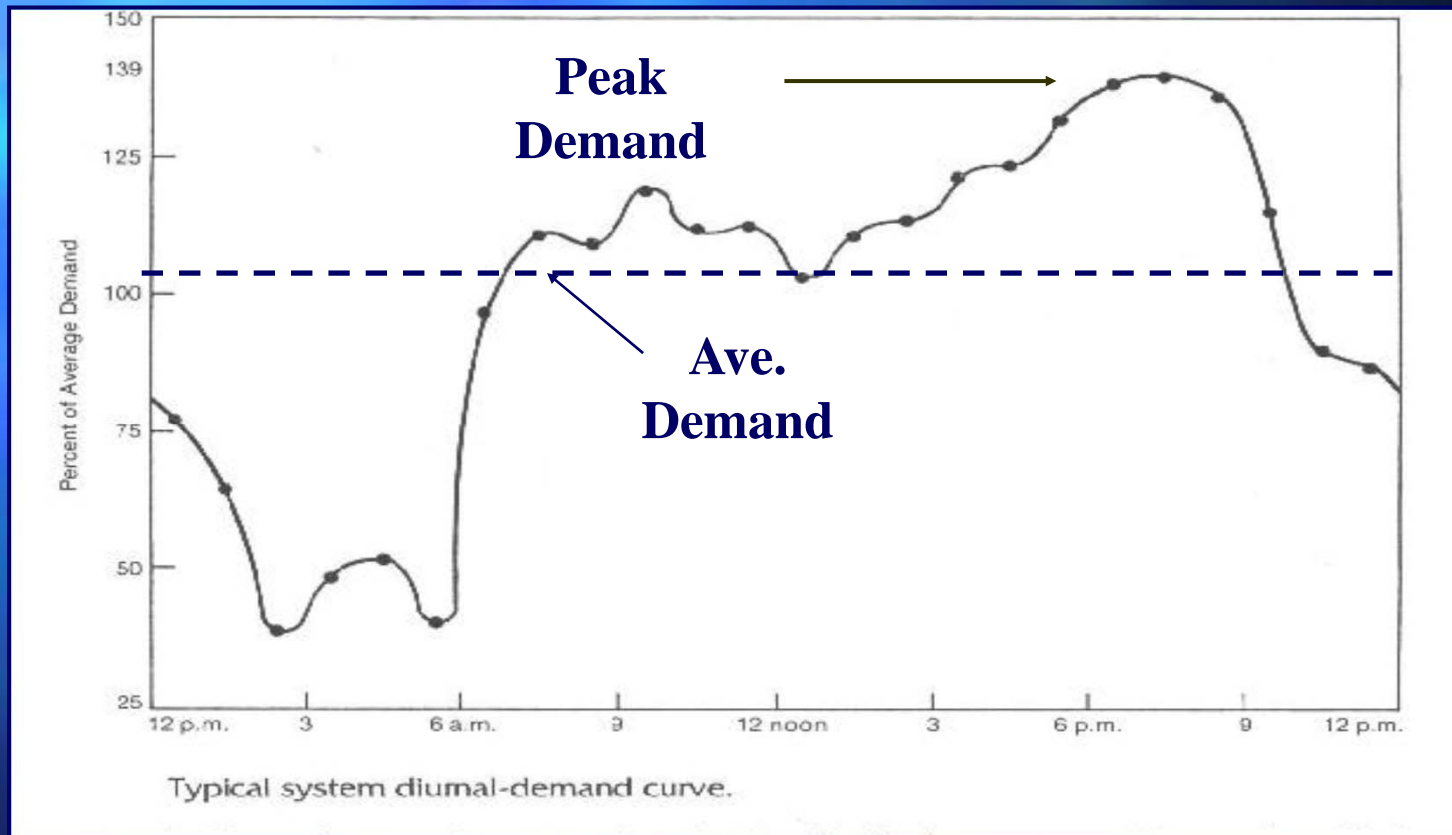
Elevated Storage



Hydropneumatic

Diurnal Flow Pattern

Plant
Flow



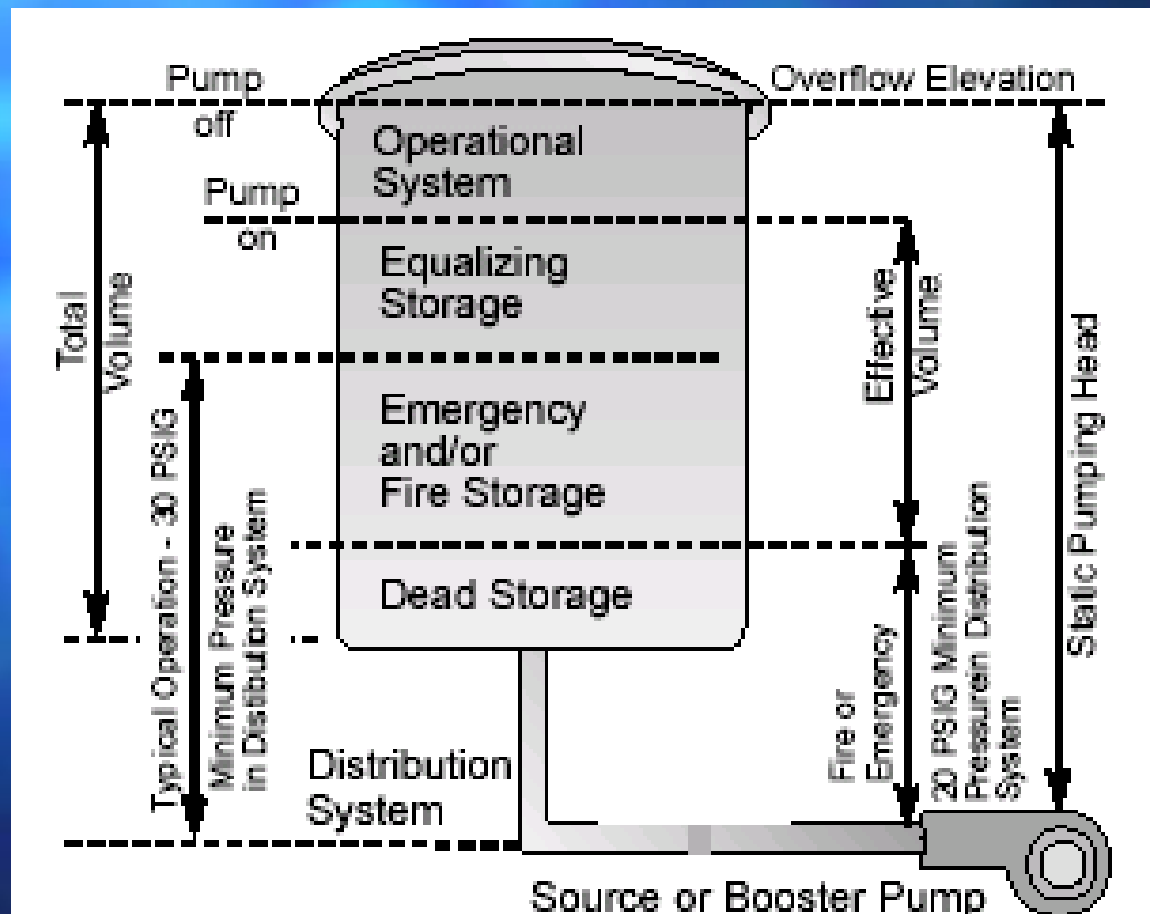
12M

12N

12M

Ave. 24 Hour Period

Schematic Illustrating the Benefits of a Storage Tank



Hydropneumatic Tanks



Types of Hydropneumatic Tanks

- Conventional (Has Water Air interface that requires a Compressor and must be NSF Approved)
- Floating Wafer (no interface)
- Flexible Separator (no interface)

Operating Considerations for Conventional Hydropneumatic Tanks

- Must have air to operate correctly
- Must have a pressure relief valve
- Need a sight glass to observe level in tank
- Must have By-pass piping for repairs
- Valve for flushing
- Air volume control
- Scheduled maintenance program



Components of Conventional Hydropneumatic System

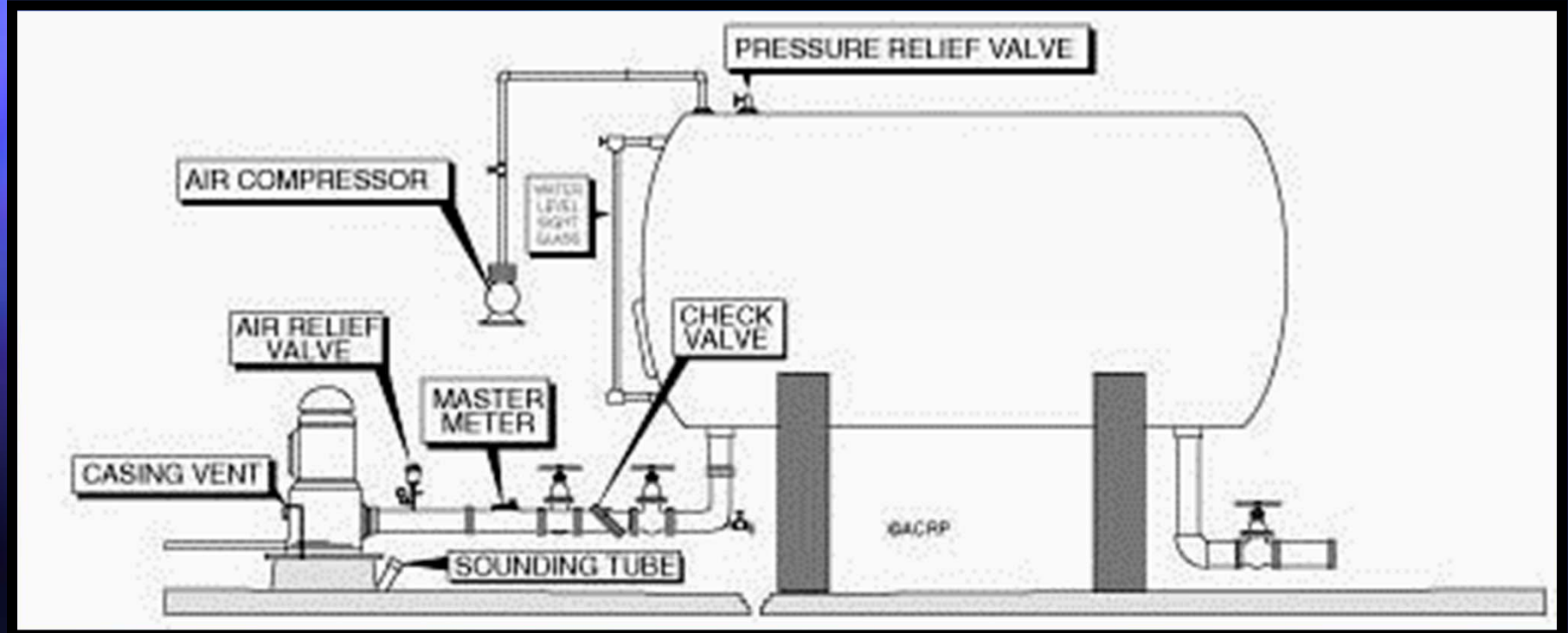
Components

- Air Volume Control -
- Relief Valve -
- Pressure Gauge -
- Motor Controls -
- Level Controls -
- Compressor -

Function

Control amount of air in tank
Prevent excessive high pressure
Monitor water/air pressure
Control cut-in and cut out
Regulate high/low water levels
Replenishes Air

Conventional Hydropneumatic Tank Schematic



Sizing Considerations for a Conventional Hydropneumatic Tank

- Tank is designed to meet peak demand
- Operating pressure is generally sized to operate between 40 and 60 psi
- The pressure pump should not cycle more than 6 to 8 times per hour

Formula for Sizing Hydropneumatic Tanks

Note: DEP requires 10X Well
Capacity in gallons of storage

$$Q = \frac{Q_m}{1 - (P_1/P_2)}$$

Q = Tank Volume in gallons

Q_m = Peak Demand Rate (gpm) X Min. of Storage

P₁ = Cut in Pressure + Atmospheric Pressure (14.7 psi)

P₂ = Cut Out Pressure + Atmospheric Pressure (14.7 psi)

Air Compressor Maintenance Considerations

- Regularly scheduled maintenance:
- Clean or replace filters
- Drain condensate frequently
- NSF approved lubrication

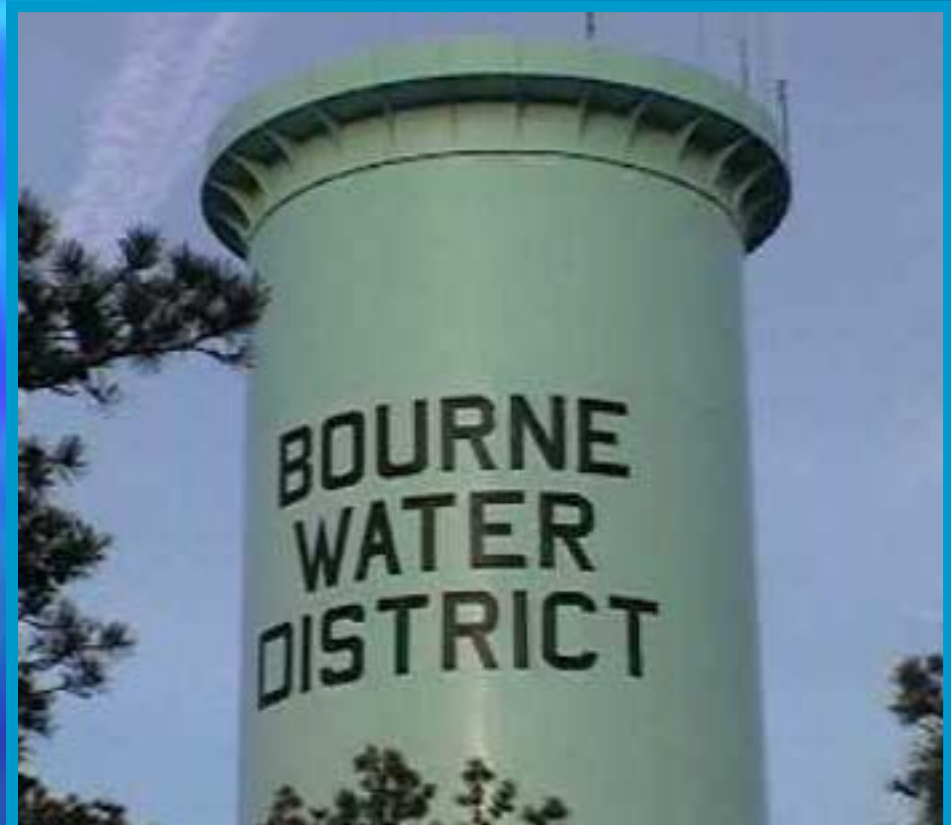


Elevated Tanks

- Stabilize distribution system pressures
- Provide water to meet peak demands
- Keeps pumps from cycling and operating in efficient ranges

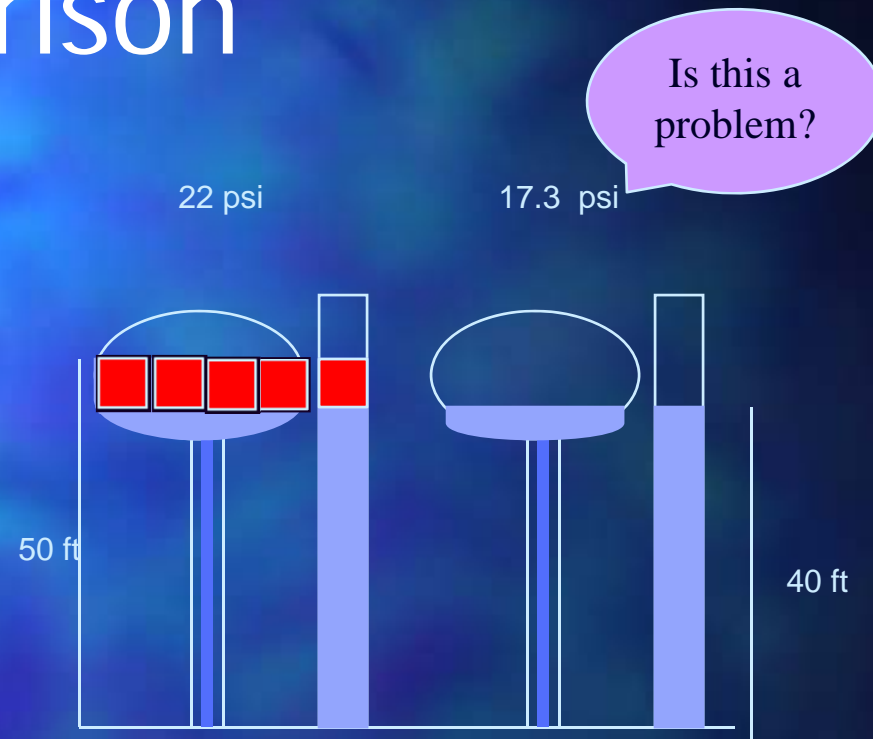


Standpipe



Elevated Tank and Standpipe Comparison

- Used to provide pressure head to the distribution system.
- Large storage capacity
- Shallow tanks with large diameter are preferred over deep one with small diameters.
- Less pressure drop in elevated tanks.



$$\text{Pressure} = \text{Water Elevation (ft)} * \text{Water Density (lb/ft}^3 \text{)} * (1 \text{ ft}^2 / 144 \text{ in}^2)$$

Where:

Water Density = 62.4 lb/ft³

Advantages Offered by Elevated Tanks

- Less variation in pressure
- Available water for fire fighting
- Storage to meet peak demands
- Allows use of lower capacity wells
- Cycling of well pumps is reduced
- Wells can be better matched to average water demand
- High service pumps and the treatment plant can operate more efficiently

Maintenance Considerations for Elevated Water Storage Tanks

- Check for Intrusion of Water
- Secure Tank Site from unauthorized access
- Clean Tank yearly recommended
(DEP 5-yr. required!)
- Ensure that overflow structures are working, secure and properly drained
- Inspect Structures for Stability, Blockages and Surface and Internal Corrosion.

Ground Storage



- Used for storing large amounts of water.
- New Tanks must be Covered!
- Not under pressure uses transfer pumps to pressurize or pump to elevated tank.
- Sometimes has aerators on top for waters that require it.

Well Requirements for Public Water Systems

Suitability of Well Construction

Bored

- ~100'
- 2-30" dia.
- Soils or Small Boulders, Fractured Formations

Jetted

- ~100'
- 2-12" dia.
- Soil Formations Only

Driven

- ~50'
- 1.25 -2"
- Soils, no Boulders & only very thin Rock Formations

Drilled

- ~1000'
- 4-24"
- All Geological Formations

Well Location Considerations

- Geologic Characteristics
- Slope of Ground Surface
- Nature of Soil and Homogeneousess
- Slope of Water Table (field determined)
- Size of Drainage Area
- Nature and Distance to Pollution Sources
- Methods in-place to Protect Well

Source Water Parameters

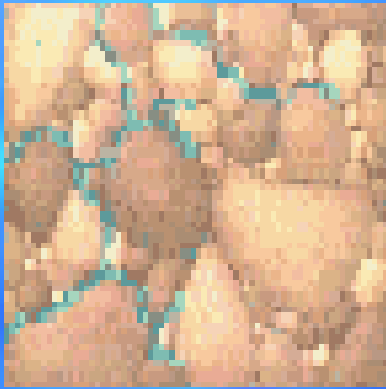
Quality and Quantity Dictates Depth of Well

- TDS — Requires RO plant
- Total Hardness
- Total Fe and Mn
- Chlorides & Sulfates
- Total Alkalinity
- Nitrate — 10mg/l Blue baby
- pH
- Corrosivity
- CO₂
- H₂S — Has to be removed.
Will eat pipes.
- Fluoride

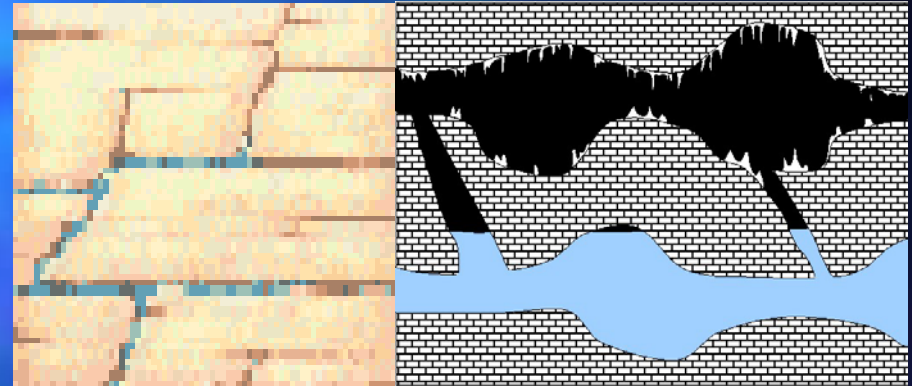
Well Yield

- Depends on Characteristics of Aquifer and Drawdown (Permeability and Thickness of Aquifer)
- Rule of Thumb is that Doubling Diameter increases Production by 10%
- Increasing Well Capacity requires Deepening
- Difficult to Predict Yield without pumping
- Based on estimating from Nearby Wells
- Driven Wells produce ~30 gpm and Jetted and Drilled Wells > 300 gpm.

Types of Porosity

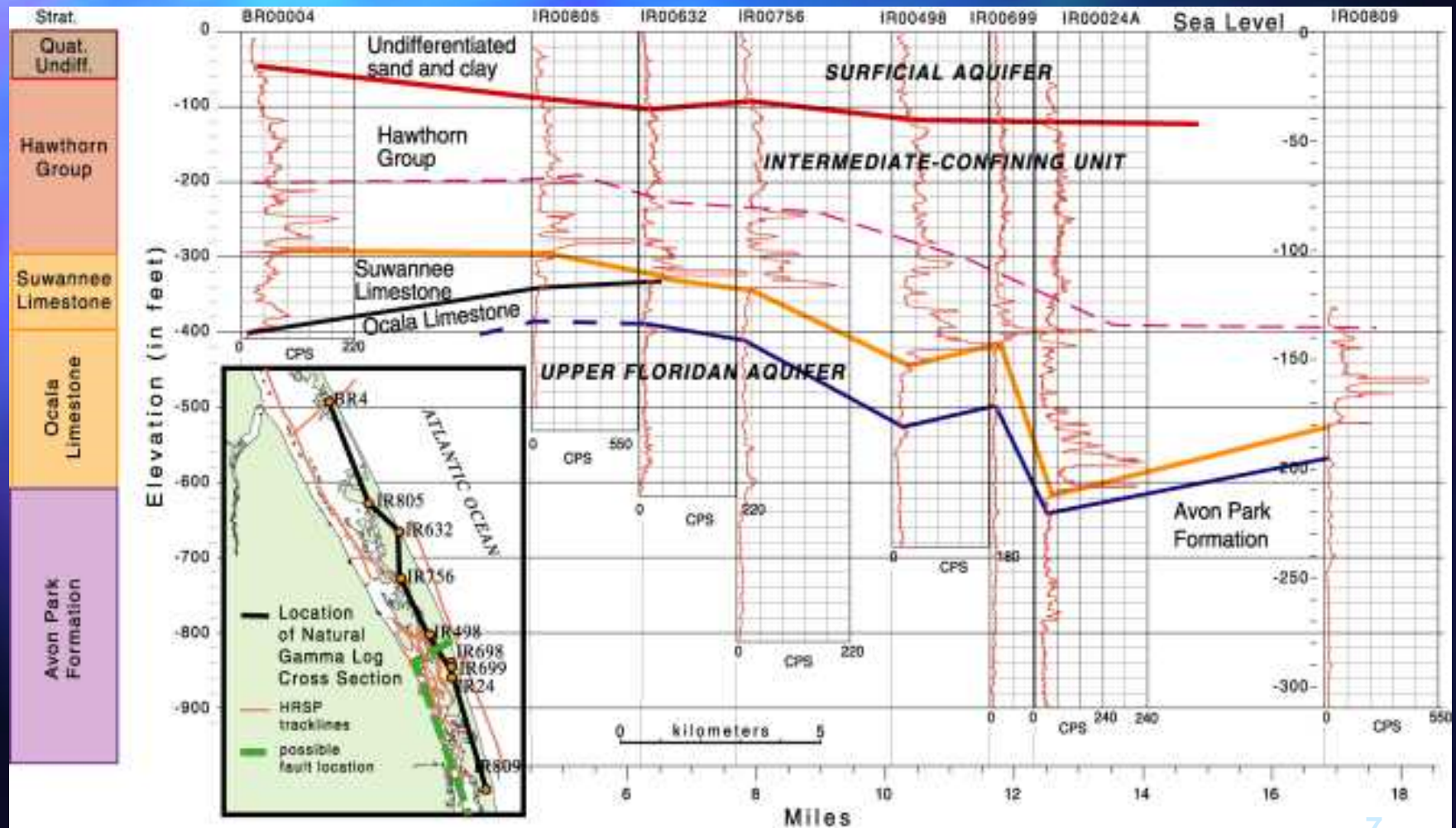


Intergranular
movement of water between
rock grains



Cavernous
movement of water
cavities and cracks
in rock that result
from erosion.

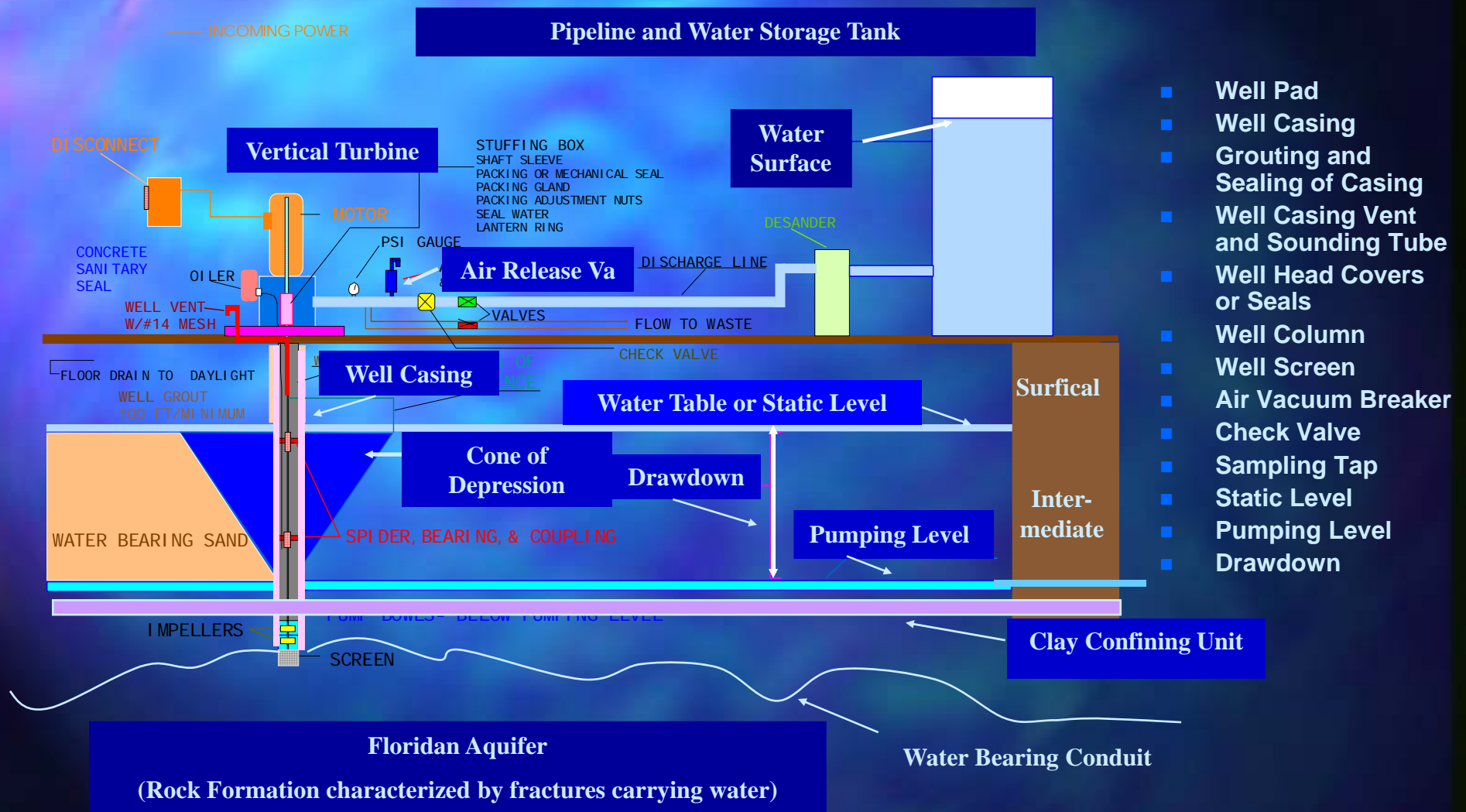
Gamma Log Identification



Determining Well Yield with Well Pump Test

- Well is Pumped for at least 4 hours
- Determine how much water is pumped per min or hour (GPM)
- Determine the depth to pumping level (maximum drawdown) over time at one or more constant pumping rates
- If well does not recover in 24 hrs. to original level, Aquifer is not dependable
- Determine the recovery of water level
- Determine the length of time the well is pumped at each test

Component Parts and Operation of a Well



- Well Pad
- Well Casing
- Grouting and Sealing of Casing
- Well Casing Vent and Sounding Tube
- Well Head Covers or Seals
- Well Column
- Well Screen
- Air Vacuum Breaker
- Check Valve
- Sampling Tap
- Static Level
- Pumping Level
- Drawdown

Well Terminology

- Static Water Level
- Dynamic or Pumping Water Level
- Drawdown
- Cone of Influence
- Well Capacity

Important Components of a Well

- Well Pad
- Well Casing
- Grouting and Sealing of Casing
- Well Casing Vent and Sounding Tube
- Well Head Covers or Seals
- Well Column
- Well Screen
- Air Vacuum Breaker
- Check Valve
- Sampling Tap

Importance of Well Grouting



Pressure Testing of Grout Seal @ ~10 psi for 1 hr. Should be Performed.

- Prevent movement of water between aquifer formations
- Preserve quality of producing zones
- Preserve Yield
- Prevent water intrusion from surface
- Protect Casing against Corrosion!

Well Disinfection is Critical in Obtaining DEP Approval

- Must Remove all Foreign Matter prior to Disinfection; grease, oil, and soil harbor bacteria, surfactant agents sometimes used should not contain phosphorus!
- Contact times of 8 hrs. for chlorine solutions of 50, 150 or 200 ppm (based on pH are effective)
- If well is not in use, chlorination should be continuous (~10 ppm Residual) to prevent bacterial growth

Methods for Disinfecting Wells

- Protect all parts and swab with 50 mg/l solution before installation
- Inject Chlorine through the column pipe not only the vent pipe!
- 50 mg/l is needed for 24 hours
- Pump well until no chlorine residual is observed
- Test for Coliform (mo-mug or Colilert has more false positives for fecal!)

Air Considerations

- Air lock - an accumulation of air in the pump housing that prevents the flow of water.
 - An air-relief valve used to prevent this condition.
 - Submersible pumps have footer valves.

Well Maintenance

- Well Yield Declines Over Time
- Failure or Wear of Pump (check pump curves!)
- Decline of Aquifer Water Levels
- Plugged or Corroded Screens
- Accumulations of Sand or Silt in the Well
- Build up of calcium carbonate in solution cavities

Acidization

- Can improve productivity and lower pumping (electricity) costs of older wells
- Injection of 18/20 Baum HCL into borehole
- Acid diversion is important, otherwise only the first interval will be affected; accomplished by packers or plugs
- Can increase specific capacitance (= pump rate/drawdown) by several hundred percent

Over Pumping Wells or Overdraft

- Can Permanently Damage Storage and Transmission Properties of the Aquifer
- Can Cause Subsidence and Compaction of the Aquifer
- Reduces Yield of the Well Field
- Can Result in Cascading of Water and Failure of the Well

Well Pump Considerations

Types of Pumps and Uses

Turbine Pumps

- Single Stage limited to 28' lift; multi-Stage 50 – 300' lift
- Submersible low head and low flow conditions (typically <100' and 100 GPM)
- Vertical Turbine high head and high flow

Positive Displacement

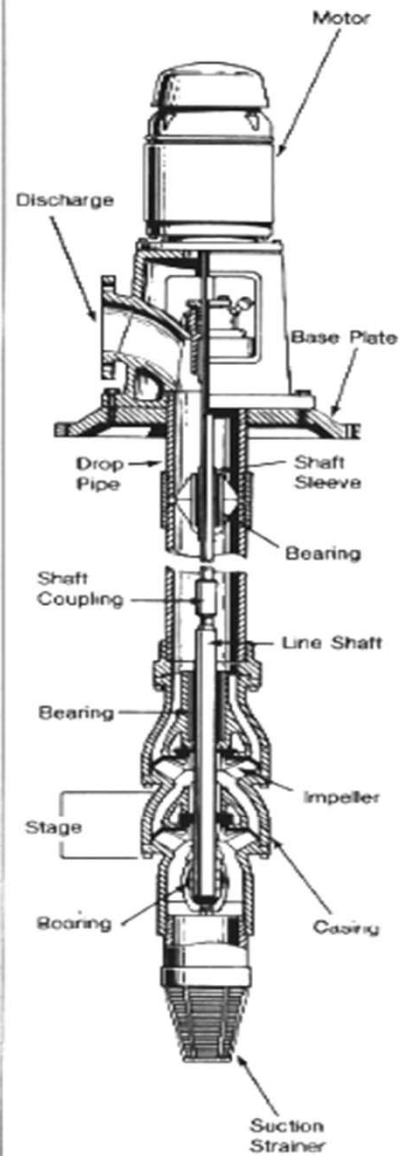
- Shallow ~25' Deep ~600'
- Limited to ~25 GPM
- High Maintenance Cost

Jet Pumps

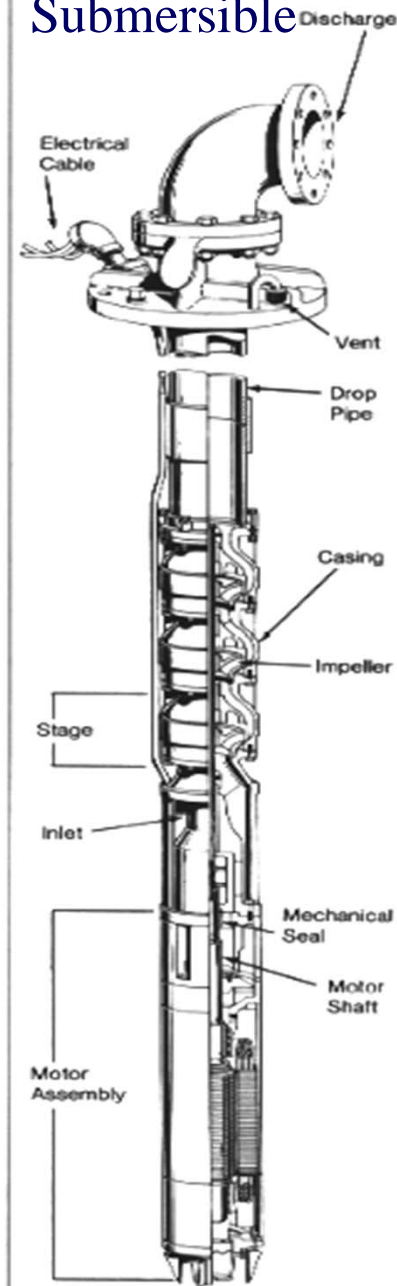
- Shallow ~20' Deep 50 - 200'
- Generally limited to small capacities < 50 GPM

Turbine Well Pumps

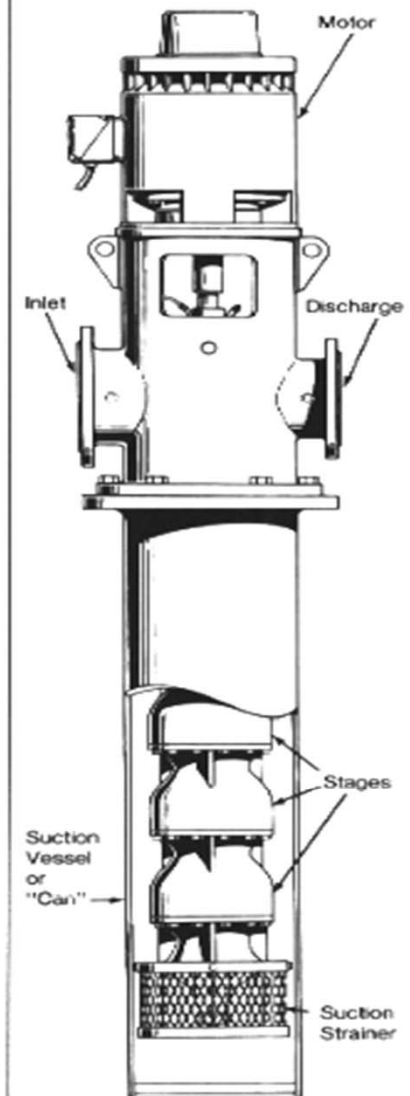
Vertical Turbine



Submersible



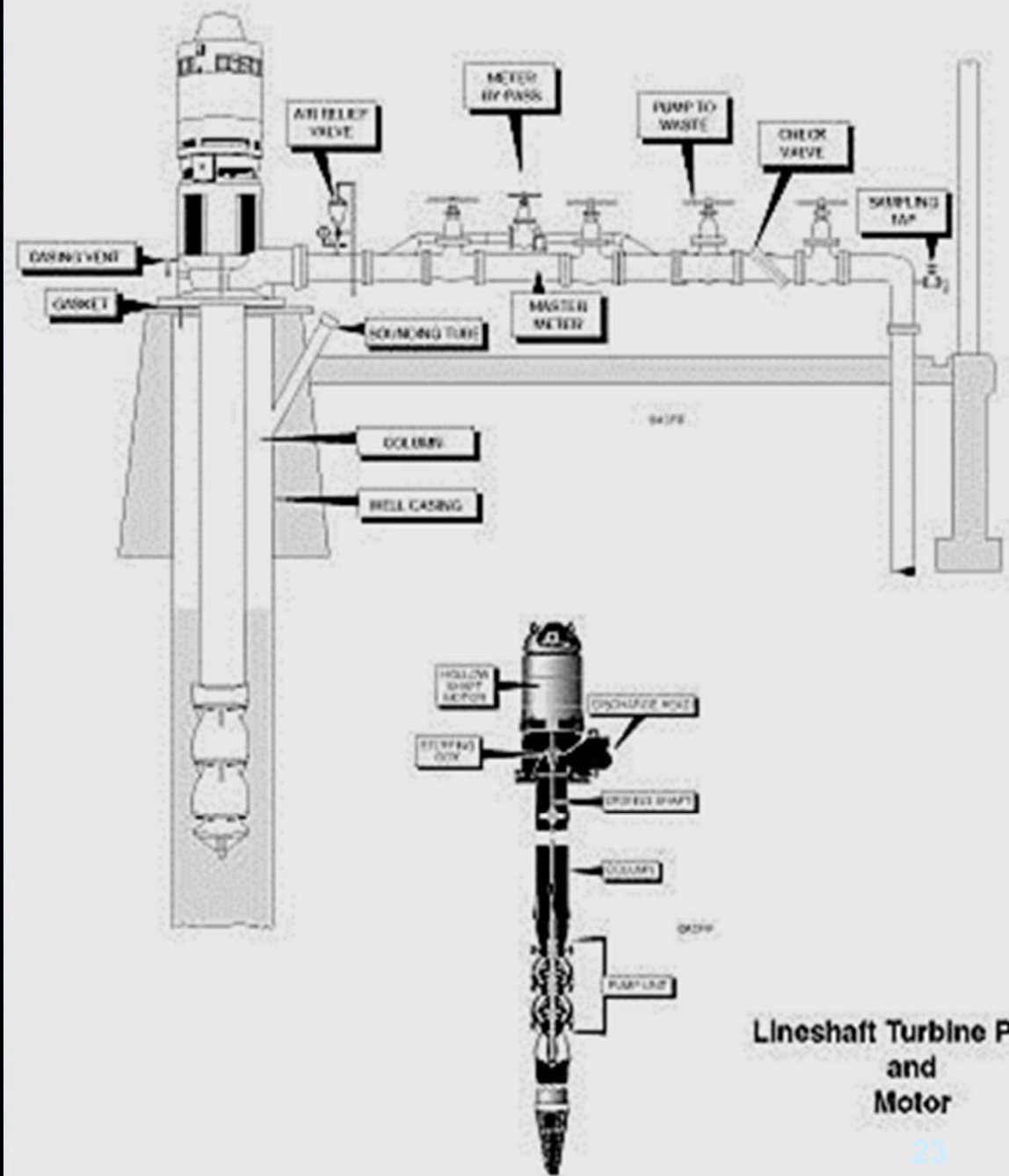
Turbine Booster



Vertical Turbine Well Pump Installation



Turbine Pump and Motor Installation

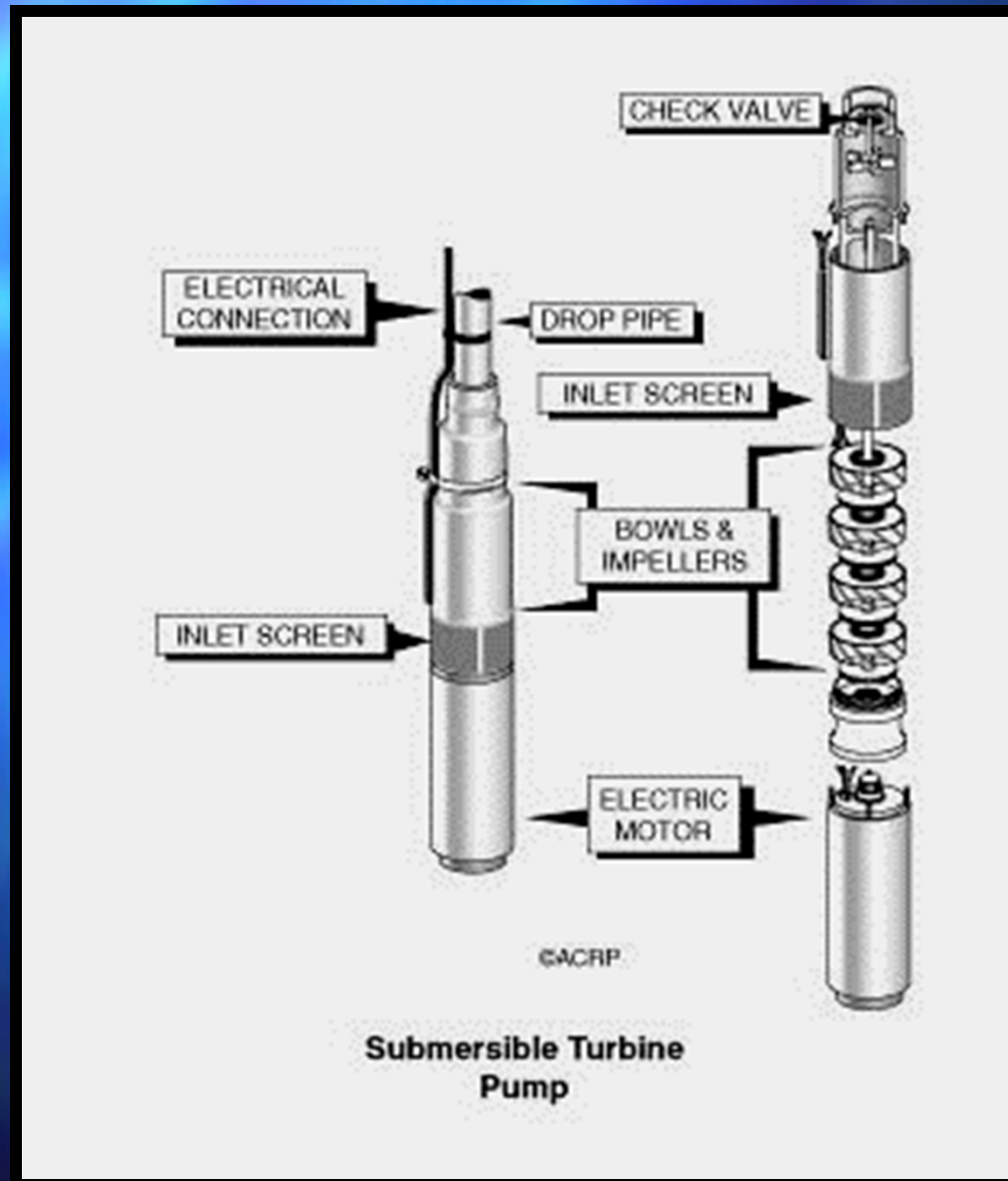


Lineshaft Turbine Pump and Motor

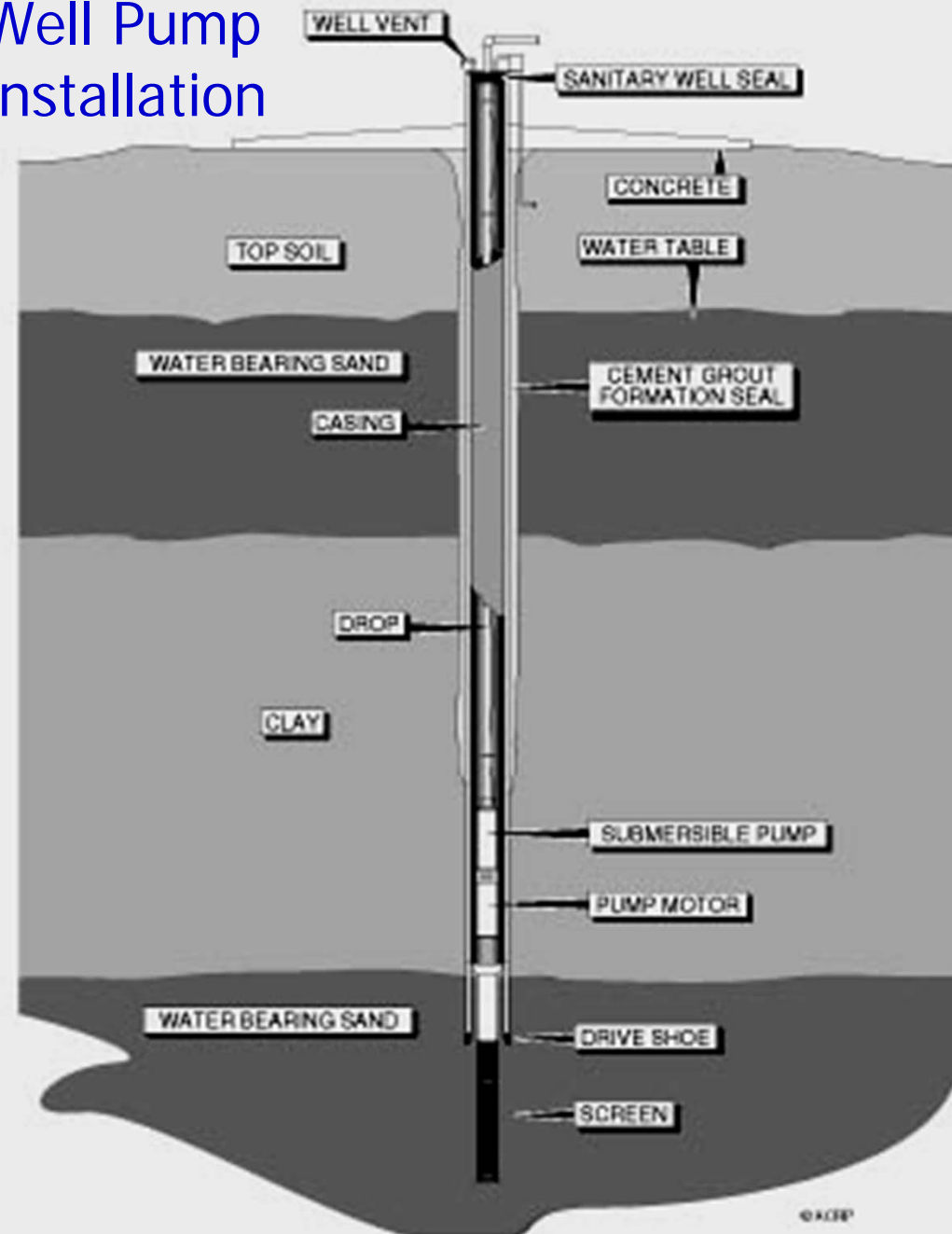
Typical Submersible Well Pump Installation



Submersible Well Pump



Submersible Well Pump Installation





Well Field Management Preventing Contamination at the Wellhead

Preventing Contamination at the Well Head

#	Observation	Likely Pathway
1	Septic tanks, broken storm or san. pipes, ponds	Through Surface Strata
2	Drainage up-hill	Surface water runoff
3	Well subject to flooding	Surface water transport of contaminants
4	Casing termination	Must be 1' and above 100 yr flood plane
5	Area around well is wet	Corroded Casing Pipe
6	Possible Abandoned wells in area	Surface water intrusion from contaminated source
7	Sanitary condition unacceptable	Contaminated water intrusion ²⁸

Preventing Contamination at the Well Head (continued)

#	Observation	Likely Pathway
8	Cracking in Well Slab	Contaminated water intrusion
9	Evidence of Algae or Mold on Slab	Birds and insects attracted by moist conditions
10	Poor Drainage	Surface water intrusion from contaminated source
11	Seal water draining into well head	Contaminated water entering borehole
12	Well Seal damaged	Contaminated water intrusion
13	Fittings pointing upward	Contaminated Water intrusion into casing
14	Well vent not properly installed	Contaminated Water intrusion into casing

Preventing Contamination at the Well Head

#	Observation	Likely Pathway
15	Check Valve absent or not working	Contaminated water back-flowing into casing
16	Cavitation or water hammer	Ck. Valve damage & water back-flowing into casing
17	Well Site Security Compromised	Contaminated Water from undesirable activities
18	Livestock or wild animals close by	Animal source of Contamination
19	Surface water evidence ID	Indicator organisms, color, temp and TOC contributing

Preventing Contamination at the Well Head

#	Observation	Likely Pathway
20	Several wells available	One well is more likely to contribute than others
21	Intermittent Well Operation	Contaminated occurring from long-term biological activity
22	Wet or extreme weather events	Contamination from run-off or from higher pumping levels.

DEP Well Setback Requirements

Minimum Setbacks

- 200 feet from septic tank if over 2000 gpd (commercial)
- 100 feet from septic tank if under 2000 gpd (residential)
- 100 feet from any sanitary hazard (pipeline)
- 300 feet from domestic wastewater residuals land application areas
- 500 feet from land application areas for reclaimed water

Water System Well Capacity Requirements

- For GWPWS serving > 350 people or 150 service connections
 - Minimum of two wells
 - Wells must meet design average daily demand with largest well out of service.
- For all GW Public Water Systems well(s) must provide capacity to meet maximum-day demand.

Water System Auxiliary Power Requirements

Community systems over 350 or more people, or 150 connections shall provide a minimum of 2 wells and auxiliary power for the operation of the systems source, treatment and pumping facilities at a rate of equal to average daily demand for the system.

- Auxiliary power shall be equipped with automatic startup unless 24 hr., 7 days per week supervision is provided.
- Auxiliary power shall be operated at least 1 per month for 4 hours under load.

Water System Wellhead Protection Requirements

- Provide wellheads with fenced & locked gate (2 hr notification to DEP for security breach).
- Provide a well site with concrete apron which is centered around well casing and is at least 6'x6'x4" and 12" above the 100 yr. flood elevation.
- Provide a flow meter for the measurement of treated water.
- Provide a check valve on the discharge line of the pump between the raw tap and chlorinator.
- No hazardous materials can be stored on-site.

Wellhead Protection

- Obtain Community Involvement
- Collect existing data, i.e. geology, hydrology, locations of underground storage tanks, septic tanks,
- Collect additional data and conduct surveys of the well head area
- Determine what land uses present a threat to groundwater quality
- Analyze the data and hydrogeology
- Test for contaminants
- Set well head protection zones from certain activities
- Obtain public support and implement new well head protection regulations