# California Department of Public Health Webcast

Evaluation and Design of Small Water Systems

## Membrane Filtration

Dale Newkirk, P.E.

# Lecture Objectives

- Learn about and compare the various kinds of membrane filtration systems
- Learn the important characteristics and design aspects of each membrane filtration system

# A Membrane is a film

- A semi-permeable membrane is a VERY THIN film that allows some types of matter to pass through while leaving others behind.

# Benefits of Membrane Filtration

- Flexible – modular membrane system
- Cost Effective – simple apparatus
- Performance – high selectivity & removal even at low pollutant concentration
- No Production of Secondary Pollutants
- Applicable to a Wide Range of Feed Characteristics
- Easy to operate
- No coagulant chemicals

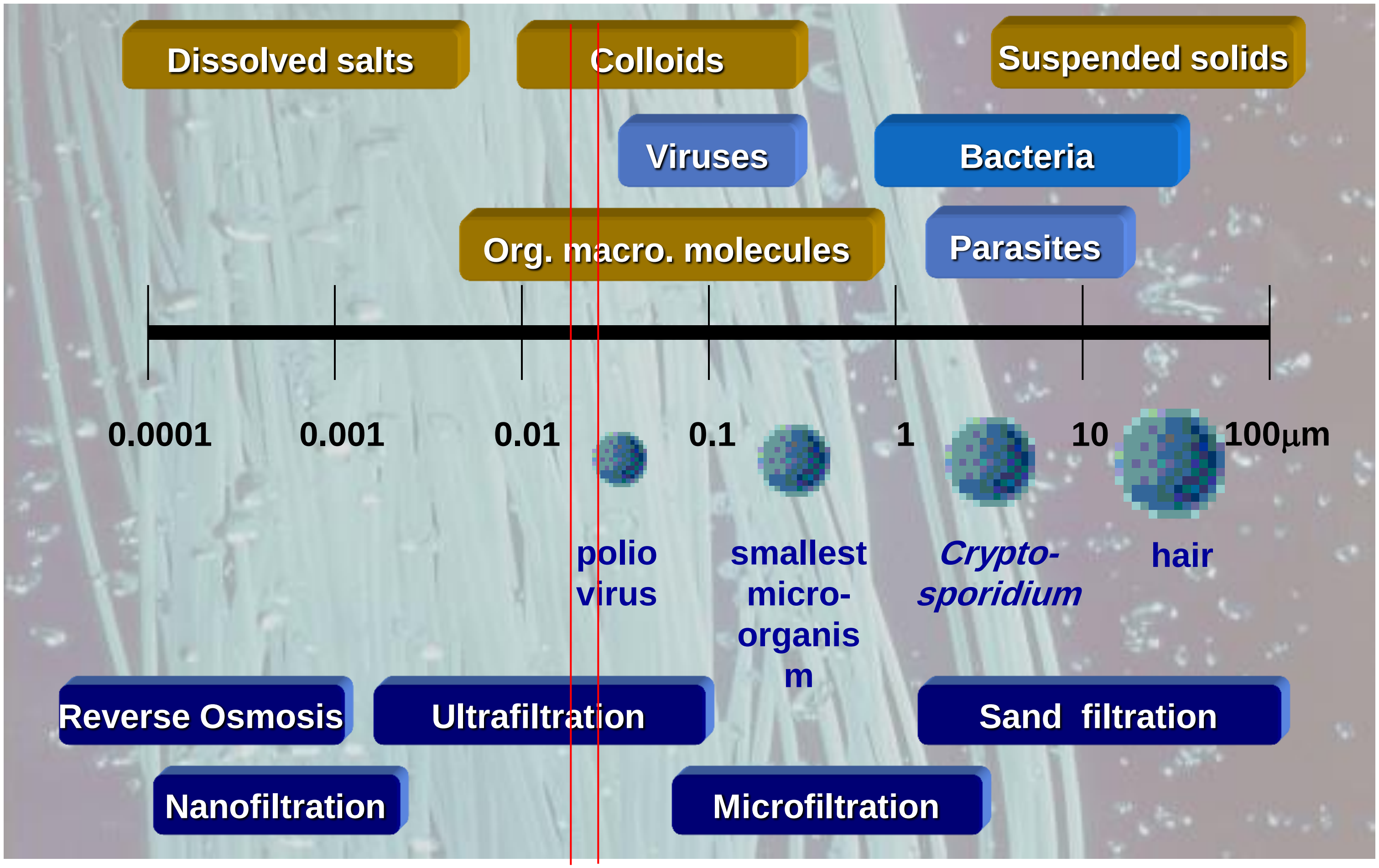
# Membrane Technology in Water Treatment

- Pressure driven – usually osmotic in nature
- Polymeric membranes
- Cross-flow and dead end schemes
- High efficiency removal of particles, colloids, organic precursors of DBPs, microorganisms, hardness and salts

# Membrane Types

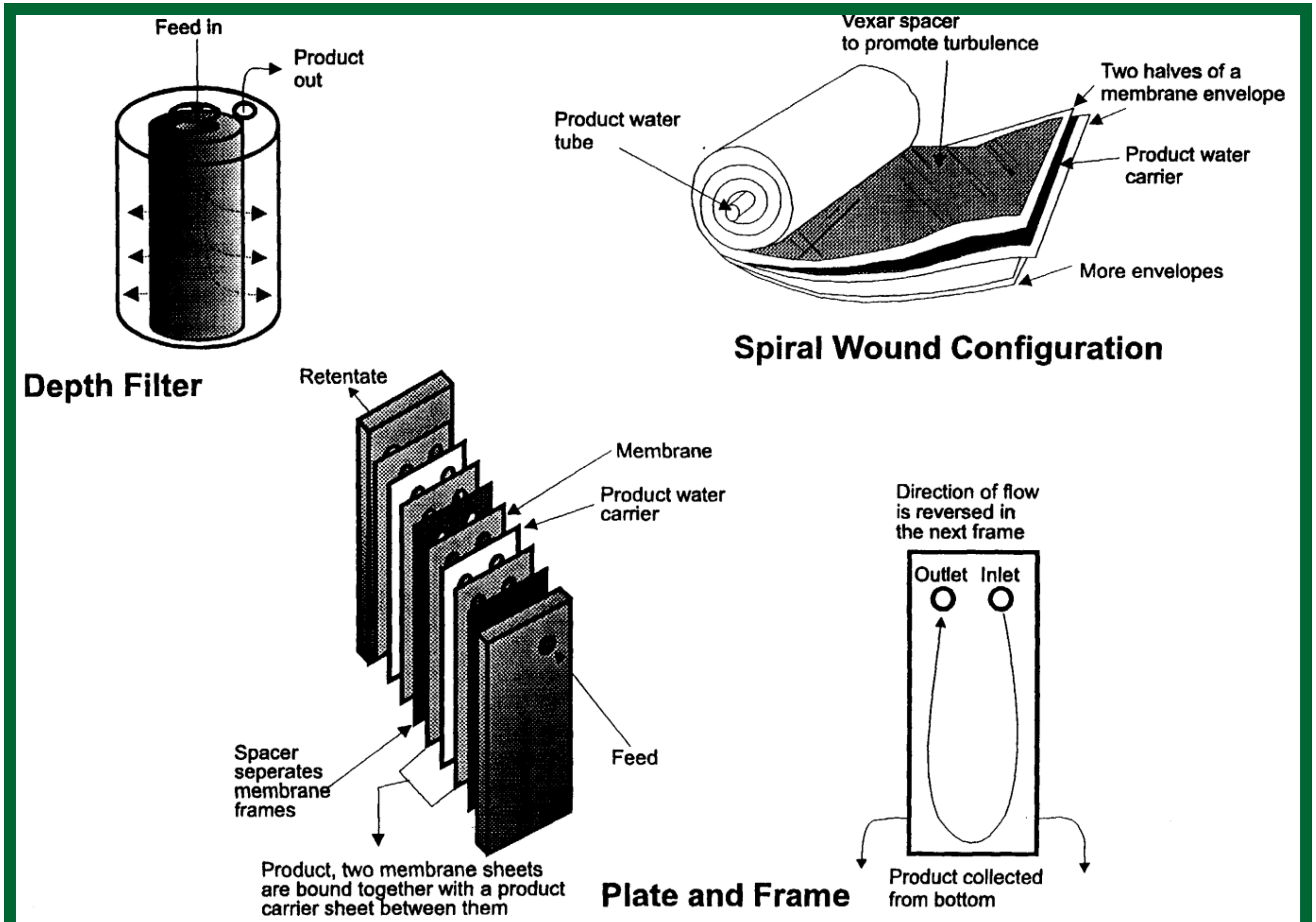
| | ED | MF | UF | NF | RO |
|---|---|---|---|---|---|
| **Retained** | Water, TSS, microbes uncharged molecules | Larger particles | Larger molecules | Higher charged ions | Most everything |
| **Transported** | Dissolved salts | Dissolved salts, small particles | Small molecules and ions | Mono-valent ions, small molecules | Very small uncharged molecules |
| **Productivity (gfd)** | Practically None | 20-100k | 10-20 | 25 | 20 |

# UF Membranes for Water Treatment

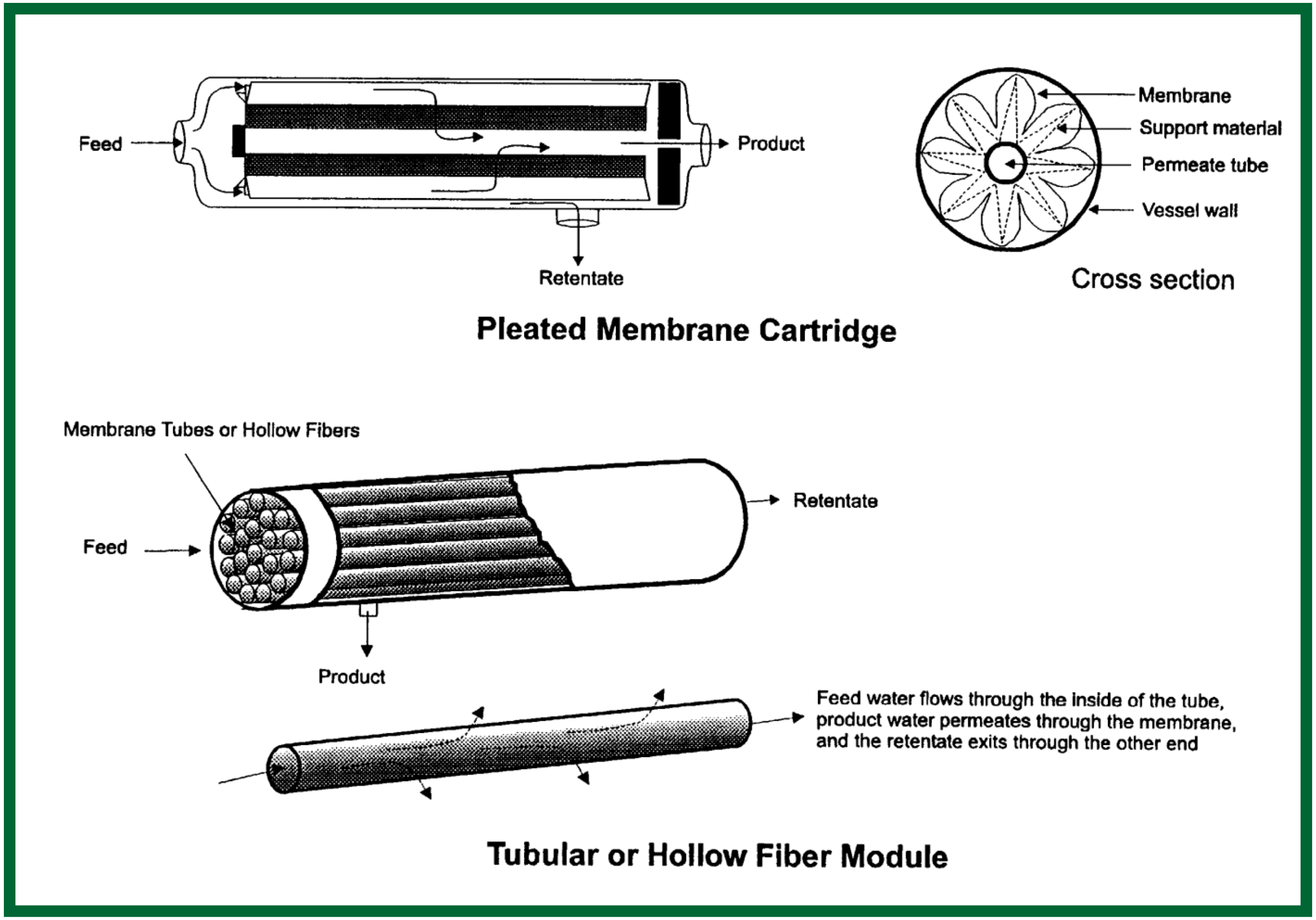



**ZW1000: 0.02 um** **ZW500: 0.04 um**

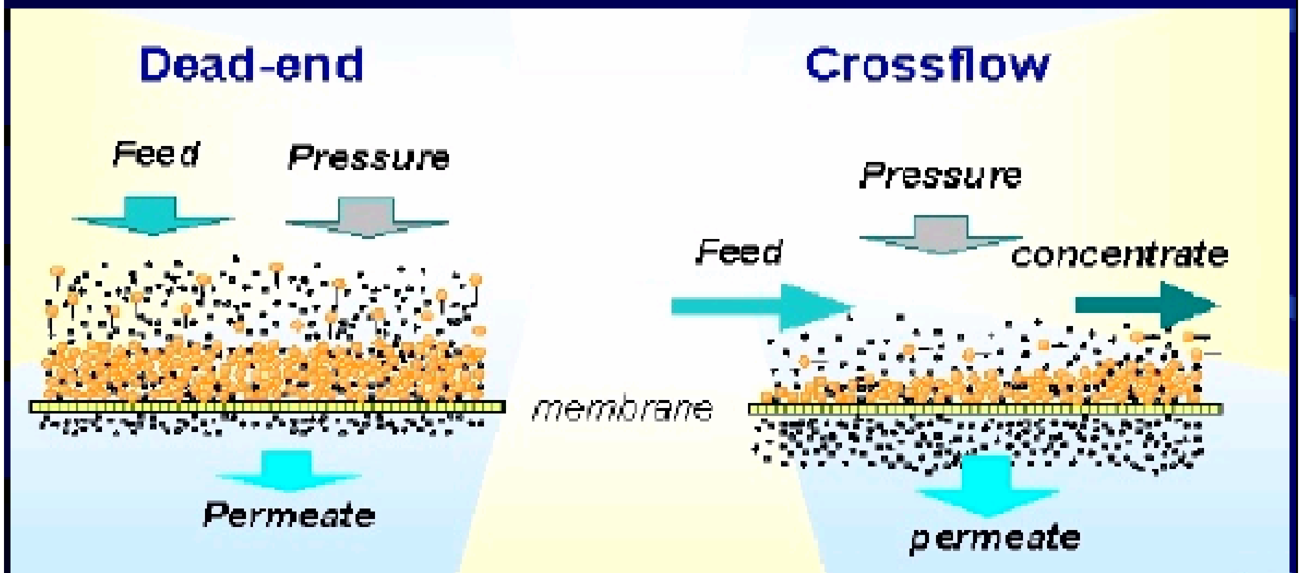
# Membrane Configurations



# More Membrane Configurations



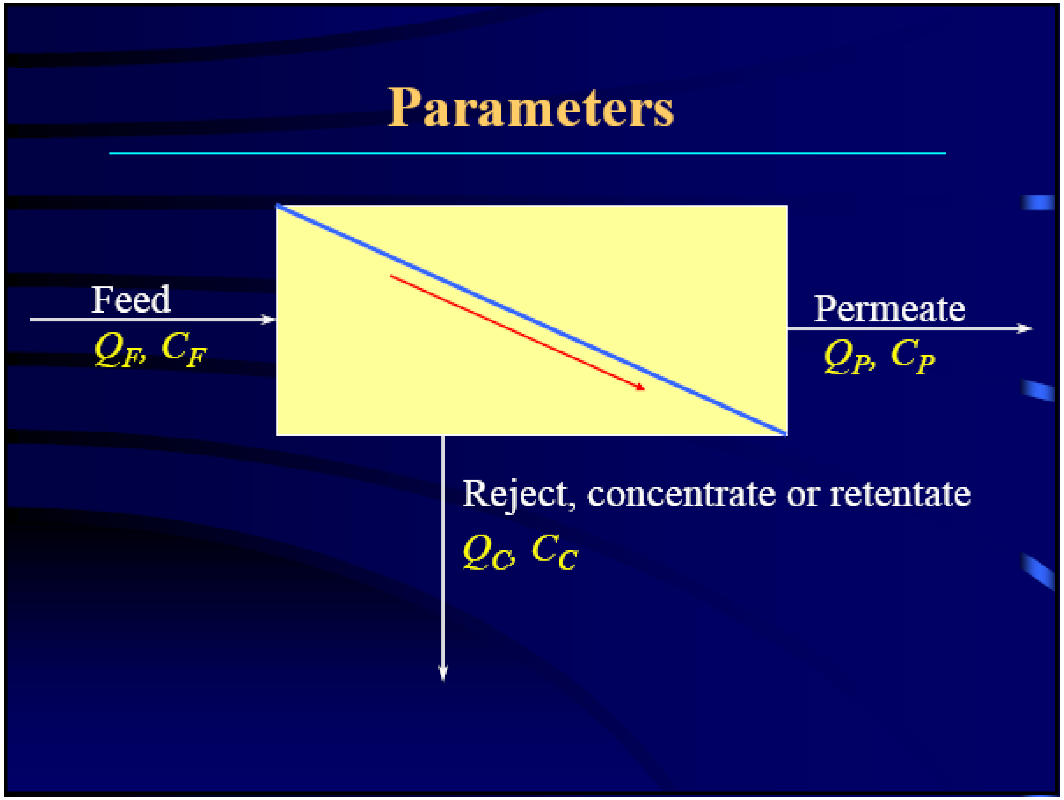
# Dead End vs. Cross Flow Membrane Filtration



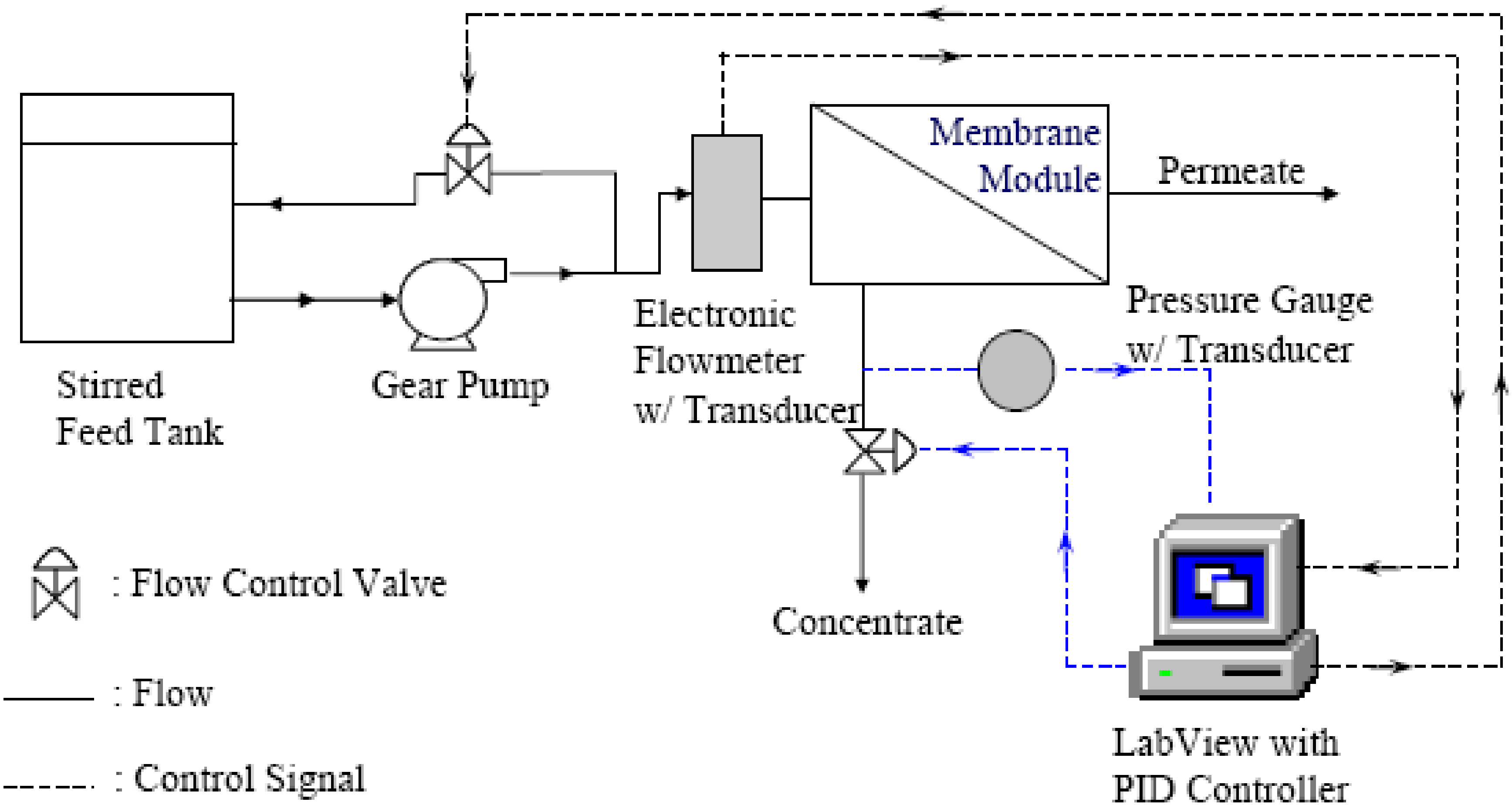

<u>Traditional (dead-end)</u>
Feed flows perpendicularly to filter media, leading to the accumulation of substrates.

<u>Membrane (cross-flow)</u>
Feed splits into concentrate (rejected) and permeate (filtrate) streams, reducing the accumulation of substrates.

# Membrane Parameters



# Typical Schematic



# Parameters in Membrane Filtration

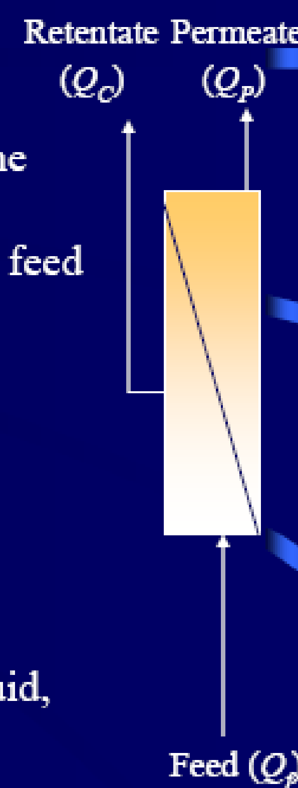
- **Feed Water Recovery** is a ratio of product water to feed water.

$$R_f = \frac{Q_P}{Q_F}$$

- **Flux** is the number of moles/volume/mass of a specified component passing per unit time through a unit of membrane surface area.
- **Solute Rejection** is the amount of solutes removed from the feed water.

$$R = \frac{C_F - C_P}{C_F}$$

- **Applied Pressure** ($\Delta P$) is the amount of pressure used for filtration by the membrane.
- **Cross-Flow Velocity** is the ratio of feed flow rate to cross-sectional area of the membrane (shearing velocity)
- **Permeability** is the passage or diffusion of a gas, vapor, liquid, or solid through a barrier without physically or chemically affecting it. (K)



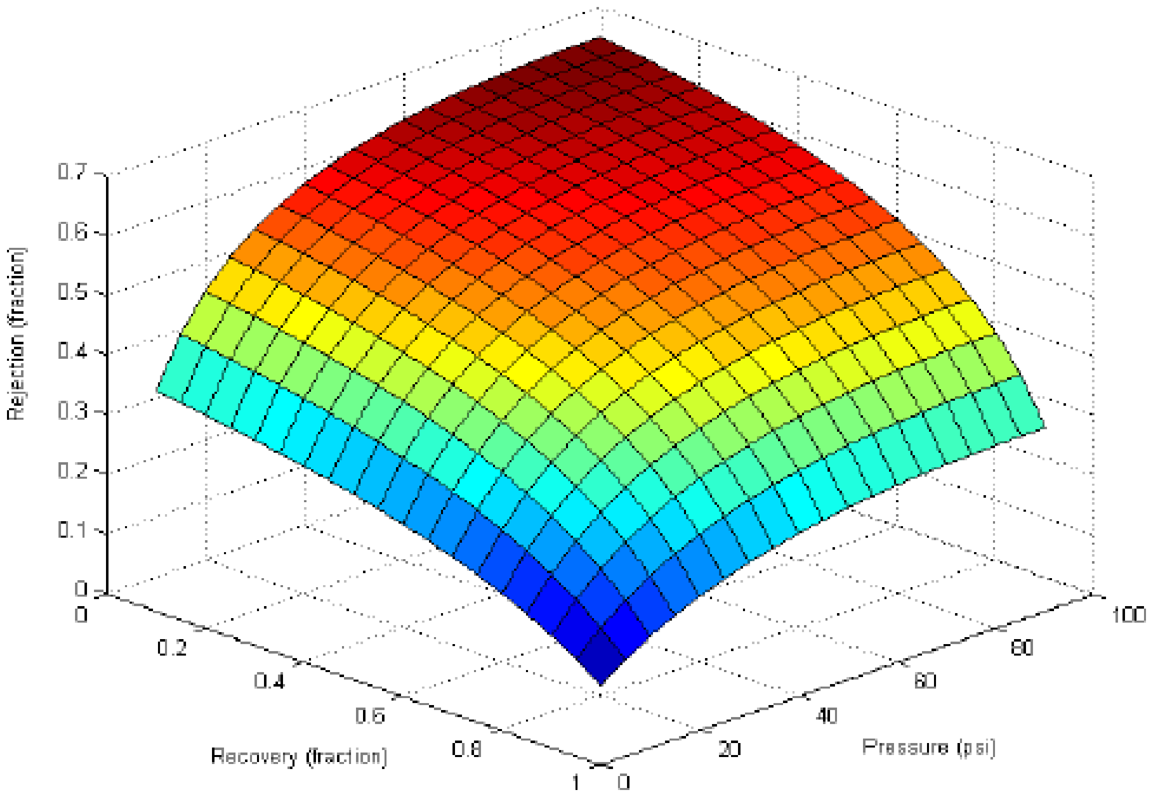
# Flux

## Transport Equation

$$Flux(J) = \frac{Q_P}{A} = K(\Delta P - \Delta \Pi)$$

$A$ = membrane area ($m^2$)
$Q_P$ = permeate production ($m^3/s$)
$K$ = permeability ($m^3/m^2$-s-Pa)
$\Delta P$ = applied pressure across membrane (Pa)
$\Delta \Pi$ = osmotic pressure difference across membrane (Pa)

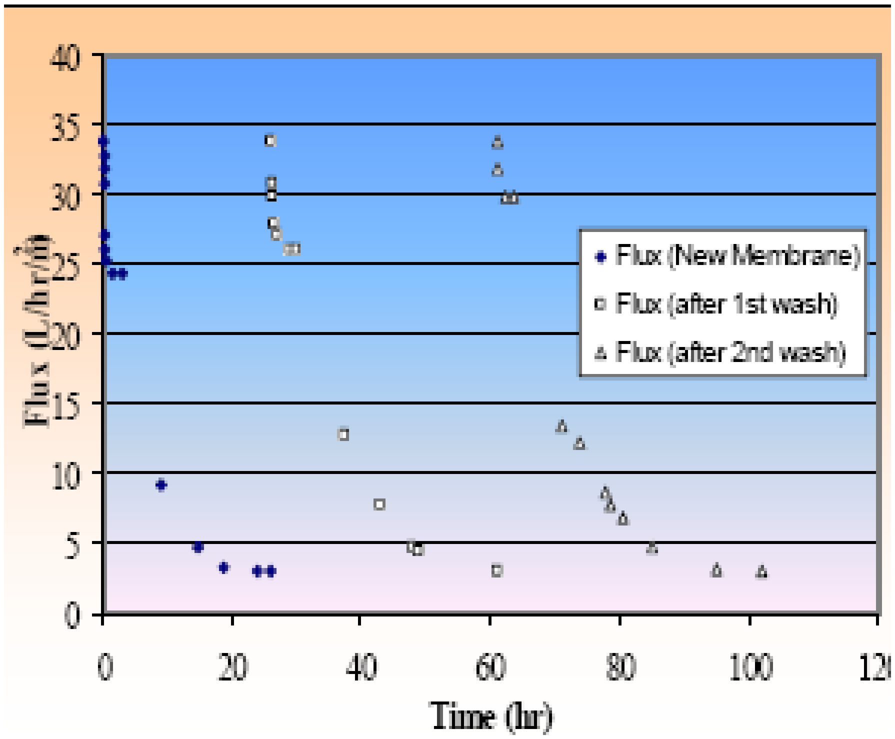
# Rejection/Recovery/Applied Pressure



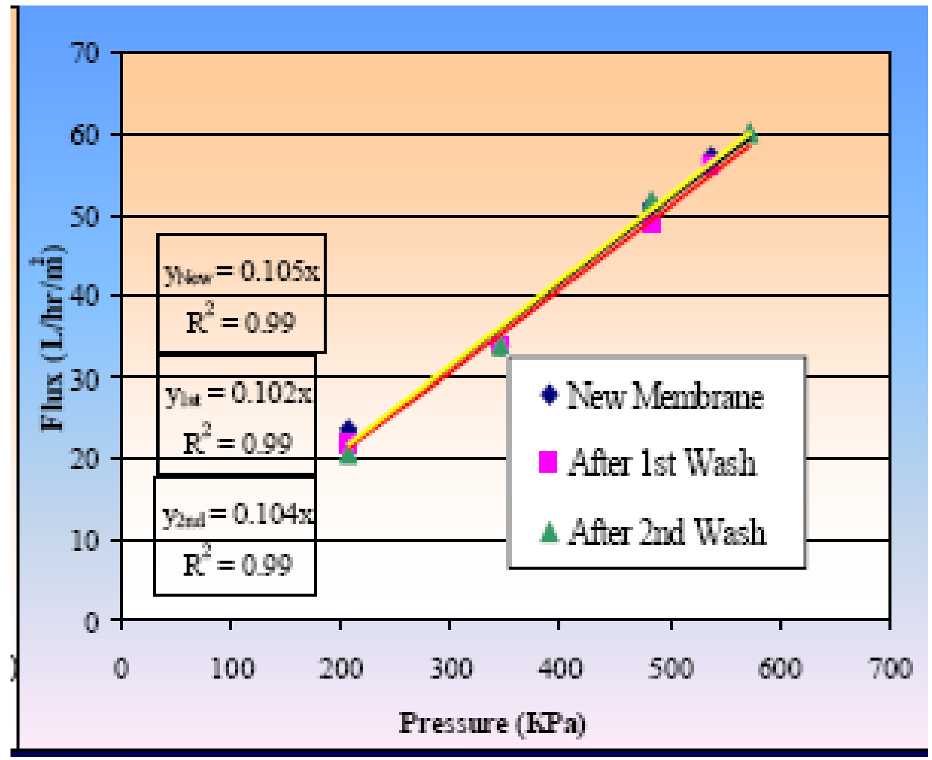
# Membrane Fouling

- Physical/chemical/biological plugging of membranes by inorganic salts, dissolved organic matters, colloids, bacteria, etc.
- Affects permeate water quality
- Increases operational burden and cost
- Reduces permeate water flux
- Reduces feed water recovery
- Damages membranes

# Filtration Cycles

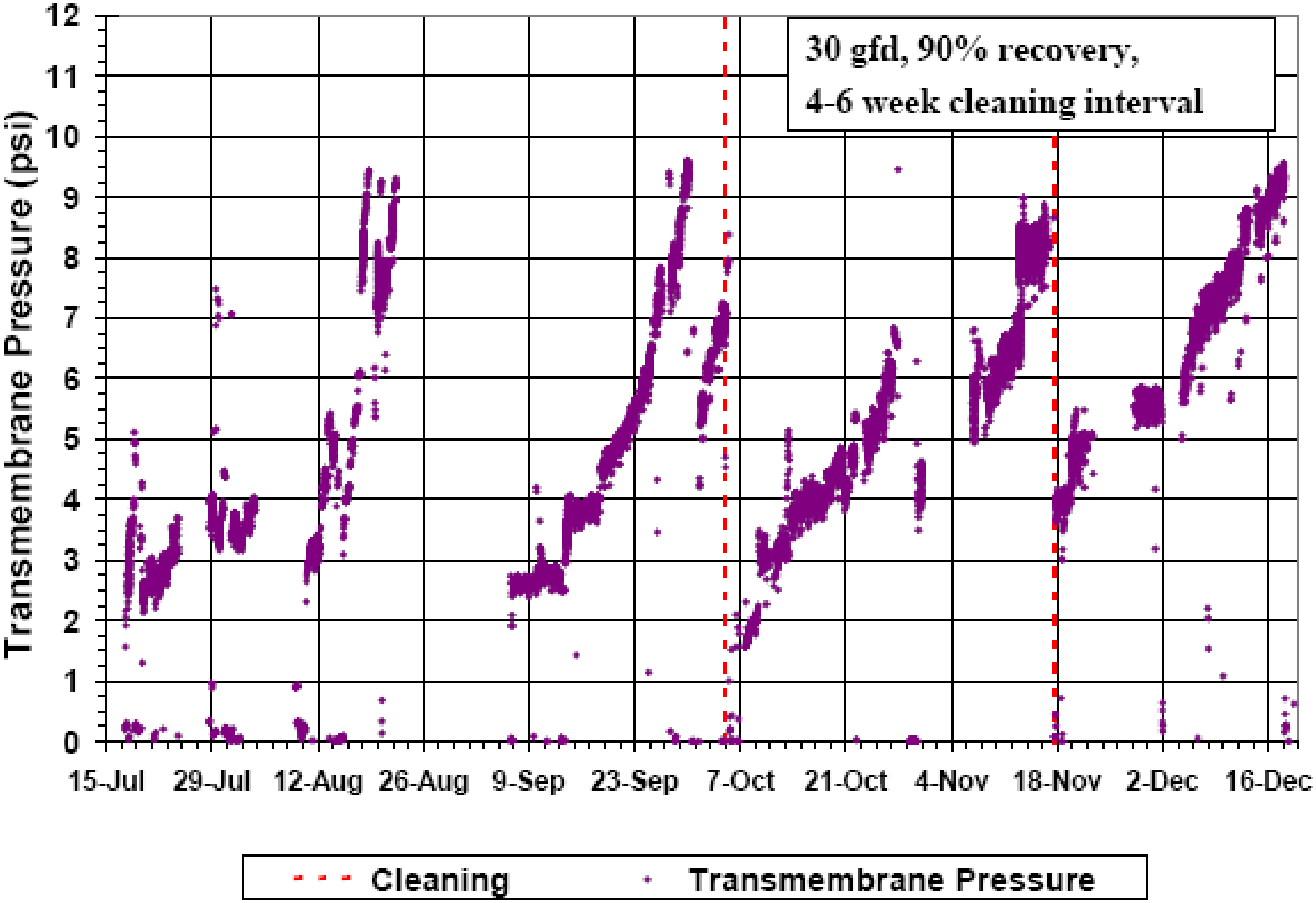



Filtration cycles




Membrane performance after back wash

# Arizona Pilot: Membrane Performance

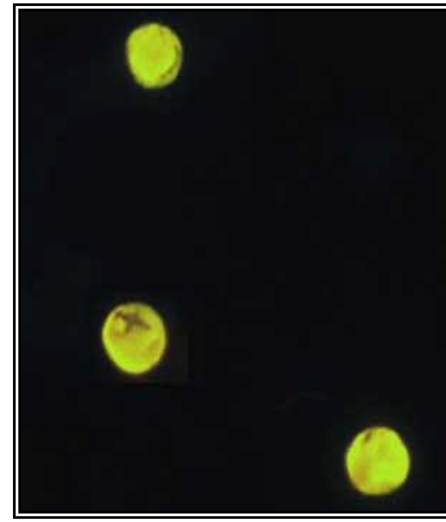


# Immersed Membrane Technology

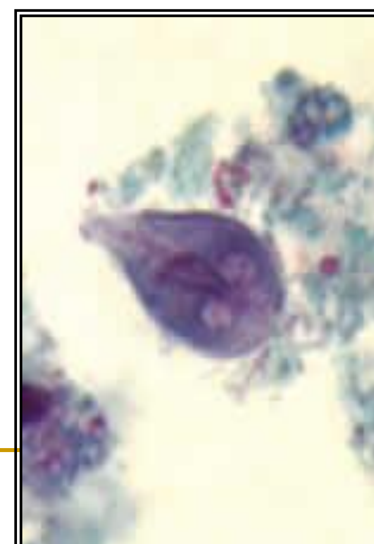
- First introduced immersed hollow fiber (HF) membrane technology in 1990
- Hollow strands of porous plastic fibers with billions of microscopic pores on the surface
- Pores form a physical barrier to impurities but allow pure water molecules to pass
- Clean water is collected inside of the hollow fiber

# UF Pathogen Removal – Size Exclusion

- Parasites are removed by size exclusion (>0.1 um), not inactivation
- California Department of Health Services Testing
  - > 9 log removal of *Giardia*
  - > 9 log removal of *Cryptosporidium*
  - >2 log removal of *MS2* virus
- Automated membrane integrity monitoring confirms LR > 4.0 log (99.99%) on a daily basis



*Cryptosporidium* Parvum (4-7μm)



*Giardia* Lamblia (10-12 μm)

**ZeeWeed® 500**

*Reinforced Membranes™*

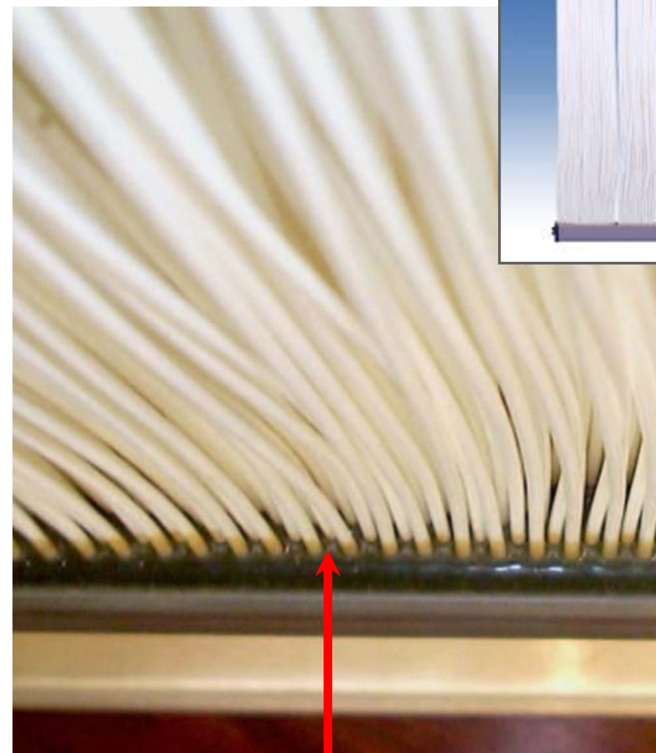
**ZeeWeed® 1000**

*Membrane Filter ™*

# ZeeWeed® 500 System

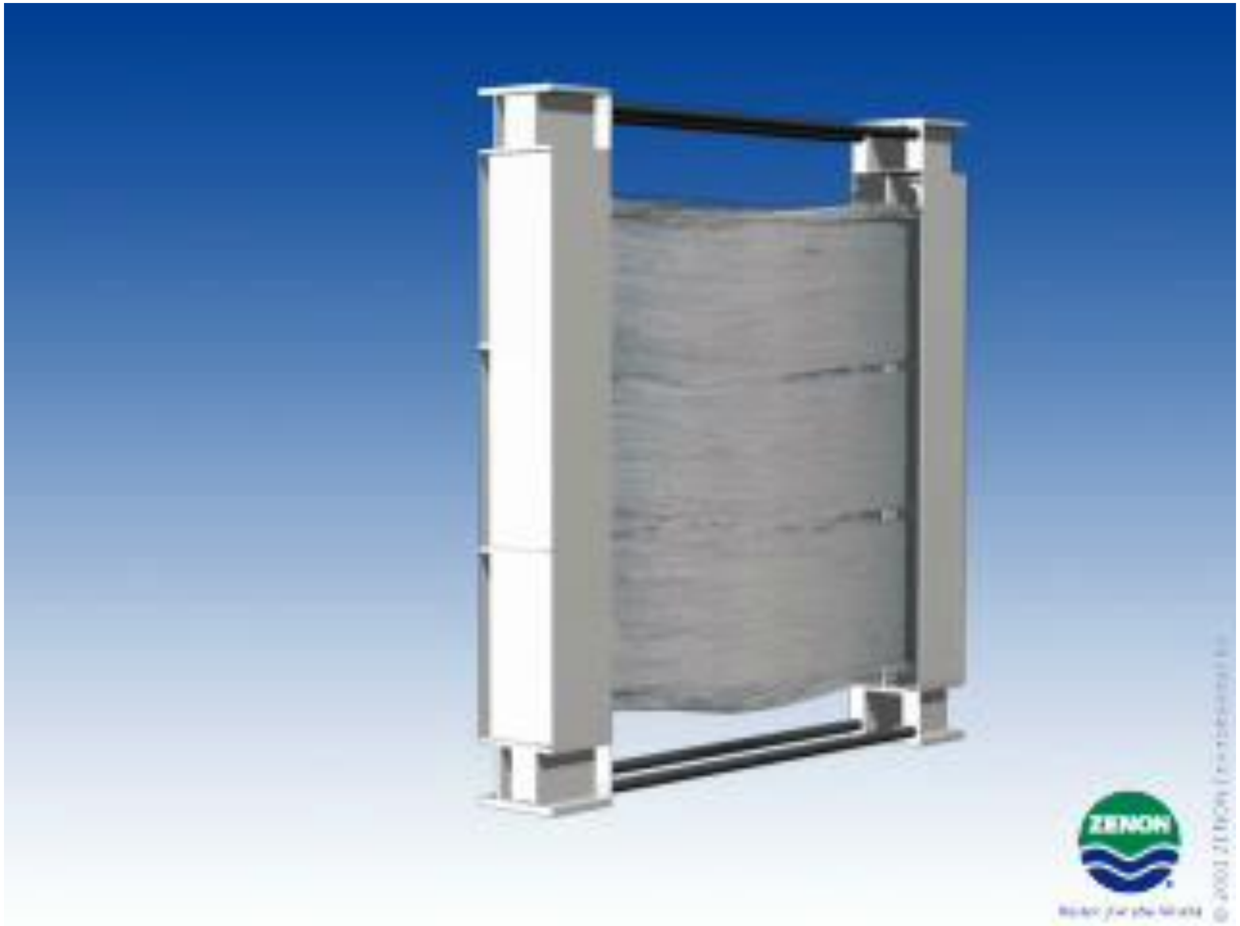
# ZeeWeed® 500 – Precision Fiber Placement

- High solids tolerance
  - Routine operation in drinking water up to 5,000 mg/L
- Proven design details
  - Efficient aeration minimizes resistance of cake layer
  - Spacing between modules and fibers eliminates bridging and solids accumulation
  - Optimum fiber slack prevents solids build-up

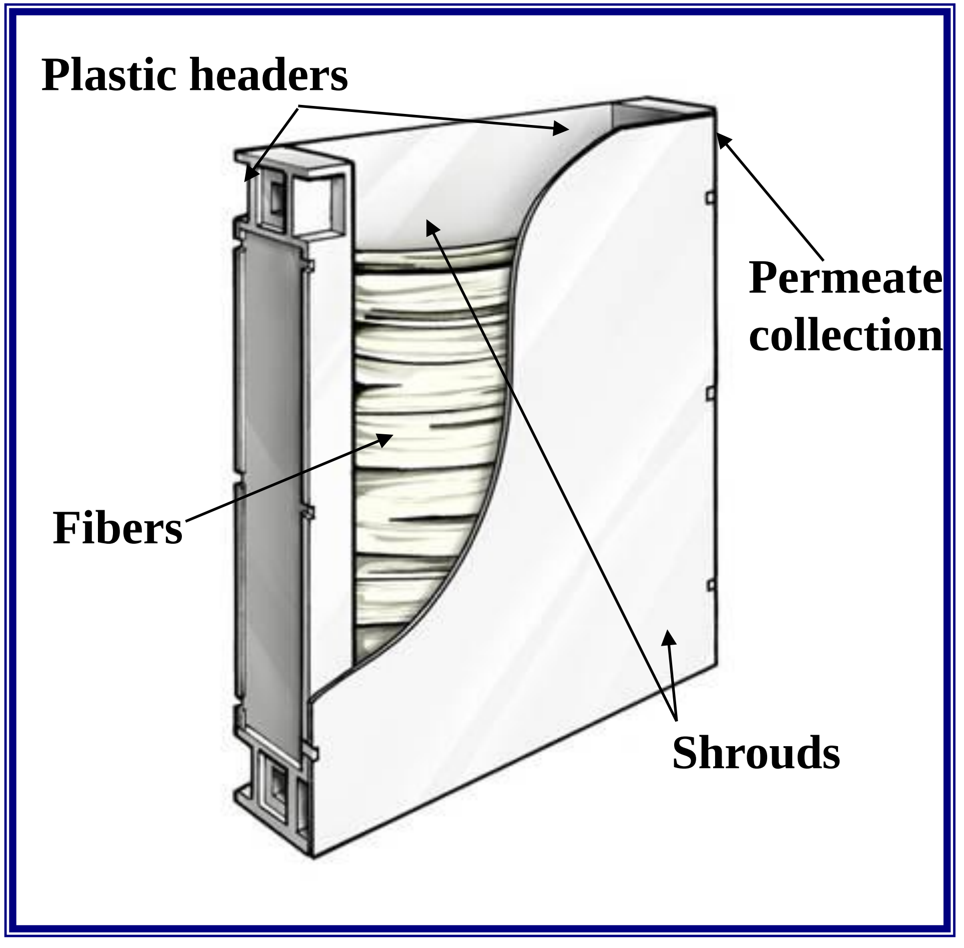


**Defined spatial distribution of fibers**

# ZeeWeed® 1000 System



# ZeeWeed® 1000 Module



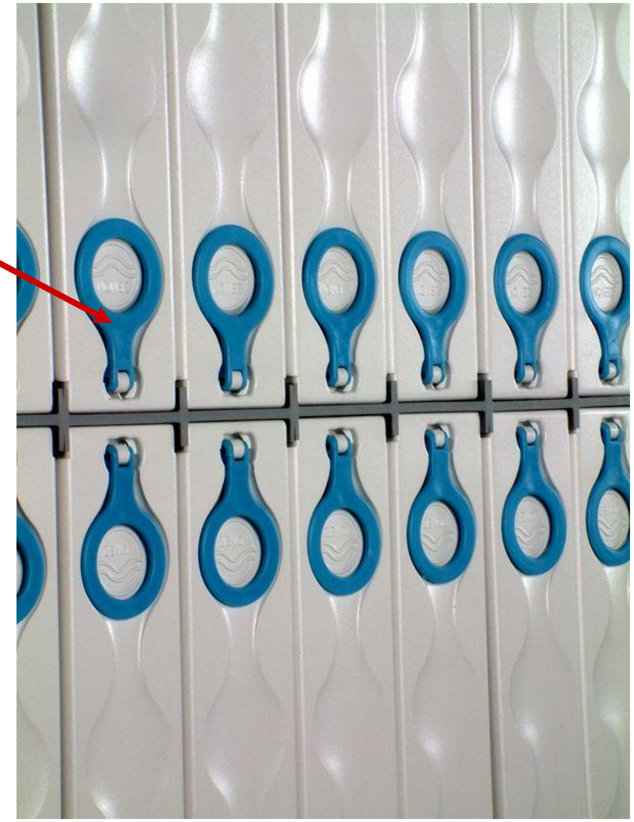

- Module = basic building block; smallest replaceable unit of a ZeeWeed® 1000 filtration system
- Horizontally-oriented hollow fibers between vertical plastic headers and enclosed in shrouds to create a vertical upwards flow channel
- 500 $ft^2$
- Easily handled by an individual

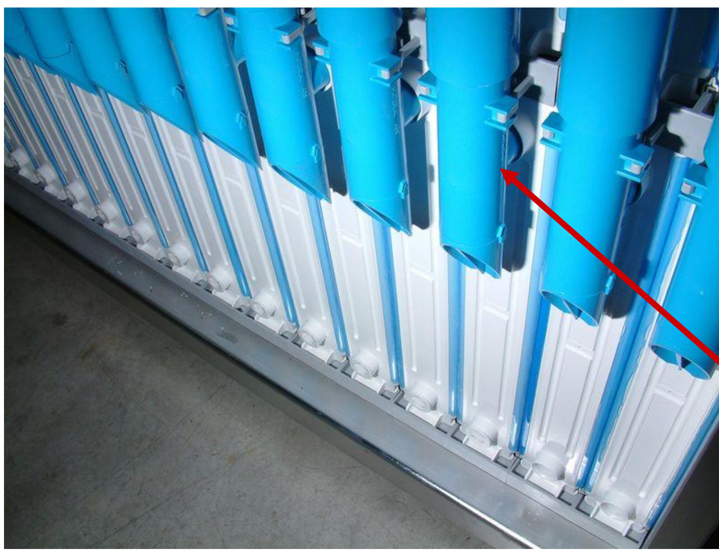
# ZeeWeed® 1000 Cassette

- 60 module standard cassette
- Optional 96 module cassette (>40 MGD facilities)
- Easy insertion and removal of elements
- Unit-body frame construction
- Hinged Straub permeate connector
- Can be operated in tank drain or overflow de-concentration modes (tank drain mode is the standard)

# ZW1000 Features

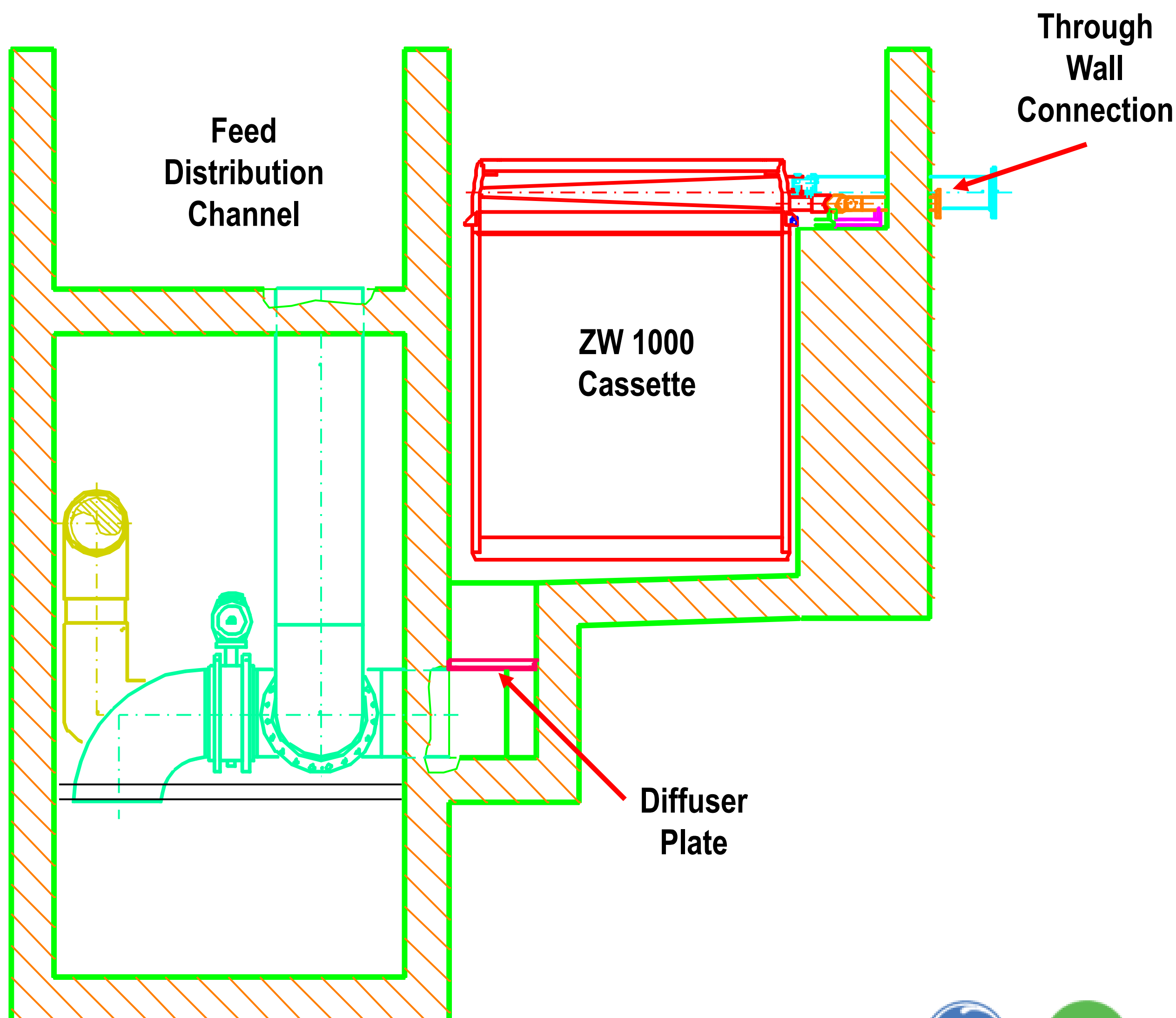
**Module Removal Handles**





**50 mm (2 in. ) Permeate Collection Pipe**

# ZW1000 V3 System

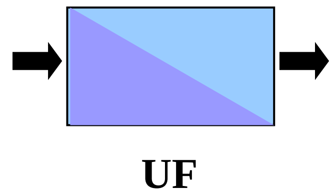


# ZW1000 V3 Application

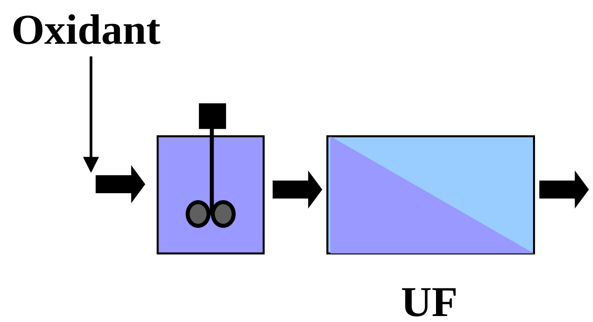
- PACl: 50 mg/L (as product)
- Alum/Ferric: < 20 mg/L
- PAC: 50 mg/L
- $KMnO_4$: ~3-4 mg/L dose
- Turbidity: 50 NTU average, Peak: 200 NTU (less with coagulant addition)
- Secondary Effluent: 25 mg/L TSS

# Treatment Options

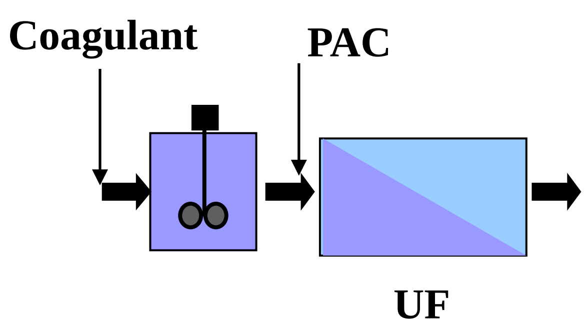
**Turbidity and Pathogen Removal**



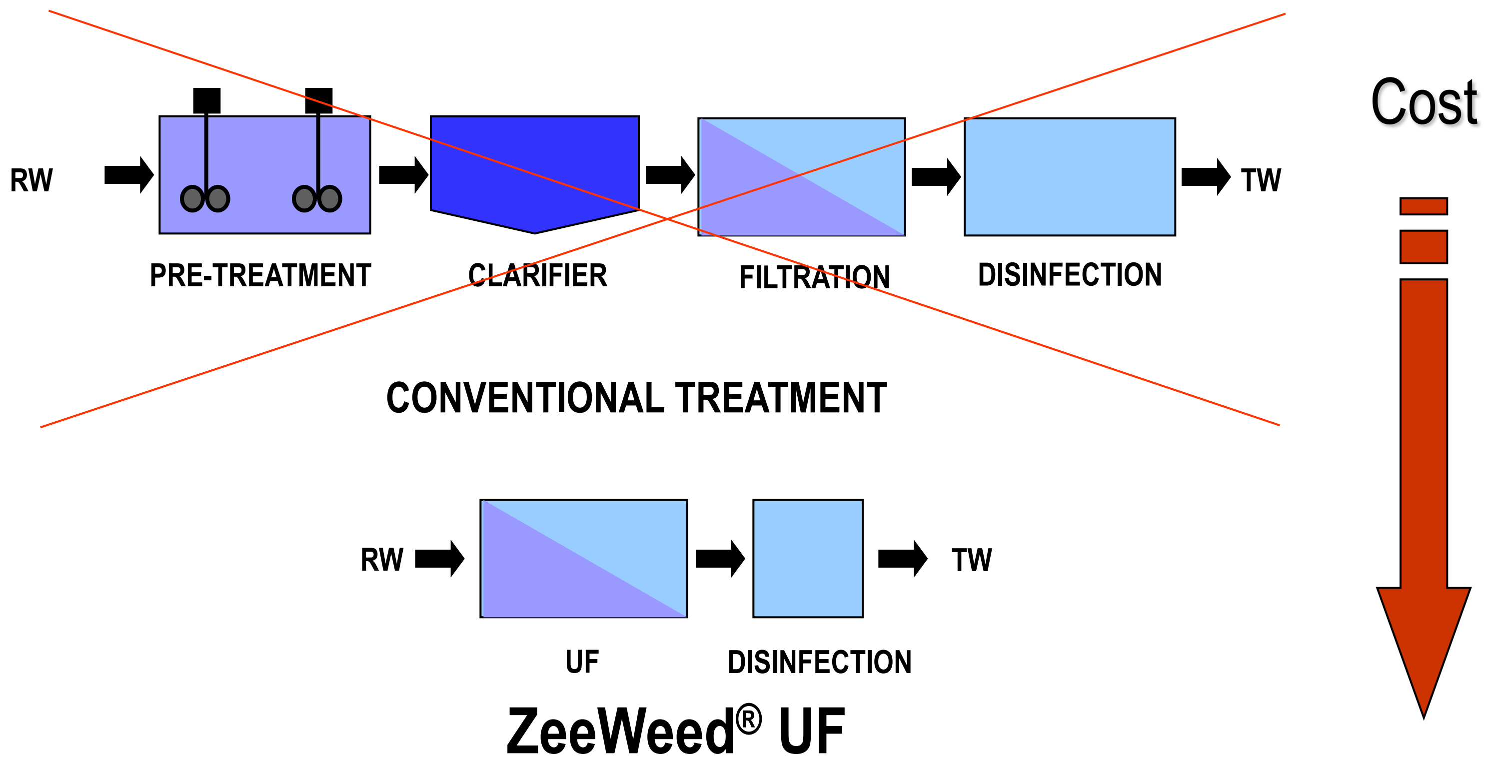

**Fe & Mn Removal**



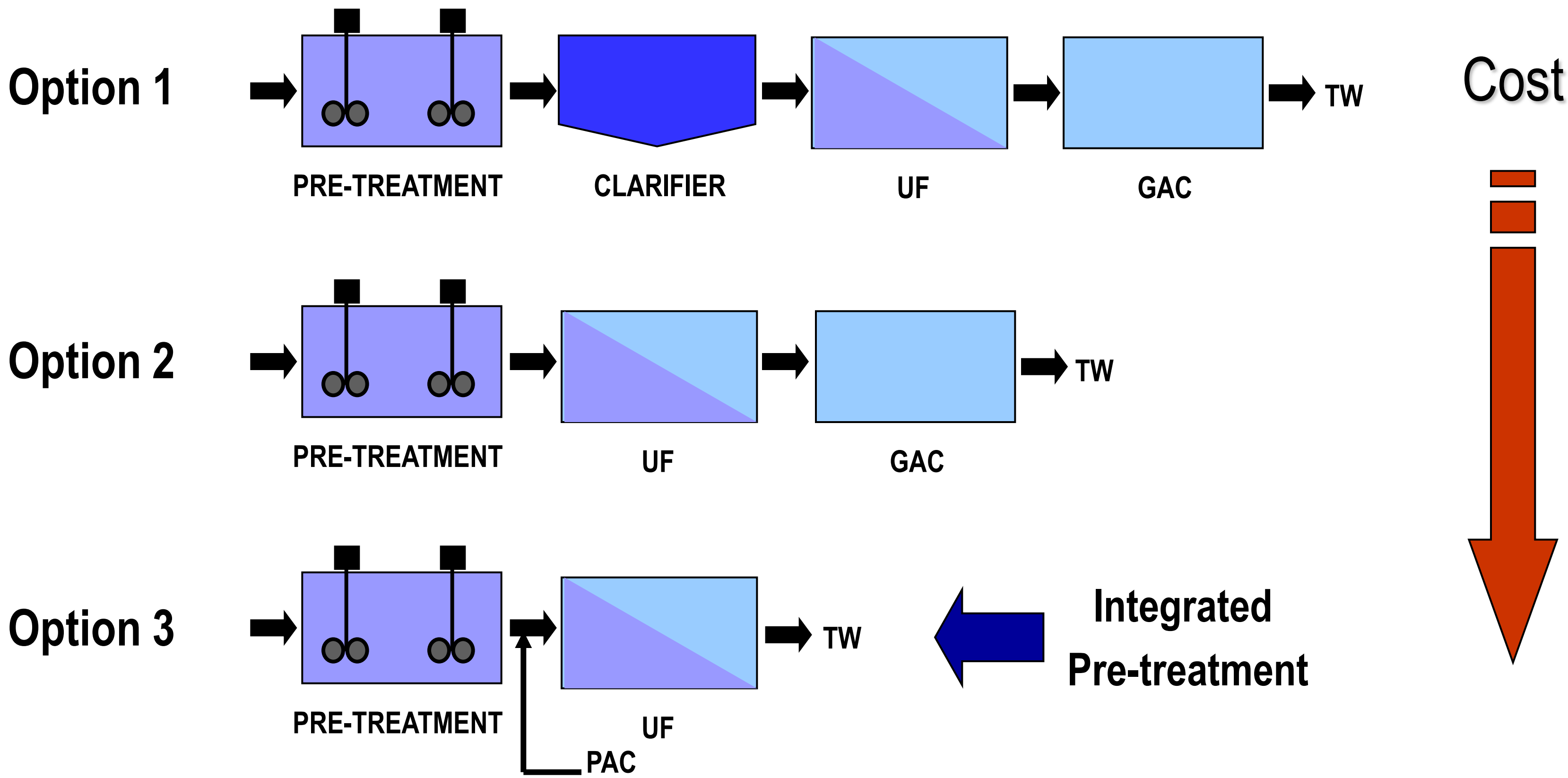

**TOC, T&O Removal**



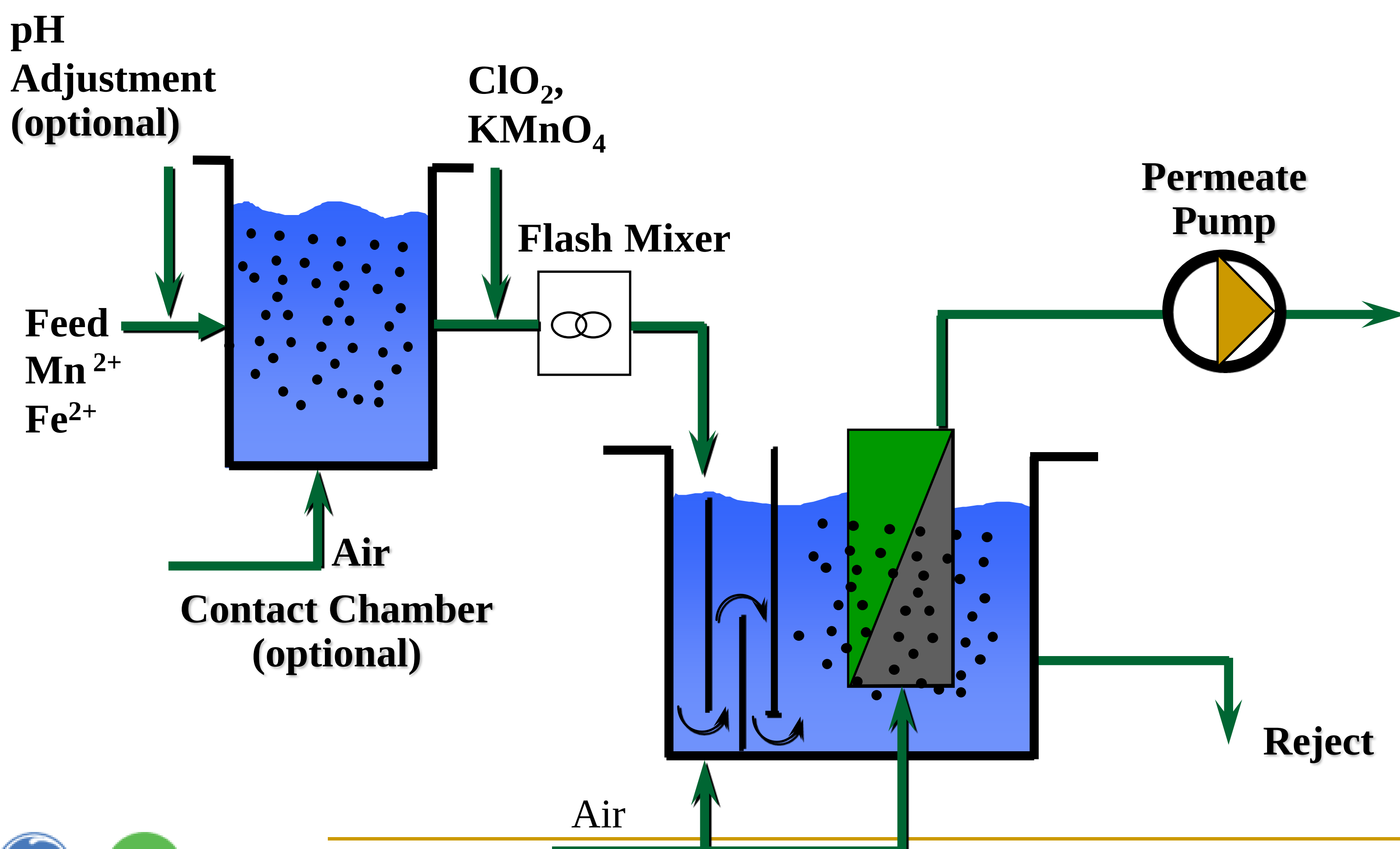
# Turbidity Removal



# Unit Process Order for NOM Removal



# Iron & Manganese Removal



# Indirect Integrity Verification with ZeeWeed

- Turbidity Monitoring (Hach 1720D)
  - One per train
  - Combined permeate

- Particle Counting
  - One Particle Counter per process train
  - Online (24 hrs/day): allowing maintained plant operation
  - PLC controlled monitoring and alarm capability
  - Reportable data collection

# ZW500 Testing

- NSF 61 Certified Ultrafilter
- NSF ETV (3 Studies)
- CDHS Testing
  - > 9 log removal of *Giardia* and *Cryptosporidium*
  - 2.5 to 4.5 log removal of virus

# Log Removal Guarantee Values for ZW500

| Pathogen | ZW1000 |
|---|---|
| *Cryptosporidium* | >4 |
| *Giardia* | >4 |
| Viruses | >2 |

# ZW1000 Testing

- NSF 61 Certified Ultrafilter
- CDHS Testing
  - Viruses 3.8 – 5.5 log

# Log Removal Guarantee Values for ZW1000

| Pathogen | ZW1000 |
|---|---|
| *Cryptosporidium* | >4 |
| *Giardia* | >4 |
| Viruses | >3.5* |

*** 4 log virus rejection available**

# Forward Pressure Type

PALL Pall Corporation

- Suspended Solids/Turbidity
- Viruses
- Bacteria
- Cysts and Oocysts
- Iron and Manganese
- Arsenic
- Organics

# AP System

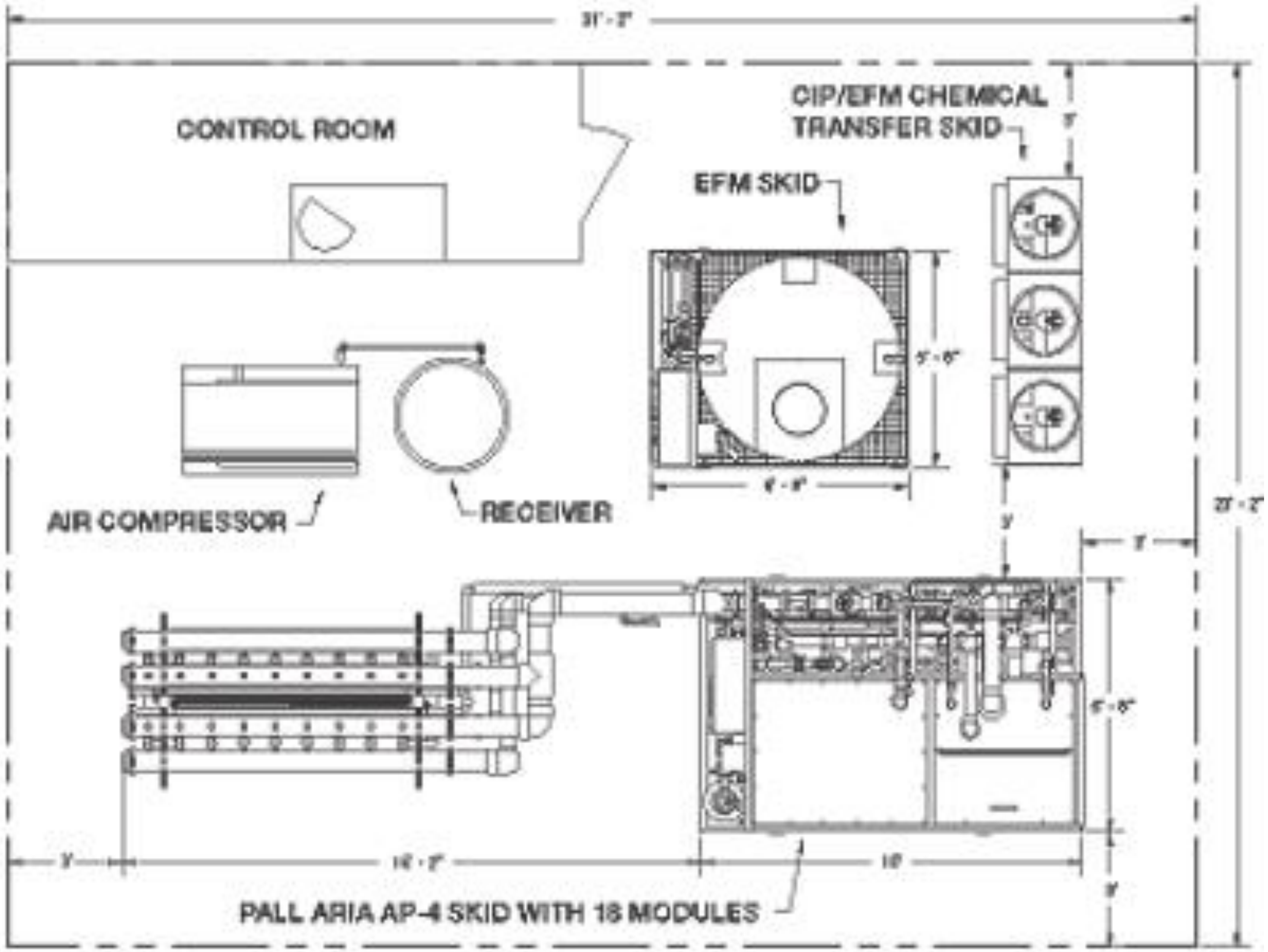
- Tough, long-service hollow fiber membranes
- Operator friendly controls
- Simple surface water treatment without coagulation
- Unique air scrub and flush operation
- High efficiency, low waste
- Excellent compatibility with chlorine and common treatment chemicals
- Minimal cost of operation
- Easy installation using modular skids
- Compact system footprint
- Full system NSF 61 listing
- ISO 9001 certified manufacturing

# Performance

| Contaminants | Typical Removal[2] | |
|---|---|---|
| | Microfiltration (MF) | Ultrafiltration (UF) |
| Giardia | >6 (log) | >6 (log) |
| Cryptosporidium | >6 (log) | >6 (log) |
| MS2 Coliphage or Bacteriophage | 0.5 – 2.5 log[3] | 4.5 – 6 log[3] |
| Turbidity | <0.1 ntu | <0.1 ntu |

[2] Based on third party testing.
[3] Virus removal varies depending on coagulation process upstream of system.

# Recommended Layout



# Operating Conditions and Design

**Operating Conditions**

- Maximum Inlet Pressure: 44 psi (3 bar)
- Maximum Operating Temperature: 104°F (40°C)
- Minimum Operating Temperature: 33°F (1°C)

**Hollow Fiber Microfiltration Module 9**

- Membrane Material: PVDF
- Pore Rating: 0.1 micron (µm)
- Fiber OD / ID: 1.3 mm/0.7 mm
- Active Filter Area: 538 ft2
- Module Size: 6" diameter x 79" long
- Housing: PVC or ABS
- Gasket: EPDM
- Potting Material: Silicone Epoxy or Urethane

# Flow Ranges for Pall Systems

## Standard System Specifications

| Model Number | Maximum Number of Modules | Filtered Water Capacity (gpm [m3/hr]) | Dimensions (L x W x H : ft [m]) Shipped[4] | Installed |
|---|---|---|---|---|
| AP-1 | 2 | 3-25 [1-7] | 6 x 2.8 x 6.5 [19 x 0.9 x 2.0] | 6 x 2.8 x 9.7[7] |
| AP-2 | 8 | 10-50 [2.3-12] | 8 x 2.8 x 6.5 [2.4 x 0.9 x 2.0] | 8 x 4.1 x 9.9[7] |
| AP-3 | 10 | 25-175 [6-40] | 10 x 4.5 x 7.5 [3 x 1.4 x 2.3] | 10 x 6.9 x 10.3[7] |
| AP-3x | 20 | 25-175 [6-40] | 10 x 4.5 x 7.5 [3 x 1.4 x 2.3][5, 6] | 22.9 x 5.7 x 10.8[5] |
| AP-4 | 36 | 5-350 [15-80] | 10 x 5.5 x 7.5 [3 x 1.7 x 2.3][5, 6] | 24 x 6.8 x 10.8[5] |
| AP-6 | 60 | 200-700 [45-150] | 10 x 6 x 7.5 [3 x 2 x 2.3][5, 6, 8] | 27 x 17 x 10.8[5, 8] |

[4] Crating add 0.5 ft. [0.15m] to each dimension.
[5] Module rack is off the skid.
[6] Module rack shipped as crated parts kit.
[7] Control skid w/attached module rack.
[8] Two freestanding tanks 6' wide x 6' high, shipped separately.

# Design Considerations

- Longer filtration cycles on sources with good water quality.
- Algae should be removed with pre screening.
- Membranes will not remove taste and odors.
- Disinfectant is needed on membrane effluent as a multi barrier and to maintain a residual in the system.
- Normal flux rates are 30 $gpd/ft^2$
- Should require a performance specification.
- Prior agreement to limit cost increase on membrane replacements.
- Membranes must be replaced every 5 to 10 years which is an on-going cost consideration.
- Most units are specified by capacity ranges.

# Samples UF and MF Costs

| Membrane | Gal/day | $ |
|---|---|---|
| UF | 50 | 4000 |
| UF | 50k | 100,000 |
| UF | 360k | 650,000 |
| MF | 500k | 525,000 |
| MF | 1,000k | 1,200,000 |

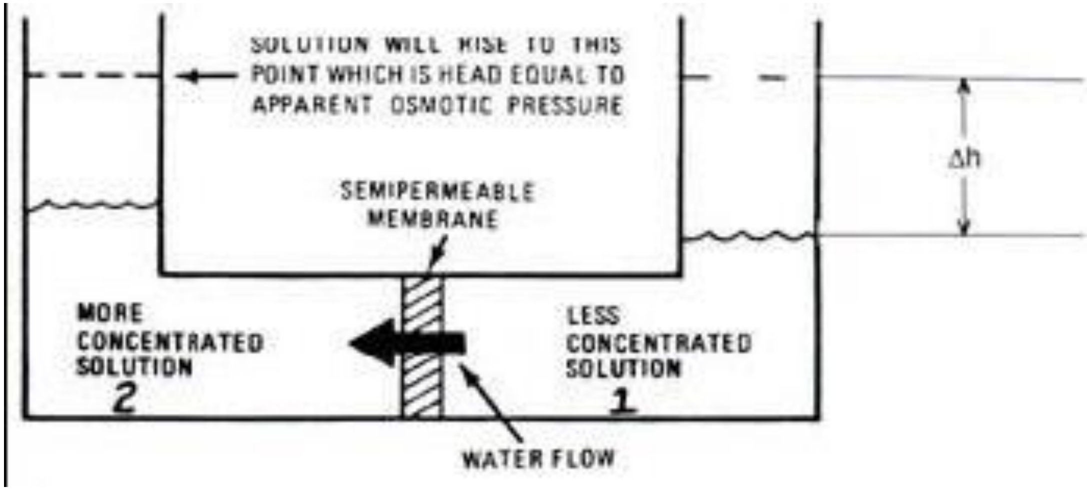
# Reverse Osmosis

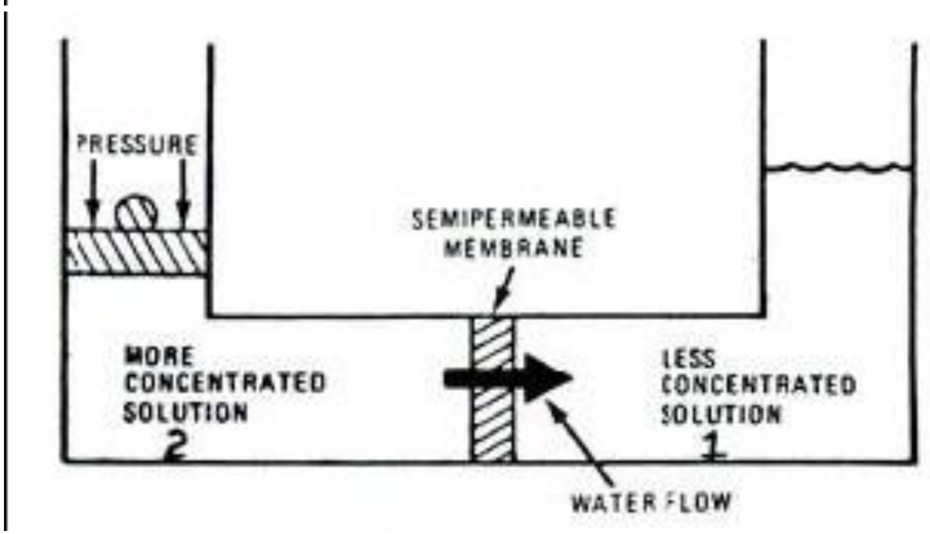
- Spiral wound or hollow fine fiber
- Pretreatment is critical to success
- NTU <1, SDI<3
- Operating pressures from 150 - 1000 psi
- Removes >95-99% TDS
- Concentrate Stream is 15-25% of flow with 4 to 6 times the TDS.

# Nanofiltration

- Cross flow or transverse flow
- Any membrane configuration
- Need turbidity <1 NTU, SDI <5
- Operating pressure 50 - 200 psi
- Used for softening or special applications

# Reverse Osmosis

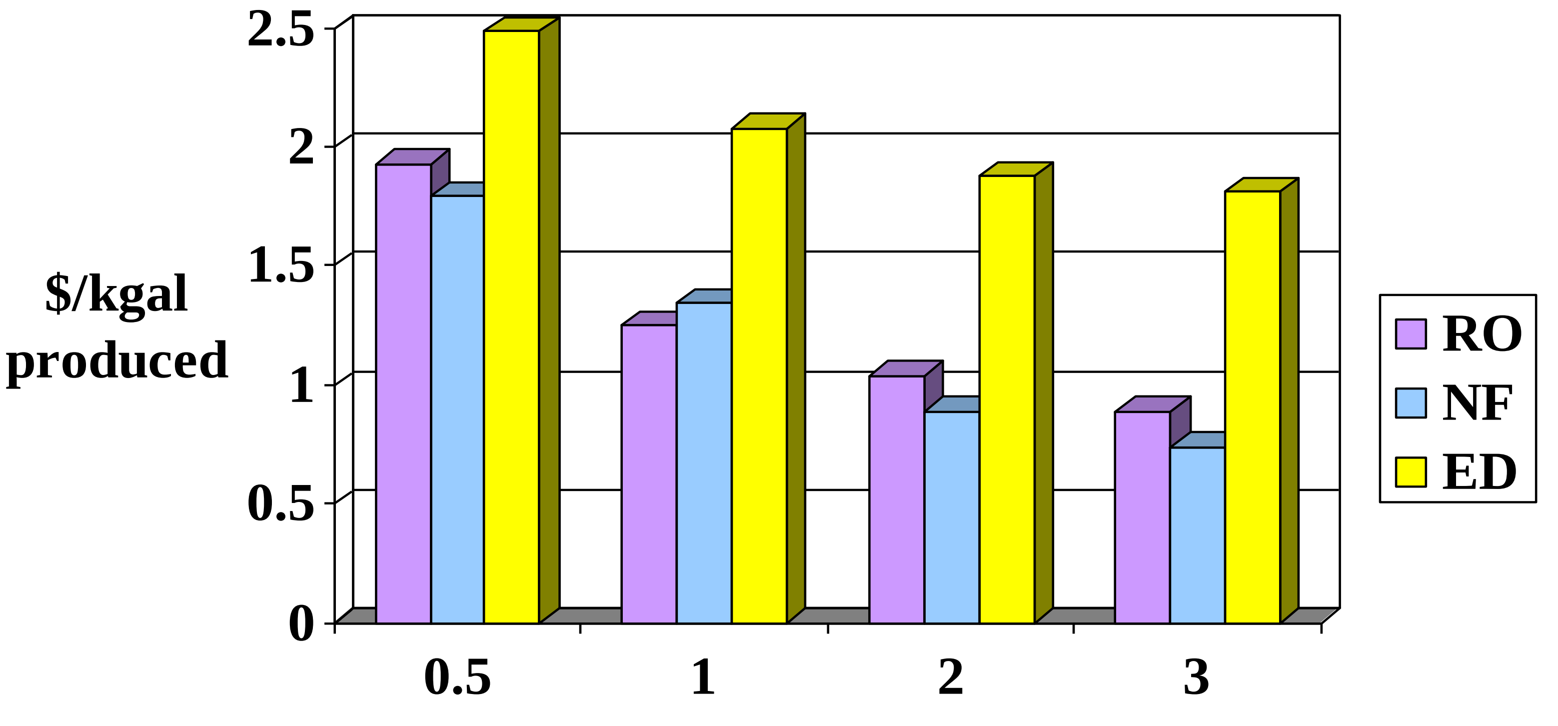


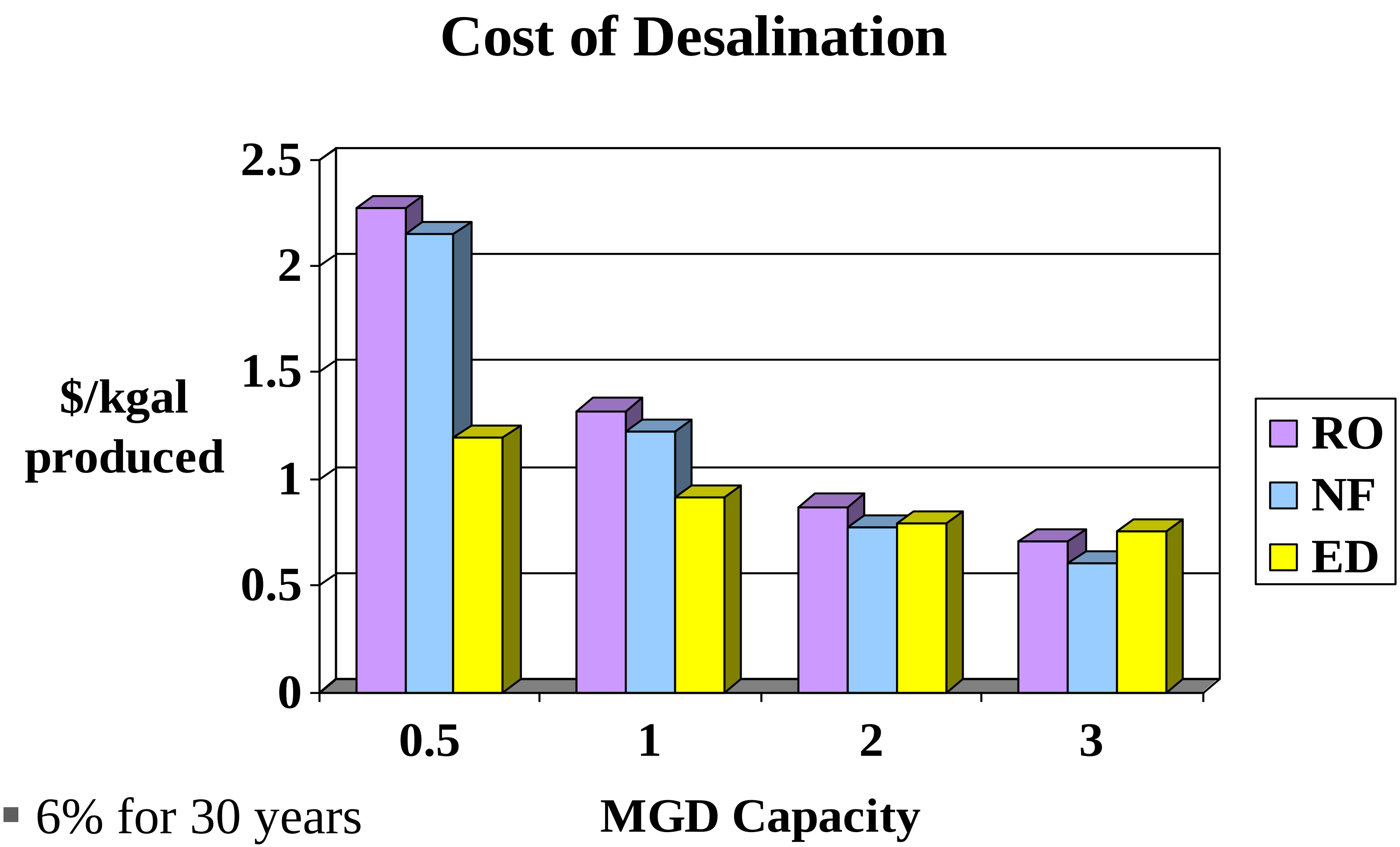

- Forward osmosis: transport from dilute to concentrate
- Reverse osmosis: transport from concentrate to dilute

# 0.1 MGD RO Package System

# Cost of Desalination




- 6% for 30 years
- **2000** mg/L TDS feed,
- product at 500 mg/L with blending



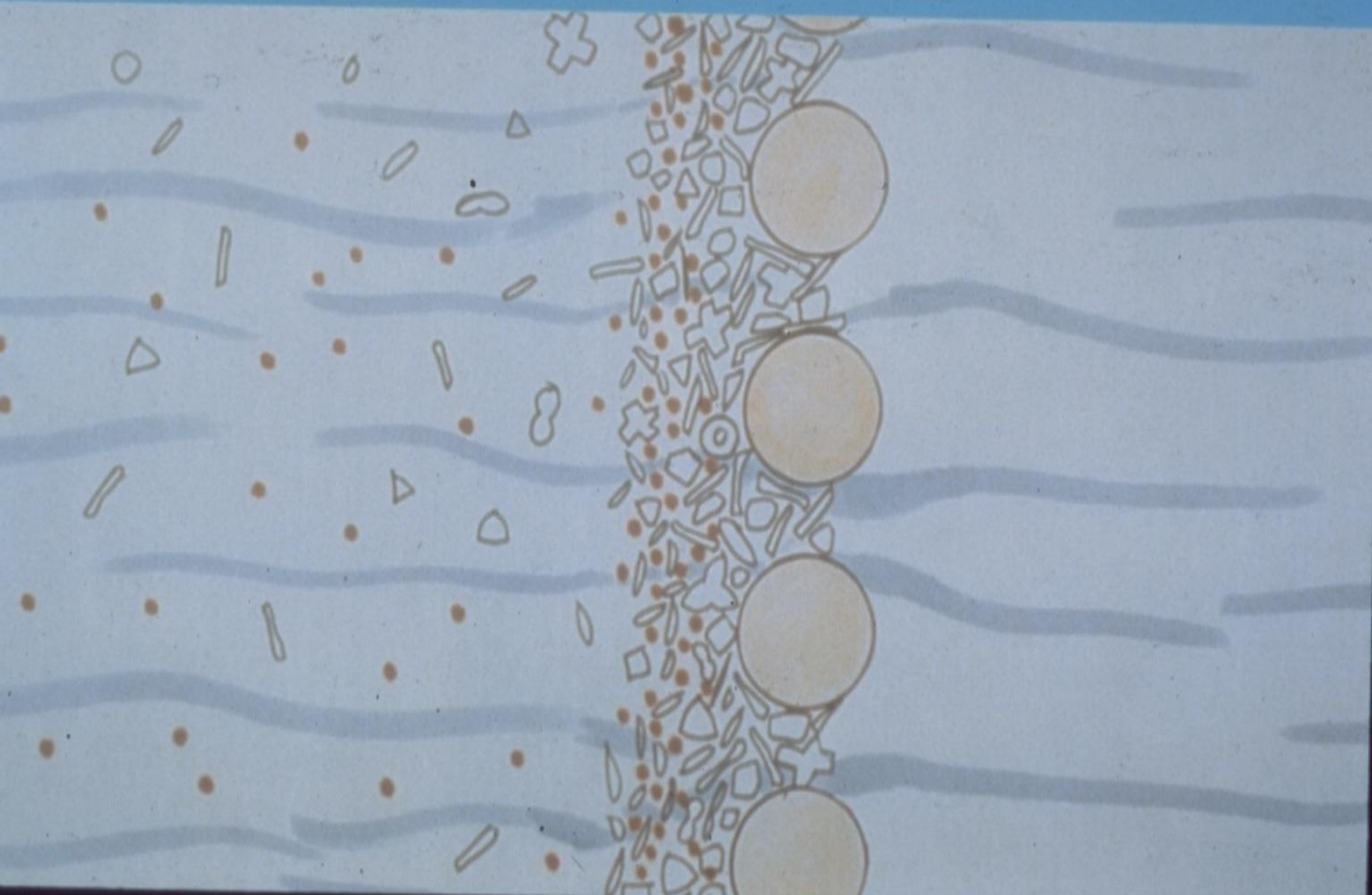

- 6% for 30 years
- **1000** mg/L TDS feed,
- product at 500 mg/L with blending

# DE Filtration

# What is DE Filtration?

- DE is composed of siliceous skeletons of microscopic plants called diatoms.
- Their 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.

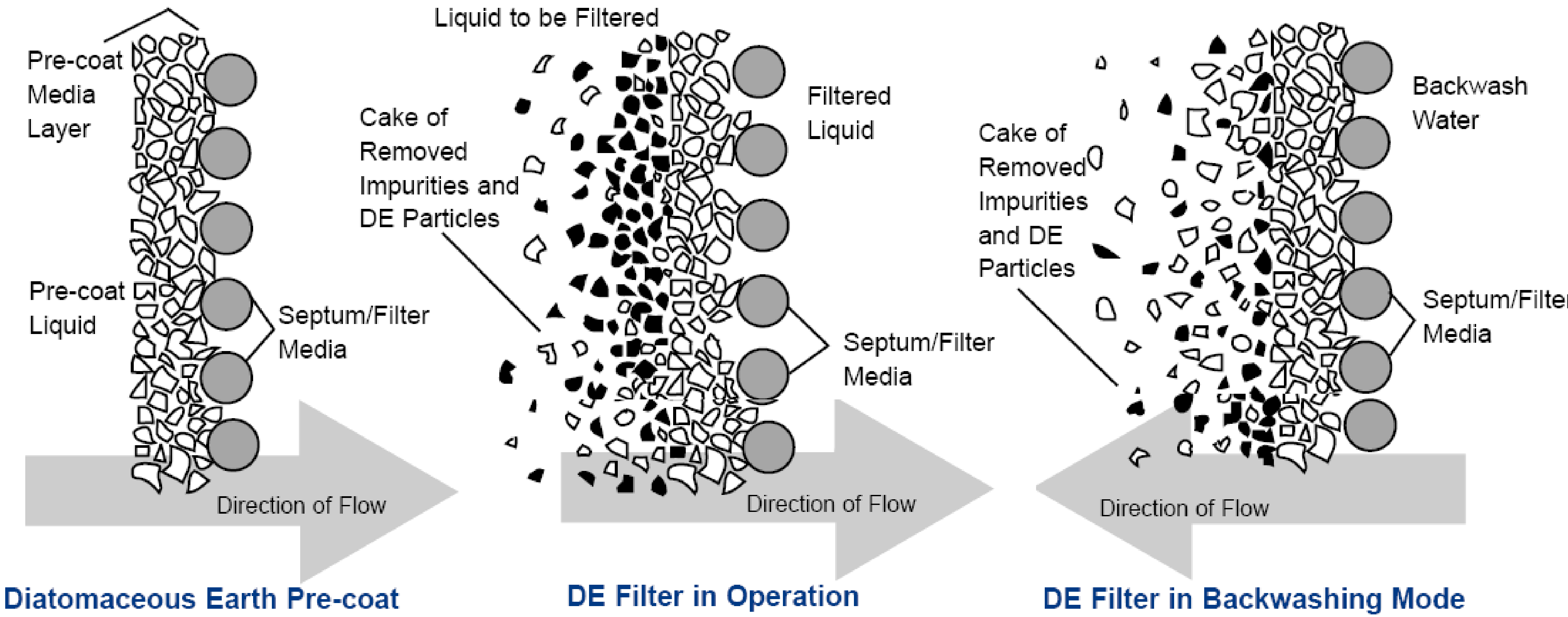
# Diatomaceous Earth Filter



# Review of Regulatory Requirement

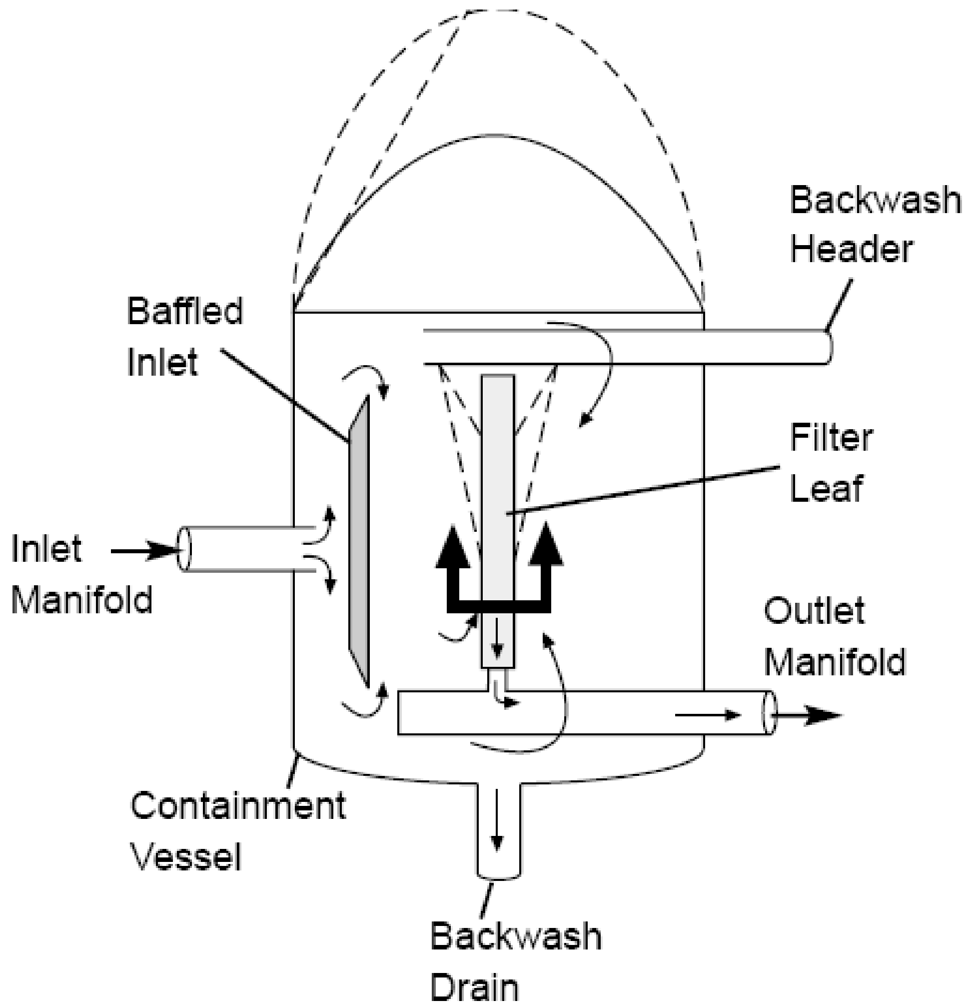
- At Least 95 Percent of the CFE Turbidity Samples Must Be < 1 NTU Each Month
- The Turbidity Must at No Time Exceed 5 NTU

# How it Works



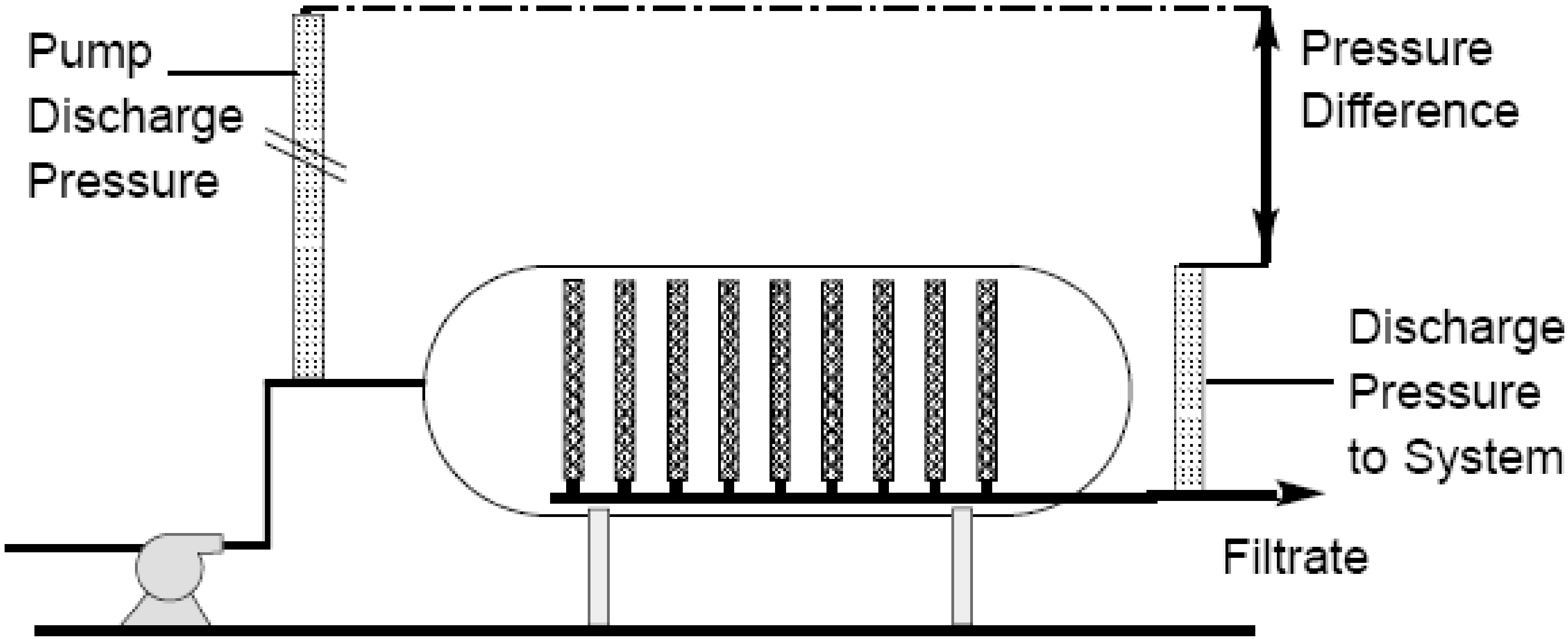

Source: Fulton, George P. 2000. *Diatomaceous Earth Filtration for Safe Drinking Water*

# Flat Leaf Filter

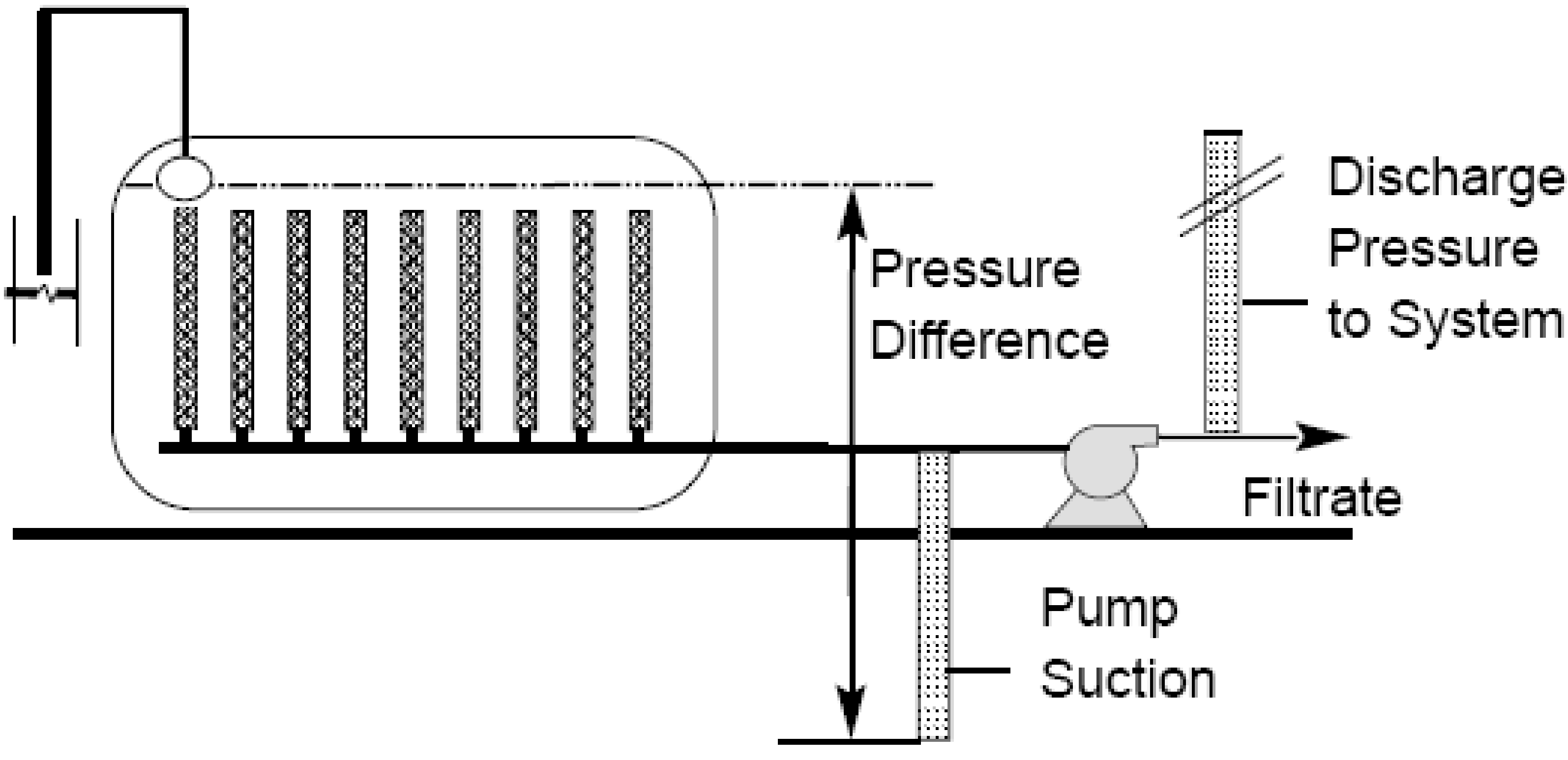



Source: Fulton, George P. 2000. *Diatomaceous Earth Filtration for Safe Drinking Water*

# Pressure Filter



# Vacuum Filter



# Principal Components

- Containment vessel
- Baffled inlet
- Filter leaves mounted on an effluent manifold
- Method of cleaning the filter leaves at the end of a run
- Drain to receive the backwash water
- Open top or access mode DE slurry preparation tank and pump feed

# Pressure vs. Vacuum Filters

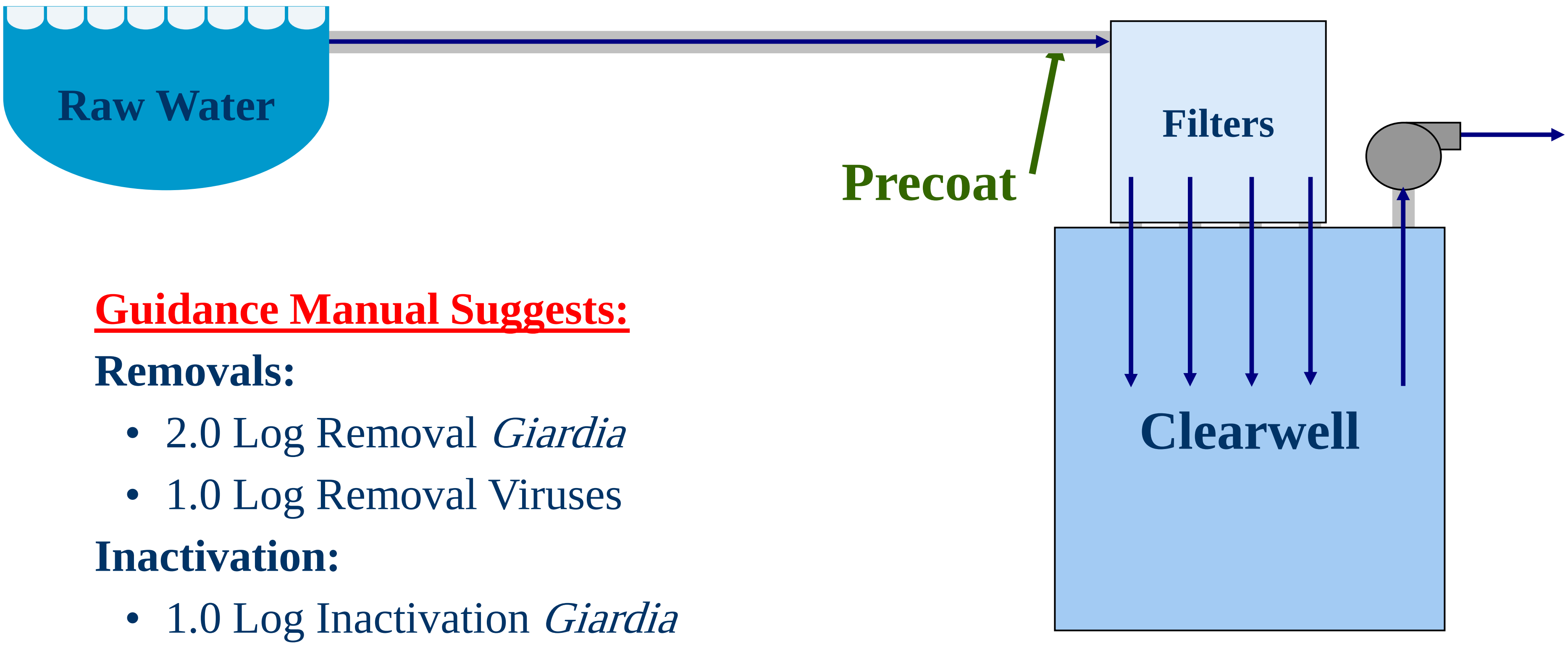
| Pressure Filters | Vacuum Filters |
|---|---|
| • Operates at higher flowrates, resulting in smaller, more compact filter units. | • Lower capital fabrication cost. |
| • Longer filter runs, reducing the use of pre-coat material and backwash water because of less frequent cleaning cycles. | • Lower maintenance costs. |
| • Less likelihood that gas bubbles will disrupt the media. | • Tanks are open at the top, making access and observation easy. |

Source: Mel J. Mirliss, Vipin Bhardwaj, and the National Drinking Water Clearinghouse

# Process Considerations

- Limited to treating source waters with an upper limit of turbidity at 10 NTU
- Filtration rates range from 0.5 to 2 gallons per minute per square foot (gpm/$ft^2$)

# §141.73—Filtration: DE




**<u>Guidance Manual Suggests:</u>**

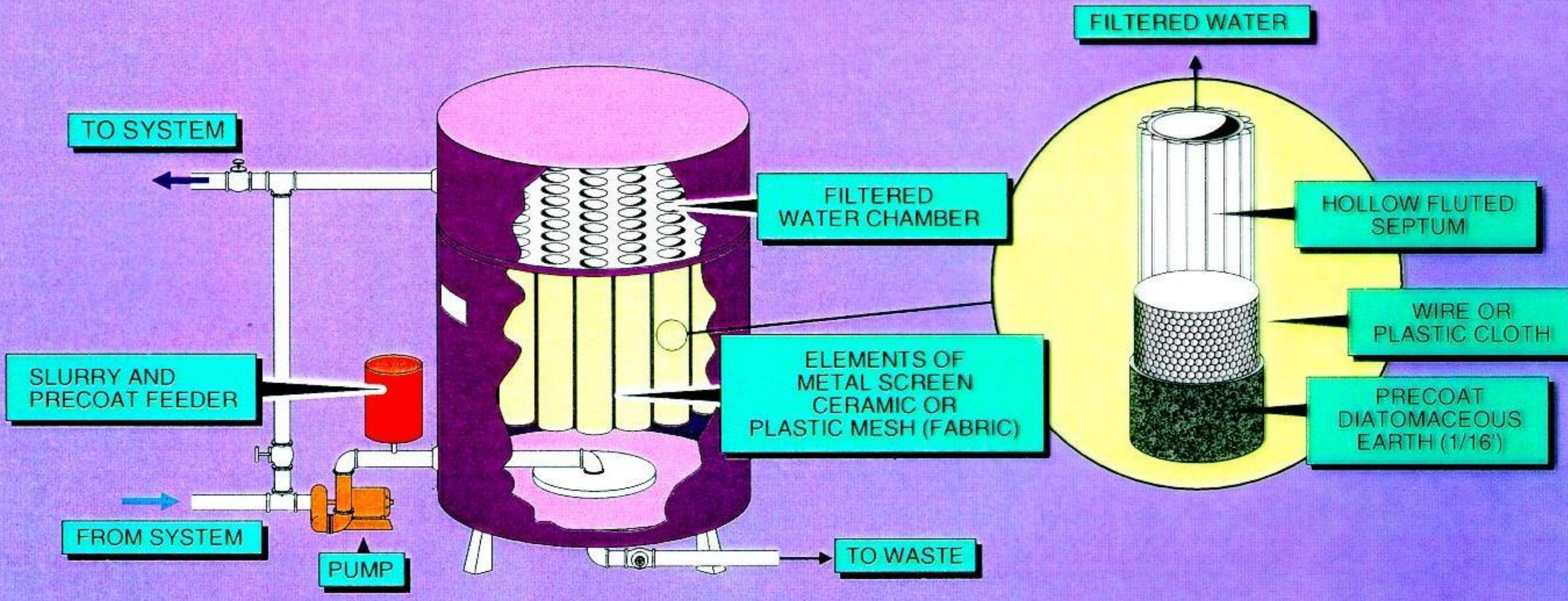
**Removals:**

- 2.0 Log Removal *Giardia*
- 1.0 Log Removal Viruses

**Inactivation:**

- 1.0 Log Inactivation *Giardia*
- 3.0 Log Inactivation Viruses

# Diatomaceous Earth Filtration



# DE Filtration Considerations

- Difficulty in maintaining a perfect film of DE of at least 0.3 cm (1/8 in)
- The minimum amount of filter precoat should be 0.2 $lb/ft^2$
- The use of a alum (1 to 2% by weight) or cationic polymer (1 mg per gram of DE) to coat the body feed improves removal of viruses, bacteria, and turbidity

# DE Filtration Considerations

- Continuous body feed is required because the filter cake is subject to cracking.
- Body feed reduces increase of headloss due to buildup on the surface.
- Interruptions of flow cause the filter cake to fall off the septum
- Filter runs range from 2 to 4 days depending on the rate of body feed and DE media size.
- An EPA study showed greater than 3.0 log removal for *Giardia* for all grades of DE.

# DE Filtration Considerations

- Percent reduction in TC bacteria, HPC, and turbidity were strongly influenced by the grades of DE used
- Coarsest grades of DE will remove:
  - 95 percent of cyst size particles
  - 20-30 percent of coliform bacteria
  - 40-70 percent of HPC
  - 12-16 percent of the turbidity

# DE Filtration Considerations

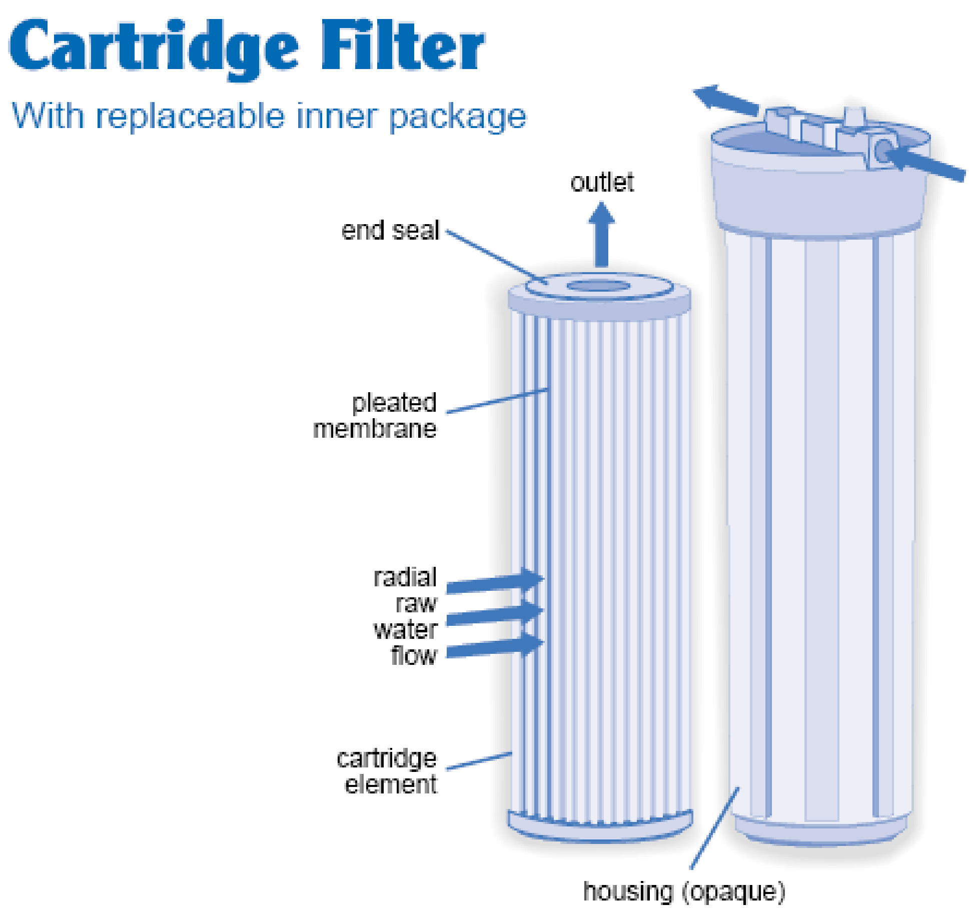
- The use of the finest grades of DE or alum coating on the coarse grades will increase the effectiveness of the process to 3 logs bacteria removal and 98 percent removal for turbidity
- Systems in Wyoming have shown as high as six logs of microorganism removal, whereas others have shown negative log removal for particles which might be the media passing the septum

# Log Removal and/or Inactivation

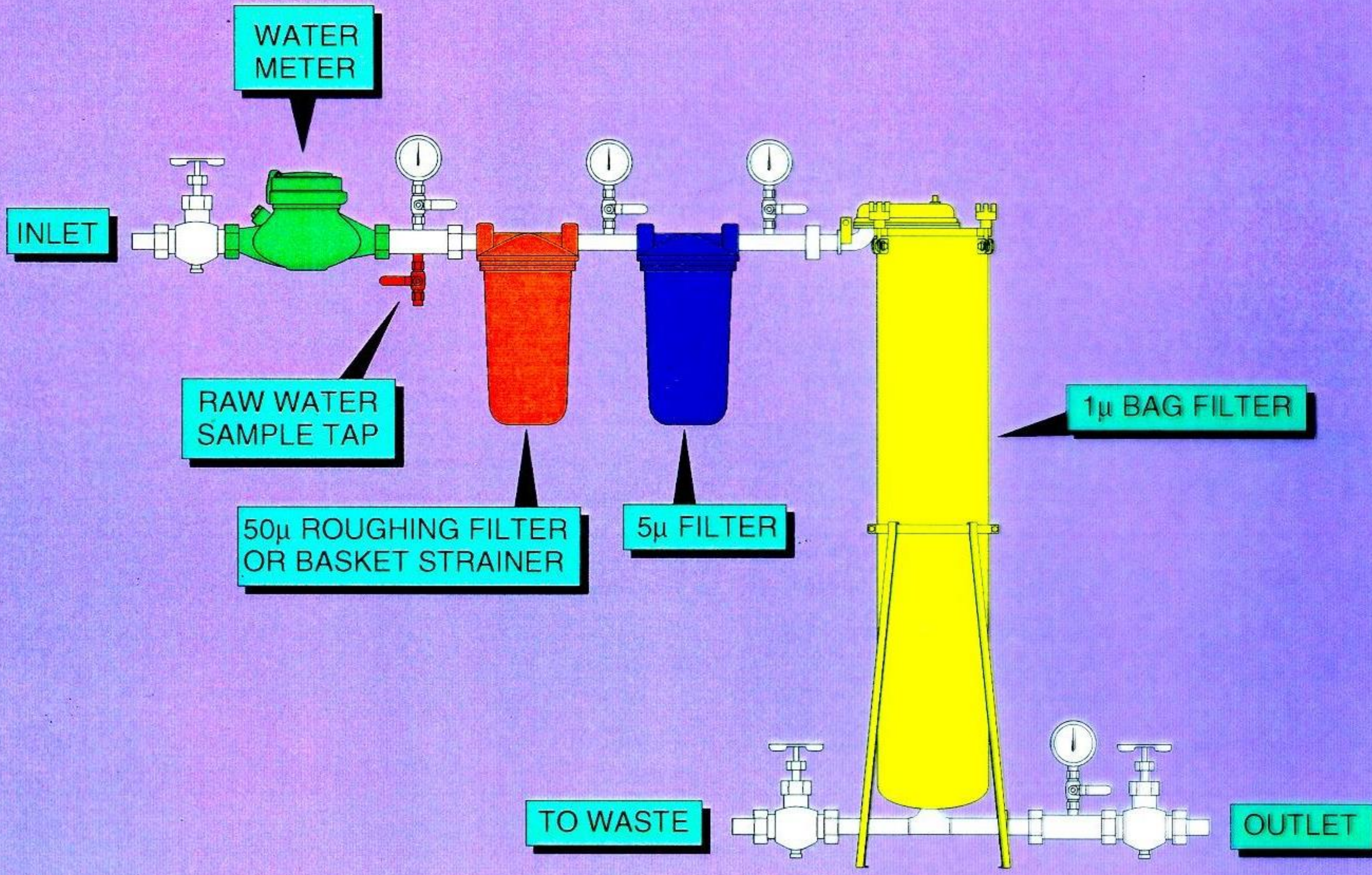
| Filters | Log Removal | | Recom. Inact. | |
|---|---|---|---|---|
| | ***Giardia*** | Viruses | ***Giardia*** | Viruses |
| Conven. | 2-3 | 1-3 | 0.5 | 2.0 |
| Direct | 2-3 | 1-2 | 1.0 | 2.0 |
| Slow Sand | 2-3 | 1-3 | 2.0 | 2.0 |
| DE | 2-3 | 1-2 | 1.0 | 3.0 |

# Bag and Cartridge Filters

# Cartridge Filter



# Bag and Cartridge Filtration




Aquafine

# Cartridge & Bag Filters

# Cartridge & Bag Filters

- Units are compact
- Operates by physically straining the water to 1.0 micron
- Made of a variety of material compositions depending on manufacturer
- Pilot testing necessary

# Cartridge & Bag Filters

- Depending on the raw water quality different levels of pretreatment are needed
- Sand or multimedia filters
- Pre-bag or cart. of 10 microns or larger
- Final bag or cart. of  2 microns or less
- Minimal pretreatment for GWUDISW

# Cartridge & Bag Filters

- Units can accommodate flows up to 50 gpm.
- As the turbidity increases the life of the filters decreases (e.g., bags will last only a few hours with turbidity > 1 NTU).

# Cartridge & Bag Filters

- Both filters have been shown to remove at least 2.0 logs of Giardia lamblia but for crypto:
  - Bags show mixed results <1 to 3 logs of removal.
  - Cartridge filters show 3.51 to 3.68 logs of removal.  Better removal due to pleats.

# Cartridge & Bag Filters

- In an MS-2 Bacteriophage challenge study no virus removal was achieved. Therefore, there must be enough disinfection contact time to exceed 4.0 logs of inactivation of viruses for both filters.

# Cartridge & Bag Filters

- Factors causing variability in performance:
  - The seal between the housing and filters is subject to leaks especially when different manufacturers housings and filters are used.
  - Products use nominal pore size (average) rather than absolute pore size.  2 um or less absolute should be used.

# Cartridge & Bag Filters

- Monitoring of filter integrity may be needed
- States to decide on what type of integrity tests may be needed

# Cartridge & Bag Filters

- For a conventional or direct filtration plant that is on the borderline of compliance installing bag/cart filtration takes the pressure off by decreasing the turbidity level to 1 NTU and increasing public health protection by applying two physical removal technologies in series.  Check with State Drinking Water programs for more information

# California Department of Public Health Webcast

Evaluation and Design of Small Water Systems

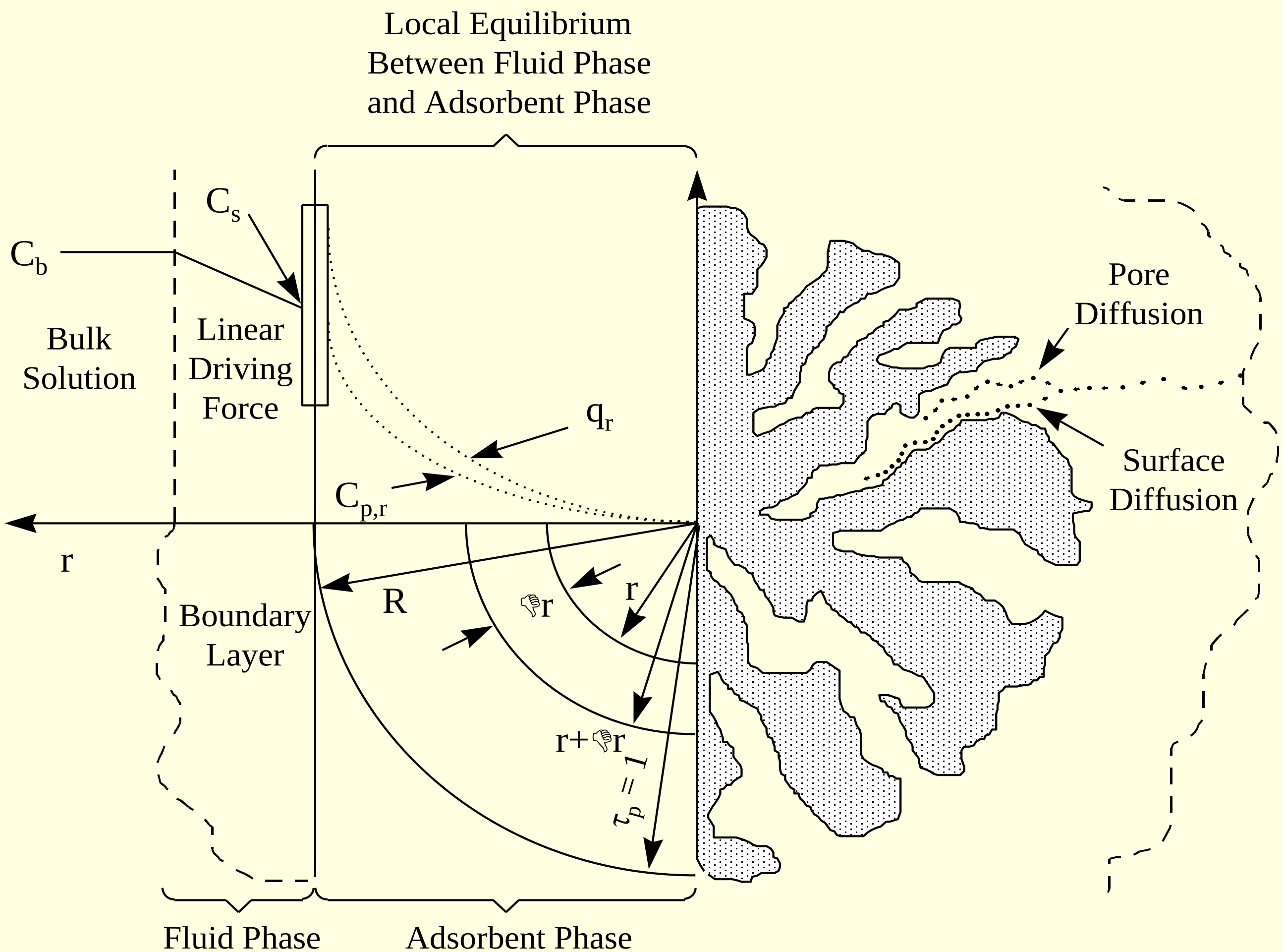
## Adsorption and Ion Exchange

Dale Newkirk, P.E.

# Lecture Objectives

- To review design of activated carbon systems including GAC and PAC.
- To review design of ion exchange systems including cationic and anionic.

# GAC Removal Mechanisms




Mass Flux $= k_f (C_b - C_s)$

Mass Flux $= -D_s \rho_a \frac{\partial q_r}{\partial r} - \frac{D_l \varepsilon_p}{\tau_p} \frac{\partial C_{p,r}}{\partial r}$

# Most Common Uses of GAC

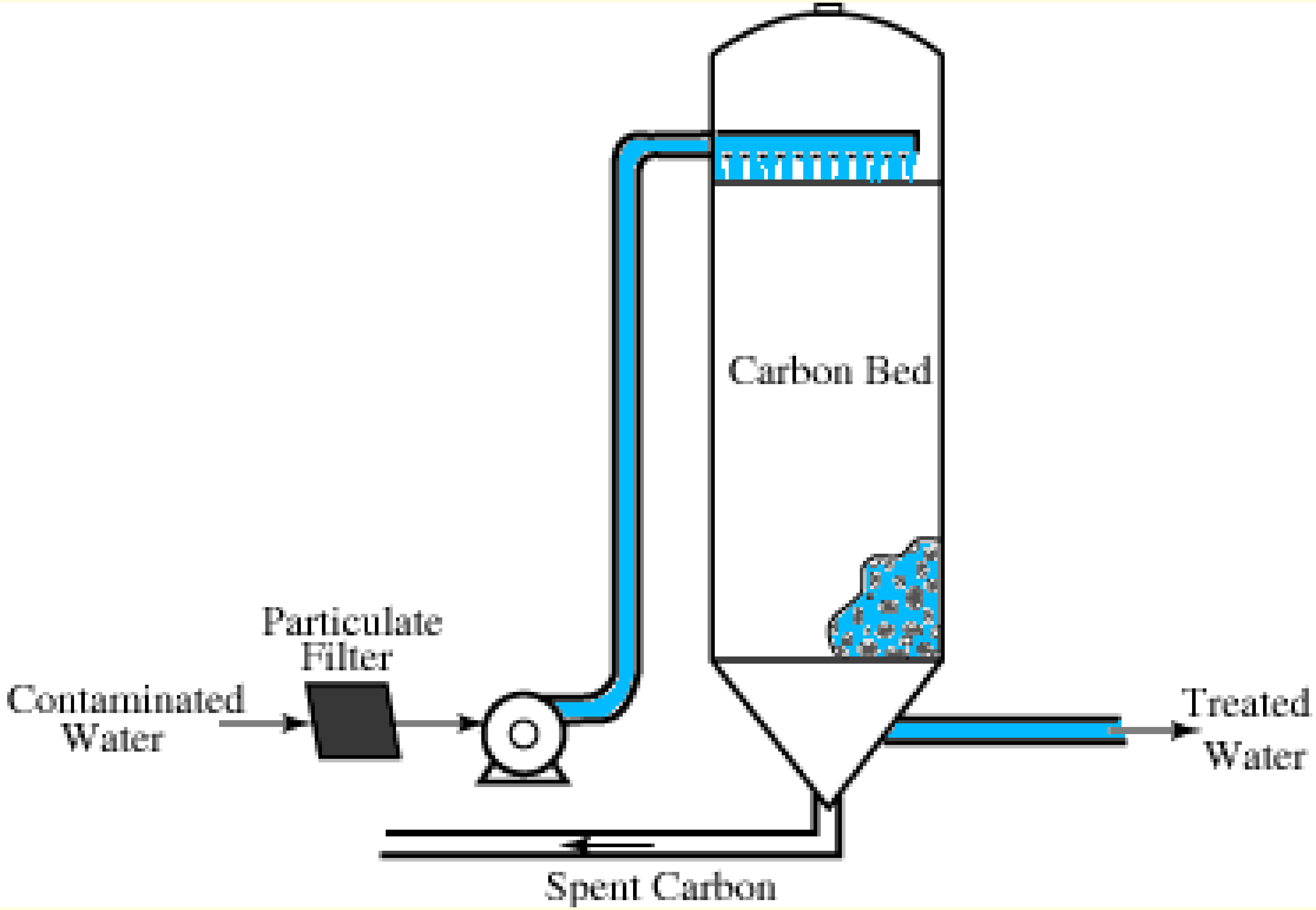
- Taste and Odor
- TOC
- DBP’s
- Organic contamination of ground water (MTBE, Pesticides, Solvents)
- Perchlorate in surface water

# OTHER ORGANIC COMPOUNDS AMENABLE TO ABSORPTION BY GAC

| Class | Example |
|---|---|
| Aromatic solvents | Benzene, toluene, xylene |
| Polynuclear aromatics | Naphthalene, biphenyl |
| Chlorinated aromatics | Chlorobenzene, PCBs, endrin, toxaphene, DDT |
| Phenolics | Phenol, cresol, resorcinol, nitrophenols, chlorophenols, alkyl phenols |
| Aromatic amines & high molecular weight aliphatic amines | Aniline, toluene diamine |
| Surfactants | Alkyl benzene sulfonates |
| Soluble organic dyes | Methylene blue, textiles, dyes |
| Fuels | Gasoline, kerosene, oil |
| Chlorinated solvents | Carbon tetrachloride, percholoroethylene |
| Aliphatic & aromatic acids | Tar acids, benzoic acids |
| Pesticides/herbicides | 2,4-D, atrazine, simazine, aldicarb, alachlor, carbofuran |

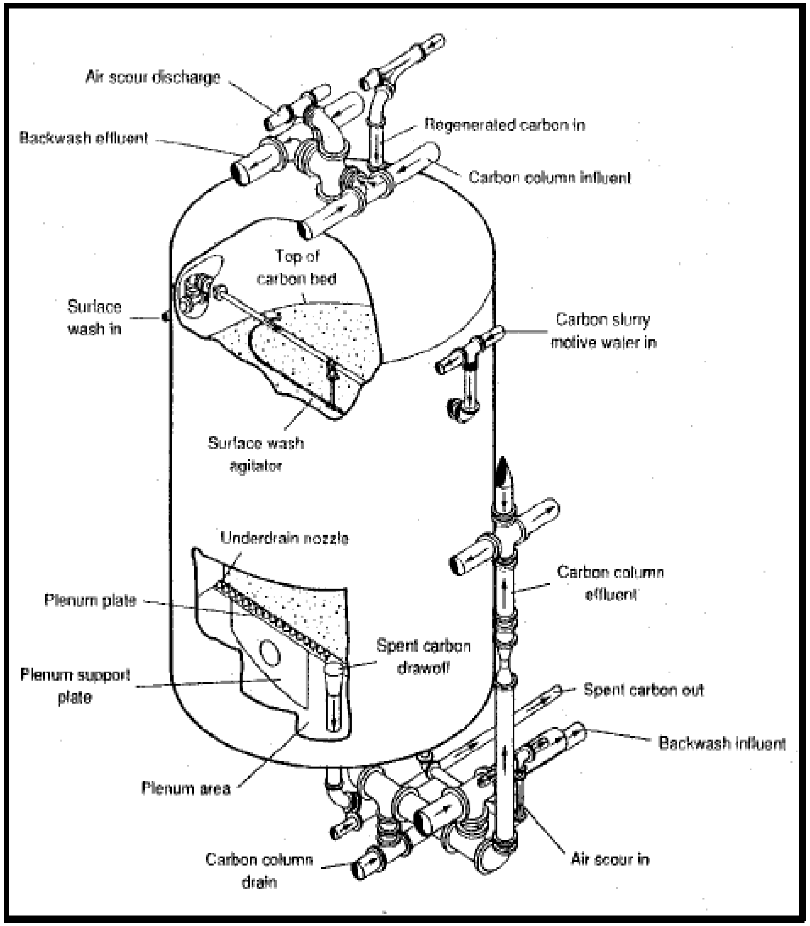
Source: U.S. EPA, 1984.

# GAC Process



Carbon Bed
Particulate Filter
Contaminated Water
Treated Water
Spent Carbon

# Typical GAC Contactor Design




Source: Tchobanoglous and Burton, 1991.

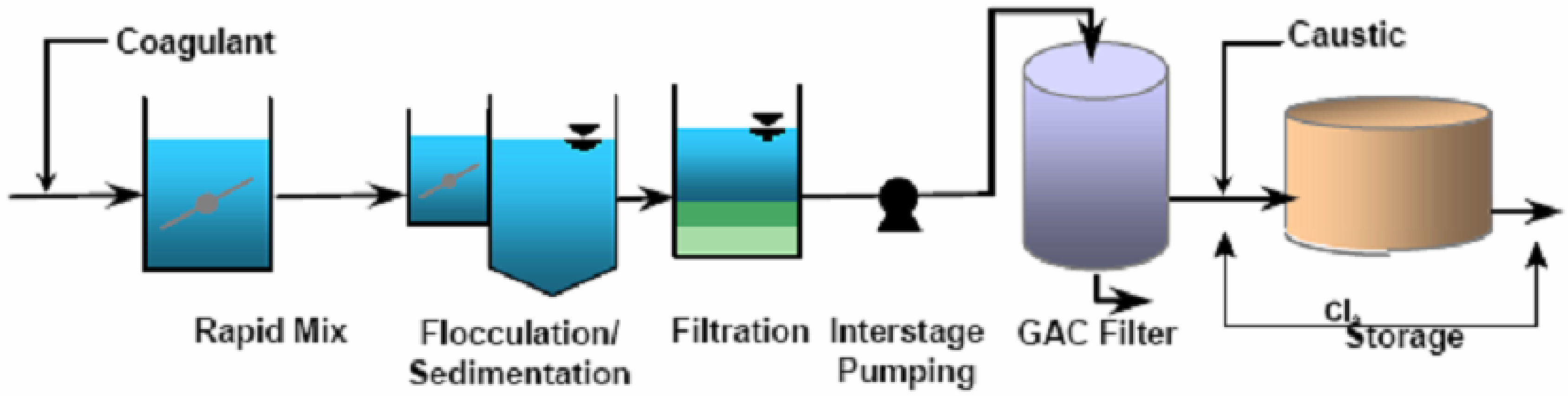
# GAC Considerations

- The presence of multiple contaminants can impact process performance.
- Single component isotherms may not be applicable for mixtures.
- Bench tests may be conducted to estimate carbon usage for mixtures.
- Streams with high suspended solids (> 50 mg/L) and oil and grease (> 10 mg/L) may cause fouling of the carbon and may require frequent treatment.

# GAC Considerations

- Type, pore size, and quality of the carbon, as well as the operating temperature, will impact process performance.
- Vendor expertise for carbon selection should be consulted.
- Highly Water-soluble compounds and small molecules are not adsorbed well.
- All spent carbon eventually need to be properly disposed.

# Typical GAC Placement

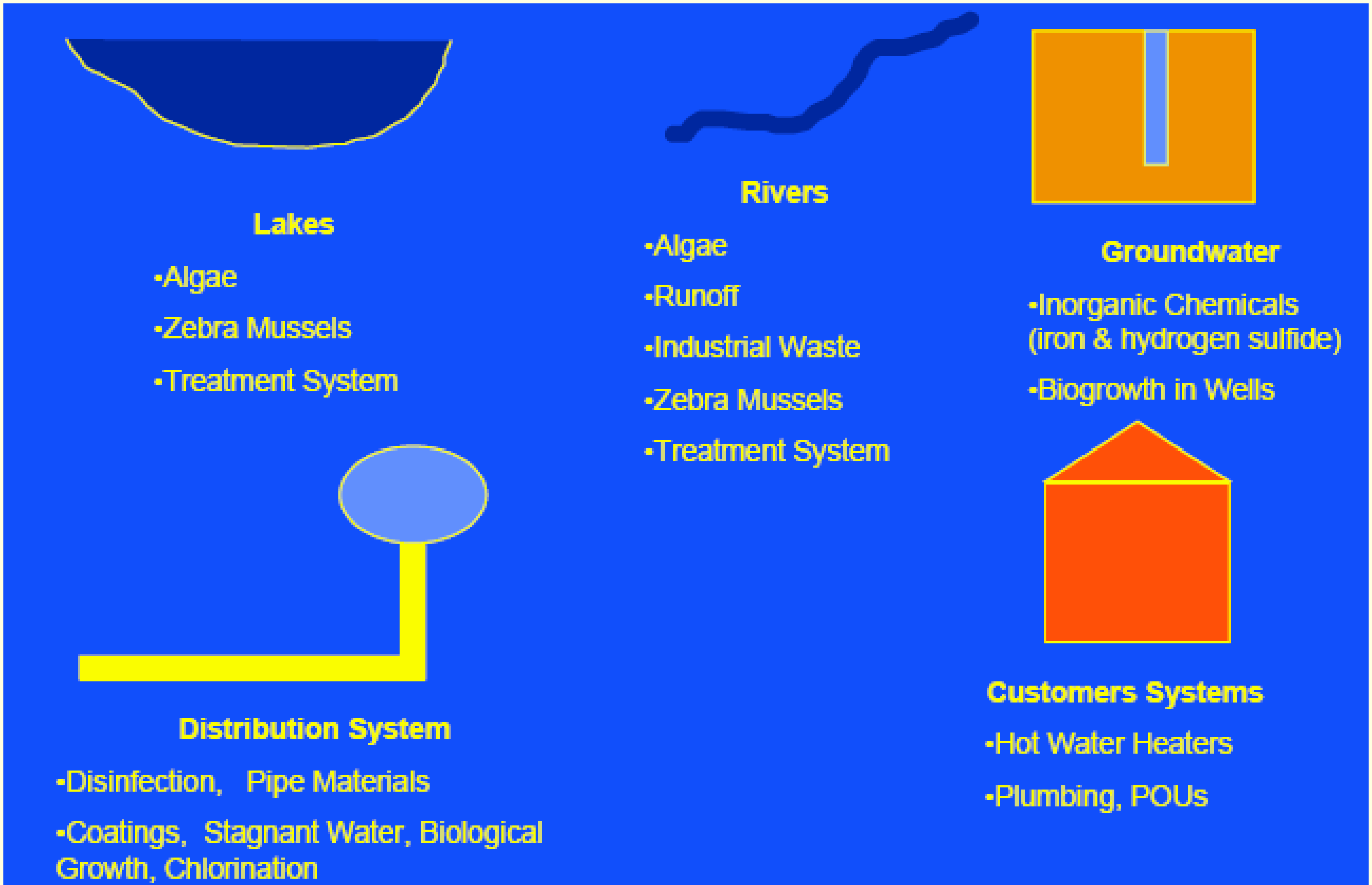



Description of Process: Install GAC filter following granular media filter.

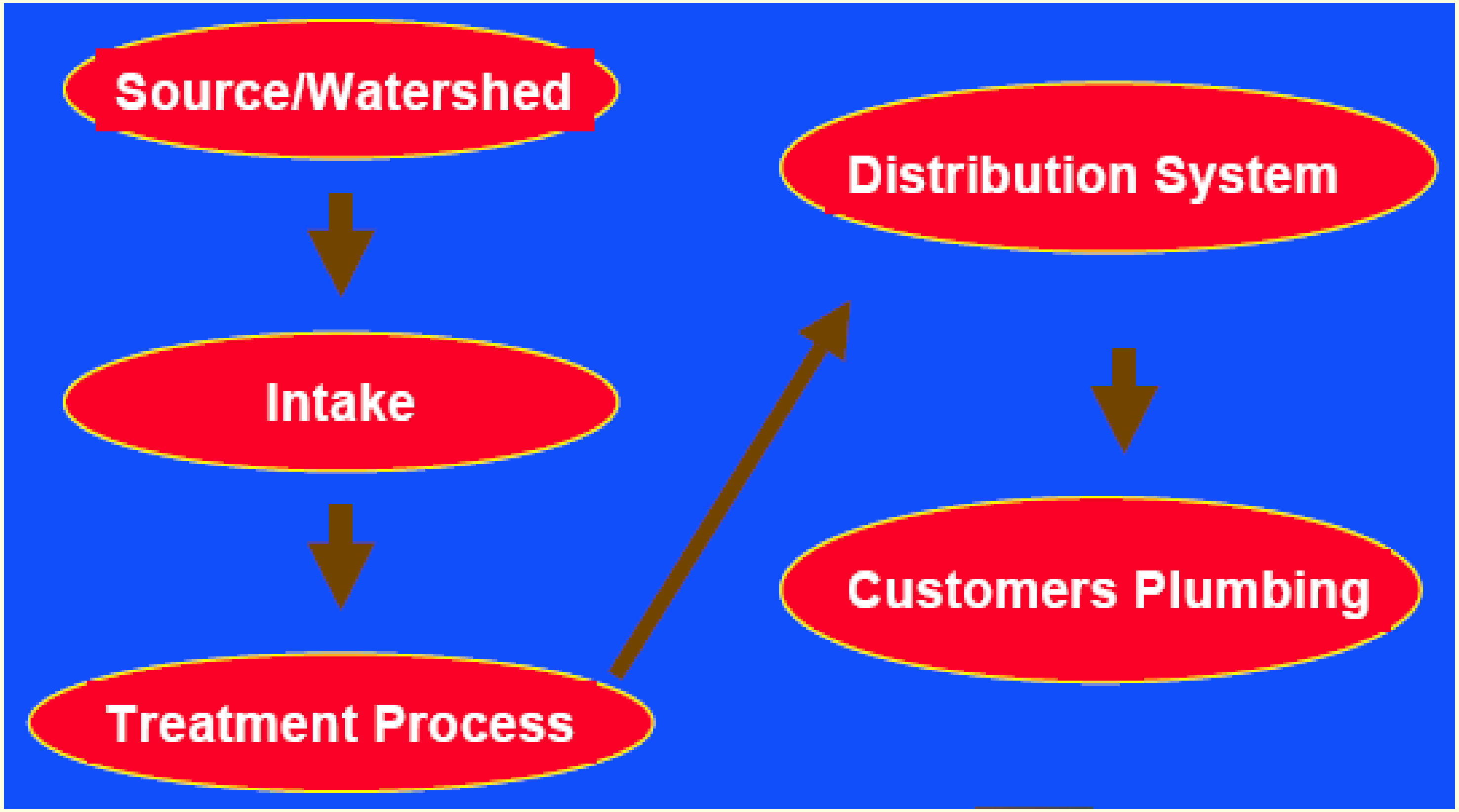
# Understanding Taste and Odor Problems

- **Algae or Microorganism Based**
- **Chlorination**
- **Inorganic Chemicals (iron, etc.)**
- **Industrial Wastes**
- **Reservoir or Pipeline Coatings**

# Sources and Locations of T&O



# Determine the Source



# Identifying Taste & Odors

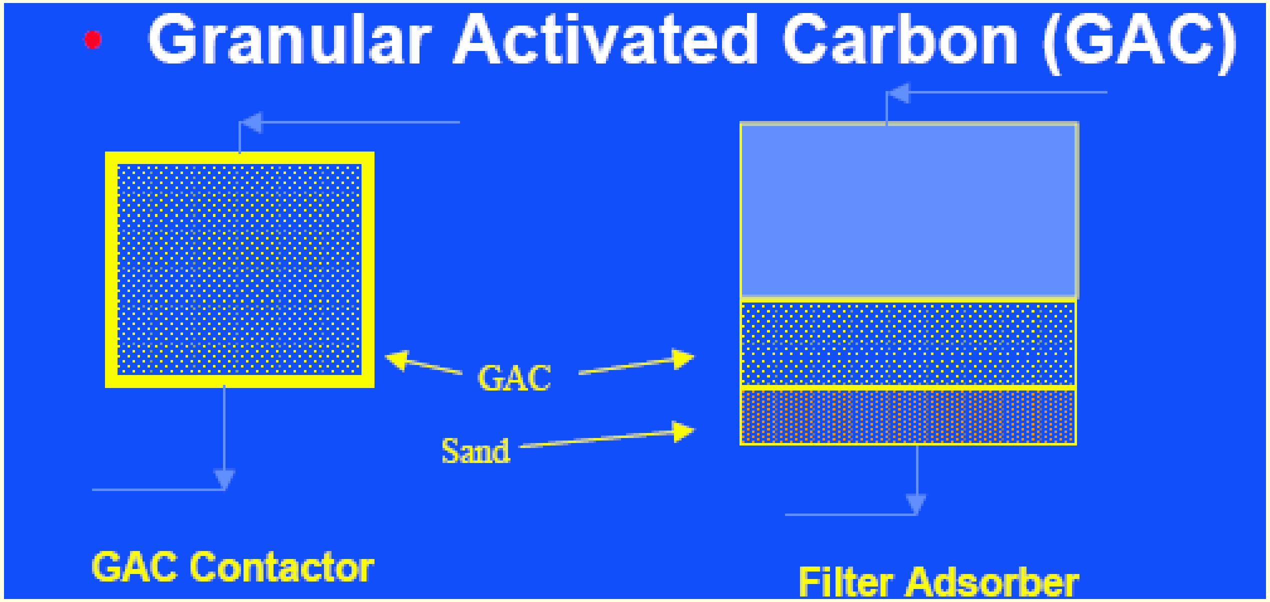
- Customer Complaints
- Flavor Panels
- Chemical Measurement
  - MIB, Geosmin, Iron, Hydrogen Sulfide
  - Chlorine Residual
  - Chloramines

# Carbon Adsorption

## Powdered Activated Carbon (PAC)

- Added as slurry or dry
- Difficult to handle
- Typical dosage (1 to 15 mg/L)
- Requires contact time
- Reacts with chlorine

# Carbon Adsorption




**GAC Contactor**

- Empty Bed Contact Time 10-20 minutes
- Reacts with chlorine
- Can Blend

**Filter Adsorber**

- Anthracite replaced with GAC
- Empty Bed Contact Time 5 -10 minutes
- Reacts with chlorine
- Can Blend

# How Do I Size a GAC Contactor?

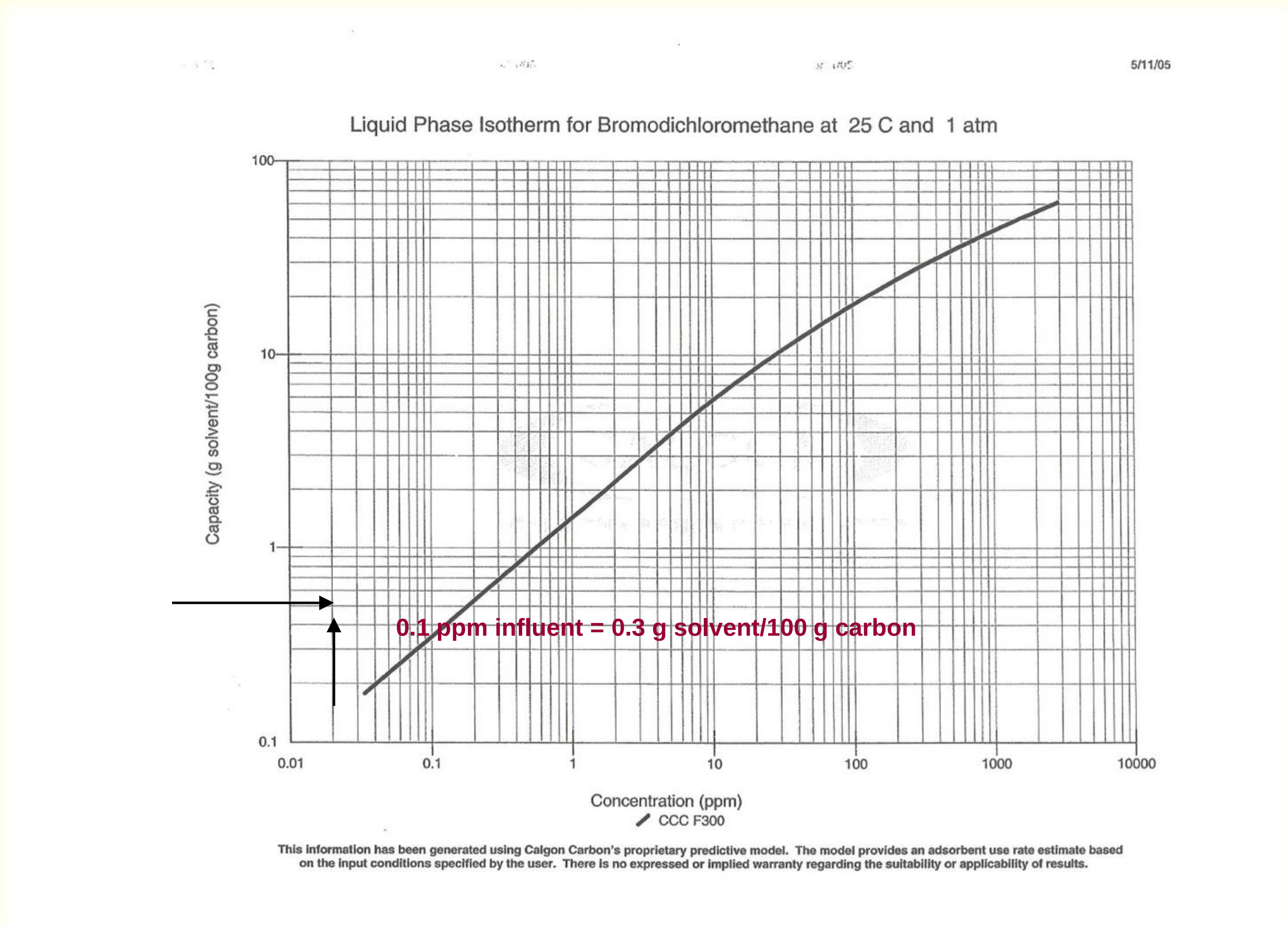
- Perform a jar test in the laboratory
- Perform a pilot test
- Use information from the literature
- Contact the GAC Vendors
- Use conservative design of 20 minutes
- Use manufacturer specifications and information on specific contaminant

# Example Specifications For GAC

| Specifications | F300 | F400 |
|---|---|---|
| Iodine Number, mg/g (min) | 900 | 1000 |
| Moisture, weight % (max %) | 2 | 2 |
| Abrasion Number (min) | 78 | 75 |
| Effective Size, mm | 0.8 - 1.0 | 0.55-0.75 |
| Uniformity Coefficient (max) | 2.1 | 1.9 |
| Ash, weight % (max) | 8 | 9 |
| Apparent Density, g/cc (min) | 0.48 | 0.44 |
| **US Sieve Series, weight %** | | |
| Larger than No. 8 (max) | 15 | - |
| Smaller than No. 30 (max) | 4 | - |
| Larger than No. 12 (max) | - | 5 |
| Smaller than No. 40 (max) | - | 4 |

# Liquid Phase Isotherm

## Calgon F300 for Bromodichloromethane



# Approximate Contactor Sizing

Given:

**Contaminant Conc. = 0.1 mg/L**
**F300 apparent density = 0.43 g/cc**
**Removes 0.3 g/100 g carbon=0.3 lb/100 lb carbon**
**1 g/cc = 62.3 $Lb/ft^3$**
**0.43 g/cc = 26.8 $Lb/ft^3$**
**100 Lb x 1/26.8 $Lb/ft^3$ = 2.73 $ft^3$ carbon**
**Removes 0.3 lb of organic**

Volume of Reactor for 3 months removal:

**$\frac{100\ gpm}{1 \times 10^6}$ x 1,440 min/day x 0.1 mg/L x 8.34 x 30 days/month x 3 months = 10.8 lbs organic**

**2.73 $ft^3$/0.3 lb organic x 10.8 lbs organic = 98.3 $ft^3$ carbon**

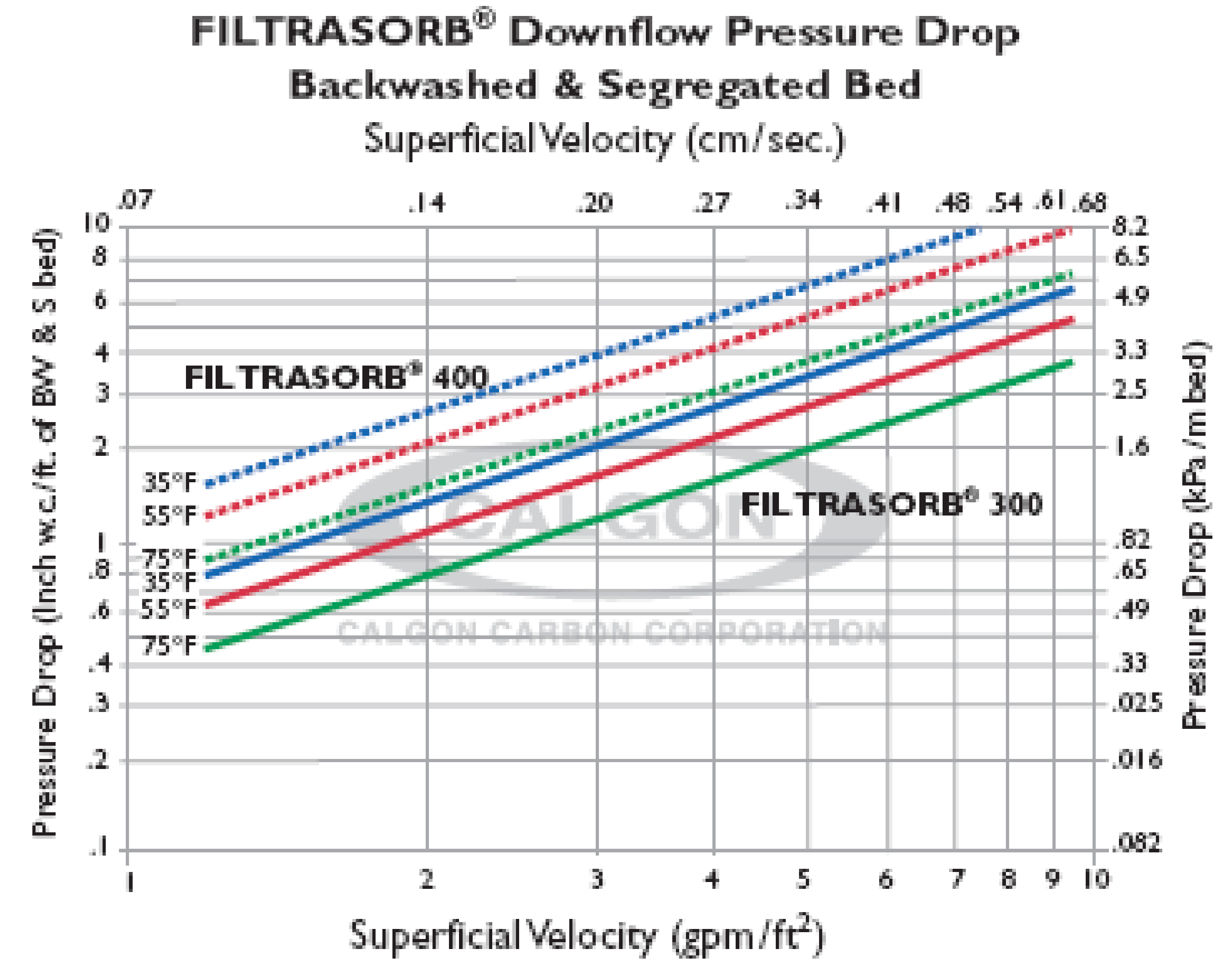
**EBCT = $\frac{100\ gpm}{7.48\ g/ft^3}$ = 13.4 $ft^3$/min $\frac{98.3\ ft^3}{13.4\ ft^3/min}$ = 7.33 minutes**

**4 ft diameter vessel = 12.6 $ft^2$**

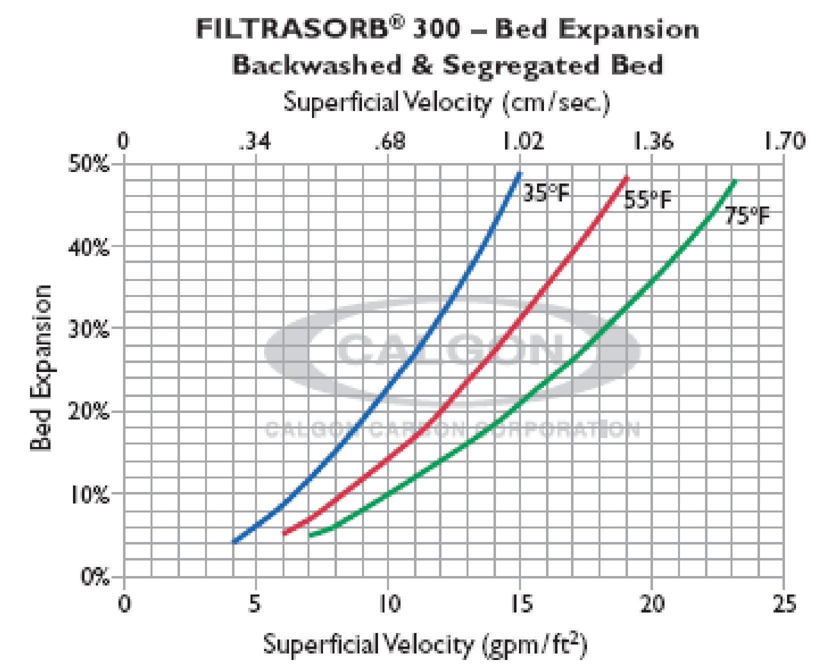
**$\frac{98.3\ ft^3}{12.6\ ft^2}$ = 7.8ft high So use 2 series reactors 4 ft in diameter by 6 feet deep (1.5 safety factor)**

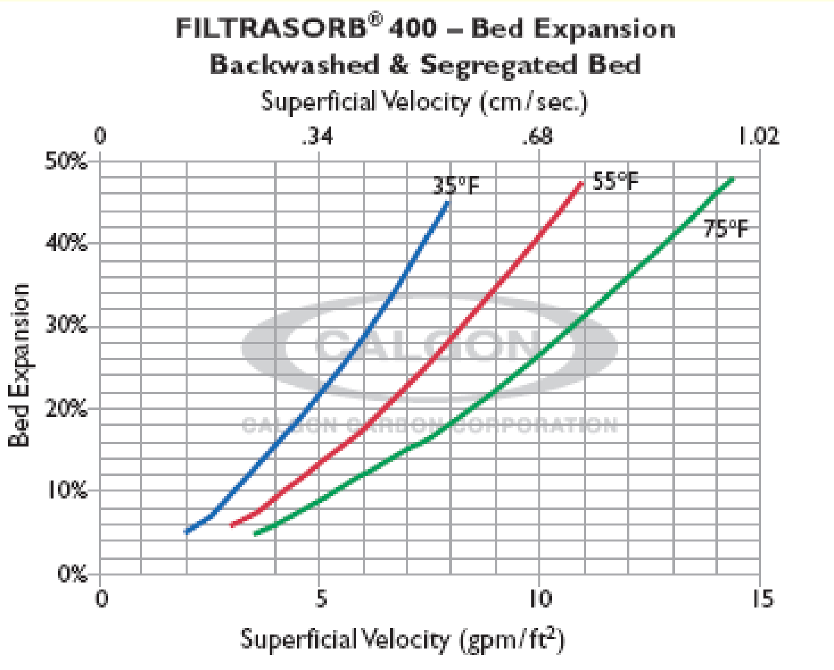
**Note: In every case, discuss with carbon supplier to verify findings. Also, in most cases EBCT should be between 10 and 20 minutes rule of thumb. In this case it is 11 minutes.**

# Filtration Rates



# Backwash Rates



| Component Name | Inlet Concentration (ppm) | Cumulative Use rates in lbs/1000 gal | |
|---|---|---|---|
| | | Coal Base 0.48g/cc | Coconut base 0.50g/cc |
| MTBE | 1 | 2.33 | 1.04 |
| t-Butanol | 1 | 1.04 | 0.6 |
| Benzene | 1 | 0.58 | 0.38 |
| Toluene | 1 | 0.29 | 0.21 |
| Ethyl Benzene | 1 | 0.09 | 0.07 |
| MTBE | 0.1 | 0.8 | 0.26 |
| t-Butanol | 0.1 | 0.29 | 0.13 |
| Benzene | 0.1 | 0.15 | 0.08 |
| Toluene | 0.1 | 0.06 | 0.04 |
| Ethyl Benzene | 0.1 | 0.02 | 0.01 |
| MTBE | 0.01 | 0.28 | 0.07 |
| t-Butanol | 0.01 | 0.09 | 0.03 |
| Benzene | 0.01 | 0.05 | 0.02 |
| Toluene | 0.01 | 0.02 | 0.008 |
| Ethyl Benzene | 0.01 | 0.003 | 0.002 |

# Ion Exchange

Hardness and Nitrate Removal

# Definition

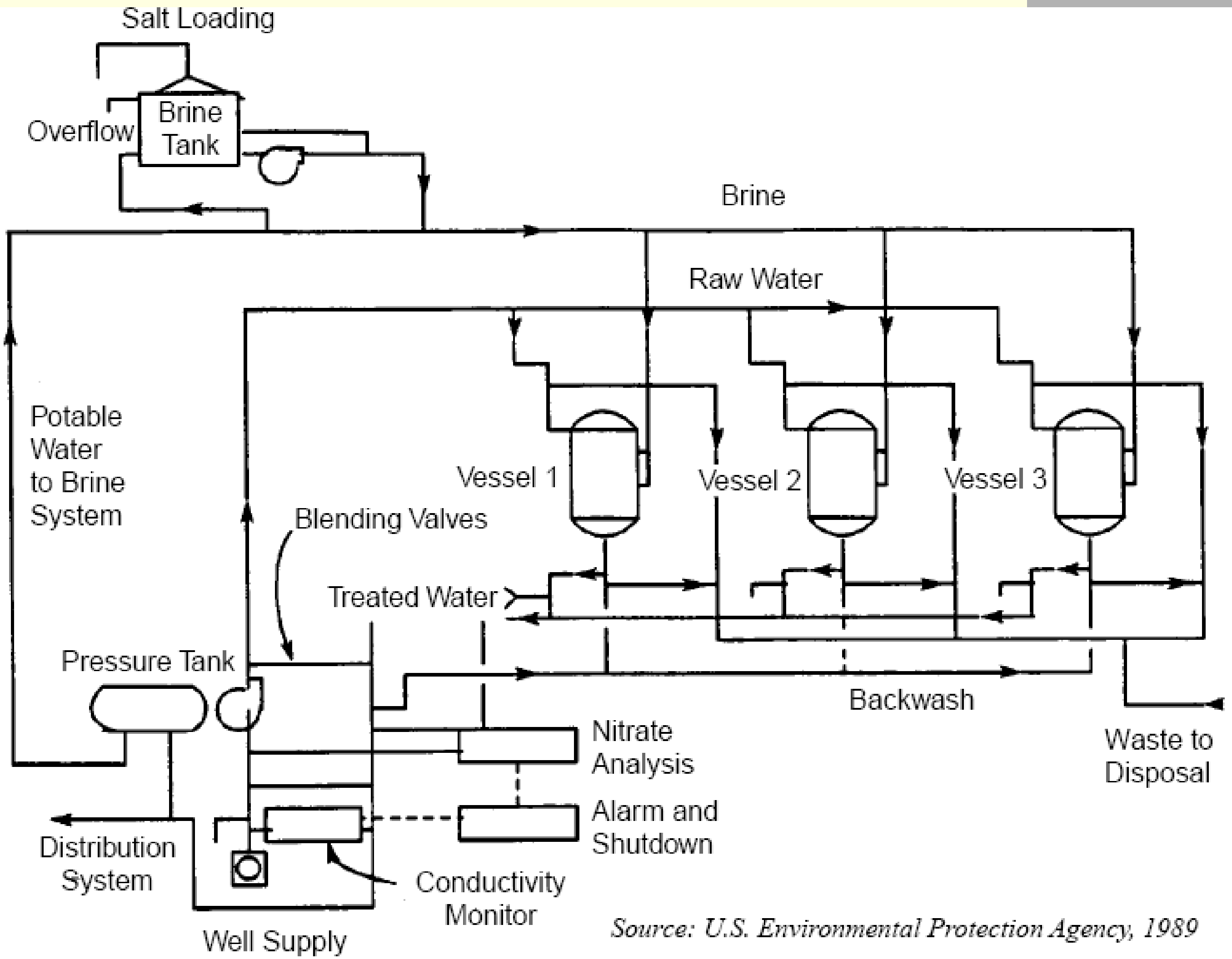
**Ion exchange** is a reversible chemical reaction wherein an ion (an atom or molecule that has lost or gained an electron and thus acquired an electrical charge) from solution is exchanged for a similarly charged ion attached to an immobile solid particle.

# Common Problems

- Hardness
- Nitrates
- Uranium
- Arsenic
- Heavy Metals

# Typical Skid Mounted Systems

# Ion Exchange Process



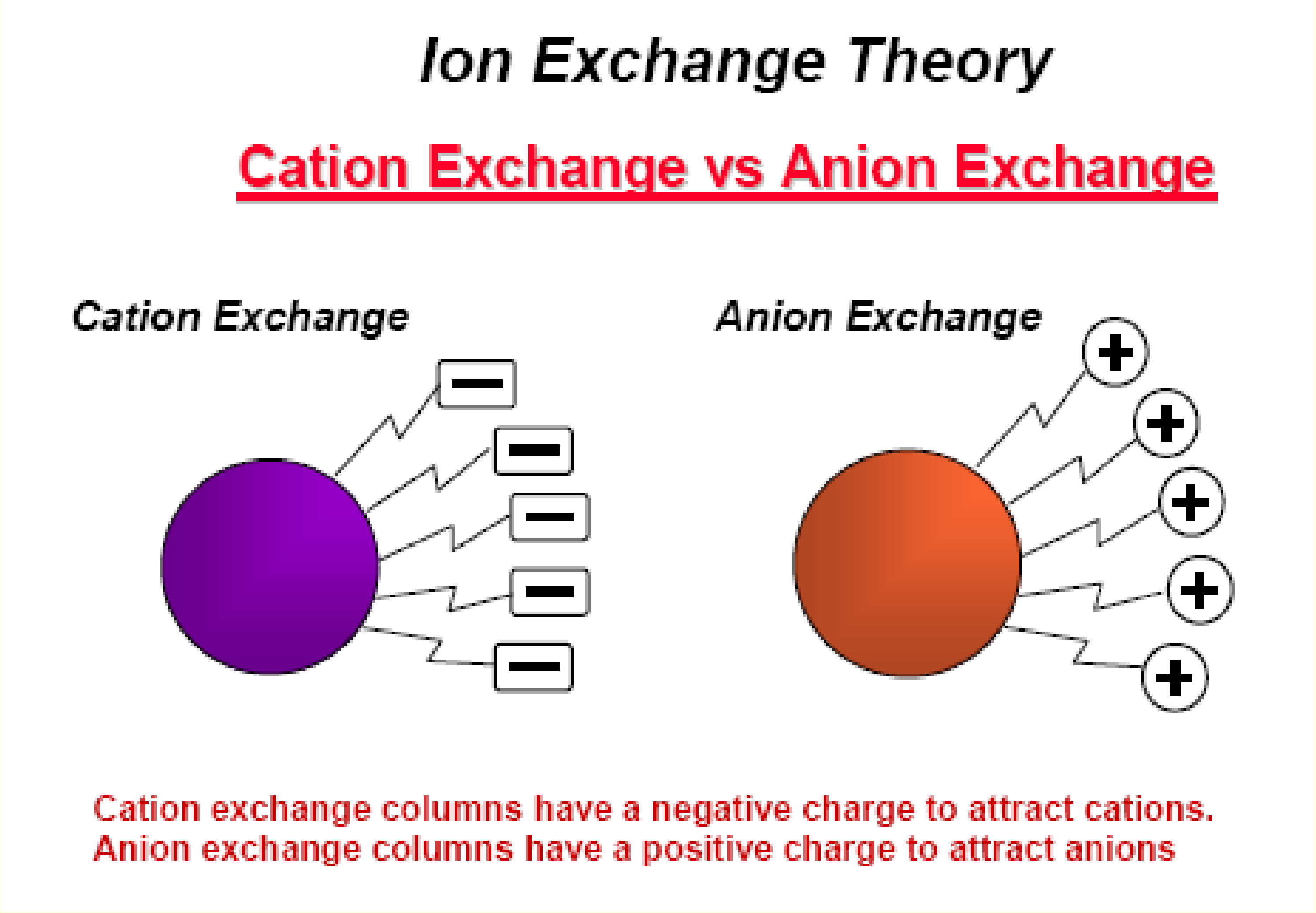

*Source: U.S. Environmental Protection Agency, 1989*

# Types of Ion Exchange Systems

+++++++ Cation exchangers, which have positively charged mobile ions available for exchange

------- Anion exchangers, whose exchangeable ions are negatively charged

# Resins



Ion Exchange Theory
Cation Exchange vs Anion Exchange
Cation Exchange
Anion Exchange
Cation exchange columns have a negative charge to attract cations.
Anion exchange columns have a positive charge to attract anions

# Strong Acid Cation Resins

- Strong acid resins are so named because their chemical behavior is similar to that of a strong acid.
- The resins are highly ionized in both the acid ($R-SO_3H$) and salt ($R-SO_3Na$) form. They can convert a metal salt to the corresponding acid by the reaction:

$$2(R-SO_3H) + NiCl_2 \rightarrow (R-SO_4),Ni + 2HCl$$

# Strong Base Anion Resins

- Strong base resins are highly ionized and can be used over the entire pH range.
- These resins are used in the hydroxide (OH) form for water deionization. They will react with anions in solution and can convert an acid solution to pure water:

$$R\text{--}NH_3OH + HCl \rightarrow R\text{-}NH_3Cl + HOH$$

# Selectivity of ion Exchange Resins Order of Decreasing Preference

Strong acid cation exchanger

1. Lead
2. Calcium
3. Nickel
4. Cadmium
5. Copper
6. Zinc
7. Magnesium
8. Potassium
9. Hydrogen
10. Ammonia
11. Sodium

Strong base anion exchanger

1. Iodide
2. Nitrate
3. Bisulfite
4. Chloride
5. Cyanide
6. Sulfate
7. Hydroxide
8. Fluoride
9. Bicarbonate

# About Ion Exchange Media

- These solid ion exchange particles are either naturally occurring inorganic zeolites or synthetically produced organic resins.
- The synthetic organic resins are the predominant type used today because their characteristics can be tailored to specific applications.
- An organic ion exchange resin is composed of high-molecular-weight polyelectrolytes that can exchange their mobile ions for ions of similar charge from the surrounding medium.
- Each resin has a distinct number of mobile ion sites that set the maximum quantity of exchanges per unit of resin.

# Regeneration Process

1. The column is backwashed to remove suspended solids collected by the bed during the service cycle and to eliminate channels that may have formed during this cycle. The back-wash flow fluidizes the bed, releases trapped particles, and reorients the resin particles according to size.
2. The resin bed is brought in contact with the regenerant solution. In the case of the cation resin, acid elutes the collected ions and converts the bed to the hydrogen form. A slow water rinse then removes any residual acid.
3. The bed is brought in contact with a sodium hydroxide solution to convert the resin to the sodium form. Again, a slow water rinse is used to remove residual caustic. The slow rinse pushes the last of the regenerant through the column.
4. The resin bed is subjected to a fast rinse that removes the last traces of the regenerant solution and ensures good flow characteristics.
5. The column is returned to service.

# About Calculations

- Resin capacity is usually expressed in terms of equivalents per liter (eq/L) of resin.
- An equivalent is the molecular weight in grams of the compound divided by its electrical charge or valence. For example a resin with an exchange capacity of 1 eq/L could remove 37.5 g of divalent zinc ($Zn^{+2}$, molecular weight of 65) from solution.
- Much of the experience with ion exchange has been in the field of water softening: therefore, capacities will frequently be expressed in terms of kg of calcium carbonate per cubic foot of resin.
- This unit can be converted to equivalents per liter by multiplying by 0.0458.
- The capacities are strongly influenced by the quantity of acid or base used to regenerate the resin.
- Weak acid and weak base systems are more efficiently regenerated; their capacity increases almost linearly with regenerate dose.

# Quick 80% Accuracy Calculation

**Cation columns**

1. Take your water TDS (total dissolved solids) analysis.
2. Look at Calcium, Magnesium and Sodium concentrations in ppm.
3. Add up the total ppm and divide by 17.1 (i.e., 250 ppm/17.1 = 14.6 grams/gal).
4. Assuming a conservative 16 kilogram/cu. ft. capacity with an economical regeneration, now divide 16,000 by 14.6 (16000/14.6 = 1095).
5. You will get over a thousand gallons of decationized water per cubic foot of resin.

# Quick 80% Accuracy Calculation

**Anion columns**

1. Next add up the anions, they should be equal to the cations plus silica ($SiO_2$) and dissolved $CO_2$ .
2. Add up the anions plus silica and carbon dioxide in ppm. Lets say total carbonate and silica is 20 ppm.
3. Take the total anion ppm and divide by 17.1 (270 (250+20)ppm /17.1 = 15.8 g/gal..).
4. Divide 14 kilogram/$ft^3$ by your answer (14,000/15.8 = 886 gallons per cubic foot).
5. A 5 gpm system would require about 2.5 cu.ft. of cation resin and about 3 cubic feet of anion resin, resulting in about 2500 gallons of DI water between regenerations.

# MIEX Ion Exchange Process- Magnetic Ion Exchange