## Cartwright Consulting Co.

www.cartwright-consulting.com

pscartwright@msn.com

**United States Office**
8324 16th Avenue South
Minneapolis, MN 55425-1742
Phone: (952) 854-4911
Fax: (952) 854-6964

**European Office**
President Kennedylaan 94
2343 GT Oegstgeest
The Netherlands
Phone: 31-71-5154417
Fax: 31-71-5156636

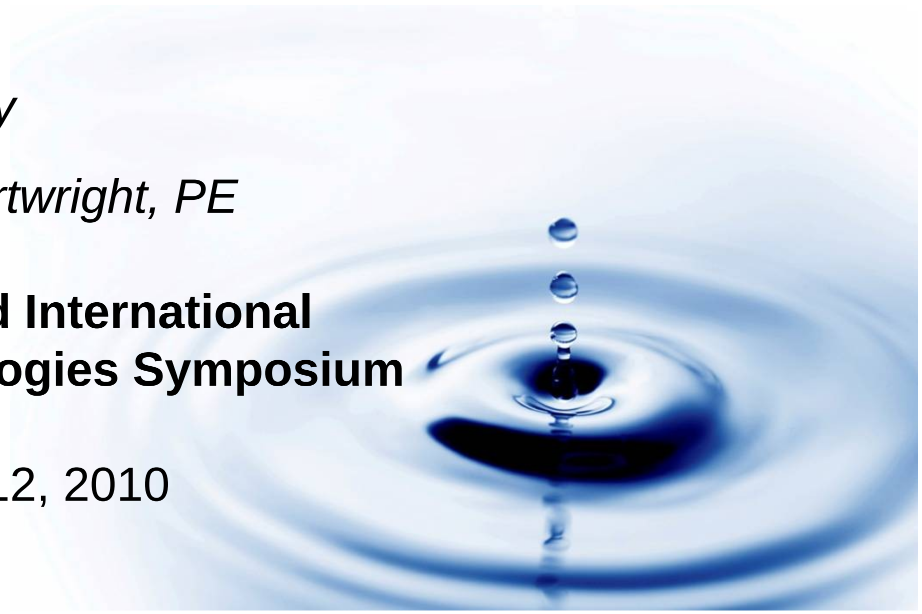

# WATER REUSE TECHNOLOGIES

*by*

*Peter S. Cartwright, PE*

**IAPMO Second International**
**Emerging Technologies Symposium**

May 11-12, 2010



# Introduction

**Of All Water on this Planet:**

97%  Seawater

2.4%  Glaciers, Ice Caps, Permanent Snow

0.6%  Rivers and Lakes

# Shortages of Acceptable Quality Due to:

- Steady migration of people into cites (increasing pressure on existing infrastructure).
- Increasing agricultural and industrial activities.
- Economic growth (as standard of living increases, so does per capita water usage).
- Recognition of new, health-related water contaminants, particularly microorganisms and PCPPs (personal care and pharmaceutical products).
- The inability of current water treatment practices to adequately purify water on a large scale.

# Reluctance to Embrace Reuse Due to:

- The "yuck" factor, particularly in reusing biological wastewater.
- Insufficient knowledge of practical reuse technologies.
- Economic factors.
- Lack of commitment.

# Water Reuse Mindset:

- ♦ Determine exactly what contaminants are present, along with their concentrations.
- ♦ Determine the quality of water required for reuse.
- ♦ Test and implement the optimum technologies to treat the wastewater for reuse.

# Waterborne Contaminants

| Class | Examples |
|---|---|
| Suspended solids | Dirt, clay, colloidal materials, silt, dust, insoluble metal oxides and hydroxides |
| Dissolved organics | Trihalomethanes, synthetic organic chemicals, humic acids, fulvic acids |
| Dissolved ionics (salts) | Heavy metals, silica, arsenic, nitrate, chlorides, carbonates |
| Microorganisms | Bacteria, viruses, protozoan cysts, fungi, algae, molds, yeast cells |
| Gases | Hydrogen sulfide, methane, radon, carbon dioxide |

| Treatment Technologies | Suspended Solids Removal | Dissolved Organic Removal | Dissolved Salts Removal | Micro-organism Removal |
|---|---|---|---|---|
| **BIOLOGICAL PROCESSES** | | | | |
| MBR (Membrane Bioreactor) | X | — | — | X |
| Activated sludge | X | X | — | X |
| Anaerobic digestion | X | X | — | — |
| Bio-filters | — | X | — | — |
| EXTENDED AERATION | | | | |
| Bio-denitrification | — | L | — | — |
| Bio-nitrification | X | X | — | — |
| Pasveer oxidation ditch | X | X | — | X |
| **CHEMICAL PROCESSES** | | | | |
| CHEMICAL OXIDATION | | | | |
| Catalytic oxidation | X | X | — | X |
| Chlorination | X | X | — | X |
| Ozonation | — | L | — | X |
| Wet air oxidation | X | X | — | X |
| CHEMICAL PRECIPITATION | — | — | X | — |
| CHEMICAL REDUCTION | — | — | X | — |
| Ion exchange | — | — | X | — |
| Liquid-liquid (solvent) | — | — | X | — |
| COAGULATION | | | | |
| Inorganic chemicals | X | X | — | X |
| Polyelectrolytes | X | X | — | X |
| **ELECTOLYTIC PROCESSES** | | | | |
| Electrodialysis | — | — | X | L |
| Electrodeionization | — | — | X | — |
| Electrolysis | — | — | X | — |
| Ultraviolet irradiation | — | — | — | X |
| EXTRACTIONS | | | | |
| INCINERATION | | | | |
| Fluidized-bed | X | X | — | X |
| **PHYSICAL PROCESSES** | | | | |
| CARBON ADSORPTION | | | | |
| Granular activated | X | X | — | — |
| Powdered | X | X | — | X |
| SPECIALTY RESINS | — | L | L | — |
| FILTRATION | | | | |
| Diatomaceous-earth filtration | X | — | — | X |
| Multi-media filtration | X | — | — | X |
| Micro-screening | X | — | — | X |
| Sand filtration | X | — | — | X |
| Flocculation-sedimentation | X | — | — | X |
| DAF (Dissolved air flotation) | X | X | — | — |
| Foam separation | X | — | X | — |
| **MEMBRANE PROCESSES** | | | | |
| Microfiltration | X | — | — | X |
| Ultrafiltration | X | X | — | X |
| Nanofiltation | X | X | L | X |
| Reverse osmosis | X | X | X | X |
| Stripping (air or steam) | X | X | — | — |
| **THERMAL PROCESSES** | | | | |
| Distillation | X | X | X | X |
| Freezing | — | X | X | — |

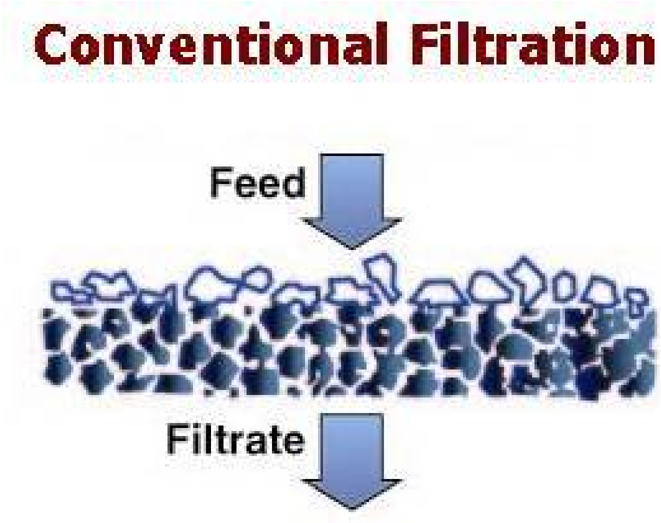
*L = under certain conditions there will be limited effectiveness*

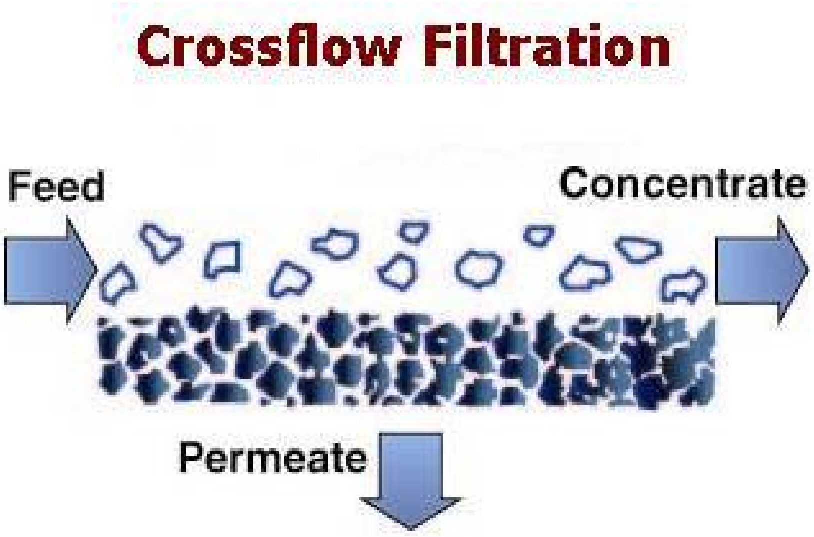
# Water and Wastewater Treatment Technologies

# Membrane Technologies

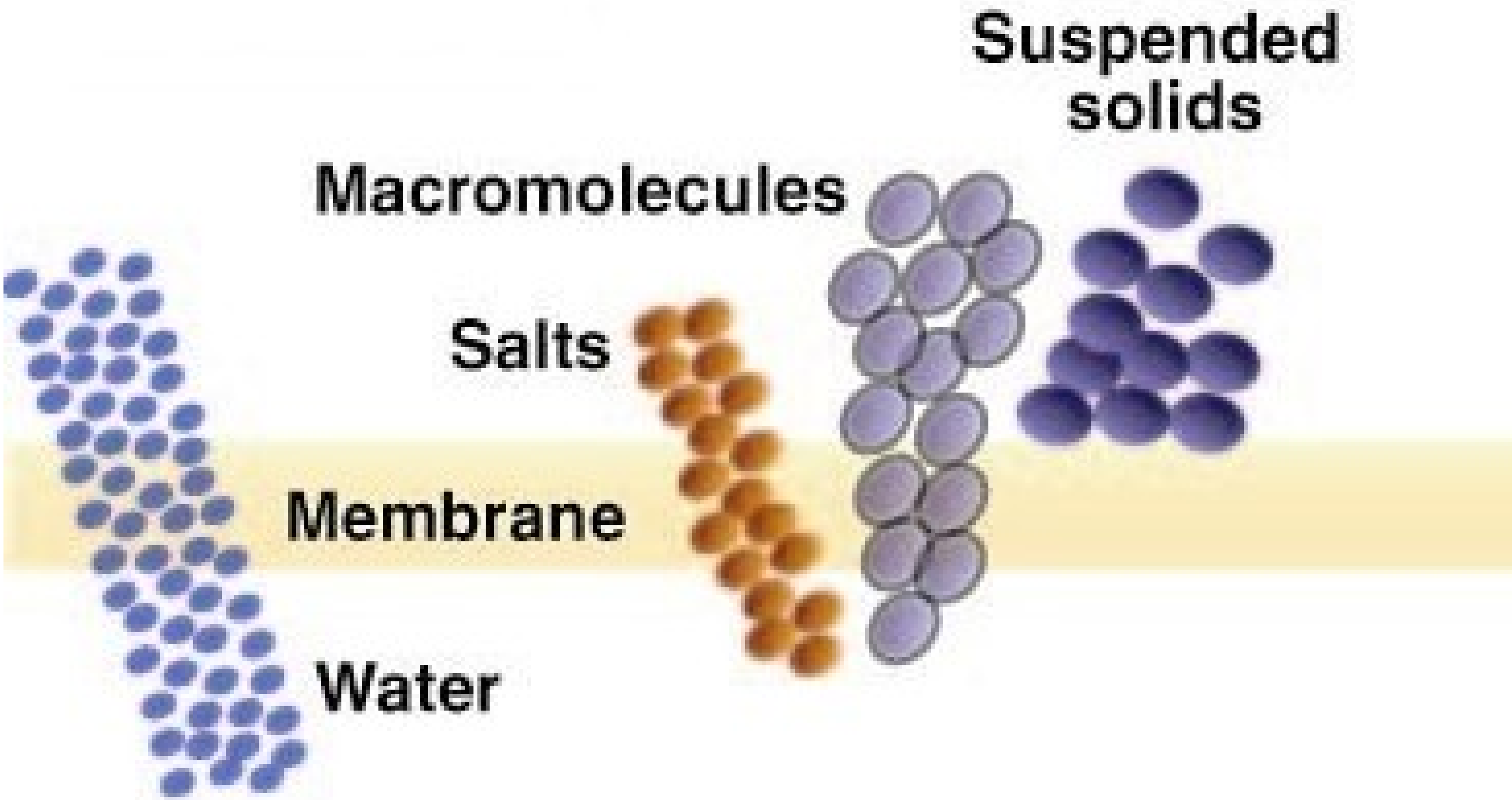
- Continuous process, resulting in automatic and uninterrupted operation
- Low energy utilization involving neither phase nor temperature changes
- Modular design – no significant size limitations
- Minimal moving parts with low maintenance requirements
- No effect on form or chemistry of contaminants
- Discrete membrane barrier to ensure physical separation of contaminants
- No chemical addition requirements to effect separation

# Conventional vs. Crossflow

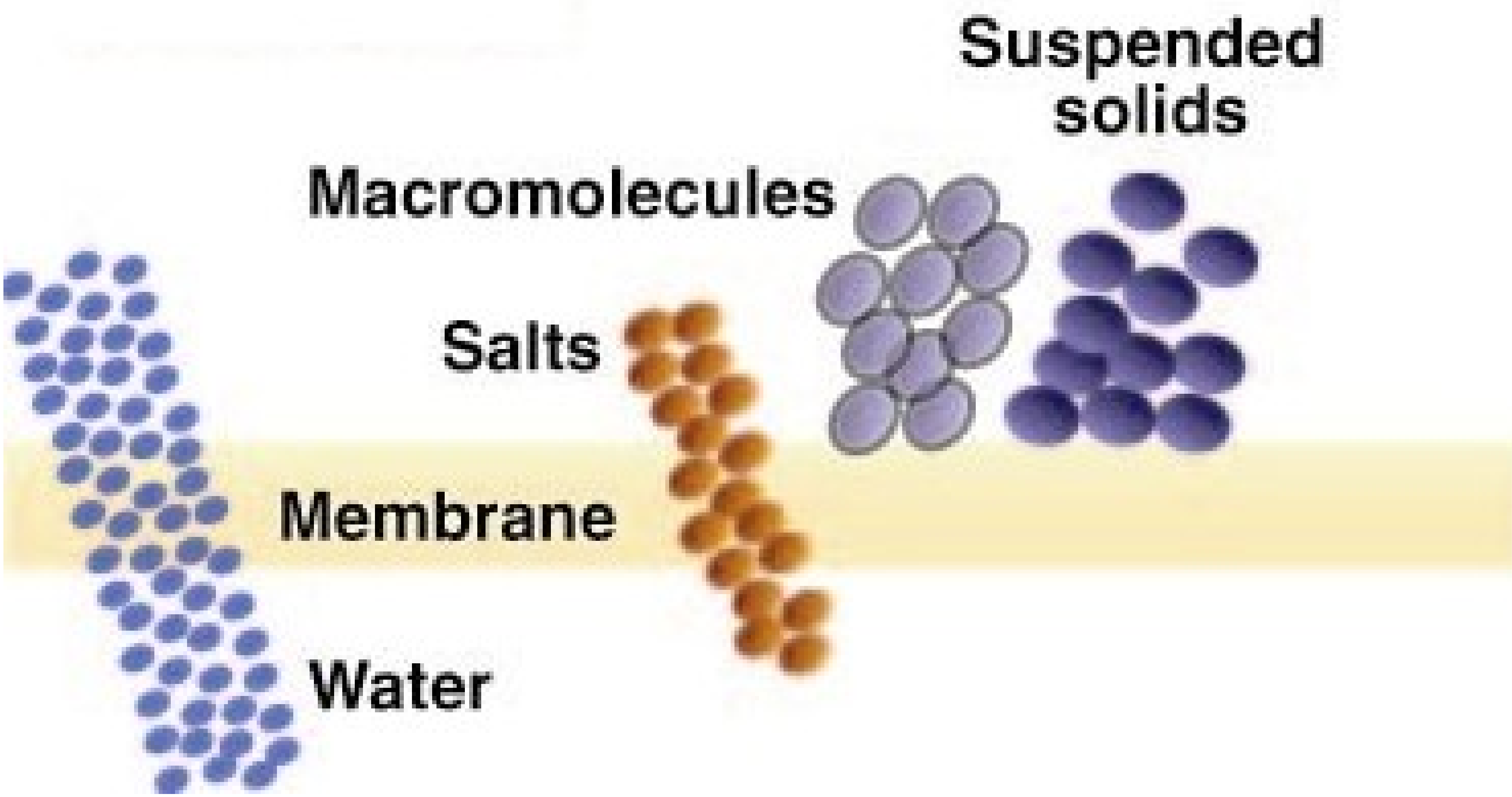


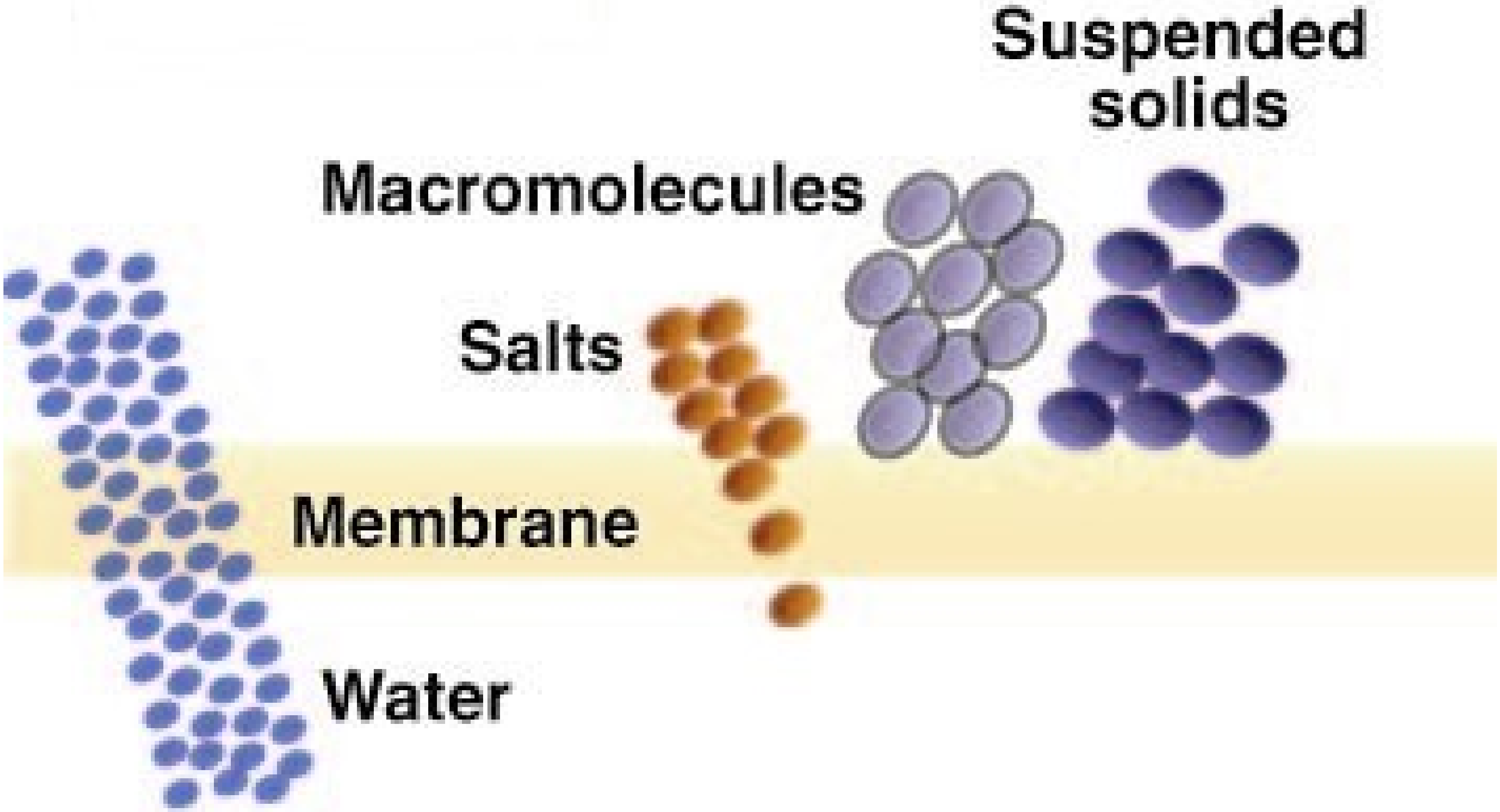
# Microfiltration



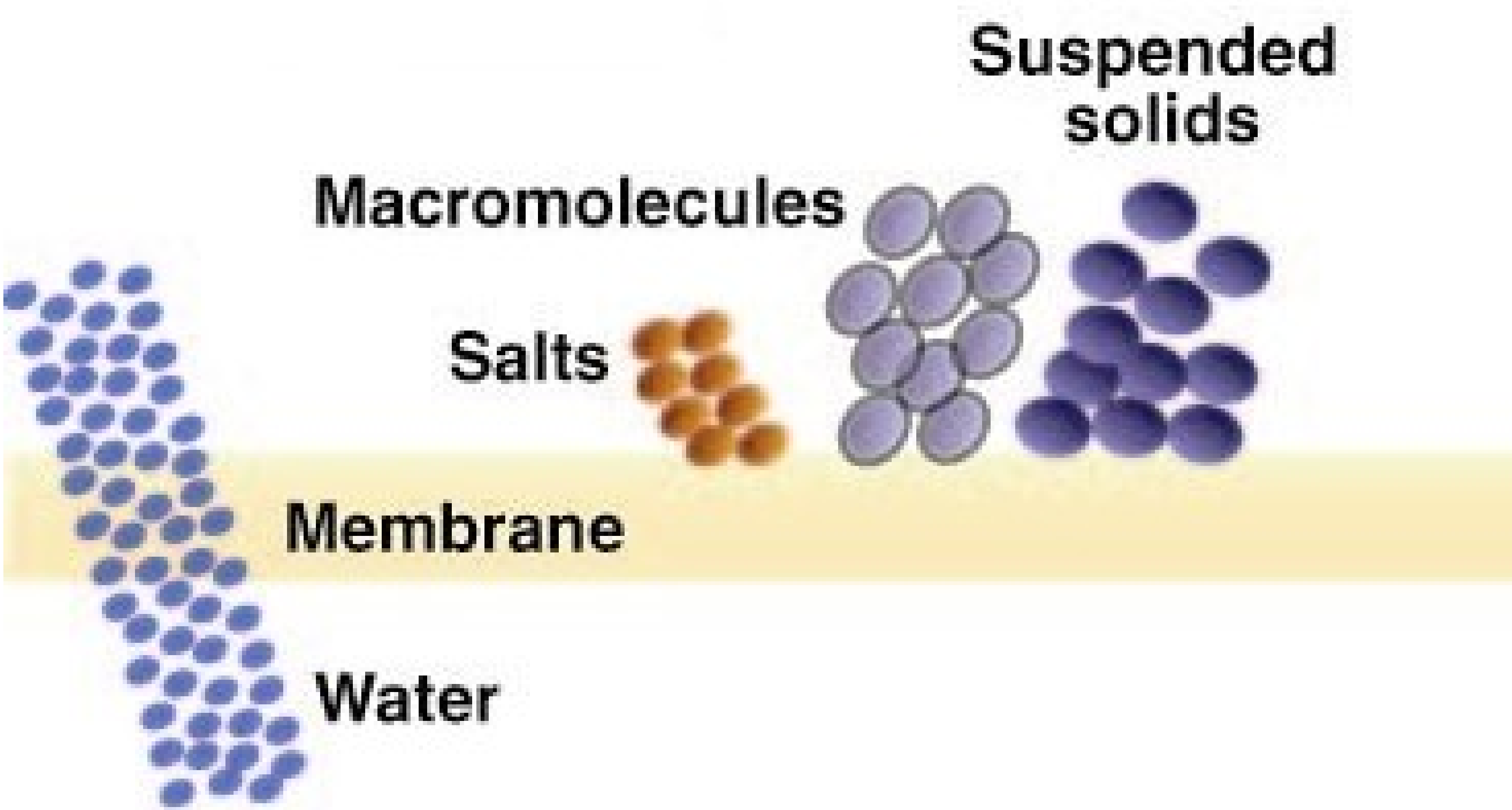
# Ultrafiltration



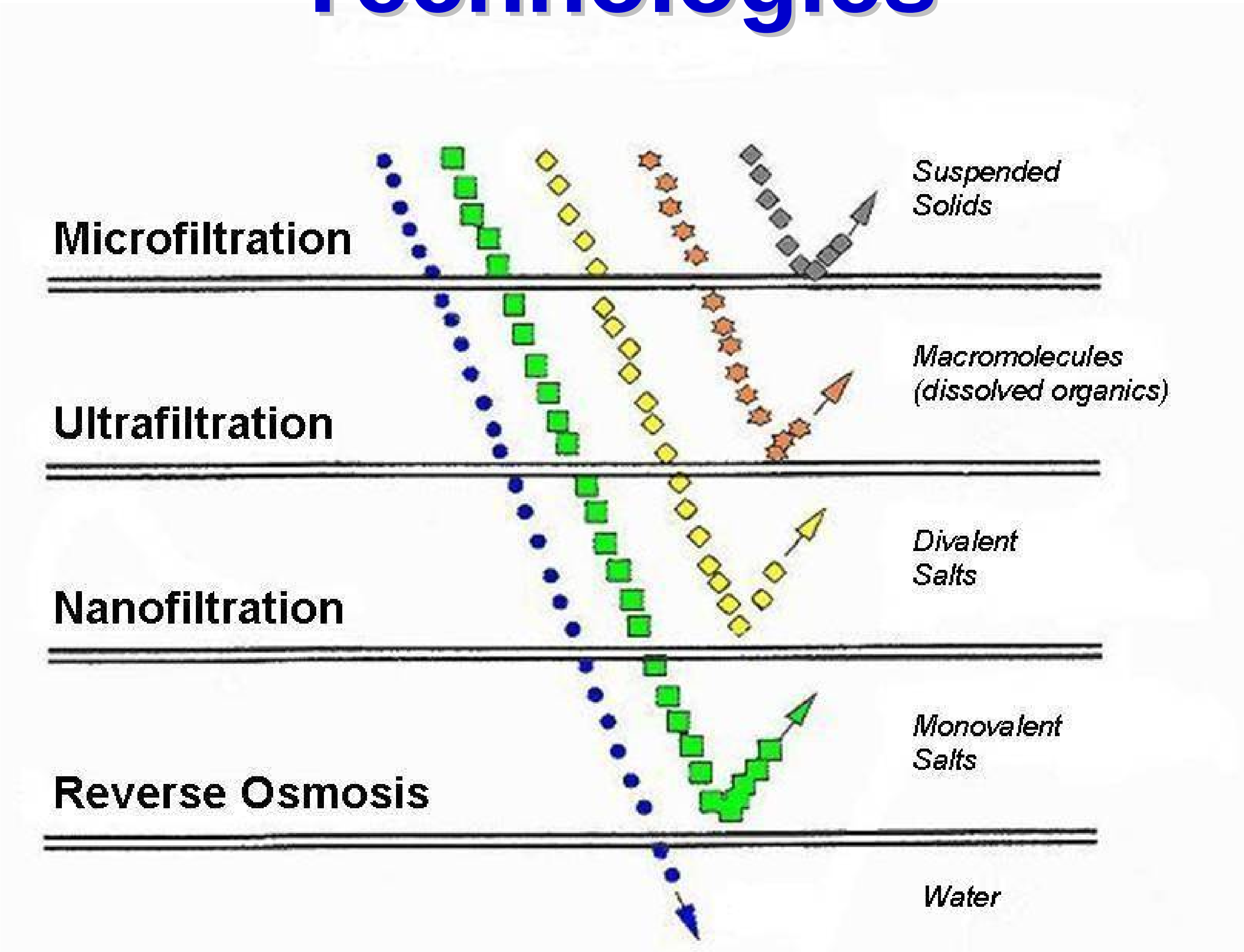
# Nanofiltration



# Reverse Osmosis



# Membrane Separation Technologies

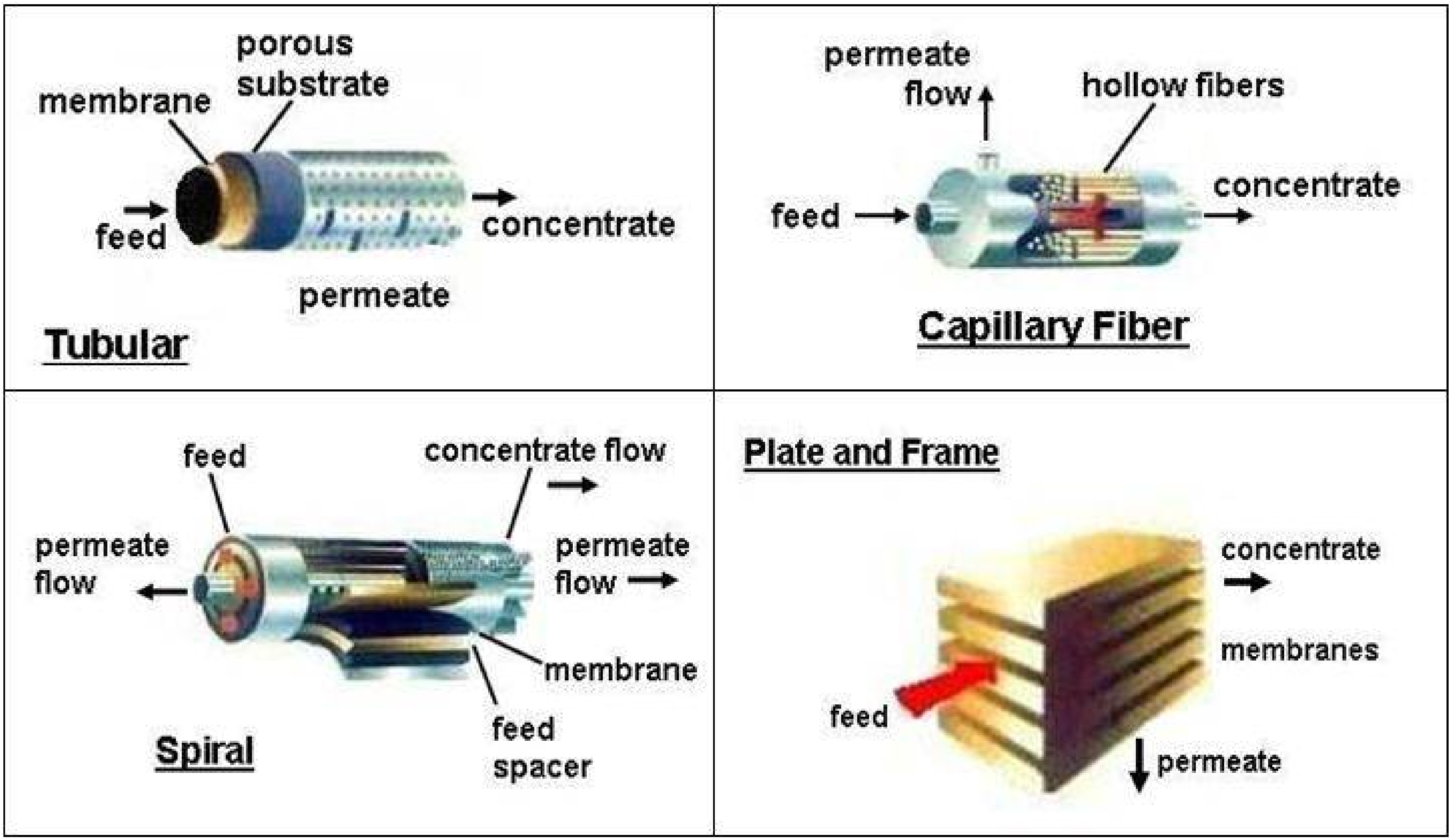


# Membrane Technologies Compared

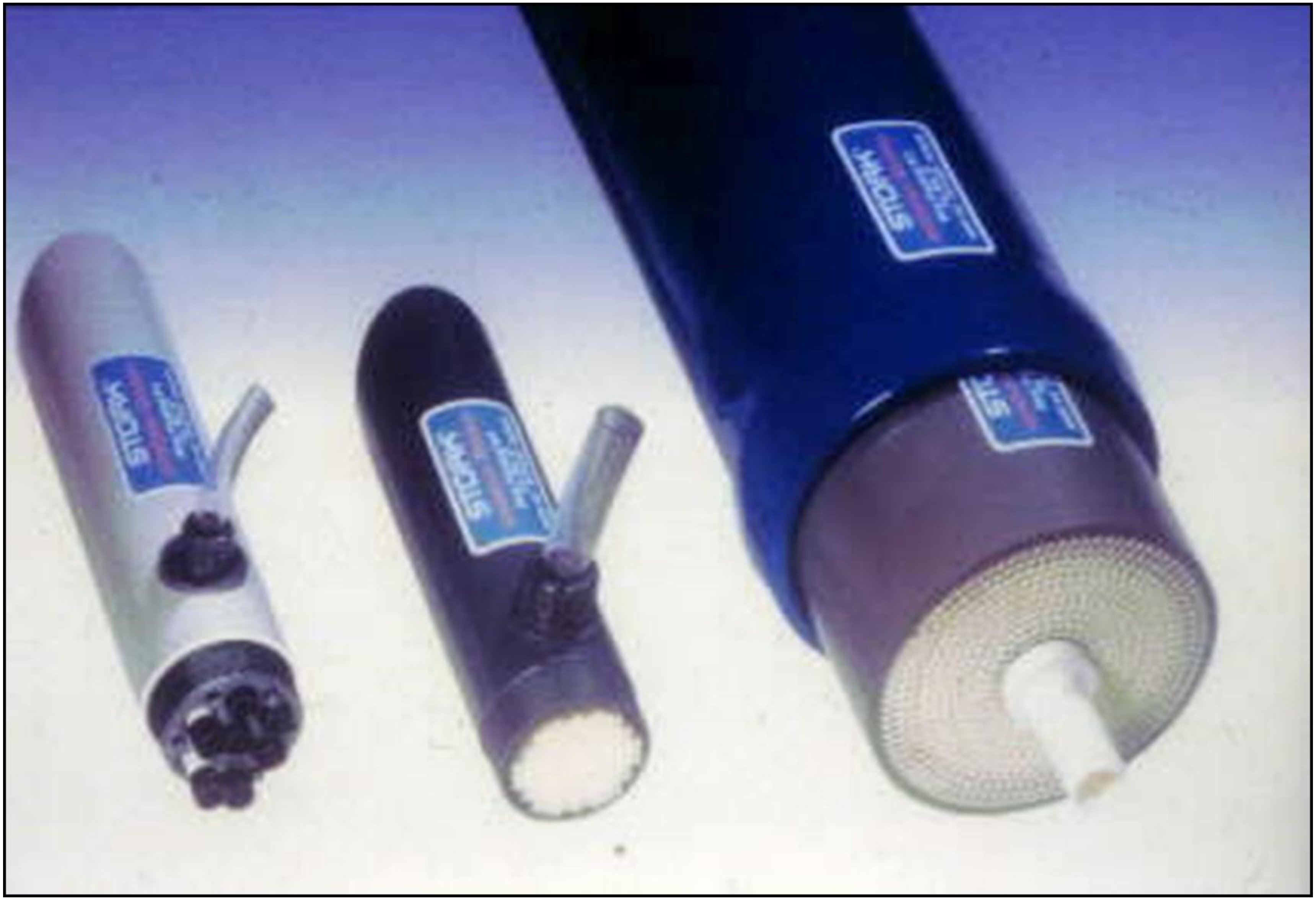
| Feature | Microfiltration | Ultrafiltration | Nanofiltration | Reverse Osmosis |
|---|---|---|---|---|
| Polymers | Ceramics, Sintered metals, Polypropylene, Polysulfone, Polyethersulfone, Polyvinylidene fluoride, Polytetrafluoroethyliene | Ceramics, Sintered metals, Polypropylene, Polysulfone, Polyethersulfone, Polyvinylidene fluoride | Thin film composites, Cellulosics | Thin film composites, Cellulosics |
| Pore Size Range (micrometers) | 0.1 - 1.0 | 0.001 - 0.1 | 0.0001 - 0.001 | <0.0001 |
| Molecular Weight Cutoff Range (Daltons) | >100,000 | 1,000 - 100,000 | 300 - 1,000 | 50 - 300 |
| Operating Pressure Range | <30 | 20 - 100 | 50 - 300 | 225 - 1,000 |
| Suspended Solids Removal | Yes | Yes | Yes | Yes |
| Dissolved Organics Removal | None | Yes | Yes | Yes |
| Dissolved Inorganics Removal | None | None | 20-95% | 95-99+% |
| Microorganism Removal | Protozoan cysts, algae, bacteria* | Protozoan cysts, algae, bacteria*, viruses | All* | All* |
| Osmotic Pressure Effects | None | Slight | Moderate | High |
| Concentration Capabilities | High | High | Moderate | Moderate |
| Permeate Purity (overall) | Low | Moderate | Moderate-high | High |
| Energy Usage | Low | Low | Low-moderate | Moderate |
| Membrane Stability | High | High | Moderate | Moderate |

** Under certain conditions, bacteria may grow through the membrane.*

# Membrane Element Configurations

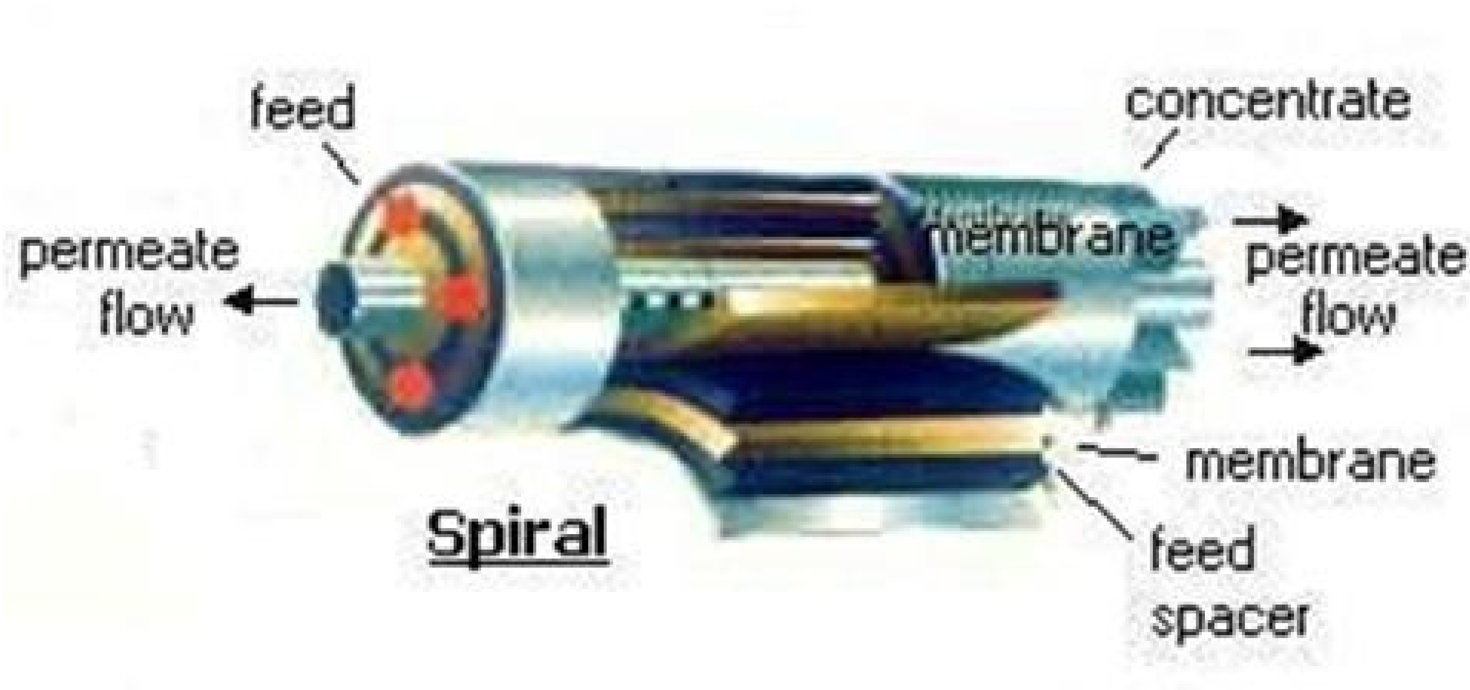


# Tubular

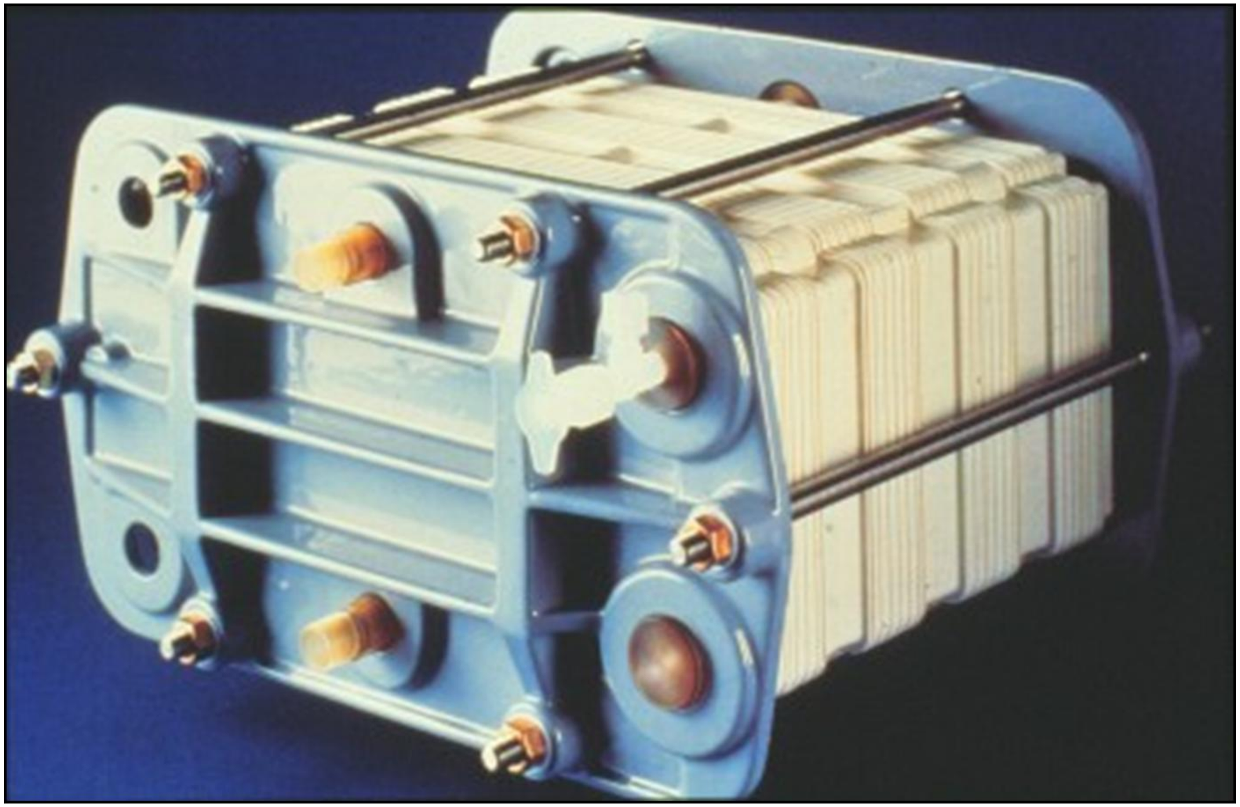


# Hollow (Capillary) Fiber

# Spiral Wound



# Plate and Frame

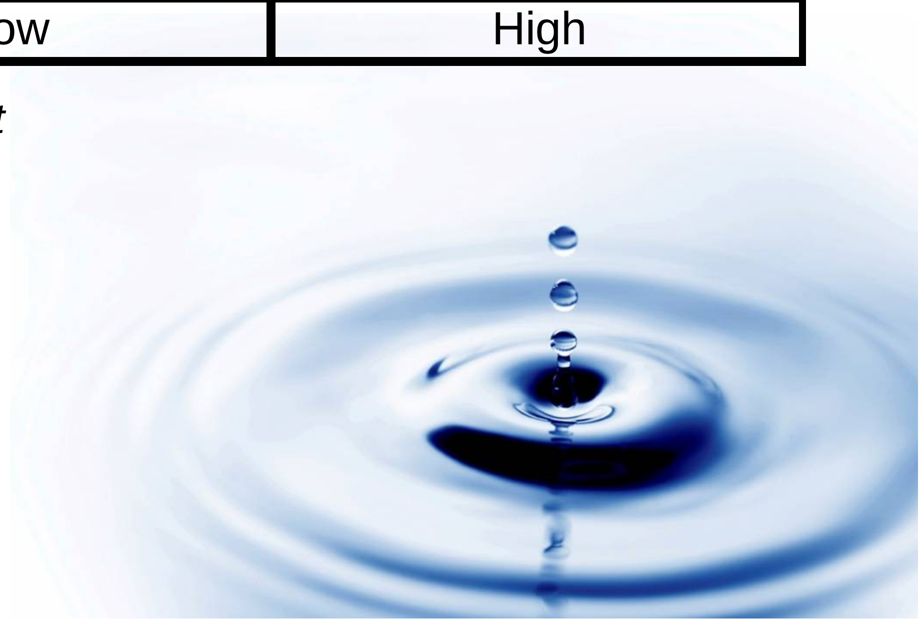


# Membrane Element Configuration Comparison

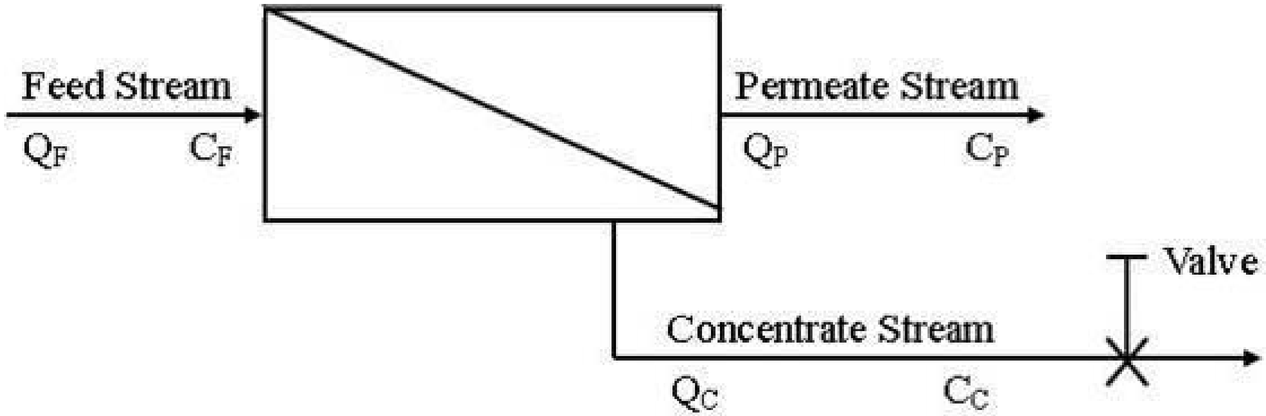
| Element Configuration | Packing Density * | Fouling Resistance ** |
|---|---|---|
| Tubular | Low | High |
| Hollow (Capillary) Fiber | Medium | Moderate |
| Spiral Wound | Medium | Low |
| Plate & Frame | Low | High |

** Membrane area per unit volume of element*

*** Tolerance to suspended solids*



# Membrane System Schematic




$Q_F$ - Feed Flow Rate
$C_F$ - Solute Concentration in Feed
$Q_P$ - Permeate Flow Rate
$C_P$ - Solute Concentration in Permeate
$Q_C$ - Concentrate Flow Rate
$C_C$ - Solute Concentration in Concentrate

$$\text{Recovery} = \frac{Q_P}{Q_F}$$

(Expressed as Percent)

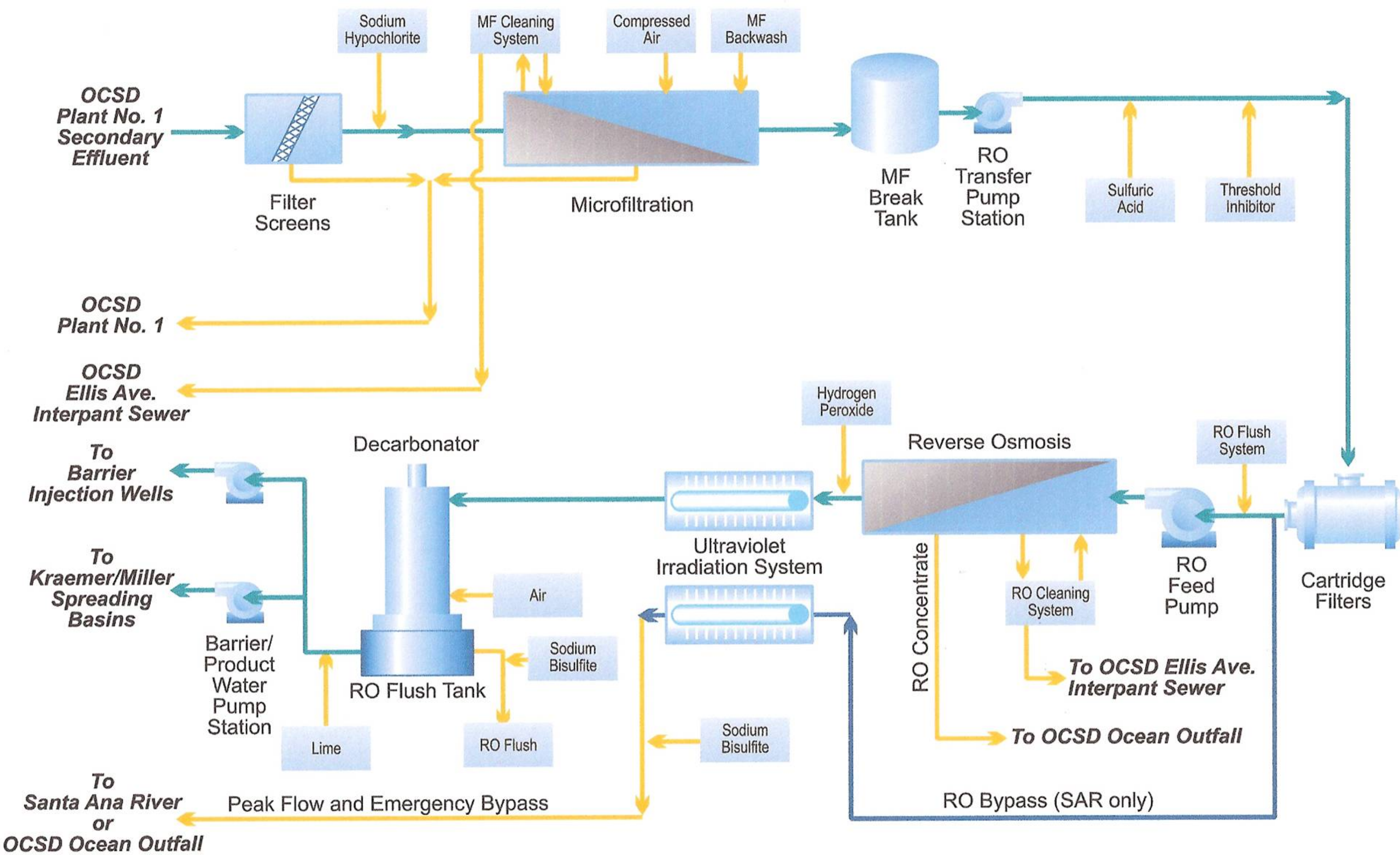
TDS = Total Dissolved Solids: Usually considered the total of the ionic contaminants (salts) in solution.

mg/L (milligrams per liter) is the same as ppm (parts per million)

# High Recovery Operation

- Higher concentration of contaminants can result in precipitation and greater propensity for fouling.
- In nanofiltration and reverse osmosis applications, the concentrated salts will result in higher osmotic pressure, requiring a higher pressure pump and a more pressure resistant system.
- Also with RO and NF, as recovery is increased, the ionic purity of the permeate decreases.
- As higher recoveries reduce the quantity of concentrate to be discharged, the higher concentration of this concentrate stream can itself present discharge problems.

# GWR System



OCSD Plant No. 1 Secondary Effluent
Sodium Hypochlorite
MF Cleaning System
Compressed Air
MF Backwash
Filter Screens
Microfiltration
MF Break Tank
RO Transfer Pump Station
Sulfuric Acid
Threshold Inhibitor
OCSD Plant No. 1
OCSD Ellis Ave. Interpant Sewer
Hydrogen Peroxide
RO Flush System
Decarbonator
Reverse Osmosis
To Barrier Injection Wells
Ultraviolet Irradiation System
RO Feed Pump
Cartridge Filters
To Kraemer/Miller Spreading Basins
Air
RO Cleaning System
RO Concentrate
Barrier/ Product Water Pump Station
Sodium Bisulfite
To OCSD Ellis Ave. Interpant Sewer
RO Flush Tank
Lime
RO Flush
Sodium Bisulfite
To OCSD Ocean Outfall
To Santa Ana River or OCSD Ocean Outfall
Peak Flow and Emergency Bypass
RO Bypass (SAR only)

# Conclusions

**Conservation**

**Collection**

**Conversion**

Require

**COMMITMENT**