Membrane Applications

2006 Surface Water Treatment Workshop
Fargo, ND

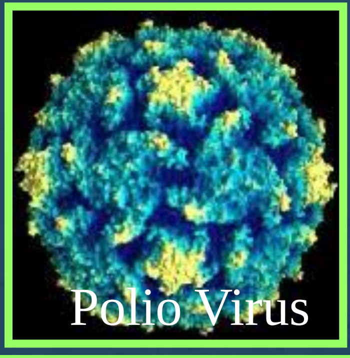
YuJung Chang, Ph.D.
HDR Engineering, Inc.

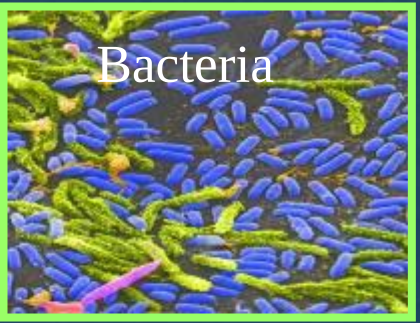
New Technologies in Demand

Increased Demand

Alternative Sources

WQ Challenges





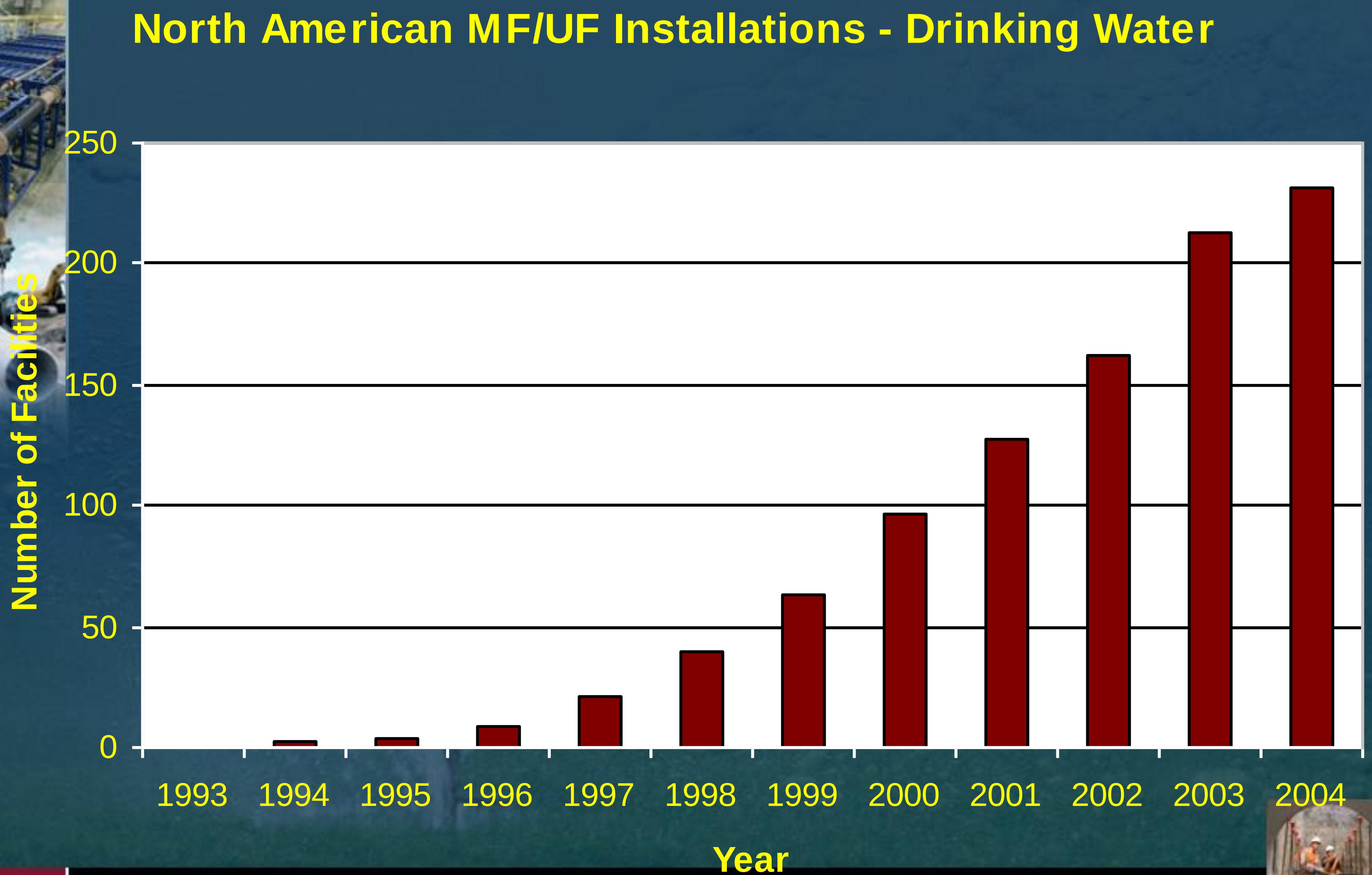
Membrane Presentation Outline

- Membrane Market Trend
- Membrane Basics
- Membrane Applications in US
- Membrane Design & Operations
- Summary

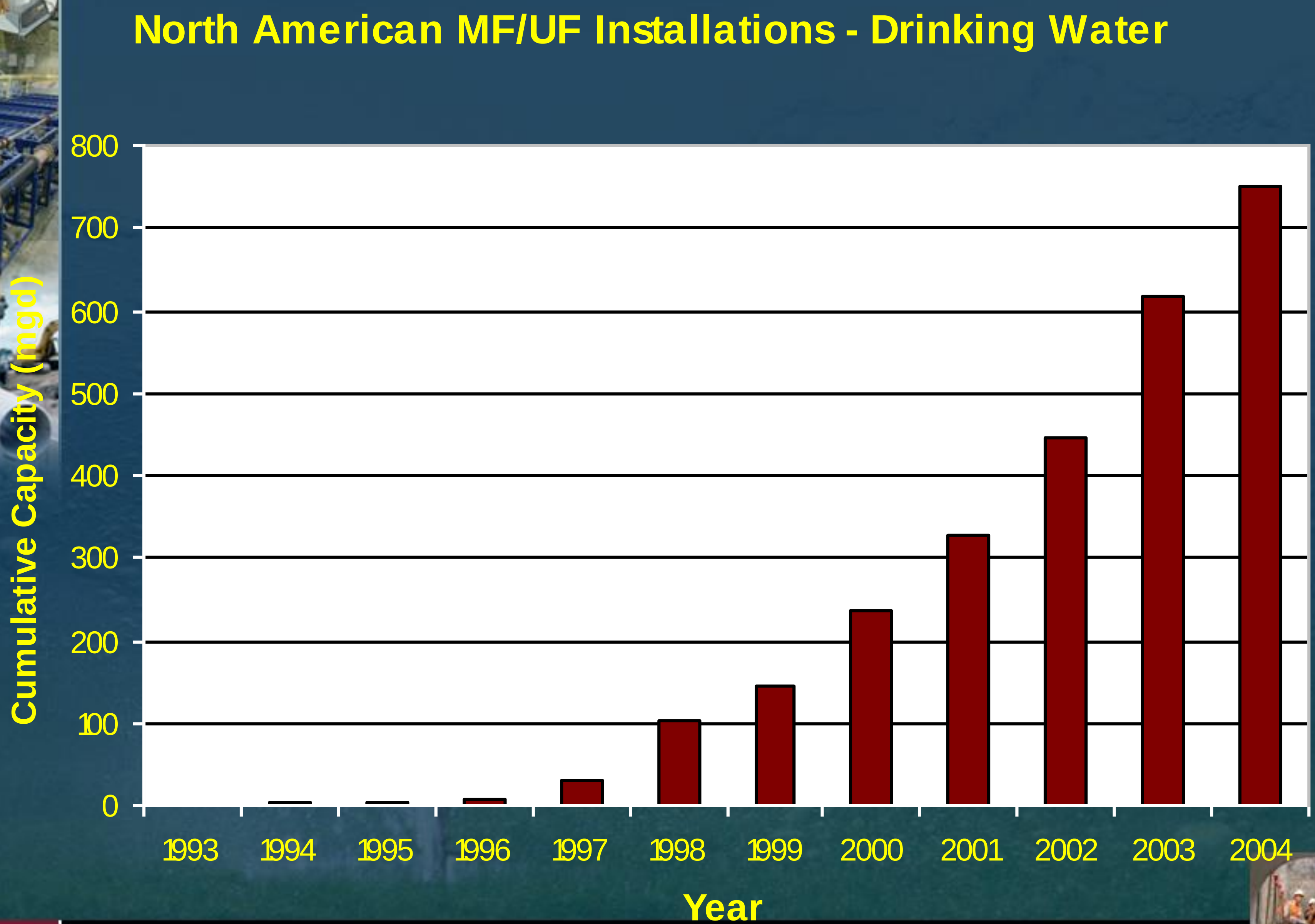
A Brief US Membrane History

- Prior to 1990 mostly RO in industrial applications
- Historically, smaller facilities (< 1 mgd)
- 1st Significant MF/UF System in North America in 1993 (Saratoga, CA – 3.6 mgd)
- Membrane Bioreactor emerged in early 1990's
- In-land brackish desalination in mid 1990's
- Over 250 Membrane WTP now on-line
- Trend is to more, and larger facilities
  - Minneapolis – 70 and 95 mgd
  - Singapore – 72 mgd

Growth of the Industry

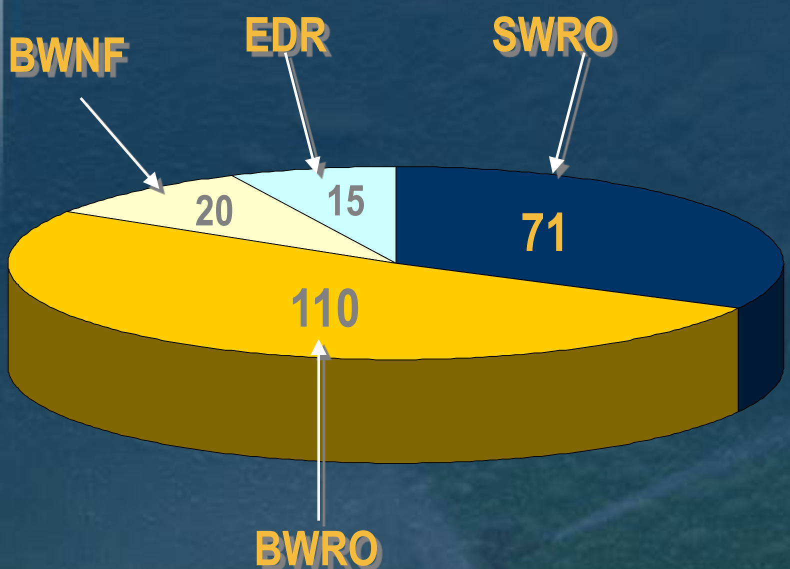


Growth of the Industry

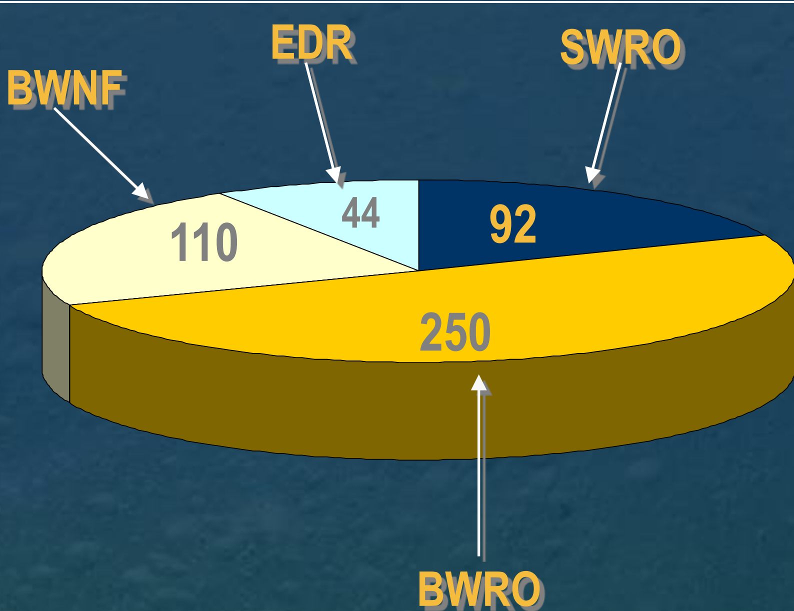


Desalination Is Growing As Well

Number of Installations



Capacity (mgd)

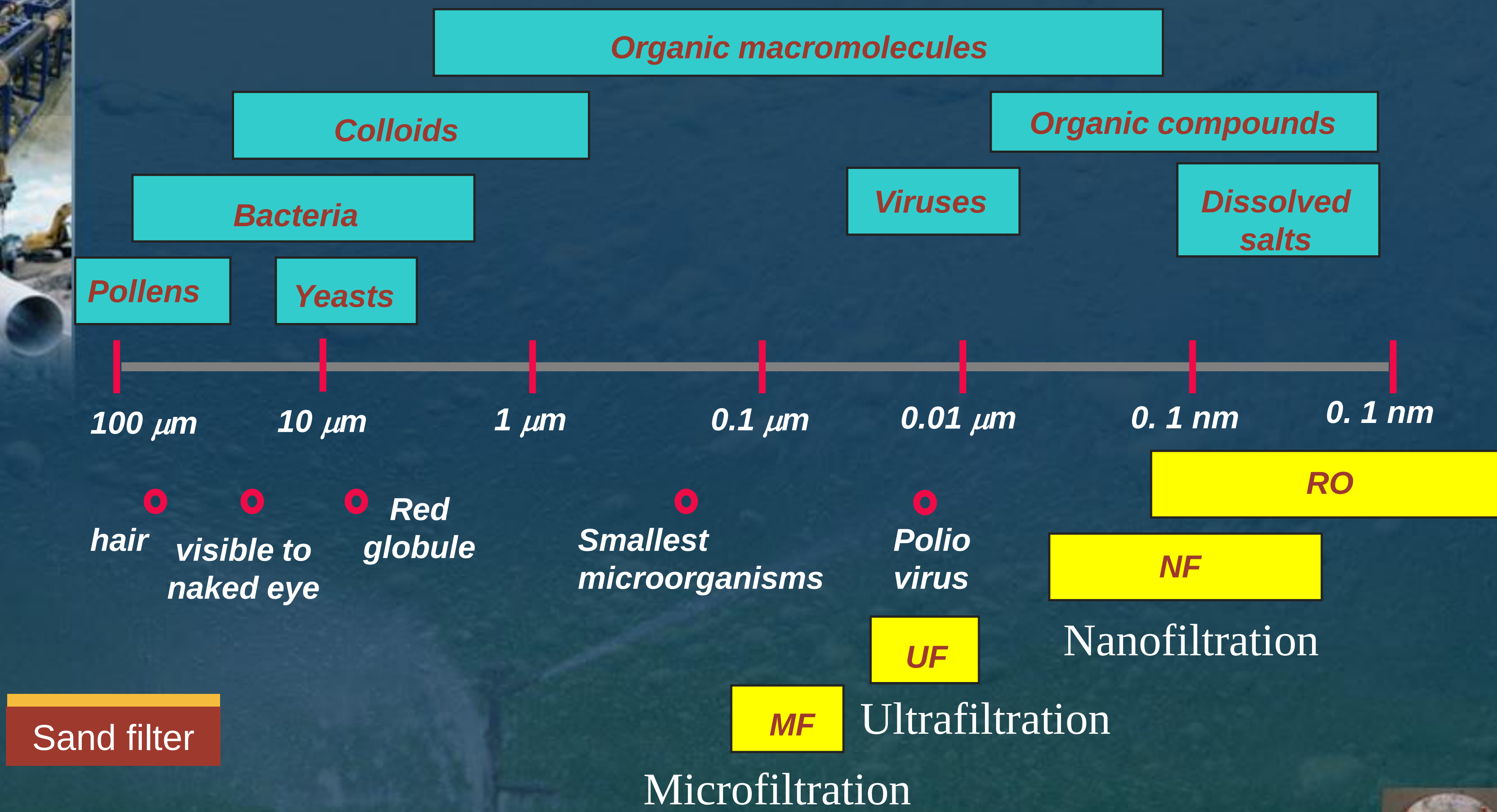


Other Perspectives

- Membrane System Sales To Reach $9 Billion by 2008 (McIlvaine Company, 2006)
  - $6.8 Billion in 2005 (33% Top End Growth)
  - Expected to Reach $10 Billion by 2010
  - Includes Desalination and Low-Pressure Membranes
- Microfiltration from $1.9 to $2.5 Billion
- Only 2.5% of US Drinking Water is Treated with MF/UF Membranes

Membrane Classifications

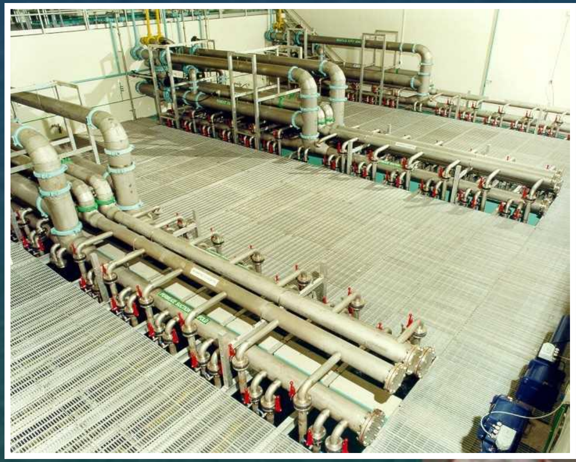
(Pore Size)



Membranes Classification
(Driving Force)

- Vacuum (Submerged Membranes)
  - Compatible with higher solid concentration
  - Can be used for retrofit
  - High energy demand with air scouring
  - Noise & evaporation concerns



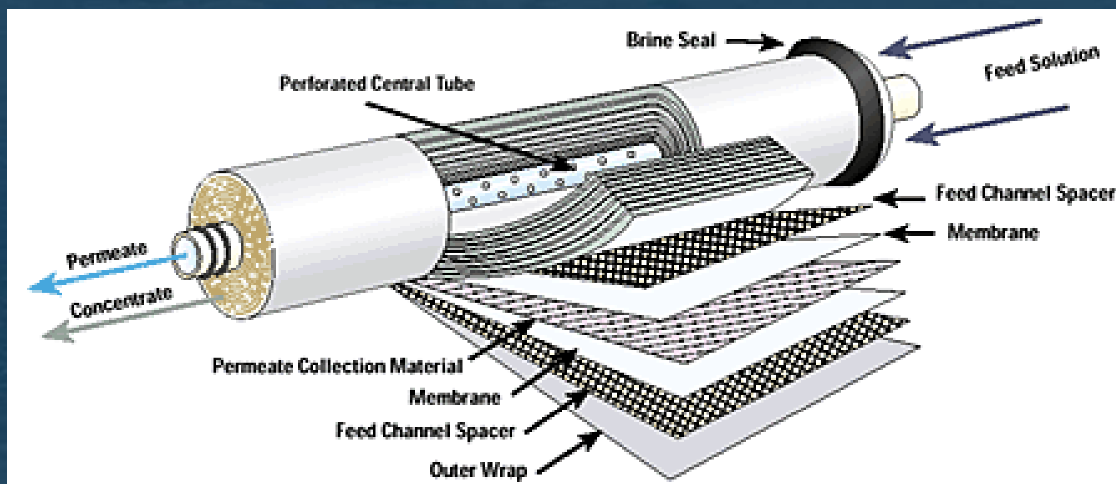



Membranes Classification
(Driving Force)

- Pressure (Canister Membranes)
  - More compact design
  - Cannot handle high solid concentration (> 100 NTU) for a substantial period of time

Membranes Classification
(Configuration)

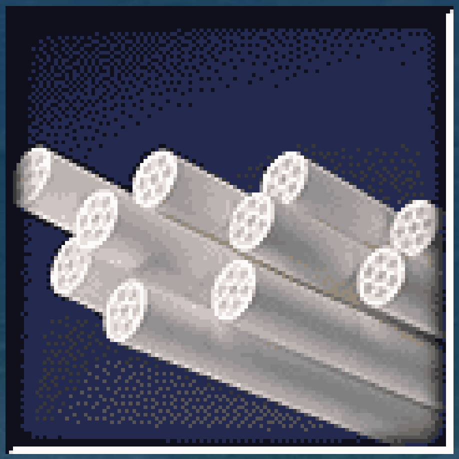
- Flat Sheet (Spiral-wound)



Mostly used in Reverse Osmosis & Nanofiltration

Membranes Classification
(Configuration)

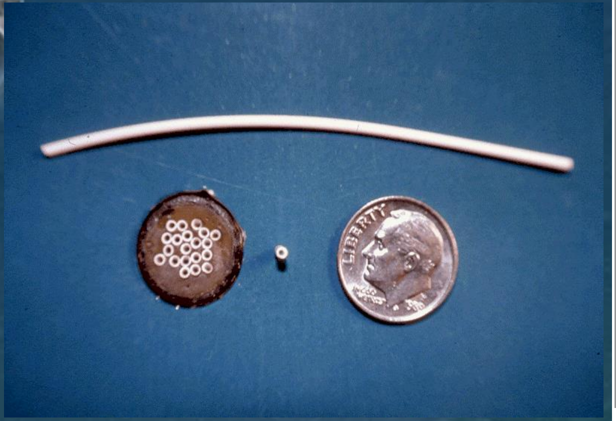
- Tubular Membranes (OD > 3 mm)

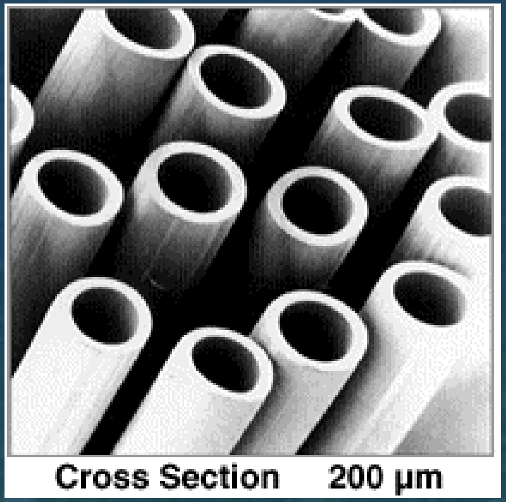


Mostly used in Industrial MF

Membranes Classification
(Configuration)

- Hollow Fiber Membranes (ID < 1.5 mm)

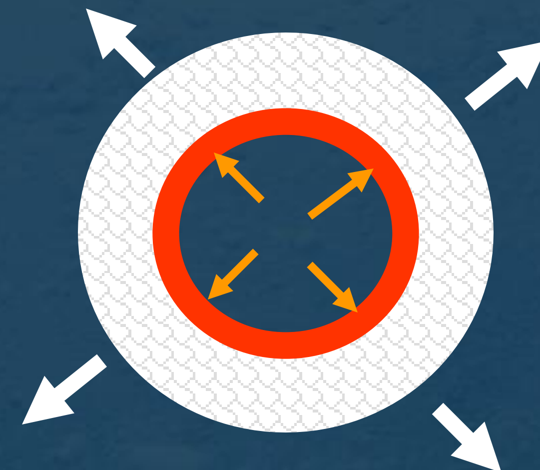




Mostly used in MF & UF

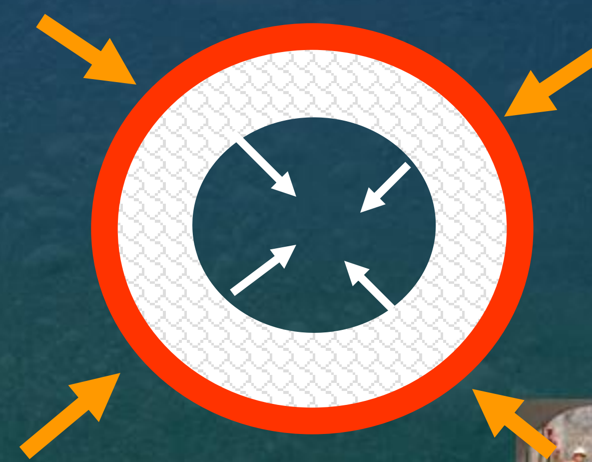
Membranes Classification
(Location of Membrane)

- Inside-out Membranes



Raw Water

Filtered Water



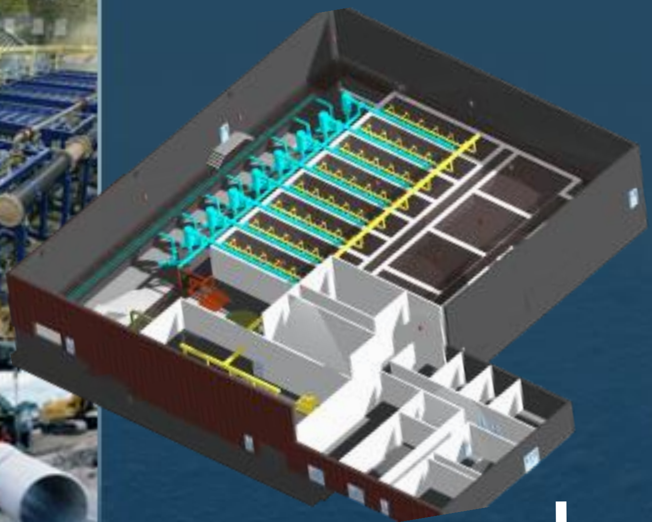
- Outside-In Membranes

Membrane Applications

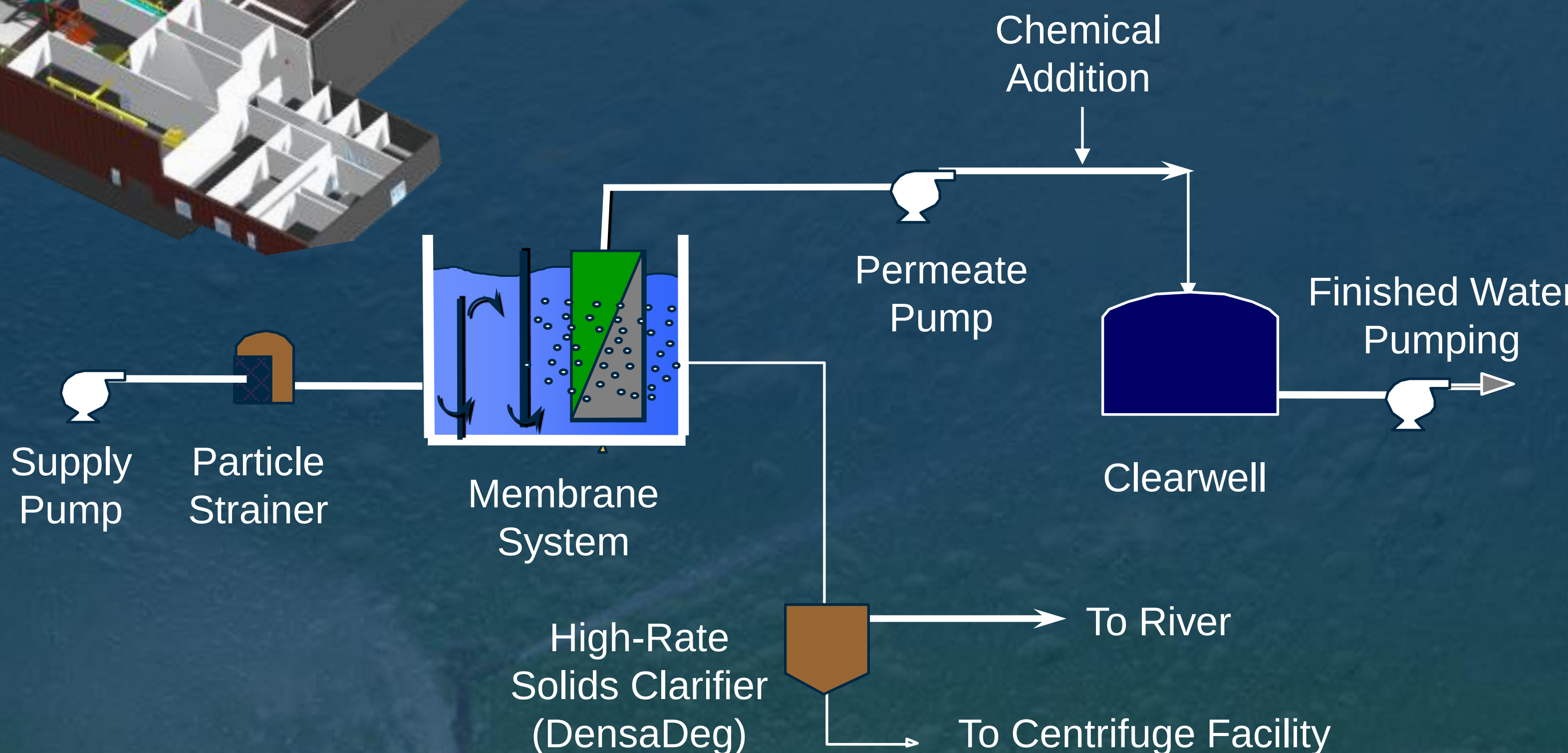
- Filtration: Low-Pressure membranes (MF/UF) for turbidity & pathogen removal
- Organic Removal: Nanofiltration (NF) for NOM removal
- Inland Brackish Desalination: RO or NF
- Seawater Desalination: RO or 2-stage NF
- Membrane Bioreactor: MF/UF MBR

Membrane Application: Filtration

City of Lancaster, PA



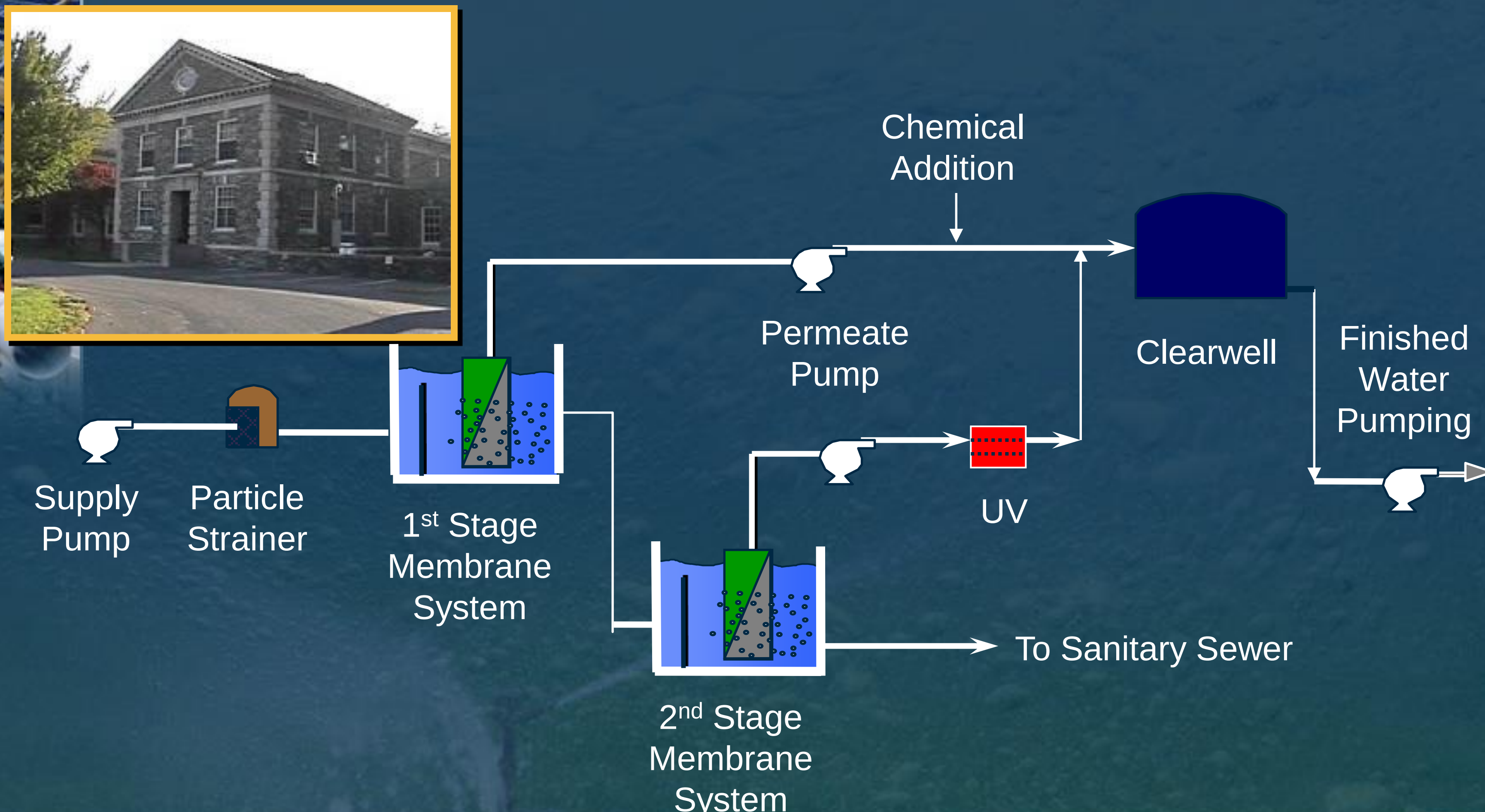
Susquehanna WTP (24 mgd)



Construction to be completed in January 2009

City of Lancaster, PA

Conestoga WTP (12 mgd)



Total construction cost (2 plants): $ 70 millions

City of Yuba City Fast-Track Filtration Upgrades

- 16 to 24 mgd expansion
- Design and construction completed in nine months
- Contract incentives and penalties
- Developed innovative approach that deferred construction of new filters and piping, resulting in a total savings of more than $2 million

Kamloops, BC, Canada

- 42 mgd Zenon UF facility
- Primary UF – Secondary UF – DAF – Centrifuge
- Membranes operate with cyclical aeration: 10 seconds on, 10 seconds off

Membrane Application: Organic Removal

Yucaipa Valley Regional Water Filtration Facility

- Pretreatment with MF (Pall), followed by NF for NOM Removal
- Direct membrane filtration with no pr
  (reservoir supply)

- 12 mgd expandable to 36 mgd
- Aesthetics extremely important

Membrane Application: Inland Brackish Desalination

Water Replenishment District: RO

- 2.5 mgd, 2-stage low pressure (150 psi) RO
- GW TDS around 2000 mg/L
- Constant flow rate, WQ
- Since 2002, RO cleaned only once (2004)

Seward, NB: RO

- 2 mgd GW RO since June 1, 2004 (Hydranautics)
- Designed to reduce nitrate from 15.2 ppm to 2 ppm
- Operators visit the plant once a day, monitor and controlled remotely from the wastewater plant

City of Goodyear, AZ

- 2.5 mgd Ground water with high TDS (1,500 mg/L) & nitrate
- RO (GE-Osmonics, 60-100 psi, 74% Recovery)
- From concept to production in 6 months (DB)
- Capital $1.42/1000 gal; O&M $0.93/1000 gal

Sarasota, FL: EDR

- 12 mgd EDR facility, largest in the US (world)
- 10 EDR units, with 30 racks for each unit
- Reduce GW TDS from 1200 to 450 mg/L
- Pretreatment for turbidity & HS

Application: Seawater Desalination

Swansea Water District, MA

- Estuary under tidal influence
- Salinity up to 32,000 mg/L
- 1.5 mgd Desalination Membrane Plant
- Pall/Dow Filmtec

Membrane Application: MBR

Cauley Creek, GA: MBR

- Constructed in 2 2.5-mgd phases (total 5 mgd)
- Plant is optimized for meeting discharge limits of 0.13 mg/L total P and 0.5 mg/L ammonia
- Staff indicated not much the plant can do to further reduce energy consumption without potentially violating system warranties or permit

Pooler, GA: MBR

- 2.5 mgd MBR, operated 24 hours, staffed 8hr/day
- The plant has discharge limits for ammonia, but not for phosphorus
- Cut back on the aeration to only night times
- Turned off UV to save energy

West Basin: MF, UV, RO

- Largest Reuse facility in US
- MF, RO, UV/H2O2
- 4 tailored reuse waters for different clients

MF

RO

UV/H2O2

Membrane Operations

Membranes v.s. Sand

- Membrane filtration mechanism
  - Sieving/Straining
- Sand filtration mechanism
  - Interception, collision, electrostatic attraction
  - Straining only happens in cake filtration

Finished Water Comparison

	Conventional	Membranes
Turbidity	0.05 ~ 0.3	< 0.1
Virus removal	2 log	> 4 log
Influent quality change	Affected	Not affected
Water chemistry change	Affected	Not affected
Operating conditions change	Affected	Not affected

Performance Comparison

	Conventional	Membranes
High feed turbidity	Shorter run time	Higher pressure (if turbidity is excessive for a long duration)
High feed TOC	Not affected	Higher pressure, need freq. chemical cleaning
High $FeCl_3$ dose	Shorter run time	$FeCl_3$ not required
Low feed temp.	Not affected	Higher pressure or lower output
Capacity increase	Shorter run time	Higher pressure, need freq. chemical cleaning

Typical Membrane Filtration Cycle

- Filtration (15 ~ 50 minutes)
- Backwash (20 sec ~ 2 min)

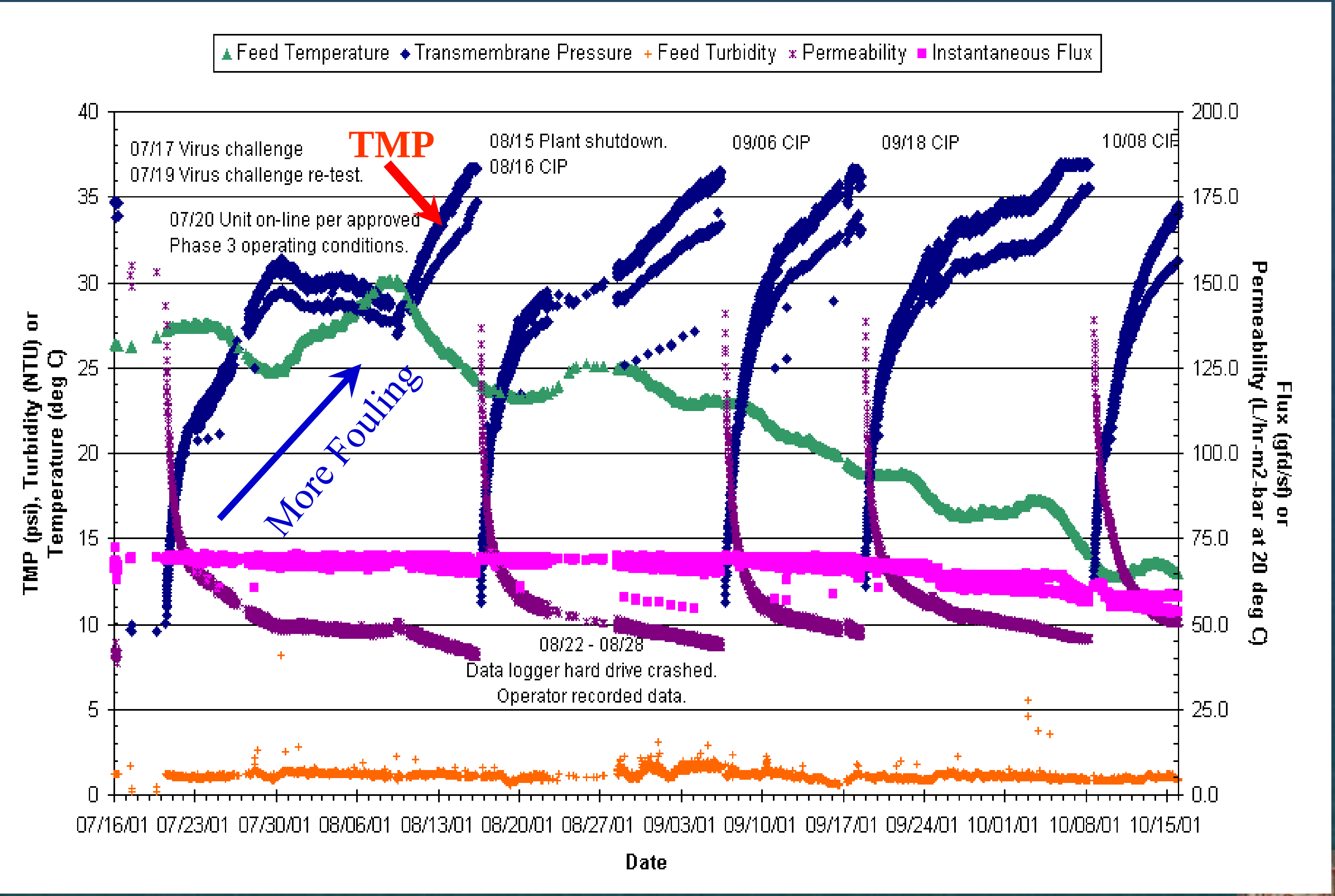
(No rinsing, surface wash, or filter-to-waste)

Special Operation/Maintenance

- Chemical Cleaning
- Membrane Repair

Membrane Fouling

Membrane Performance



Fouling is Part of Membranes

- All membranes are subject to fouling, no exception
- Fouling is acceptable as long as it is reversible and manageable (i.e., can be removed in a reasonable fashion)

Potential Fouling Material

Natural Organic Matter

- NOM with high SUVA
- TOC > 4 mg/L would be a concern
- Organic fouling is “sticky” and difficult to clean
- Organic may serve as “cement” to bind other particulates and form a strong cake layer
- Caustic cleaning (e.g. NaOH) and strong oxidant (e.g. H_2O_2) are effective for NOM fouling cleaning

Potential Fouling Material

Particulate/Colloids

- Inorganic particles alone would not cause much fouling
- Inorganic particle cake layer could be easily removed by backwash
- Excessive turbidity could clog membrane fiber lumens
- Inorganic particles mixed with NOM could cause substantial fouling
- Organic colloids could cause significant fouling and could be difficult to clean

Potential Fouling Material

Inorganic Material

- Precipitation of Ca, Mn, Mg, Fe, and Al could cause significant fouling
- Fine inorganic colloids (< 0.05 μm) could clog membrane pores and cause fouling
- Prefer a negative Langelier Index
- Acid, EDTA, SBS cleaning could be effective for inorganic fouling

Langelier Index = Actual pH – Saturation pH

Saturation pH = 2.18 - log[Ca^{+2}] - log[HCO$_3^-$]

L.I. > 0 : Oversaturated (tend to precipitate)

L.I. < 0 : Undersaturated (tend to dissolve more)

Potential Fouling Material

Synthetic Polymers

- Polymers used for coagulant/filter aids & backwash water treatment
- Presence of polymers in feed water could cause dramatic fouling, and sometimes irreversible
- Free residual polymer is worse than particle-associated polymer
- Cationic polymers are worst
- Some polymers can be easily cleaned with chlorine and therefore are consider compatible with membranes

Fouling Mitigation

Pretreatment

- Reduce TOC level (< 4 mg/L)
- Reduce Turbidity (< 5 NTU)
- Reduce Hardness (< 150 mg/L)
- Avoid substantial change in water chemistry, such as pH and other pretreatment chemicals
- Prevent Oil and Polymers from entering the feed water

Fouling Mitigation

Operation

- Use crossflow if turbidity is high (For Inside-out membranes)
- Bleed a portion of the concentrate to avoid solid buildup
- Operate at a lower flux (lower TMP)
- Enhance pretreatment

Fouling Mitigation
Cleaning Strategy

1. Frequent BW (shorter filtration cycle)
2. Longer BW duration
3. Higher BW pressure
4. Add cleaning chemicals in BW water
5. Frequent chemical cleaning

Membrane Cleaning

Membrane Fouling Mechanisms

- Organic & Inorganic
- Particulate & Soluble
- Various Mechanisms
  - Surface & Pore
  - Adsorption, precipitation, coagulation

Membrane Cleaning

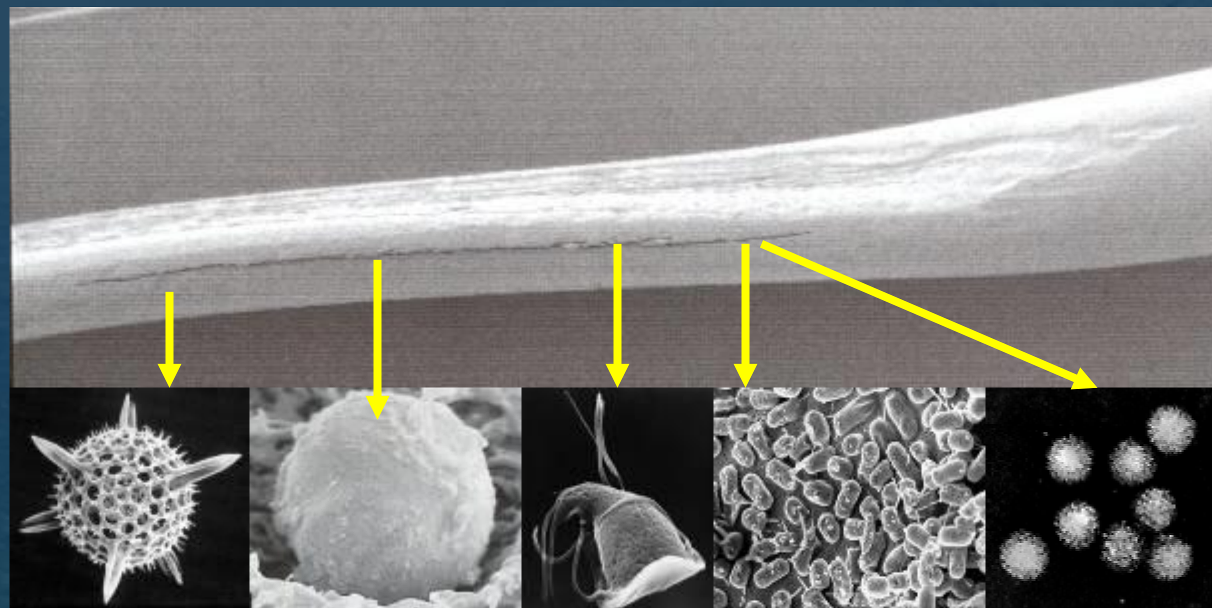
- Hydraulic Cleaning (10~30 minutes)
  - Water/Air Backwash
  - Air Scouring
  - Water Flushing
- Chemical Cleaning (1~8 weeks)
  - Free Chlorine (Sodium Hypochlorite)
  - Acid/Base
  - Other strong oxidants, such as H_2O_2
  - Reducing agent, such as SBS
  - Chelating chemicals, such as EDTA
  - Proprietary Chemicals (surfactants)

Summary of Fouling Material & Cleaning Chemicals

Cleaning Chemical	For Fouling Material
NaOCl	Biological; NOM; Synthetic polymers
Acids (HCl, H_2SO_4, Citric Acid)	Inorganic deposits
NaOH	NOM
Sodium bi-sulfite (SBS)	Reducible metals (Fe, Mn)
H_2O_2	NOM
EDTA	Metals

Membrane Integrity

Membrane failure is rarely catastrophic – less serious than microbial penetration of rapid sand filter beds.



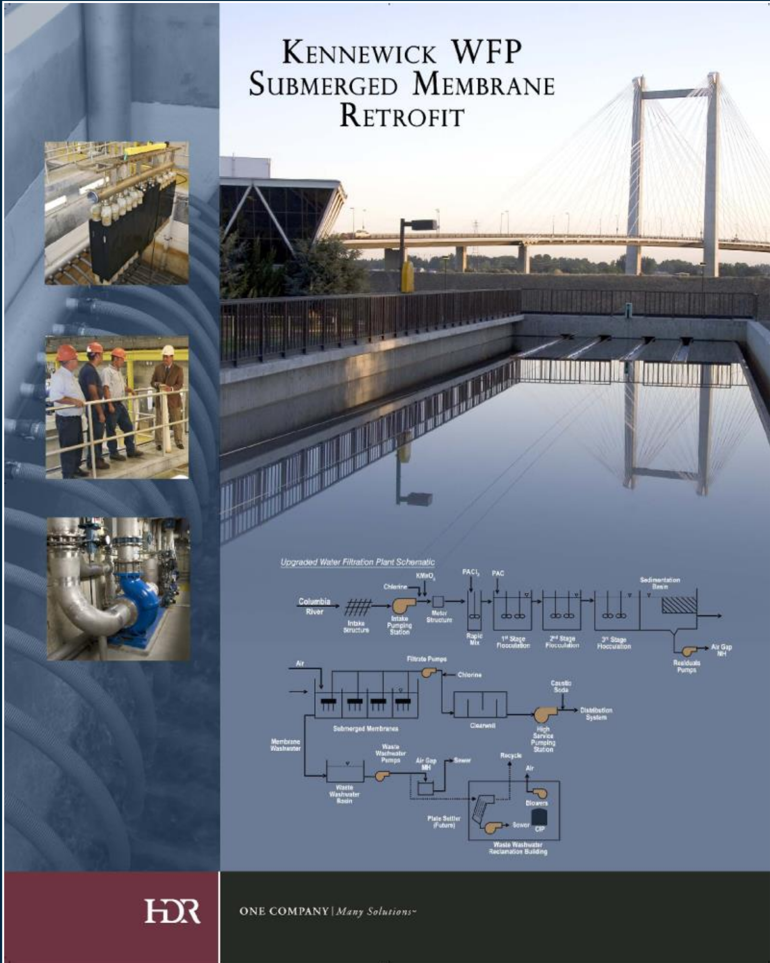
- **Membranes fail incrementally – one fiber at a time.**
- **Statistically, individual fiber breaks are insignificant to the overall microbial water quality.**

Membrane Integrity Monitoring

- On-Line Turbidity Monitoring
  - 0.08 NTU 95% of the time, 0.1 NTU max.
- On-Line Particle Count
  - Baseline establishment (< 50 particles/mL)
  - Sensitivity: Number of fiber breakage?
- Pressure Holding Test
- Virus Seeding Test (UF)

Special Case Study: Kennewick, WA

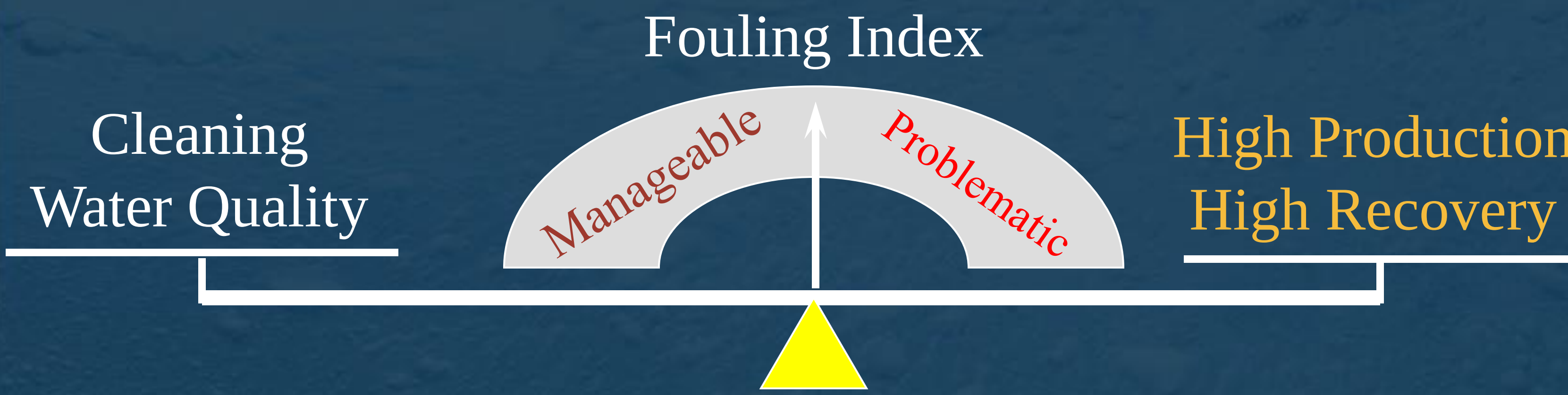
Conventional Water Plant Retrofit with Submerged Membranes



Retrofit Concept

- Increase capacity from 7.5 mgd to 20 mgd with the same footprint
- Minimize construction of new filter basins
- Design to production in 6 months (April 2005)
- First retrofit project > 10 mgd in US

The Secret of Membranes…



- Finding the balance point between Fouling-Enhancers and Fouling Reducers is the KEY!

Take Away Points

- Membranes Offers a Wide Range of Applications
- Membrane is a Mature Technology
- A Successful Membrane Operation Depends on
  - The Selection of an Appropriate System
  - Optimized Operating Conditions/Protocols that Yield Manageable Membrane Fouling
  - Experience Design Engineer

Questions?

YuJung.Chang@hdrinc.com

(425) 450-6275