



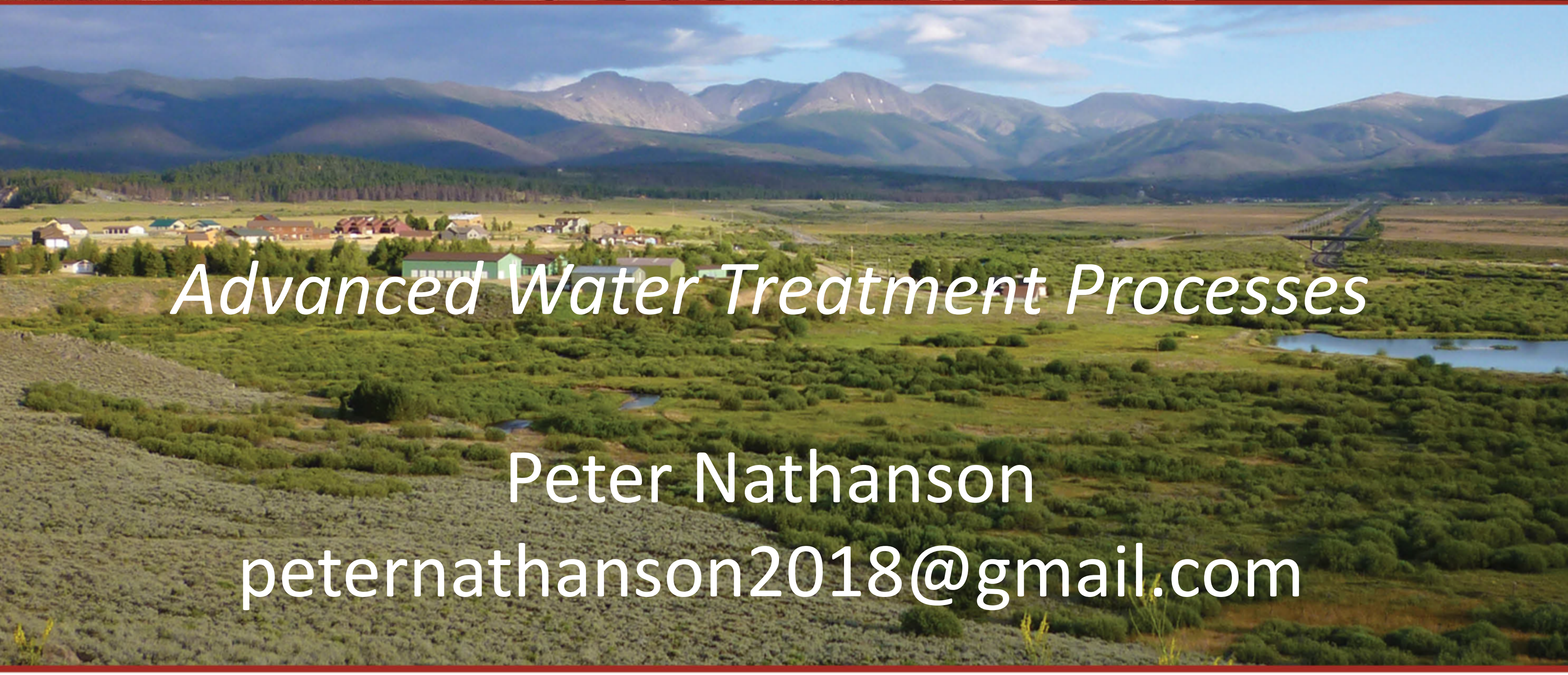

Advanced Water Treatment Processes

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Daniel B. Stephens & Associates, Inc.

Topics – Chs. 12 & 15 Water Ops Study Guide

- Surface Water Treatment
- Non-Membrane Systems
  - Activated Carbon
  - Ozone
  - UV
  - Zeolites
- Membrane Systems
  - MF
  - UF
  - NF
  - RO
  - ED
- Basis for Inclusion – existing & future applications
  - Potable Reuse: IPR, DPR

Reasons for Water Treatment

- Protect public health
  - Remove disease-causing microorganisms
  - Remove turbidity (suspended particles)
  - Enhanced coagulation
  - Meet state or national primary MCLs and secondary MCLs (SMCLs)

- Provide palatable water

Turbidity

- Physical characteristic: The cloudy appearance of water caused by the presence of suspended or colloidal matter
  - Suspended solids, colloidal in size
  - The property of water that causes light to be scattered or absorbed
  - Can cause problems with
    - Taste
    - Odor
    - Hiding place for microorganisms
    - Interfere with disinfection
- Measured in nephelometric turbidity units (NTU)

Distribution

Flash-mix

Filtration

Disinfectant

Clearwell

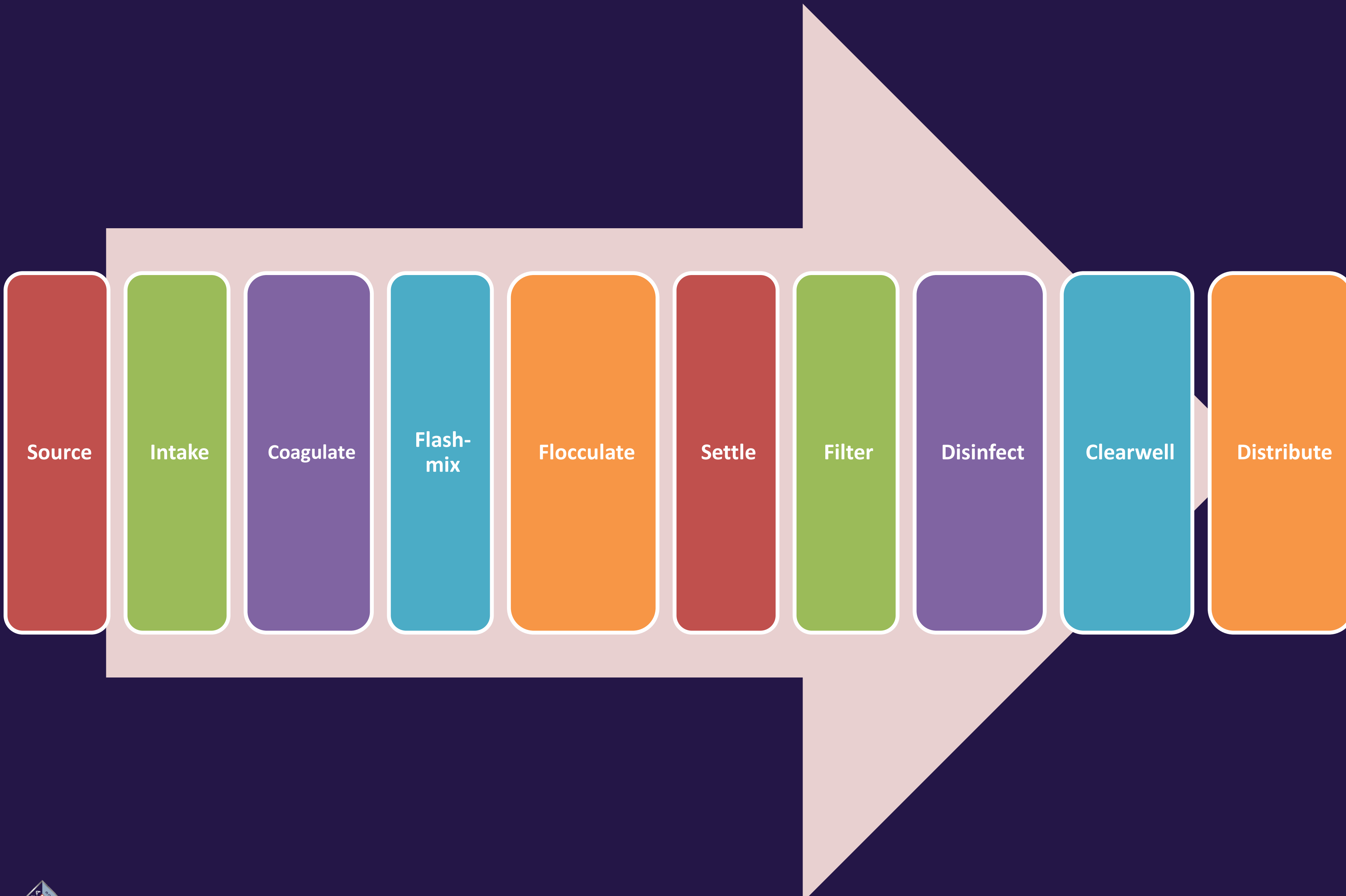
Source

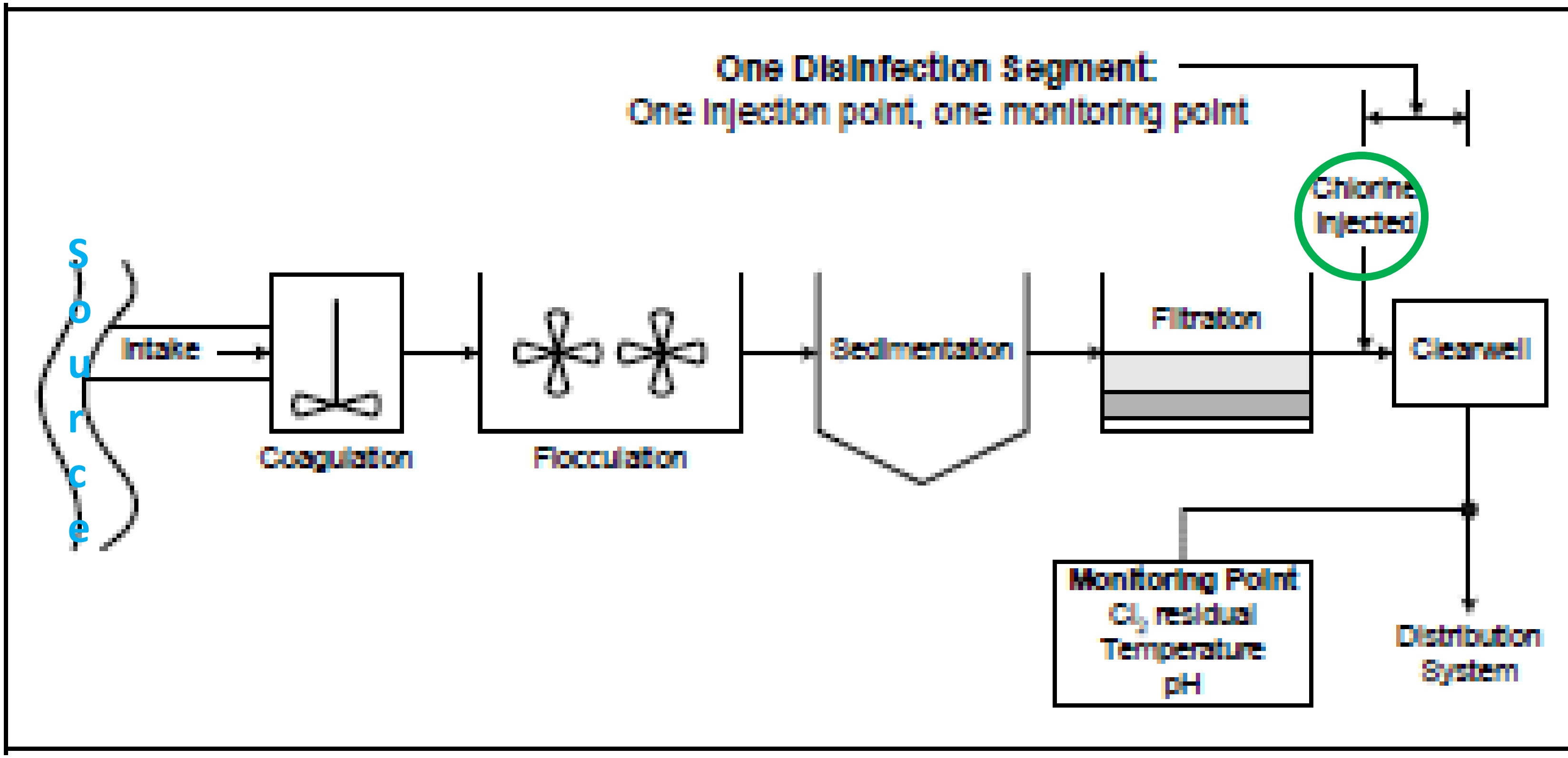
Coagulant

Flocculation

Sedimentation

Intake

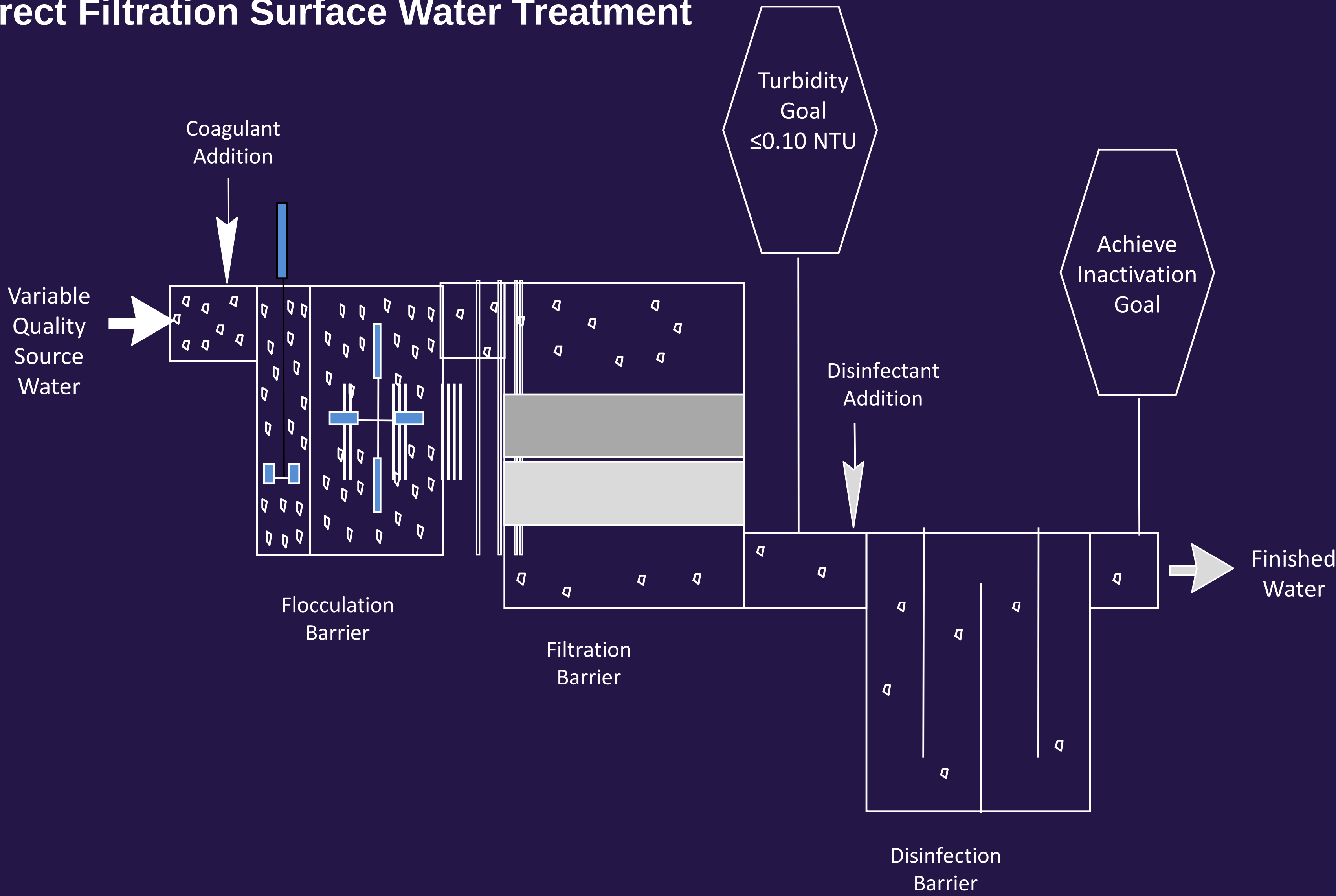

Source
Intake
Coagulate
Flash-mix
Flocculate
Settle
Filter
Disinfect
Clearwell
Distribute

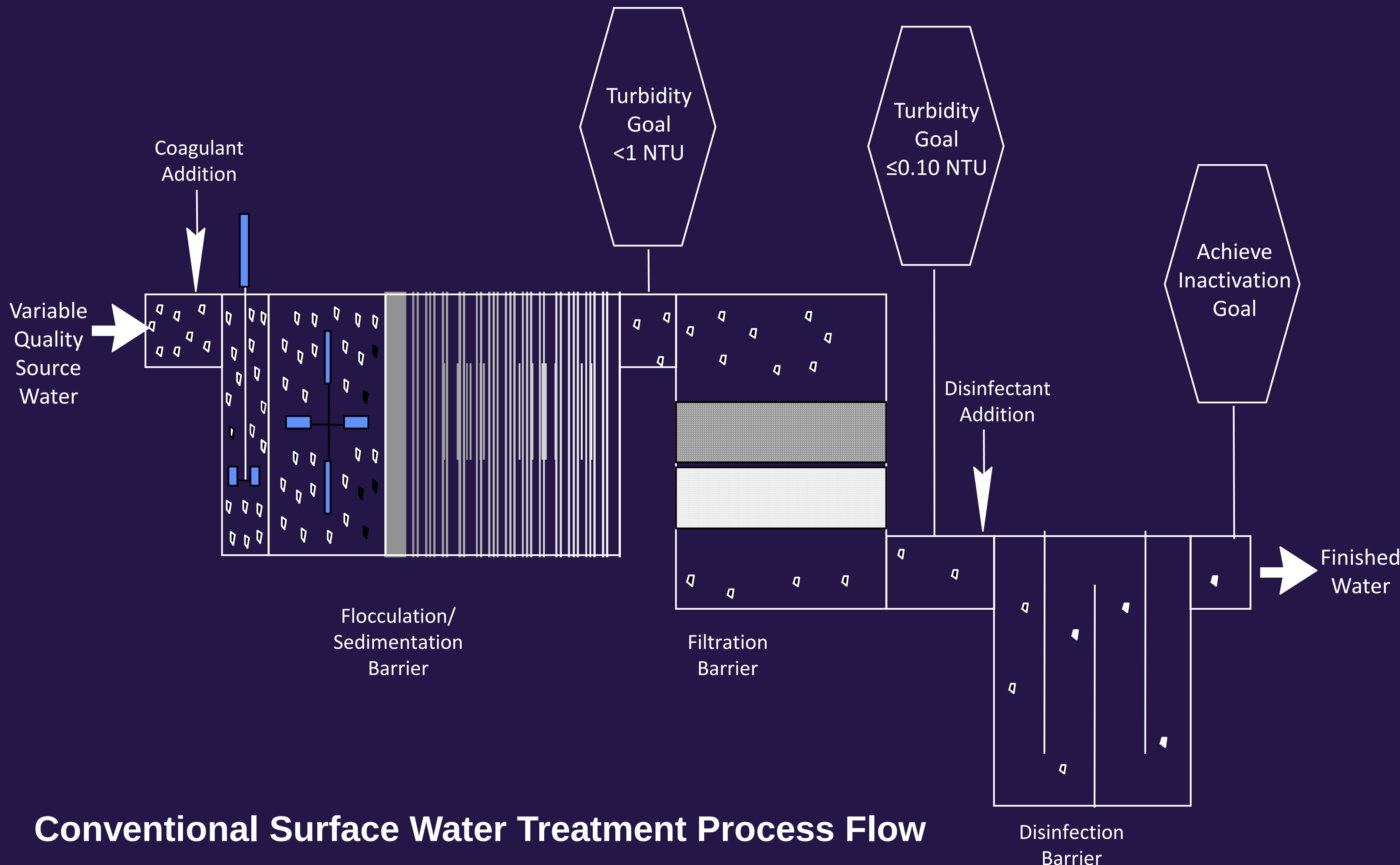


EPA Guidance Manual LT1 ESWTR Disinfection Profiling and Benchmarking

Figure 2-1: Plant Schematic Showing A Conventional Filtration Plant With One Disinfection Segment

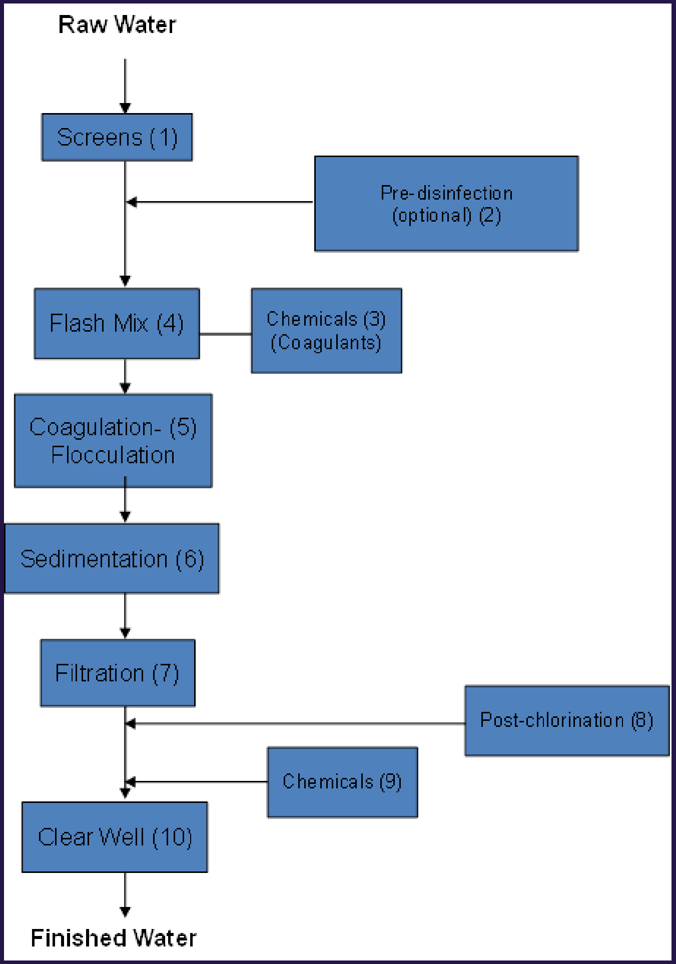
Direct Filtration Surface Water Treatment





Conventional Surface Water Treatment Process Flow

Treatment Process



- Removes leaves, sticks, fish, and large debris
- Kills most disease-causing organisms and helps control taste- and odor-causing substances
- Causes very fine particles to clump together into larger particles
- Mixes chemicals with raw water containing fine particles that will not readily settle or filter out of the water
- Gathers together fine, light particles (FLOC) to aid the sedimentation and filtration processes
- Settles out larger suspended particles
- Filters out remaining suspended particles
- Kills disease-causing organisms and provides chlorine residual for distribution system
- Controls corrosion
- Provides chlorine contact time for disinfection and stored water for high demand.

Surface Water Treatment

Removal

- Coagulation/ Flocculation
- Sedimentation
- Filtration

Inactivation

- UV
- Ozone

Types of Intake–Outlet Structures

- Single- or fixed-level intake structures
  - Single-level structures are usually located in the deepest portion of the stream or reservoir
  - Most suitable in relatively shallow lakes and reservoirs that do not stratify significantly and exhibit fairly uniform water quality from top to bottom throughout the year
  - Ease of operation and maintenance
  - Lower capital cost
  - Difficult to inspect, maintain, and repair if installed in deep water
  - With deep installation during months of stratification, water quality likely anaerobic

Types of Intake–Outlet Structures (cont.)

- Multi-level intakes
  - In lakes and reservoirs, generally located in 15 feet or more of water to provide multiple intake levels
  - Inlets usually located at least 4 to 6 feet from surface
  - At intervals of 5 to 10 feet depending on water depth
  - Commonly found in a vertical tower
  - Can be adjusted to draw highest quality water during months of stratification

Single- or Fixed-Level Intake Structures

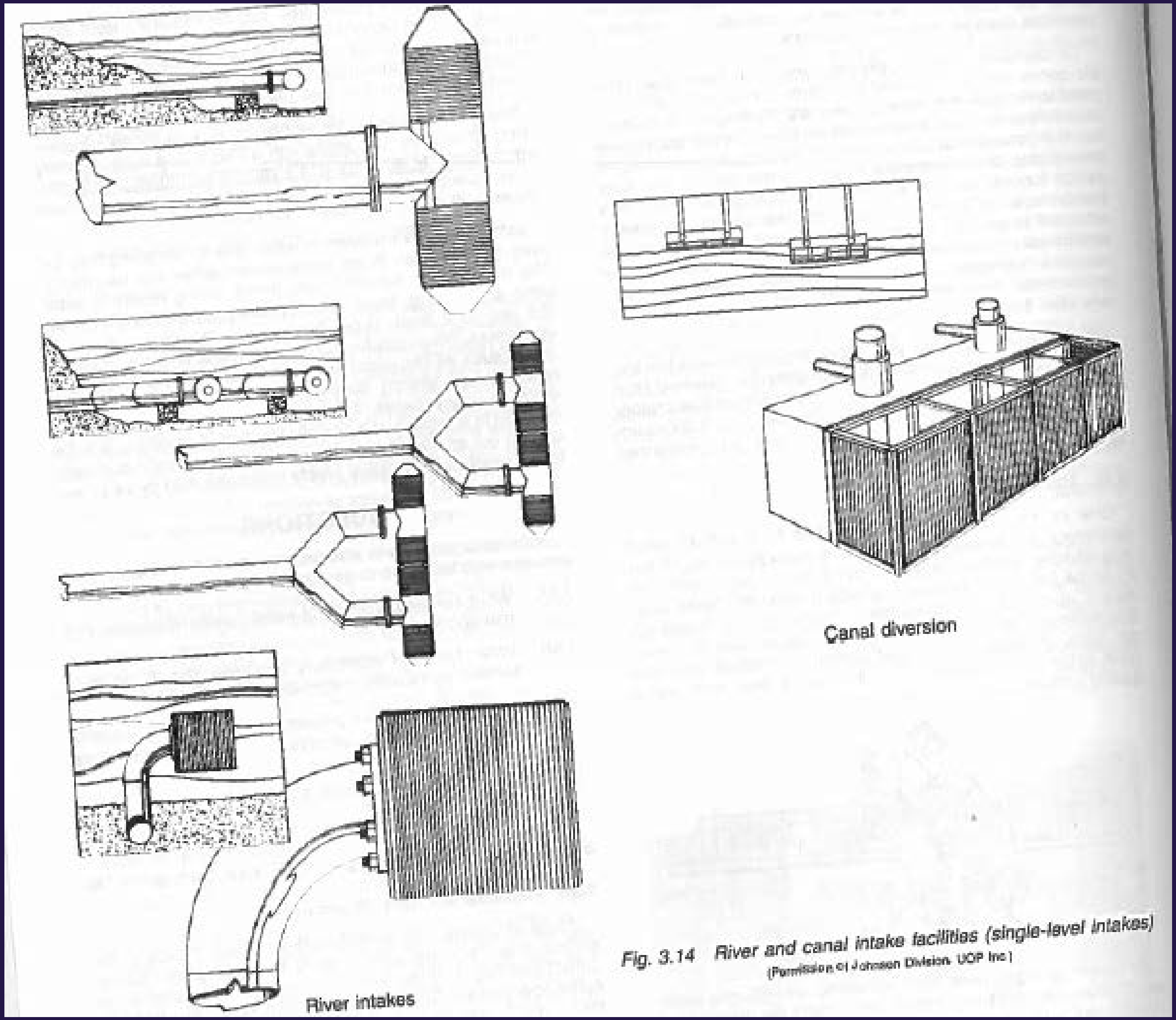
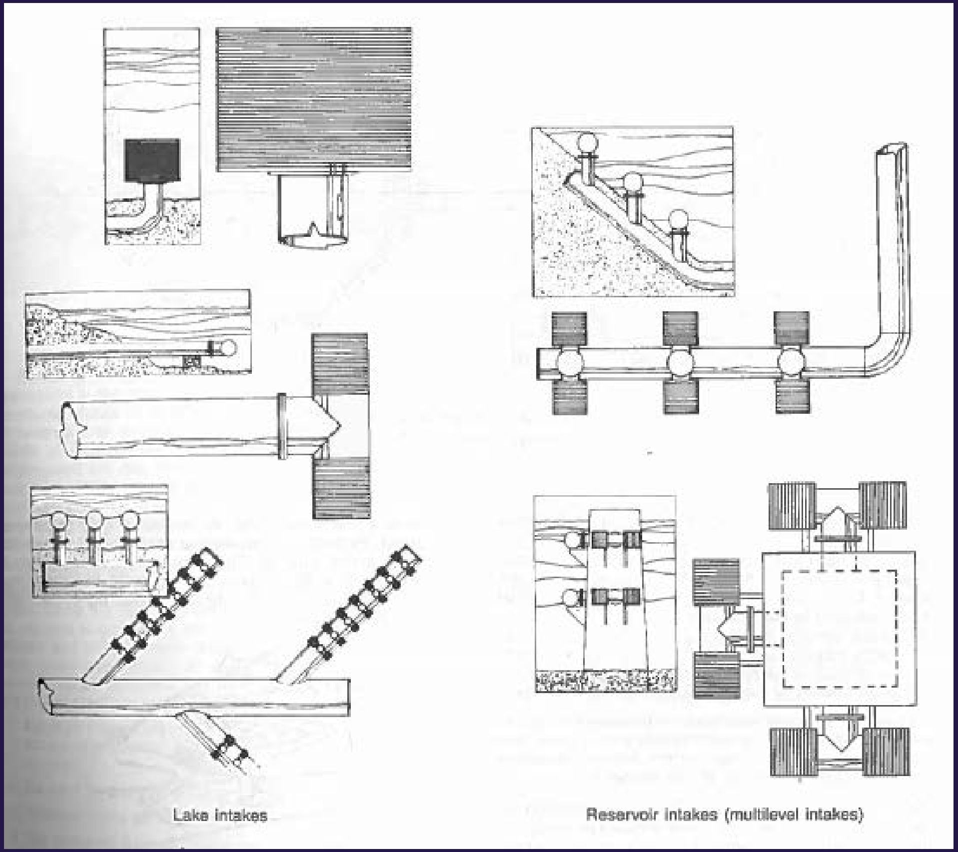
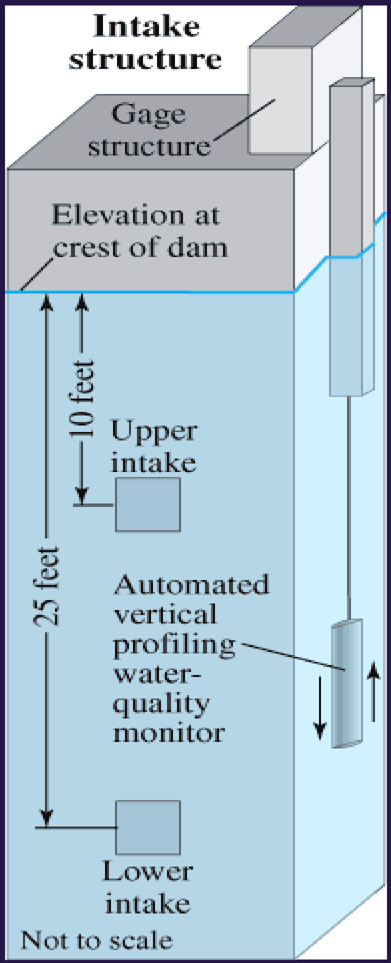


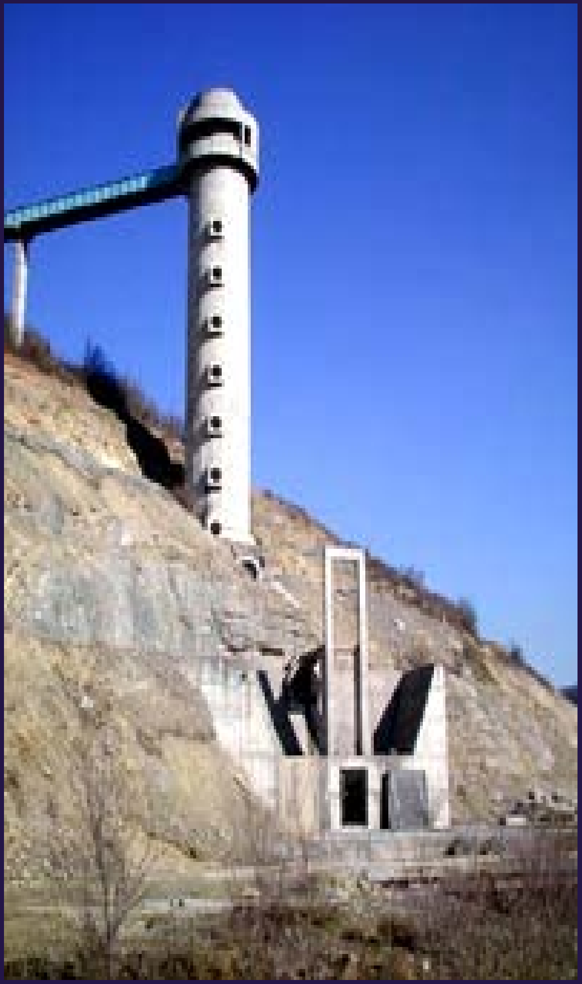
Fig. 3.14 River and canal intake facilities (single-level intakes)
(Permission of Johnson Division, UOP Inc.)

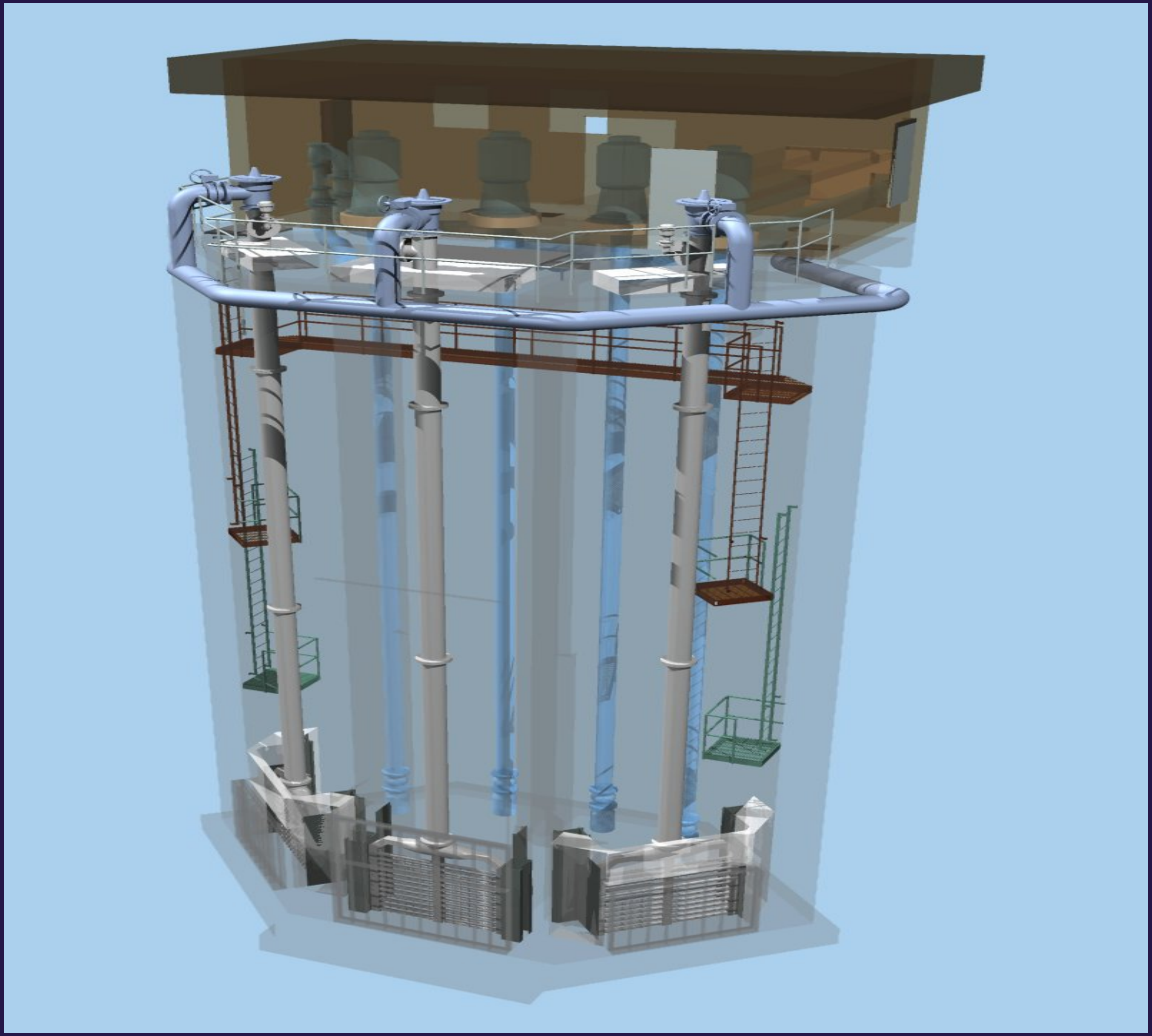
Single- or Fixed-Level Intake Structures

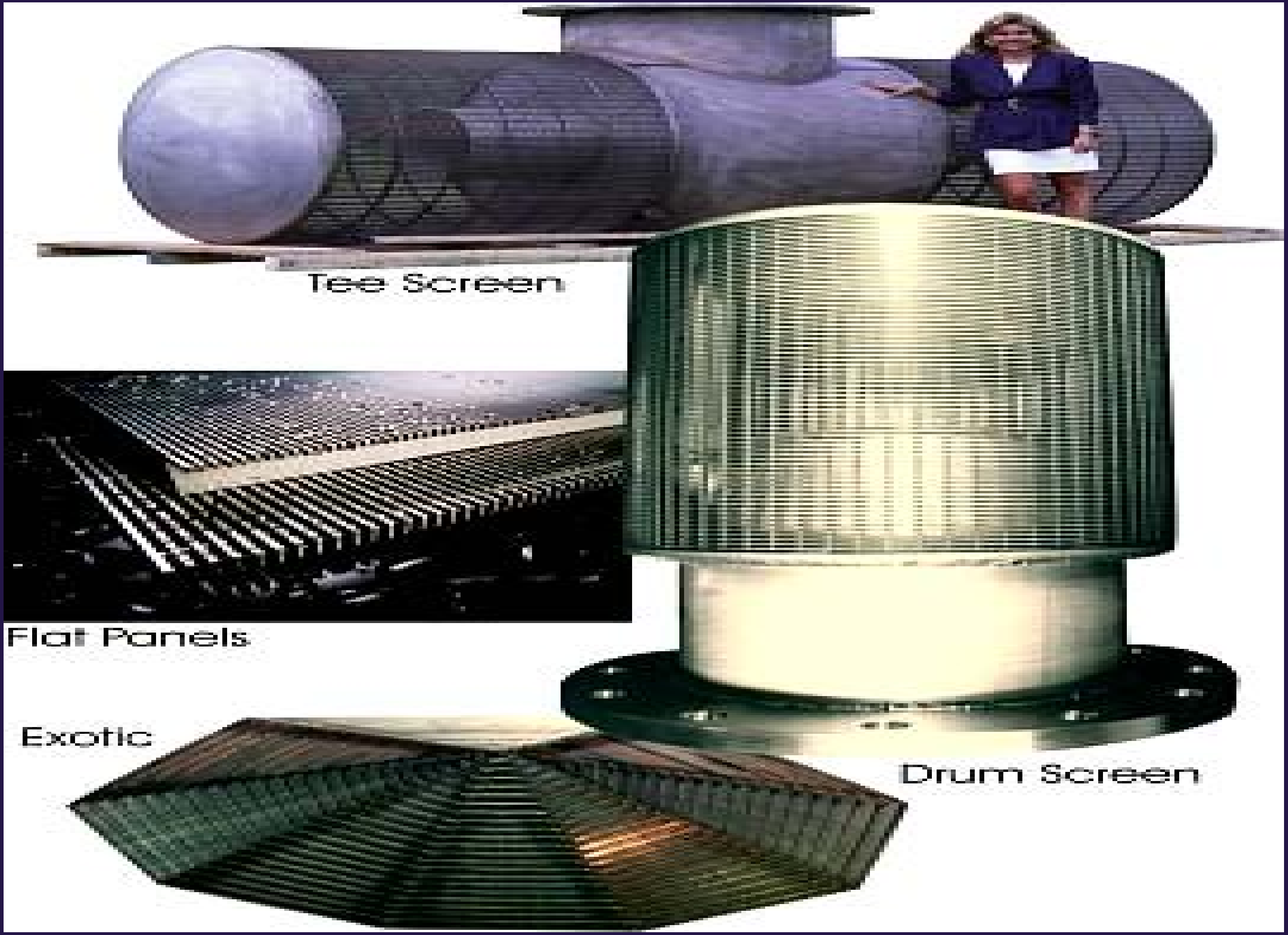


Multi-Level Intake Structures







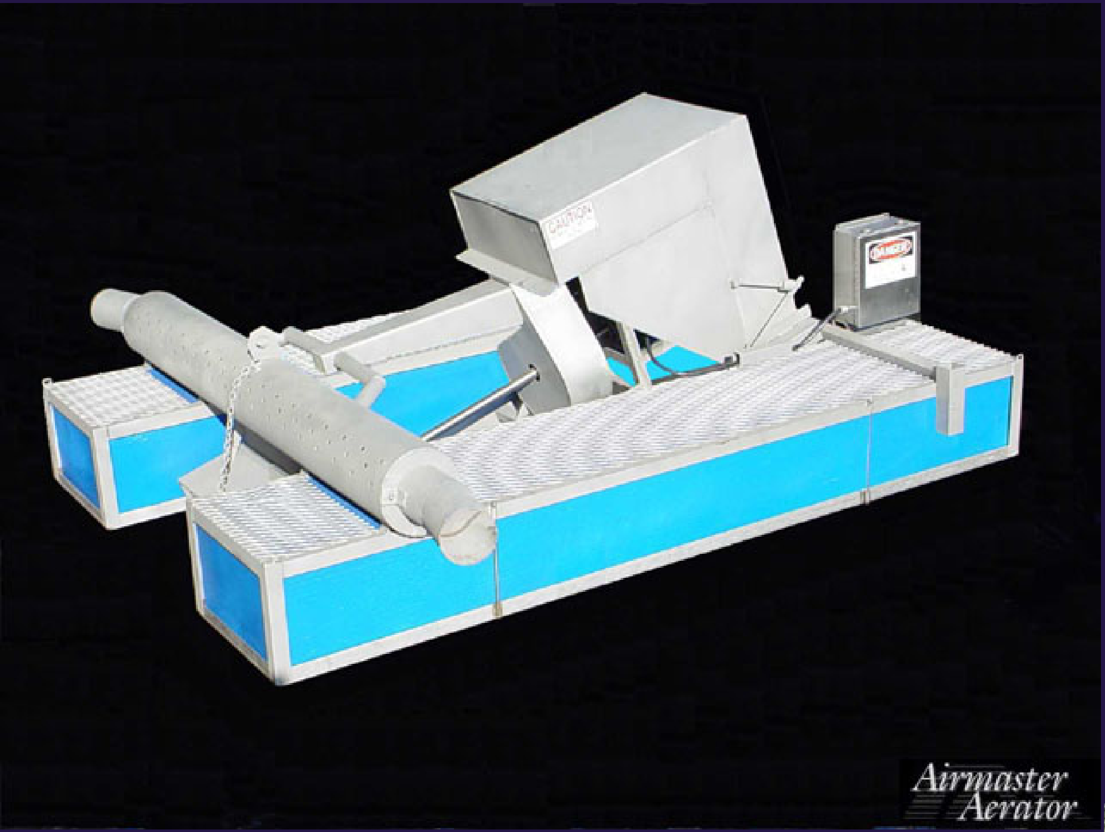

Tee Screen
Flat Panels
Exotic
Drum Screen

Reservoir Management

- Aeration: process of adding air to water
- Reaeration: introduction of air through forced air diffuser into the lower layer of the reservoir
- Destratification: development of vertical mixing with body of water to eliminate or partially eliminate separate layers of water based on temperature, oxygen concentration, total dissolved solids, or plant/animal life

Reservoir Management (cont.)

- Purpose of reaeration/destratification programs
  - Primary: to eliminate, control, or minimize negative effects of thermal stratification and oxygen depletion
  - Secondary: increase recreational values, fisheries, and aesthetic conditions
  - Helps break up surface ice during winter freeze and prevent winter fish kills
  - Improves water quality with addition of dissolved oxygen
  - Helps prevent anaerobic conditions during periods of stratification
  - Helps reduce algal blooms


Airmaster
Aerator

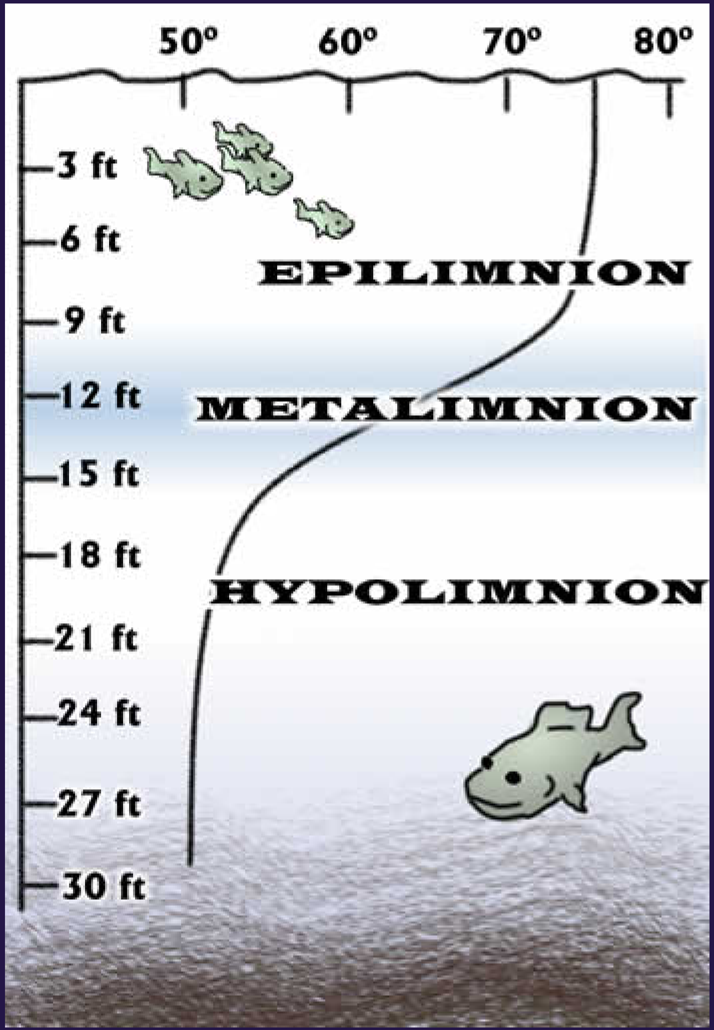

THE WATER MOVERS


7 3 2003

Thermal Stratification

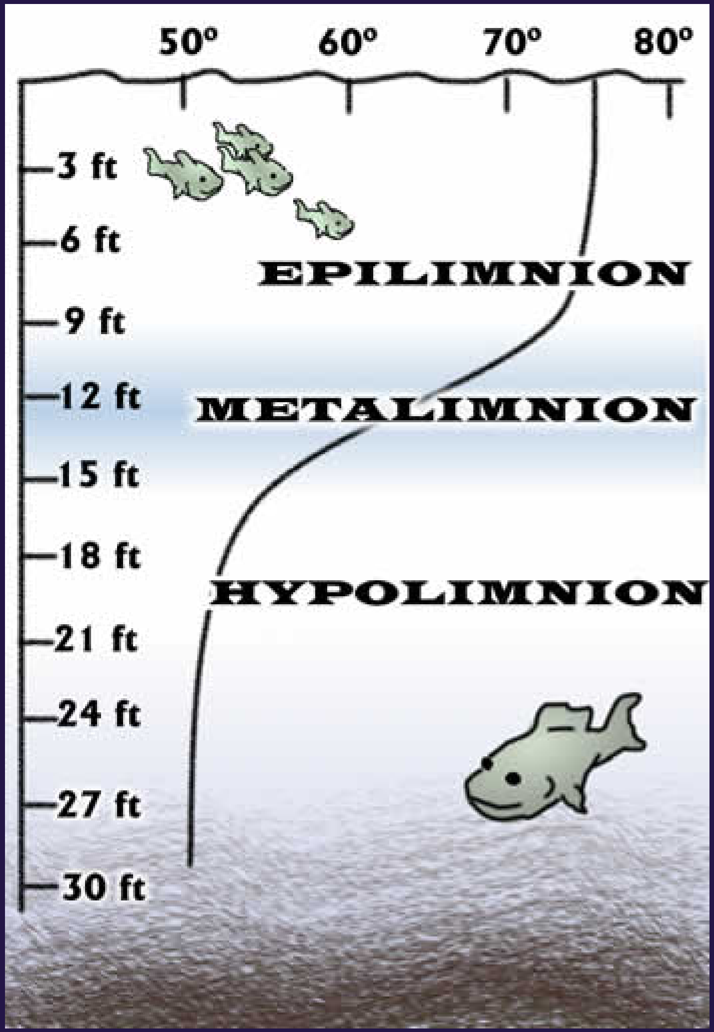
- Turnover: when reservoir water mixes from the surface to the bottom
- What can happen to the water quality during/after turnover?

Thermal Stratification (cont.)



- A volume of water is heaviest at 4°C (39.2°F) - just above freezing. The same volume of water becomes lighter as it warms. So in a reservoir, the water is warmest at the top and coldest at the bottom.
- As the sun continues to heat the water at the top, the difference in temperature between the top and bottom increases. Eventually, there are two distinct layers: the epilimnion at the top and the hypolimnion at the bottom. Between these two layers is a third, less distinct, transition layer called the metalimnion.

Thermal Stratification (cont.)



- Due to the temperature difference (and therefore density difference) between the epilimnion and the hypolimnion, they do not typically mix together during the summer. It takes a major climactic event to accomplish this mixing, thought the reservoir will mix in the autumn as the surface water cools. Often in the summer, the hypolimnion will become depleted of oxygen. The bacteria responsible for decomposition consume the oxygen, and access to the oxygen in the atmosphere is cut off by the stratification.

Coagulation and Flocculation

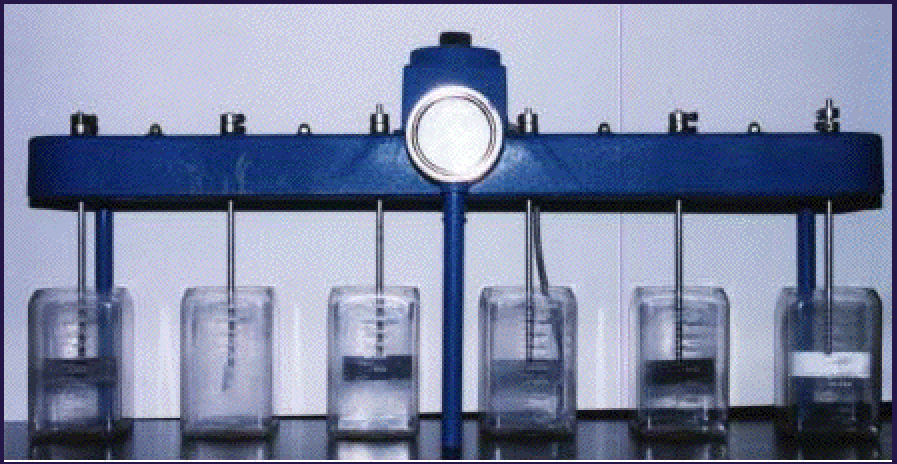
- The purpose of coagulation/flocculation is to remove particulate impurities, nonsettleable solids, and color.
- Nonsettleable particles in water are removed by use of coagulating chemicals.

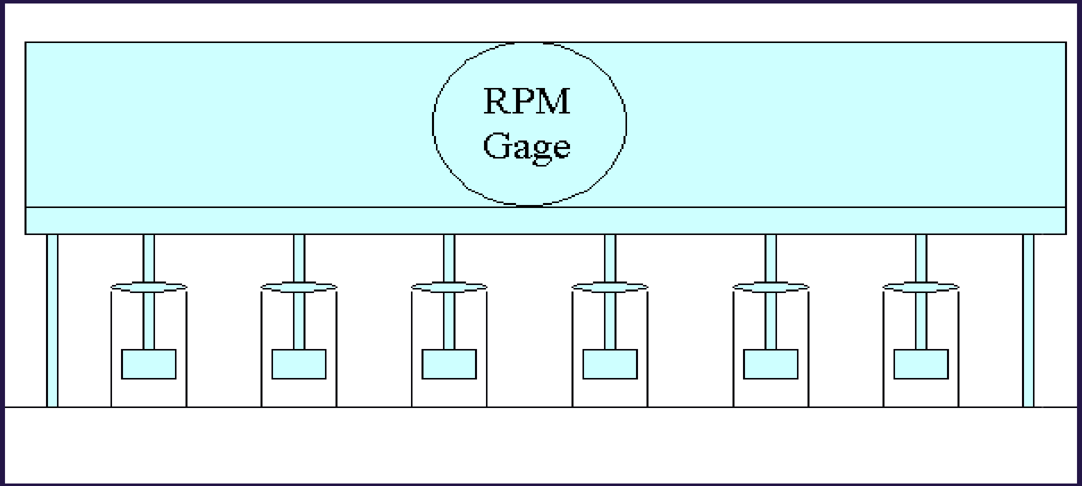
Coagulation and Flocculation (cont.)

Chemical name	Chemical formula	Primary coagulant	Coagulant aid
Aluminum Sulfate	$Al_2(SO_4)_3 \cdot 14\ H_2O$	X	
Ferrous Sulfate	$FeSO_4 \cdot 7\ H_2O$	X	
Ferric Sulfate	$Fe_2(SO_4)_3 \cdot 9\ H_2O$	X	
Ferric Chloride	$FeCl_3 \cdot 6\ H_2O$	X	
Cationic Polymer	Various	X	X
Calcium Hydroxide	$Ca(OH)_2$	X (a)	X
Calcium Oxide	CaO	X (a)	X
Sodium Aluminate	$Na_2Al_2O_4$	X (a)	X
Bentonite	Clay		X
Calcium Carbonate	$CaCO_3$		X
Sodium Silicate	Na_2SiO_3		X
Anionic Polymer	Various		X
Nonionic Polymer	Various		X

(a) Used as primary coagulants only in water softening processes.

Jar Testing





Jar Testing

- Common laboratory procedure used to determine the optimal operating conditions for water or wastewater treatment
- Allows adjustments to
  - pH
  - Variations in coagulant or polymer dose
  - Alternating mixing speeds
  - Testing of different coagulant or polymer types

Jar Testing (cont.)

- Simulates the coagulation/flocculation processes that encourage removal of suspended colloids and organic matter that can lead to turbidity, odor, and taste problems

Flash Mix

- Method of mixing
  - Coagulation takes place in matter of seconds
  - Important for chemicals used in coagulation to be added and disperse quickly
  - Accomplished in a unit/process called flash mix/ rapid mix

Flash Mix (cont.)

- Various methods used for this process
  - Hydraulic mixing: uses flow energy in the system
    - Baffles or throttling valves
    - Sufficient water velocity causes turbulence
  - Mechanical mixing
    - Paddles, turbines, or propellers
  - Diffuser and grid systems
    - Perforated tubes or nozzles used to uniformly disperse the coagulant into the water
  - Pump blender
    - Directly and forcibly pumps the coagulant through diffuser piping

Flocculation

- Follows flash mix and takes place in a basin or series of basins that steadily reduce mixing energy
  - Too little agitation will prevent floc formation.
  - Too much agitation will destroy the floc (floc shear).
  - Velocity in the flocculation basin should be 1 foot per second (fps).
- Objective is to create a floc of sufficient size, density, and toughness: approximately 0.1 to 3 mm in size for settling and removal.

Flocculation (cont.)

- Detention time
  - Direct filtration: 5 to 20 minutes
  - Conventional filtration: 30 minutes
- Basin configuration
  - Generally rectangular in shape
  - Usually two to three stages with decreasing mixing energy

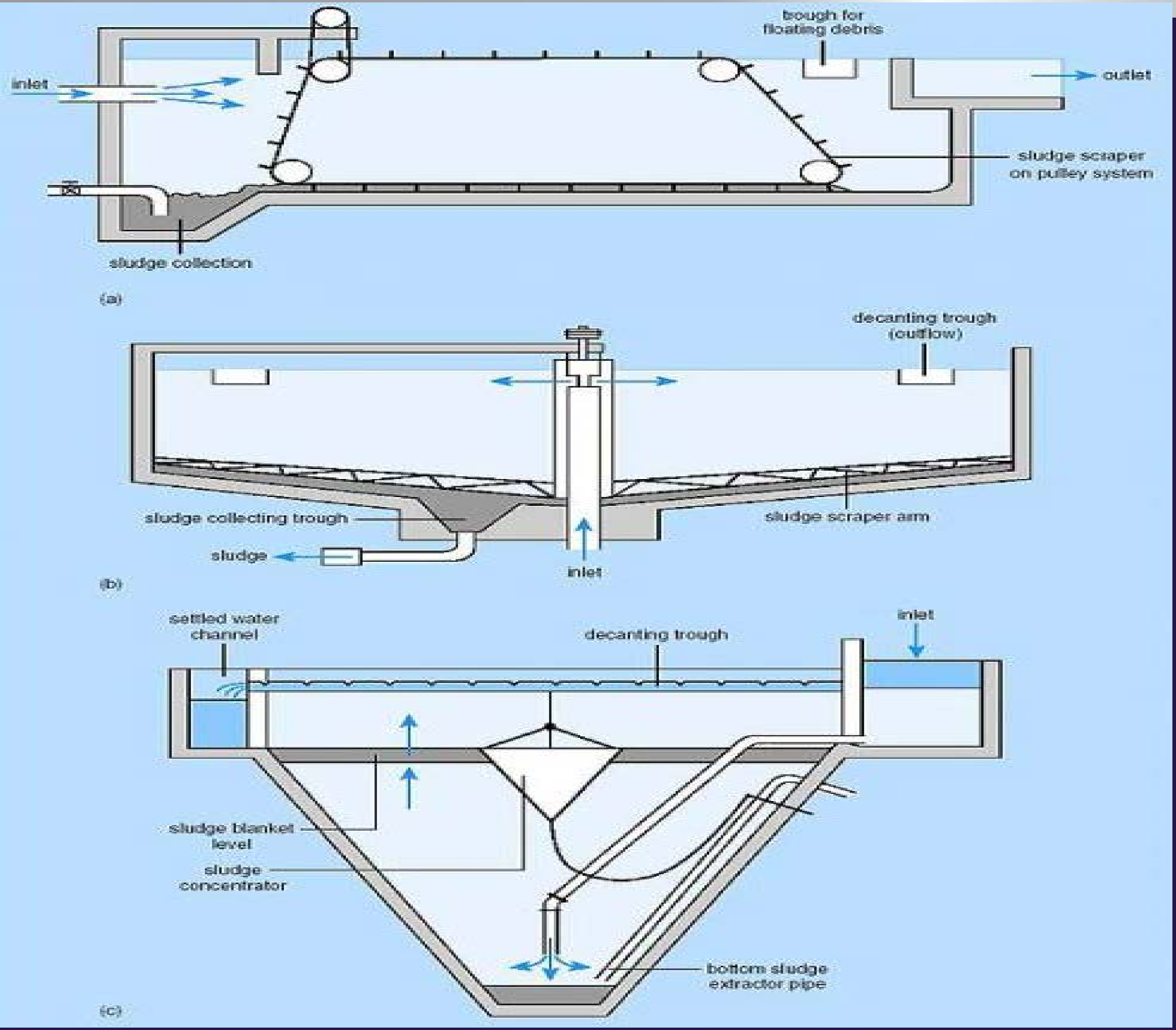
Paddle-Wheel Flocculators

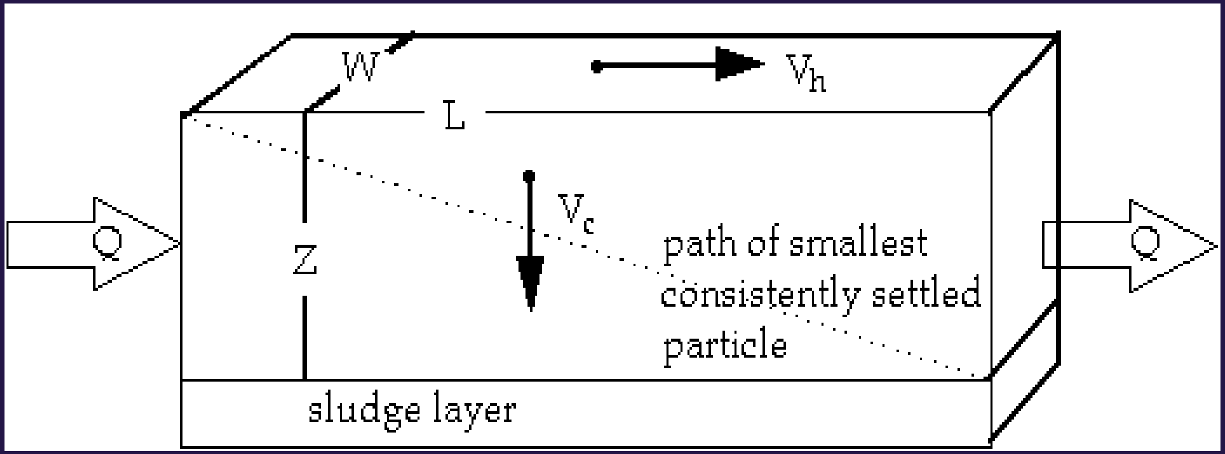
Sedimentation

- A typical sedimentation basin can be divided into four zones:
  - Inlet zone: should provide a smooth transition, have a perforated baffle to evenly distribute the flocculated water over the entire cross section of the basin to reduce short-circuiting
  - Settling zone: the largest portion of the basin, provides a calm region that allows the floc to settle; detention times around 3 hours, velocities from 0.01 to 0.03 fps, usually 8 to 12 feet deep, surface loading rates around 900 gpd/ft^2

Sedimentation (cont.)

- A typical sedimentation basin can be divided into four zones (cont.):
  - Sludge zone: located at the bottom of the basin for the temporary storage of the settled particles; also allows for compaction of the sludge
  - Outlet zone/effluent: provides a smooth flow transition from the sedimentation basin to the next treatment process (usually filtration)


trough for
floating debris
inlet
outlet
sludge scraper
on pulley system
sludge collection
(a)
decanting trough
(outflow)
sludge collecting trough
sludge scraper arm
sludge
inlet
(b)
settled water
channel
decanting trough
inlet
sludge blanket
level
sludge
concentrator
bottom sludge
extractor pipe
(c)


W
L
V_h
V_s
Z
Q
Q
path of smallest
consistently settled
particle
sludge layer

Filtration

- Purpose is to remove particulates, impurities, and floc.
- Conventional filtration is preceded by coagulation, flocculation, and sedimentation.
- Direct filtration does not include the sedimentation process.
- Filtration is a physical and chemical process.

Filtration (cont.)

- Turbidity removal is based on the following factors:
  - Chemical characteristics of the water being treated (source water quality)
  - Nature of suspension (physical and chemical characteristics of the suspended particles in the water)
  - Types and degree of coagulation, flocculation, and sedimentation
  - Filter type and operation
    - Gravity filtration (sand, dual media, and mixed media)
    - Single media (sand)
    - Diatomaceous earth
    - Slow sand

Filter Anatomy

- Filter boxes can be rectangular, square, round, or as the outer segment of a ring. Depth and surface dimensions will vary depending on the volume of water to be filtered.
- The rate of flow controller maintains a constant flow of water throughout the filter run. As the filter media becomes clogged, the rate of flow controller opens a valve on the effluent line that compensates for the head loss through the filter.

Filter Anatomy (cont.)

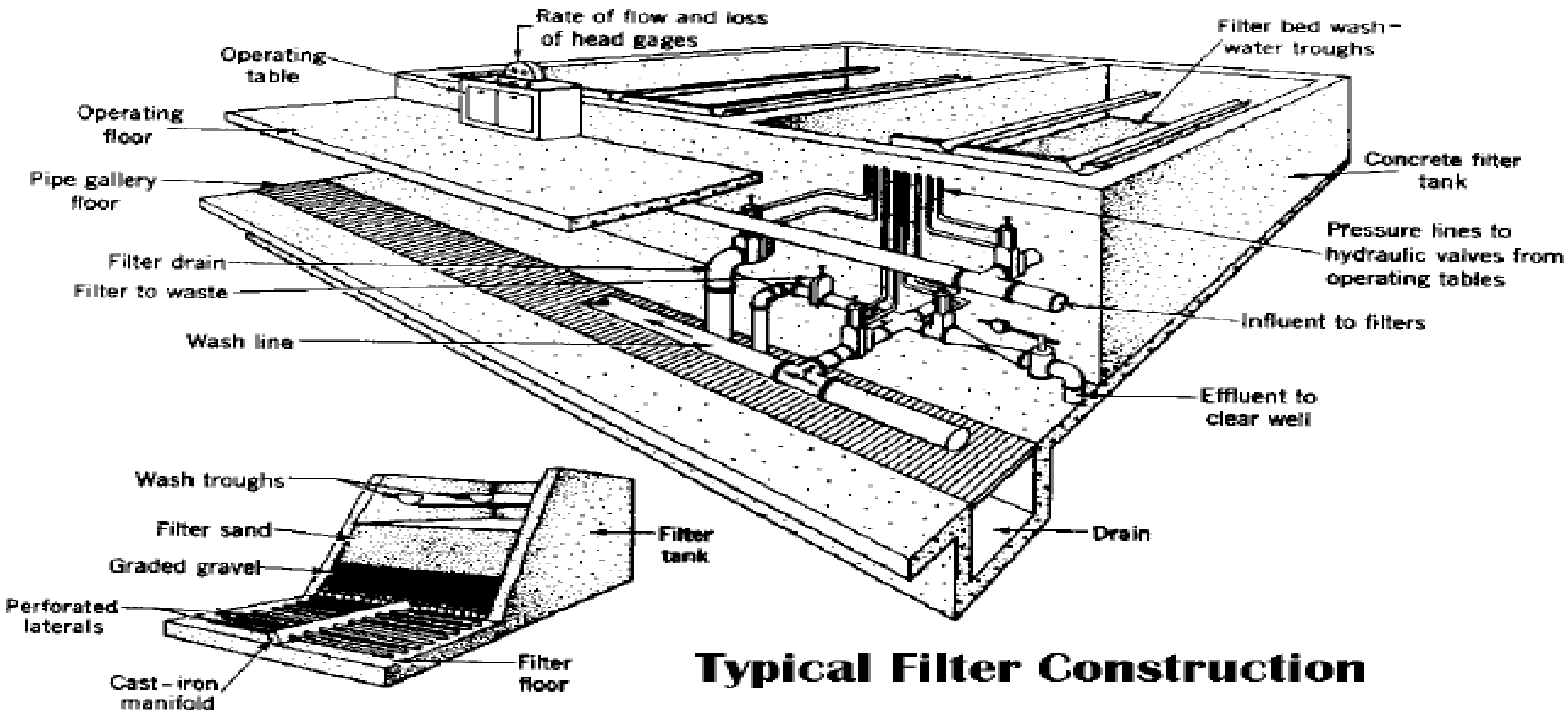
- A loss of head gauge indicates when the filter is in need of backwashing. The loss of head is determined by the difference between the level of water in the filter and the level of a column of water that represents the pressure in the effluent line.
- The underdrain serves three basic functions:
  - Supports the filter media
  - Collects the filtered water
  - Evenly distributes the backwash water throughout the filter.

Filter Anatomy (cont.)

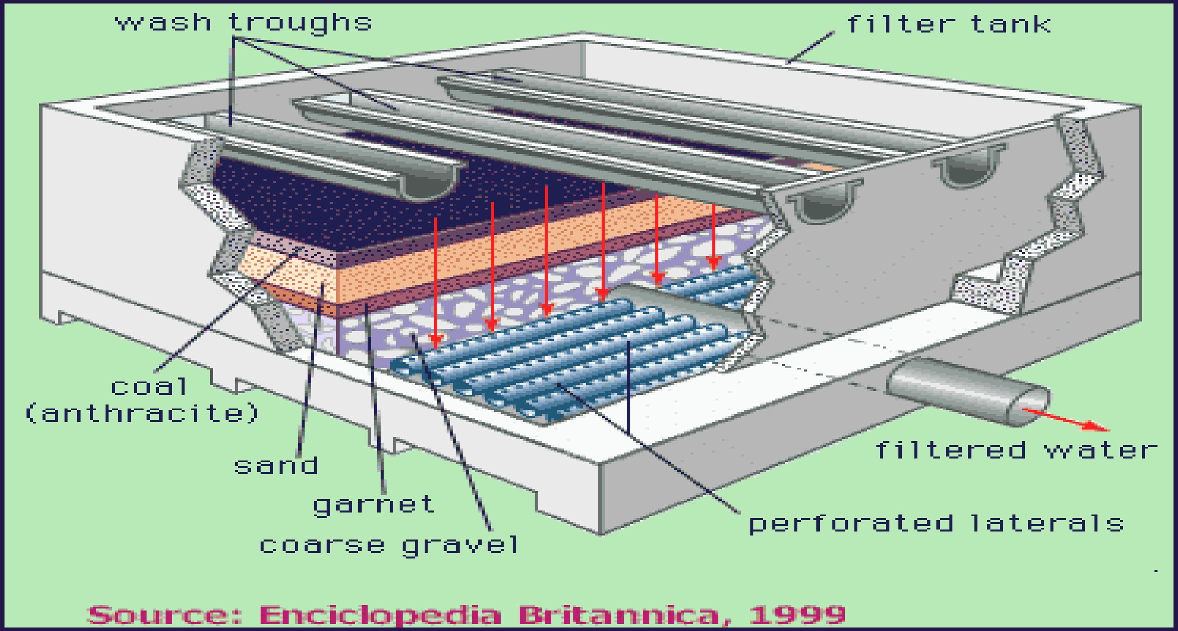
- Backwash troughs collect backwash water and transport it out of the filter. The rim of the troughs should be 24 to 28 inches above the filter media (32 to 36 inches for anthracite).
- Surface washers are used during the backwash cycle to agitate and break up the top layer of the sand where most of the dirt is trapped. This step helps reduce the amount of backwash water needed for a filter by reducing the time it takes to properly clean the filter.

Filter Anatomy (cont.)

- Backwash valves and a pump supply backwash water to the filter.
  - Capable of supplying at least 15 gpm/ft^2 of filter area.
  - Enough backwash water must be available to run the backwash for 7 to 15 minutes on average.



Typical Filter Construction


wash troughs
filter tank
coal
(anthracite)
sand
garnet
coarse gravel
filtered water
perforated laterals
Source: Enciclopedia Britannica, 1999

Gravity Filtration

- The water level above the media forces the water through the filter media.
- Filter media configurations:
  - Single-media: sand, anthracite coal, or granular activated carbon
  - Dual-media: sand and anthracite coal
  - Multimedia or mixed-media: sand, anthracite coal, and garnet

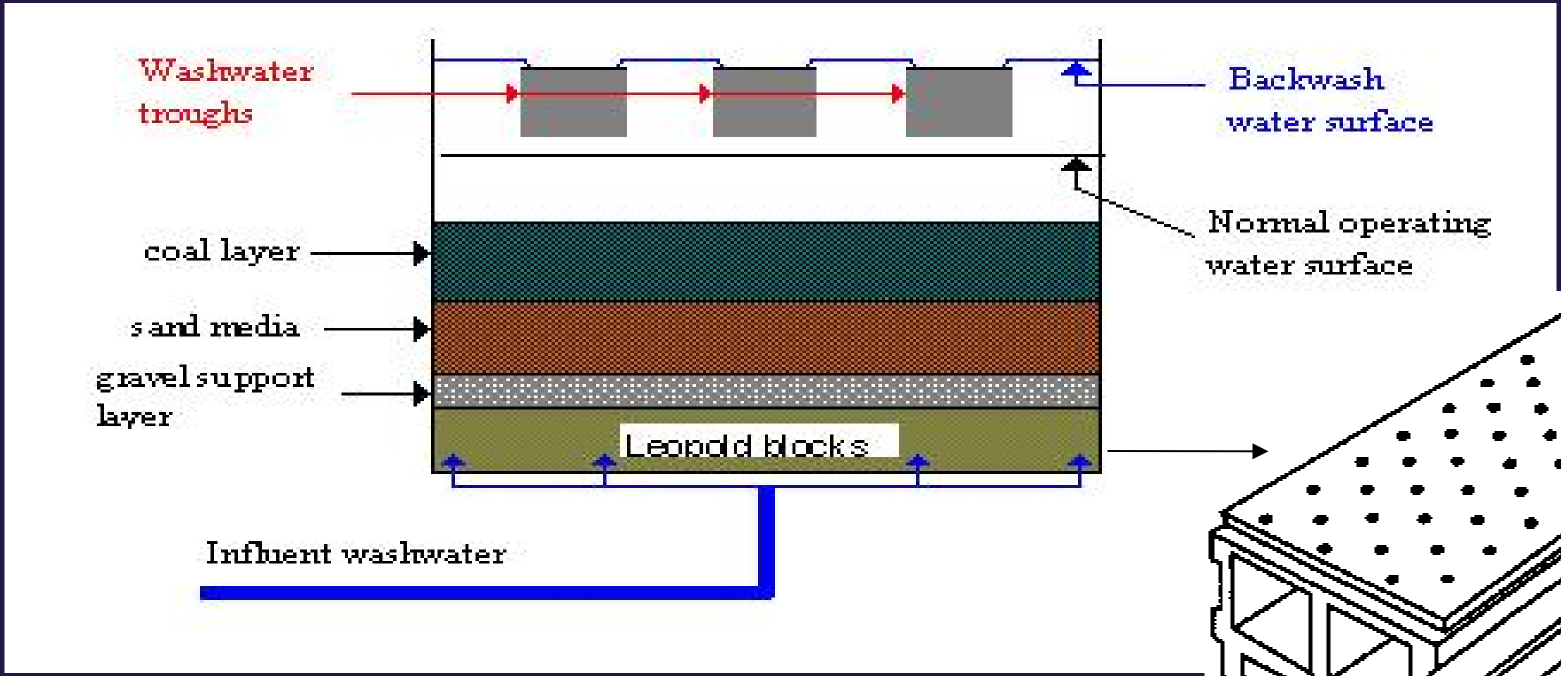
Gravity Filtration (cont.)

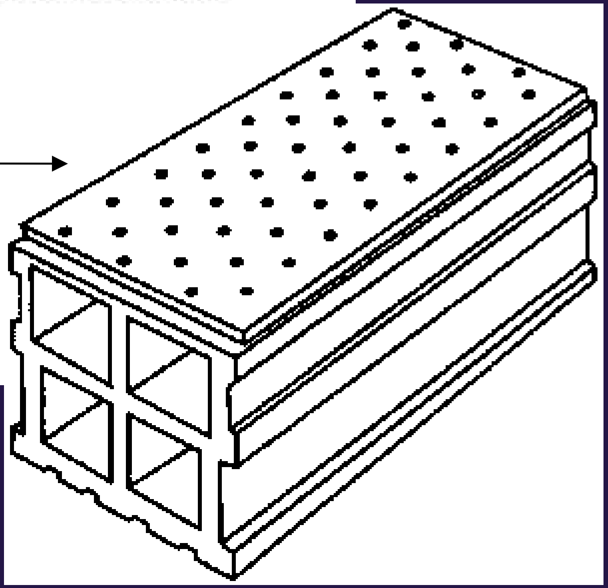
- Filtration rates (hydraulic loading):
  2 to 10 gpm/ft^2
- Includes rapid sand filters and high-rate filters

Dual-Media Filters

- Use a filter bed of both anthracite coal and silica sand, usually 12 to 18 inches of coal on top of 8 to 12 inches of sand. The upper layer of lighter and coarser anthracite has voids about 20% larger than the sand, resulting in a larger to smaller grading of the media in the direction of flow.
- Filter rate of 3 to 5 gpm/ft^2
- After backwashing, the filter media separates, with the heavier sand falling to the bottom and the lighter coal on top. The larger floc particles are trapped in the surface of the coal layer, while the finer particles are held in the sand. This creates deeper particle penetration into the filter bed and allows higher filtration rates.

Dual-Media Filters (cont.)

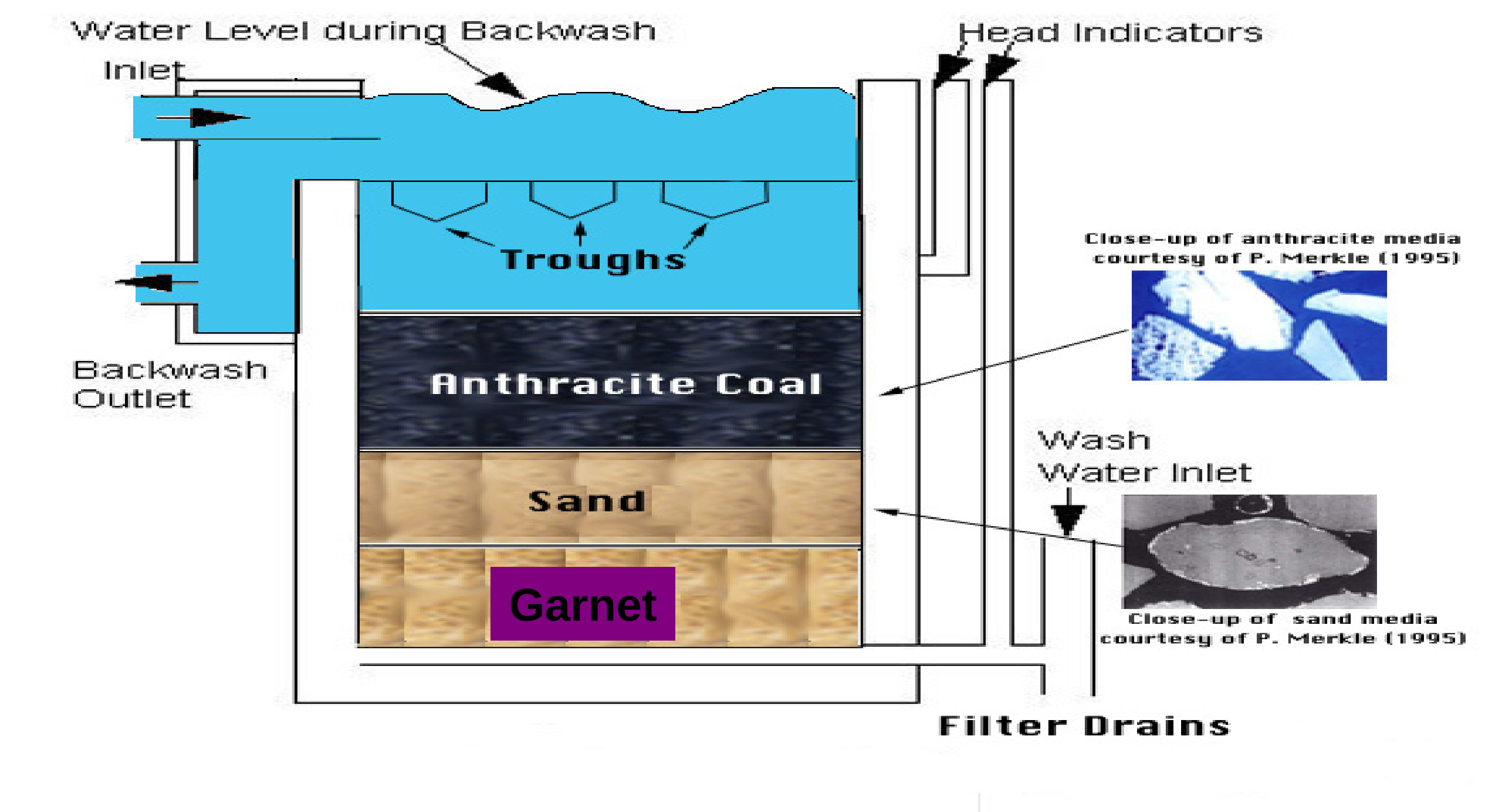




Multimedia Filters

- Use coal, silica sand, and garnet sand.
- Provide the highest filtration rate of any gravity filter: 5 to 8 gpm/ft^2.
- Garnet sand has specific gravity of about 4.2, which is greater than that of coal (1.6) or silica sand (2.6). A multimedia filter bed will consist of 4 to 6 inches of garnet sand on the bottom, 8 to 10 inches of silica sand in the middle, and 12 to 18 inches of anthracite coal on top. Because of the difference in specific gravities, separation of the media occur after backwashing with little intermixing. A typical multimedia filter has particle sizing gradually decreasing from about 0.7 mm at the top to 0.2 mm at the bottom. Mixed media are also used in pressure filters.

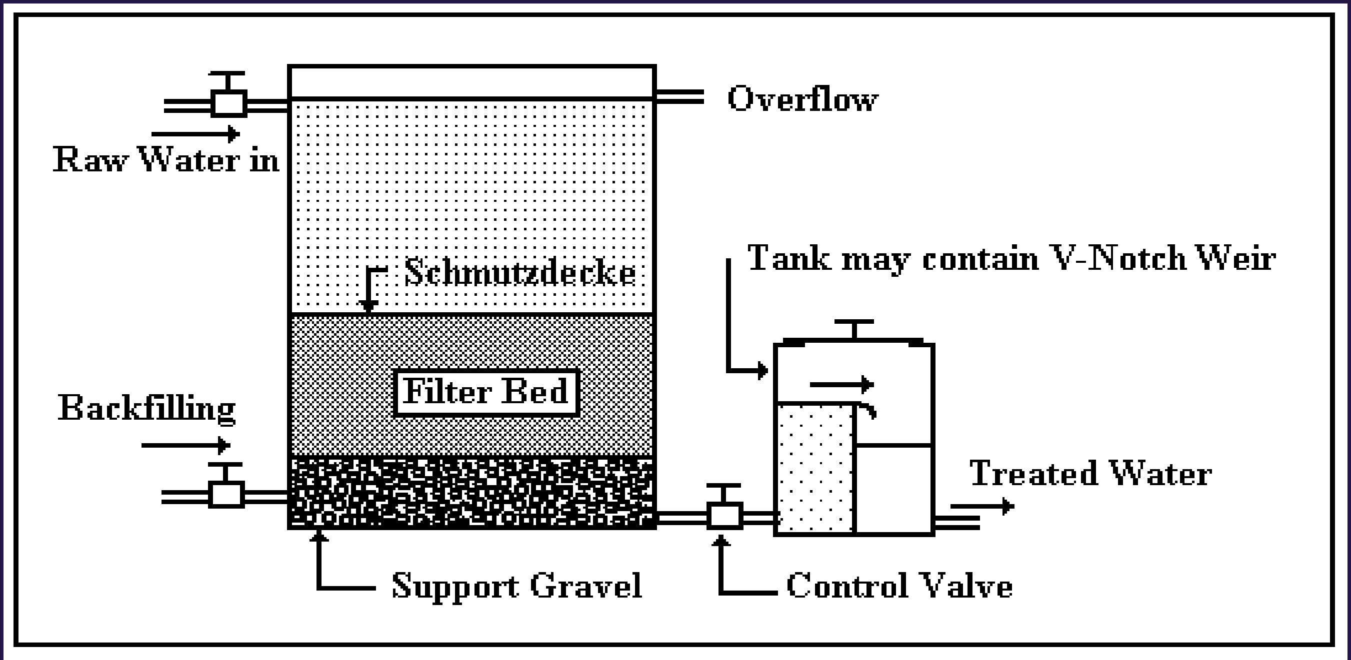
Multimedia Filters (cont.)



Slow Sand Filters

- The first type of gravity filter used for water treatment.
- Filtration rate: 0.015 to 0.15 gpm/ft^2.
- Consists of a box and underdrain filled with about 3.5 feet of filter sand. Suspended material collects on the surface of the filter bed, forming a layer known as "smutzdecke."
- When the filter gets clogged, it is taken out of service and cleaned by scraping the top inch of so of sand off the filter bed. This material must be replaced after several cleanings to restore the original media depth. After a filter is cleaned, it must be filtered to waste for several days before being put back in service. Therefore, a system must have two filters to provide continuous service.

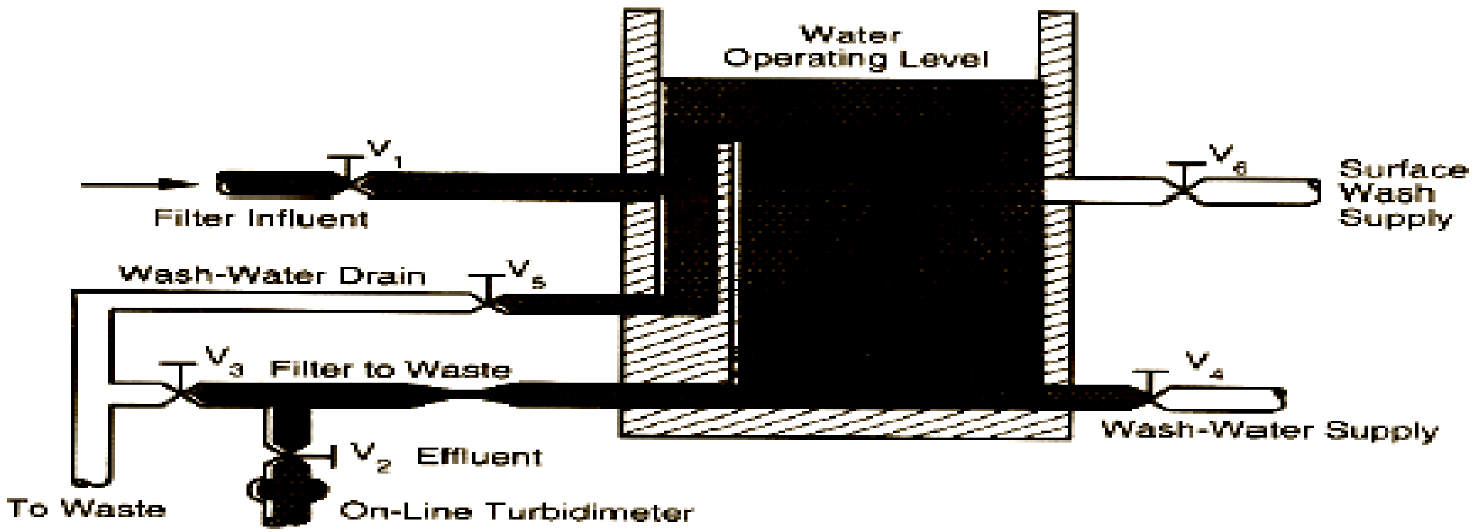
Slow Sand Filters (cont.)



Filter Backwash

- When a filter has been in operation for its optimum number of hours or its head loss reaches a predetermined pressure, the filter is taken out of service and backwashed. The proper procedure for backwashing filters is very important. This is a typical procedure for backwashing a sand filter. However, the operator should always follow manufacturer's instructions to avoid possible damage to the underdrain or media bed.

Filter Backwash (cont.)



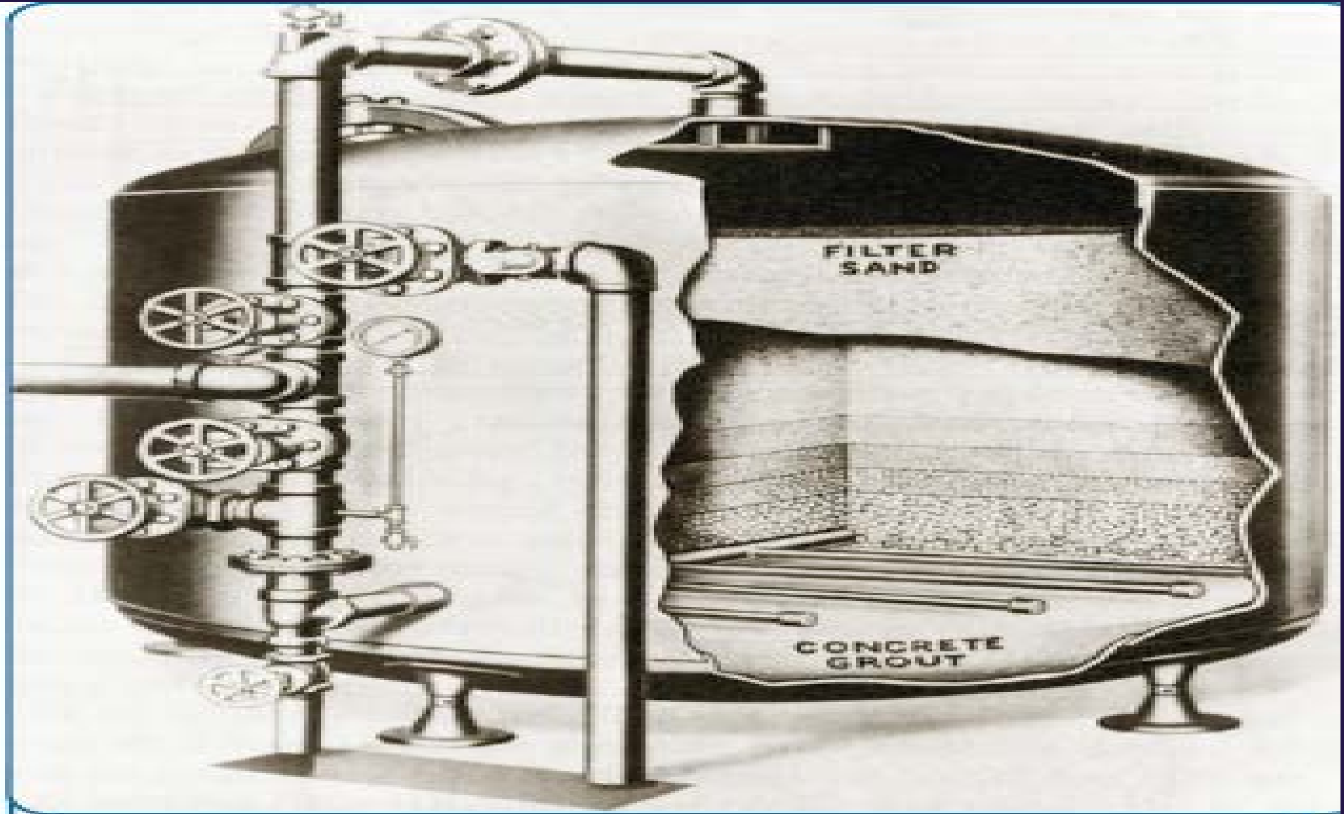
Valve Position During Filtration

Valve	*Filtering*	*Backwashing*	*Filtering to Waste*
V_1 — Influent	Open	Closed	Open
V_2 — Effluent	Open	Closed	Closed
V_3 — Filter to Waste	Closed	Closed	Open
V_4 — Wash-Water Supply	Closed	Open	Closed
V_5 — Wash-Water Drain	Closed	Open	Closed
V_6 — Surface Wash Supply	Closed	Open	Closed

Pressure Filters

- Operate under the same principles as gravity filters, except that the influent is forced through the filter under pressure
- Steel cylinders that use sand or other media to remove particulates
- Pressure filters must be backwashed when the media gets clogged with solids. This is usually accomplished by manually operating the filter valves to reverse the flow through the filter bed. Pressure filters have about the same filter rate as gravity filters with the same type of media. Diatomaceous earth is another type of media that may be used instead of sand in some pressure filters.

Pressure Filters (cont.)



Typical vertical pressure filter with concrete grout fill in bottom, pipe headers, lateral under drains, gravel support bed, and filter sand, (Courtesy of Infilco Degremont, Inc.) illustration from *Handbook of Public Water Systems*, second edition, HDR Engineering, Inc

Topics – Chapter 15 Water Ops Study Guide

- Non-Membrane Systems
  - Activated Carbon
  - Ozone
  - UV
  - Zeolites
- Membrane Systems
  - MF
  - UF
  - NF
  - RO
  - ED
- Basis for Inclusion – existing & future applications
  - Potable Reuse: IPR, DPR

Non-Membrane Systems

- Used for dissolved solids removal, disinfection
  - Activated carbon
  - Ozone
  - UV
  - Zeolites

Non-Membrane Systems

Activated carbon

Types of Carbon

- Activated carbon
  - Powdered – PAC
  - Granular – GAC
  - Extruded – EAC
  - Biological – BAC
- Impregnated
- Polymer-coated

General Characteristics

- Very porous – surface area : particle size
- A**d**sorption removal process
- Highly selective for organic compounds
  - Such as…?
- Activation of coal, wood, coconut char
  - Lo temp bake/hi temp furnace
  - Specific pore sizes for different apps
  - Diameters ≤ 1.0mm; avg 0.15-0.25mm

Powdered Activated Carbon

- Very fine particle size – crushed or ground
  - 80-mesh sieve - 0.177mm and smaller
- Hi surface area : volume ratio
  - Small diffusion distance
- Added directly to existing treatment processes rather than used in dedicated reaction vessel due to high head loss
  - Raw water intakes, Rapid mix
  - Settlers, Gravity filters

Granular Activated Carbon

- Fine particle size – larger than PAC
  - 50-mesh sieve - 0.297mm
- Lower surface area : volume ratio than PAC
- Preferred for adsorption of gases and vapors
- Can be used in dedicated reaction vessels

Extruded Activated Carbon

- PAC mixed with binder, extruded into cylinders 0.8-130mm in diameter
- Mainly used for gas-phase apps
  - Low pressure drop
  - High mechanical strength
  - Low dust content

Biological Activated Carbon

- Used for enhanced organic removal thru biological processes
- Typically aerated biological reactor
  - Promotes biological growth within carbon particle pores
- Pre-ozonation breaks down larger organics into smaller molecules more suitable for biological degradation
- Initial organic removal thru typical carbon adsorption
- Biological removal increases as adsorption decreases

Specialty Types of Carbon

- Impregnated
  - Specific ions such as I, **Ag**, Al, Mn, Zn, Fe, Li, Ca
  - Air, water pollution control
- Polymer-coated
  - Biocompatible polymer for smooth, permeable coating
  - Toxic substance removal from blood

Selecting, Evaluating Performance

- Small molecule adsorption - Iodine #
  - 500-1200 mg I/g carbon
  - Micropore content 0-20 A or up to 2 nm
  - Equivalent to 900-1100 m^2/g carbon
  - Bed volumes to exhaustion (breakthrough) vs Langmuir isotherms
- Large molecule adsorption – molasses #
  - Typical range 95-600
  - Micropore content >20 A or >2 nm
  - Degree of decolorization of molasses solution

Selecting, Evaluating Performance (cont'd)

- Medium to large molecule adsorption – tannin std
  - 200-362 ppm
- Medium molecule adsorption – methylene blue std
  - 11-28 g methylene blue/100 g carbon
  - Micropore content 20-50 A or 2-5 nm
- Dechlorination half-value std
  - Depth of carbon bed reqd to reduce chlorine (flowing) from 5-2.5 ppm; lower the half-value better the performance
- Apparent density
  - Higher density implies better quality product

Selecting, Evaluating Performance (cont'd)

- Hardness/abrasion #
  - Resistance to attrition
- Ash content
  - Reduces activity and regeneration
  - Acid/water soluble more sig than total ash content
- Carbon tetrachloride activity
  - Measurement of porosity thru vapor adsorption
- Particle size distribution
  - Finer particles better access to surface area & faster rates of adsorption

Selecting, Evaluating Performance (cont'd)

- Criteria
  - Removal targets, such as?
  - Source material for carbon
  - How it is activated
  - Adsorption isotherms
  - Physical properties
  - Design criteria
  - Regeneration
  - Life cycle costs
  - Disposal

Non-Membrane Systems

Ozone – O_3

Ozone Characteristics

- Strong oxidizer
- Odor threshold ~0.01 ppm
- 0.1-1 ppm headaches, burning eyes, respiratory irritation
- Destructive to latex, plastics, animal lung tissue
- No residual; ~0.5-hr half-life
- Oxidizes metals, NO, C, S^{-2}, H_2S
- On-site generation

Ozone Generation

- Corona discharge – from dry air (most common)
  - 3-6% ozone
- UV light – narrow-band
  - 0.5% or lower ozone
  - Not practical for moving air or water applications
- Cold plasma – from pure oxygen; $$$$$
  - ~5% ozone
- Electrolytic (EOG) – from water
  - Splits water in to H_2, O_2 and O_3
  - removes H_2

Non-Membrane Systems

Ultraviolet Light - UV

UV Characteristics

- Wavelength 10-400 nm
  - between x-rays (shorter than uv) & visible (longer than uv)
  - Energy 3-124 eV
- Invisible to human eye
- Black lights
- Typically non-ionizing
- Many apps depending on wavelengths 230-400 nm
  - Disinfection of water 240-280 nm; viruses, bacteria, protozoa
- No residual

UV Operation

- SODIS – solar water disinfection
  - Natural sunlight thru PET; at least 6-hr
    - UV-A, increased water temp
- Interferences
  - Turbidity 5 NTU
  - TSS 10 mg/L
  - Hardness 102.6 ppm

  Mn 0.05 mg/L

  pH 6.5-9.5

  Fe 0.3 mg/L
- Lamp replacement
- Sleeve cleaning
- Power supply
- Energy flux, W/m^2 – design vs operating conditions

Non-Membrane Systems

Zeolites

(as adsorbents)

Zeolite Characteristics

- Microporous aluminosilicate minerals
  - Water purification, catalysts, nuclear reprocessing, medicine, ag, production of laundry detergents
  - Cation selective: Na, K, Ca, Mg, others; ion exchange (IX)
- Natural and synthetic
- Molecular sieve
  - Ability to sort target molecules based on size exclusion
  - Max size of target molecule or ion that enters zeolite pore controlled by dimension of channel
    - Ring size of aperture

Zeolite Operation

- Filtration media comparison
  - Sand, sand/anthracite, multimedia; pressure or gravity
  - 1.7-1.9x solids loading capacity/ft^3
  - Hi-purity zeolite > conventional granular media

- Better at fine particle removal
  - Pressure app rates 12-20 gpm/ft^2
    - zeolites 0.5-10μ; sand ~20μ; sand/anthracite ~15μ; multi ~12μ
  - Gravity app rates 15 gpm/ft^2
    - Zeolite filtrate average NTU 1/3 multimedia

Zeolite Operation (cont'd)

- Application rates
  - Pre-filtration for RO, GAC: 12 gpm/ft^2
  - Turbidity removal: 15 gpm/ft^2
  - High volume, lower quality reqts: 18-20 gpm/ft^2
- Backwash rates ~ 20 gpm/ft^2; 35% bed expansion
  - Air scour
- Similar to pressure filters with conventional media
- Cost
- Durability

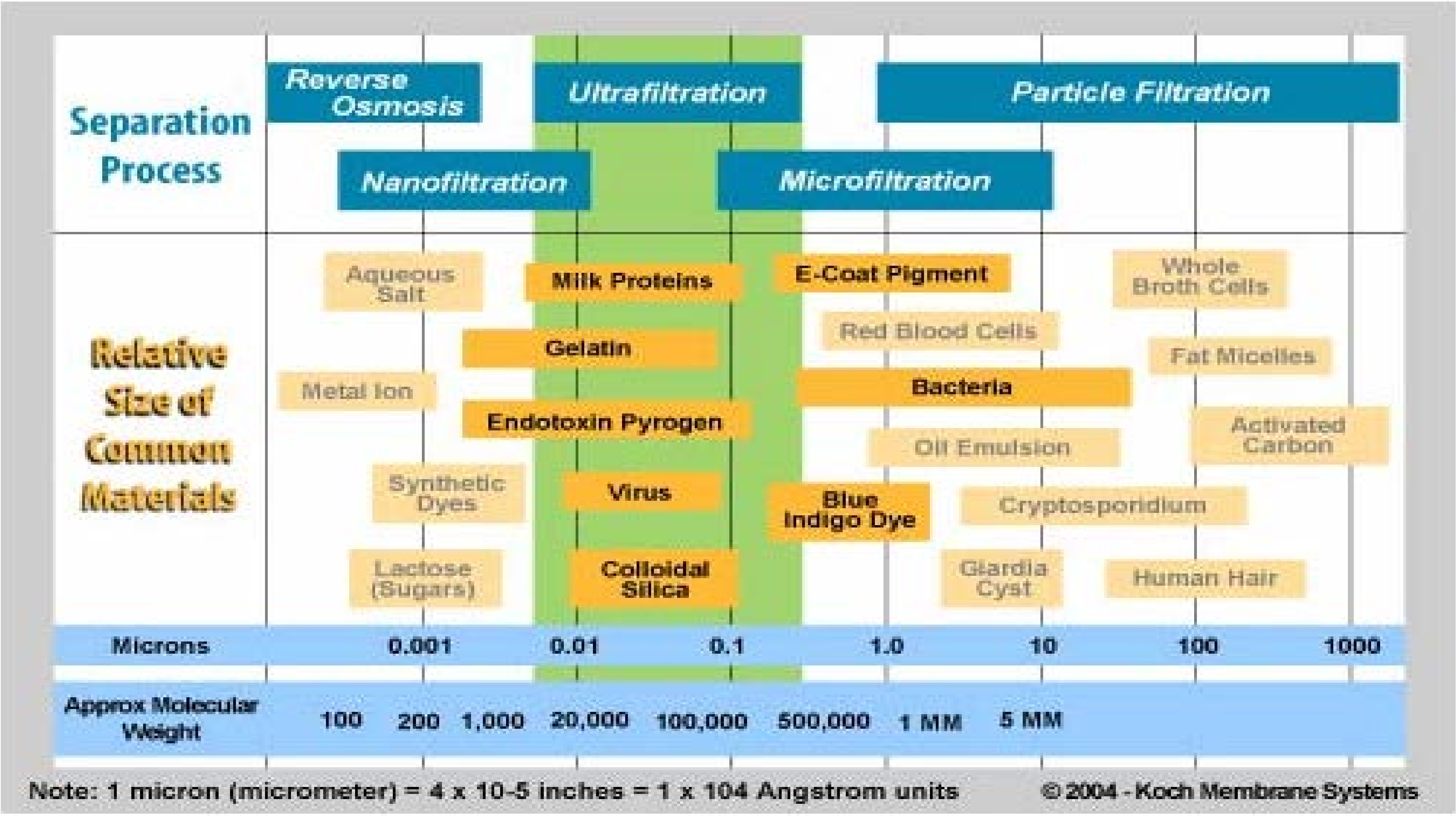
Membrane Systems

- Mostly for pressure-driven dissolved solids removal
  - Microfiltration - MF
  - Ultrafiltration - UF
  - Nanofiltration - NF
  - Reverse Osmosis – RO
  - Electrodialysis – ED (electro-driven)

Membrane Systems

General Considerations

Size of Materials Removed by Various Processes



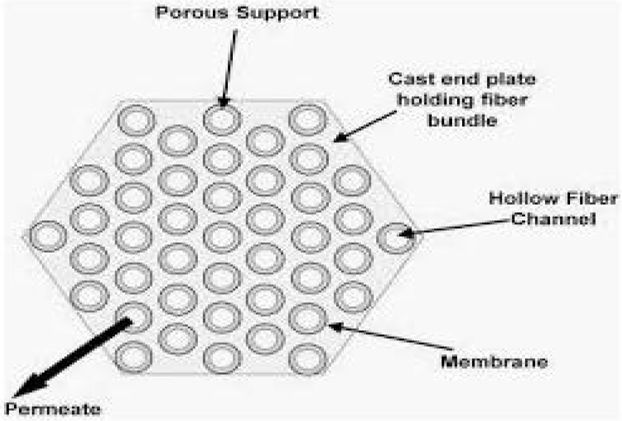
Membranes – General Considerations

- Removal targets determine pore size
  - NOM
  - chemicals
  - pathogens
- Compatibility
  - Oxidants, including permanganate
  - pH
- Life expectancy
- Cost
- Polyvinylidene Fluoride, polypropylene, polysulfone

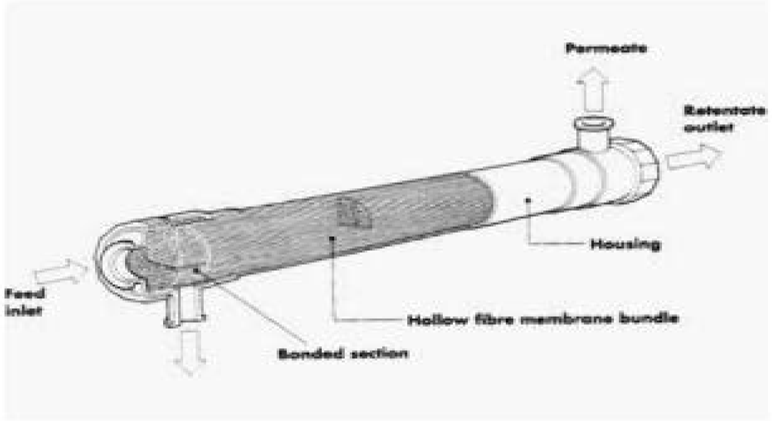
Membrane Configuration

- Flat sheet
  - electrodialysis application, R&D all others
- Hollow fiber
  - Up to 1-in diameter tube
    - Single membrane per vessel; several tubes in a bundle
- Hollow fine fiber
  - 10-100's µm (human red blood cell 5 µm; human hair 75 µm)
- Spiral Wound
  - Membrane wound around center perforated product tube
  - Water travels tangentially from outside in

Configuration Examples

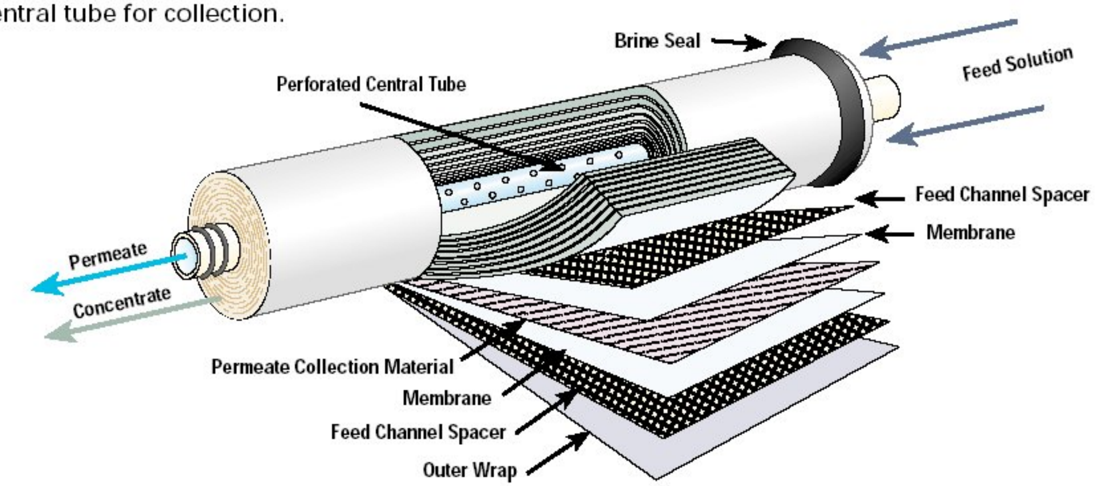


Hollow Fibre Module - an overview ...
sciencedirect.com



Hollow Fibre Module - an overview ...
sciencedirect.com

The spiral membrane is constructed of one or more membrane envelopes wound around a perforated central tube. The permeate passes through the membrane into the envelope and spirals inward to the central tube for collection.



The illustration above represents a simplified spiral-wound membrane element. Recovery can be as high as 90% and systems may be capable of chemical cleaning in place (CIP).

System Configuration

- Pressure vessels: 1 to 7 membranes per vessel
- Array
  - pressure vessels manifolded together
  - Design configuration 2:1, 4:2, 3:2:1 (# vessels per manifold)
- Reject staged max water recovery (lower quality)
  - Reject water is feed water to next vessel
- Product staged max water quality
  - Product or permeate is feed for next stage
- pH
  - Feed 4 – 10; cleaning 1 - 13

System Performance

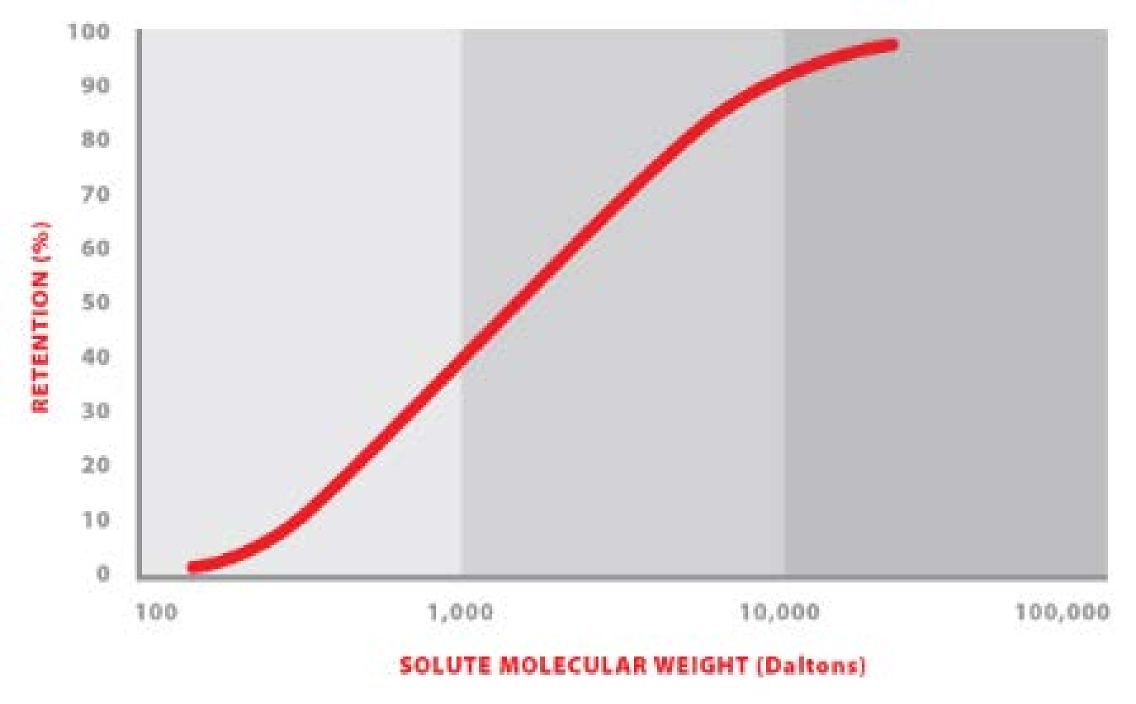
- MF, UF remove particulates, pass soluble
- MF
  - product water < 0.05 NTU
  - Pretreatment process for NF, RO
- All membranes exceed SWTR log-removal reqt for Crypto, Giardia (3-log) and viruses (4-log)
- Nominal pore size – smallest pore size in membrane
- Molecular weight cutoff - MWCO
  - lowest molecular weight (in Daltons) at which greater than 90% of a solute with a known molecular weight is retained by the membrane

System Performance - MWCO (cont'd)

- Dextran, polyethylene glycol and proteins of various molecular weights are commonly used to rate the MWCO of membranes
- Qualification methods for molecular weight vary across membrane manufacturers
  - no set industry standard for MWCO determination
  - limitations to this measurement technique
- Advisable to select MWCO at least 2x smaller than the molecular weight of the smallest target solute requiring removal by membrane

System Performance - MWCO (cont'd)

Retention versus Molecular Weight



Dalton, the unified atomic mass unit (symbol: u, Da, AMU) is a standard unit of mass on an atomic or molecular scale. One unified atomic mass unit is approximately the mass of one nucleon (either a single proton or neutron) and is numerically equivalent to 1 g/mol.

Operating Parameters

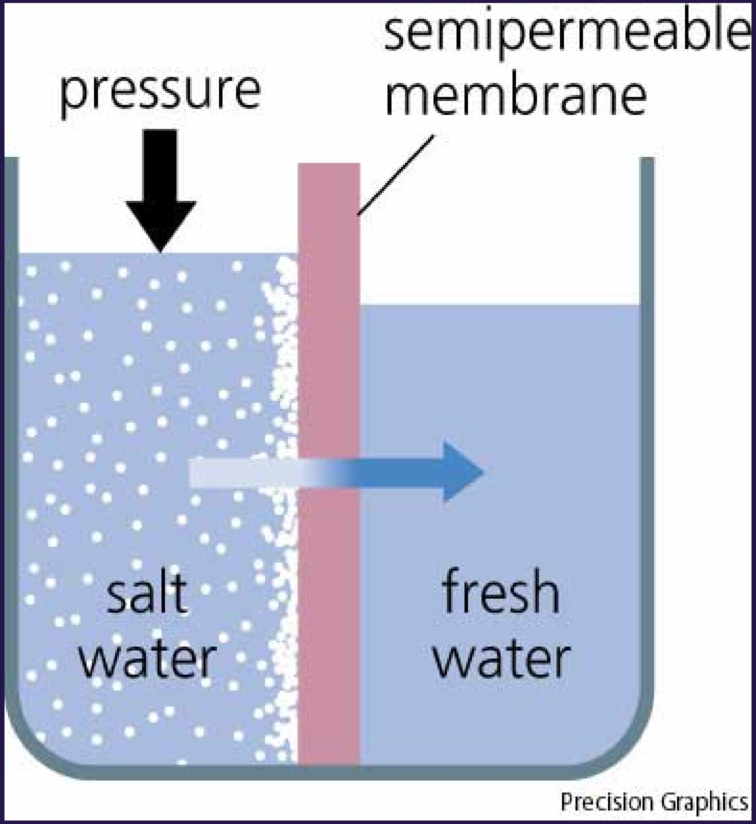
- MF: intermediate between multimedia & UF
  - 0.03-1.2 µm pore size; 5-30 psi operating pressure
- UF
  - particulates, protozoa, bacteria, viruses, organics > MWCO of membrane; 80-100K MWCO; 10-50 psi
- NF
  - 200-400 D dissolved organics, multivalent +/- ions, some monovalent, DBPs; 300-600 psi
- RO: almost all organics & inorganics; DPR application
  - MF pre-filter
  - semi-permeable membrane; <1 A pore size/<0.0001 µm
  - Water passes; dissolved contaminates rejected
    - Not boron, dissolved gases
  - 60-1500 psi (home systems-desalinization systems)

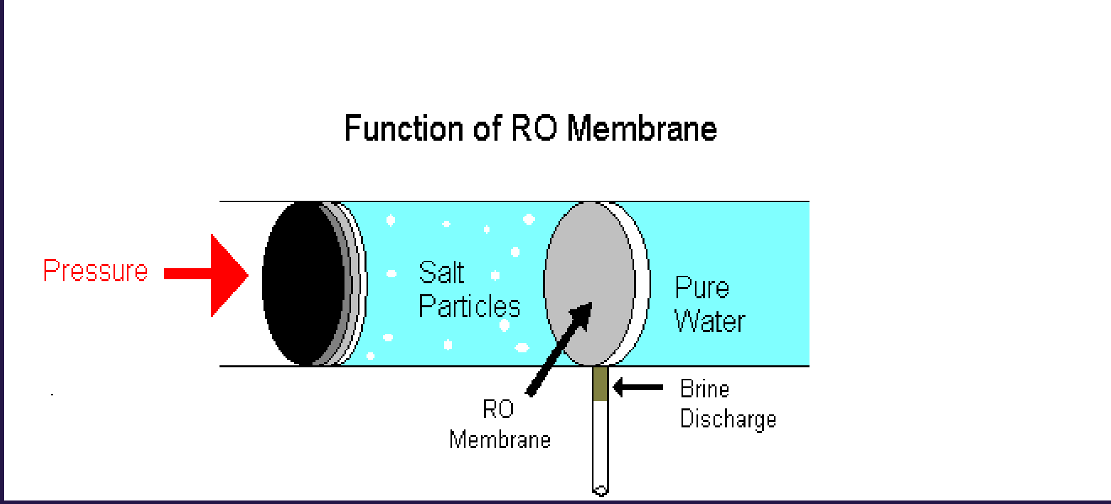
Reverse Osmosis (RO, R/O)

- Reverse osmosis: a common treatment technology that produces high-purity water

- Works by forcing water (reverse) under great pressure against a semipermeable membrane, where contaminant exclusion occurs
  - Water molecules form a barrier that allows other water molecules to pass through while excluding most contaminants.

Reverse Osmosis (cont'd)





System Operations

- High velocity (turbulent) feed; 15 ft/sec
- Pretreatment
  - Bag, cartridge filters
  - Chemical
    - Conventional coagulation, flocculation, sedimentation
    - Direct
    - TDS to colloids for MF/UF
  - Complex contaminants
  - pH adjust
- Once-through maximizes water quality
- Feed & bleed maximizes water recovery

Routine Cleaning

- Filtrate flow rate is design flow of system
  - **Minimum** filtrate flow for system
- Clean flow usually 50-100% higher than design flow
  - Decline from clean flow down to design flow threshold for cleaning
  - Think 'filter run' between backwash for granular filtration
- Chemical compatibility
- Paced with production levels
  - Single cleaning – entire system off-line; usually 1 train
  - Split cleaning – 1 or more trains in production while 1 train off-line for cleaning

Cleaning Methods

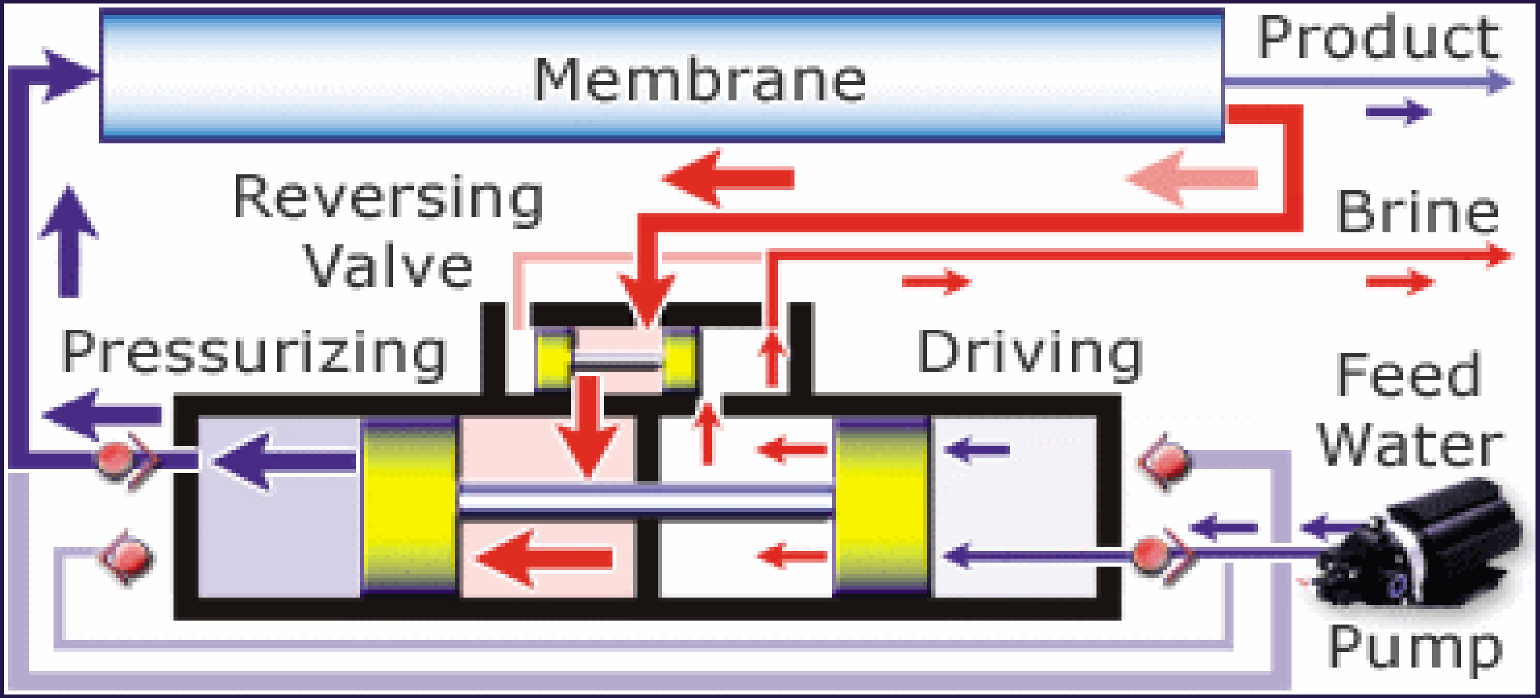
- MFGER SPECS!
- Air bump initiated at permeate flow threshold
  - 1-2 sec of 30-35 psi air filtrate (flooded) to feed side
  - Forces filtered water back thru membrane to dislodge particles
  - Discharged thru reject port back to head of plant
- Back pulse initiated based on time; 15-20 min
  - 20 sec of 10-12 psi air
  - No discharge

Cleaning Methods (cont'd)

- Backwash initiated at permeate flow threshold
  - 10-15 min of 20 psi product water back thru membrane
  - Discharged thru reject port back to head of plant
- Forward flush initiated at permeate flow threshold
  - 100% reject flow sent to head of plant
  - Increase in flow velocity provides scour
  - Permeate flow checked against threshold, design, clean targets
    - Return to normal ops
    - Initiate reverse flush

Cleaning Methods (cont'd)

- Reverse flush
  - Multi-port membrane modules needed to change direction of flow into module
  - Directs highest velocity feed water into opposite end of module
- Typical cleaning cycle
  - Flush solids from membrane
  - Back pulse
  - Recirculation of cleaning solution
  - Flush cleaning solution to target pH
  - Repeat cleaning steps as needed


Membrane
Product
Reversing
Valve
Brine
Pressurizing
Driving
Feed
Water
Pump

Membrane Systems

Electrodialysis- ED

ED Types

- ED or Unidirectional electrodialysis
  - Ions xfr through membranes from less concentrated to more concentrated solution under direct electric current
  - Used mainly in highly saline apps
    - Drinking water from sea water
- EDR, ED reversal
  - Direct current polarity is periodically reversed
  - Provides automatic flushing of membrane surface
  - Little or no pretreatment of feed water
- Little to no application for municipal water systems due to high O&M

Supervisory Control and Data Acquisition - SCADA

SCADA Uses

- RTUs – Radio Telemetry Units; simplest form
  - Typically line-of-sight communication between tank levels and wells
  - Could include central terminal unit for pre-programmed operations, data mgt
- Full-system SCADA; most sophisticated
  - Controls all system components
  - Pre-programmed ops
  - If/then ops
  - Data mgt including compliance, process control reporting

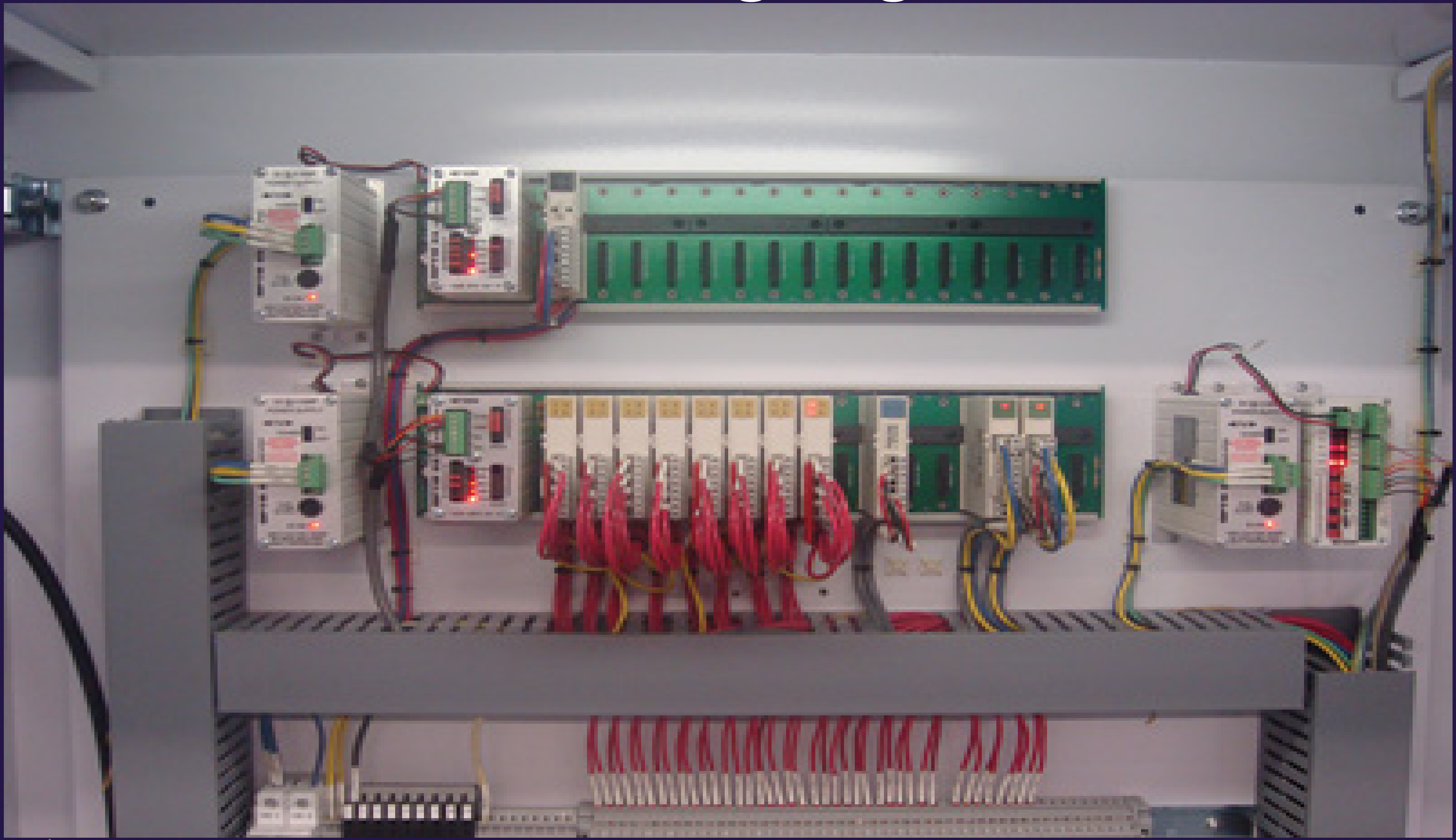
SCADA Benefits

- System and information management
- Regulatory requirements
- Reduce operating costs
- NRW
- Improve customer service

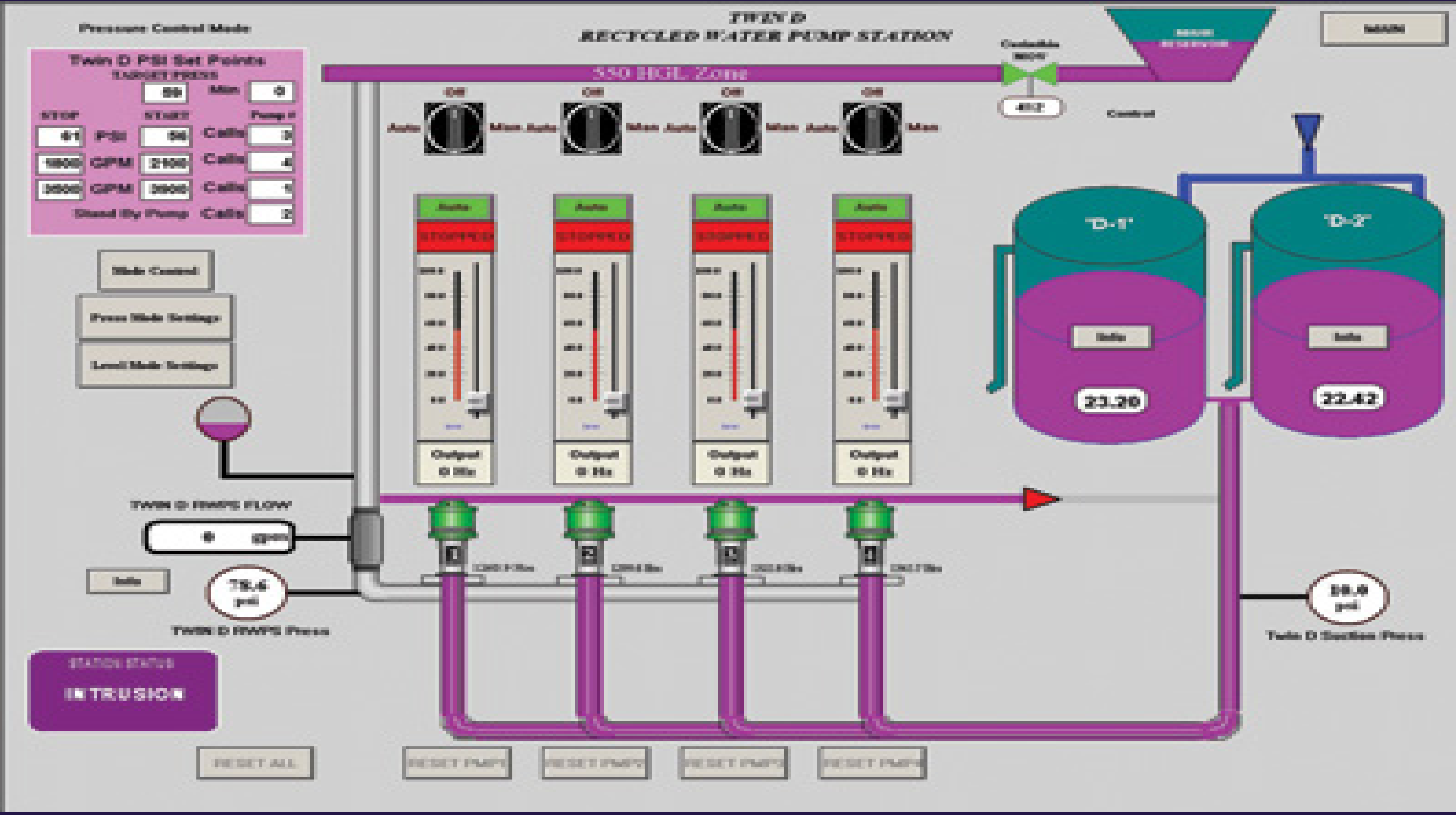
SCADA Components

- Central computer
- Communication equipment
- Programmable logic controllers
- Sensors for conditions and parameters; 4-20 mA
  - SWLs, PWLs
  - Tank levels and volumes
  - Flow rates, pressures
  - Pump (water, chemical) and valve status
  - Temperature, pH, chlorine residual, other WQPs
  - Turbidity, other PDWS based on treatment MCL objectives

SCADA Racks of Analog/Digital I/O Controls



SCADA Example Screen



SCADA Example

- https://www.youtube.com/watch?v=rj44AkHmVCo

SCADA Considerations

- Hardware I/O flexibility
  - Additions to infrastructure
  - Condition/parameter additions for existing infrastructure
- Software
  - Compatibility with hardware
  - Programmability (proprietary?)
- Data management
  - Process control, including trend analysis
  - reporting; internal, regulatory (DIT, MOR_t, MOR_i, MOR_{toc})
- Security – local, internet/cloud
- Cost

Advanced Water Treatment Processes

THANX!

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