UC Davis ECI 189I

Evaluation and Design of Small Water Systems

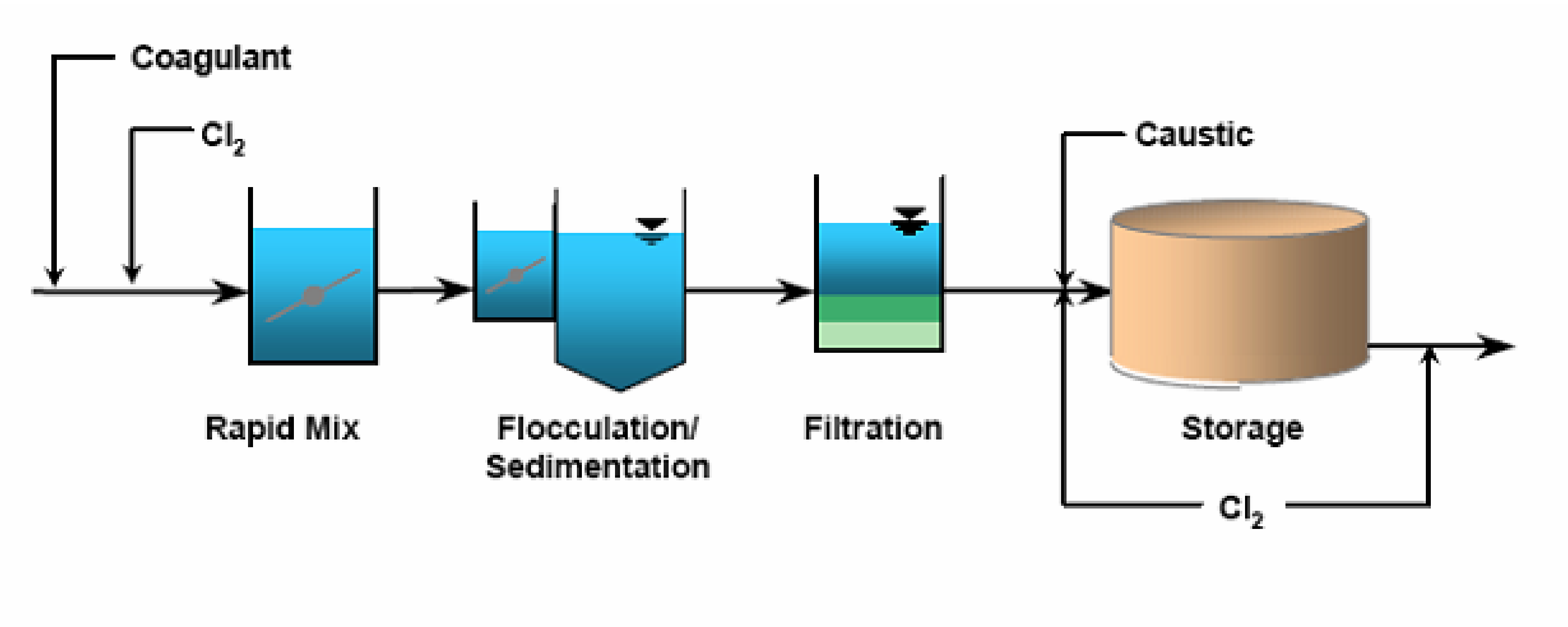
Conventional Water Treatment Systems

Dale Newkirk, P.E. & Professor Jeannie Darby

Lecture Objectives

- Review process design of pretreatment systems found in conventional WTPs.
- Review process design of granular filters including:
  - Mono media
  - Dual media
  - Mixed media
  - Slow sand

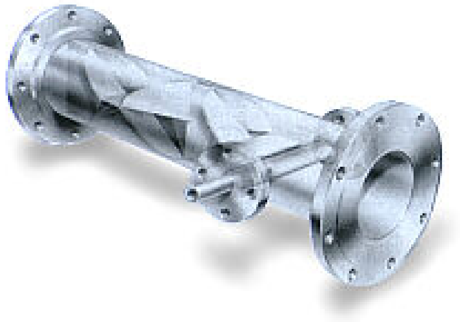
Conventional Treatment Layout



Rapid Mix - Coagulation

- Process introduces coagulant chemicals into the treatment process at the head works to stabilize electrostatic charges.
- Most common chemicals include alum or iron salts as primary coagulant and cationic polymer as secondary coagulant.
- Many small systems only use cationic polymers.
- Rapid mixing energy is determined by a factor called G which is a measure of energy applied as Hp to viscosity of water expressed as sec $^{-1}$.
- Alum and iron salts require a high G of 1000.
- Secondary coagulants such as cationic polymer requires a G of approximately 300.
- Jar testing is most common means of determining chemical dosage requirements.

Jar Testing/Mixing



What is G all about?

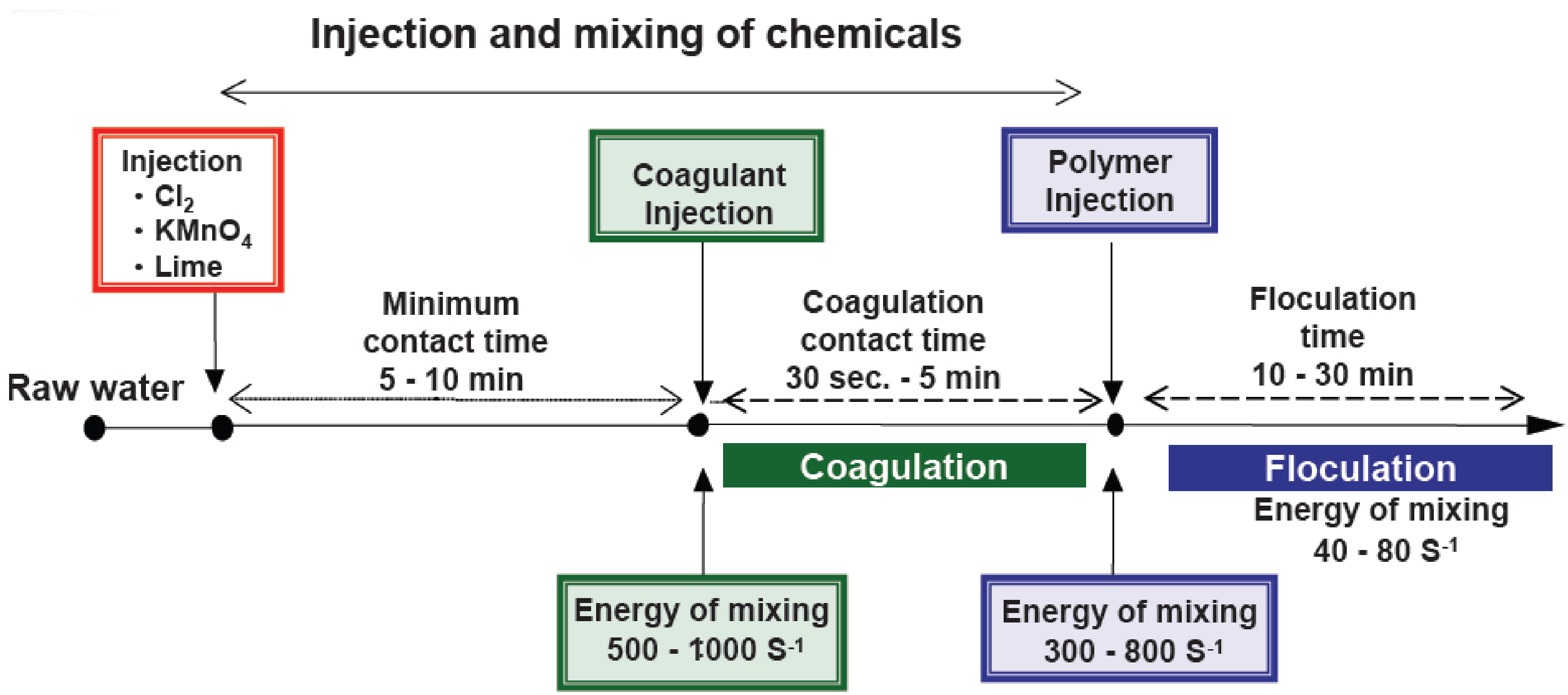
G = (W/m)0.5 sec^{-1} where

W = total power dissipated in the tank volume and

m = absolute viscosity of the fluid

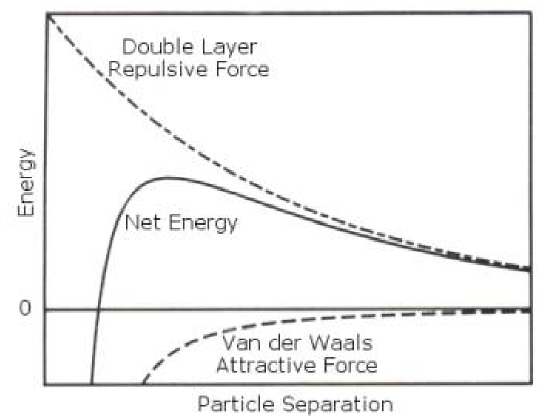
GT is mixing energy expressed as G multiplied by the contact time in the basin or chamber

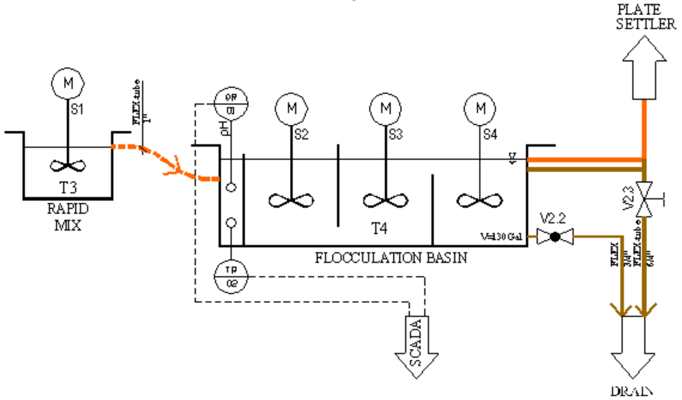
Typical Range of G and Mixing Times for Various Processes



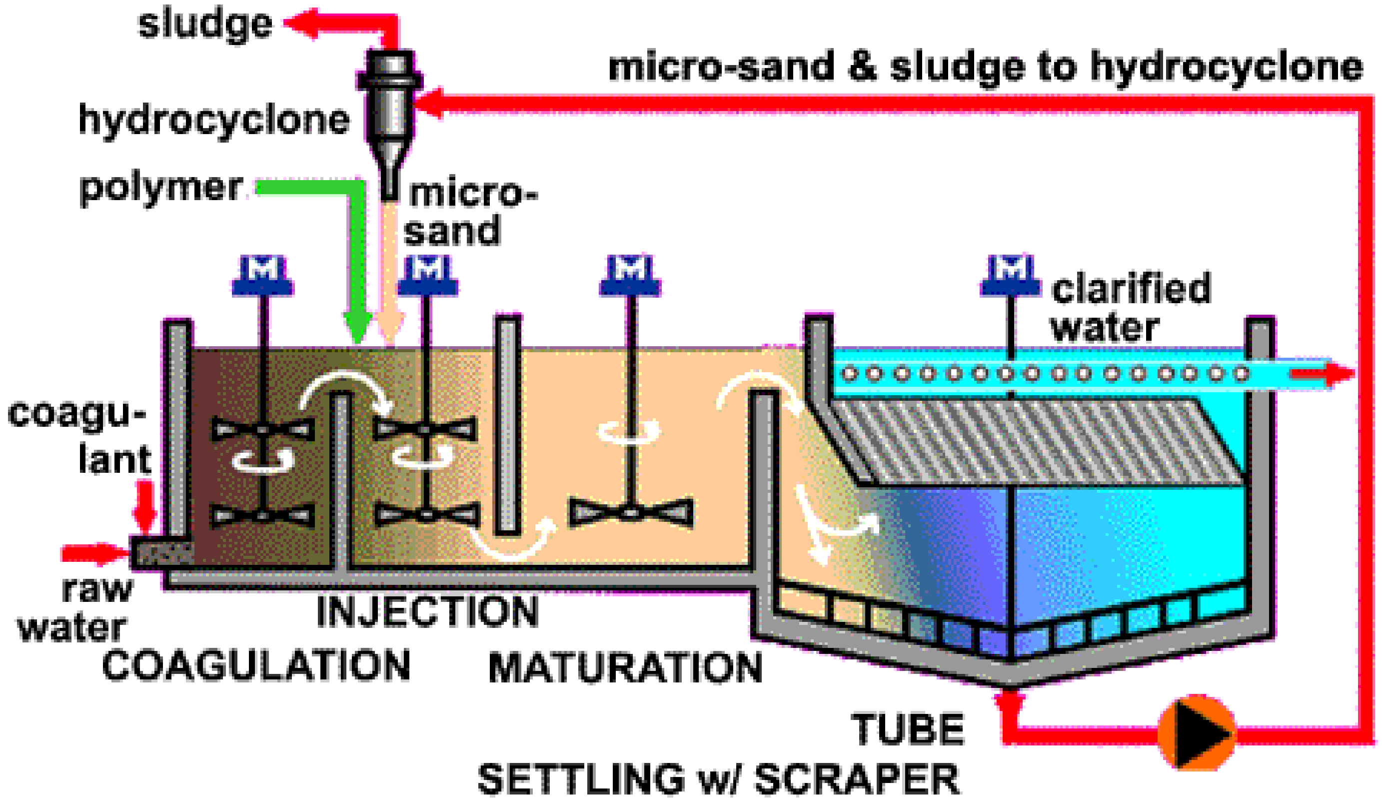
Flocculation

- Process designed to increase particle size of colloids to floc for removal.
- Many types of flocculation equipment including:
  - Roughing filter
  - Paddle wheel (Horiz.&Vert.)
  - Turbines
  - Trident up flow plastic beads
  - Baffles



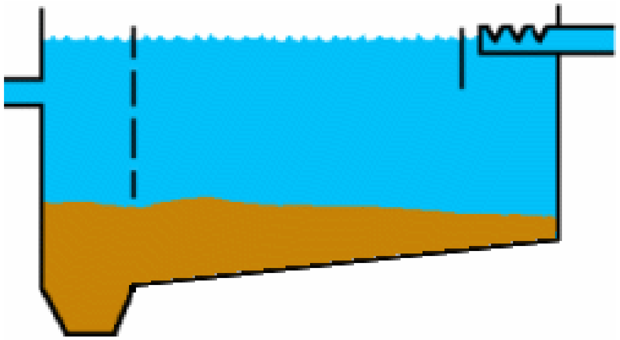


Actiflow System



Sedimentation

- Removes floc and separates from water prior to filtration.
- Do not exceed surface loading rates of 1 gpm/ft^2 for gravity basins.
- Do not exceed 2 gpm/ft^2 for tube settlers.
- Various high rate systems claim to handle up to 3.5 gpm/ft^2.
- Dissolved Air Floatation operates in reverse of gravity system



Typical Design Parameters

- Rectangular basin
- Depth: 7-16 ft
- Influent baffle to reduce flow momentum
- Slope of bottom toward sludge hopper >1%
- Continuous sludge removal with a scraper velocity <15 ft/min
- Detention time: 4-8 hours
- Flow through velocity: <0.5 ft/min
- Overflow rate: <1 $gpm/ft.^2$
- Weir loading: 15,000-20,000 gal/day-ft

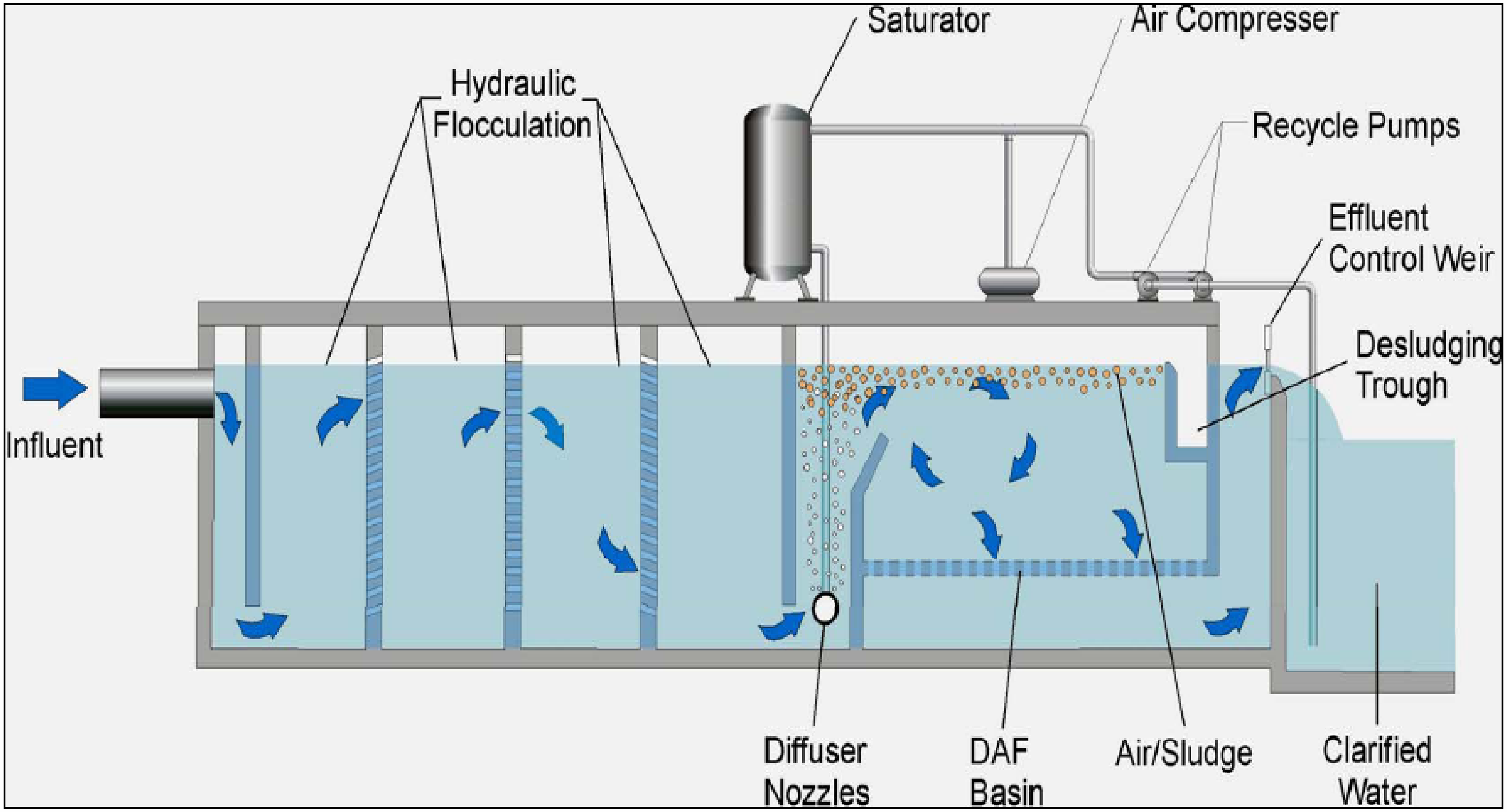
Typical Surface Loading Rates

Clarifier Design Factors

Surface Overflow Rate (gpm/ft^2)	
Alum floc	0.4 – 0.7
Lime softening	0.4 – 1.4
Tube settlers (overall basin rate)	1.0 – 3.0
Plate settlers (overall basin rate)	2.0 – 6.0
Upflow units	0.7 – 1.8
Lime softening/Upflow units	0.7 – 2.2
Detention Time (hour)	1.5 – 4
Velocity (fpm)	1.0 – 3.0

(Modified from AWWA and ASCE, 1998)

Use of Dissolved Air Floatation



Roughing Filter Design Parameters

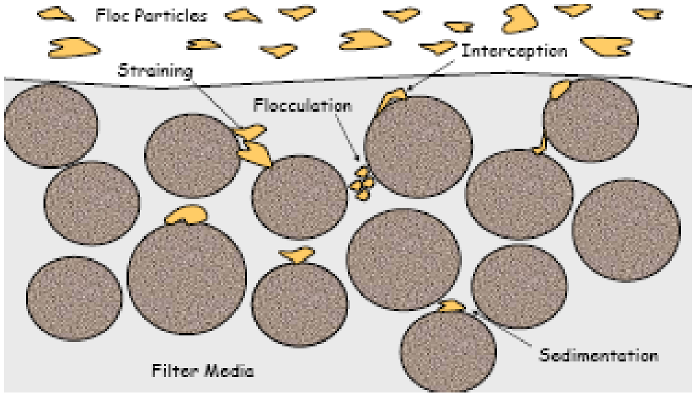
Examples of roughing filter design and performance for turbidity removal.

Reference	Filter type	Flow (m^3/d)	Media size range (mm)	Filtration rate (m/h)	Length or depth of media (m)	Mean filtered water turbidity (ntu)	Mean percent removed
Evans (1999)	URFS	18	40, 20, and 10 in 3 filters	0.6	3 at 0.5 m	2.7	70
Galvis et al. (1994)	URFS	812	25 to 3	0.7	2.0	0.7	70
Galvis et al. (1994)	URFS	588	20 to 6	0.6	1.8	2.7	53
Galvis et al. (1994)	URF	760	25 to 3	0.7	1.0	5.0	66
Li et al. (1996)	HRF	Full scale, nd	5 to 1.2	0.7	nd	Influent turbidity reduced from a few hundred ntu to <100 ntu	
Wegelin (1994)	HRF	260	nd	1.2	nd	About 4	nd

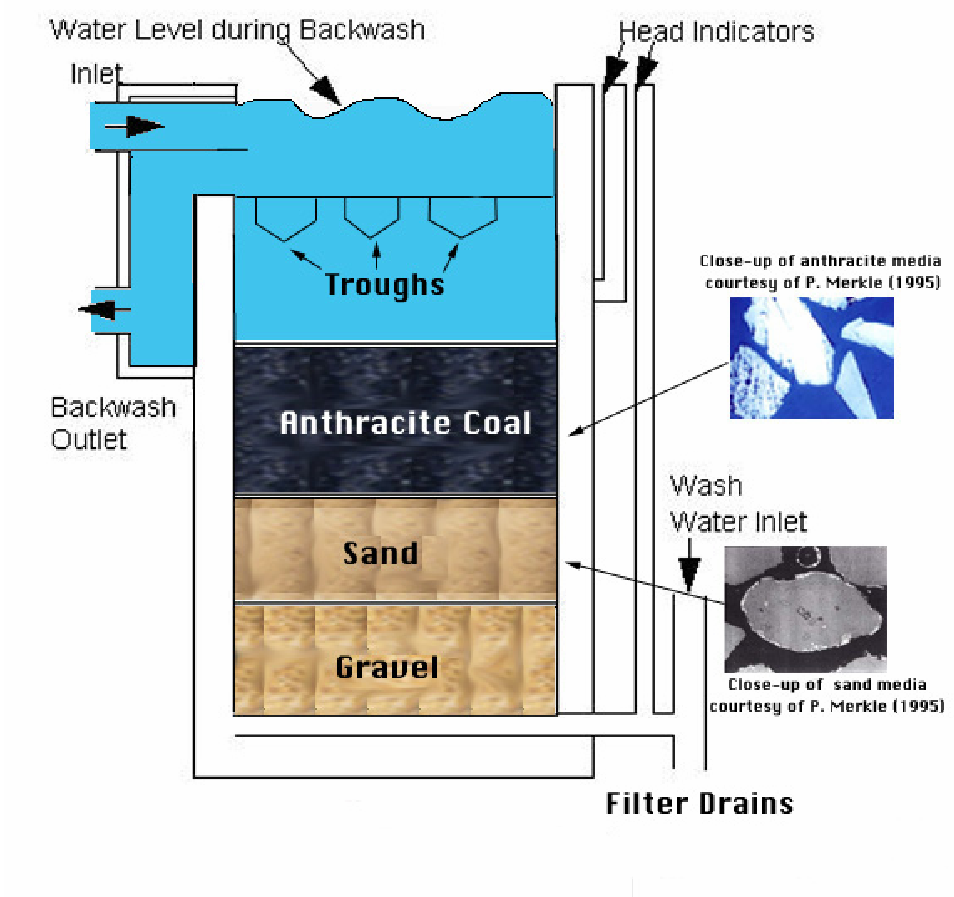
Note: URFS, upflow roughing filters in series; URF, upflow roughing filter; HRF, horizontal roughing filter; nd, no data provided.

Granular Media Filters

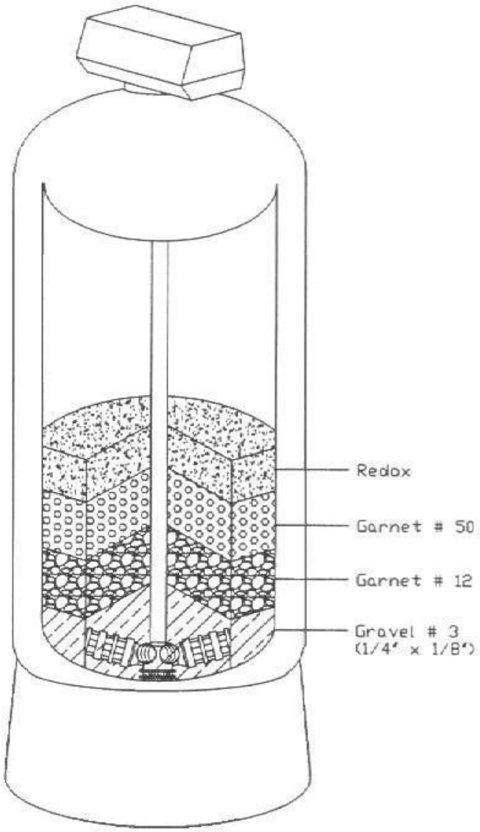
- Most commonly used surface water treatment for small systems.
- Relies on coagulation, flocculation, and sometimes sedimentation to remove the bulk of solids.
- Requires greatest operator skill.

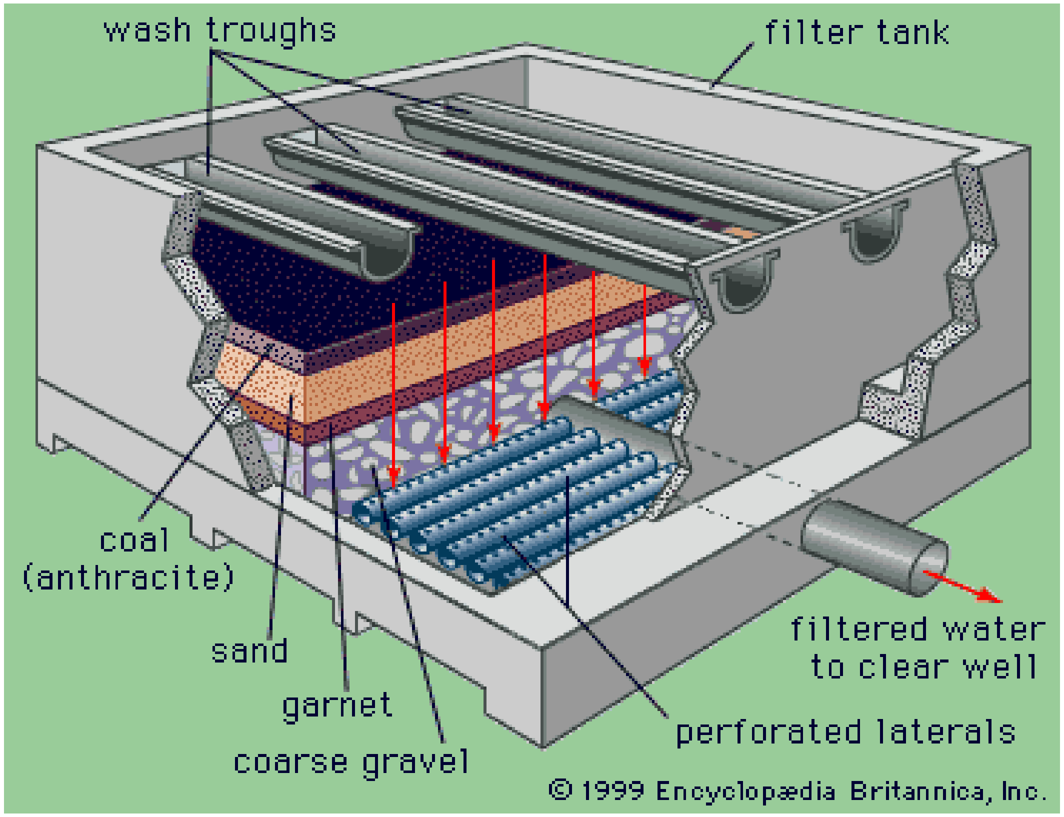


Granular Media Filters



Filter Cross Sections





Guidelines for Turbidity Limitations on Various Filtration Systems

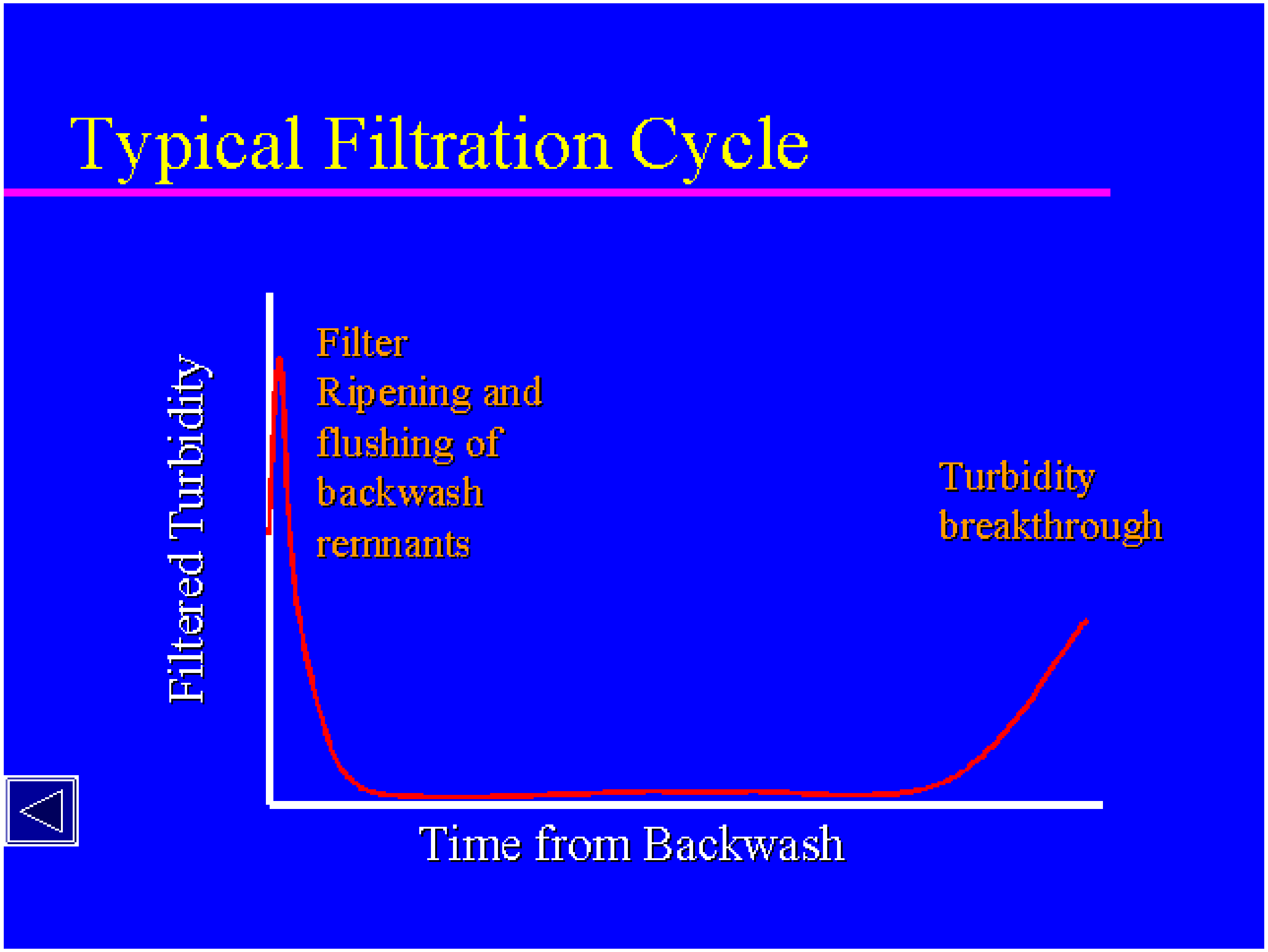
Raw Water Quality Limitations for Various Filtration Technologies

Parameter	Filtration Technology				
	Rapid Rate	**Slow Sand**	**DE**	**Membrane**	**Bag or Cartridge**
Average Turbidity[1]	<50 NTU[2]	<1 NTU	<5 NTU	<100 NTU	<5 NTU
Maximum Turbidity[1]	<100 NTU	<10 NTU	<10 NTU	<200 NTU	<10 NTU
Color	<75 SCU[3]	<10 SCU	<10 SCU	<10 SCU	<10 SCU

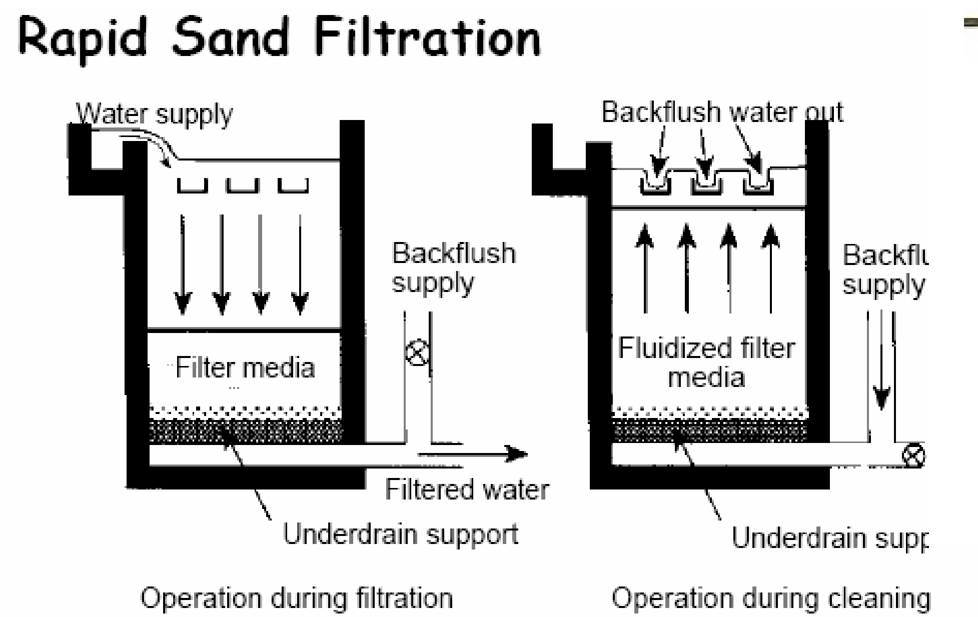
Notes:

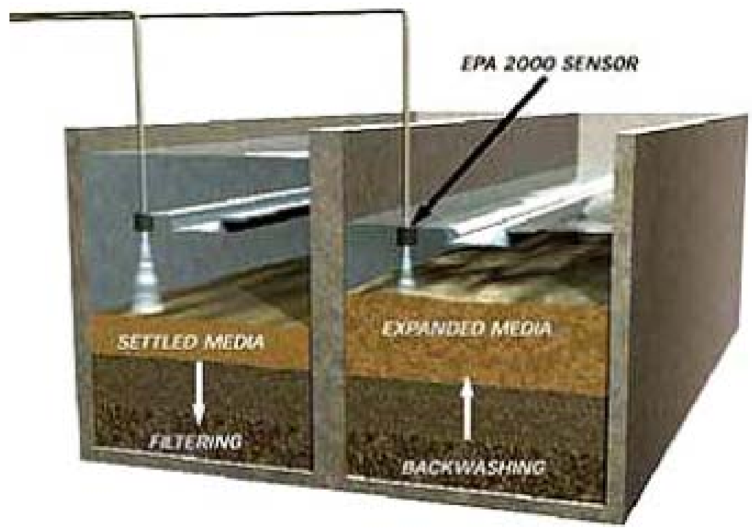
1. Raw water with turbidity higher than that shown in Table 2-1 may be treated; however, pre-treatment may be necessary to ensure that adequate performance is achieved.
2. NTU = Nephelometric Turbidity Units
3. SCU = Standard Color Units

Filter Cycle

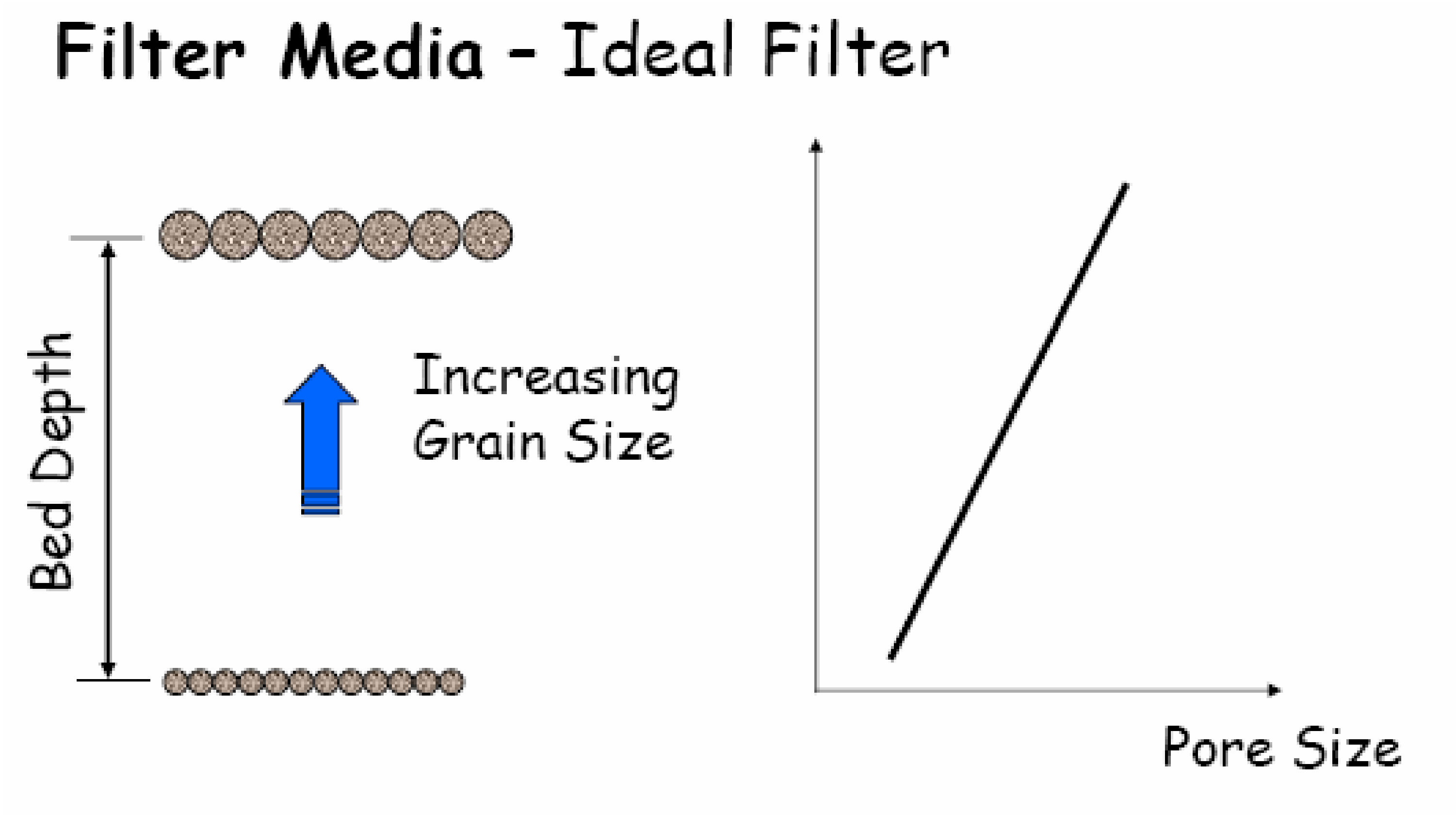


Filter Operation

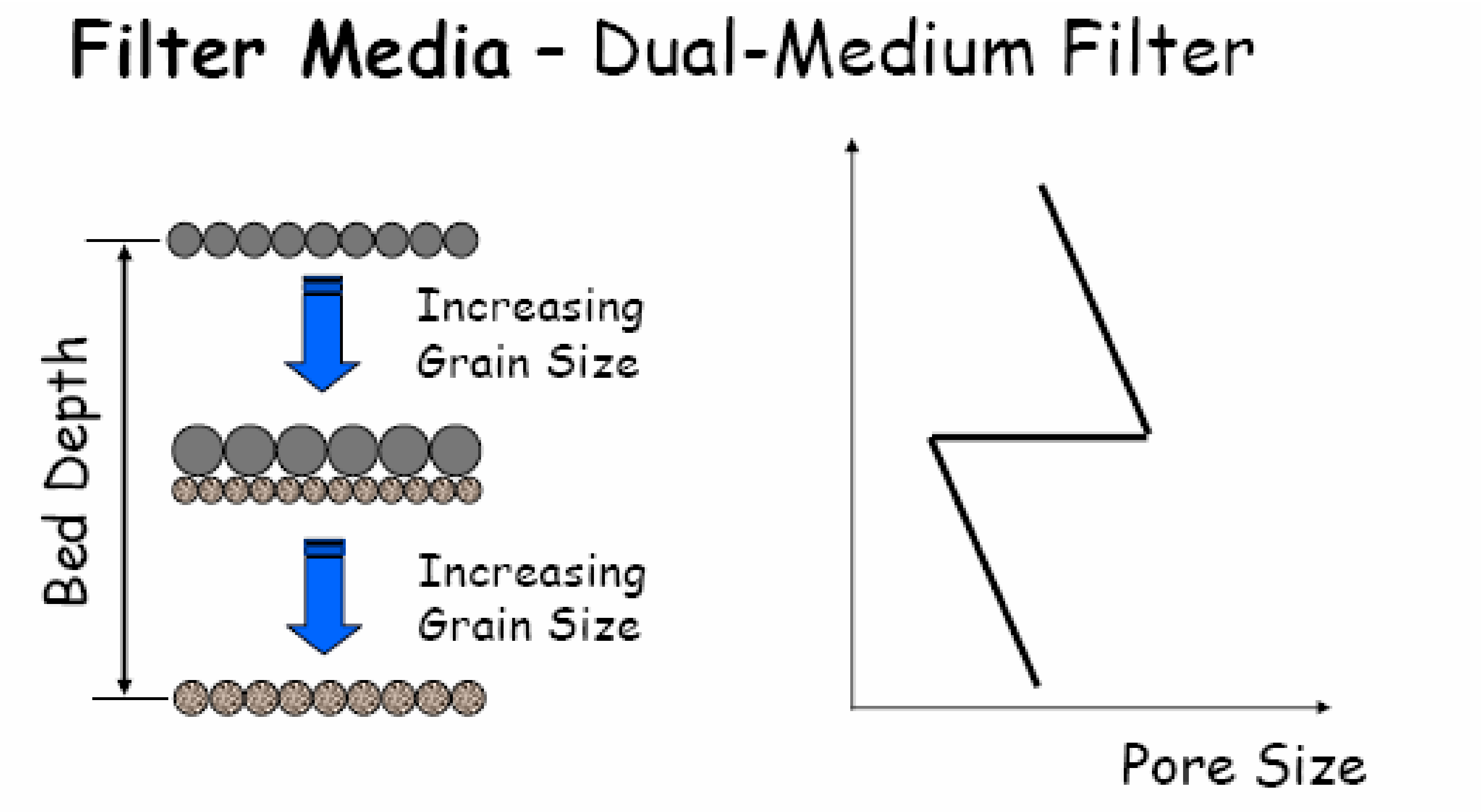




Ideal Filter



Practical Filter Design



Filter Media Specification

- A filter medium is defined by **effective size** and **uniformity coefficient**.
- **Effective size** is the 10–percentile diameter; that is, 10% by weight of the filter material is less than this diameter, D_{10}
- **Uniformity coefficient** is the ratio of the 60–percentile size to the 10–percentile size (D_{60} /D_{10})

Typical Specifications

- Conventional sand medium has an effective size of 0.45 – 0.55 mm, a uniformity coefficient less than 1.65
- A sand filter bed with a relatively uniform grain size can provide effective filtration throughout its depth

Typical Granular Medias

- **Dual–media filter** beds usually employ anthracite and sand However, other materials have been used, such as activated carbon and sand
- **Multimedia filter** beds generally use anthracite, sand, and garnet. However, other materials have been used, such as activated carbon, sand, and garnet.

Advantage of Multi Media Filters

- The main advantages of multimedia filters compared to single–medium filters are:
  - Longer filtration runs,
  - Higher filtration rates, and
  - The ability to filter a water with higher turbidity

Filter Calculations

- Surface loading rate/Filtration rate
- Backwash rate (Backwash)

Typical Maximum Filtration Rates

Filter/Media Type	Filtration Rate (gpm/ft^2)
Pressure – All media types	2
Gravity – Rapid Sand/Constant Rate	2
Gravity – Rapid Sand/ Declining Rate	3
Gravity – Dual or Multiple Media/Constant Rate	5
Gravity – Dual or Multiple Media/Declining Rate	6.5

(Source: TNRCC, 1997)

Backwash rates and times

Recommended Backwash Rates

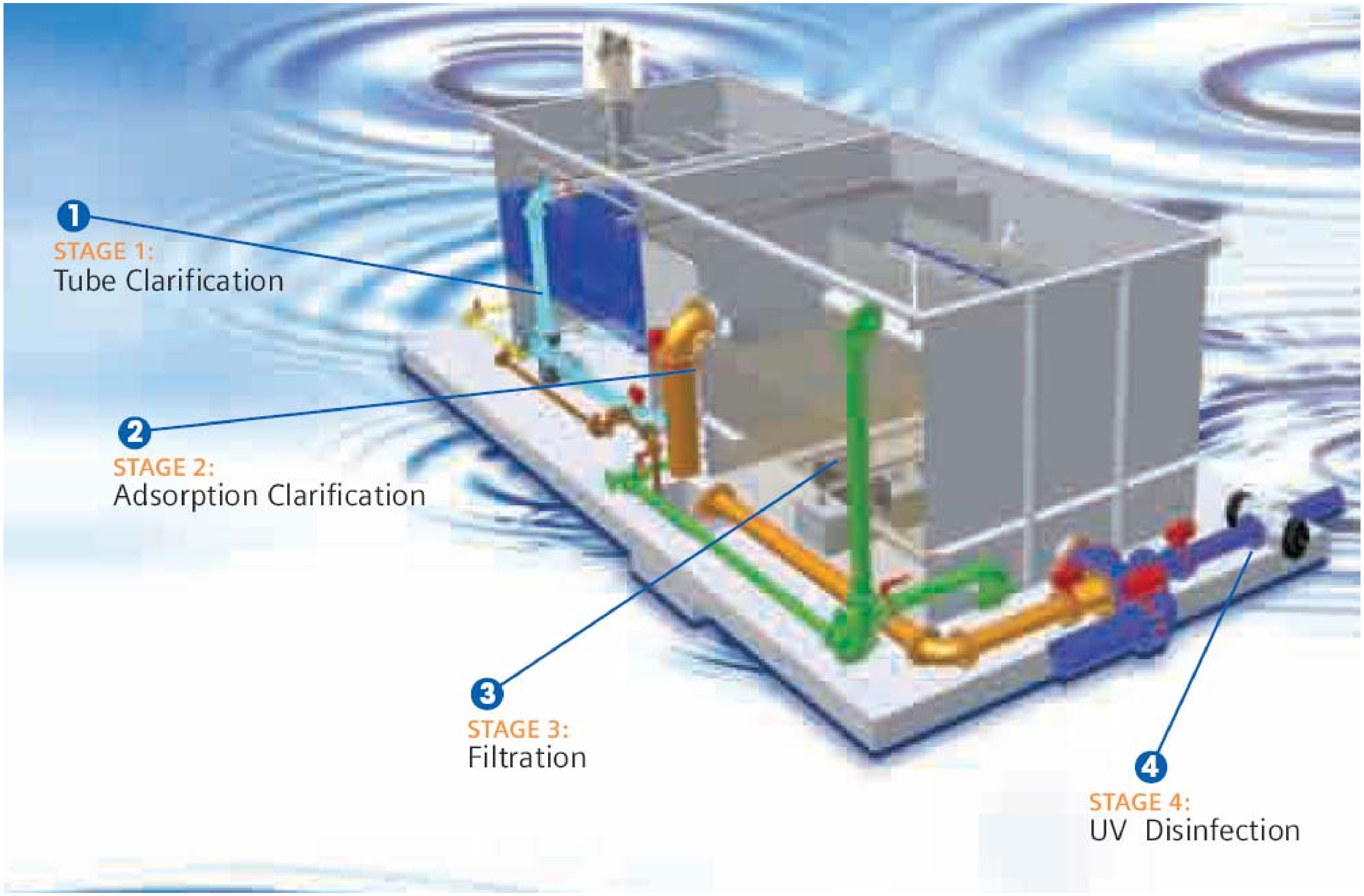
Backwash Method	Water Wash Rate (gpm/ft^2)	Water Wash Duration (minutes)	Air Scour Rate ($scfm/ft^2$)	Air Scour Duration (minutes)
Upflow Water Wash (1step)	15–23	3–15	–	–
Upflow Low Rate Water Wash with Initial Air Scour (2 steps)				
(1) Air Scour	–	–	1–2	3–5
(2) Low Rate Water Wash	5–7.5	3–5	–	–
Upflow High Rate Water Wash with Initial Air Scour (2 steps)				
(1) Air Scour	–	–	2–5	3–5
(2) High Rate Water Wash	15–23	3–5	–	–
Concurrent Upflow Water Wash and Air Scour (2 steps)				
(1) Concurrent Air and Water First	6.3–7.5	5–10	6–8	5–10
(2) Water Wash only	6.3–15	5–10	–	–
Upflow Water Wash with Surface Wash (3 steps)				
(1) Surface Wash only	0.5–2.0	1–3	–	–
(2) Low Rate Water Wash*	5–7.5	5–10	–	–
(3) High Rate Water Wash*	15–23	1–5	–	–
*with concurrent surface wash				

(Source: AWWA and ASCE, 1998)

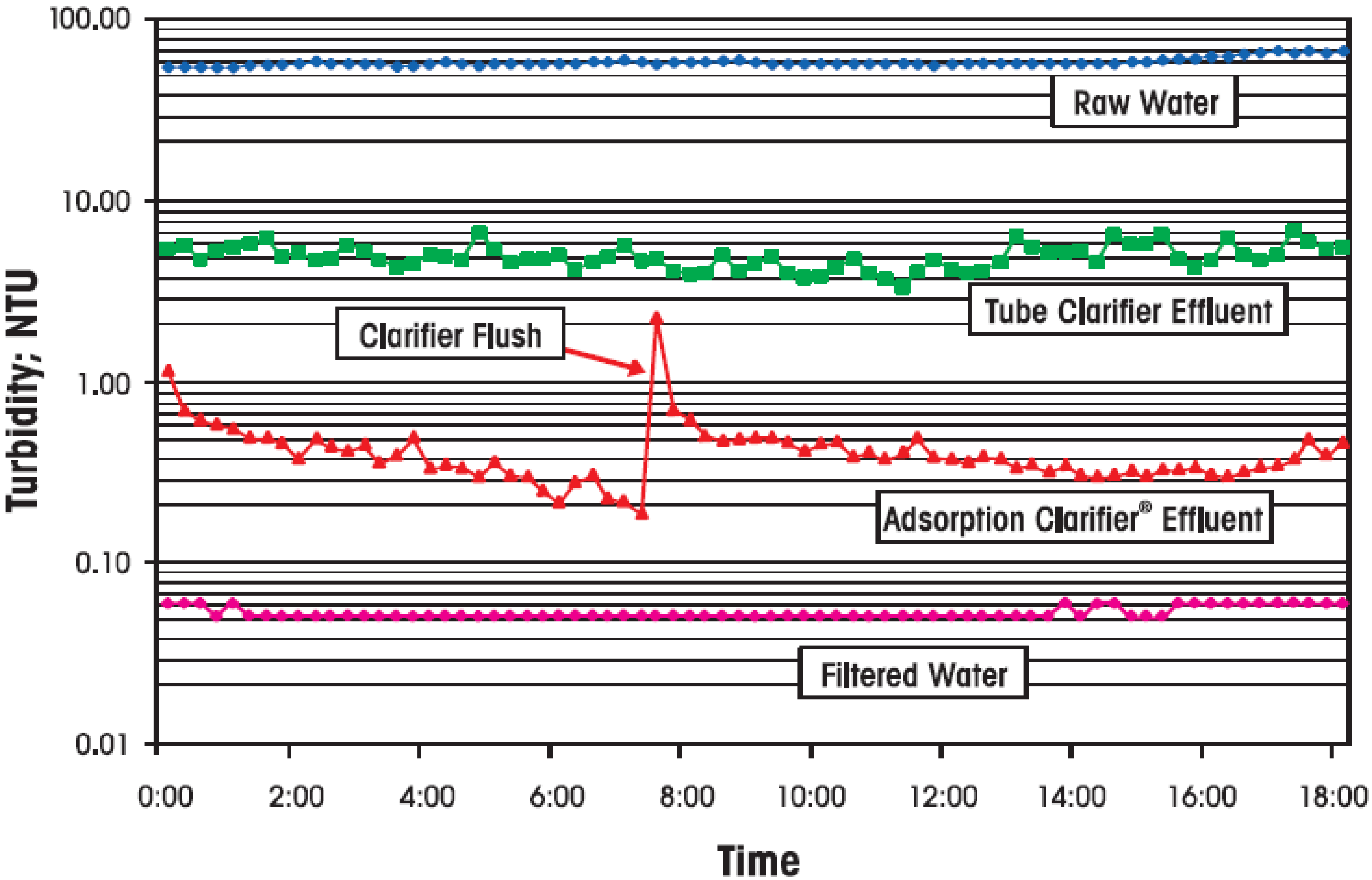
Direct Filtration Systems

- Exclude sedimentation and sometimes flocculation (in-line filters)
- Require finer floc known as pin floc
- Large floc will over load filter and shorten run times.
- Can only handle waters up to 10 Ntu
- Most commonly used for small water systems with adequate water quality

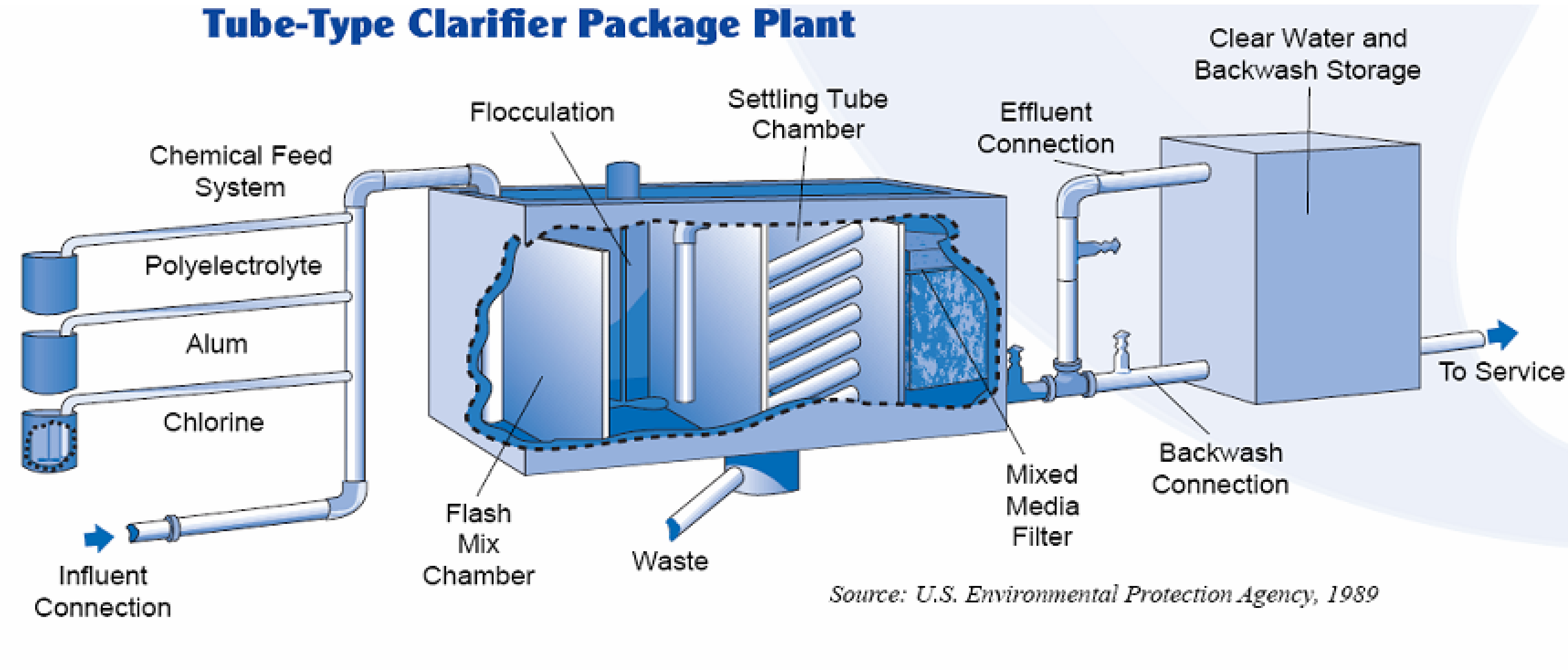
US Filter Trident System



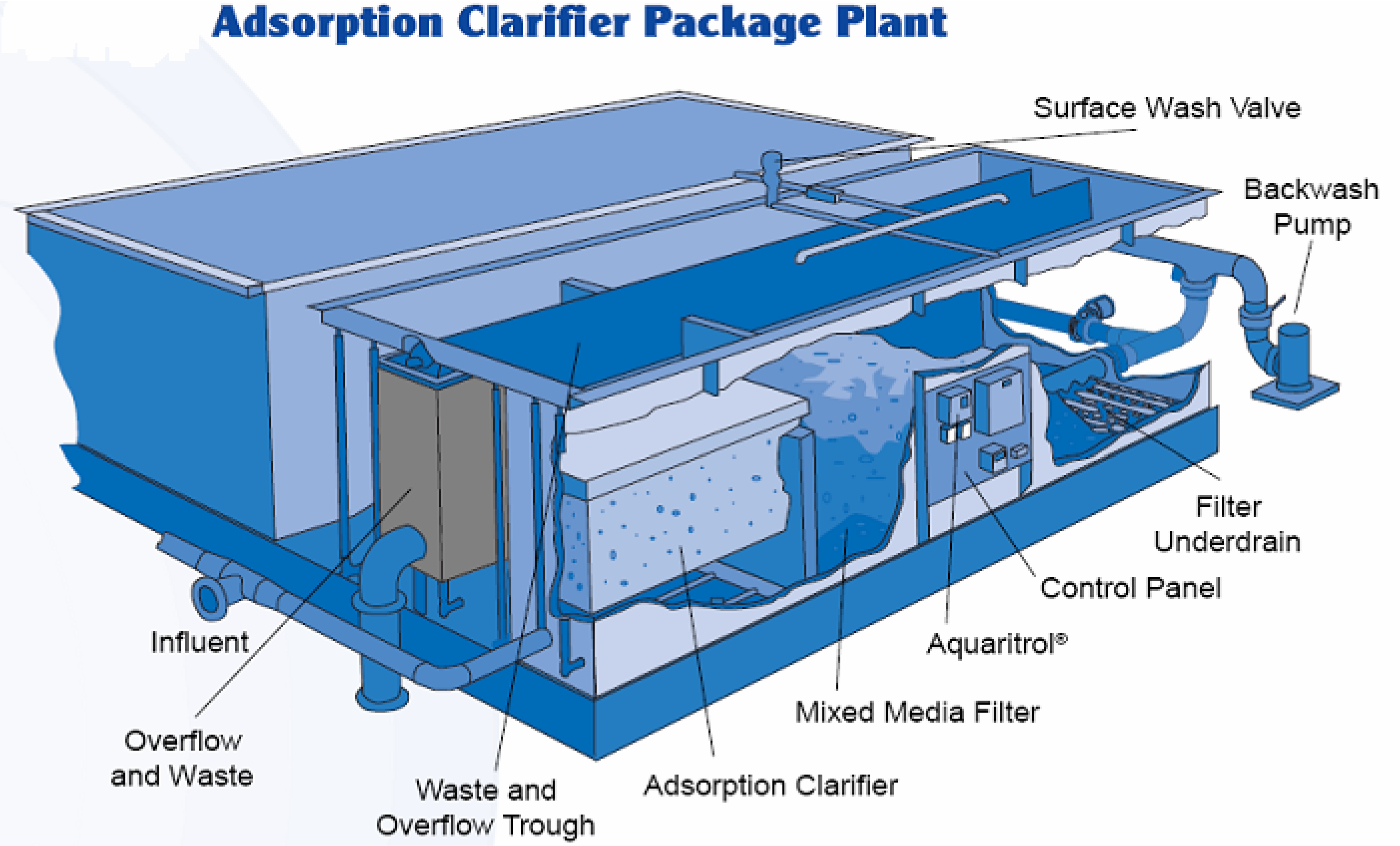
Trident® HS System Turbidity Performance



Tube Clarifier Package Plant

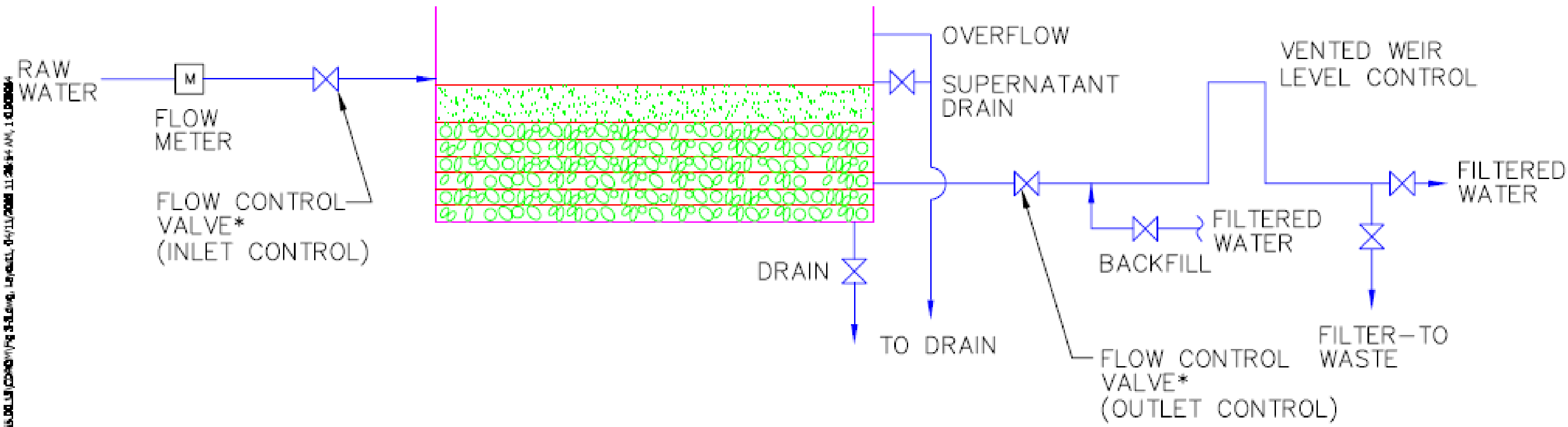


Adsorption Clarifier Package Plant



Source: U.S. Environmental Protection Agency, 1989

Slow Sand Filtration



NOTE: * FILTERS CAN USE EITHER INLET CONTROL VALVES OR OUTLET CONTROL VALVES OR BOTH

FIGURE 3—3 SLOW SAND FILTRATION PROCESS FLOW DIAGRAM

Design Criteria

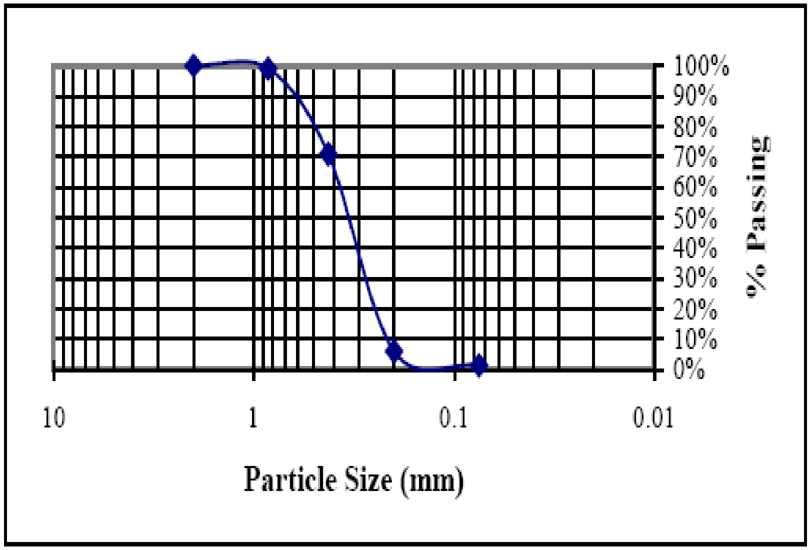
Recommended Number of Filter Basins

Design Flow	Recommended Number of Basins
<450 gpm	2
450 – 900 gpm	3
900 – 1,400 gpm	4
1,400 gpm – 2,100 gpm	5

Sand Gradation Criteria

Parameter	Recommended Value
Effective Diameter (d_{10})	0.15 – 0.30 mm
Uniformity Coefficient (d_{60}/ d_{10})	< 2.5
% Passing #200 sieve unwashed	< 3%
% Passing #200 sieve washed	< 0.1%

Filter Cross Section



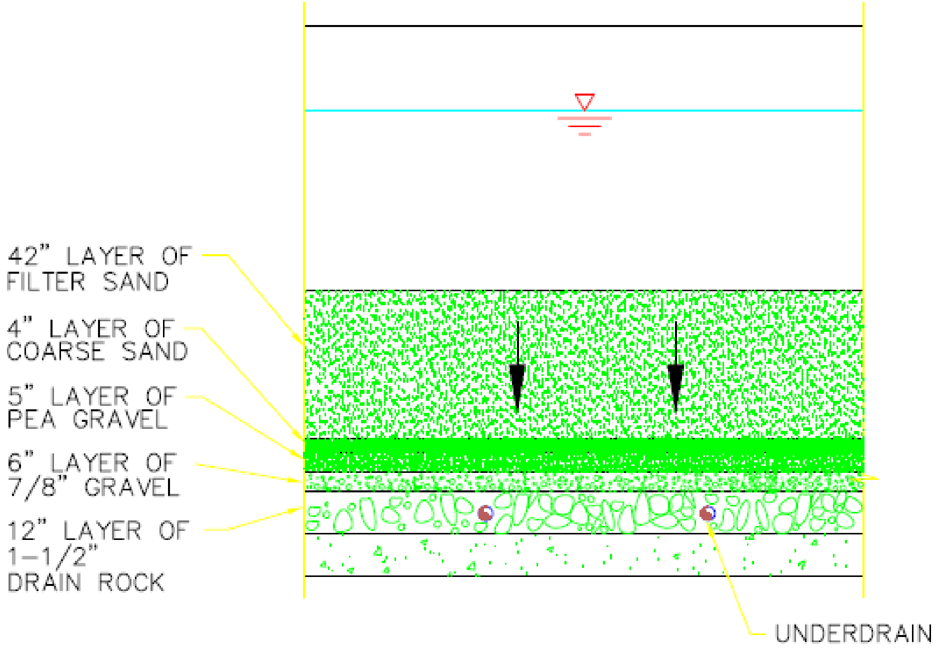
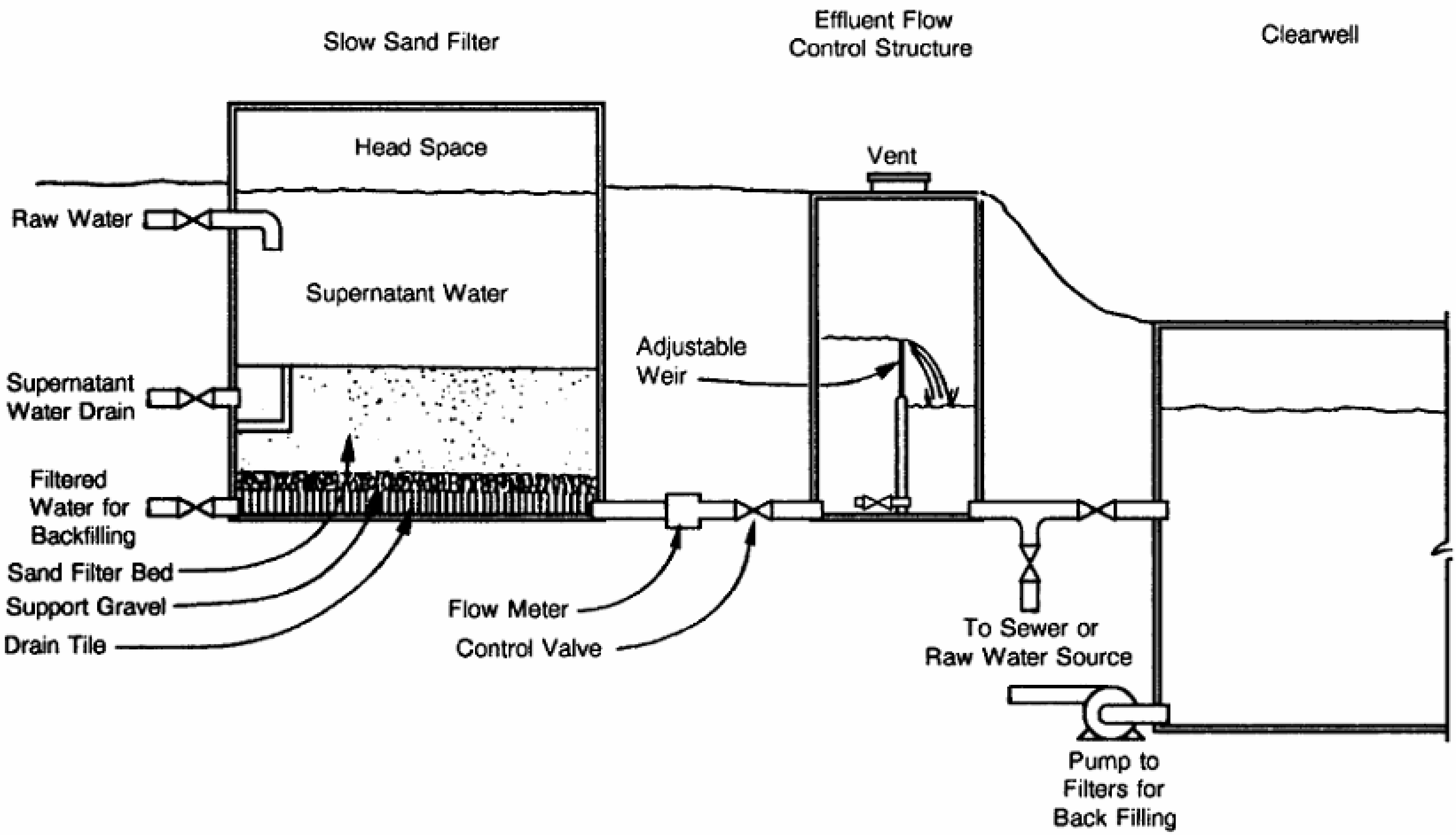


FIGURE 3-5 SLOW SAND FILTER MEDIA TYPICAL SECTION

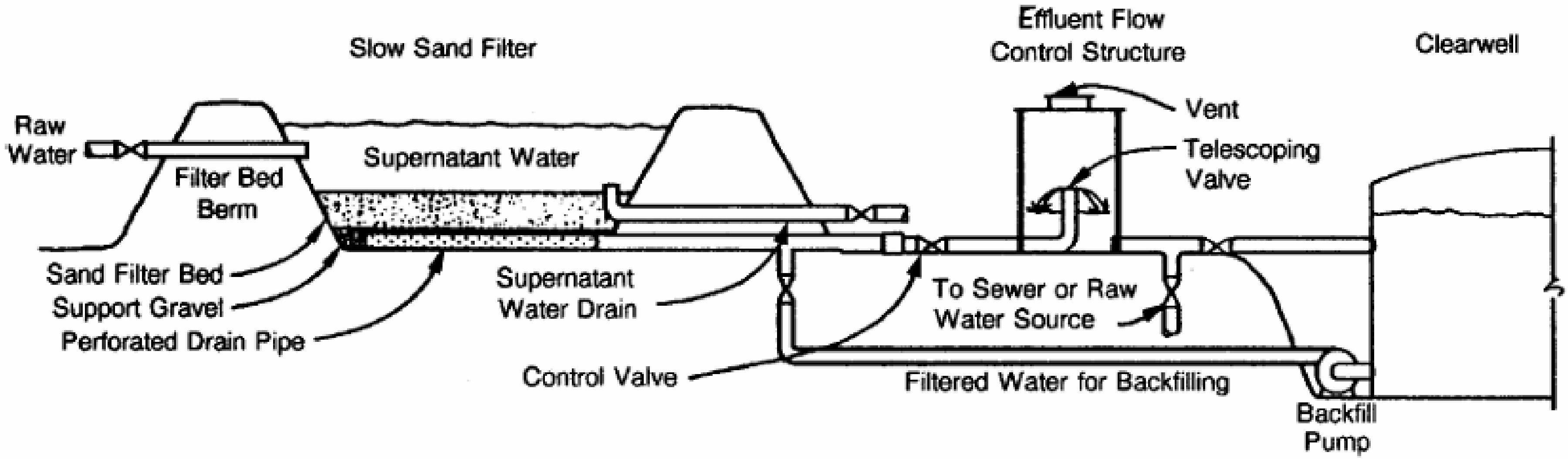
Filter Operation

Covered slow sand filter with effluent rate control (U.S. Environmental Protection Agency 1990).



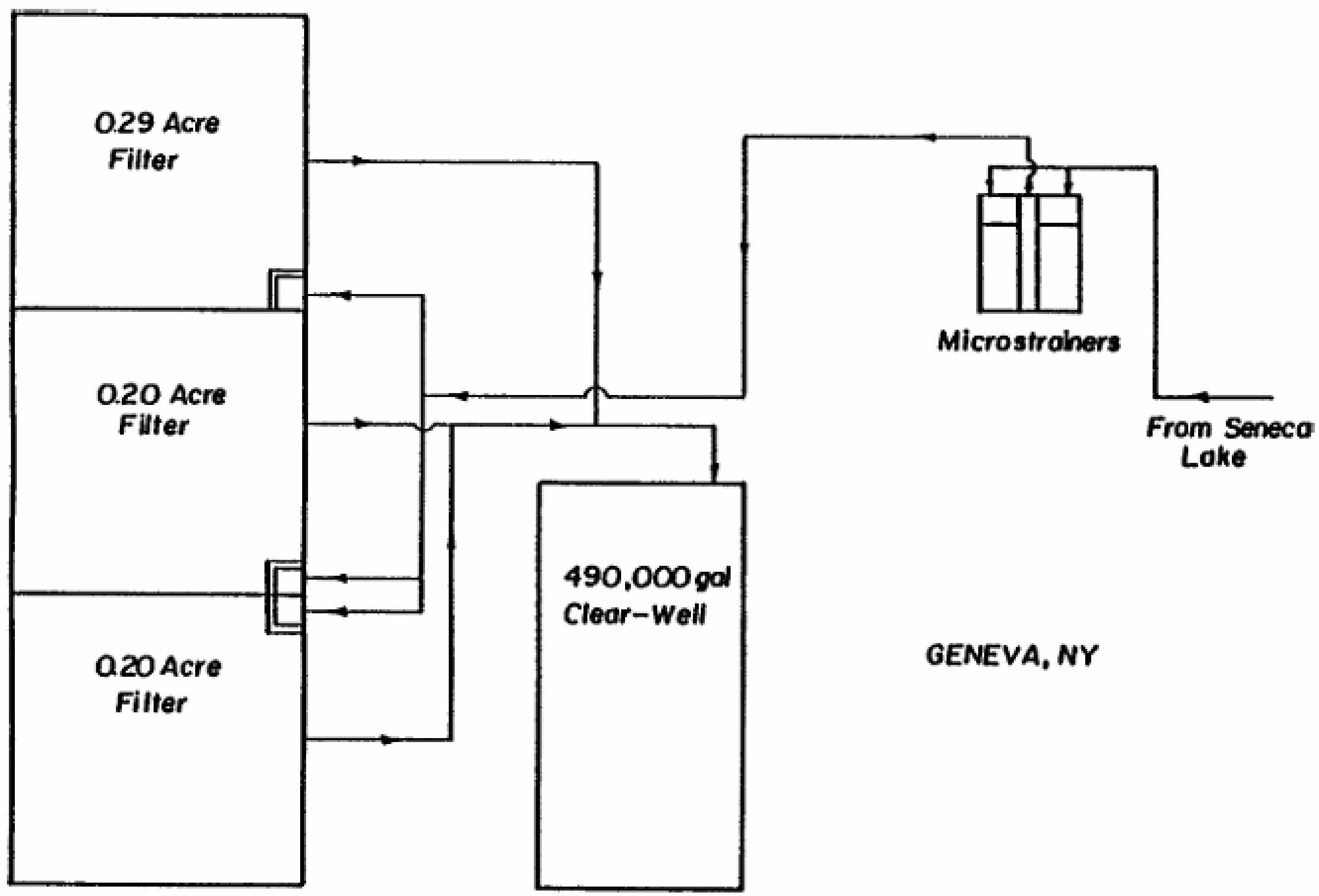
Low Cost Alternative

Open slow sand filter with effluent rate control (U.S. Environmental Protection Agency 1990).



Typical Site Layout

Layout of a small slow sand filter plant (Letterman and Cullen 1985).



Microbiological Removals

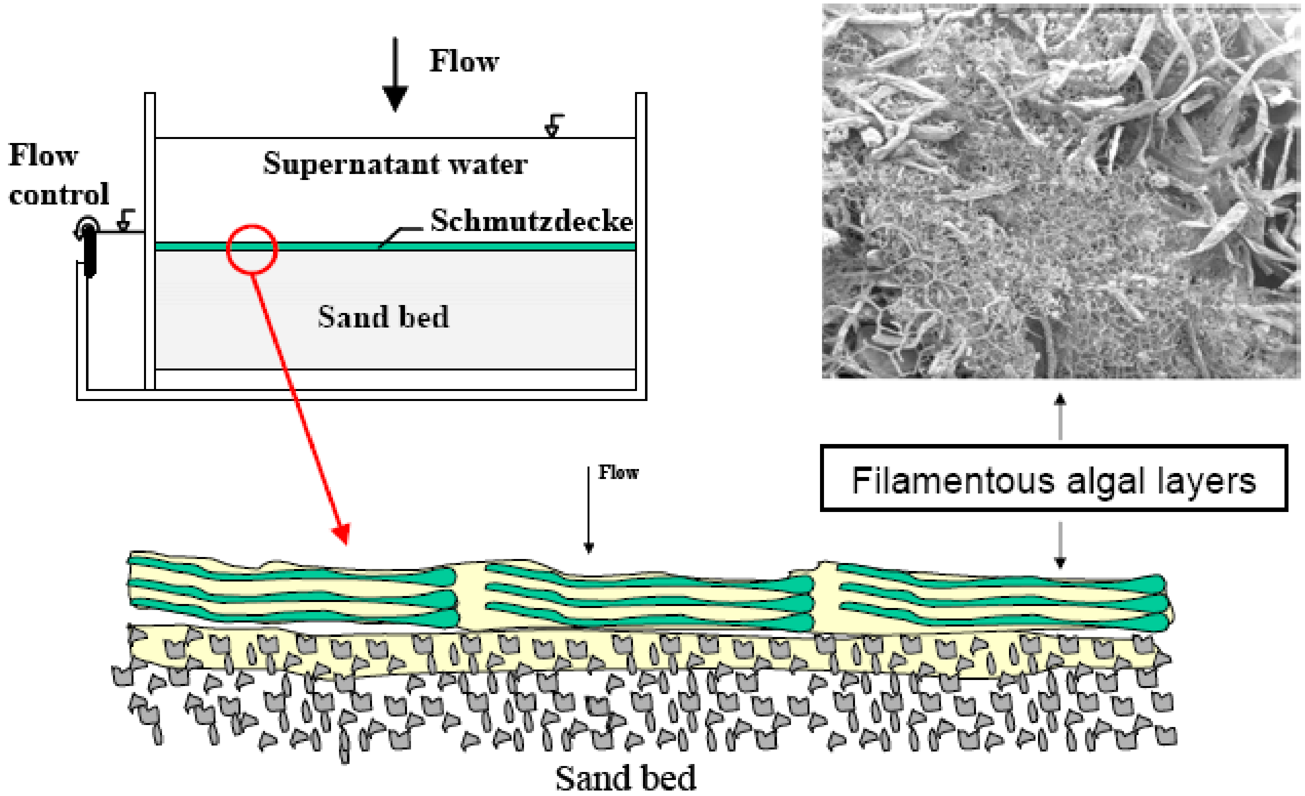
Microorganism removal by slow sand filtration.

Reference	Organism	Filtration rate (m/h)	Temperature (°C)	Removal percentage
Poynter and Slade (1977)	Poliovirus	0.2	16 to 18	99.997 average
Poynter and Slade (1977)	Poliovirus	0.4	16 to 18	99.865 average
Poynter and Slade (1977)	Poliovirus	0.2	5 to 8	99.68 average
Poynter and Slade (1977)	Poliovirus	0.5	5 to 8	98.25 average
Bellamy et al. (1985*b*)	Total coliform bacteria	0.12	17	97 average
Bellamy et al. (1985*b*)	Total coliform bacteria	0.12	5	87 average
Bellamy et al. (1985*a*)	*Giardia*	0.12	5 to 15	99.994 average
Bellamy et al. (1985*a*)	*Giardia*	0.4	5 to 15	99.981 average
Bellamy et al. (1985*b*)	*Giardia*	0.12	17	>99.93 to >99.99
Bellamy et al. (1985*b*)	*Giardia*	0.12	5	>99.92 to >99.99
Pyper (1985)	*Giardia*	0.08	0.5	93.7
Pyper (1985)	*Giardia*	0.08	0.5 to 0.75	99.36 to 99.91
Pyper (1985)	*Giardia*	0.08	7.5 to 21	99.98 to 99.99
Ghosh et al. (1989)	*Giardia*	0.3	4.5 to 16.5	>99.99
Ghosh et al. (1989)	*Giardia*	0.4	4.5 to 16.5	99.83 to 99.99
Ghosh et al. (1989)	*Cryptosporidium* oocysts	0.15 to 0.40	4.5 to 16.5	>99.99
Hall et al. (1994)	*Cryptosporidium* oocysts	0.2	Not stated	99.8 to 99.99
EES and TWU (1996[a])	*Cryptosporidium* oocysts	0.29	12 to 14	>99.99

[a]Economic and Engineering Services, Inc. and Thames Water Utilities. 1996. Salem slow sand filtration pilot study microbiological challenge test results. Unpublished report.

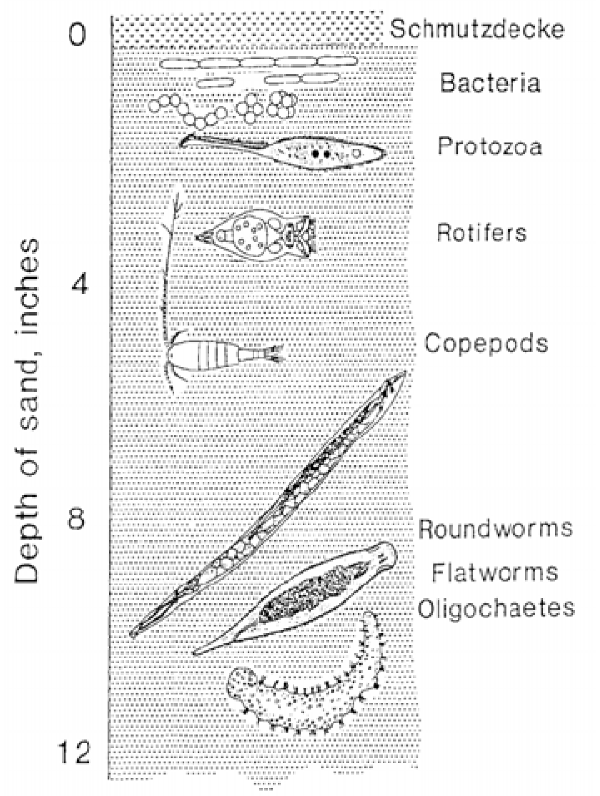
Schmutzdecke

Schmutzdecke:



Biological Make-up of Schmutzdecke

'Schmutzdecke' /Surface Sand Layer



Surface of SSF - gelatinous biological layer develops → Schmutzdecke

- bacteria, algae, protozoa and colloidal debris
- other organisms at some depth into bed
- fully requires 'ripening period' (days - weeks) for microbial community to fully re-develop after cleaning

Schmutzdecke

- conveys a significant barrier-type (straining) filtration role
- depth filtration in lower sand layers

- effects biological treatment
- production of 'biologically stable' waters

SSF produce filtrates of very high particulate, biological and bacteriological quality

Reading Assignments

- Read US Army Corps of Engineers
  - Section 6-8
  - Review Lecture Notes
- EPA – Ultraviolet Disinfection Guidance Manual
  - ***(Will be put on the website on Friday)***
- EPA – Alternative Disinfectants and Oxidant Guidance Manual
  - ***(Will be put on the website on Friday)***