ENVE 301
Environmental Engineering Unit Operations

Lecture 14
Filtration - I

SPRING 2014

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Filtration

- Settled water has a turbidity in the range from 1 to 10 NTU (typically 2 NTU)
- Level of turbidity interferes with the disinfection process
- Turbidity must be reduced further after the sedimentation process.
- EPA requires treated water turbidity level to be below 0.3 NTU (1 NTU is regulatory)
- Filtration is used to remove turbidity to required levels

Filtration

- Filtration is a <u>solid-liquid separation </u>technique
- Liquid passes through a porous medium to remove as much fine suspended solids as possible.
- Particulates removed may be those already present in the source water or generated during the treatment processes

Filtration – what can be removed.

- Silt
- Clay
- Microorganisms (bacteria, viruses, protozoan cycsts)
- Colloidal or precipitated humic substances
- Other natural organic matters from the decay of vegetations
- Precipitates of aluminum or iron used in coagulation
- Calcium carbonate, magnesium hydroxide precipitates from lime softening
- Iron and/or manganese precipitates

Filtration

Applications in Water treatment

- Filtration is applied to chemically coagulated and settled waters
- In case of low-turbidity waters, Direct filtration is applied to remove turbidity

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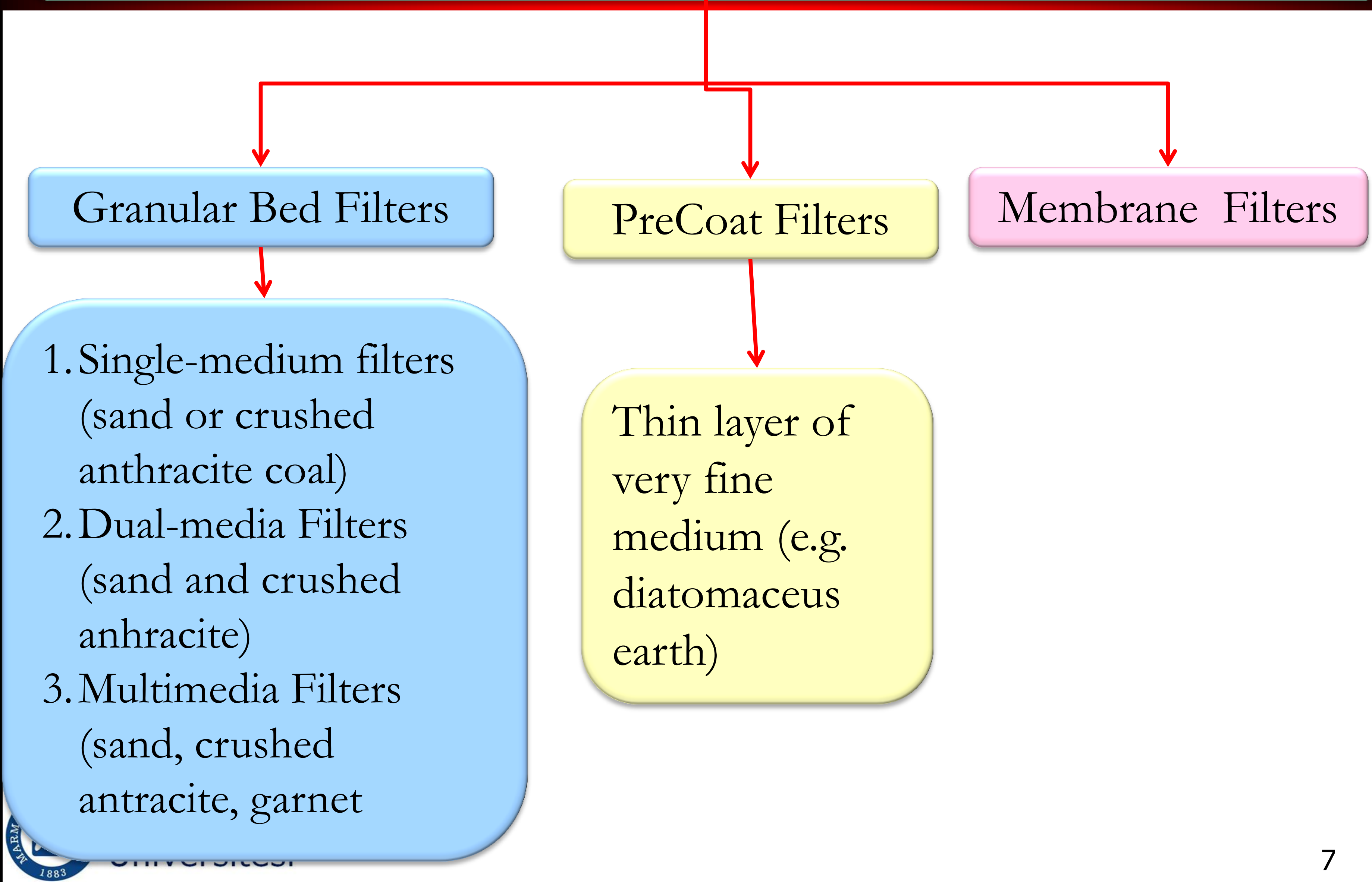
Filtration

Applications in Wastewater treatment

- Untreated secondary effluents
- Chemically treated secondary effluents
- Chemically treated raw wastewaters

FILTER TYPES



Granular Bed Filters

1. Single-medium filters (sand or crushed anthracite coal)
2. Dual-media Filters (sand and crushed anhracite)
3. Multimedia Filters (sand, crushed antracite, garnet

PreCoat Filters

Thin layer of very fine medium (e.g. diatomaceus earth)

Membrane Filters

Granular Bed Filtration

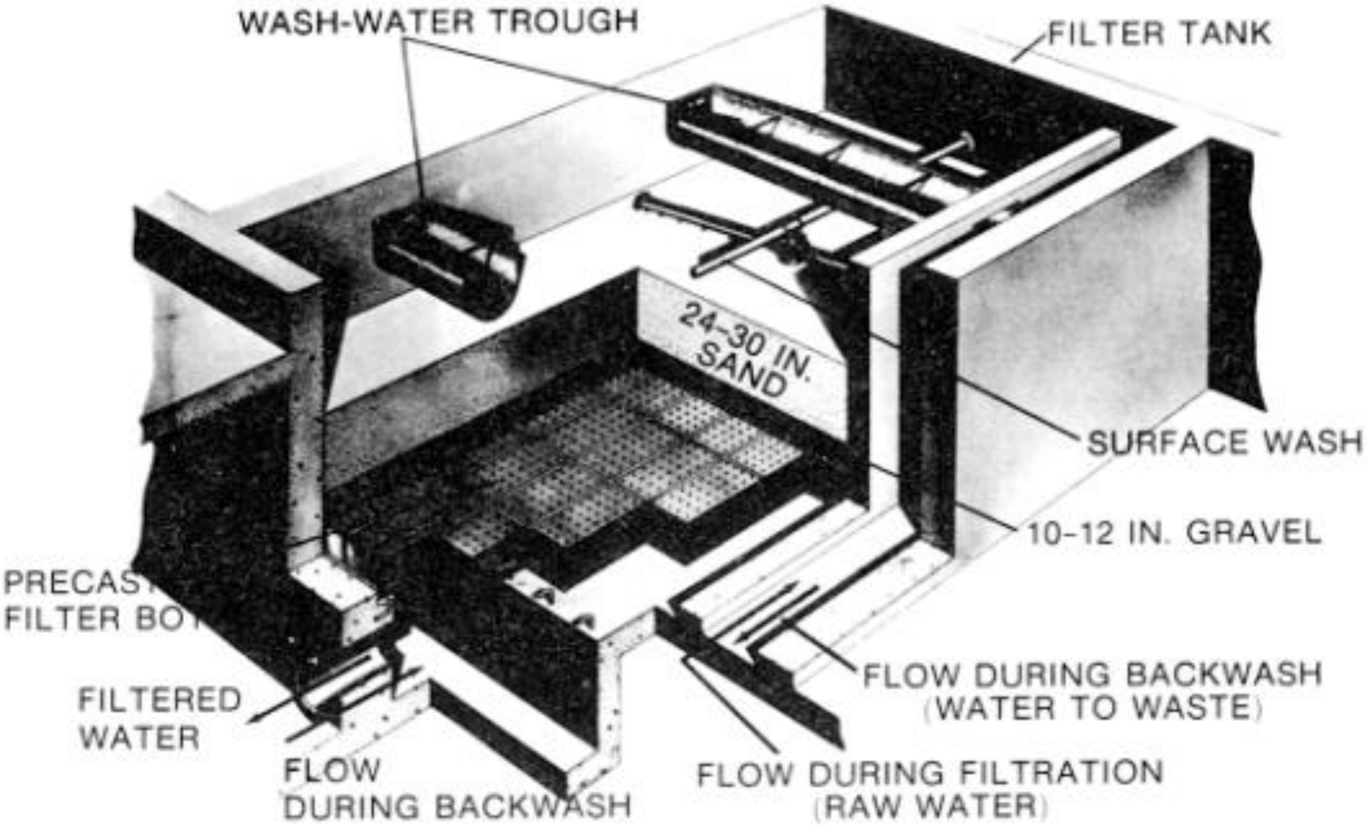


FIGURE 8.1 A rapid sand filtration system. (*Source:* Courtesy of F. B. Leopold

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Pre-coat Filter

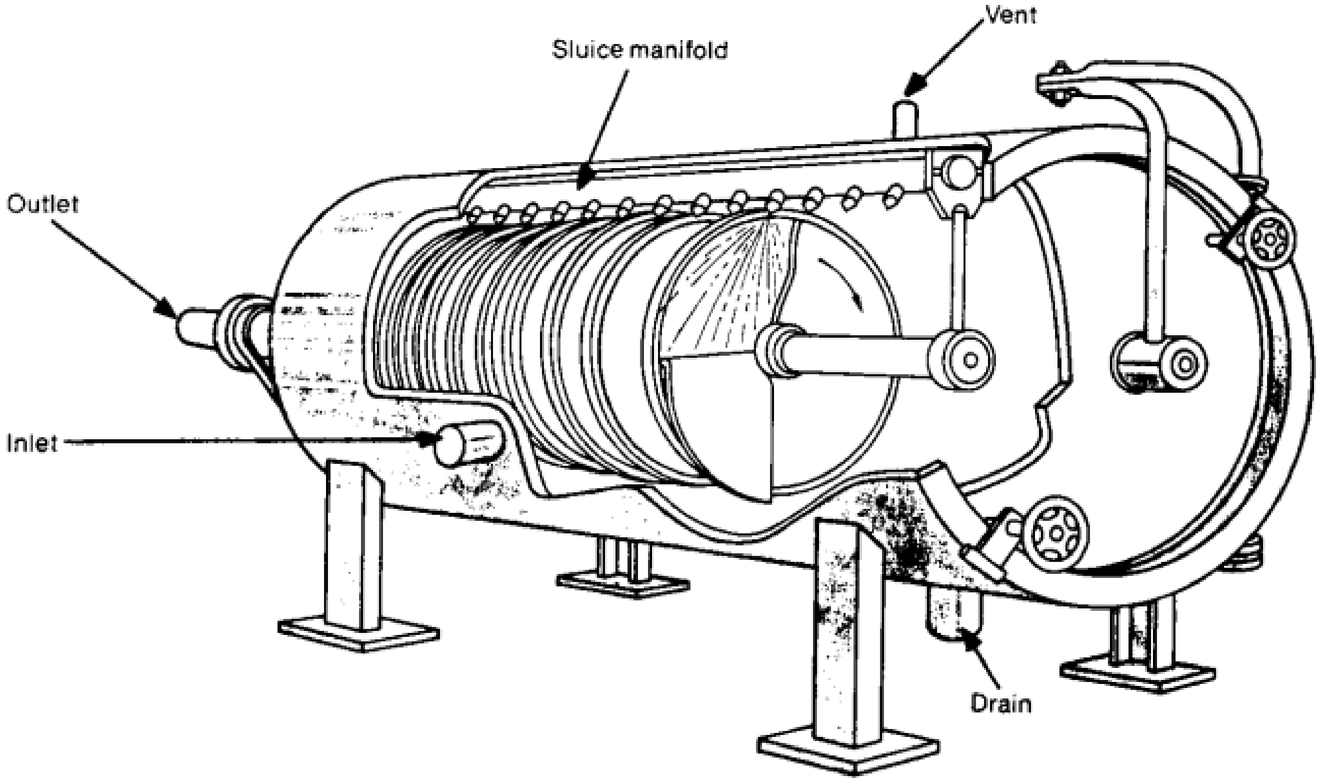


FIGURE 8.2 Precoat filter of rotating leaf type (sluice type during backwash). (*Source:* Courtesy of Manville Products Corporation.)

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Filtration

Filter types according to hydraulic arrangement

1. **Gravity Filters**: Open to atmosphere, flow through the medium is achieved through gravity
2. **Pressure Filters**: Utilize a pressure vessel to contain the filter medium. Water is derived to vessel under pressure and leaves the at slightly reduced pressure.

Filtration

- Filters can also be classified by the rate of filtration (flow rate per unit area)
- Rapid granular bed filters: higher filtration rates compared to slow sand filters
- Slow sand filters etc.

Filtration

- Filtration can also be classified as
  - Depth filtration: solids are removed within the granular material (e.g. Rapid granular filters)
  - Cake filtration: solids are removed on the entering face of the granular material (e.g. Pre-coat or membrane filters)
- Slow sand filters utilize both depth and cake filtration

Filtration

- After a period of operation (*filter cycle*), filters become clogged and must be cleaned
- Rapid sand filters are cleaned by backwashing →upright high rate flow of water
- Slow sand filters are cleaned by scraping the dirt from the surface

Granular-Medium Filtration

- Filtration mechanism is essentially the same for all the filters
- Cleaning (backwashing) phase is quite different depending on whether the filter operation is of the semicontinuous or continuous one.

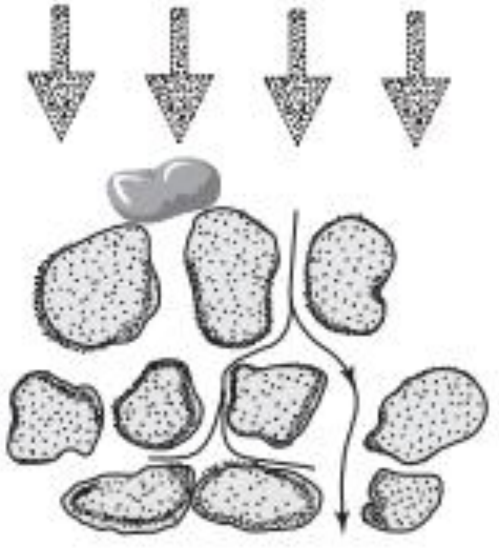
Granular-Medium Filtration
Particle removal mechanisms

- The principal mechanisms of removal of material within the granular bed filtration are
  1. Straining
  2. Sedimentation
  3. Impaction
  4. Interception
  5. Adhesion
  6. Chemical adsorption
  7. Physical Adsorption
  8. Flocculation
  9. Biological growth

Granular-Medium Filtration
Particle removal mechanisms

1. Straining

- Mechanical :Particles larger than the pore space of the filtering medium are strained out mechanically
- Chance contact: Particles smaller than the pore space are trapped within the filter by chance contact



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

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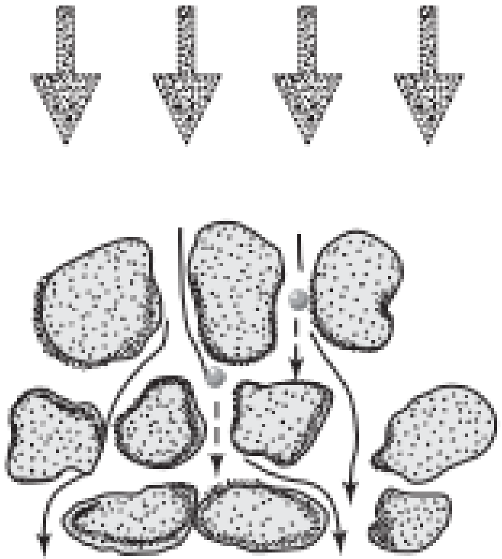
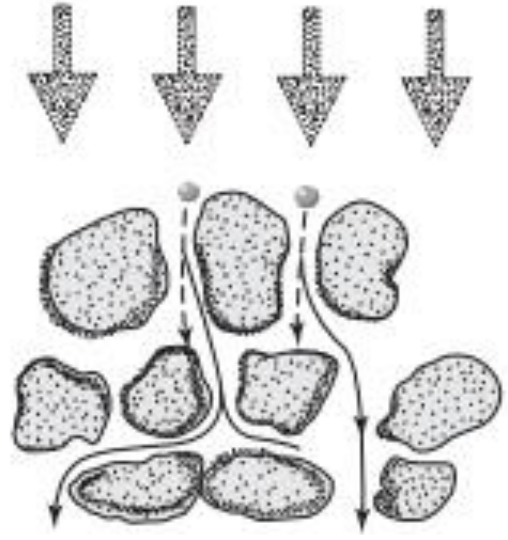
Granular-Medium Filtration
Particle removal mechanisms

2. Sedimentation: Particles settle on the filtering medium within the filter



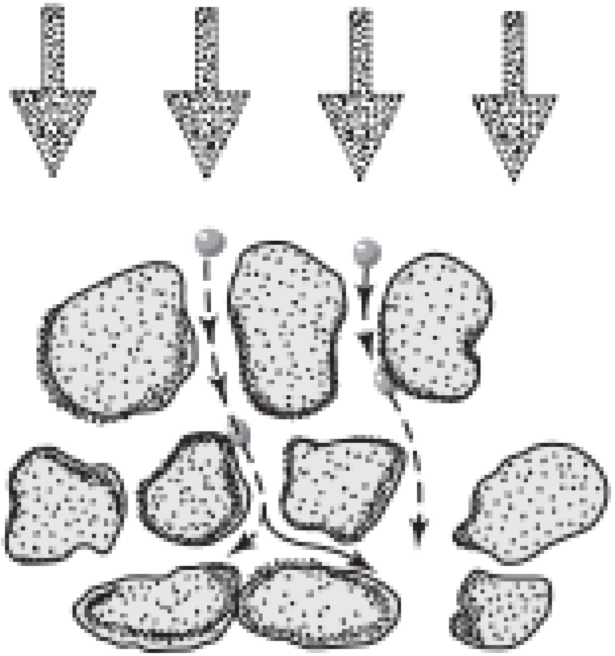
3. Impaction: Heavy particles will not follow the flow streamlines



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice.* 2010. McGrawHill

Granular-Medium Filtration
Particle removal mechanisms

4. Interception: Many particles are removed when they come in contact with the surface of the filtering medium



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

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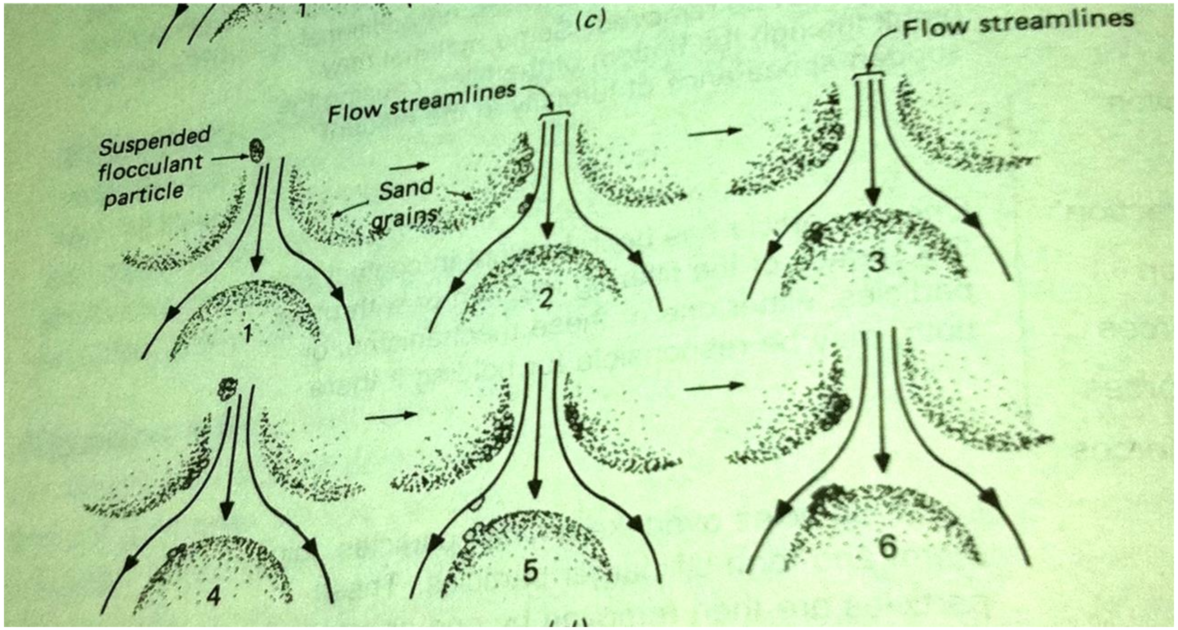
Granular-Medium Filtration
Particle removal mechanisms

5. Adhesion: Flocculant particles become attached to the surface of the filtering medium

- Some material is shreared away and pushed deeper into the filter bed because of the water



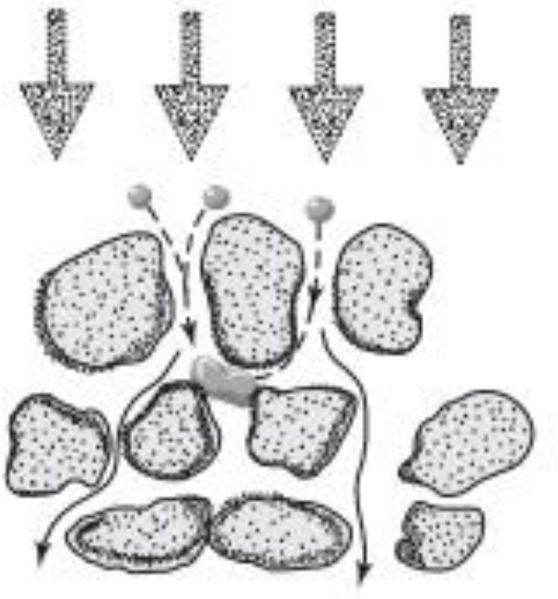
Ref: Metcalf & Eddy, Inc. (2003). *Wastewater Engineering-Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.

Granular-Medium Filtration
Particle removal mechanisms

6. Chemical adsorption
    - Bonding
    - Chemical interaction
7. Physical adsorption
    - Electrostatic forces
    - Electrokinetic forces
    - Van der Waals forces

Granular-Medium Filtration
Particle removal mechanisms

8. Flocculation: Large particles overtake smaller particles. These particles are then removed by one of the removal mechanisms



Ref: Davis M.L. *Water and Wastewater Treatment: Design Principles and Practice*. 2010. McGrawHill

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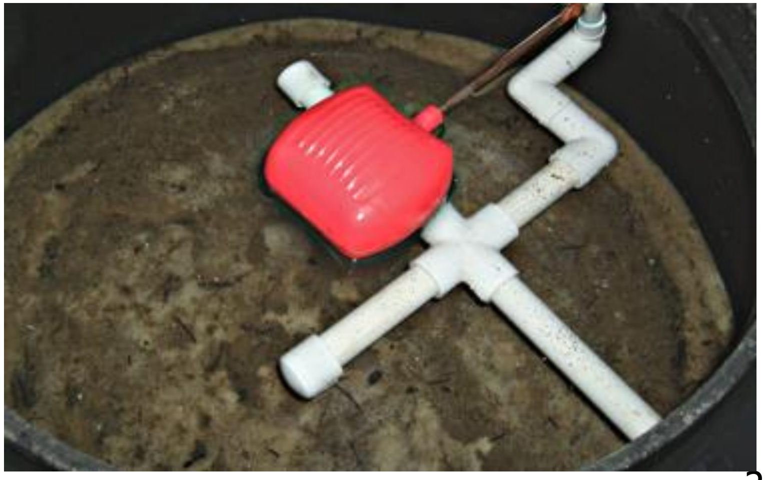
Granular-Medium Filtration
Particle removal mechanisms

9. Biological growth: Biological growth will reduce the pore volume and may enhance the removal of particles with any of the removal mechanisms.

- Substances collected on the surface of filter + required nutrients → biological growth (slimy layer)
- Layer known as "schmutzdecke"

http://www.slowsandfilter.org/f_valve.html



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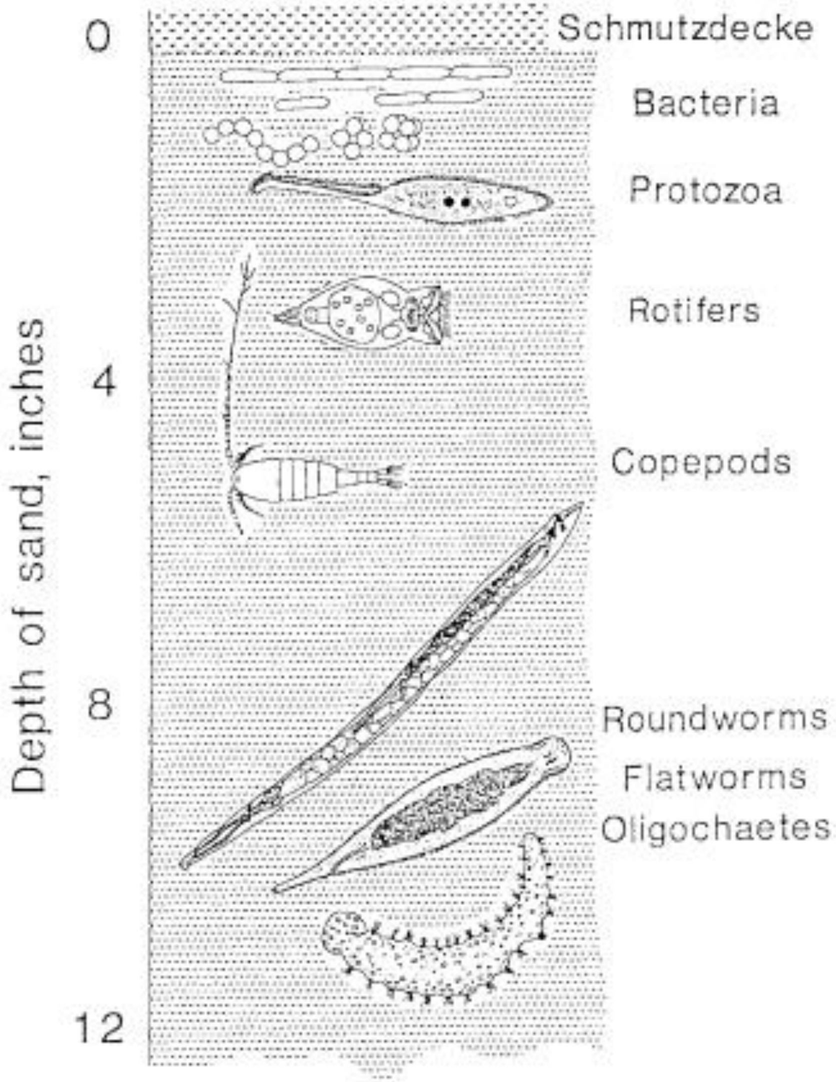
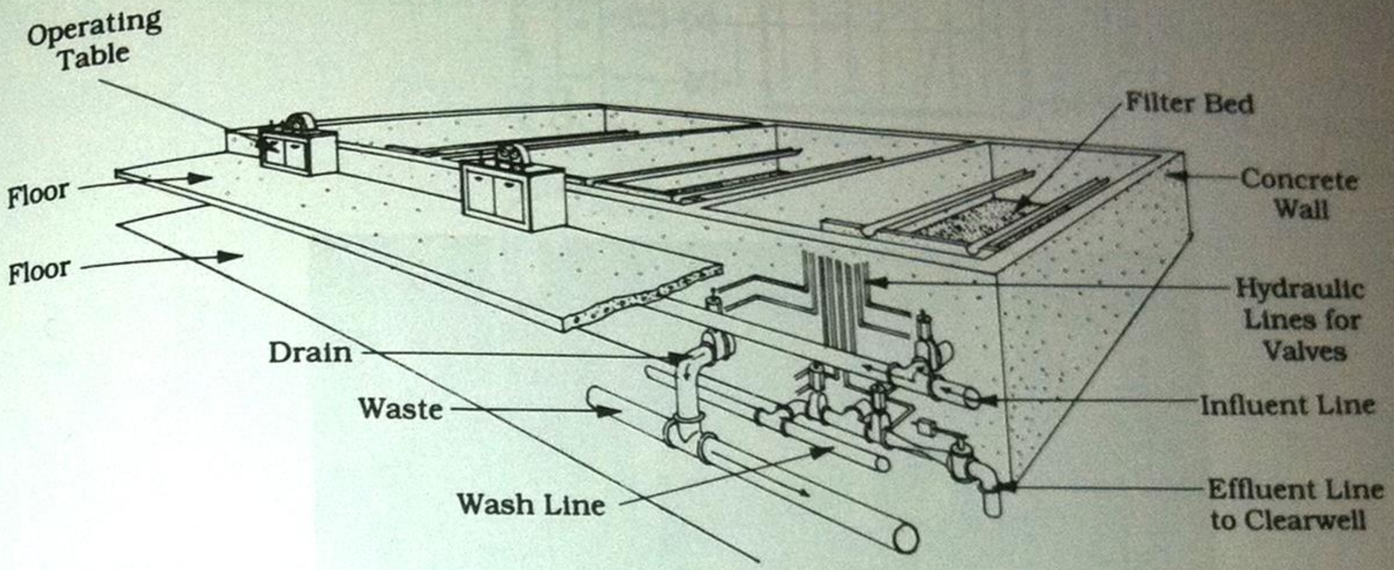
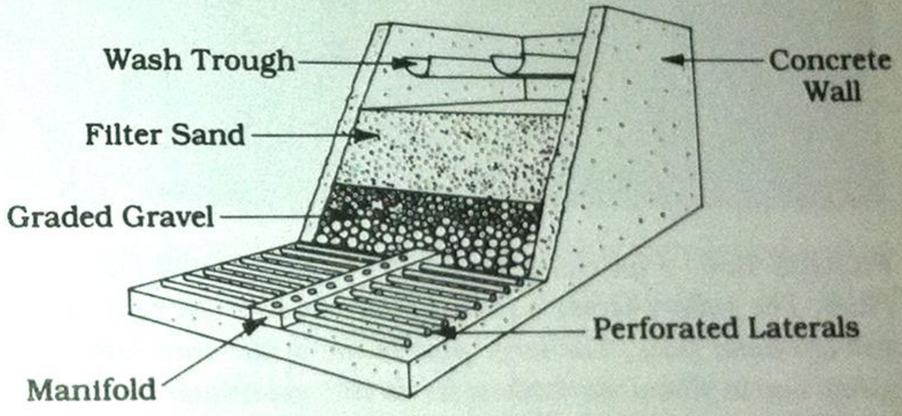


FIGURE 8.32 Typical slow sand filter biota at different depths. (*Source:* American Public Health Association, American Water Works Association, and Water Environment Federation. 1995. *Standard Methods for the Examination of Water and Wastewater,* 19th ed. Washington, D.C.: APHA.)

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999



(a) Perspective of a Battery of Filters



(b) Perspective through a Filter

FIGURE 10.2 *Gravity Filters and Accessories*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

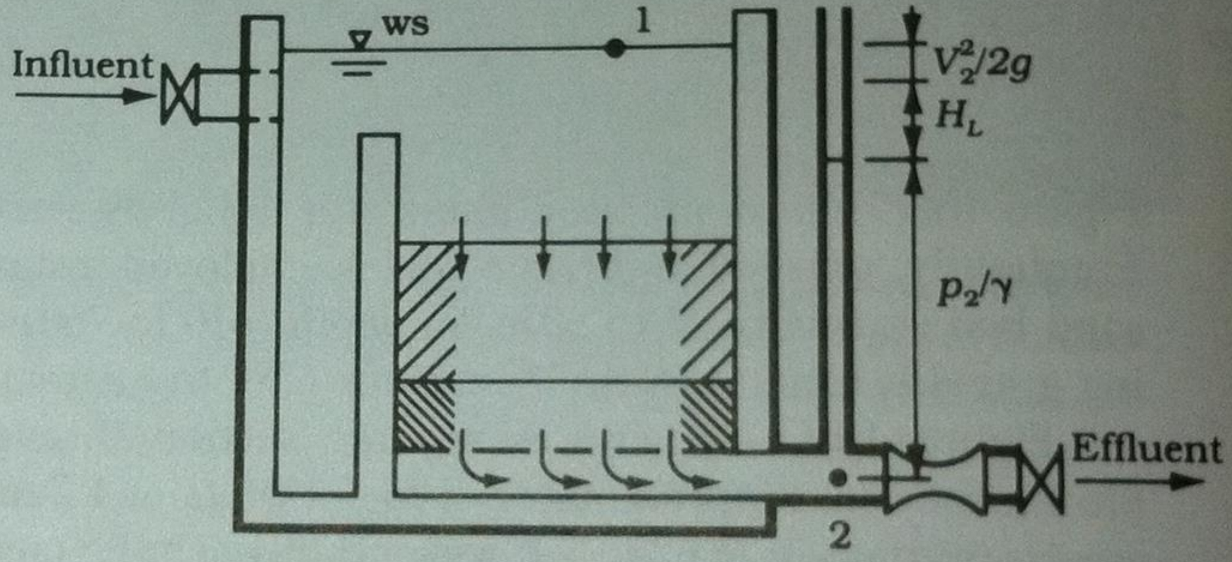


FIGURE 10.11 *Schematic Section Showing a Filter during Filtration*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

Removal of Microorganisms by Filtration

- *Giardia lambia* and *Cryptosporidium parvum* are highly resistant to disinfection – waterborne outbreaks in North America
- Rapid filtration, slow sand filtration, diatomaceus earth filtration and membrane filtration is effective in removing pathogenic microorganisms

Removal of Microorganisms by Filtration

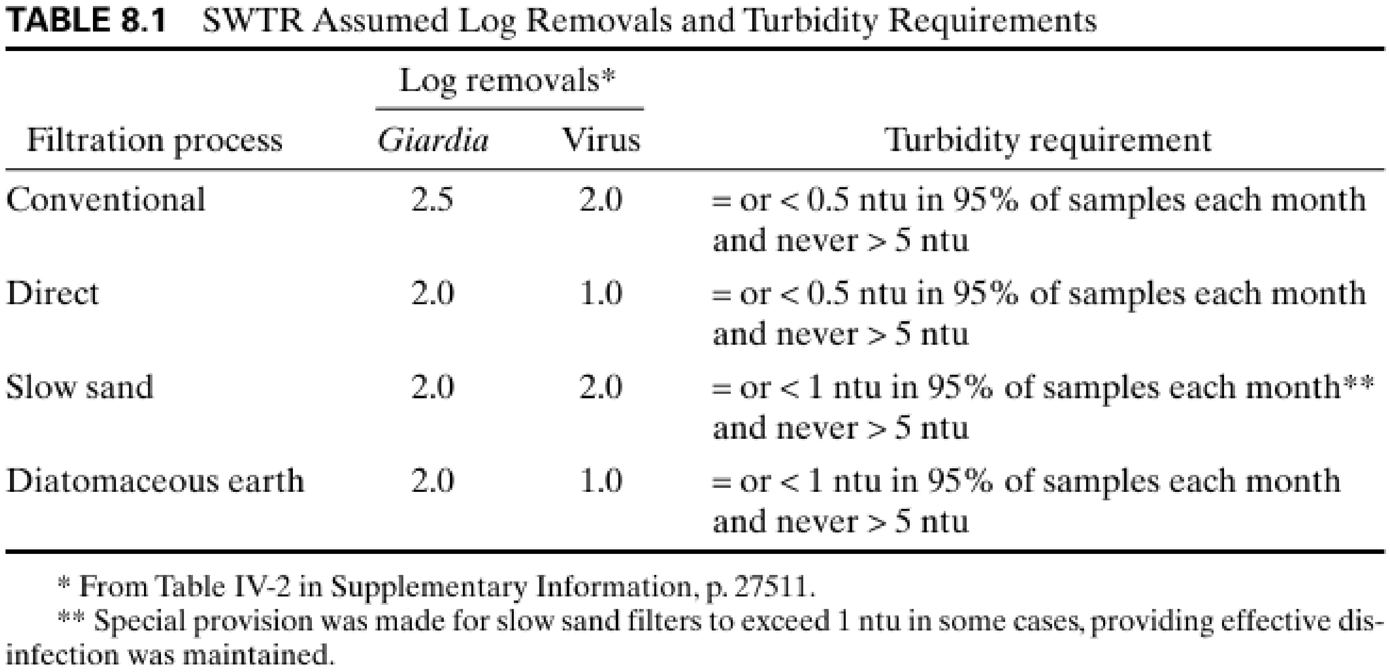


TABLE 8.1 SWTR Assumed Log Removals and Turbidity Requirements

	Log removals*		
Filtration process	*Giardia*	Virus	Turbidity requirement
Conventional	2.5	2.0	= or < 0.5 ntu in 95% of samples each month and never > 5 ntu
Direct	2.0	1.0	= or < 0.5 ntu in 95% of samples each month and never > 5 ntu
Slow sand	2.0	2.0	= or < 1 ntu in 95% of samples each month** and never > 5 ntu
Diatomaceous earth	2.0	1.0	= or < 1 ntu in 95% of samples each month and never > 5 ntu

* From Table IV-2 in Supplementary Information, p. 27511.

** Special provision was made for slow sand filters to exceed 1 ntu in some cases, providing effective disinfection was maintained.

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Filter Media

- Common types of filter media are
  - Silica sand
  - Anthracite coal
  - Garnet
  - Ilmenite

} Naturally occuring high density minerals

- Other types of media
  - Granular activated carbon → odor removal (filtration and adsorption)

Filter Media – Granular Bed

- Garnet→ generic term for reffering to several different minerals – silicates of iron, aluminum and calcium mixtures
  - Specific gravity range from 3.6-4.2

Ref: http://www.throop.com/sand-garnet.php

- Ilmenite→ iron titanium ore
  - Specific gravity range from 4.2-4.6

Ref: http://www.tradeboss.com/default.cgi/action/viewproducts/productid/26394/productname/Philippine_ilmenite_sand_pebbles/

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Filter Media - Precoat

- Diatomaceous earth is composed of fossilized skeletons of microscopic diatoms (most common precoat filter medium)
- Deposits of these materials from ancient lakes or oceans are processed and used in filtration
- Mean pore sizes of the grades used in water treatment are 5-17 µm

Ref: http://www.small-farm-permaculture-and-sustainable-living.com/natural_flea_killer.html

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Filter Media - Precoat

- Perlite is the less common precoat filter medium. It comes from glassy volcanic rock

- Contains 2-3% water

Filter Media

- Filter media has number of properties affecting filtration performance
  - Size
  - Shape
  - Density
  - Hardness
  - Porosity
  - Size distribution

Filter Media

Grain size and size distribution

- Grain size has an important effect on filtration efficiency and on backwashing requirements
- Grain size affects
  - Clean water headloss
  - Build-up of head loss during the filter cycle

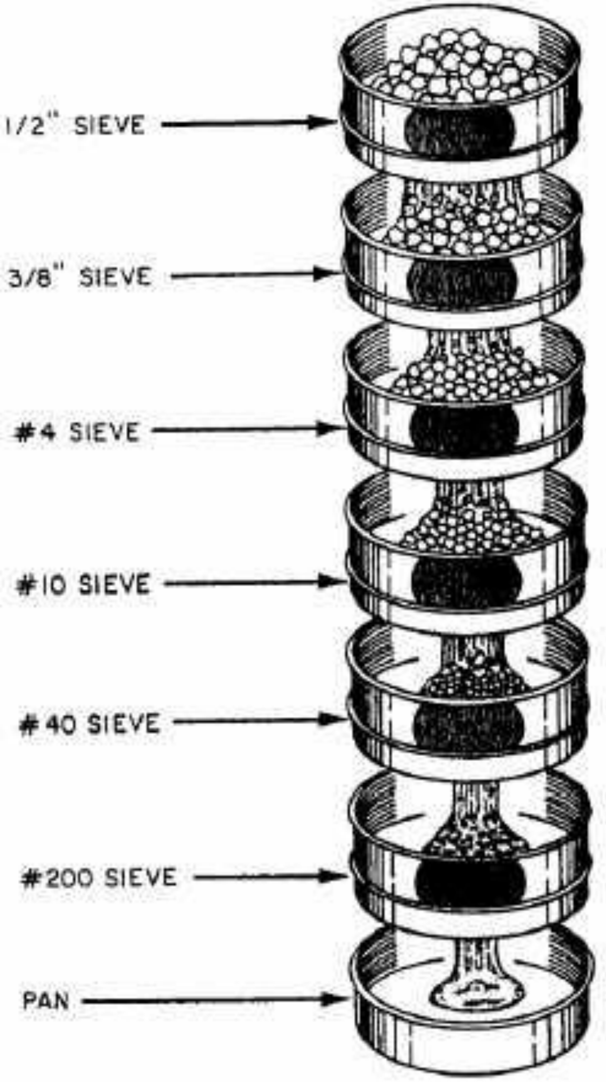
Filter Media

- As the size of the granular media gets smaller, pore openings will be smaller → filtration efficiency would increase.
- However, as the size of pores decrease, headloss through the medium would increase
- As the size of the granular media increase, pore size would also increase, which would cause headloss to decrease
- However, small particles may pass through these large pores

Filter Media

- Uniform Media:
- Uniformly graded deep bed filters are relatively coarse media ranging from 0.5 mm to 6.0 mm
- UC is typically 1.2-1.3
- Greater media depth is substituted for the lack of fine media
- Depths of 1.2 – 1.8 are common (some cases 2.4 m)
- Filters of this type are not expanded during backwash
- This filters designed for air and air/water backwash

Grain Size - Sieve Analysis



Ref: http://enginemechanics.tpub.com/14080/css/14080_127.htm

Filter Media – Size gradation

- Size gradation of filter media is described by two parameters
  - Effective size (ES)
  - Uniformity coefficient (UC)
- ES is that size for which 10% of the grains are smaller by weight (d_{10})
- 10% passing point of the curve for sieve analysis
- UC is the measure of the size range of the media

Filter Media – Size gradation

- UC is the ratio of d_{60} to d_{10} .
- (d_{60}) size is also read from the sieve analysis curve, it is the size for which 60% of the grains are smalled by weight

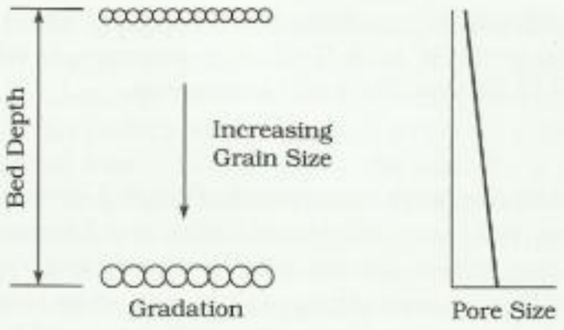
$$ES = d_{10}$$

$$UC = d_{60} / d_{10}$$

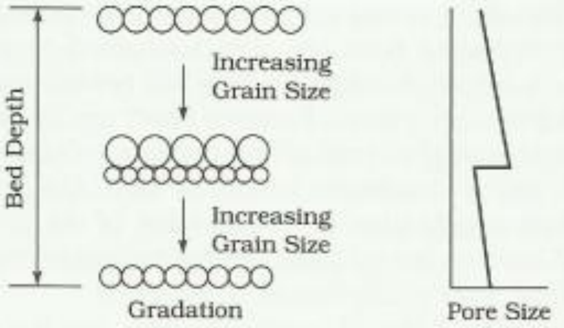
Filter Media – Size gradation

- Required backwash rate of the filter can be calculated by d_{90} (90% of the grains are smaller by weight)

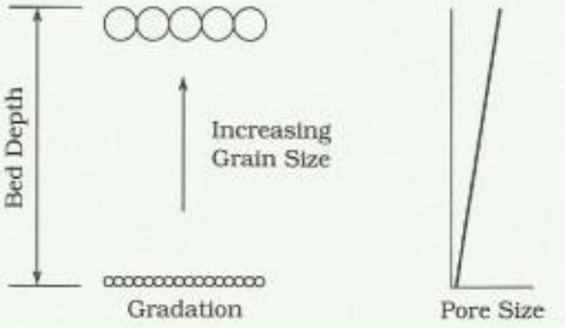
$$d_{90} = d_{10}(10^{1.67 \log \mathrm{UC}})$$



(a) Single-Medium Filter



(b) Dual-Medium Filter

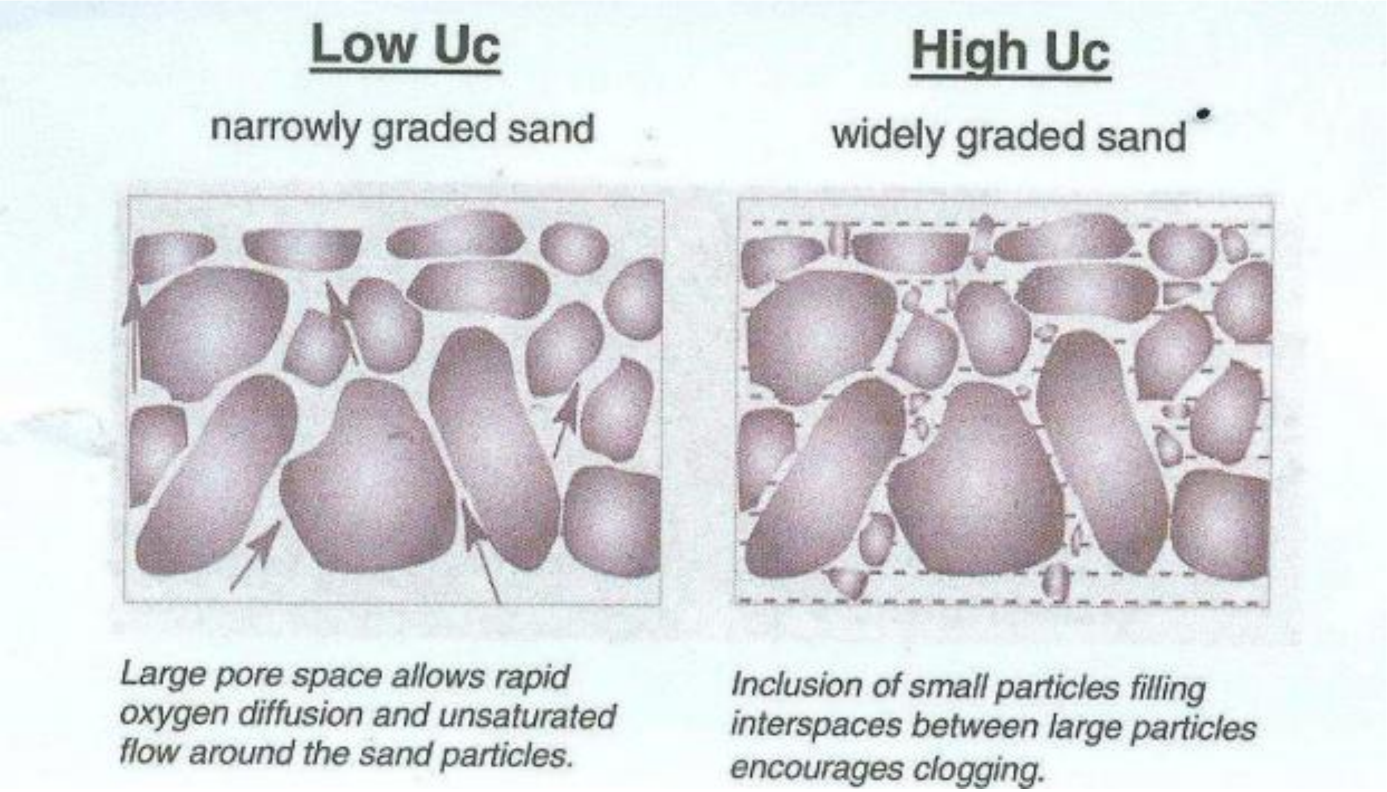


(c) Ideal Filter

FIGURE 10.22 *Gradation and Pore Size in Various Filters*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

Filter Media



Low Uc

narrowly graded sand

Large pore space allows rapid oxygen diffusion and unsaturated flow around the sand particles.

High Uc

widely graded sand

Inclusion of small particles filling interspaces between large particles encourages clogging.

Sieve Analysis

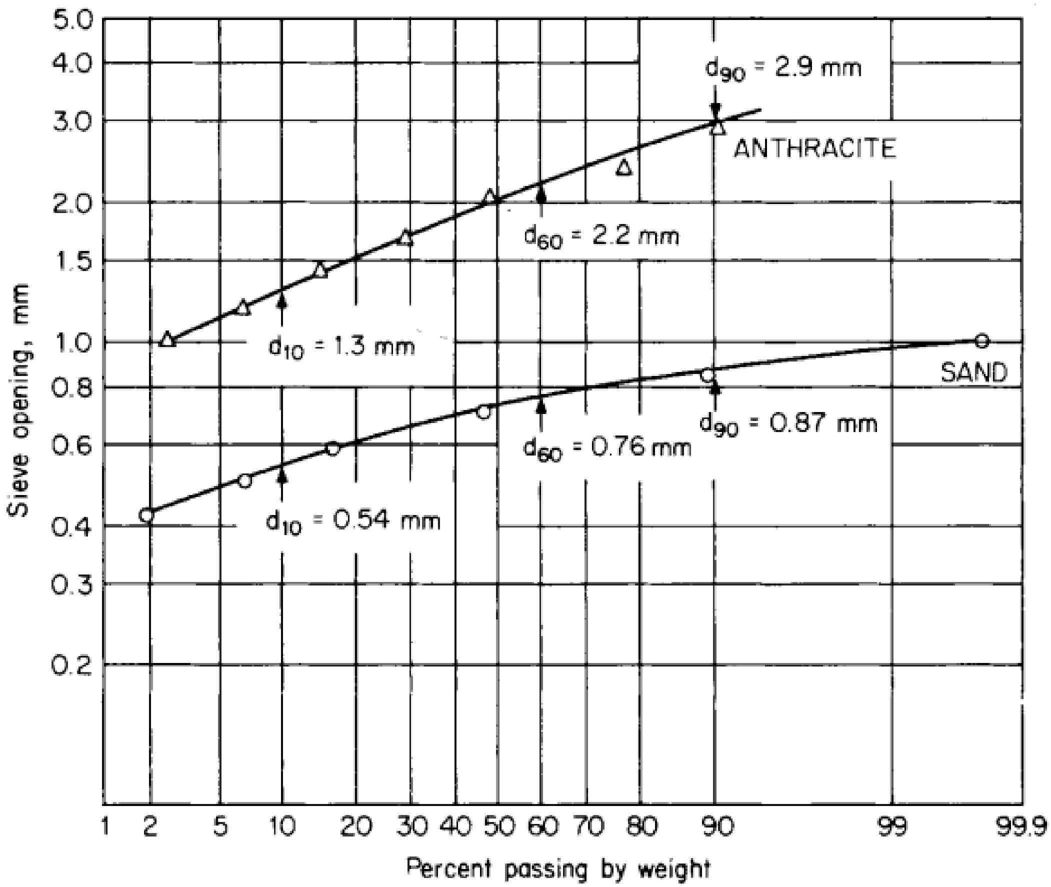


FIGURE 8.3 Typical sieve analysis of two filter media.

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Grain Shape and Roundness

- The shape and roundness of the filter grains is important because they affect the
  - backwash flow requirements of the medium
  - the fixed bed porosity
  - the headloss for flow through the medium
  - the filtration efficiency
  - the ease of sieving
- Different measures of grain shape have evolved in the literature – sphericity is an accepted terminology

Sphericity

$$\Psi = \frac{\text{surface area of sphere having same volume with particle /Vs}}{\text{surface area of particle /Vp}}$$ (Since Vs = Vp)

$$\psi = \frac{\text{surface area of sphere having same volume with particle}}{\text{surface area of particle}}$$

For a sphere--> $V_s = \frac{\pi d^3}{6}$ $A_s = \pi d^2$

For an irregular shape particle; $\Psi = \frac{\pi d^2 / \pi d^3 / 6}{A_p / V_p} \Rightarrow \frac{A_p}{V_p} = \frac{6}{\Psi d}$

Grain Density and Porosity

- Grain density: Mass per unit grain volume
- Grain density is important because it affects the backwash flow requirements for a filter medium.
- High density grains require higher wash rates
- Fixed bed porosity: Ratio of void volume to total bed volume, expressed as percentage

$$Porosity = \frac{Void\ Volume}{Total\ bed\ volume} = \frac{V_V}{V_T}$$

Grain Density and Porosity

- Porosity affects
  - Backwash flow rate
  - Fixed-bed head loss
  - Solids holding capacity of the medium
- Fixed bed porosity is affected by grain sphericit
- Less spherical particles have higher fixed-bed porosity
- Low UC → no effect on porosity
- High UC → nesting of small grains in pores may decrease the porosity

Grain Density and Porosity

- Fixed bed porosity is determined by
    - Placing a sample of known mass and density in a transperent tube with known diameter
    - The depth of the filter medium is measured to calculate the bed volume

$$Grain\,Volume = \frac{Total\,mass\,in\,column}{density}$$

$$Void\,volume = Bed\,volume - grain\,volume$$

Grain Density and Porosity

- Fixed bed porosity: Affected by the extent of compaction in the medium
- Loose-bed porosity: Bed is agitated by inversion and allowed to settle freely (no compaction), highest porosity will be obtained

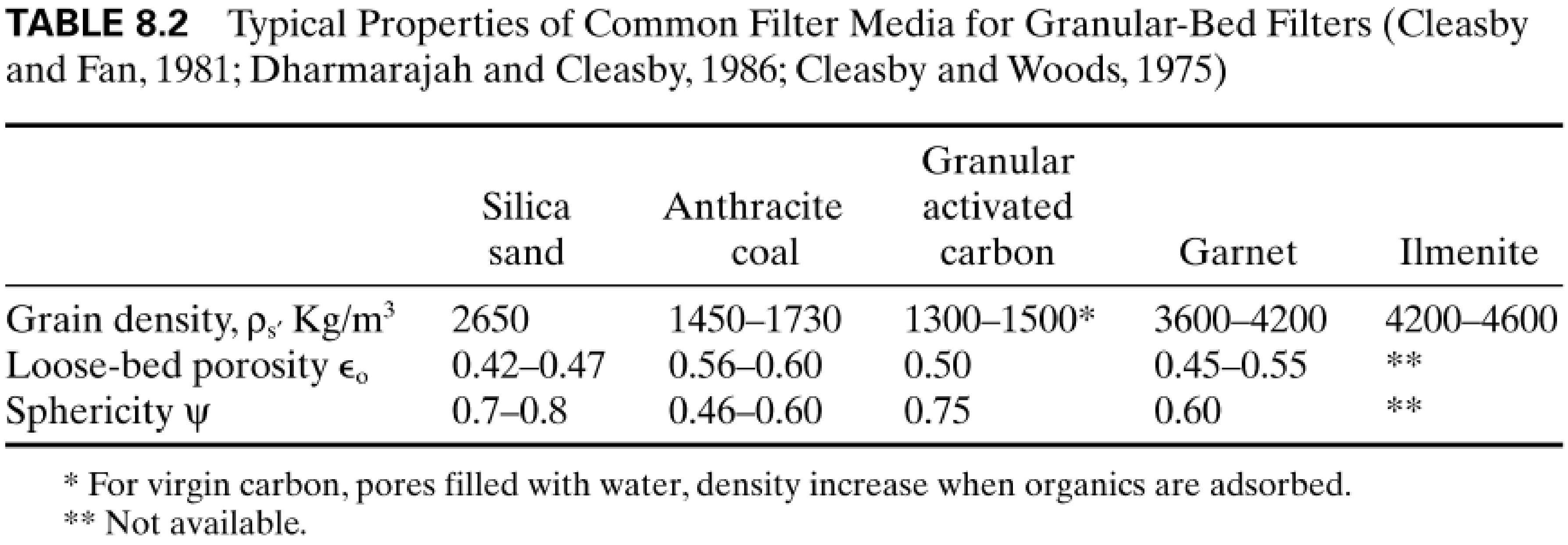


TABLE 8.2 Typical Properties of Common Filter Media for Granular-Bed Filters (Cleasby and Fan, 1981; Dharmarajah and Cleasby, 1986; Cleasby and Woods, 1975)

	Silica sand	Anthracite coal	Granular activated carbon	Garnet	Ilmenite
Grain density, ρ_s, Kg/m^3	2650	1450–1730	1300–1500*	3600–4200	4200–4600
Loose-bed porosity ϵ_o	0.42–0.47	0.56–0.60	0.50	0.45–0.55	**
Sphericity ψ	0.7–0.8	0.46–0.60	0.75	0.60	**

* For virgin carbon, pores filled with water, density increase when organics are adsorbed.
** Not available.

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

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Rapid Sand Filtration

Filtration rate = 5 – 25 $m^3/m^2.hr$

gravity filter (typical filt. rate 8- 12 m/hr) or pressure filter (up to 25 m/hr)

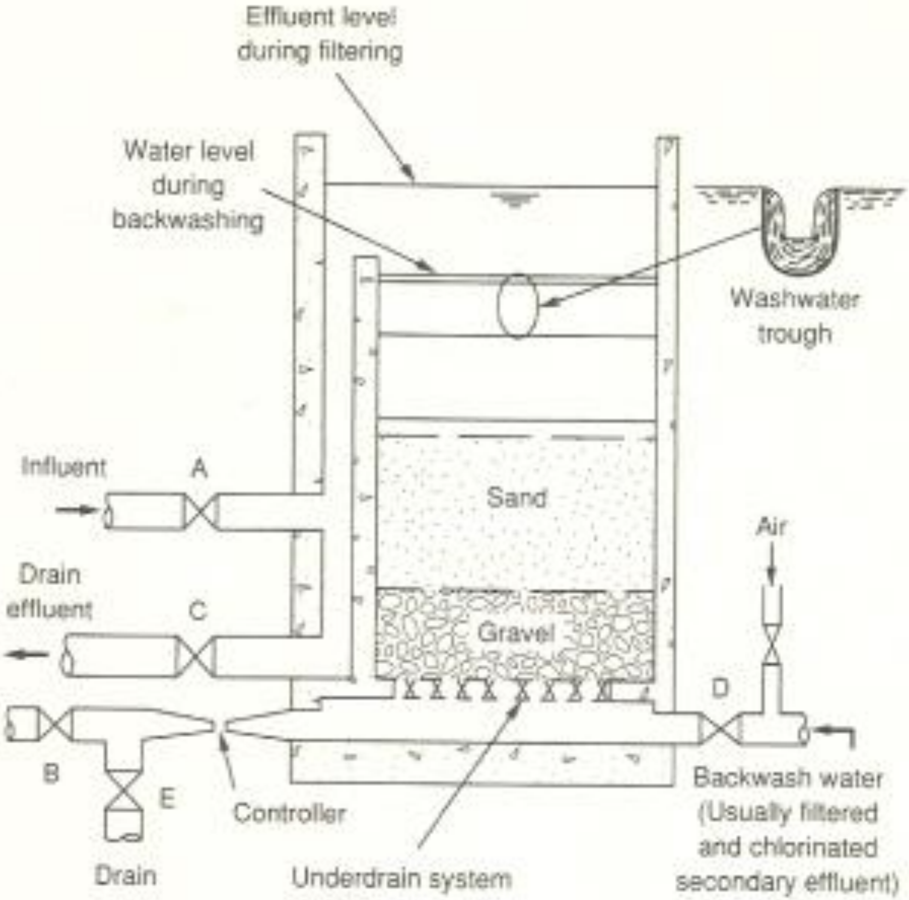
<u>During operation;</u>

solids are removed from the water and accumulate within the voids and on top surface of the filter medium

this clogging results in a gradual increase in headloss

after a period of operation, the filter is cleaned by backwashing with an upward flow of water

Operating time between backwashes → a Filter Cycle or a Filter Run
Headloss at the end of filter run→ Terminal Head Loss



How filter operates:

1. Open valve A. (This allows effluent to flow to filter.)
2. Open valve B. (This allows effluent to flow through filter.)
3. During filter operation, all other valves are closed.

How filter is backwashed:

1. Close valve A.
2. Close valve B when water in filter drops down to top of overflow.
3. Open valves C and D. (This allows water from wash water tank to flow up through the filtering medium, loosening up the sand and washing the accumulated solids out of the filter. Filter backwash water is returned to head end of treatment plant.)

How to filter to waste (if used):

1. Open valves A and E. All other valves closed. Effluent is sometimes filtered to waste for a few minutes after filter has been washed to condition the filter before it is put into service.

FIGURE 6-24
Definition sketch for operation of conventional downflow, granular-medium, gravity-flow filter.

Ref: Metcalf & Eddy, Inc. (2003). *Wastewater Engineering-Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.

Desing Parameters

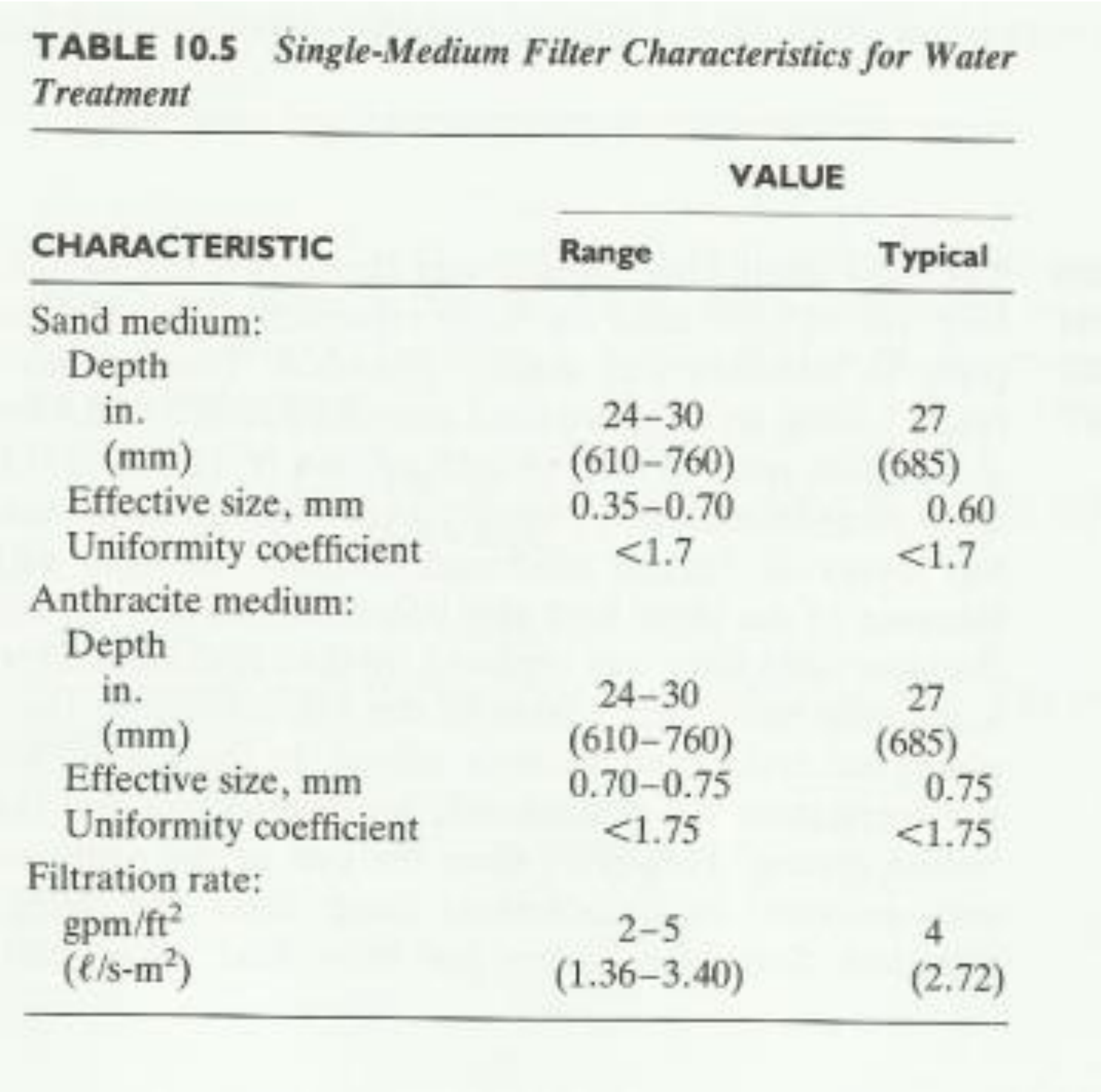


TABLE 10.5 *Single-Medium Filter Characteristics for Water Treatment*

CHARACTERISTIC	VALUE Range	 Typical
Sand medium:		
Depth		
in.	24–30	27
(mm)	(610–760)	(685)
Effective size, mm	0.35–0.70	0.60
Uniformity coefficient	<1.7	<1.7
Anthracite medium:		
Depth		
in.	24–30	27
(mm)	(610–760)	(685)
Effective size, mm	0.70–0.75	0.75
Uniformity coefficient	<1.75	<1.75
Filtration rate:		
gpm/ft^2	2–5	4
$(\ell/\text{s-m}^2)$	(1.36–3.40)	(2.72)

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

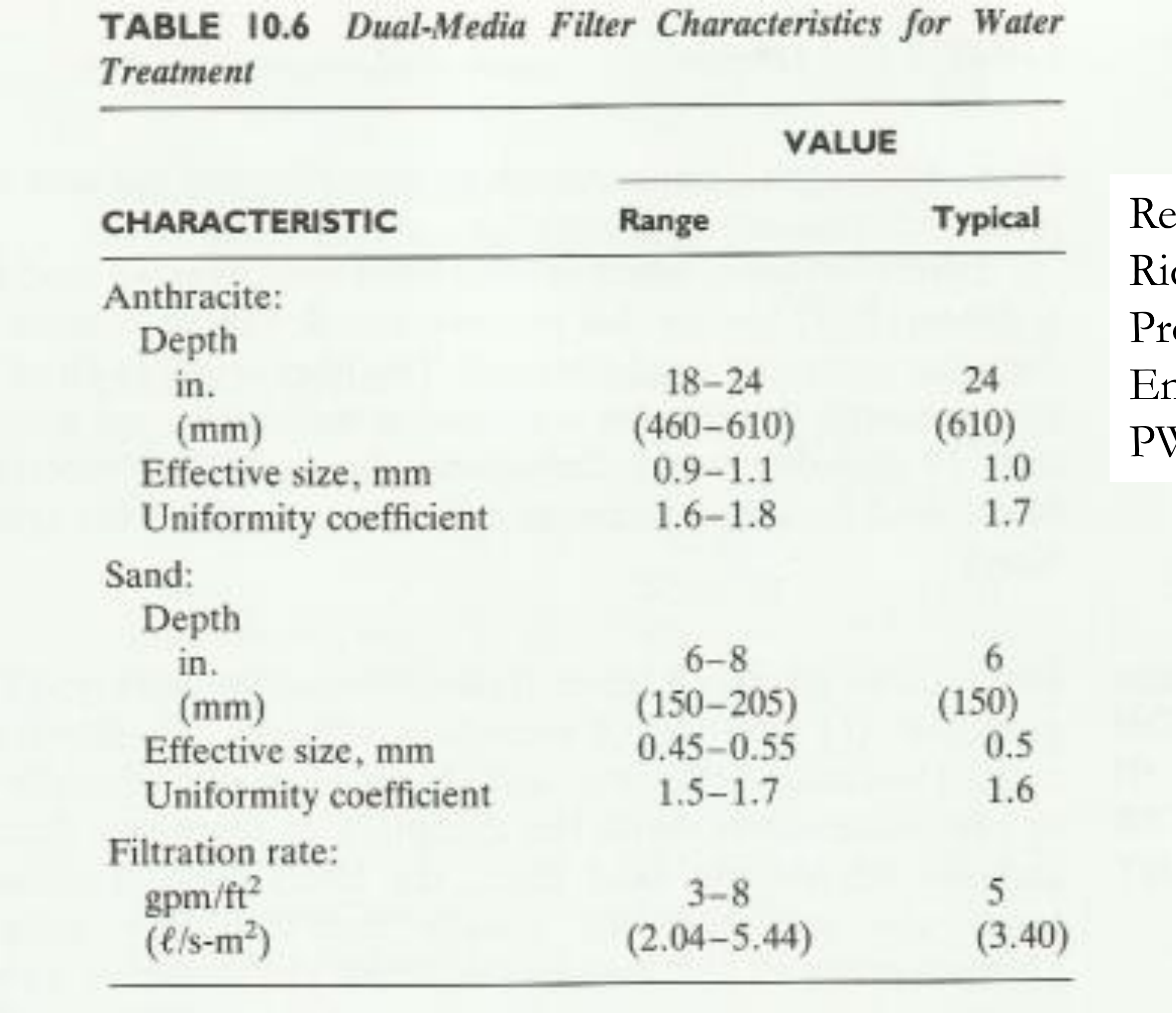


TABLE 10.6 *Dual-Media Filter Characteristics for Water Treatment*

	VALUE	
CHARACTERISTIC	Range	Typical
Anthracite:		
Depth		
in.	18–24	24
(mm)	(460–610)	(610)
Effective size, mm	0.9–1.1	1.0
Uniformity coefficient	1.6–1.8	1.7
Sand:		
Depth		
in.	6–8	6
(mm)	(150–205)	(150)
Effective size, mm	0.45–0.55	0.5
Uniformity coefficient	1.5–1.7	1.6
Filtration rate:		
gpm/ft^2	3–8	5
$(\ell/s\text{-}m^2)$	(2.04–5.44)	(3.40)

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

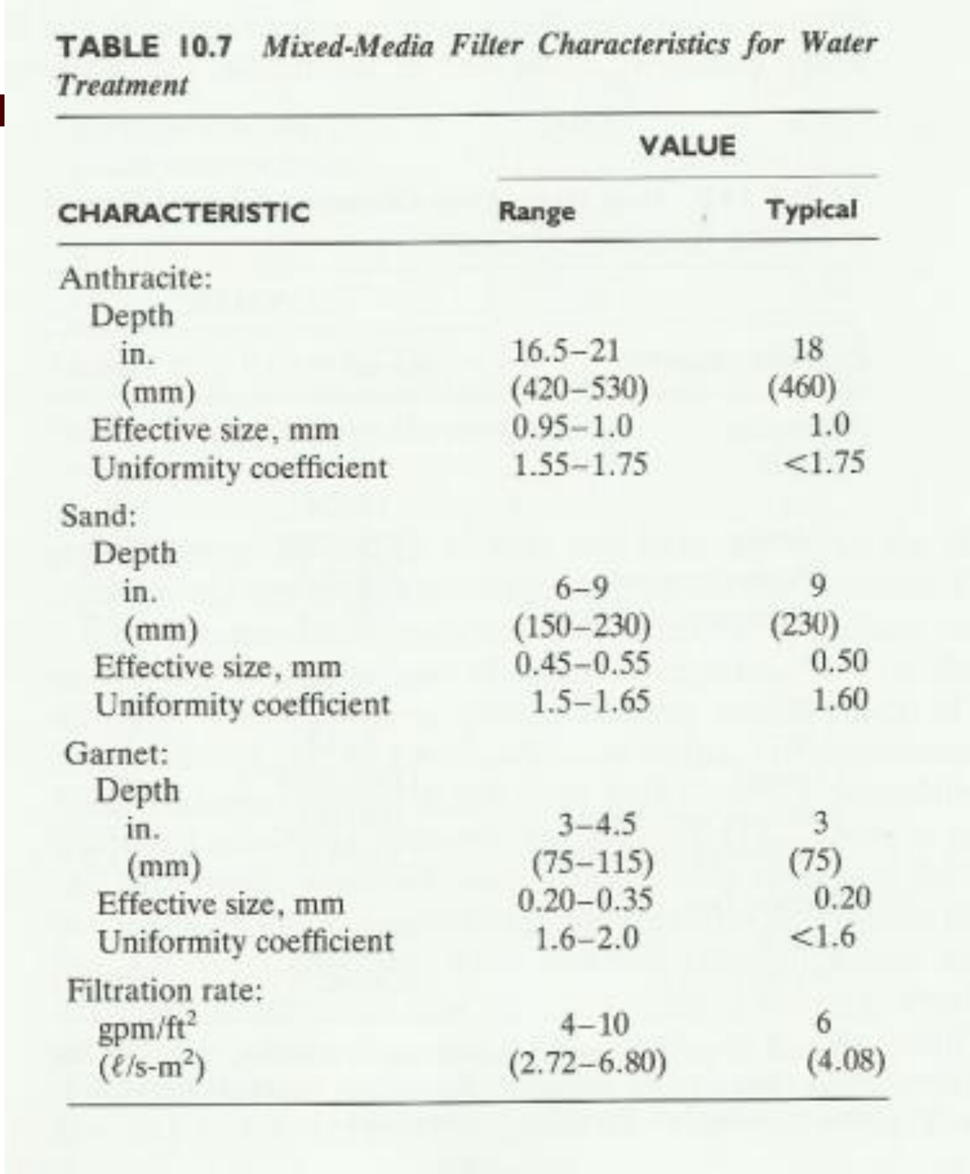


TABLE 10.7 *Mixed-Media Filter Characteristics for Water Treatment*

CHARACTERISTIC	VALUE Range	 Typical
Anthracite:		
Depth		
in.	16.5–21	18
(mm)	(420–530)	(460)
Effective size, mm	0.95–1.0	1.0
Uniformity coefficient	1.55–1.75	<1.75
Sand:		
Depth		
in.	6–9	9
(mm)	(150–230)	(230)
Effective size, mm	0.45–0.55	0.50
Uniformity coefficient	1.5–1.65	1.60
Garnet:		
Depth		
in.	3–4.5	3
(mm)	(75–115)	(75)
Effective size, mm	0.20–0.35	0.20
Uniformity coefficient	1.6–2.0	<1.6
Filtration rate:		
gpm/ft^2	4–10	6
(ℓ/s-m^2)	(2.72–6.80)	(4.08)

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

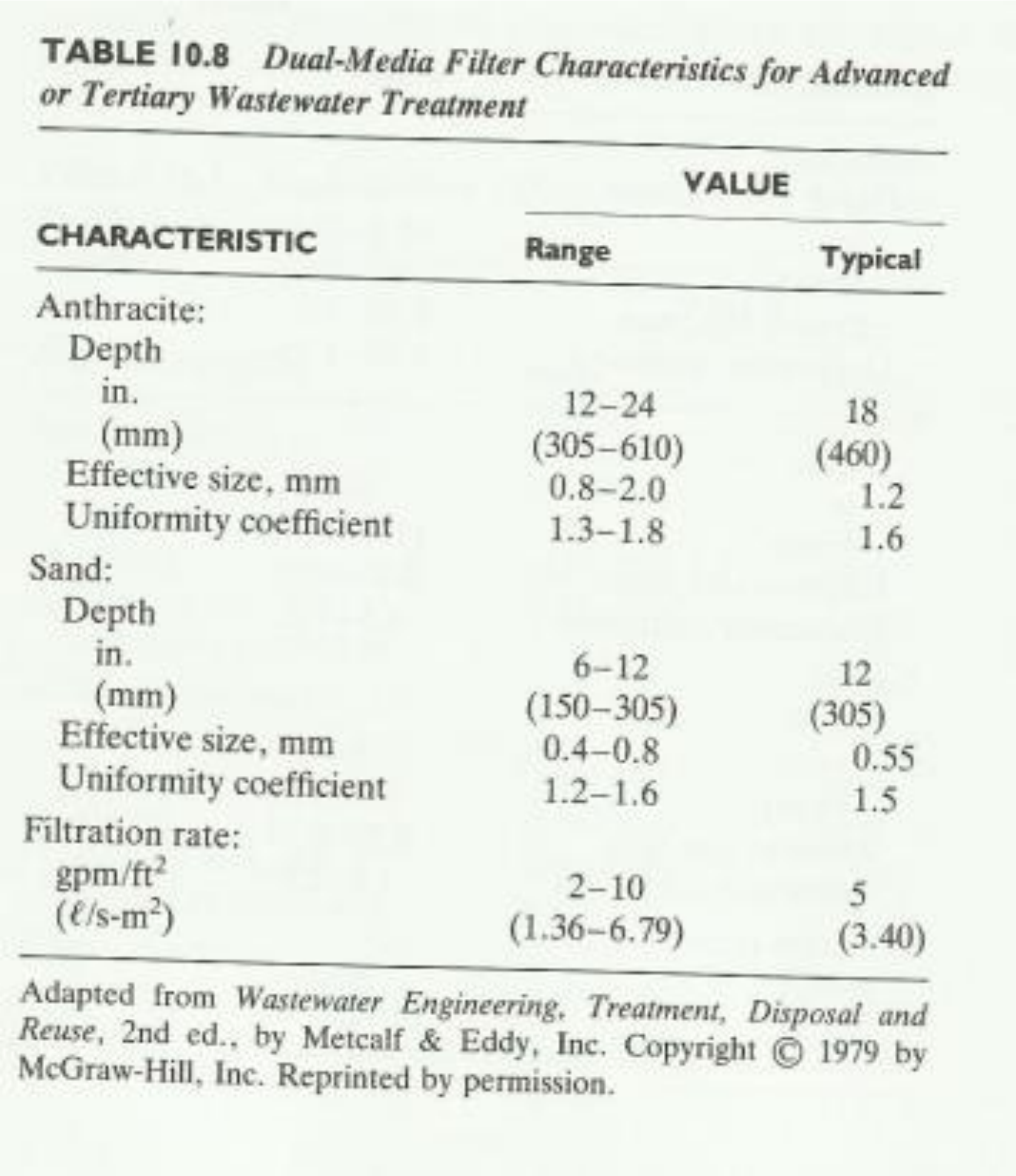


TABLE 10.8 *Dual-Media Filter Characteristics for Advanced or Tertiary Wastewater Treatment*

CHARACTERISTIC	VALUE	
	Range	Typical
Anthracite:		
Depth		
in.	12–24	18
(mm)	(305–610)	(460)
Effective size, mm	0.8–2.0	1.2
Uniformity coefficient	1.3–1.8	1.6
Sand:		
Depth		
in.	6–12	12
(mm)	(150–305)	(305)
Effective size, mm	0.4–0.8	0.55
Uniformity coefficient	1.2–1.6	1.5
Filtration rate:		
gpm/ft^2	2–10	5
(ℓ/s-m^2)	(1.36–6.79)	(3.40)

Adapted from *Wastewater Engineering, Treatment, Disposal and Reuse*, 2nd ed., by Metcalf & Eddy, Inc. Copyright © 1979 by McGraw-Hill, Inc. Reprinted by permission.

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

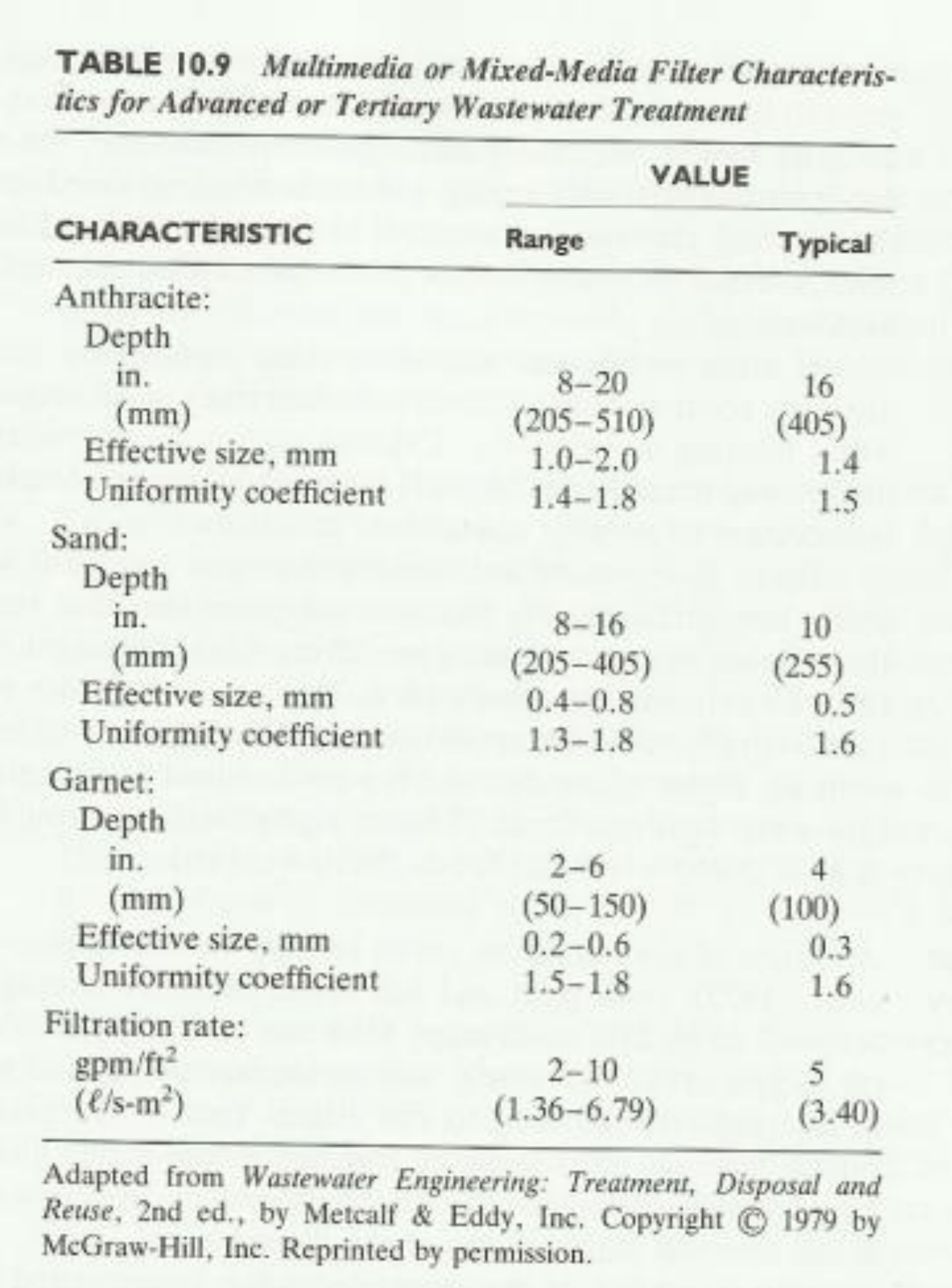


TABLE 10.9 *Multimedia or Mixed-Media Filter Characteristics for Advanced or Tertiary Wastewater Treatment*

CHARACTERISTIC	VALUE	
	Range	Typical
Anthracite:		
Depth		
in.	8–20	16
(mm)	(205–510)	(405)
Effective size, mm	1.0–2.0	1.4
Uniformity coefficient	1.4–1.8	1.5
Sand:		
Depth		
in.	8–16	10
(mm)	(205–405)	(255)
Effective size, mm	0.4–0.8	0.5
Uniformity coefficient	1.3–1.8	1.6
Garnet:		
Depth		
in.	2–6	4
(mm)	(50–150)	(100)
Effective size, mm	0.2–0.6	0.3
Uniformity coefficient	1.5–1.8	1.6
Filtration rate:		
gpm/ft^2	2–10	5
$(\ell/\text{s-m}^2)$	(1.36–6.79)	(3.40)

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Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

Desing Parameters

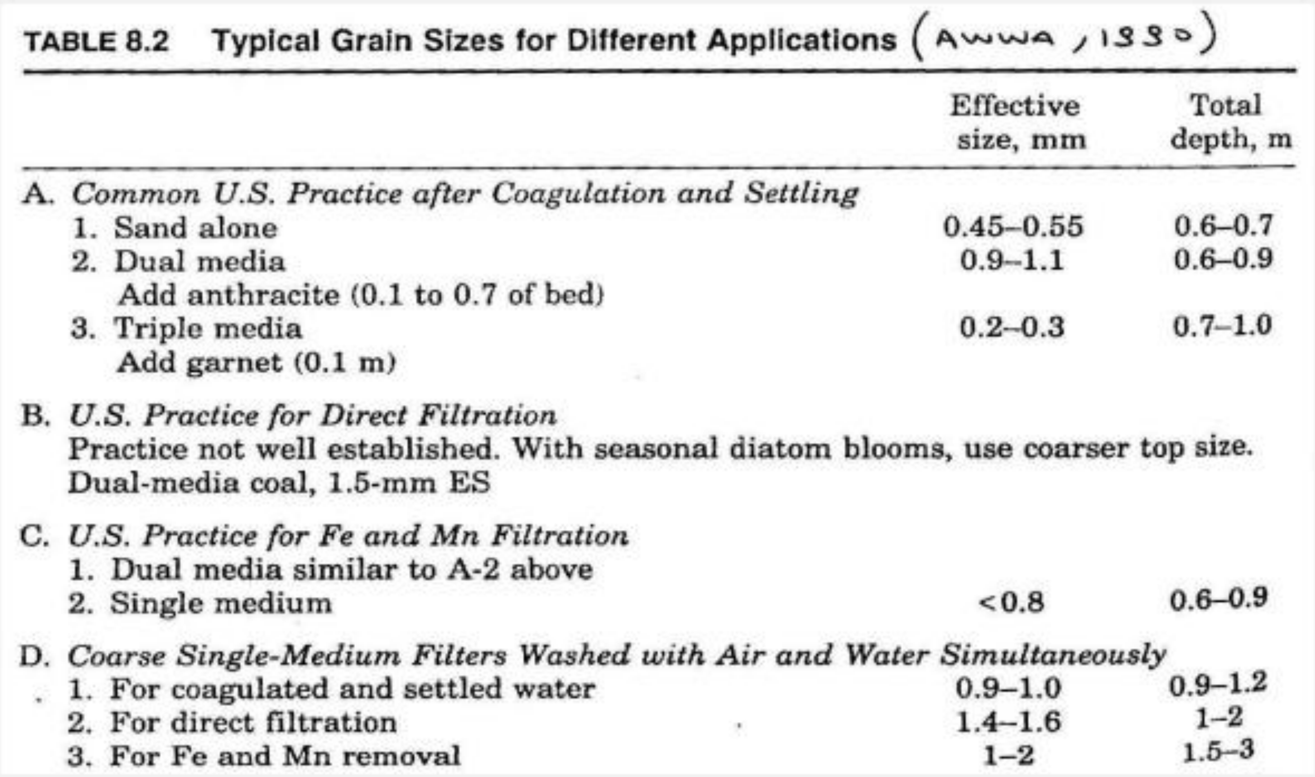


TABLE 8.2 Typical Grain Sizes for Different Applications (AWWA, 1990)

	Effective size, mm	Total depth, m
A. *Common U.S. Practice after Coagulation and Settling*		
1. Sand alone	0.45–0.55	0.6–0.7
2. Dual media Add anthracite (0.1 to 0.7 of bed)	0.9–1.1	0.6–0.9
3. Triple media Add garnet (0.1 m)	0.2–0.3	0.7–1.0
B. *U.S. Practice for Direct Filtration* Practice not well established. With seasonal diatom blooms, use coarser top size. Dual-media coal, 1.5-mm ES		
C. *U.S. Practice for Fe and Mn Filtration*		
1. Dual media similar to A-2 above		
2. Single medium	<0.8	0.6–0.9
D. *Coarse Single-Medium Filters Washed with Air and Water Simultaneously*		
1. For coagulated and settled water	0.9–1.0	0.9–1.2
2. For direct filtration	1.4–1.6	1–2
3. For Fe and Mn removal	1–2	1.5–3

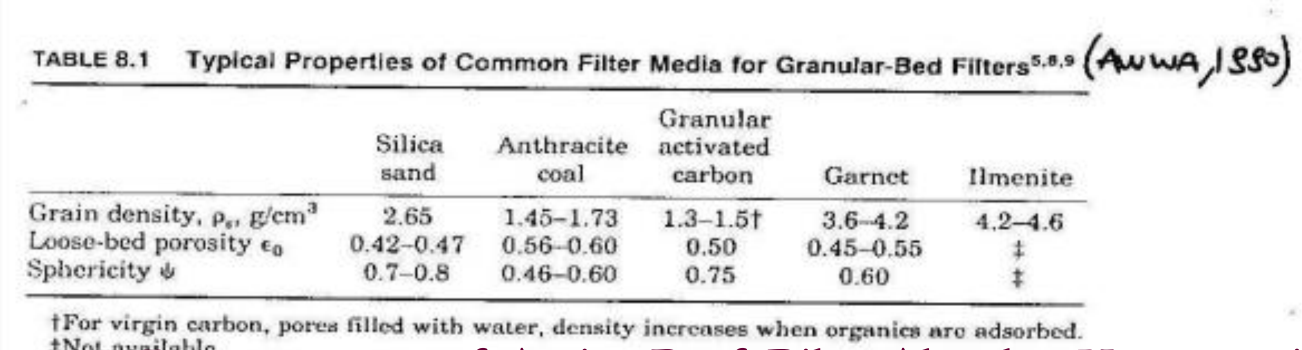


TABLE 8.1 Typical Properties of Common Filter Media for Granular-Bed Filters[5,8,9] (AWWA, 1990)

	Silica sand	Anthracite coal	Granular activated carbon	Garnet	Ilmenite
Grain density, ρ_s, g/cm^3	2.65	1.45–1.73	1.3–1.5†	3.6–4.2	4.2–4.6
Loose-bed porosity ϵ_0	0.42–0.47	0.56–0.60	0.50	0.45–0.55	‡
Sphericity ψ	0.7–0.8	0.46–0.60	0.75	0.60	‡

†For virgin carbon, pores filled with water, density increases when organics are adsorbed.
‡Not available.

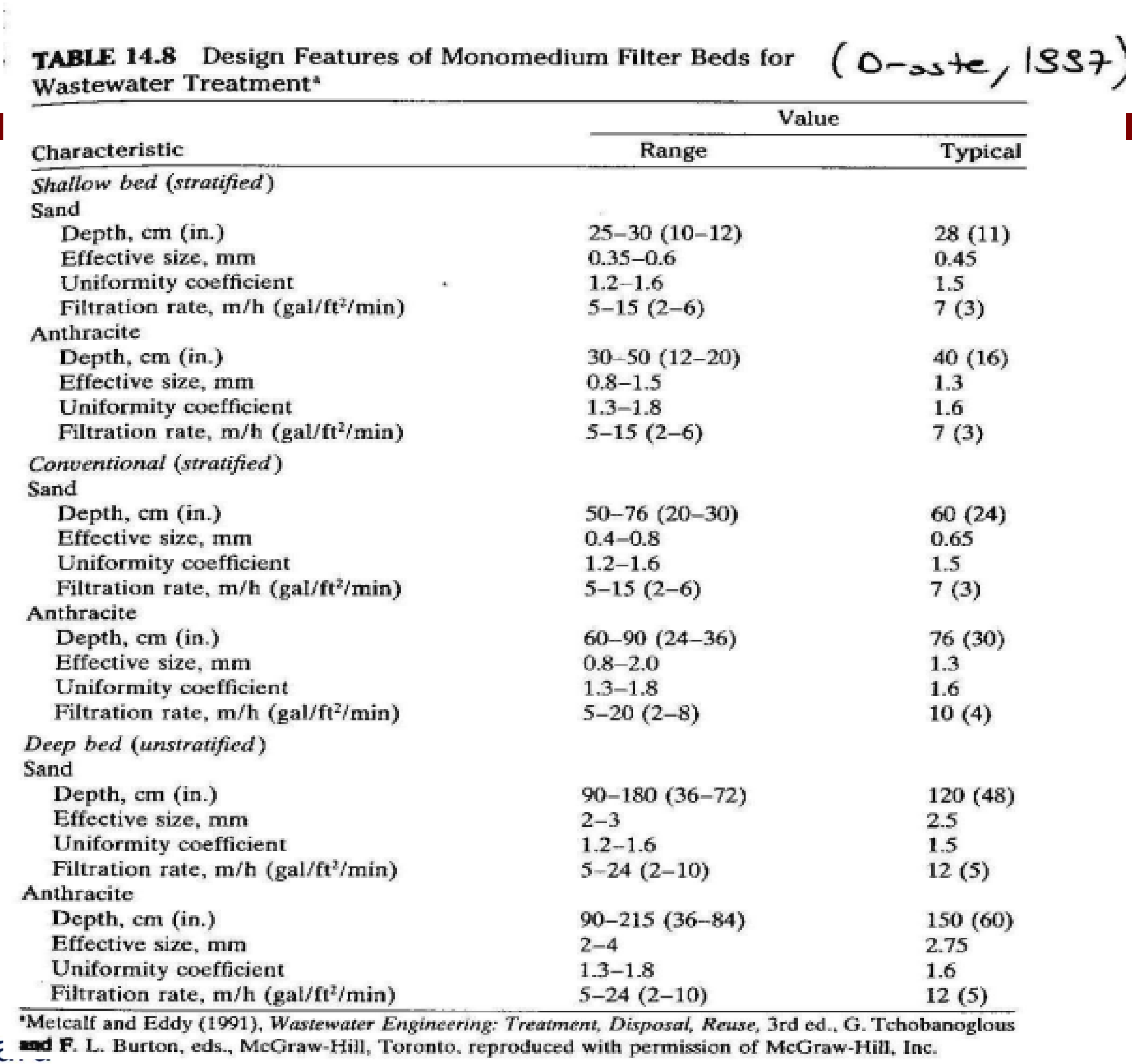


TABLE 14.8 Design Features of Monomedium Filter Beds for Wastewater Treatment[a] (Qasim, 1999)

Characteristic	Value	
	Range	Typical
Shallow bed (stratified)		
Sand		
Depth, cm (in.)	25–30 (10–12)	28 (11)
Effective size, mm	0.35–0.6	0.45
Uniformity coefficient	1.2–1.6	1.5
Filtration rate, m/h (gal/ft²/min)	5–15 (2–6)	7 (3)
Anthracite		
Depth, cm (in.)	30–50 (12–20)	40 (16)
Effective size, mm	0.8–1.5	1.3
Uniformity coefficient	1.3–1.8	1.6
Filtration rate, m/h (gal/ft²/min)	5–15 (2–6)	7 (3)
Conventional (stratified)		
Sand		
Depth, cm (in.)	50–76 (20–30)	60 (24)
Effective size, mm	0.4–0.8	0.65
Uniformity coefficient	1.2–1.6	1.5
Filtration rate, m/h (gal/ft²/min)	5–15 (2–6)	7 (3)
Anthracite		
Depth, cm (in.)	60–90 (24–36)	76 (30)
Effective size, mm	0.8–2.0	1.3
Uniformity coefficient	1.3–1.8	1.6
Filtration rate, m/h (gal/ft²/min)	5–20 (2–8)	10 (4)
Deep bed (unstratified)		
Sand		
Depth, cm (in.)	90–180 (36–72)	120 (48)
Effective size, mm	2–3	2.5
Uniformity coefficient	1.2–1.6	1.5
Filtration rate, m/h (gal/ft²/min)	5–24 (2–10)	12 (5)
Anthracite		
Depth, cm (in.)	90–215 (36–84)	150 (60)
Effective size, mm	2–4	2.75
Uniformity coefficient	1.3–1.8	1.6
Filtration rate, m/h (gal/ft²/min)	5–24 (2–10)	12 (5)

[a] Metcalf and Eddy (1991), *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd ed., G. Tchobanoglous and F. L. Burton, eds., McGraw-Hill, Toronto, reproduced with permission of McGraw-Hill, Inc.

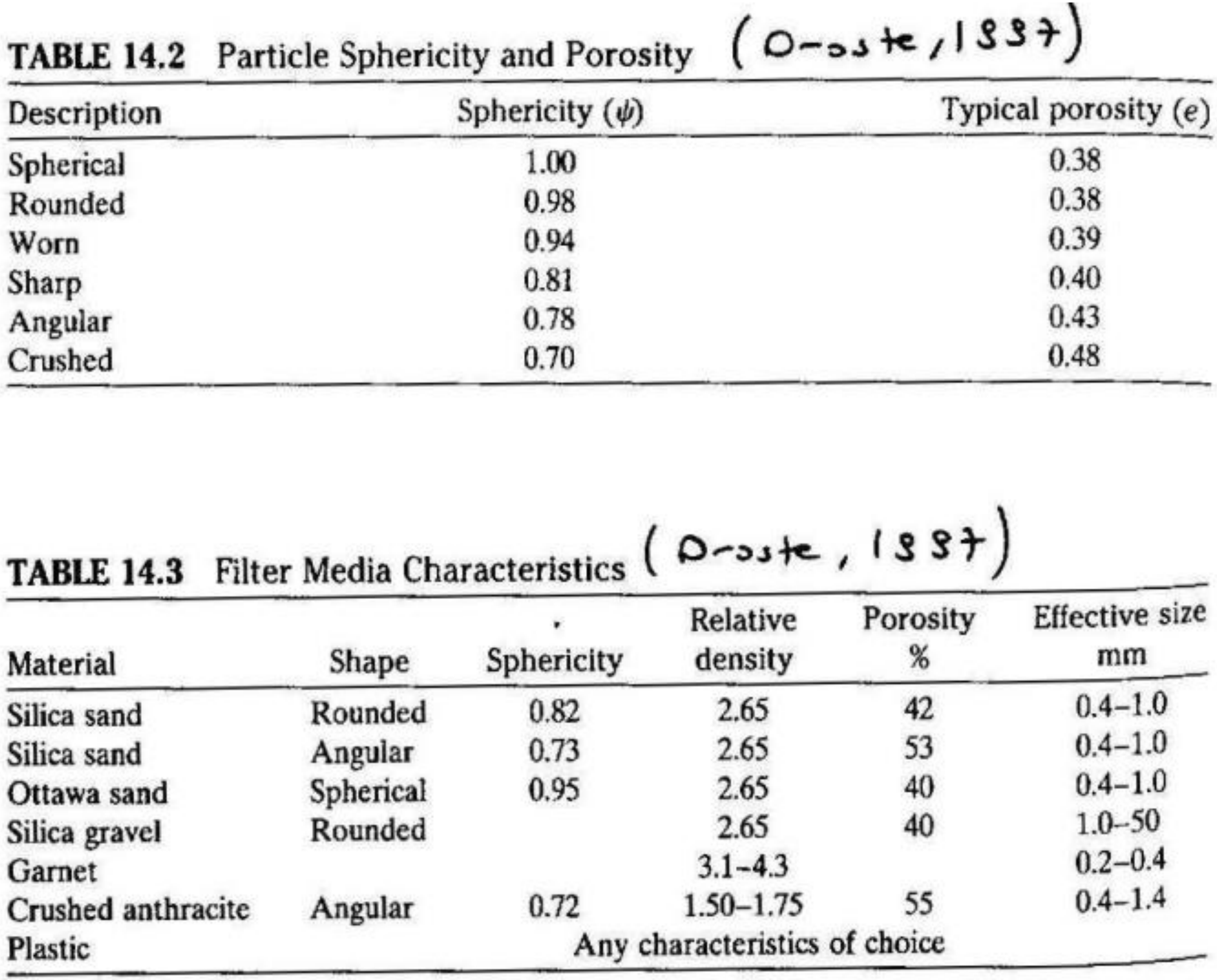


TABLE 14.2 Particle Sphericity and Porosity (Droste, 1997)

Description	Sphericity (ψ)	Typical porosity (e)
Spherical	1.00	0.38
Rounded	0.98	0.38
Worn	0.94	0.39
Sharp	0.81	0.40
Angular	0.78	0.43
Crushed	0.70	0.48

TABLE 14.3 Filter Media Characteristics (Droste, 1997)

Material	Shape	Sphericity	Relative density	Porosity %	Effective size mm
Silica sand	Rounded	0.82	2.65	42	0.4–1.0
Silica sand	Angular	0.73	2.65	53	0.4–1.0
Ottawa sand	Spherical	0.95	2.65	40	0.4–1.0
Silica gravel	Rounded		2.65	40	1.0–50
Garnet			3.1–4.3		0.2–0.4
Crushed anthracite	Angular	0.72	1.50–1.75	55	0.4–1.4
Plastic		Any characteristics of choice			

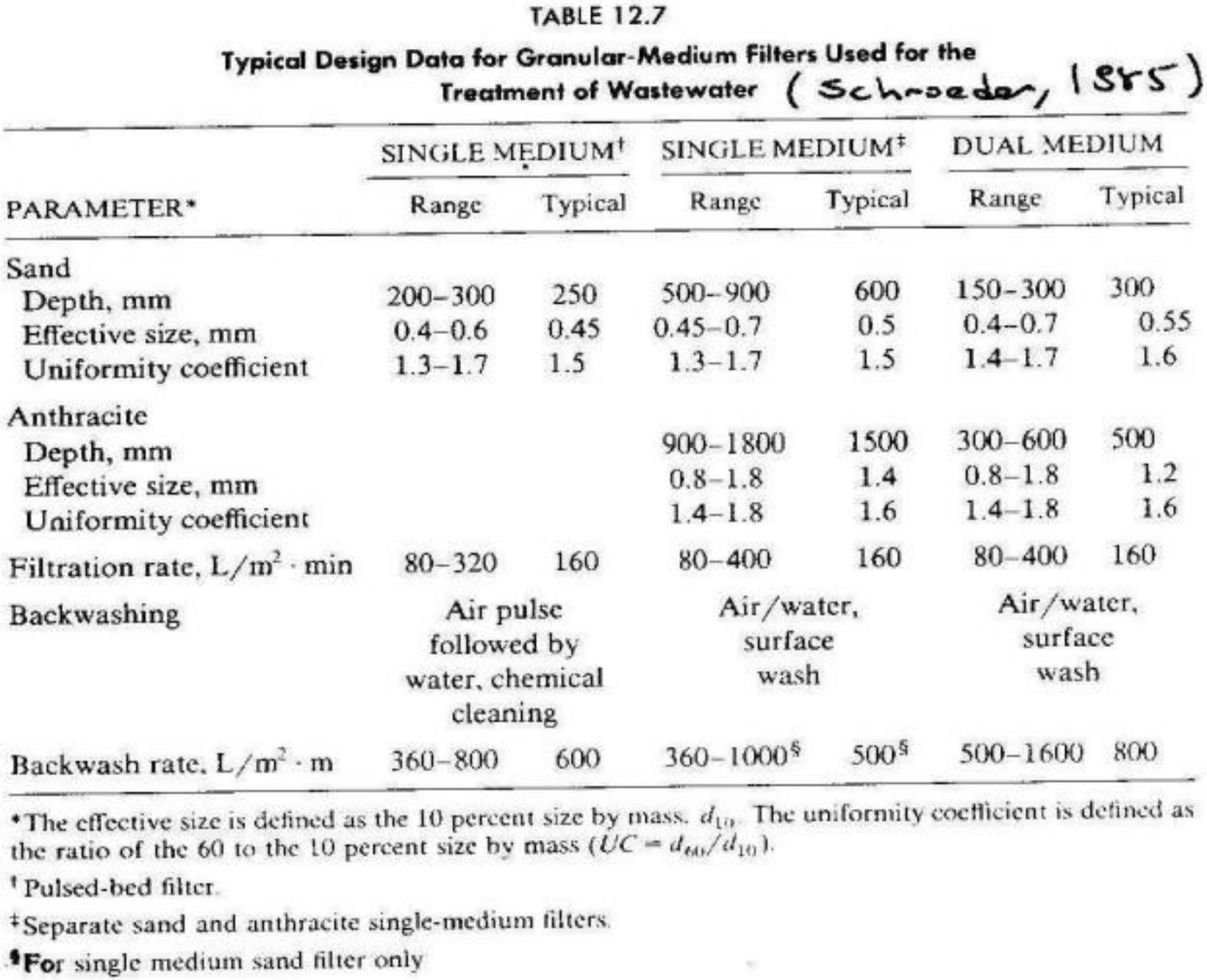


TABLE 12.7

Typical Design Data for Granular-Medium Filters Used for the Treatment of Wastewater (Schroeder, 1985)

PARAMETER*	SINGLE MEDIUM† Range	SINGLE MEDIUM† Typical	SINGLE MEDIUM‡ Range	SINGLE MEDIUM‡ Typical	DUAL MEDIUM Range	DUAL MEDIUM Typical
Sand						
Depth, mm	200–300	250	500–900	600	150–300	300
Effective size, mm	0.4–0.6	0.45	0.45–0.7	0.5	0.4–0.7	0.55
Uniformity coefficient	1.3–1.7	1.5	1.3–1.7	1.5	1.4–1.7	1.6
Anthracite						
Depth, mm			900–1800	1500	300–600	500
Effective size, mm			0.8–1.8	1.4	0.8–1.8	1.2
Uniformity coefficient			1.4–1.8	1.6	1.4–1.8	1.6
Filtration rate, $L/m^2 \cdot min$	80–320	160	80–400	160	80–400	160
Backwashing	Air pulse followed by water, chemical cleaning		Air/water, surface wash		Air/water, surface wash	
Backwash rate, $L/m^2 \cdot m$	360–800	600	360–1000§	500§	500–1600	800

*The effective size is defined as the 10 percent size by mass, d_{10}. The uniformity coefficient is defined as the ratio of the 60 to the 10 percent size by mass ($UC = d_{60}/d_{10}$).

† Pulsed-bed filter.

‡ Separate sand and anthracite single-medium filters.

§ For single medium sand filter only

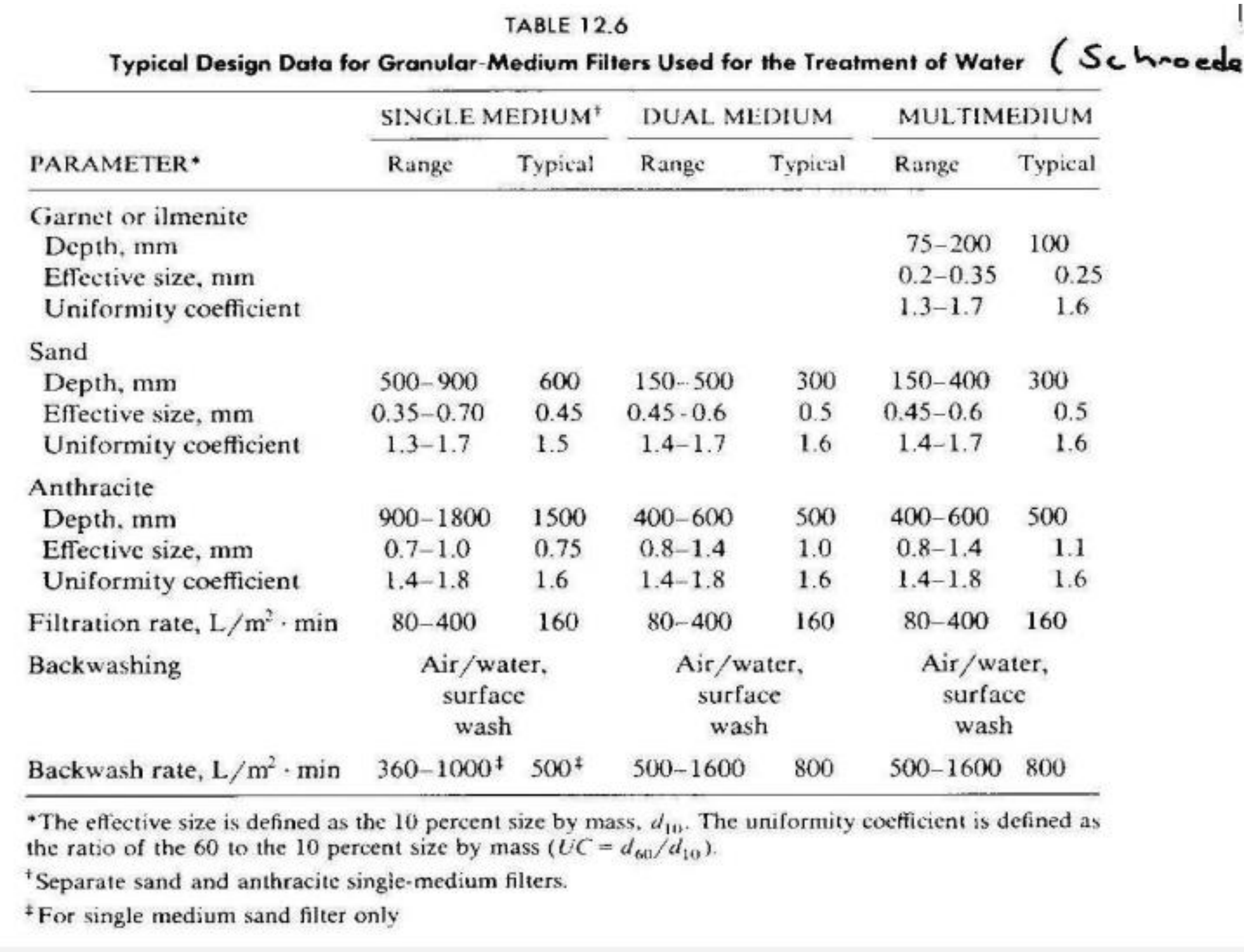


TABLE 12.6

Typical Design Data for Granular-Medium Filters Used for the Treatment of Water (Schroede

	SINGLE MEDIUM[†]		DUAL MEDIUM		MULTIMEDIUM	
PARAMETER*	Range	Typical	Range	Typical	Range	Typical
Garnet or ilmenite						
Depth, mm					75–200	100
Effective size, mm					0.2–0.35	0.25
Uniformity coefficient					1.3–1.7	1.6
Sand						
Depth, mm	500–900	600	150–500	300	150–400	300
Effective size, mm	0.35–0.70	0.45	0.45–0.6	0.5	0.45–0.6	0.5
Uniformity coefficient	1.3–1.7	1.5	1.4–1.7	1.6	1.4–1.7	1.6
Anthracite						
Depth, mm	900–1800	1500	400–600	500	400–600	500
Effective size, mm	0.7–1.0	0.75	0.8–1.4	1.0	0.8–1.4	1.1
Uniformity coefficient	1.4–1.8	1.6	1.4–1.8	1.6	1.4–1.8	1.6
Filtration rate, $L/m^2 \cdot min$	80–400	160	80–400	160	80–400	160
Backwashing	Air/water, surface wash		Air/water, surface wash		Air/water, surface wash	
Backwash rate, $L/m^2 \cdot min$	360–1000[‡]	500[‡]	500–1600	800	500–1600	800

---

*The effective size is defined as the 10 percent size by mass, d_{10}. The uniformity coefficient is defined as the ratio of the 60 to the 10 percent size by mass ($UC = d_{60}/d_{10}$).

[†] Separate sand and anthracite single-medium filters.

[‡] For single medium sand filter only

Underdrain System

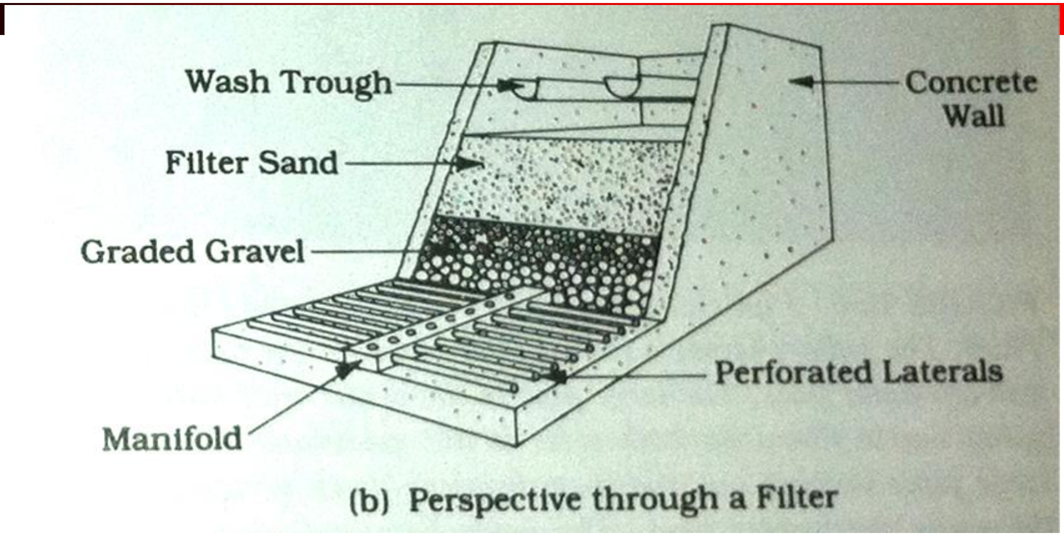
- Underdrain systems have two purposes
  - To collect water that passes through the filter media
  - To distribute the backwash water uniformly
- Support gravel is required when openings of the underdrain system are larger than the filter medium directly above it
- Uneven distribution of washwater can displace support gravel

Underdrain System

- There are four basic types of underdrain systems
  - Pipe Laterals
  - Blocks
  - False Bottom
  - Porous Bottom

Underdrain System

Pipe Laterals



(b) Perspective through a Filter

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

- Pipe laterals were very popular due to low cost and their adaptability to be used in pressure filters
- Problems: High head loss, poor washwater distribution
- Not used very often anymore.

Underdrain System

Pipe Laterals

- Pipe underdrain systems contain centrally located manifold pipe
- Small, equally spaced laterals are attached
- Lateral pipes have one or two rows of perforations on their bottom (6 – 19 mm).
- Orifices OR laterals spaced at 8 to 30 cm
- Approximately 45 cm of support gravel is used

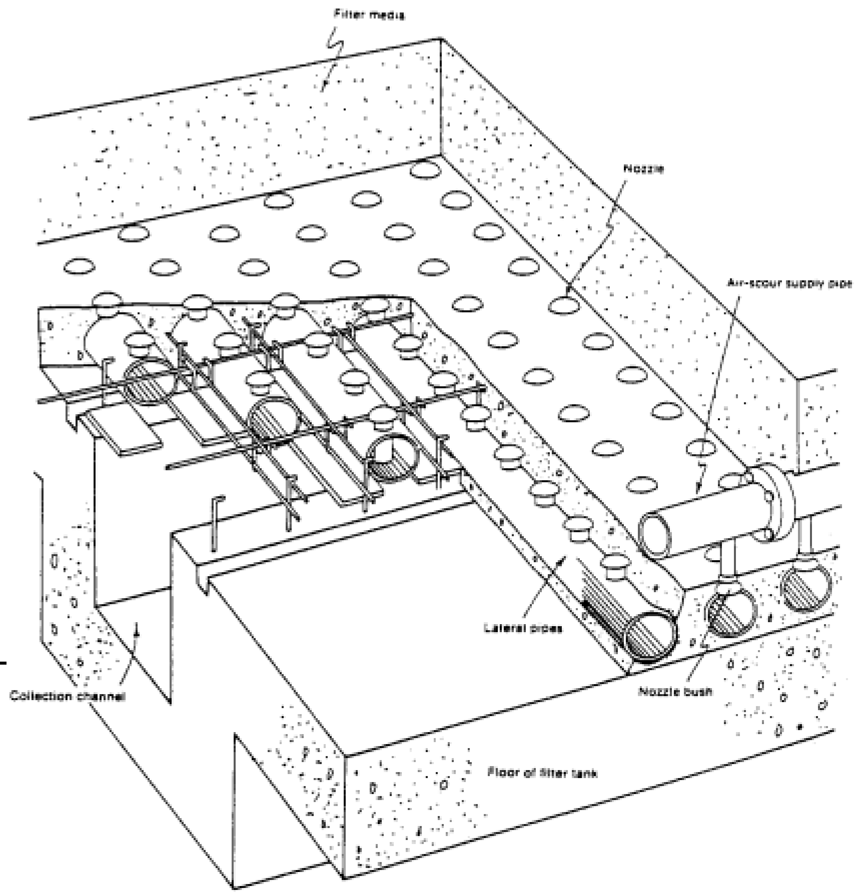


FIGURE 8.11 Pipe lateral underdrain with nozzles. *(Courtesy of Paterson Candy Ltd.)*

Ref: American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

- Total area of orifices (surface area of bed): 0.0015 to 0.005:1
- Cross-sectional area of lateral (total area of orifices served): 2 to 4:1
- Cross-sectional area of manifold (total area of laterals served): 1.5 to 3:1

Underdrain System

Blocks

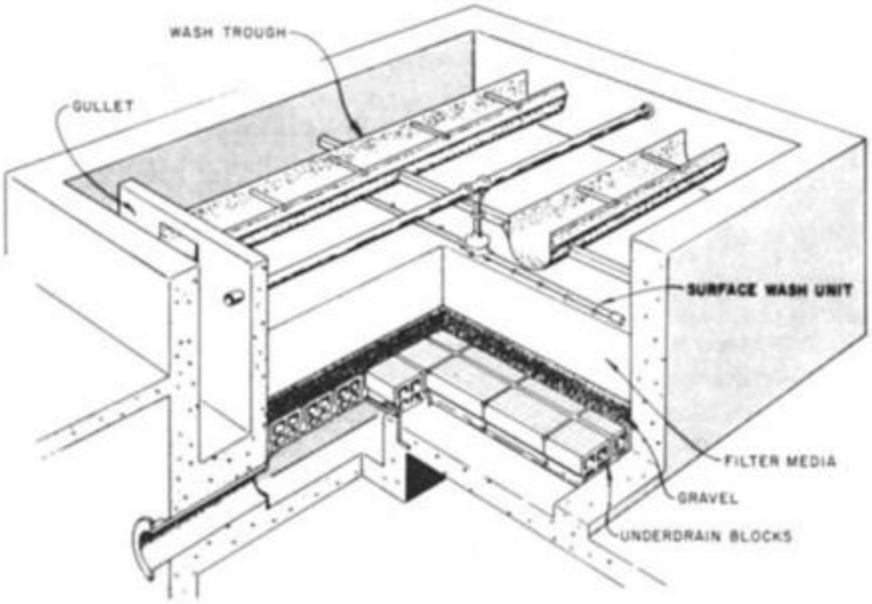


FIGURE 8.12 Typical gravity filter. (*Source: F. B. Leopold Co., Inc.*)

- Vitrified clay blocks are commonly used
- 6 mm dispersion orifices are located at the top of each block
- Support gravel is used

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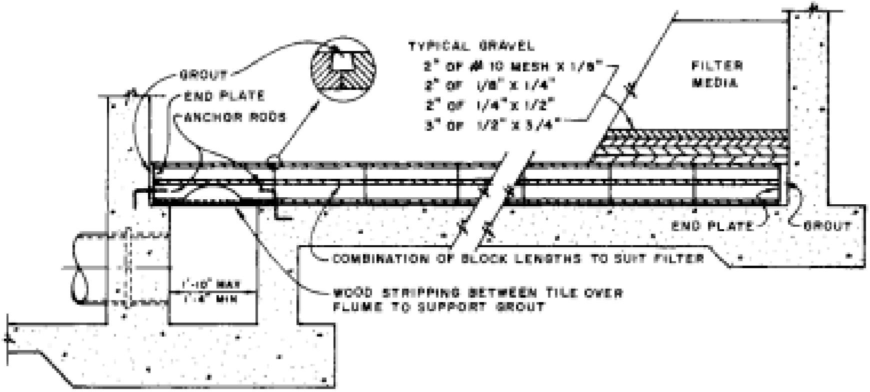
Ref: American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

Underdrain System

Blocks



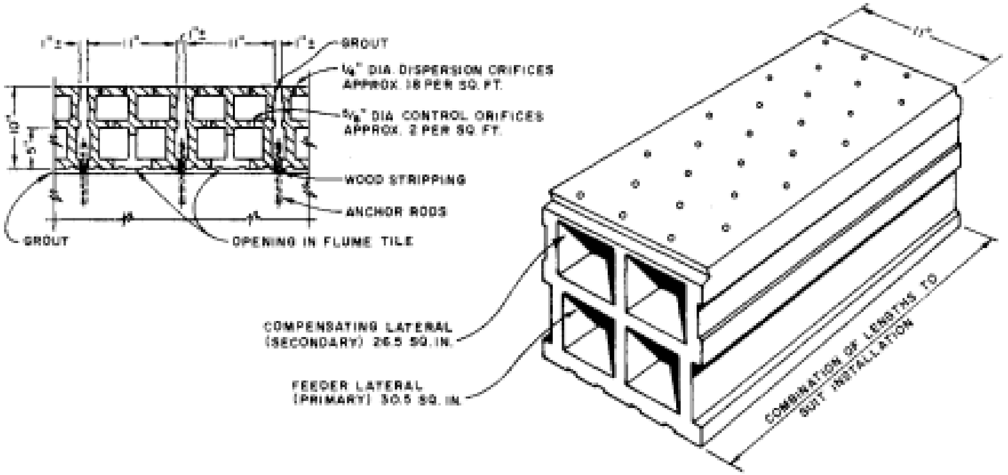


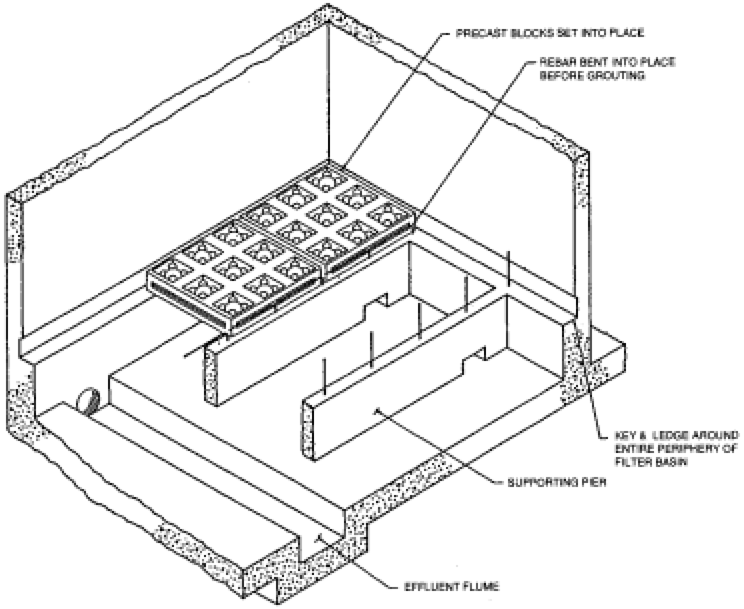
FIGURE 8.14 Plastic block underdrain designed for use with air/water wash. (*Source: F. B. Leopold Co., Inc.*)

Ref: American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

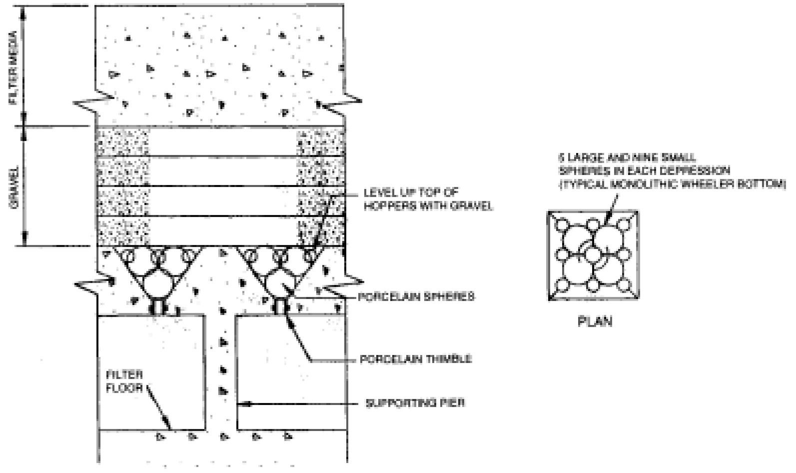
Underdrain System

False Bottoms

- This underdrain system contains uniformly spaced inverted pyramidal depressions
- Unglazed porcelains spheres are placed at the depressions
- Some false bottom underdrain systems have nozzles



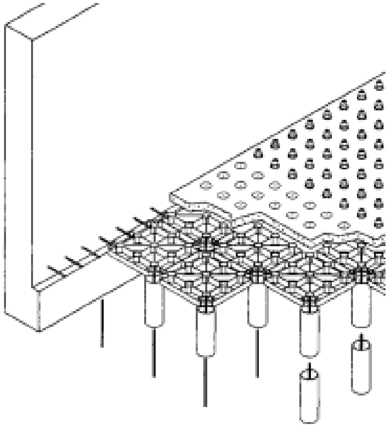
PRECAST WHEELER BOTTOM



ARRANGEMENT OF SPHERES, SAND AND GRAVEL

PLAN

MONOLITHIC WHEELER BOTTOM



Ref: American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

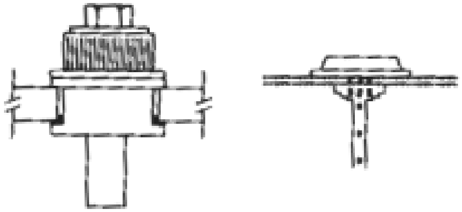
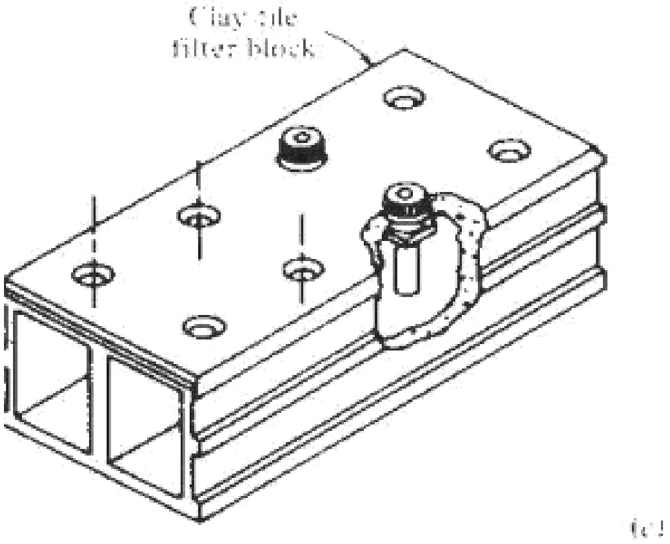
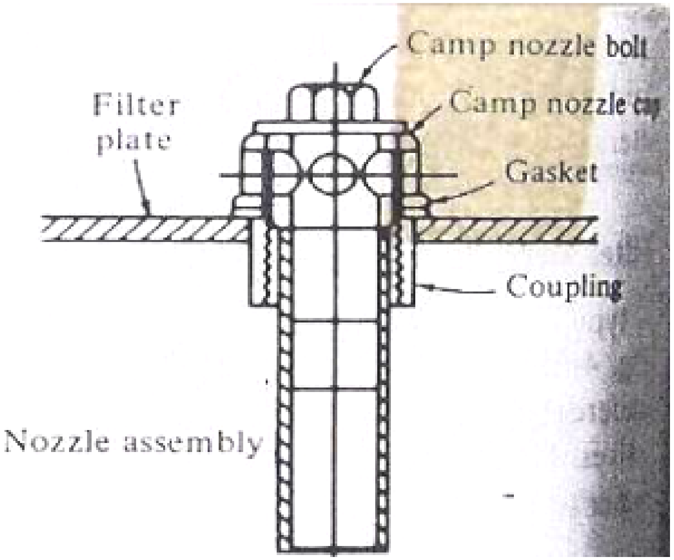


Figure 14.8 Strainers used in false-bottom underdrains without gravel.





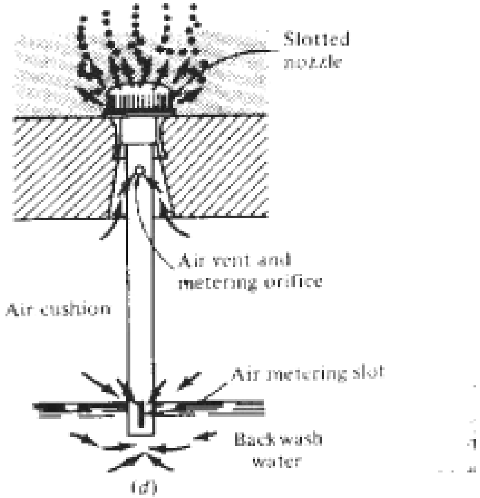


Figure 4-29 Proprietary filter underdrains: (a) BIF, Unit of General Signal Corp.; (b) F.

Lecture notes of Assist. Prof.
Bilge Alpaslan Kocamemi

Lecture notes of Assist. Prof. Bilge Alpaslan Kocamemi

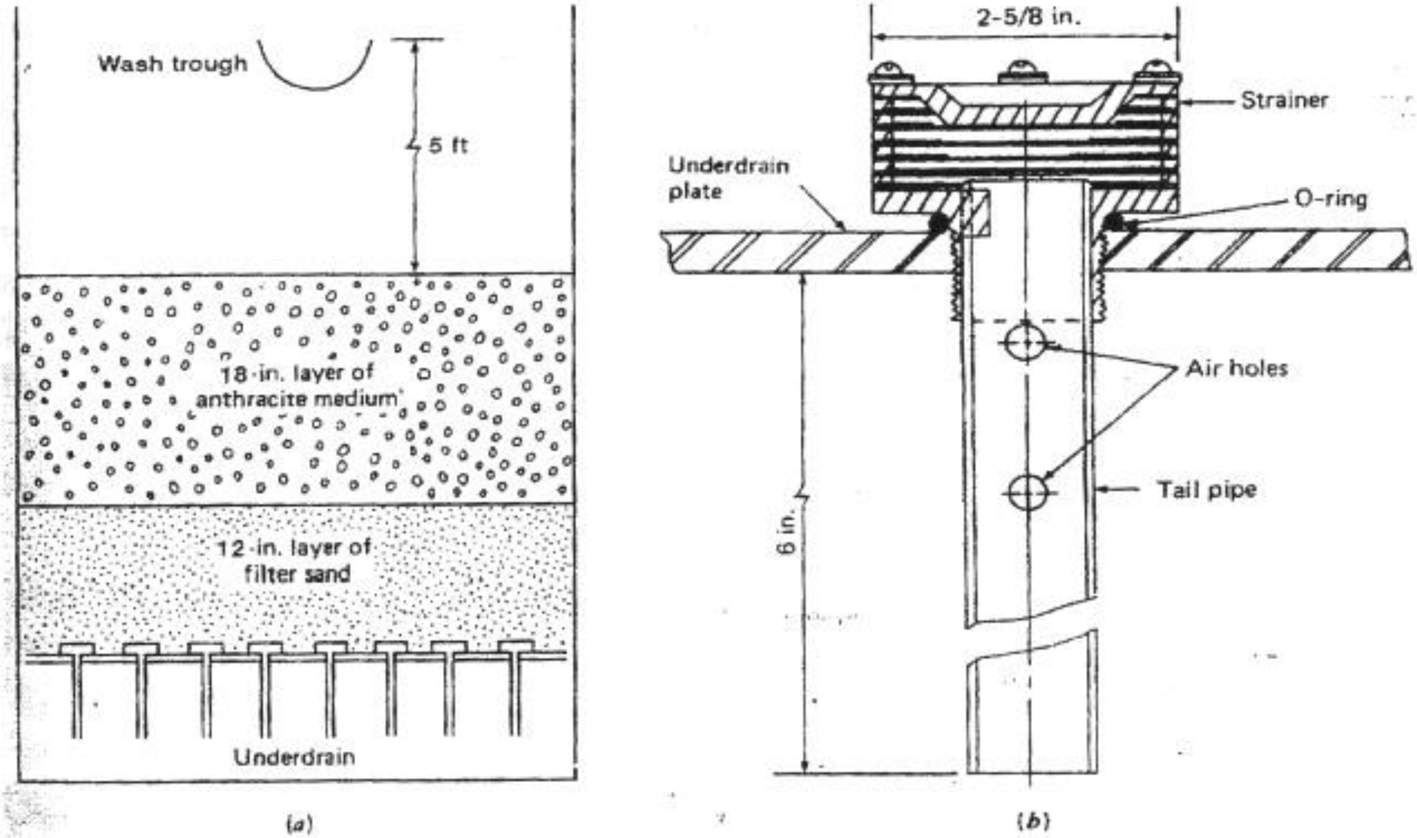
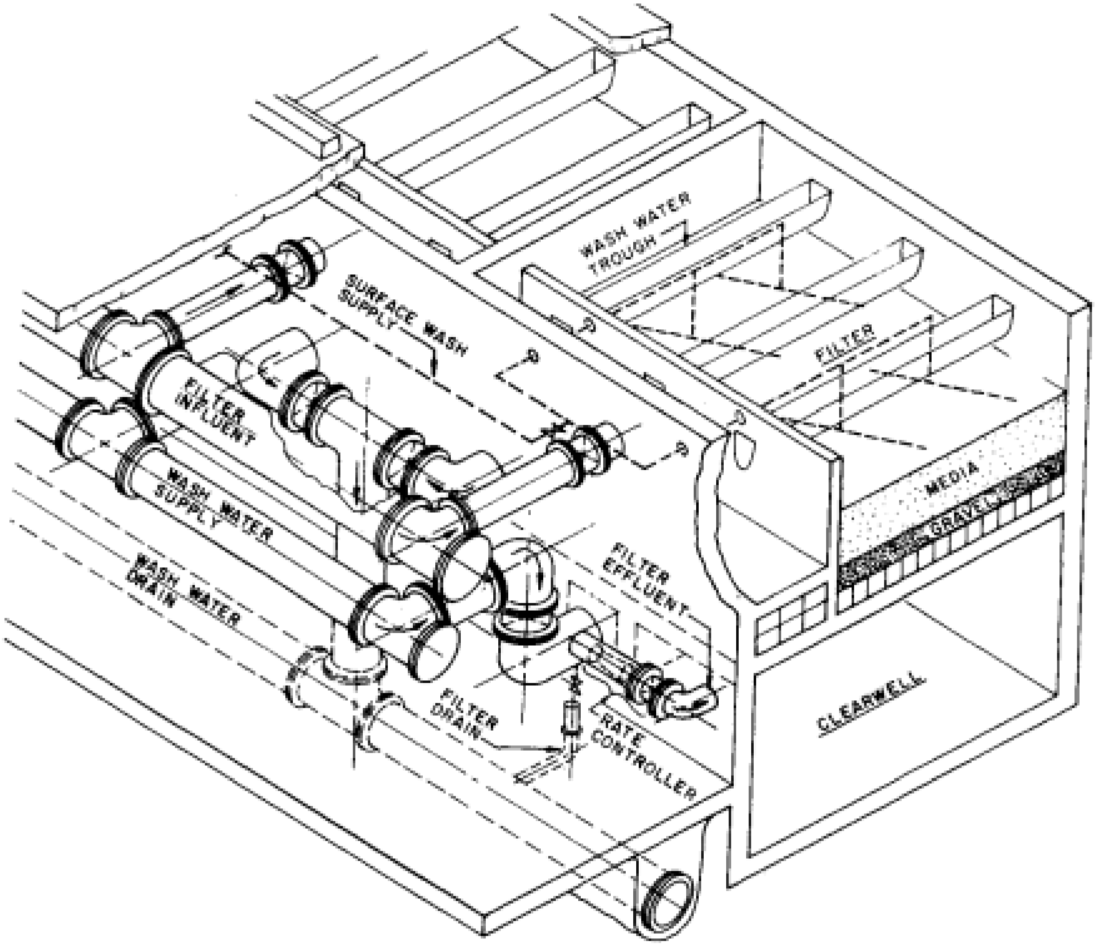


Figure 7-15 Underdrain system for air scouring and water backwashing of a granular-media filter. (*a*) Cross section of the filter. (*b*) Detail of the air-water nozzle. (Courtesy of General Filter Co., Ames, IA.)

Headloss calculation through the underdrain openings

Orifice Equation à Headloss = $C_d V^2/(2g)$ where C_d = discharge coeff. for the orifice

Gravity Filter Piping



FIGU **Ref:** American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

Backwash of Rapid Filters

- In between the filter cycles, filters need to be backwashed to remove deposited suspended material
- Backwashing is required when
  - Headloss across the filter increases
  - Filter water quality deteriotes
  - Maximum time limit has been exceeded

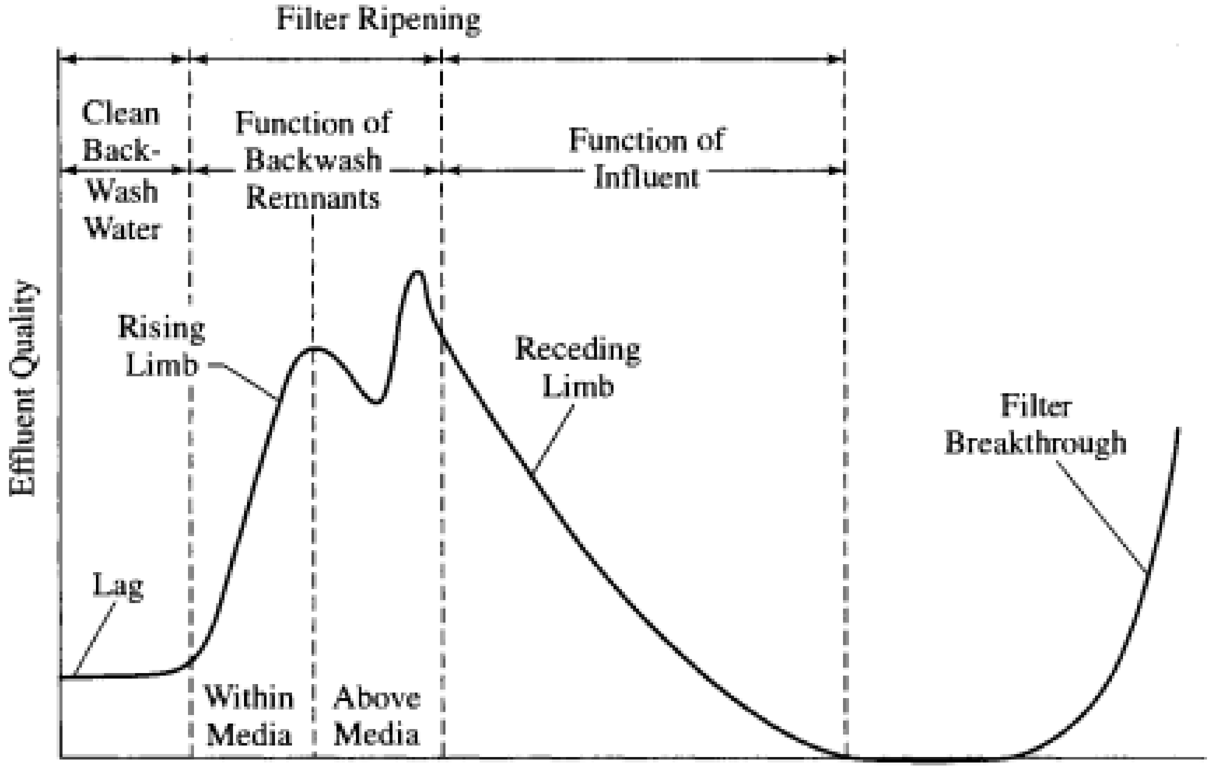


FIGURE 8.21 Characteristics of initial effluent quality. (*Source: Amirtharajah and Wetstein, 1980.*)

Ref: American Water Works Association. Water Treatment Plan Desing 4th ed. McGraw Hill, 1998

Backwash of Rapid Filters

- Backwashing methods
  - Upflow water backwash with full fluidization
  - Surface wash + fluidized bed wash
  - Air scour assisted backwash

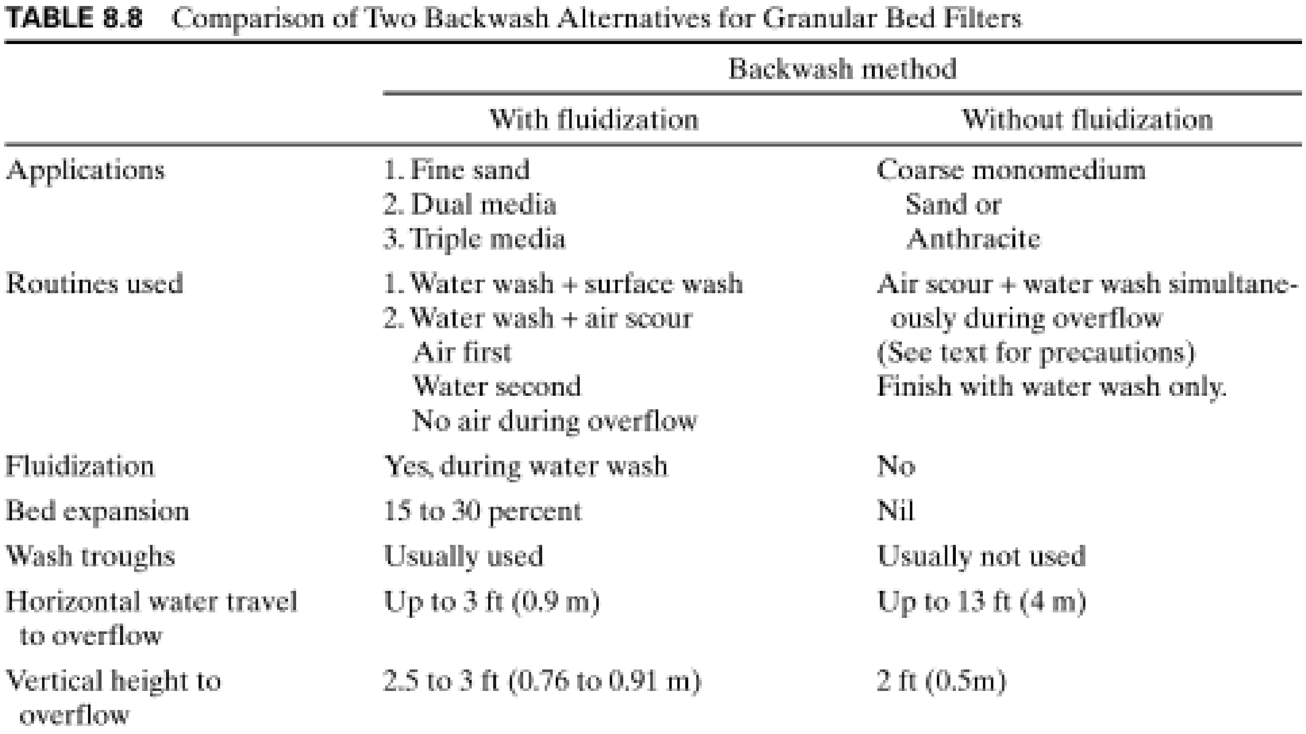


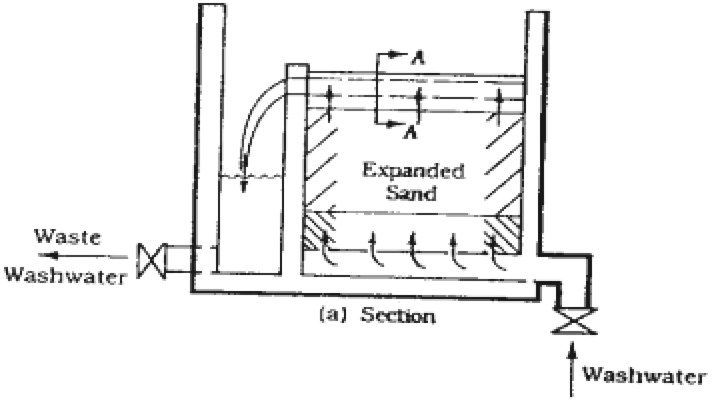
TABLE 8.8 Comparison of Two Backwash Alternatives for Granular Bed Filters

	Backwash method	
	With fluidization	Without fluidization
Applications	1. Fine sand 2. Dual media 3. Triple media	Coarse monomedium Sand or Anthracite
Routines used	1. Water wash + surface wash 2. Water wash + air scour Air first Water second No air during overflow	Air scour + water wash simultaneously during overflow (See text for precautions) Finish with water wash only.
Fluidization	Yes, during water wash	No
Bed expansion	15 to 30 percent	Nil
Wash troughs	Usually used	Usually not used
Horizontal water travel to overflow	Up to 3 ft (0.9 m)	Up to 13 ft (4 m)
Vertical height to overflow	2.5 to 3 ft (0.76 to 0.91 m)	2 ft (0.5m)

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

The amount of water required for backwash

Figure 4.15. Schematic Showing Filter during Backwashing



The washwater may be supplied :

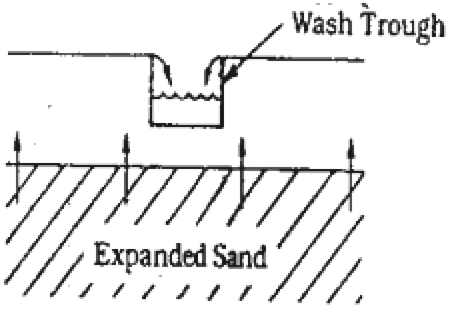
by a pump which pumps directly from clear well
by an elevated storage tank

Volume of washwater = 1 – 5% of water filtered

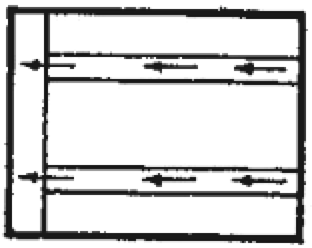
Collection of washwater

Washwater may be collected and removed from the filter by :

a system of troughs and gullets (used extensively in U.S design)
only gullets (used in European design)



Section A-A through Wash Trough



(c) Washwater Flow

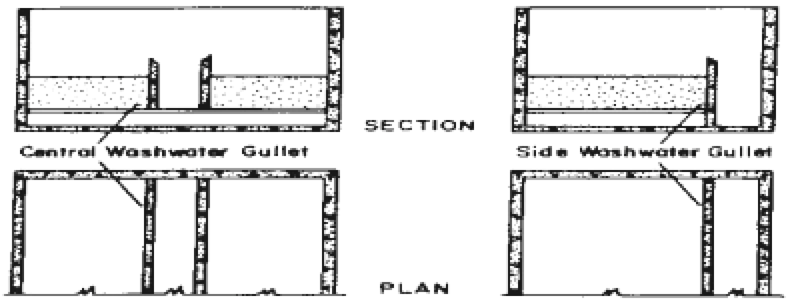


Figure 8.12. Arrangements for washwater gullets. Source: Arboleda, 1973.

Upflow Water Backwash with full fluidization

- Washwater is introduced from the bottom of the bed through the underdrain system
- Backwash water should be turned on gradually over a 30 s time interval to prevent bed disturbance
- Filter medium gradually assumes the fluidized state
- The backwash flow is continued until the waste washwater is reasonable clear (< 10NTU)

Surface wash + fluidized bed wash

- Surface wash has been used extensively
- Jets of water from orifices is injected→ Orifices located 2.5 to 5 cm above the surface of the fixed bed.
- Orifice dia. 2-3 mm
- Surface jets are operated 1 to 2 min before the upflow wash
- Surface wash is terminated 2-3 min before the end of upflow wash

Air scour assisted backwash

- Air scour system supply air to the full filter area from orifices located under the filter medium
- Improves the effectiveness of the backwash system
- If air scour is used during overflow, there is the rish of loosing media
- Air scour system can be used with fine sand, dual media and triple media

Air scour alone before the backwash

- Water level should be lowered to 15 cm below the edge of the backwash overflow
- Air scour alone should be turned on for 1-2 min
- Air scour is turned off
- Waswater is turned-on <u>at a low rate</u> to expel most of the air from the bed before overflow occurs
- Water wash rate is increased to fluidize and restratify the bed, and filter is clean

Simultaneous air scour and backwash

- Lower the water level to just above the surface of the filter medium.
- Turn on air scour for 1 to 2 minutes.
- Add low-rate water wash at below half the minimum fluidization velocity as water level rises.
- Shut off air scour about 15 cm below overflow level while water wash continues. Most air will be expelled before overflow.
- After overflow occurs, increase the water wash rate to fluidize and restratify the bed, and wash until clean.

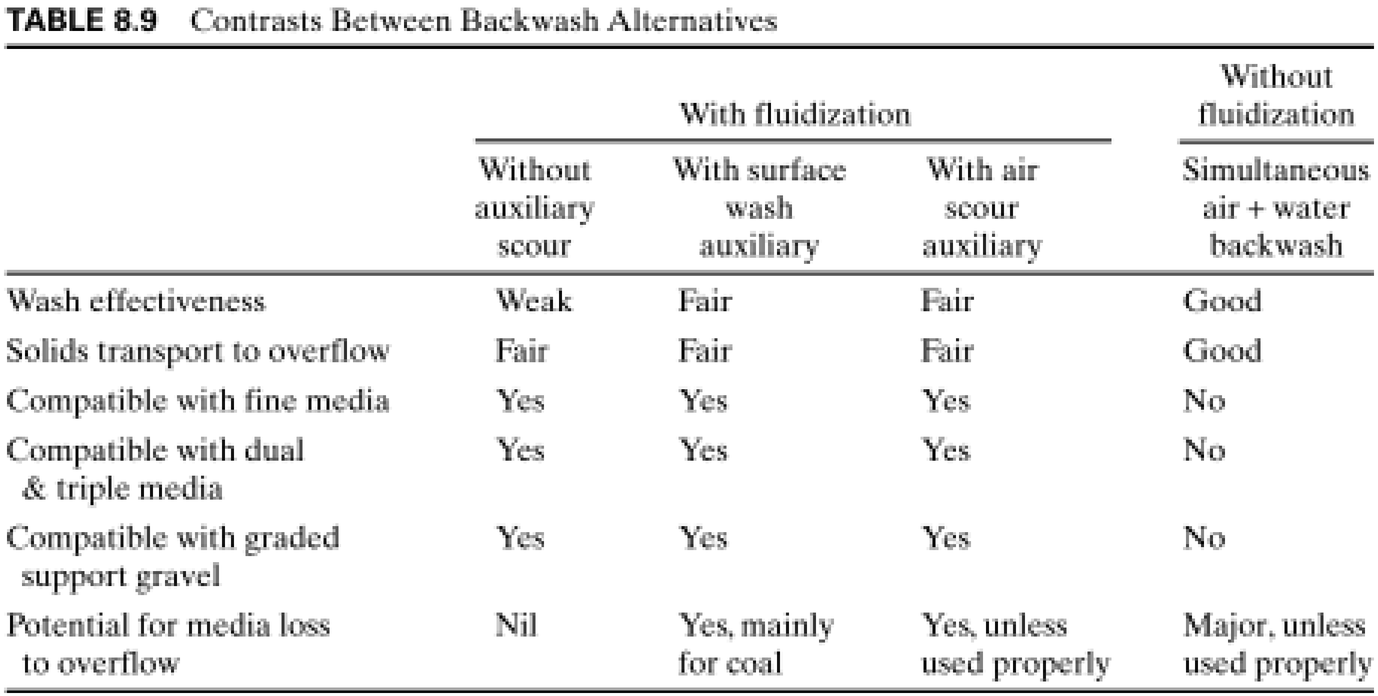


TABLE 8.9 Contrasts Between Backwash Alternatives

	With fluidization			Without fluidization
	Without auxiliary scour	With surface wash auxiliary	With air scour auxiliary	Simultaneous air + water backwash
Wash effectiveness	Weak	Fair	Fair	Good
Solids transport to overflow	Fair	Fair	Fair	Good
Compatible with fine media	Yes	Yes	Yes	No
Compatible with dual & triple media	Yes	Yes	Yes	No
Compatible with graded support gravel	Yes	Yes	Yes	No
Potential for media loss to overflow	Nil	Yes, mainly for coal	Yes, unless used properly	Major, unless used properly

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

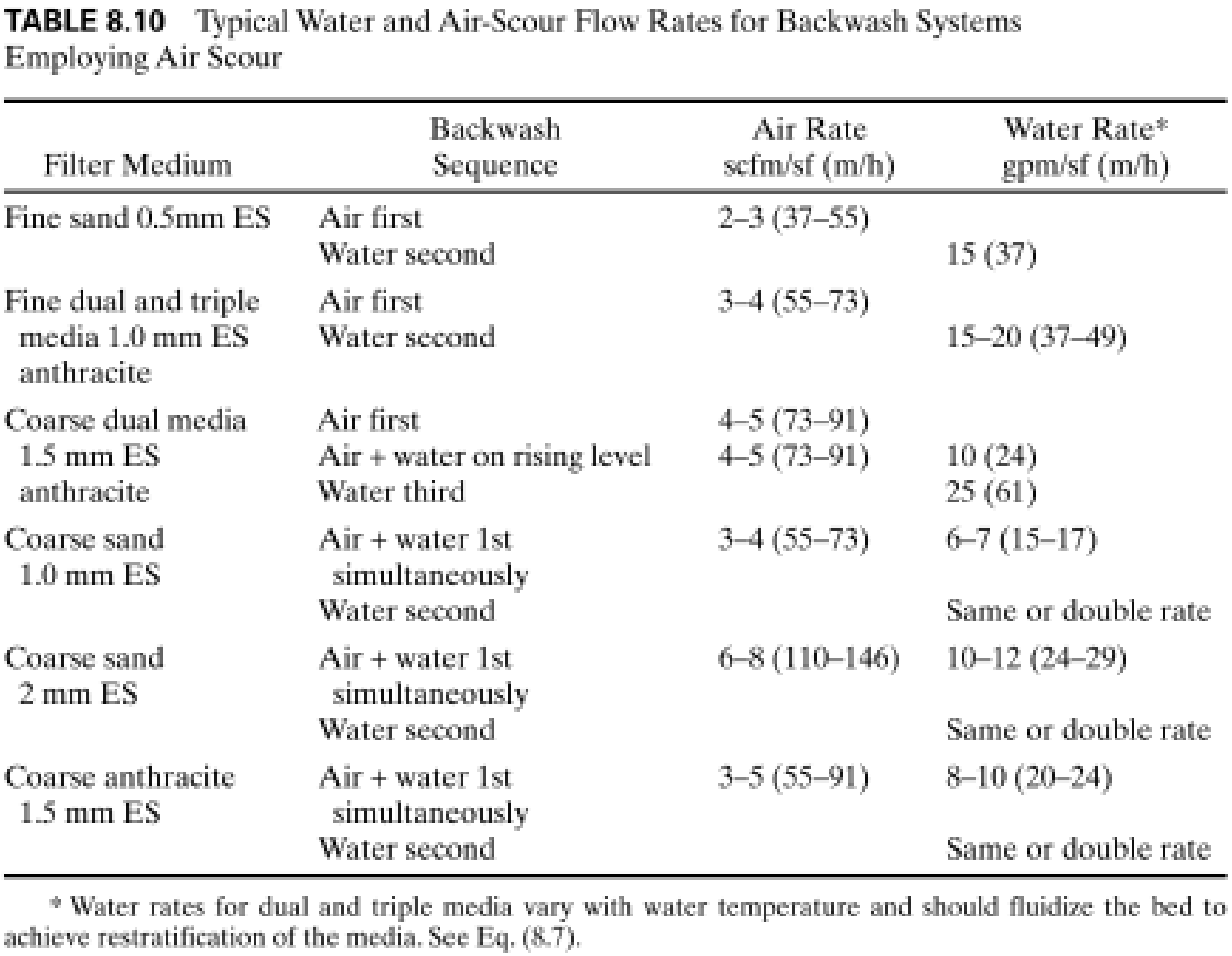


TABLE 8.10 Typical Water and Air-Scour Flow Rates for Backwash Systems Employing Air Scour

Filter Medium	Backwash Sequence	Air Rate scfm/sf (m/h)	Water Rate* gpm/sf (m/h)
Fine sand 0.5mm ES	Air first	2–3 (37–55)	
	Water second		15 (37)
Fine dual and triple media 1.0 mm ES anthracite	Air first	3–4 (55–73)	
	Water second		15–20 (37–49)
Coarse dual media 1.5 mm ES anthracite	Air first	4–5 (73–91)	
	Air + water on rising level	4–5 (73–91)	10 (24)
	Water third		25 (61)
Coarse sand 1.0 mm ES	Air + water 1st simultaneously	3–4 (55–73)	6–7 (15–17)
	Water second		Same or double rate
Coarse sand 2 mm ES	Air + water 1st simultaneously	6–8 (110–146)	10–12 (24–29)
	Water second		Same or double rate
Coarse anthracite 1.5 mm ES	Air + water 1st simultaneously	3–5 (55–91)	8–10 (20–24)
	Water second		Same or double rate

* Water rates for dual and triple media vary with water temperature and should fluidize the bed to achieve restratification of the media. See Eq. (8.7).

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999