Water Treatment

- **Water treatment** describes those industrial-scale processes used to make water more acceptable for a desired end-use.
- These can include use for drinking water, industry, medical and many other uses.

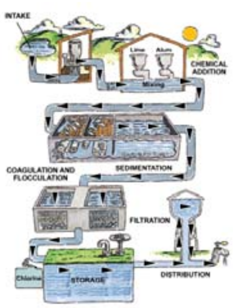
Water Treatment

- The goal of all **water treatment** process is to remove existing contaminants in the water, or reduce the concentration of such contaminants so the water becomes fit for its desired end-use.
- One such use is returning water that has been used back into the natural environment without adverse ecological impact.

Water Treatment

Basis water treatment consists of four processes:

- Coagulation/Flocculation
- Sedimentation
- Filtration
- Disinfection



Water Treatment

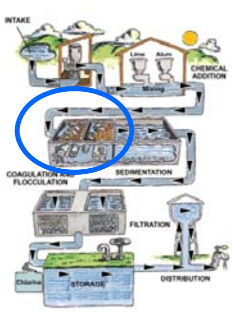
Coagulation

- This process helps removes particles suspended in water.
- Chemicals are added to water to form tiny sticky particles called "floc" which attract the particles.

Water Treatment

Flocculation

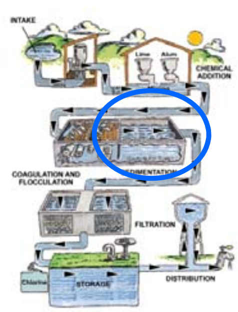
- Flocculation refers to water treatment processes that combine or coagulate small particles into larger particles, which settle out of the water as sediment.



Water Treatment

Sedimentation

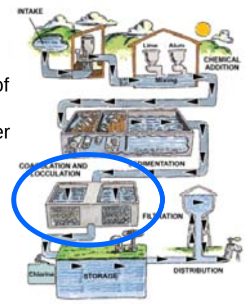
- The heavy particles (floc) settle to the bottom and the clear water moves to filtration.



Water Treatment

Filtration

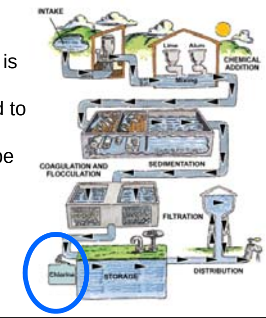
- The water passes through filters, some made of layers of sand, gravel, and charcoal that help remove even smaller particles.



Water Treatment

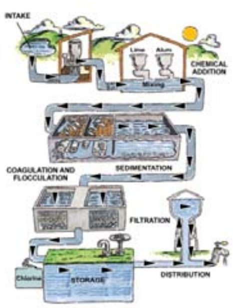
Disinfection

- A small amount of chlorine is added or some other disinfection method is used to kill any bacteria or microorganisms that may be in the water.



Water Treatment

1. **Coagulation**
2. **Flocculation**
3. **Sedimentation**
4. **Filtration**
5. **Disinfection**
6. **Fluoridation**
7. **Stabilization**
8. **Collect and test water samples**



Water Treatment

1. **Coagulation** - Aluminum or iron salts plus chemicals called polymers are mixed with the water to make the particles in the water stick together.
2. **Flocculation** - The coagulated particles are slowly mixed so that they can collide and form larger particles, known as "floc."
3. **Sedimentation** - Water flows through a large tank which allows the "floc" to settle to the bottom of the tank and be removed.
4. **Filtration** - Water is passed through filters made of sand and anthracite coal to filter out remaining particles.

Water Treatment

5. **Disinfection** - Chlorine is added to reduce risks from remaining bacteria and other disease-causing organisms and to maintain water quality through the distribution pipe system.
6. **Fluoridation** - Fluoride is added to provide dental benefits.
7. **Stabilization** - Small amounts of lime (calcium hydroxide) or sodium hydroxide are added to make the water less corrosive to pipes and plumbing.
8. **Collect and test water samples**

Water Filtration

- Filtration is used to separate nonsettleable solids from water and wastewater by passing it through a porous medium
- The most common system is filtration through a layered bed of granular media, usually a coarse anthracite coal underlain by a finer sand.

Water Filtration

Filters may be classified according to the types of media used as follows:

- ***Single-media filters***: These have one type of media, usually sand or crushed anthracite coal.
- ***Dual-media filters***: These have two types of media, usually crushed anthracite coal and sand.
- ***Multi-media filters***: These have three types of media, usually crushed anthracite coal, sand, and garnet.

Water Filtration

Filters may be classified according to the types of media used as follows:

Water Filtration

- In water treatment all three types are used; however, the dual- and multi-media filters are becoming increasingly popular.
- Particle removal is accomplished only when the particles make physical contact with the surface of the filter medium.

Water Filtration

- Filtration was actually developed prior to the discovery of the germ theory by Louis Pasteur in France.
- Louis Pasteur (1822 - 1895) was a French chemist and microbiologist.
- He is remembered for his remarkable breakthroughs in the causes and preventions of diseases.

Water Filtration

- In the 1700s the first water filters for domestic application were applied. These were made of wool, sponge and charcoal.
- In 1804 the first actual municipal water treatment plant designed by Robert Thom, was built in Paisley, Scotland.
- The water treatment was based on slow sand filtration, and horse and cart distributed the water.
- Some three years later, the first water pipes were installed.

Water Filtration

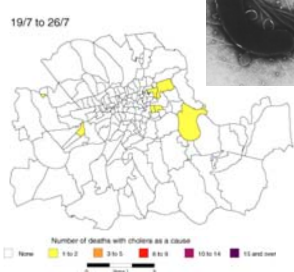
- In 1854 it was discovered that a cholera epidemic spread through water.
- The outbreak seemed less severe in areas where sand filters were installed.
- British scientist John Snow found that the direct cause of the outbreak was water pump contamination by sewage water.
- He applied chlorine to purify the water, and this paved the way for water disinfection.

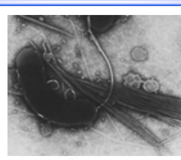
Water Filtration

- John Snow (1813 - 1858) was an English physician and a leader in the adoption of anaesthesia and medical hygiene.
- He is considered to be one of the fathers of epidemiology, because of his work in tracing the source of a cholera outbreak in Soho, England, in 1854.

Water Filtration

Water Filtration



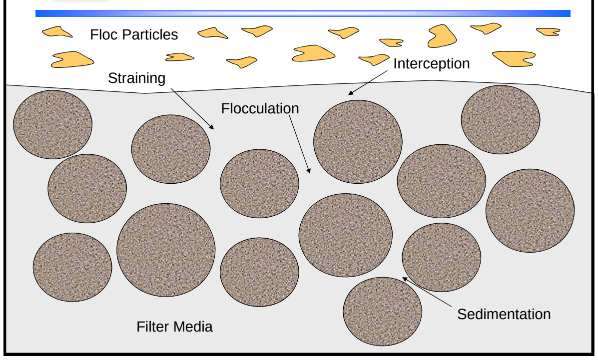


Water Filtration

How does filtration work?

Let's examine the physical and chemical mechanisms of filtration

Water Filtration



Water Filtration

- Larger particles may be removed by straining
- Particles may also be removed by sedimentation
- Others may be intercepted by and adhere to the surface of the medium due to inertia
- Filtration efficiency is greatly increased by destabilization or coagulation of the particles prior to filtration

Water Filtration

Gravity Granular-Media Filtration

- Gravity filtration through beds of granular media is the most common method removing colloidal impurities in water processing
- Initially, surface straining and interstitial removal results in accumulation of deposits in the upper portion of the filter media

Water Filtration

Gravity Granular-Media Filtration

- Because of the reduction in pore area, the velocity of water through the remaining voids increases, shearing off pieces of capture floc and carrying impurities deeper into the filter bed
- The effective zone of removal passes deeper and deeper into the filter

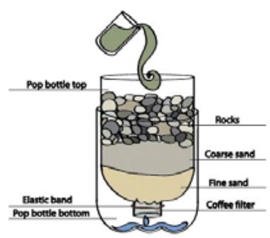
Water Filtration

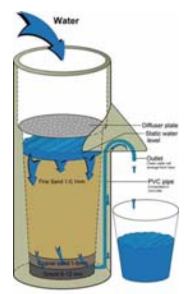
Gravity Granular-Media Filtration

- Eventually, clean bed depth is no longer available and breakthrough occurs, carrying solids out in the underflow and causing termination of the filter run

Water Filtration

Gravity Granular-Media Filtration





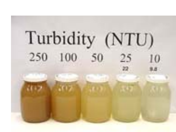
Water Filtration

Turbidity

- Turbidity is a measurement of the clarity of water run
- Clouded water is caused by suspended particles scattering or absorbing the light
- Turbidity is an indirect measurement of the amount of suspended matter in the water

Water Filtration

Turbidity



Water Filtration

Turbidity

- However, since solids of different sizes, shapes, and surfaces reflect light differently, turbidity and suspended solids do not correlate well.
- Turbidity is normally gauged with an instrument that measures the amount of light scattered at an angle of 90° from a source beam.
- The units of turbidity are usually in Nephelometric Turbidity Units (NTU).

Water Filtration

Slow Sand Filtration

- The early filtration units developed in Great Britain used a process in which the hydraulic loading rate is relatively low.
- Typical slow sand filtration velocities are only about 0.4 m/hr.
- At these low rates, the filtered contaminants do not penetrate to an appreciable depth within the filtration medium.

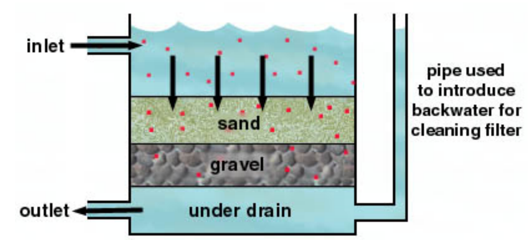
Water Filtration

Slow Sand Filtration

- The filter builds up a layer of filtered contaminants on the surface, which becomes the active filtering medium
- Slow sand filters are cleaned by taking them off line and draining them. The organic or contaminant layer is then scraped off.
- The filter can then be restarted. After water quality reaches an acceptable level, the filter can then be put back on line.

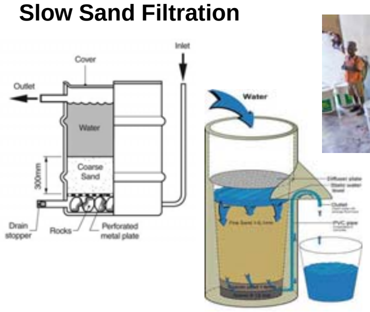
Water Filtration

Slow Sand Filtration



Water Filtration

Slow Sand Filtration



Water Filtration

Rapid Sand Filtration

- In rapid sand filtration much higher application velocities are used
- Filtration occurs through the depth of the filter
- A comparison of rapid and slow sand filtration is shown in the table below

Filtration Type	Application Rate	
	m/hr	gal/ft^2-day
Slow Sand	0.04 to 0.4	340 to 3400
Rapid Sand	0.4 to 3.1	3400 to 26,000

Water Filtration

Rapid Sand Filtration

- In the United States, filter application rates are often expressed as volumetric flowrate per area, or gal/min-ft^2, which is actually a velocity with atypical units.

Filtration Type	Application Rate	
	m/hr	gal/ft^2-day
Slow Sand	0.04 to 0.4	340 to 3400
Rapid Sand	0.4 to 3.1	3400 to 26,000

Water Filtration

Hydraulic Loading Rate

Let's compute the hydraulic loading rate on our filters in lab:

Flowrate: 1,000 ml/min

Area of filter: 3.5 in. diameter filter

$$Loading\ Rate = \frac{Flowrate}{Area}$$

$$= \frac{1{,}000\,{}^{ml}\!/\!_{min}}{\frac{\pi(3.5\text{in.})^2}{4}} \times \frac{1 gallon}{3{,}785\,\text{ml}} \times \frac{144\text{in.}^2}{\text{ft.}^2} = \boxed{3.954\,{}^{gpm}\!/\!_{ft^2}}$$

Water Filtration

Hydraulic Loading Rate

Let's compute the hydraulic loading rate on our filters in lab:

Flowrate: The one you used in lab last week.

Area of filter: 3.5 in. diameter filter

$$Loading\ Rate = \frac{Flowrate}{Area}$$

$$= \frac{Flowrate\,{}^{ml}\!/\!_{min}}{\frac{\pi(3.5\text{in.})^2}{4}} \times \frac{1 gallon}{3{,}785\,\text{ml}} \times \frac{144\text{in.}^2}{\text{ft.}^2}$$

Water Filtration

Hydraulic Loading Rate

Let's compute the hydraulic loading rate on our filters in lab:

Flowrate (ml/min)	Loading Rate (gpm/ft^2)
1,000	3.954
1,250	4.943
1,500	5.932

Water Filtration

Hydraulic Loading Rate

A hydraulic loading rate of 3.954 gpm/ft.^{2} could be classified as:

1. A high-end direct filtration (1-6 gpm/ft.^{2})
2. A mid-range rapid filter (range of 2-10 gpm/ft.^{2} with 5 gpm/ft.^{2} normally the maximum design rate)

Water Filtration

Hydraulic Loading Rate

To convert the hydraulic loading rate to the U.S. standard of gpd/ft.^{2}, convert minutes to days

$$Loading\ Rate = \frac{Flowrate}{Area}$$

$$= 3.954\,\frac{\text{gpm}}{\text{ft.}^2} \times 60\,{}^{min}\!/\!_{hr} \times 24\,{}^{hr}\!/\!_{day}$$

$$= \boxed{5{,}694\,{}^{gpd}\!/\!_{ft.^2}}$$

Water Filtration

Hydraulic Loading Rate

A hydraulic loading rate of 5,694 gpd/ft.^{2} could be qualifies as a rapid sand filter

Filtration Type	Application Rate	
	m/hr	gal/ft^2-day
Slow Sand	0.04 to 0.4	340 to 3,400
Rapid Sand	0.4 to 3.1	3,400 to 26,000

Water Filtration

Hydraulic Loading Rate

Let's compute the hydraulic loading rate for flowrates in class:

Flowrate: 1,250 and 1,500 ml/min

Area of filter: 3.5 in. diameter filter

$$Loading\ Rate = \frac{Flowrate}{Area}$$

$$= \frac{Flowrate\left(\frac{ml}{min}\right)}{\frac{\pi(3.5\,in.)^2}{4}} \times \frac{1\,gallon}{3{,}785\,ml} \times \frac{144\,in.^2}{ft.^2}$$

Water Filtration

Hydraulic Loading Rate

Let's compute the hydraulic loading rate for flowrates in class:

Flowrate: 1,250 and 1,500 ml/min

Area of filter: 3.5 in. diameter filter

Flowrate of 1,250 ml/min ➔ 4.943 gpm/ft.^{2}

Flowrate of 1,500 ml/min ➔ 5.932 gpm/ft.^{2}

Water Filtration

Hydraulic Loading Rate

To convert the hydraulic loading rate to the U.S. standard of gpd/ft.^{2}, convert minutes to days

$$Loading\ Rate = \frac{Flowrate}{Area}$$

$$= 4.943\,\frac{gpm}{ft.^2} \times 60\,\frac{min}{hr} \times 24\,\frac{hr}{day}$$

$$= \boxed{7{,}118\,\frac{gpd}{ft.^2}}$$

Water Filtration

Hydraulic Loading Rate

Let's compute the hydraulic loading rate for flowrates in class:

Flowrate: 1,250 and 1,500 ml/min

Area of filter: 3.5 in. diameter filter

Flowrate of 1,250 ml/min ➔ 7,118 gpd/ft.^{2}

Flowrate of 1,500 ml/min ➔ 8,541 gpd/ft.^{2}

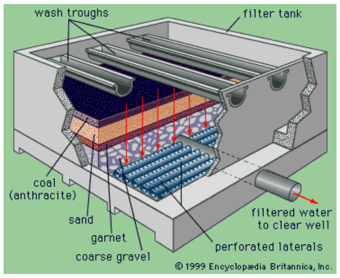
Water Filtration

Rapid Sand Filtration

- The water above the filter provides the hydraulic pressure (head) for the process.
- The filter medium is above a larger gravel, rock, or other media for support.
- Below the rock is usually an underdrain support of some type.
- The water flows through the filter and support media, exiting from a pipe below.

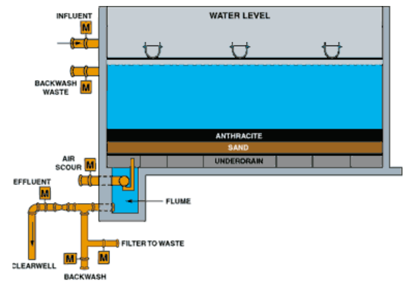
Water Filtration

Rapid Sand Filtration



Water Filtration

Rapid Sand Filtration



Water Filtration

Rapid Sand Filtration

- Most modern filters employ two separate filter media in layers:
  - The lower layer is composed of a dense, fine media, often sand
  - The upper layer is composed of a less dense, coarse media, often anthracite coal
- The coarse upper layer removes larger particles before they reach the fine layer, allowing the filter to operate for a longer period before clogging.

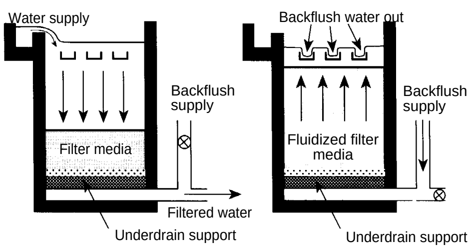
Water Filtration

Rapid Sand Filtration

- As the filter begins to clog from accumulated solids, less water will pass through it. At some point cleaning is required.
- Usual filter operation before cleaning is from a few hours to 2 days.
- Cleaning is accomplished by reversing the flow of water to the filter, or backwashing.

Water Filtration

Rapid Sand Filtration



Operation during filtration

Operation during cleaning

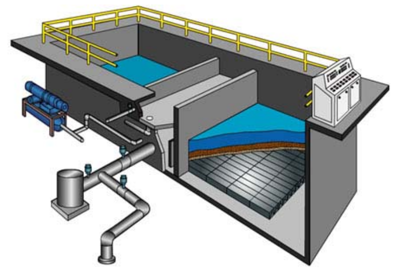
Water Filtration

Rapid Sand Filtration

- The backwash velocity is sufficient to fluidize the bed - that is, to suspend the bed with the reverse flow.
- After backwashing, the filter is again placed in operation

Water Filtration

Water Filtration



http://www.fbleopold.com/flash/media.swf

Water Filtration

Backwash Velocity

The backwash velocity may be estimated using the following equation

$$v = v_s \alpha_e^{4.5}$$

where v is the backwash velocity (ft./s)

v_s is the settling velocity of the filter media (ft./s)

α_e is the porosity of the expanded filter

Water Filtration

Backwash Velocity

Once the backwash velocity has been estimated, the depth of the expanded filter bed may be computed

$$L_e = \frac{L(1-\alpha)}{1-\left(\frac{v}{v_s}\right)^{0.22}}$$

where L is depth of the filter media (ft.)

L_e is depth of the expanded filter media (ft.)

α is the porosity of the filter media

Water Filtration

Backwash Velocity Example

Determine the required backwash velocity to expand the sand filters in lab to a porosity of 0.70.

Also, determine the depth of the expanded filter bed.

Assume the following data about our lab filters:

1. Depth of sand bed 0.5 ft.
2. Sand with a particle diameter of 0.5 mm or 0.02 in. with a settling velocity of 0.27 ft./s
3. Sand porosity is 0.35

Water Filtration

Backwash Velocity Example

The backwash velocity may be estimated using the following equation

$$v = v_s \alpha_e^{4.5}$$

$$= \left(0.27\ \text{ft.}/\text{s}\right)(0.70)^{4.5}$$

$$= \boxed{0.054\ \text{ft.}/\text{s}}$$

Water Filtration

Backwash Velocity Example

Determine the hydraulic loading rate of the backwash

$$Velocity = 0.054\,\text{ft.}/\text{s} = 0.054\,\text{ft.}^3/\text{ft.}^2\text{s}$$

$$= 0.054\,\text{ft.}^3/\text{ft.}^2\text{s} \times \frac{7.48\,\text{gallons}}{\text{ft.}^3} \times \frac{86{,}400\,\text{s}}{\text{day}}$$

$$= \boxed{34{,}900\,\text{gpd}/\text{ft.}^2}$$

The backwash loading rate is about 7 times larger than the filter loading rate

Water Filtration

Backwash Velocity Example

Once the backwash velocity has been estimated, the depth of the expanded filter bed may be computed

$$L_e = \frac{L(1-\alpha)}{1-\left(\frac{v}{v_s}\right)^{0.22}}$$

$$= \frac{0.5\text{ft.}(1\text{-}0.35)}{1\text{-}\left(\frac{0.054\,\text{ft.}/\text{s}}{0.27\,\text{ft.}/\text{s}}\right)^{0.22}} = \boxed{1.09\text{ ft.}}$$

Water Filtration

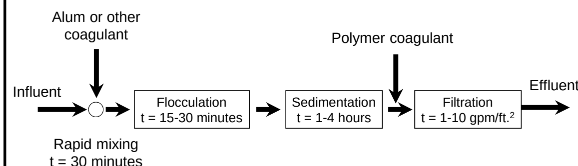
Backwash Velocity Group Problems

Switch presentations

Water Filtration

Traditional Filtration

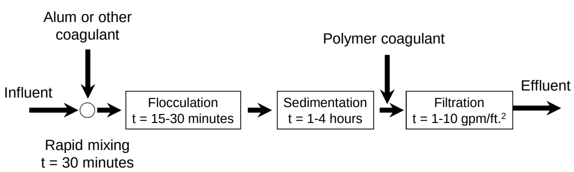
A typical scheme for water filtration consists of flocculation with a chemical coagulant and sedimentation prior to filtration.



Water Filtration

Traditional Filtration

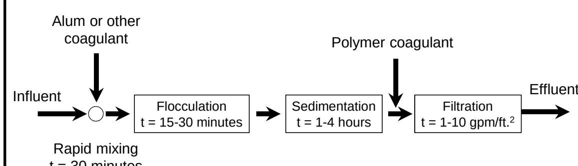
Under the force of gravity water passes downward through the media that collect the floc and particles.



Water Filtration

Traditional Filtration

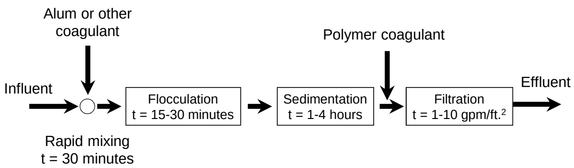
When the media become filled or solids break through, a filter bed is cleaned by backwashing.



Water Filtration

Traditional Filtration

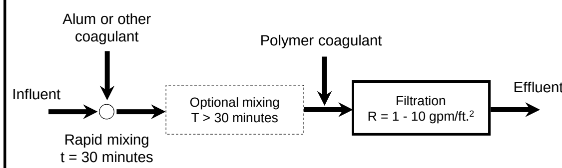
Filtration rates following flocculation and sedimentation are in the range of 2-10 gpm/ft.^{2} with 5 gpm/ft.^{2} normally the maximum design rate.



Water Filtration

Direct Filtration

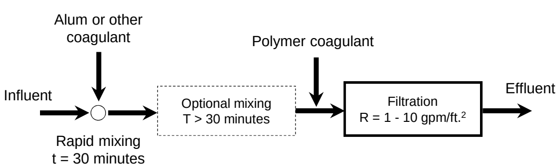
The process of direct filtration does not include sedimentation prior to filtration.



Water Filtration

Direct Filtration

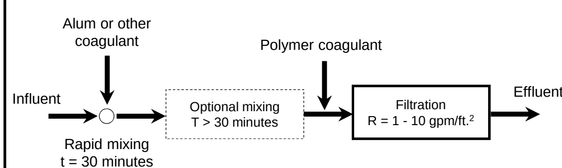
The impurities removed from the water are collected and stored in the filter.



Water Filtration

Direct Filtration

Contact flocculation of the chemically coagulated particles in the water takes place in the granular media.



Water Filtration

Direct Filtration

Successful advances in direct filtration are attributed to:

- Development of coarse-to-fine multimedia filters
- Improved backwashing systems, and
- Availability of better polymer coagulants

Filtration rates in direct filtration are usually 1-6 gpm/ft.^{2}

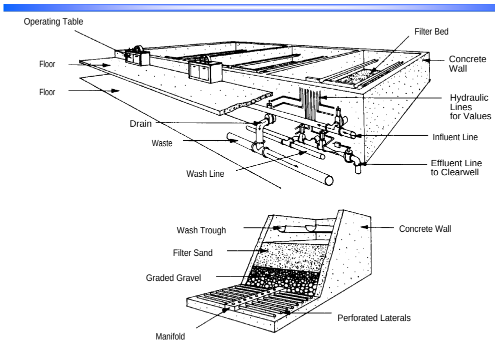
Water Filtration

Description of a Typical Gravity Filter System

During filtration, the water enters above the filter media through an inlet flume.

After passing downward through the granular media and the supporting gravel bed, it is collected in the underdrain system

Water Filtration



Water Filtration

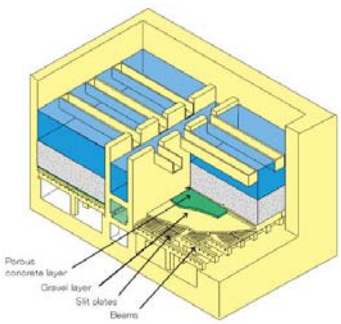
Description of a Typical Gravity Filter System

During backwashing, wash water passing upward through the filter carries out the impurities that accumulated in the media

The flow is directed upward, hydraulically expanding the filter media

The water is collected in the wash-water troughs that discharge to the outlet flume

Water Filtration



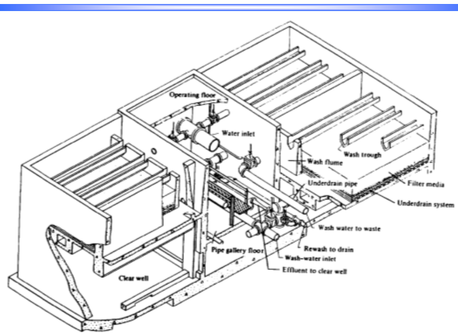
Water Filtration

Description of a Typical Gravity Filter System

The filters are placed on both sides of a pipe gallery that contains inlet and outlet piping, wash-water inlet lines, and wash-water drains.

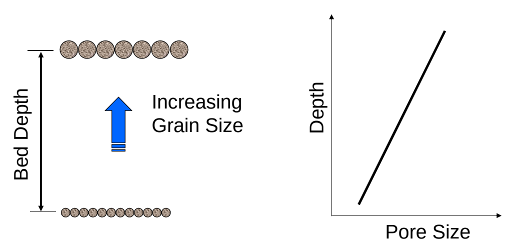
A clear well for storage of filtered water is located under a portion of the filter bed area

Water Filtration



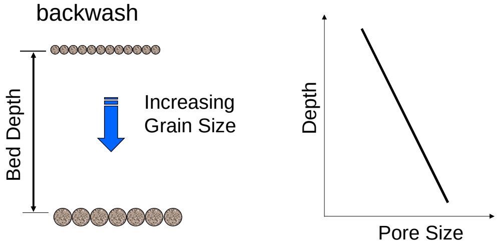
Water Filtration

Filter Media - Ideal Filter



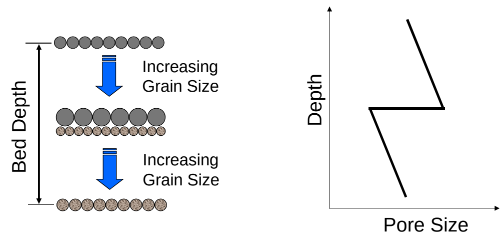
Water Filtration

Filter Media - Single Medium Filter after backwash



Water Filtration

Filter Media - Dual-Medium Filter



Water Filtration

Filter Media

Broadly speaking, filter media should possess the following qualities:

1. Coarse enough to retain large quantities of floc,
2. Sufficiently fine particles to prevent passage of suspended solids,
3. Deep enough to allow relatively long filter runs, and
4. Graded to permit backwash cleaning.

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Filter Media

These attributes are ***not* compatible**. For example:

1. Fine sand retains floc and tends to shorten the filter run
2. For a course sand the opposite would be true

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Filter Media

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})

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Filter Media

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

Water Filtration

Multimedia Filters

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.

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Multimedia Filters

The main advantages of multimedia filters compared to single-medium filters are:

1. Longer filtration runs,
2. Higher filtration rates, and
3. The ability to filter a water with higher turbidity

Water Filtration

Multimedia Filters

The advantages of the multimedia filters are due to:

1. The media particle size,
2. The different specific gravities of the media, and
3. The media gradation.

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Any Questions?