Water Treatment

Session Objectives

- To demonstrate the need for treatment of surface waters and some groundwaters for drinking purposes.
- To introduce the concept of the multiple barrier principle and to describe the more common and important key processes.
- To describe the function of each treatment process in treating drinking-water.
- To provide a basic outline on the selection of technology.
- The discuss the assessment of water treatment plants.

Water Treatment

Introduction

All surface water and some groundwaters require treatment prior to consumption to ensure that they do not represent a health risk to the user. Health risks to consumers from poor quality water can be due to microbiological, chemical, physical or radioactive contamination.

However, microbiological contamination is generally the most important to human health as this leads to infectious diseases which affect all populations groups, many of which may cause epidemics and can be fatal. Chemical contamination, with the exception of a few substances such as cyanide and nitrate, tends to represent a more long-term health risk. An example of this is nitrate which can cause methaemoglobinaemenia in babies. Substances in water which affect the clarity, colour or taste of water may make water objectionable to consumers and hence ability to recover costs. As many microorganisms are found associated with particles in water, physical contamination may also represent a health risk as it extends microbial survival.

Most treatment systems are designed to remove microbiological contamination and those physical constituents which affect the acceptability or promote microorganism survival - largely related to the suspended solids in the water. A disinfectant is nearly always included in treatment plants of any size. This is done for two main reasons: firstly it is added to inactivate any remaining bacteria as the final unit of treatment; and, more importantly, to provide a residual disinfectant which will kill any bacteria introduced during storage and/or distribution.

The multiple barrier principle

Treatment processes usually function either through the physical removal of contaminants through filtration, settling (often aided by some form of chemical addition) or biological removal of microorganisms. It is usual for treatment to be in a number of stages, with initial pre-treatment by settling or pre-filtration through coarse media, sand filtration (rapid or slow) followed by chlorination. This is called the **multiple barrier principle.**

This is an important concept as it provides the basis of comprehensive treatment of water and provides a system to prevent complete treatment failure due to a breakdown of a single process. For instance, with a system which comprises addition of coagulation-flocculation-settling, followed by rapid sand filtration with terminal disinfection, failure of the rapid sand filter does not mean that untreated water will be supplied. The coagulation-flocculation-settling process will remove a great deal of the suspended particles, and therefore many of the microorganisms in the water, and the terminal disinfection will remove many of the remainder. Provided the rapid sand filter is repaired reasonable quickly, there should be little decrease in water quality.

A key element in the multiple barrier principle is to ensure that the source of water is protected and maintained at as high a quality as possible. This is sometimes easier for groundwater sources on a local scale, although there are obvious difficulties for both ground and surface water on a larger scale.

Treatment processes - advantages and disadvantages

There are many different treatment process available and whose suitability is a function of the source water quality, level of operator training and resources available for operation and maintenance. It is imperative that the selection of technology for treatment plants is done taking the above into consideration to ensure that they remain sustainable.

Prefiltration

As many secondary filtration processes, and in particular slow sand filtration, require low influent turbidities, some form of pretreatment to reduce suspended solids load is required. One way to achieve this is by using prefiltration of water through coarse media, usually gravel or coarse sand. Prefilters can have many different configurations: horizontal; vertical upflow; and vertical upflow-downflow. Vertical prefilters have become increasingly popular as they require far less land than horizontal prefilters and can take faster flow runs through them. An alternative are pressure filters, through which water is pumped at pressure to remove the suspended solids load.

Prefilters have an advantage in that they do not require chemicals, have limited working parts and are robust. They do however, require frequent cleaning and maintenance and are ineffective in removing fine particles, thus where the suspended solid load is primarily made up of silt and clay particles prefiltration is ineffective. Prefiltration is a physical process designed to remove suspended solids and therefore it's efficiency in removal of microorganisms is a function of the microbes associated with particles. Virus removal is poor and prefiltration is not effective in the removal of cysts or bacteria associated with fine particles.

Sedimentation

Sedimentation is the removal of suspended solids through the settling of particles moving through a tank at a slow rate. There are a number of forms of sedimentation. In water treatment plants treating source water a high proportion of suspended solids of coarser grades (e.g. sand and coarse silt) a grit chamber may be used to remove the largest particles through simple sedimentation. In this process, water is passed through a tank at a slow rate and suspended solids fall out of suspension. In small supplies, simple sedimentors may also be used, which functioning in a similar fashion to grit chambers, although with a slower rate of water throughflow. Simple sedimentation will not remove fine grained particles because the flow rates remain too high and the retention time is insufficient. A further common fault with simple sedimenters is that design flow rates are rarely achieved in practice and a certain element of ‘short-circuiting’ can occur unless construction, operation and maintenance is very careful.

As a result of the drawbacks in simple sedimentation, it is common to find that the sedimentation process is enhanced through the addition of chemicals - or coagulation. Coagulants carry a charge and therefore attract charged clay particles. The particles begin to aggregate and form ‘flocs’. Once the flocs reach a critical mass, they sink to the bottom of the settler. The outlet of the sedimenter is generally around the top of the structure, thus the clear water is removed by a surface channel. This system can be further refined with the use of modular or plate settlers which reduces the time require for settling by providing a wider surface area for aggregation of particles.

The most commonly used coagulants is aluminium sulphate, although there are other coagulants available including ferric salts (sulphates and chlorides) and polyelectrolytes. Coagulants are dosed in solution at a rate determined by raw water quality near the inlet of a mixing tank or flocculator. It is essential that the coagulant is rapidly and thoroughly mixed on dosing, this is may be achieved through the use of a hydraulic jump. The water then passes into the settler to allow aggregation of the flocs. Increasing use is now being made of synthetic polymer compounds or polyelectrolytes. As these are highly charged, there is a rapid increase in the formation of flocs, particularly where clay makes up a large proportion of the suspended solid load.

The advantages of the coagulation is that it reduces the time required to settle out suspended solids and is very effective in removing fine particles which are otherwise very difficult to remove from water. Coagulation can also be effective in removing protozoa, bacteria and viruses, particularly when polyelectrolyte is used, as the highly charged coagulant attracts the charged microorganisms into the flocs. Coagulation can also be effective in removing by precipitation certain contaminants such as lead and barium.

The principle disadvantages of using coagulants are the cost and the need for accurate dosing, jar testing and dose adjustment and frequent monitoring. Coagulants can be expensive to buy (particularly polyelectrolyte) and need accurate dosing equipment to function efficiently. Staff need to be adequately trained to carry out jar tests to determine coagulant dosage.

Sand Filtration

Sand filtration can be either rapid or slow. The difference between the two is not a simple matter of the speed of filtration, but in the underlying concept of the treatment process. Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process.

Slow sand filters have an advantage over rapid sand filters in that they produce microbiologically "clean" water which should not require disinfection to inactivate any bacteria, although the addition of a disinfectant to provide a residual for the distribution system is still advisable. However, because of their slow flow rate, slow sand filters require large tracts of land if they are to supply large populations and can be relatively labour intensive to operate and maintain. As the reestablishment of the schumtzdecke takes several days, the plant has to have sufficient capacity to supply the water demand when one or more filters are out of action.

Rapid sand filtration is now commonly used worldwide and is far more popular than slow sand filtration. The principal factor in this decision has been the smaller land requirement for rapid sand filters and lower labour costs. However, rapid sand filters do not produce water of the same quality as slow sand filters and a far greater reliance is placed on disinfection to inactivate bacteria. It is also worth noting that rapid sand filters are not effective in removing viruses.

Slow sand filters

Slow sand filters operate at slow flow rates, 0.1 - 0.3 metres per hour. The top layers of the sand become biologically active by the establishment of a microbial community on the top layer of the sand substrate. These microbes usually come from the source water and establish a community within a matter of a few days. The fine sand and slow filtration rate facilitate the establishment of this microbial community. The majority of the community are predatory bacteria who feed on water-borne microbes passing through the filter.

The microbial community forms a layer called the schumtzdecke and can develop up to 2cm thick before the filter requires cleaning. Once the schumtzdecke becomes too thick and the rate of filtration declines further it is scraped off, a process done every couple of months or so depending on the source water. Once this has been carried out, the slow sand filter will not be fully functional for another 3 to 4 days until a new schumtzdecke has developed, although this procedure can be speeded up by seeding the filter with bacteria from the removed schumtzdecke. Slow sand filtration is extremely good at removing microbial contamination and will usually have no indicator bacteria present at the outlet. Slow sand filters are also effective in removing protozoa and viruses.

Slow sand filters require low influent turbidity, below 20TU and preferably below 10TU. This means that efficient pretreatment is required to ensure that the filters do not become overloaded. Slow sand filters can cope with shock turbidities of up to 50TU, but only for very short periods of time before they block. The sand used in slow sand filters is fine, thus high turbidities cause the bed to block rapidly and necessitates more frequent cleaning and therefore greater time out of action. Nevertheless, slow sand filters are still used in London and were relatively common in Western Europe until comparatively recently and are still common elsewhere in the world. The move away from slow sand filtration has largely been a function of rising land prices and labour costs which increased the cost of slow sand filter produced water, where this is not the case, slow sand filters still represent a cost-effective method of water treatment.

Rapid sand filters

Rapid sand filters work at much higher rates of flow (up to 20 meters per hour) and essentially rely on physical removal of suspended solids, including any floc carried over from the settlers. Although rapid sand filters achieve some reduction in microbial populations in water as it removes particles to which bacteria are attached, it is not a biological treatment and the use of a terminal disinfectant is vital to ensure that bacteria in the water have been inactivated. Rapid sand filters require frequent cleaning (daily or twice daily) which is achieved through backwashing filters with clean water to re-suspended the sediment. Cleaning takes relatively little time and the filters can be put back into operation immediately.

Rapid sand filters are far smaller than slow sand filters and are commonly employed in 'batteries'. The rapid flow rate through these filters means that demand can be more easily met from smaller plants. Rapid sand filters do not require low influent turbidities, as they are essentially a physical treatment process, although higher suspended solids loads will result in more frequent cleaning. Backwashing is usually rapid and filters are not out of commission for mare than a matter of minutes. Cleaning and operation can be largely mechanised and air scour is commonly employed to make backwashing more effective. With the small land requirement, several rapid sand filters can be accommodated in small area and thus it is easy to maintain capacity to meet demand when filters are being cleaned.

Disinfection

Only a very brief discussion of disinfection is included here for completeness sake and for further information please refer to session XIV of the Teaching Pack or to Chapter 6 of Volume 1 of the Guidelines and Chapter 6 of Volume 3.

All water supplies should be disinfected in order to protect public health. Disinfection inactivates any remaining bacteria in the water after previous treatment steps and provides a residual disinfectant to inactivate bacteria introduced by any subsequent ingress of contaminated water during storage or distribution.

At present, the principal disinfectant used worldwide is chlorine, although alternatives are being increasingly investigated and process such as ozonation are becoming more important in industrialized countries. It is important to note that all disinfectants produce by-products and that the greater knowledge about the by-products formed from the use of chlorine because it is this most widely used disinfectant should not compromise it's use. It is also important that disinfection of water supplies is never compromised because of a risk of potential health effects from by-products in the final water. Any health impacts from chemical contamination is likely to be long-term, whereas the absence of disinfection puts the consumers at risk from infectious diarrhoeal disease.

Other Treatment Processes

The above treatment process are all designed to make drinking-water safe by the removal of microorganisms and suspended solids. However, drinking-water, particularly from groundwater sources, may also contain chemical contaminants which must be removed. Generally the removal of chemicals from water is more difficult and much more expensive than removing microbiological or physical contaminants. Basic filtration and coagulation techniques are not generally effective for the majority of chemicals.

As there are many different chemicals which could be dealt with, a few relevant examples will be provided. Iron can be a major constituent of both ground and surface waters (where it is commonly associated with bacteria and algae). Although iron does not represent any health risk, it causes problems of acceptability of the water as many consumers find the colour off-putting and because it stains clothes. The principal method of removing iron from water is through aeration or oxidation of the Fe^{2+} to the Fe^{3+} species. This is easily achieved by flowing the water over a simple cascade and followed by sedimentation. Note aeration is also used for waters known to be anoxic or oxygen deficient.

A variety of processes are used for the removal of organic and inorganic contaminants including ion exchange and precipitation. For instance, fluoride may be removed through coagulation with lime or by ion exchange using calcinated burnt bone or activate alumina. Granulated activated carbon (GAC) is commonly used for pesticide removal through adsorption. This is expensive but unfortunately no other process appears to work effectively and therefore GAC remains the sole option.

Selecting Technology

When selecting technology and systems of treatment it is vital that as full a picture as possible of the source water quality is available. It is important to know what is in the water before trying to design appropriate treatment systems. It is equally important to maintain a thorough monitoring programme through the plant to ensure that each stage of treatment is working effectively and efficiently.

All waters may need treatment before they are fit for human consumption, although surface waters tend to be more vulnerable to contamination than groundwater. All surface waters will require treatment prior to consumption. Furthermore, all water supplied through distribution systems should be disinfected to provide a residual disinfectant which provides ongoing protection from bacterial growth and survival.

Water Treatment

Presentation Plan

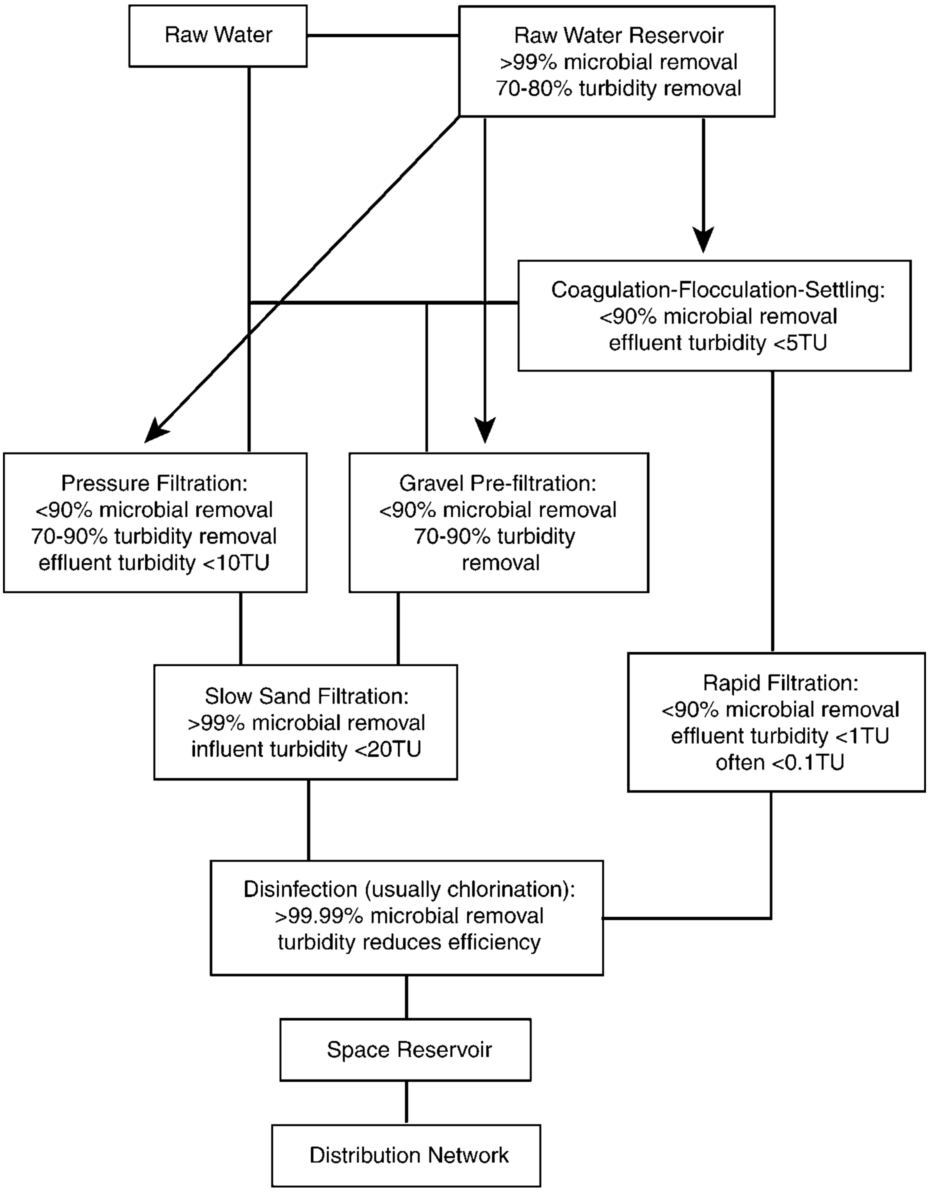
Section	Key points	OHP
Introduction	• need to treat all surface waters and some groundwaters • contamination may be microbiological, chemical or physical • microbiological contamination is most important as it causes highly infectious disease with short-term impacts • chemical contamination tends to have longer term effects on health • suspended solids affect microbial survival and the acceptability of water • always disinfect water supplies and maintain a residual in the water for protection against contamination during distribution and storage	
Multiple Barrier Principle	• need to have more than a single process during treatment • prevents breakdown in one process leading to complete treatment failure • source must be well protected	**1**
Treatment processes	• many processes available, the suitability of each is a function of source quality, operator capacity and financial resources • technology selection must be made on the basis of the above to ensure sustainability • often need to reduce turbidity before treating water as this may interfere with treatment • prefiltration is a physical process which removes suspended solids • prefilters can be horizontal, vertical upflow or vertical upflow-downflow • main advantage is limited working parts and doesn't use chemicals • disadvantages include poor ability to remove fine material, microbial removal poor and may need frequent cleaning • sedimentation is achieved by the settling of particles in slow moving water • simple sedimenters do not use chemical coagulants and are not effective in removing fine material	**2,3** **4,5**

Section	Key Points	OHP
	• settling is improved through addition of coagulants to form larger aggregates which speeds up settling and removes fine material • modular and plate settlers improve settling efficiency • alum is the most common coagulant, others include polyelectrolytes and ferric salts such as sulphate and chloride • advantages include removal of fine particles, removal of some viruses, quick, compact disadvantages include expense, need for good monitoring capacity, need trained operators	
Treatment processes	• sand filtration can be rapid or slow • slow sand filtration is a biological process and rapid sand filtration a physical process • slow sand filters a biologically active top layer called the schumtzdecke which is composed of predatory bacteria • schumtzdecke kills bacteria and viruses • require cleaning @ every 2 months, take 3-4 days to recover • rapid sand filters work at much faster rates and remove suspended solids • advantages of slow sand filtration include production of good quality water, relatively simple to operate • disadvantages include large land requirement, labour intensive, requires low turbidity water • advantages of rapid sand filtration include small land requirement	**6,7**
Treatment plant assessments	• assessments of treatment plants may be carried out for a number of different reasons • routine assessments often carried out by water suppliers to ensure performance is efficient and optimised • assessments may also be undertaken when there is a failure in water quality or a failure to produce water of adequate quality • assessments involve the evaluation of each unit process to ensure that it performs efficiently and to identify any process failures and causes of failures • assessments should also evaluate the suitability of combinations of technologies (e.g. sometimes find simple sedimenters combined with slow sand filters when turbidity was relatively high - led to failure) • assessments should be linked to performance optimisation	**8, 9**

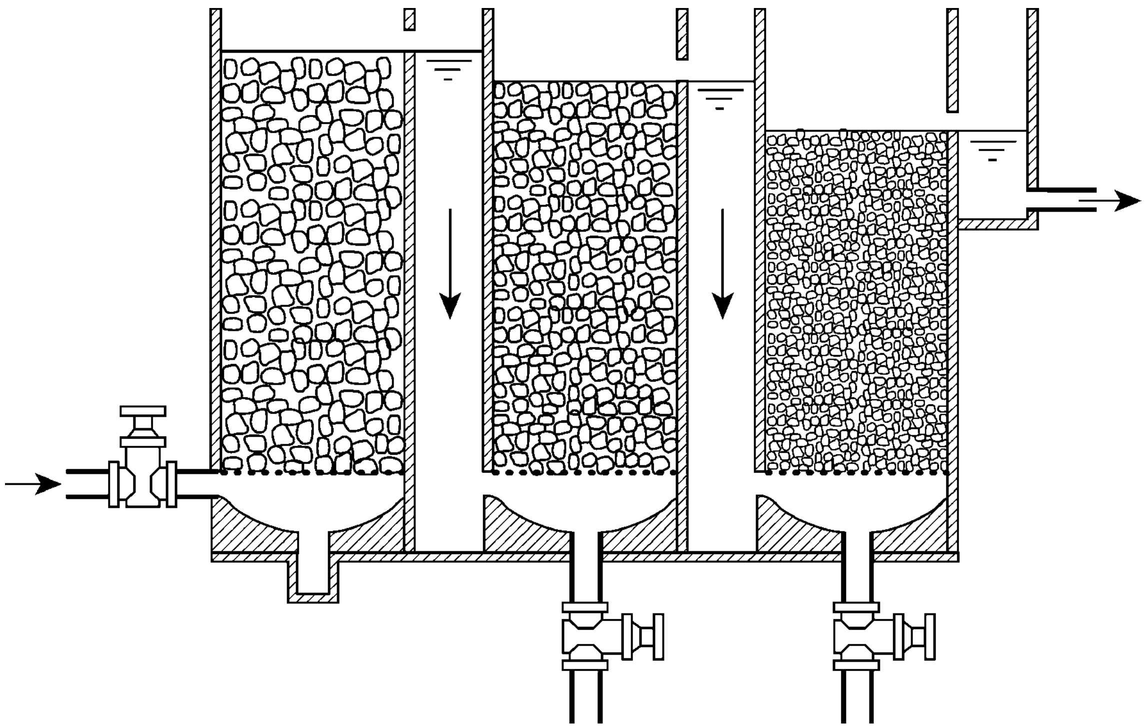
Section	Key Points	OHP
Conclusion	• both surface and groundwater may require treatment before distribution • source water quality (and likely variations) should be known before selecting technologies • technologies should be used which reflect capacity to operate the plant and which provide adequate treatment • a multiple barrier principle should always be used when treating water • source protection is also vital	

NB: OHPs 8 and 9 may be used when discussing water treatment plant monitoring and assessment

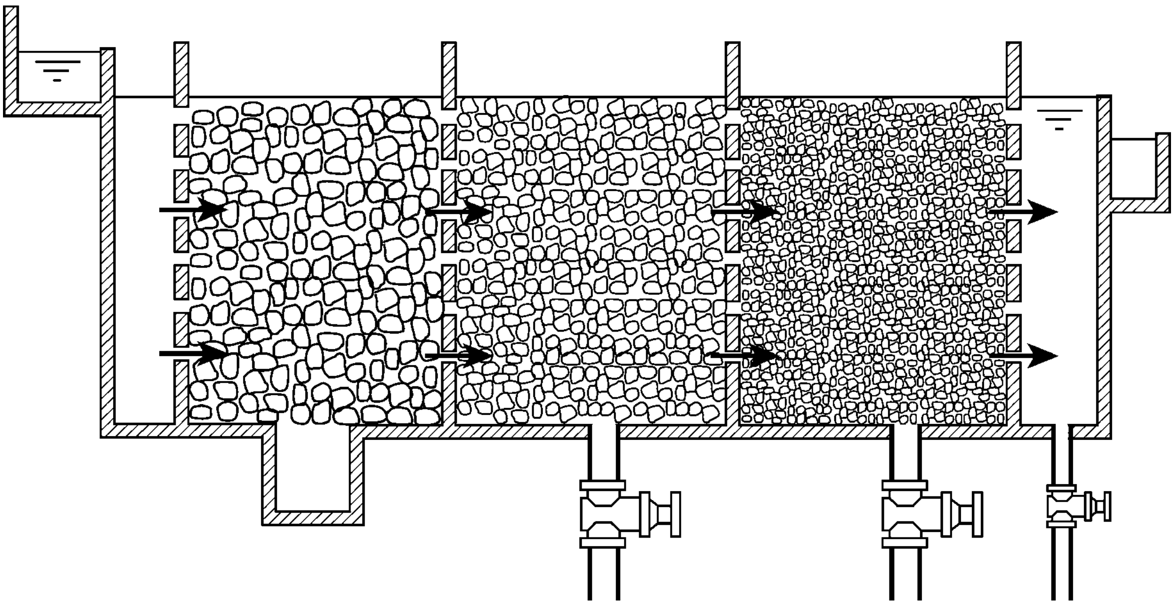
The Multiple Barrier Principle of Water Treatment



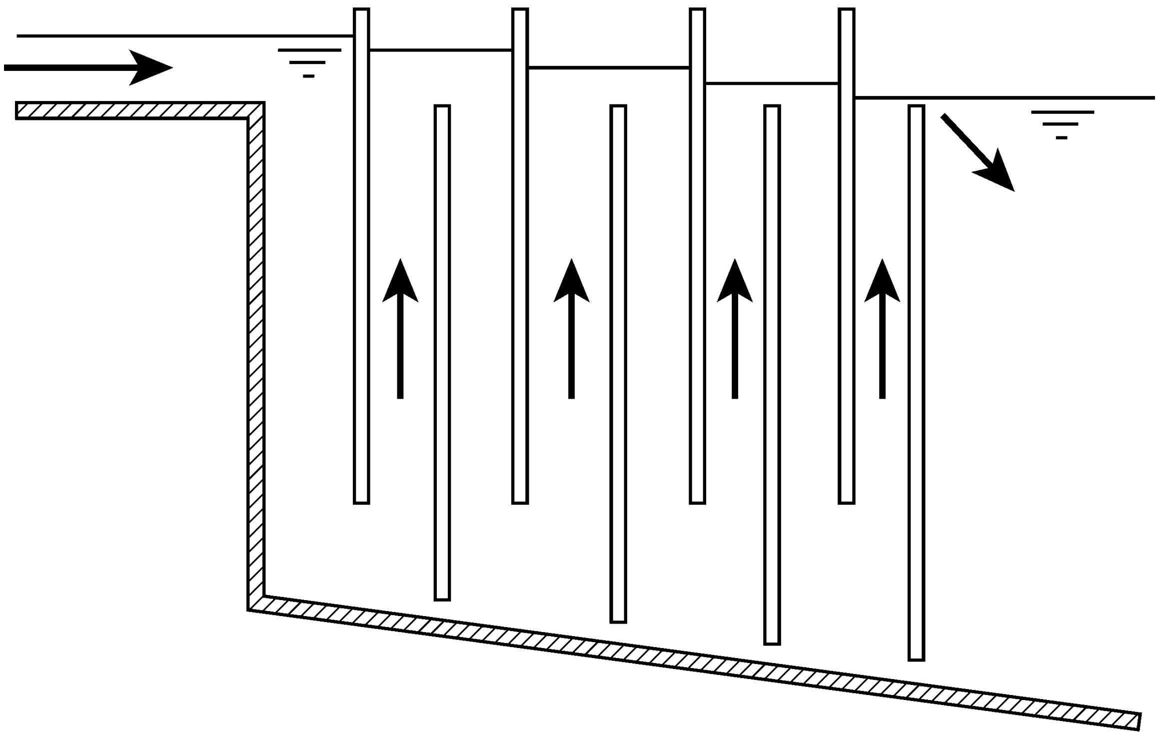
Upflow-Downflow Prefilter



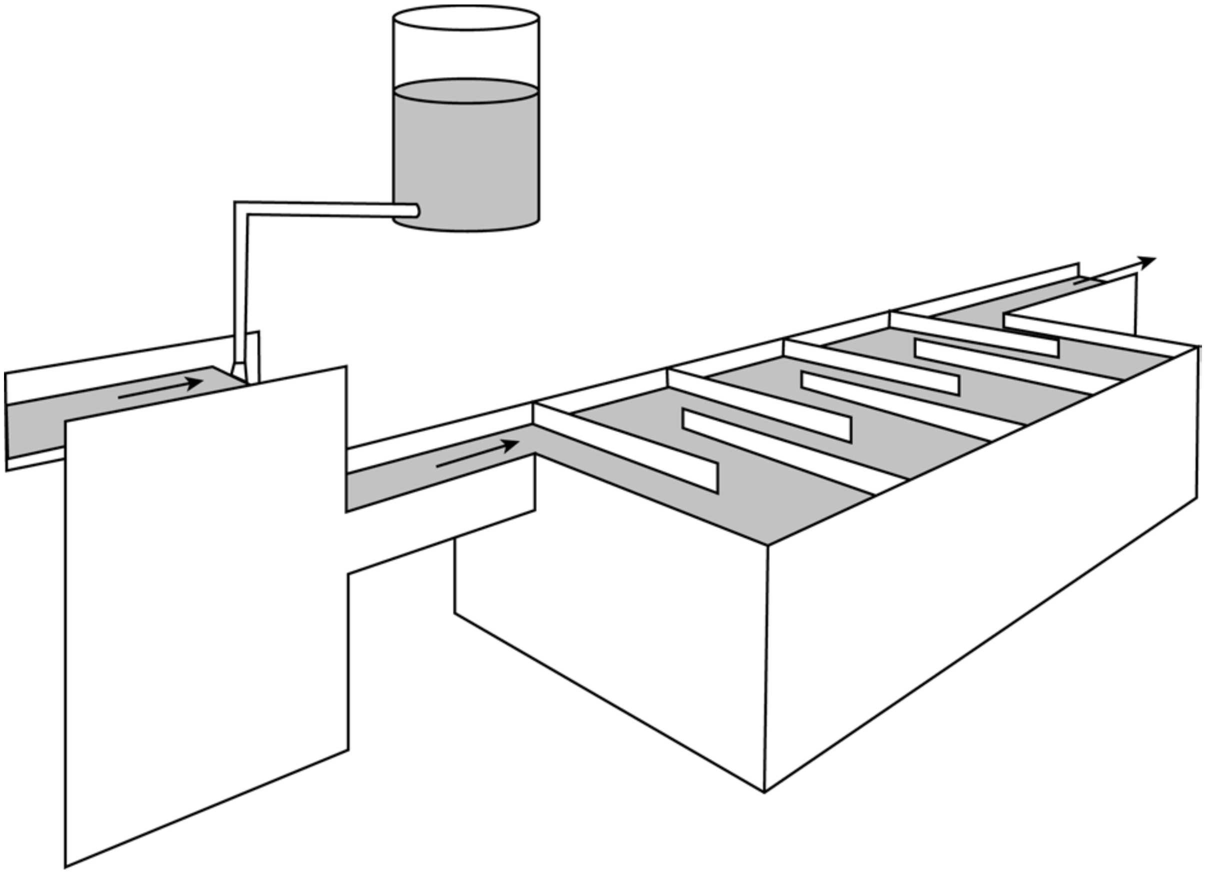
Horizontal Flow Prefilter



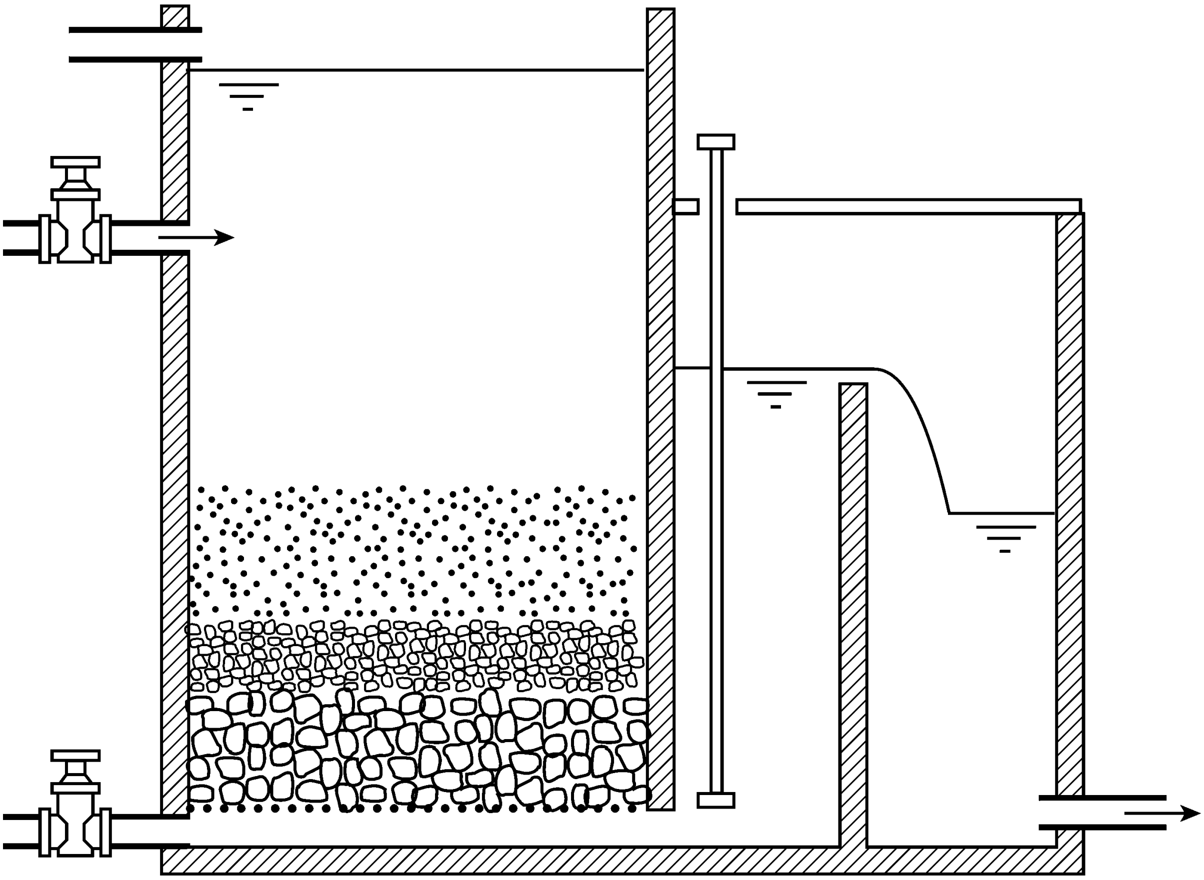
Flocculator



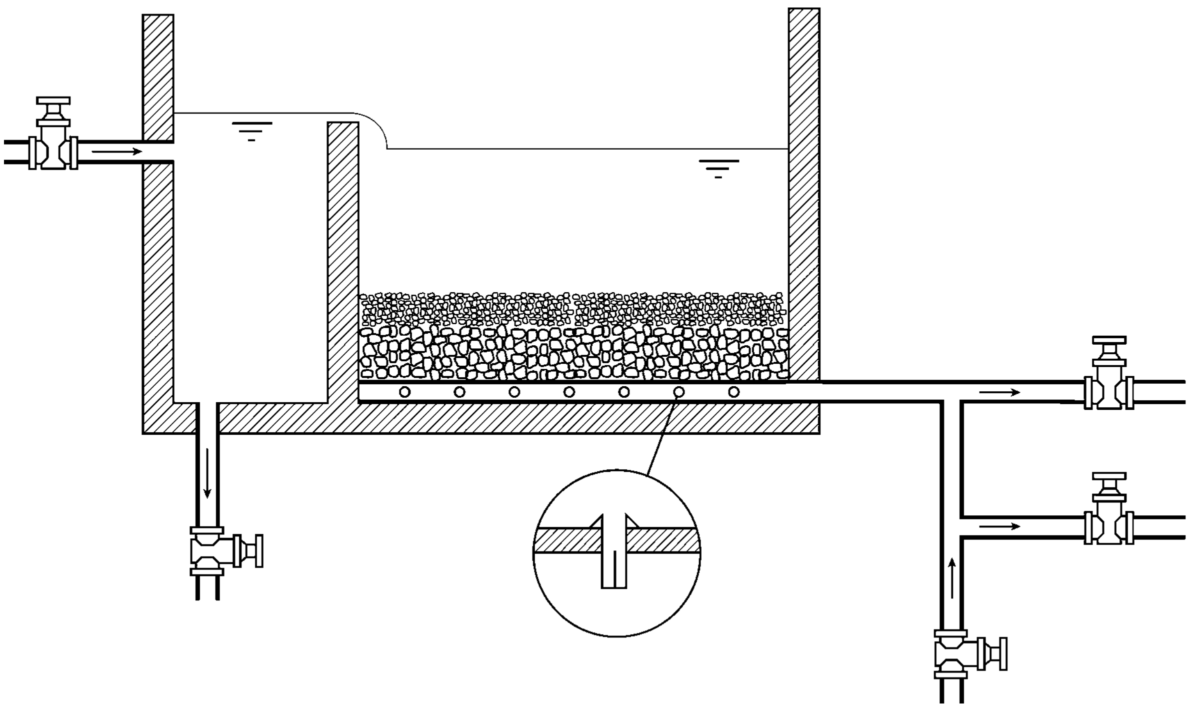
Coagulant Dosing



Slow Sand Filter



Rapid Sand Filter



Water Treatment Plant Assessments

When and why the should be carried out:

- Routine assessment of operational efficiency and state of equipment
- When contamination is found
- When disease outbreaks occur
- If disinfection dosing requirements suddenly change

Water Treatment Plant Assessments Parameters

Raw Water:

turbidity, pH, alkalinity, coliforms, major ions, nutrients, known problem substances

Coagulation-flocculation-settling:

turbidity, pH, residual aluminum, residual acrylamide, coliforms

Prefiltration:

turbidity, pH, coliforms

Sand filtration (rapid/slow):

turbidity, pH, coliforms

Disinfection:

residual (usually chlorine), pH, turbidity, coliforms (thermotolerant and total)