COMPANION TO
A Drop of Knowledge:
The Non-operator's Guide to
Waste Water Systems

A Drop of Knowledge

The Non-operator's Guide to
Drinking Water Systems

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RURAL COMMUNITY ASSISTANCE PARTNERSHIP

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Introduction to Drinking Water Systems

What are water systems?

In the United States, there are approximately 155,000 public water systems. The U.S. Environmental Protection Agency (EPA) classifies these systems according to the number of people they serve, the source of their water, and whether they serve the same customers year-round or on an occasional basis. Most public water systems are owned by the municipality they serve, but they can also be owned by private companies, nonprofit corporations, or individuals.

According to EPA's definition, a public water system transports water that has been treated or otherwise made safe for human consumption through a system of pipes and other constructed conveyances to at least 15 service connections or to a destination where at least an average of 25 individuals are served at least 60 days out of the year.

The term *public water system* includes the following:

- Any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system
- Any collection or pretreatment storage facilities not under such control, which are used primarily in connection with such system.

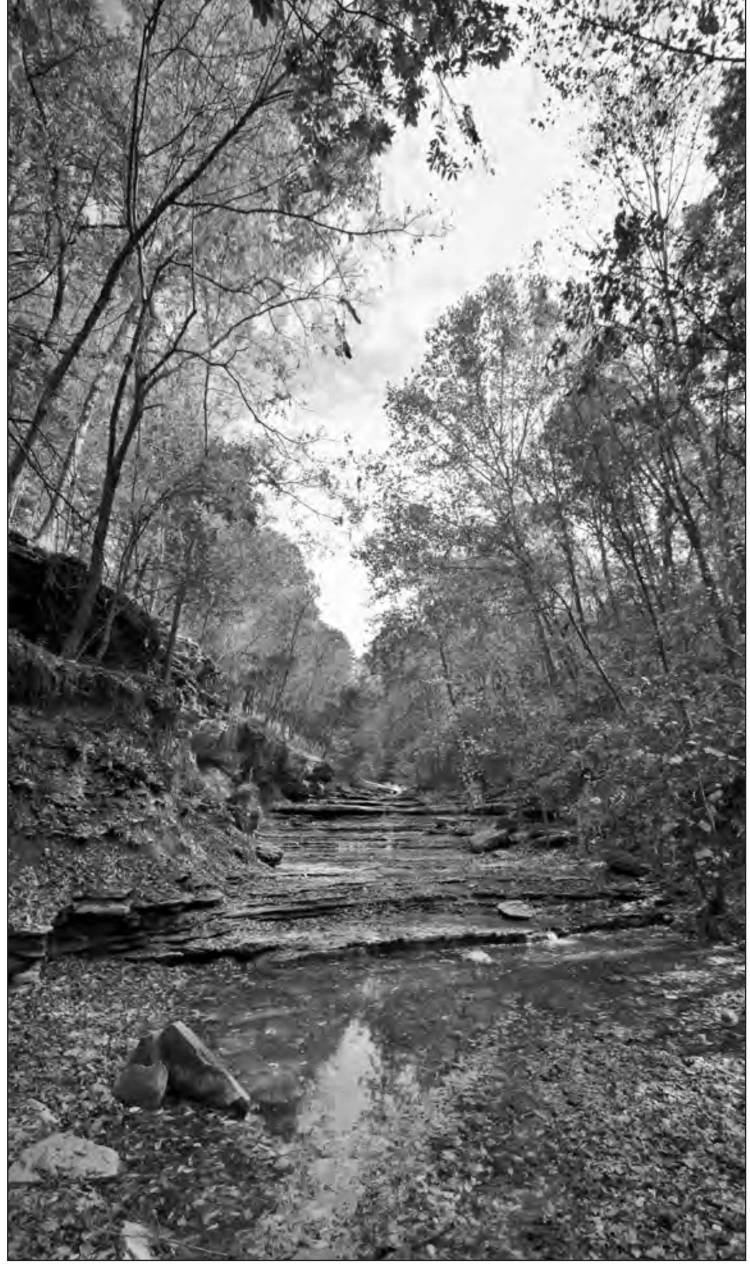
EPA has defined three types of public water systems:

- *Community water system:* A public water system that supplies water to the same population year-round.
- *Non-transient non-community water system:* A public water system that regularly supplies water to at least 25 of the *same* people at least six months per year, but not year-round. Some examples are schools, factories, office buildings, and hospitals that have their own water systems.
- *Transient non-community water system:* A public water system that serves at least 25 *different* people for 60 days or more each year. Some examples are gas stations, campgrounds, and restaurants or bars with their own water supply, where people do not remain for long periods of time.

EPA mandates that each state and tribal drinking water primacy agency (regulatory office) inspect its drinking water systems on a regular basis. These inspections are called sanitary surveys, and they are scheduled according to system type. Here is the schedule:

System type	Frequency
Non-community water system (transient and non-transient)	Every 5 years
Community water system	Every 3 years
Community water systems with outstanding performance based on prior sanitary surveys	Every 5 years

Individual state or tribal primacy agencies can inspect more often if they choose to.



Melissa Jones, CRG

Source water

Community water systems typically get their water from one of two sources or a combination: groundwater or surface water. According to EPA, the majority of small, rural public water systems use groundwater. Large, metropolitan areas tend to use surface water.

Each of these source water supplies has unique characteristics that require different treatment procedures. Because of this, they are further categorized into three groups: groundwater, groundwater under the direct influence of surface water (GWUDI), and surface water.

Groundwater

The majority of drinking water systems get their water from groundwater wells, but they serve smaller populations. These are typically considered small and very small systems (501 to 3,300 and 25 to 500 people, respectively, according to EPA's classification of systems).

Groundwater, which is obtained by drilling wells, is water located below the ground surface in pores and spaces in the rock. The well depths can range from about 25 feet to beyond 1,000 feet.

Because there is less contamination in groundwater and there is less potential for pollution, the list of rules that groundwater systems must comply with is shorter. The list includes:

- Safe Drinking Water Act (SDWA)
- 1986 amendments to the SDWA
- 1996 amendments to the SDWA

Some of the specific rules included in the SDWA and the amendments are:

- Ground Water Rule
- Total Coliform Rule (TCR)
- Revised Total Coliform Rule
- Lead and Copper Rule
- Revised Lead and Copper Rule
- Public Notification Rule
- Revised Public Notification Rule
- Arsenic Rule

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Well-Cross Section

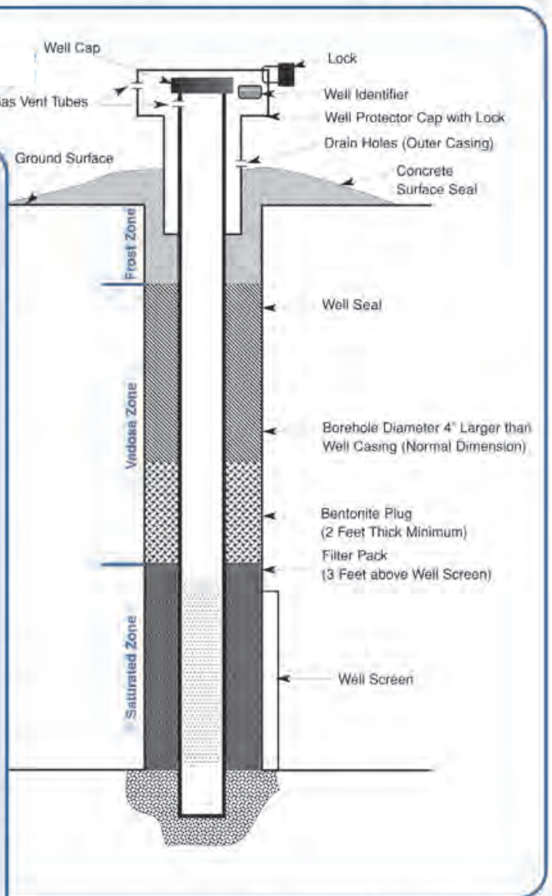

Figure 1: Definitions

Well seal:
A seal is a cylindrical layer of material, usually cement, bentonite, or clay, that surrounds the casing up to a certain depth in the well. It prevents runoff or other contaminants from entering the well, and serves to further protect the casing.

Well Screen:
Well screen is a cylindrical sieve-like structure that serves as the intake portion of the well. It is a metallic pipe that has holes or perforated sections or slotted sections that is placed on the water- carrying zones of the aquifer.

Filter pack:
A filter pack is made up of sand or gravel that is smooth, uniform, clean, well-rounded, and siliceous. It is placed in the annulus of the well between the borehole wall and the well screen to prevent formation material from entering the screen.

Vadose Zone:
This is the zone that contains water under pressure less than that of the atmospheric pressure. It is the layer of soil between the water table and the ground surface.

Potentiometric surface:
This is an imaginary surface representing the total head of groundwater in a confined aquifer that is defined by a level to which water will rise in the well.

Adapted by the National Environmental Services Center from Groundwater and Wells, Fletcher G. Driscoll, PhD

Ground water under the direct influence of surface water (GWUDI)

A series of tests determines if a system is one with GWUDI. Required testing may vary from state to state, but it is generally based on source design and construction, an area's source water protection programs, local geology, and historical testing data.

How does groundwater come under the direct influence of surface water? The proximity of a well to a surface water source plays a major role. Also, groundwater that has no confining layer to protect it from surface water infiltration can be vulnerable.

Because some disease-causing pathogens found in surface water (e.g., *Giardia lamblia* and *Crypotosporidium*) are extremely hard to kill with conventional amounts of chlorine or ultraviolet light (UV), GWUDI sources must be treated more thoroughly than groundwater. If a source is determined to be under the direct influence of surface water, the system can either find a new source or install chlorine disinfection and filtration, in accordance with all of the Surface Water Treatment Rules.

Kay Mulligan, RCAC

Surface water

The majority of the population uses surface water for its consumption because surface water is more abundant and easily accessible. Surface water is water that collects above ground in a stream, river, lake, reservoir, or ocean.

Surface water typically contains more contaminants than groundwater. Surface water also has a greater potential to be contaminated because it is an open water supply that is vulnerable to pollution from direct discharge of an outfall pipe or channel and storm water runoff. Direct discharges can come from industrial sources or from certain older sewer systems that overflow during wet weather. Storm water runoff becomes contaminated when rainwater washes over contaminated soil, such as agricultural operations, and either dissolves the contamination or carries contaminated soil particles along with it.

Because of these pollution concerns, surface water regulations are more stringent. For example, surface water not only requires more testing on the raw and finished water, but it also requires more monitoring during the treatment process that often must be continuous and recorded to meet federal regulations.

The federal regulations that surface water systems must abide by include:

- SDWA (also applies to groundwater)
- 1986 amendments to the SDWA
- 1996 amendments to SDWA

Some of the specific rules included in the SDWA and its amendments are:

- Surface Water Treatment Rule
- Stage 1 Disinfectants and Disinfection Byproducts Rule (DDBPR1)
- Stage 2 Disinfectants and Disinfection Byproducts Rule (DDBPR2)
- Total Coliform Rule (TCR)
- Revised Total Coliform Rule
- Public Notification Rule
- Revised Public Notification Rule
- Interim Enhanced Surface Water Treatment Rule (IESWTR)
- Long-term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR)
- Long-term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)
- Lead and Copper Rule
- Revised Lead and Copper Rule
- Arsenic Rule
- If the water treatment plant has surface discharge of backwash water (after settlement), it would need the National Pollutant Discharge Elimination System (NPDES) permit through the Clean Water Act.
- State and local laws may also apply

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Systems with more than one source

Water systems sometimes have more than one source of water for capacity reasons. Perhaps one well or stream does not have the volume or capacity to supply the population. Another reason is that an area's population may fluctuate according to the season as with ski resorts or summer getaways. A third reason is that individual sources may not be suitable on their own as drinking water supplies. For instance, one source may be contaminated with high levels of fluoride, arsenic, or radionuclides, while another source may be free of such contaminates but limited in supply. Blending the water from more than one source, however, may dilute the contaminants to reduce their concentrations to below the maximum contaminant level (MCL), which is the level EPA has deemed safe. An MCL is the legal threshold limit on the amount of a substance that is allowed in public water systems under the SDWA. The limit is usually expressed as a concentration in milligrams per liter (mg/L), which is the same as parts per million (ppm), or micrograms per liter (μg/L), which is the same as parts per billion (ppb) of water.

Purchasers

Drinking water systems that do not treat or produce water but buy it from a water system are referred to as purchasers. Purchaser systems can also buy from other purchaser systems, which are known as consecutive purchaser systems. Purchaser systems get the finished (treated) water through one or more master meters and distribute it through their distribution systems. Even though the purchaser does not produce the water, monitoring for certain contaminants, such as disinfection byproducts, bacteria, lead, and copper, and the disinfectant residual levels, is still necessary.

How Does Source Water Become Drinking Water?

The information in the introduction of this guide helped you to identify the characteristics of your system, including where your community gets its source water. Except in very rare cases, source water is not potable water. Once a community has established a reliable source of water, there are still many steps before raw water becomes drinking water, especially if the source is surface water. This section describes the course that water takes when it travels from the source, through the water treatment process, and finally to the tap.

MULTIPLE-BARRIER APPROACH

Water systems in the United States typically rely on a multiple-barrier approach to insure their customers have clean, safe drinking water. This approach is a system of procedures, processes, and tools that work together to prevent or reduce the contamination of drinking water from source to tap, thus reducing risks to public health.

A drinking water system has three main parts: 1) the source water (watershed/aquifer); 2) the drinking water treatment plant; and 3) the distribution system. These elements are managed in an integrated manner using procedures and tools such as:

- water-quality monitoring and management of water supplies from source to tap
- legislative and policy frameworks
- public involvement and awareness
- guidelines, standards and objectives
- research and the development of scientific and technological solutions

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With the multiple-barrier approach, potential control barriers are identified along with their limitations. The barriers can be physical, such as filtration and disinfection to purify water, or they can be processes or tools that improve the overall management of a drinking water system, such as legislation that dictates EPA policies, guidelines and standards, ongoing training and education for system operators or and communication strategies that utilities can use to communicate with the media or the public.

The multiple-barrier approach also helps ensure the long-term sustainability of water supplies. Through wellhead and source water protection programs, the multiple-barrier approach can prevent water supplies from becoming contaminated—not only assuring a purer water supply, but also reducing treatment and its associated costs.

GROUNDWATER SYSTEMS FROM SOURCE TO TAP

Groundwater is just what it sounds like: water that comes from the ground. Groundwater comes from rain, snow, sleet, and hail that soaks into the ground. The water moves down into the ground because of gravity, passing between particles of soil, sand, gravel, or rock until it reaches a depth where the ground is filled, or saturated, with water. The area that is filled with water is called the saturated zone, and the top of this zone is called the water table. The water table may be very near the ground's surface, or it may be hundreds of feet below.

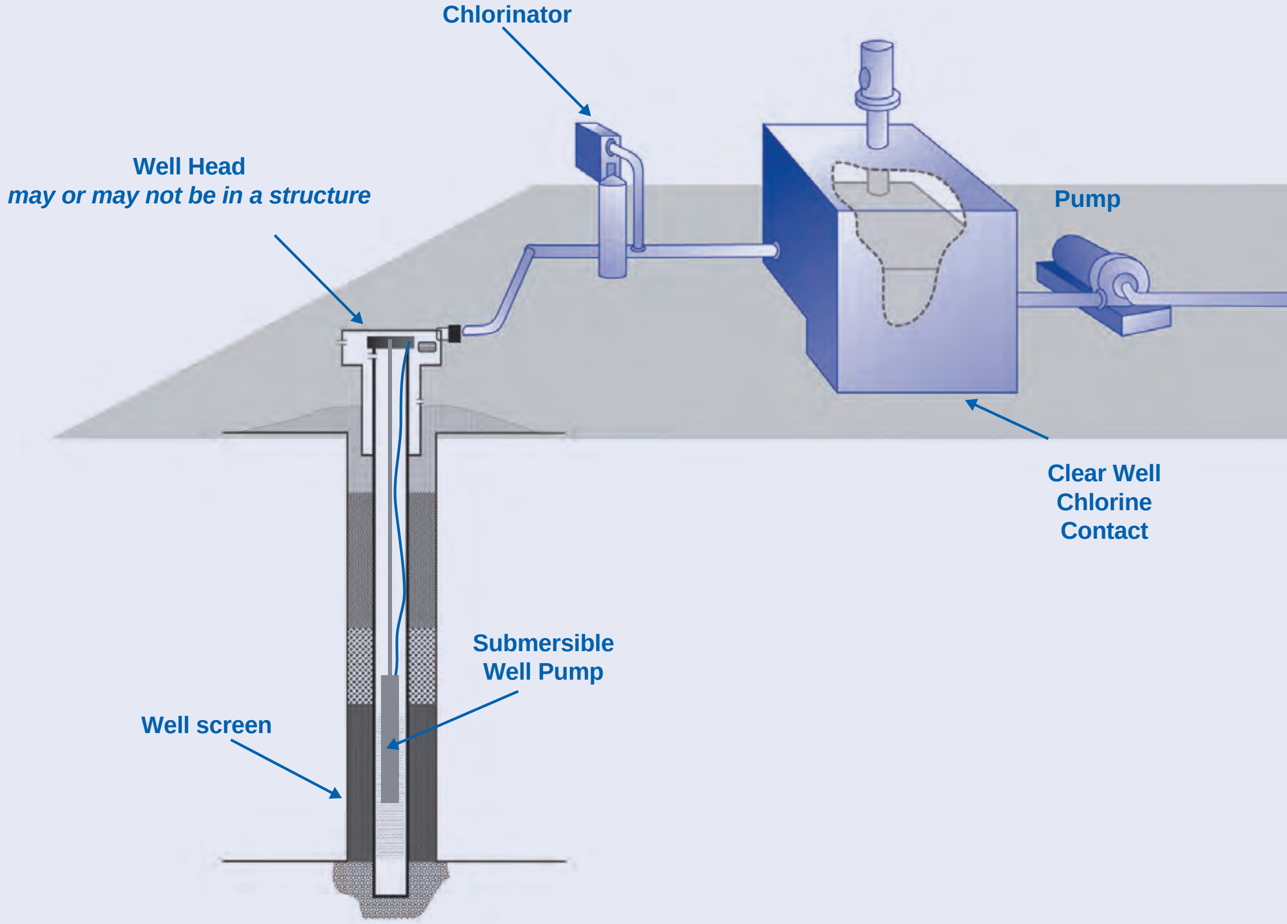
Groundwater is naturally filtered to some extent when it passes through the earth to underground reservoirs called aquifers. This water typically does not contain as much organic material or microorganisms as surface water, so it requires less treatment.

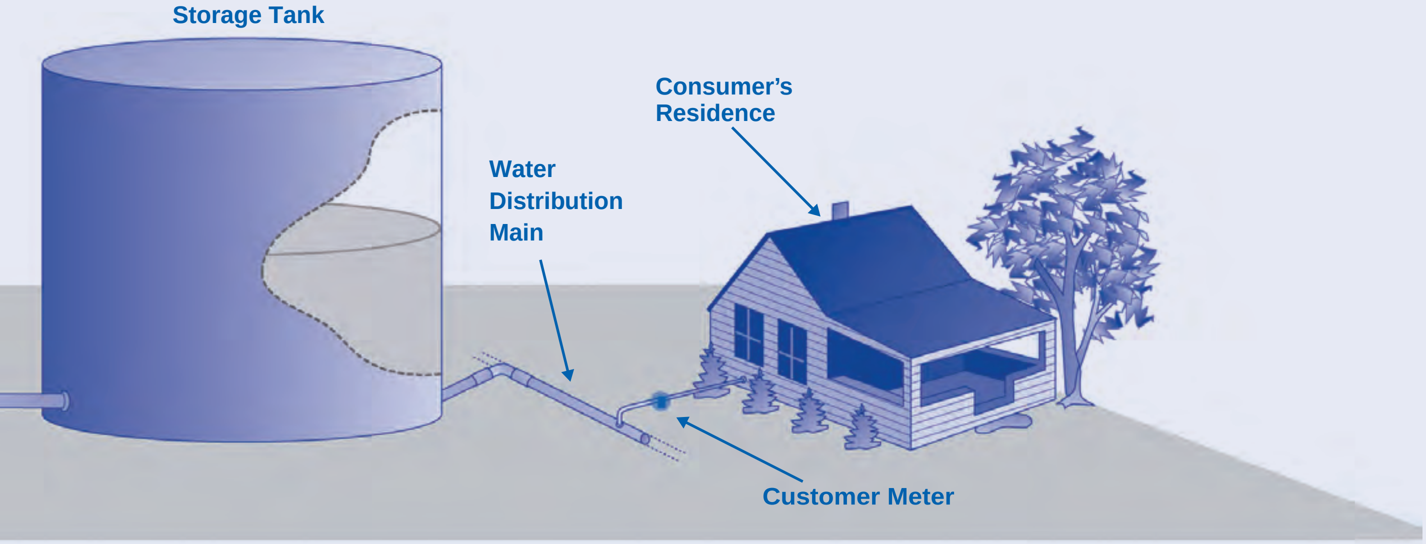
Small communities often get their water from wells large enough to support their populations. Wells are typically bored or drilled into underground aquifers to access the available groundwater. Electric submersible pumps, vertical turbine pumps, or other mechanical pumps draw the water to the surface, where it is treated and then provided to the community's residents through the distribution system.

Wells can vary greatly in depth, volume and quality. Well water may contain more minerals in solution than surface water and may require treatment to soften the water by removing minerals such as calcium, iron and manganese.

In small water systems, the role of pumping equipment is extremely critical. Because these systems are frequently constructed without back-up pumps, a single pump could fail and cause customers to be without water for an extended period of time. Additionally, small systems that use hydropneumatic tanks have very little stored water, and, therefore, a pump failure can result in customers being completely out of water within a matter of minutes.

Groundwater Treatment Process





Source: National Environmental Services Center

SOURCE TO DRINKING

Groundwater systems with only chlorine disinfection

Many groundwater systems require little treatment to make the water they produce safe for human consumption. These systems are not under the direct influence of surface water and continually test negative for bacteria. They also typically have little or no turbidity (cloudiness or muddiness) and test negative for contaminants. In this case, treatment usually consists of a disinfectant that is added to maintain a disinfectant residual in the distribution system. Adding a disinfectant ensures that any microorganisms that may be in the distribution system are killed before the water reaches customers. If the groundwater system serves a population of more than 3,300 (in some states this number may be less) the system must continuously monitor the disinfectant levels at the treatment plant (as it is leaving the plant).

Groundwater systems with filtration and disinfection

Turbidity, microorganisms, and chemical contaminants can all affect groundwater systems. If a groundwater system has contaminants, such as arsenic, nitrates, nitrites, or chromium, its operators must take precautions to protect the health of people who drink the water. These contaminants may be naturally occurring runoff from surrounding agricultural sites or other businesses or industries, or from sources that cannot be pinpointed. In any case, the best available drinking water treatment technologies must be employed to remove these contaminants to meet the requirements of the SDWA.

Groundwater systems that are determined to be under the direct influence of surface water must meet all of the regulatory and treatment criteria of surface water (discussed in a later section).

Distribution

A distribution system is a system of pipes, pumps, and other conveyances that propel water to customers' taps. Most of this system is underground, leading from the water system to the consumers' taps. A more detailed explanation of distribution systems is in the chapter titled "How does drinking water get to my home?" (page 30)

SURFACE WATER SYSTEMS FROM SOURCE TO TAP

Because it contains more contaminants, surface water is more complex to make safe to drink through the treatment process. The first challenge is getting it into the treatment plant.

Melissa Jones, CRG

Intakes

Surface water enters the treatment facility through an intake. An intake draws raw water through a suction line that typically has a screen or other device attached to avoid drawing in fish, other wildlife, and garbage.

Intakes can be fixed in place or be adjustable to draw raw water in at different levels from the river, stream, or reservoir. This sometimes provides for a better quality or quantity of water at different times of the year. A raw water pump, located near the source water, may be used.

In some cases, drinking water systems can use gravity to get the raw water into the treatment plant. This is true if the raw water source is higher than the treatment plant.

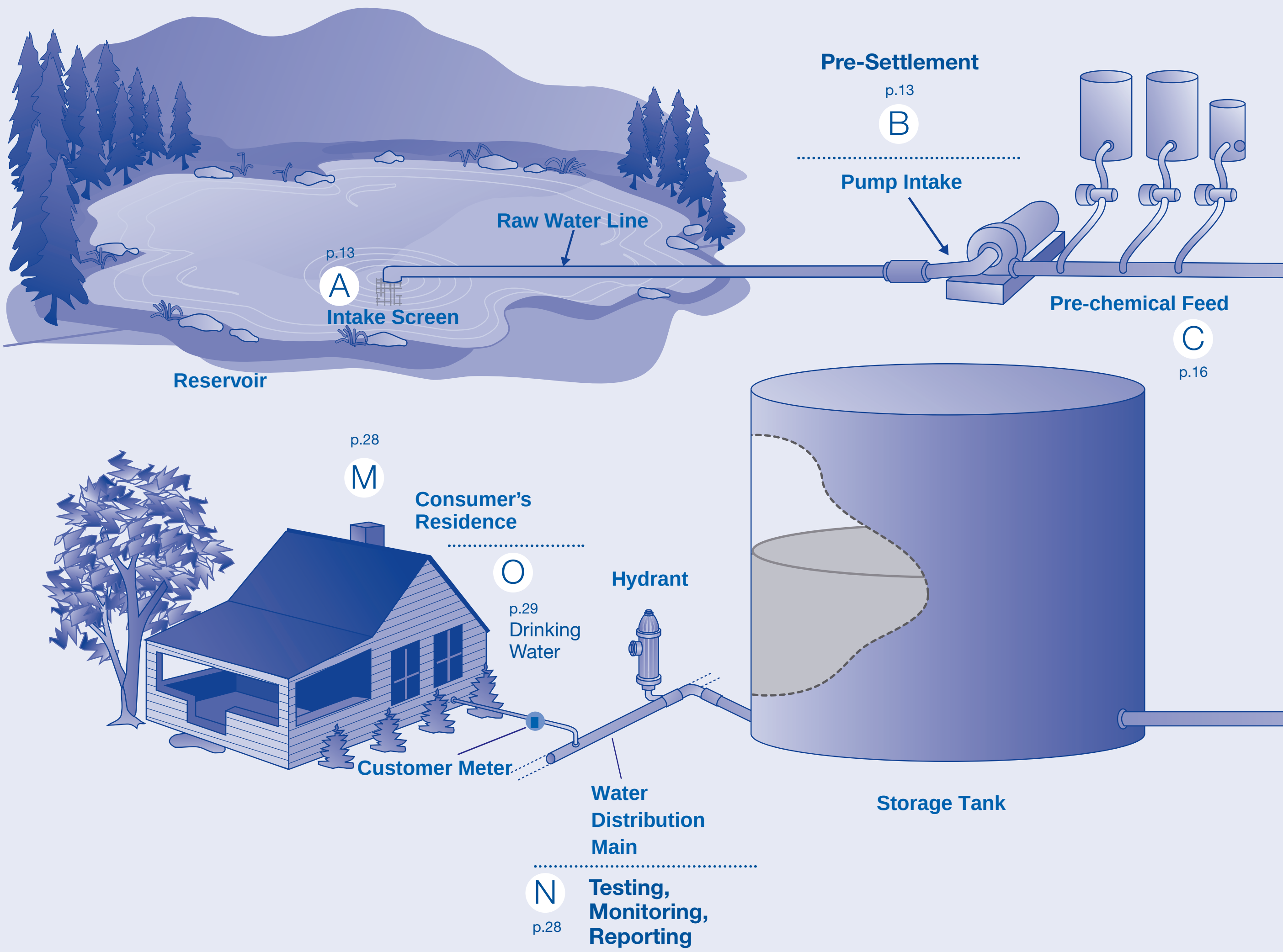
Pre-settlement

Pre-settlement is necessary if the raw water is very turbid or contains contaminants that need time to settle. Most drinking water systems use either earthen or concrete basins for pre-settlement. The raw water is pumped or gravity-fed to the basin. While in the basin, the water is allowed to sit so that solids can sink to the bottom of the basin. Then water that is close to the surface, usually just a few inches below the top of the basin, is pumped, or gravity is used to get the water to the next step in the treatment system.

In addition to settling water before treatment processes, pre-treatment chemicals, such as coagulants, may be used to help clarify the water.

SURFACE WATER SYSTEMS FROM SOURCE TO TAP
▶ Intakes (A)
▶ Pre-settlement (B)
Pre-treatment chemicals (C)
Coagulation (D)
Flocculation (E)
Sedimentation (F)
Ion exchange (G)
Filtration (H)
Sludge disposal (I)
Post-treatment chemicals (J)
Taste and odor control (K)
Clear well (L)
Point of use/point of entry (M)
Testing, monitoring and reporting (N)
Clean, safe drinking water (O)
Refer to the diagram showing these steps on pages 14-15.

Surface Water Treatment Process



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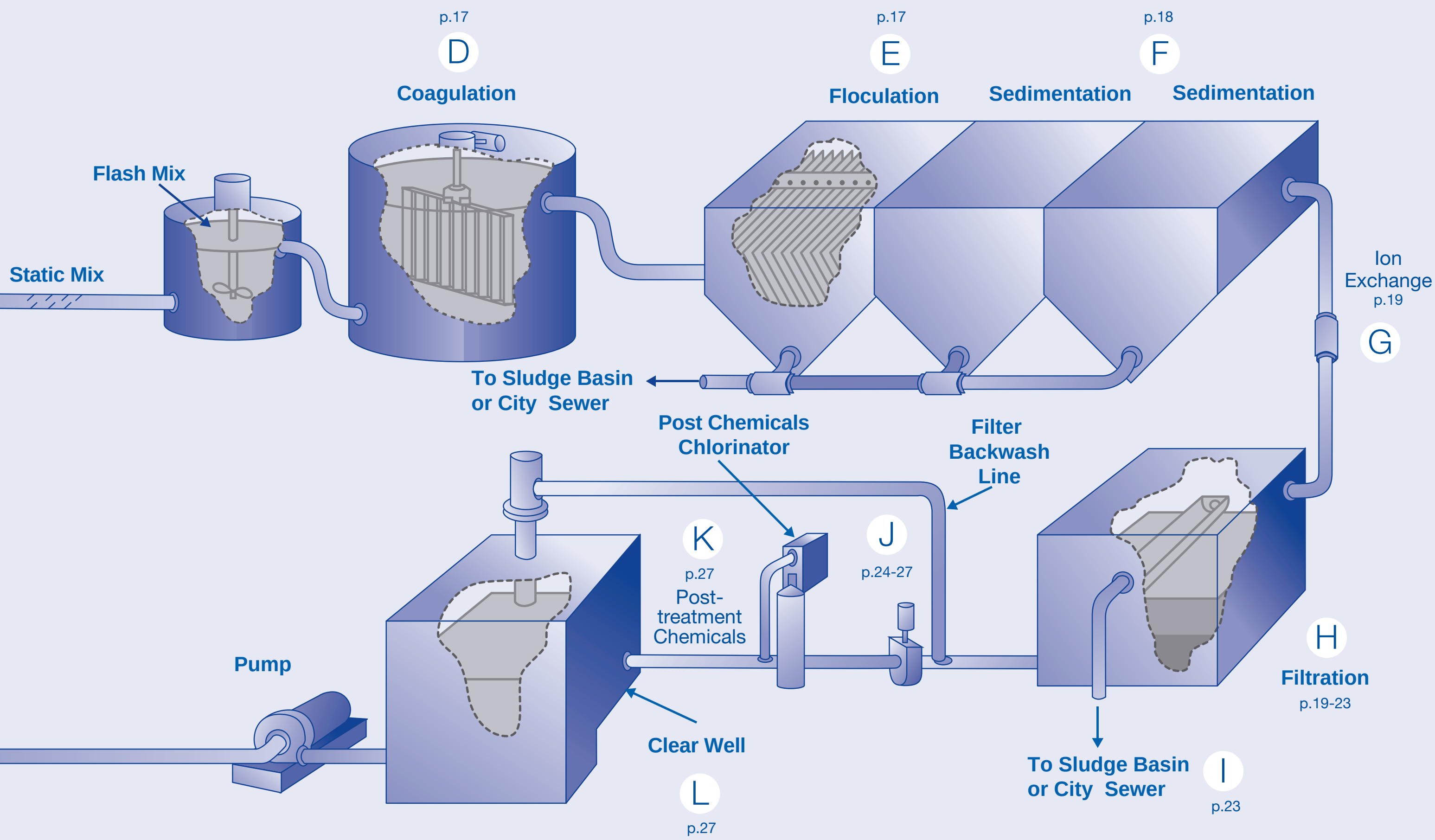


Source: National Environmental Services Center

Refer to the diagram showing these steps on pages 14-15.

Pre-treatment chemicals

Adding chemicals to raw water *at* or *before* the start of the treatment process is called pre-treatment. Chlorine or potassium permanganate is sometimes added at the beginning of treatment to oxidize contaminants in the source water. Oxidation of organic contaminants reduces the formation of disinfection byproducts. Oxidation of certain inorganic contaminants (e.g., metals) will cause them to come out of solution and form solids that can settle or be removed by filtration. Keeping the pre-chlorine dosage low may help reduce the disinfection byproducts in the distribution system but still must be adequate to kill the bacteria that may be in the water.

If the water is acidic, the pH (a measure of acidity) can be adjusted using chemicals, such as soda ash, lime, and caustic soda, among others. Adjusting the pH helps prevent corrosion in the distribution lines and aids in the coagulation process.

Most surface water systems that deal with turbidity usually add a coagulant, a chemical that helps make dirt particles stick together so that they become heavier and settle more easily. Typical coagulant chemicals are alum (potassium aluminum sulfate or potash alum) or a polymer, such as polyaluminum chloride.

Mixing of pre-treatment chemicals

When the pre-treatment chemicals are added, they should be thoroughly mixed with the raw water. Proper mixing of the chemicals can speed the process and even reduce the amount of chemicals used and, in the long run, save money. Static mixers or flash chambers are used for mixing pre-treatment chemicals.

Coagulation

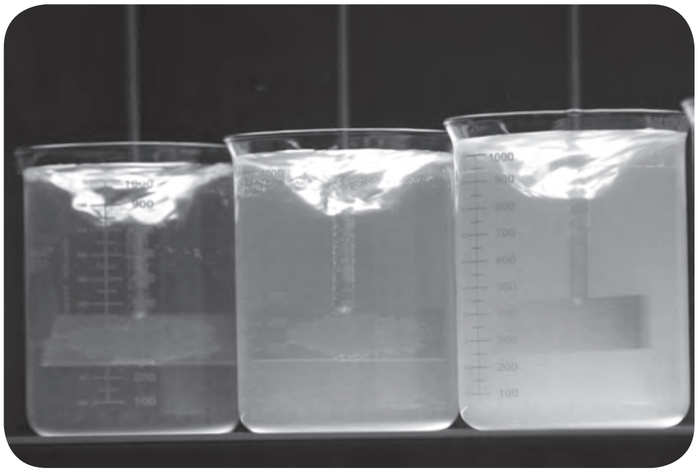
When the raw water and chemicals are mixed, the coagulation process begins. Coagulation chemicals cause organic and other particulates to combine. When particulates combine, they are more easily removed from the treated water because they become heavier and sink or settle to the bottom of the tank or basin. This action allows the cleaner water on the surface to move on to the next step in the treatment plant.

Although the terms *coagulation* and *flocculation* are often used interchangeably, or the single term *flocculation* is used to describe both, they are, in fact, two distinct processes. Factors that affect the coagulation process include temperature, pH, alkalinity (a measure of a solution's ability to neutralize acids), mixing of the chemicals, the type of chemical, and turbidity levels.

Flocculation

When the coagulant is added, the smaller dirt particles stick together and form bigger particles. This is called the "floc." In the flocculation process, water flows into a tank or tanks with paddles that provide slow mixing of the coagulant chemicals. This brings small particles together to form larger particles or clumps. If the mixing is too fast, the flocs will break apart into small particles that are difficult to remove by settling or filtering.

The flocculation process can start as water leaves the flash mix chamber or tank and typically moves into a series of two or more very slow moving paddle mixers. The second paddle is sometimes slower than the first. The paddle mixers can be similar to the flash mix but at a much slower rate. A gradual stilling or calming of the water helps the floc form and keeps it from breaking apart.



Source: National Environmental Services Center

Source: National Environmental Services Center

Refer to the diagram showing these steps on pages 14-15.

Sedimentation

After the dirt particles have "flocked" together, they need a place to "settle out" or sink to the bottom of the tank or basin. The key factors in good sedimentation are surface area, time, calm water, and a way to remove the sedimentation once it has sunk to the bottom of the tank or basin.

The larger the area of the tank, the calmer the water, and the more time for the process, the better the sedimentation. The tank or basin must be deep enough for the sedimentation process. Water should enter the sedimentation basin as slowly as possible. Keeping the water calm ensures that the dirt settles faster. Baffling or curtain walls can help keep the water calm. Time can be extended with baffling or curtain walls that make the flow zigzag from one end of the treatment basin to the other. If the line of flow is too straight and short, it could short-circuit the flow path. Consequently, the flocculation and sedimentation process will be disrupted.

Once the sediment sinks to the bottom of the tank, it has to be removed or it will build up and cause problems in the next step of the treatment process. Some sediment basins have cone-shaped bottoms where the sediment is collected. Others have bottoms that slope to one end or have squeegee baffles that very slowly scrape the bottom, collecting the sediment at one end.

The sediment is then pumped out into a sludge basin, or, if the water treatment plant is connected to a city sewer system, it's pumped into the sewer system. Some plants without automated sediment collection must periodically drain the sedimentation basin and manually clean it out. Even some automated plants should be drained and cleaned occasionally.

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Ion exchange

Hard water contains high levels of minerals, such as calcium and magnesium, known as hardness ions. Hardness ions usually aren't harmful, but they can cause a number of unwanted effects in everyday life, such as soap that won't get sudsy. The biggest concerns, however, are with pumping fixtures and pipes, and the build-up of scale and corrosion, possibly leading to costly breakdowns and replacements. Ion exchange is the substitution of one ion for another and is one treatment method that can combat hard water issues. For example, if sodium chloride is added to water that is considered hard because it contains high levels of calcium, the sodium ions will exchange with calcium ions, which will help soften the water.

While ion exchange is primarily used to remove magnesium and calcium, it may also effectively remove a high percentage of barium, cadmium, chromium, silver, radium, nitratesselenium, and arsenic. In addition, ion exchange can be a good treatment choice to remove radionuclides, although these and other contaminants may result in the ion exchange reclamation water being hazardous. In such cases, disposal of the waste can be difficult and expensive.

Direct filtration

After sedimentation, filtration is generally the next step. However, some systems use direct filtration, meaning that the raw water goes straight to the filters, bypassing coagulation, flocculation, and sedimentation. If the raw water, either groundwater or surface water, is good quality (it has low turbidity and few, if any, other contaminants, even during storm events or seasonal changes), then filtration may be the only treatment the water needs, aside from disinfection.

SOURCE TO DRINKING

SURFACE WATER SYSTEMS FROM SOURCE TO TAP
Intakes (A)
Pre-settlement (B)
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Taste and odor control (K)
Clear well (L)
Point of use/point of entry (M)
Testing, monitoring and reporting (N)
Clean, safe drinking water (O)
Refer to the diagram showing these steps on pages 14-15.

Filtration

Federal and state laws require many water systems to filter their water to remove contaminants that didn't settle out during coagulation, flocculation, and sedimentation processes. Filtration simply means passing the water through a permeable fabric or a bed of porous material, such as sand, that collects, catches, or gathers suspended solids from an incoming flow. Filtration methods include slow and rapid sand filtration, pressure vessel filters, membrane filtration, cartridge filtration, bag filtration, and diatomaceous earth filtration.

When the filter's pores become clogged, they need to be cleaned. This typically involves a backwash, which is reversing the flow and increasing the speed at which water passes back through the filter. This, in effect, blasts the clogged particles off and out of the filter. Although every filter is unique, the principles of backwashing are similar for all filters except slow sand filters, in which the top few inches are periodically skimmed off.

Types of filters

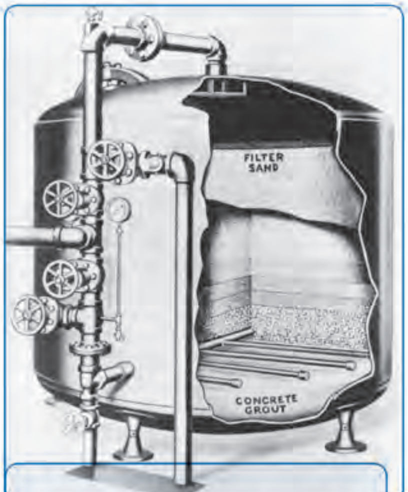
Rapid sand filters

Rapid sand filters are the most common types of filters. These are concrete or steel boxes that contain different types and sizes of sand that are layered about three feet thick. Support gravel keeps the sand in place and acts as an underdrain for the filtered water to exit through. Rapid sand filters are most widely used to treat surface water supplies to remove turbidity and microorganisms.

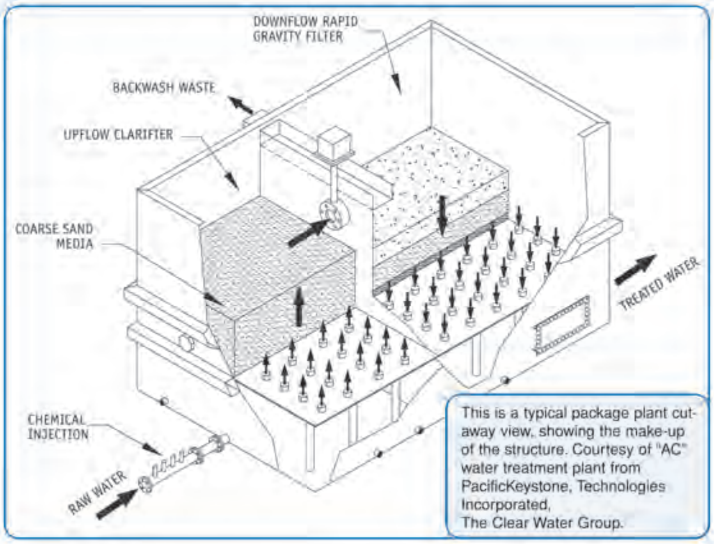
This photo shows a cross-section structure of a typical rapid sand filter.

Pressure vessel filters

These filters are very similar in design to rapid sand filters. However, pressure vessel filters are entirely contained and pressurized. They may be either vertical or horizontal. When water passes through these filters, the pressure aids in moving the water quickly through the filter media, yet they effectively filter out particles.



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



This is a typical package plant cut-away view, showing the make-up of the structure. Courtesy of "AC" water treatment plant from PacificKeystone, Technologies Incorporated, The Clear Water Group.

Source for all images on this page: Inflico Degremont, Inc.

SOURCE TO DRINKING

Slow sand filters

Biological processes are important for slow sand filters. In fact, for a slow sand filter to work properly, it must form a biofilm. This gelatinous layer, referred to as the *Schmutzdecke*, provides the treatment that makes the water potable. The *Schmutzdecke* contains microorganisms that trap and break down algae, bacteria, and other organic matter before the water reaches the filter medium. A slow sand filter bed consists of fine sand that is three to four feet deep and is supported by a one-foot layer of gravel and an underdrain system. Slow sand filters are simple in design, require little or no treatment chemicals, power, or replacement parts, and little operator training is necessary for them to function well. The slow rate of flow through the filter makes this type of filter less efficient for larger populations.

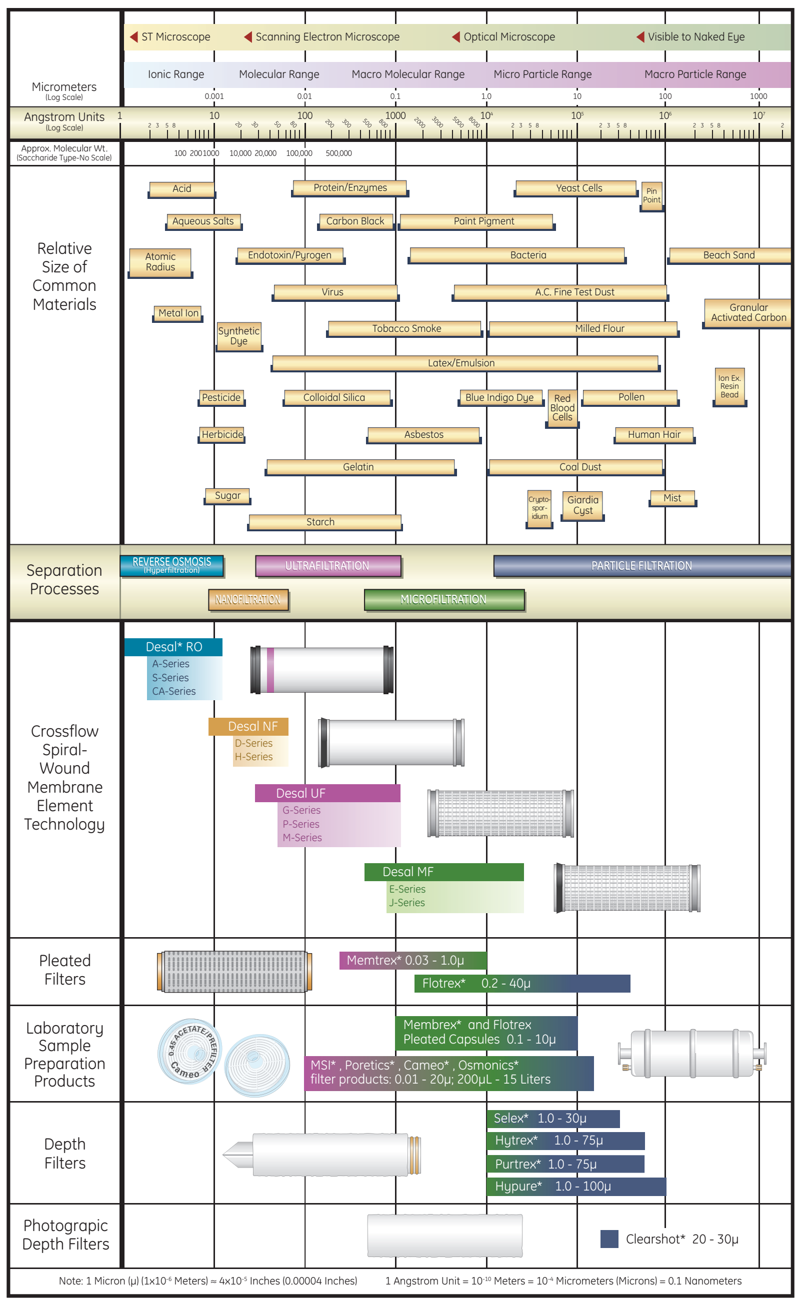
Membrane filters

With membrane filters, water passes through a semi-permeable membrane, a porous material whose filtering capability is determined by the size of its pores. The pores act as a barrier to particles that are larger than the pores while water passes freely through the membrane. Membrane processes include microfiltration, ultrafiltration, nanofiltration, and reverse osmosis.

Cartridge filters

Cartridge filters are considered for point-of-use or point-of-entry technology that is suitable for removing microbes and turbidity in small systems. Water is strained through these filters using a porous medium. They can remove particles that measure micrometers in size, which is one-millionth of a meter (a strand of hair usually has a diameter of 20 to 180 micrometers; red blood cells are approximately 8 micrometers in diameter). These filters are suitable for removal of a number of different contaminants.

Filtration Spectrum



Filtration Spectrum © 2011 General Electric Co.

Bag filters

Bag filters are very similar to cartridge filters in that an element (the bag) is doing the physical filtration and needs to be backwashed and/or replaced at regular intervals, depending on the source water. Some, if not all, states require pilot testing with the source water before bag filters or cartridge filters are used. Bag and cartridge filters are usually for low flows.

Diatomaceous earth filters

Diatomaceous earth filtration is a process that uses diatoms or diatomaceous earth—the skeletal remains of small, single-celled organisms—as the filter media. This type of filtration relies on a layer of diatomaceous earth approximately 1/8-inch thick placed on a filter element. This method is frequently referred to as pre-coat filtration. This media may be placed in pressure vessels or operated under a vacuum in open vessels. Diatomaceous earth filters are simple to operate and are effective in removing spores, algae and asbestos from water. Some microorganisms can assume a dormant form that enables them to survive high temperatures, dryness, and lack of nourishment for long periods of time. Under proper conditions, the microorganisms may revert to their actively multiplying form.

Sludge disposal

Most surface water systems and some groundwater systems have to deal with sludge disposal. The sludge comes from all of the particulates that settle in the sedimentation basins and are caught from the filters when backwashed.

Backwash recycling is an option that can come in handy in times of need, such as a drought. Recycling backwash water is often a standard procedure, and some states require systems to recycle it. Recycling backwash water involves using a separate basin or basins that can hold the volume of several backwashes to settle out solids and transferring the water back to the head of the plant to be run through the treatment processes again.

Keep in mind that the Filter Backwash Recycling Rule includes a provision that no more than 10 percent of the incoming flow can be decanted backwash water. The sludge that remains in the backwash or sludge basin after decanting will eventually have to be pumped out and either hauled to a landfill or to a sewage treatment plant for proper disposal. Most states do not allow land application of sludge from a drinking water plant because of possible heavy metals and other concentrated contaminants.

SURFACE WATER SYSTEMS
FROM SOURCE TO TAP

- Intakes (A)
- Pre-settlement (B)
- Pre-treatment chemicals (C)
- Coagulation (D)
- Flocculation (E)
- Sedimentation (F)
- Ion exchange (G)
- ▶ Filtration (H)
- ▶ Sludge disposal (I)
- Post-treatment chemicals (J)
- Taste and odor control (K)
- Clear well (L)
- Point of use/point of entry (M)
- Testing, monitoring and reporting (N)
- Clean, safe drinking water (O)

Refer to the diagram showing these steps on pages 14-15.

SURFACE WATER SYSTEMS
FROM SOURCE TO TAP

Refer to the diagram showing these steps on pages 14-15.

Post-treatment chemicals

In addition to using chemicals early in the treatment process, there are chemicals that are added toward the end of the process. The most important of these chemical treatments is disinfection, which serves as a crucial part of the multiple-barrier approach to the provision of safe water.

Disinfection

Whether treated water comes from a filter or is unfiltered from a groundwater source, it is disinfected as the water flows into the clear well tank. This is known as post-disinfection.

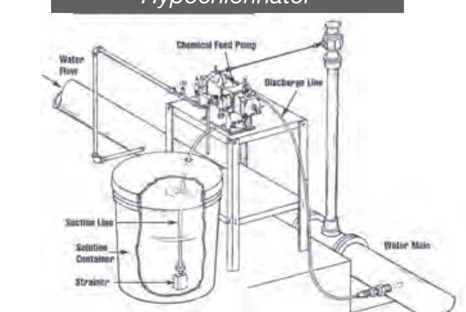
In some plants, post-disinfection may be all the disinfection that is needed. Disinfection is the process of destroying a large portion of microorganisms in drinking water with the probability that pathogenic (disease-causing) organisms are killed in the process.

Chlorine

Chlorine is the most common chemical used for disinfection. It is typically used in either liquid (sodium hypochlorite solution or a solution made from calcium hypochlorite powder) or gaseous form. The liquid form is supplied to the water by a hypochlorination system. Hypochlorination is the most common means of disinfection for small water systems.

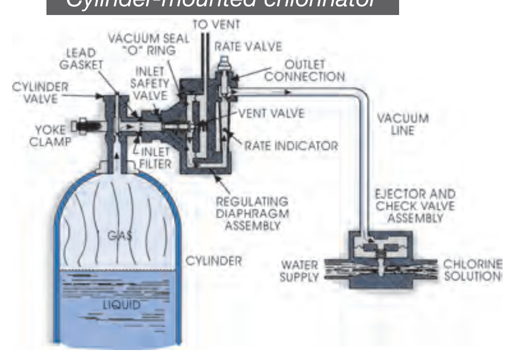
- ***Hypochlorination feed systems***
  The typical hypochlorination system consists of a chemical feed pump, a solution of sodium or calcium hypochlorite, and electrical and flow control systems.

Hypochlorinator



Adapted by the National Environmental Services Center from Wallace and Tiernan Division, Pennwalt Corp.

Cylinder-mounted chlorinator



Source: National Environmental Services Center

- **Chlorine dosage, chlorine demand and disinfectant residual**

  The total amount of chlorine fed into a volume of water by the chlorine feed equipment is referred to as dosage and is calculated in milligrams per liter (mg/L). When injected into water, it combines readily with certain inorganic substances (e.g., hydrogen sulfide, ferrous iron, nitrate, etc.) and with organic impurities, including microorganisms and nitrogen compounds (e.g., animal wastes, ammonia from fertilizers, etc.). The amount of chlorine that combines with various components of the water is called the chlorine demand. The chlorine dosage must be adequate to meet the chlorine demand and still achieve the desired disinfectant residual concentration.

- **Chlorine testing**

  The kit used for chlorine testing must be EPA-approved. This can be verified by checking with your local state regulatory staff. The test kits are provided with detailed instructions on proper running of chlorine tests. It is also important to insure that all chemicals used in the testing procedure are used before the expiration date on the packages.

Chlorine safety and handling

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Chlorine, whether in gas, solution, or powdered form, is the most dangerous chemical used at most drinking water systems. Proper storage, use, transport, and personal protection can save lives. Exposure to chlorine can lead to:

- skin burns
- lung congestion
- pulmonary edema
- pneumonia
- pleurisy
- bronchitis
- death

Chlorine gas is greenish-yellow in color. It is much heavier than air, which means it will sink to low spots—whether these are near the floor of a building or in a populated valley downhill from the treatment plant. Chlorine gas cylinders must be secured to floors or walls and labeled. Transport vehicles and the building where the chlorine is stored must be identified with signs. Plant staff working with chlorine gas must be equipped with a self-contained breathing apparatus (SCBA) with a mask that has been fitted to the user. Work with chlorine gas cylinders should be conducted only with a trained, SCBA-equipped partner standing by. In the event of a leak in the building where chlorine gas is stored or being worked with, staff in building should keep their heads high and leave the building as soon as possible.

Sodium hypochlorite solution is pale yellow in color and is very corrosive and aggravating to skin and respiratory passages. Calcium hypochlorite powder (called HTH in the water industry) is also extremely reactive. Appropriate personal protective equipment for liquid and powdered forms of chlorine includes:

- safety glasses or full-face shield
- long sleeves
- rubber gloves
- respirator (half or full-face)
- long pants
- steel-toed shoes

Plant managers should notify emergency personnel (police and firefighters) of the type and location of the disinfectant(s) used at the plant.

Refer to the diagram showing these steps on page 14.

Other disinfectant and treatment measures

Other disinfectant products may be used, such as chloramines, ozone, or ultraviolet light, or additional tasks may be performed that affect water quality, such as fluoridation, pH adjustment, and the use of sequestering agents. In simple terms, to sequester a mineral or molecule is to keep it in suspension. However, the ultimate result is that the sequestered compound or molecule is made unavailable to interact with the surrounding environment.

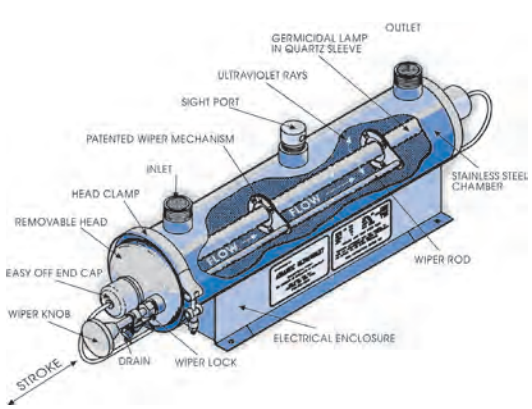
Chloramines form when chlorine is added to water that contains ammonia or when ammonia is added to water that contains chlorine (hypochlorite or hypochlorous acid). Chloramines are sometimes used in low concentrations as a secondary disinfectant in municipal water distribution systems because they are much more stable than chlorine. It is also believed that chloramines are less likely to produce disinfection byproducts, such as chloroform, although there are still small amounts produced. In addition, chloramines do not have a chlorine aftertaste.

Ozone is a powerful oxidizing and disinfecting agent. Many municipal drinking water systems use ozone to kill bacteria instead of the more common chlorine because it has a very high oxidation potential. Ozone does not form organochlorine compounds, which are toxic, but ozone can form a toxic disinfection byproduct when the raw water contains bromine. Ozone does not remain in the water after treatment. The drinking water regulations mandate that these systems must maintain a disinfectant residual in the distribution system.

Ultraviolet light radiation can be used to disinfect. The ultraviolet light is generated by a special lamp. When it penetrates the cell wall of an organism, the cell's genetic material is disrupted, and the cell is unable to reproduce. As with ozone, a disinfectant residual is needed to maintain a safe barrier against any contaminants in the distribution system. Again, this residual is usually achieved with chlorine.

Another disinfectant is **chlorine dioxide.** It is a synthetic, green-yellowish gas with a chlorine-like, irritating odor and is explosive under pressure. It is difficult to transport and is usually manufactured on-site.

Ultraviolet light purifier



Source: National Environmental Services Center

Disinfection byproducts

Disinfection byproducts are formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter (e.g., decaying vegetation) present in the source water. Different disinfectants produce different types of disinfection byproducts. Disinfection byproducts for which drinking water regulations have been established include trihalomethanes, haloacetic acids, bromate, and chlorite.

Trihalomethanes (THM) are a group of four chemicals that can be formed when chlorine is used to control microbial contaminants in drinking water: chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The Stage 1 Disinfectants/Disinfection Byproducts Rule regulates total trihalomethanes (TTHM) at a maximum allowable annual average level of 80 micrograms per liter (µg/L), which is the same as 80 parts per billion (ppb).

Haloacetic acids, known as HAA5, are another group of chemicals that can be formed when chlorine is used to control microbial contaminants in drinking water. The regulated haloacetic acids are: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. The maximum allowable annual average for the HAA5 group is 60 micrograms per liter (µg/L), which is the same as 60 parts per billion (ppb).

Bromate is a chemical that can be formed when ozone used to disinfect drinking water reacts with naturally occurring bromide found in some source water. The maximum allowable annual average for bromate is 10 micrograms per liter (µg/L), which is the same as 10 parts per billion (ppb).

Chlorite is a byproduct formed when chlorine dioxide is used to disinfect water. Chlorite in drinking water is regulated at a monthly average level of 1 milligram per liter (mg/L), which is the same as 1 part per million (ppm).

Taste and odor control

Activated carbon, although not a chemical, is used to control taste and odor problems. It is typically added in granular form to the sediment basin or on top of the filters. The contaminants are adsorbed onto the activated carbon.

Some systems add fluoride at the end of the treatment process to reduce tooth decay in their customers. Fluoridation does not affect the appearance, taste or smell of drinking water. It is normally accomplished by adding one of three compounds to the water: sodium fluoride, fluorosilicic acid, or sodium fluorosilicate. Fluoride can occur naturally in some groundwater systems, even to the extent of too much of it, which would have to be blended or reduced by membrane filtration.

Before the finished or treated water enters the distribution system, additional chemical adjustments may be needed to restore the water to a safe pH range and to prevent it from being corrosive.

Clear well

After filtration, the water goes to a clear well, which is really just a storage tank. The clear well is usually at the plant, but at some systems, it could be the first or *only* storage tank in the distribution system. Drinking water systems use the clear well for disinfection (usually chlorine) contact time. Contact time gives the disinfectant time to kill any microorganisms that may have made it through the treatment process. Also, drinking water systems often use the clear well to store water that will be used to backwash the filters.

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Refer to the diagram showing these steps on page 14.

Point-of-use/Point-of-entry (POU/POE)

Some small water systems find complying with EPA's MCL requirements difficult because of the cost associated with installing large-scale treatment technologies. In these situations, POU/POE water-treatment systems in customers' homes may provide a low-cost alternative to centralized water systems, if the state rules allow them.

The 1996 SDWA lists POU/POE systems as options for compliance technologies. When a water system uses this technology to comply with a National Primary Drinking Water Regulation, the SDWA states that the public water system or a person under contract with the public water system shall own, control, and maintain the POU/ POE system to ensure proper operation, maintenance and compliance. The act also states that the treatment mechanism should be equipped with mechanical warnings that automatically notify customers of operational problems.

Testing, monitoring and reporting

Testing and monitoring can be very costly for a small drinking water system. Despite the cost, both raw and finished water must be tested regularly. Each drinking water system is required by law to monitor and report on numerous water-quality parameters from source to tap. The monitoring is a large part of the multiple-barrier approach and is important to assure that water quality remains high and the health of the water system's customers is protected.

Monitoring plans are required by your primacy agency. A water system's monitoring plan must include:

1. system summary
2. water source details
3. water treatment details
4. distribution system details
5. individual rule (regulation) sampling plans, which meet regulations

Primacy agencies usually have monitoring plan templates available online. Schedules for sampling will be provided to the water system by the primacy agency.

Sampling plans must describe sampling sites, established test parameters and monitoring frequencies, field-monitoring protocols, and laboratory strategies. The most commonly monitored test parameters to determine the water quality in the general distribution system include coliform bacteria, heterotrophic plate count bacteria, disinfectant residual, temperature, turbidity, pH, color, and disinfection byproducts.

State and tribal agencies usually require utilities to submit their sampling and monitoring plans for approval.

Testing or analyzing at the plant

The operator of a small drinking water system has many responsibilities, including collecting water samples and testing or having the water quality tested by someone else to make sure it is safe to drink and aesthetically agreeable to customers. The operator must take samples at various treatment stages to make sure that the systems are functioning properly.

Continuous monitoring devices, such as chlorine residual or turbidity analyzers, are good examples of automatic process-control testing. These automatic or inline analyzers provide continuous data to the operator about how the equipment is operating and the quality of the water being produced. These continuous monitoring devices can be expensive and are mandatory even in small systems.

Compliance testing

Compliance testing includes checking for the 87 different contaminants on the National Primary Drinking Water Regulations list and the 15 contaminants on the National Secondary Drinking Water Regulations list. It also includes monitoring the distribution system. The national primary and secondary drinking water standards have set limits or maximum contaminant levels (MCLs). EPA sets these standards for drinking water quality.

To set an MCL for a contaminant, EPA first determines how much of the contaminant may be present with no adverse health effects. This level is called the maximum contaminant level goal (MCLG). MCLGs are non-enforceable public health goals. The legally enforced MCL is then set as close as possible to the MCLG. The MCL for a contaminant may be higher than the MCLG because of difficulties in measuring small quantities of a contaminant, a lack of available treatment technologies, or if EPA determines that the costs of treatment would outweigh the public health benefits of a lower MCL. In the last case, EPA will set the MCL to balance the cost of treatment with the public health benefits.

For some contaminants, EPA establishes a treatment technique (TT) along with an MCL. TTs are required processes intended to reduce the level of a contaminant in drinking water. An example of a TT is reducing the corrosiveness of water in order to lower the concentration of lead and copper.

Primary drinking water standards are health-based and are enforceable by law. Secondary standards are esthetic and are not enforceable.

Some contaminants may cause esthetic problems with drinking water, such as the presence of unpleasant tastes or odors, or cosmetic problems, such as tooth discoloration. Since these contaminants do not cause health problems, there are no legally enforceable limits on their presence in drinking water. However, EPA recommends maximum levels of these contaminants in drinking water.

The amount, frequency and scheduling of tests depends on the system's population size and the detection of any contaminants. For small and very small drinking water systems, reduced monitoring for some contaminants may be granted if certain contaminants were not detected in the past, such as the four different radionuclides or lead and copper. Also some waivers can be granted for future testing if the initial required tests show the levels to be zero or below a certain limit. Reduced monitoring or waivers do not apply to all the contaminants. However, reduced monitoring waivers may be granted with a source water assessment.

The distribution system must be monitored for chlorine residual, pH, bacteria, lead and copper, and disinfection byproducts (DBPs). The DBPs test samples are taken where the water has the longest residence time, which is usually at the farthest reaches of the distribution system. These DBPs develop when chlorine is added to water that has high total organic carbon (TOC).

One way to reduce the DBPs is to reduce the TOCs or reduce the chlorine dosage at the treatment plant but still maintain safe chlorine levels to kill the microorganisms and maintain a residual in the distribution system.

Clean, safe drinking water

Once the source water has passed through all of the steps described above, it is considered "finished" water. Now, this vital resource can be distributed to homes and businesses in your community.

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SOURCE TO DRINKING