

## Lesson 16:

### Distribution Systems

#### Objective

In this lesson we will answer the following questions:

- What are the major components of the distribution system?
- How does an operator know his pumps and valves are big enough for the water supply?
- How much water must a system plan for to provide enough water for a population?

#### Reading Assignment

Read the online lecture.

#### Lecture

Distribution system infrastructure is generally the major asset of a water utility. The American Water Works Association (AWWA) defines the water distribution system as "including all water utility components for the distribution of finished or potable water by means of gravity storage feed or pumps through distribution pumping networks to customers or other users, including distribution equalizing storage." These systems must also be able to provide water for nonpotable uses, such as fire suppression and irrigation of landscaping.

Distribution lines span almost 1 million miles in the U.S. and include an estimated 154,000 finished water storage facilities. As the population grows and communities expand, 13,200 miles of new pipes are installed each year. Because distribution systems represent the vast majority of physical infrastructure for water supplies, they constitute the primary management challenge from both an operational and public health standpoint. Furthermore, their repair and replacement represent an enormous financial liability; EPA estimates the 20-year water transmission and distribution needs of the country to be \$183.6 billion with storage facility infrastructure needs estimated at \$24.8 billion.

A distribution system is a network of water lines (pipes) that deliver treated water to consumers. The distribution system, or infrastructure, consists of the following major components:

- Pipes (transmission lines) for delivering water
- Pumps for pumping and maintaining pressure
- Valves to control water flow
- Reservoirs and elevated tanks for water storage
- Meters to measure the quantity of water supply
- Fire hydrants to provide sufficient pressurized water for firefighting

We will cover pumps and motors in a separate lesson.

#### Infrastructure

Distribution system infrastructure is generally considered to consist of the pipes, pumps, valves, storage tanks, reservoirs, meters, fittings, and other hydraulic equipment that connect treatment plants or well supplies to consumers' taps. The characteristics, general maintenance requirements, and desirable features of the basic infrastructure components in a drinking water distribution system are briefly discussed here.

#### Pipes

The system of pipes that transport water from the source, such as a treatment plant, to the customer are often categorized from largest to smallest as transmission or trunk mains, distribution mains, service lines, and premise plumbing.

- **Transmission or trunk mains** usually convey large amounts of water over long distances such as from a treatment facility to a storage tank within the distribution system. They are frequently 24 inches in diameter, or greater. A dual-purpose main, which is used for both transmission and distribution, is normally 16-20 inches in diameter.
- **Distribution mains** are typically smaller in diameter than the transmission mains and generally follow the city streets. They are usually 4-12 inches in diameter.

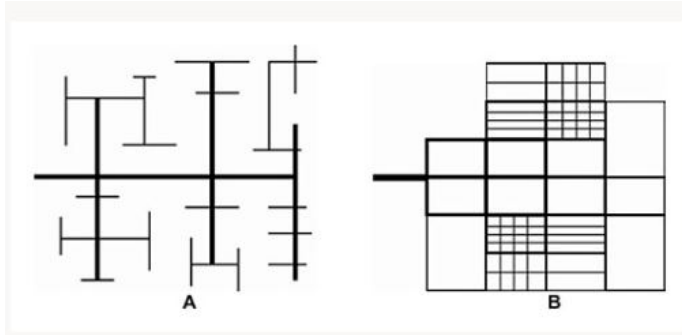
- **Service lines** carry water from the distribution main to the building or property being served. Service lines can be of any size, but are usually 1 inch in diameter, or smaller.
- **Premise plumbing** refers to the piping within a building or home that distributes water to the point of use. In premise plumbing the pipe diameters are usually comparatively small, leading to a greater surface-to-volume ratio than other distribution system pipes. This type of piping is the building owner's responsibility.

The three requirements for a pipe include its ability to deliver the quantity of water required, to resist all external and internal forces acting upon it, and to be durable and have a long life.

The materials commonly used for this are ductile iron, pre-stressed concrete, polyvinyl chloride (PVC), reinforced plastic, and steel.

### Pipe-Network Configurations

The two basic configurations for most water distribution systems are the **branched** and **grid/loop** configurations, illustrated below:



*Branched configuration*

*Grid/Loop Configuration*

A **branch system** is similar to that of a tree branch, in which smaller pipes branch off larger pipes throughout the service area, such that the water can take only one pathway from the source to the consumer. This type of system is most frequently used in *rural areas*. This makes sense, right? Why waste so much piping to loop back around to your neighbor who may live 10 miles away in a rural setting. Pipe the water to the consumer who needs it and stop.

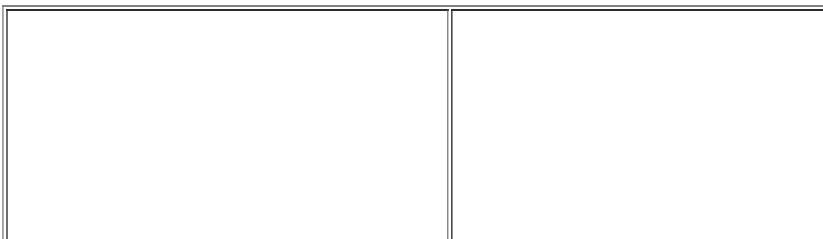
A **grid/loop system**, which consists of connected pipe loops throughout the area to be served, is the most widely used configuration in *large municipal areas*. In this type of system there are several pathways that the water can follow from the source to the consumer. Looped systems provide a high degree of reliability should a line break occur because the break can be isolated with little impact on consumers outside the immediate area. Also, by keeping water moving, looping reduces some of the problems associated with water stagnation, such as adverse reactions with the pipe walls, and it increases fire-fighting capability. However, loops can be dead-ends, especially in suburban areas like cull-de-sacs, and have associated water quality problems. Most systems are a combination of both looped and branched portions.

Design of water networks is very much dependent on the specific topography and the street layout in a given community. A typical design might consist of transmission mains spaced from 1.5 to 2 miles apart with dual-service mains spaced 3,000 to 4,000 feet apart. Service mains should be located in every street.

### Storage Tanks and Reservoirs

Storage tanks and reservoirs are used to provide storage capacity to meet fluctuations in demand (or shave off peaks), to provide reserve supply for fire-fighting use and emergency needs, to stabilize pressures in the distribution system, to increase operating convenience and provide flexibility in pumping, to provide water during source or pump failures, and to blend different water sources.

The recommended location of a storage tank is just beyond the center of demand in the service area. Elevated tanks are used most frequently, but other types of tanks and reservoirs include in-ground tanks and open or closed reservoirs. Common tank materials include concrete and steel.





*Elevated Storage Tank*



*In-ground Storage Tank*



*Open Reservoir*



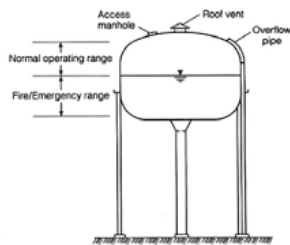
*Closed Reservoir*

An issue that has drawn a great deal of interest is the problem of low water turnover in these facilities resulting in long detention times. Much of the water volume in storage tanks is dedicated to fire protection, and unless utilities properly manage their tanks to control water quality, there can be problems attributable to both water aging and inadequate water mixing.

Excessive water age can be conducive to depletion of the disinfectant residual, leading to biofilm growth, other biological changes in the water including nitrification, and the emergence of taste and odor problems.

Improper mixing can lead to stratification and large stagnant (dead) zones within the bulk water volume that have depleted disinfectant residual. Security is an important issue with both storage tanks and pumps because of their potential use as a point of entry for deliberate contamination of distribution systems.

Storage within a distribution system enables the system to process water at times when treatment facilities otherwise would be idle. It is then possible to distribute and store water at one or more locations in the service area that are closer to the user. The principle advantages of distribution storage include the fact that storage equalizes demands on supply sources, production works, and transmission and distribution mains. As a result, the sizes or capacities of these elements need not be so large. Additionally, system flows and pressures are improved and stabilized to better serve the customers throughout the service area. Finally, reserve supplies are provided in the distribution system for emergencies, such as firefighting and power outages.



The location, capacity, and elevation (if it is elevated) of distribution storage are closely associated with system demands and the variations in demand that occur throughout the day in different parts of the distribution system. System demands can be determined only after a careful analysis of an entire distribution system. In normal water system operations, some water from storage should be used each day, not only to maintain uniformity in production and pumping, but also to ensure circulation of the stored water to prevent aging of the water, which affects water quality.

Storage in the distribution system is normally brought to full capacity each night and is increased during low-demand periods of the day. Normally, it is more advantageous to provide several storage units in different parts of the water distribution system than it is to provide an equivalent capacity at a central location. Smaller pipelines are required to serve decentralized storage and, other things being equal, a lower flow-line elevation and pumping head result.

## Hydrants

Hydrants are primarily part of the fire fighting aspect of a water system. Proper design, spacing, and maintenance are needed to ensure an adequate flow to satisfy fire-fighting requirements. Fire hydrants are typically exercised and tested annually by water utility or fire department personnel. Fire flow tests are conducted periodically to satisfy the requirements of the water system calibration program, or of the Insurance Services Office. Fire hydrants are installed in areas that are easily accessible by fire fighters and are not obstacles to pedestrians and vehicles.

In addition to being used for fire fighting, hydrants are also for routine flushing programs, emergency flushing, preventive flushing, testing and corrective action, and for street cleaning and construction projects. A fire hydrant has at least *two 2.5-inch outlets* and a *gate valve* between itself and the water main. It should be able to *deliver 600 gpm* with a *head loss not over 2.5 lb in the hydrant* and *5 lb from the main to the outlet*. There should be a good drainage of water around it after the fire hydrant valve is closed.

## Infrastructure Design and Operation

The function of a water distribution system is to deliver water to all customers of the system in sufficient quantity for potable drinking water and fire protection purposes, at the appropriate pressure, with minimal loss, of safe and acceptable quality, and as economically as possible. To convey water, pumps must provide working pressures, pipes must carry sufficient water, storage facilities must hold the water, and valves must open and close properly. Indeed, the carrying capacity of a water distribution system is defined as its ability to supply adequate water quantity and maintain adequate pressure. Adequate pressure is defined in terms of the minimum and maximum design pressure supplied to customers under specific demand conditions. The maximum pressure is normally in the range of 80 to 100 psi; for example, the Uniform Plumbing Code requires that water pressure not exceed 80 psi at service connections, unless the service is provided with a pressure-reducing valve. The minimum pressure during peak hours is typically in the range of 40 to 50 psi, while the recommended minimum pressure during fire flow is 20 psi.

## Residential Drinking Water Provision

Of the 34 billion gallons of water produced daily by public water systems in the U.S., approximately 63 percent is used by residential customers for indoor and outdoor purposes. Outdoor water use varies from region to region and includes irrigation. Most of the water supplied to residences is used primarily for laundering, showering, lawn watering, flushing toilets, or washing cars, and not for consumption. Nonetheless, except in a few rare circumstances, distribution systems are assumed to be designed and operated to provide water of a quality acceptable for human consumption. Normal household use is generally in the range of 200 gpd with a typical flow rate of 2 to 20 gpm.

## Fire Flow Provision

Besides providing drinking water, a major function of most distribution systems is to provide adequate standby fire flow, the standards for which are governed by the National Fire Protection Association. Fire flow requirements for a single family house vary from 750 to 1,500 gpm; for multi-family structures the values range from 2,000 to 5,000 gpm; for commercial structures the values range from 2,000 to 10,000 gpm, and for industrial structures the values range from 3,000 to over 10,000 gpm. The duration for which these fire flows must be sustained normally ranges from three to eight hours.

In order to satisfy this need for adequate standby capacity and pressure, most distribution systems use standpipes, elevated tanks, and large storage reservoirs. Furthermore, the sizing of water mains is partly based on fire protection requirements set by the Insurance Services Office. The minimum flow that the water system can sustain for a specific period of time governs its fire protection rating, which is then used to set the fire insurance rates for the communities that are served by the system. As a consequence, fire flow governs much of the design of a distribution system, especially for smaller systems. Generally, nearly 75 percent of the capacity of a typical drinking water distribution system is devoted to fire fighting. The effect of designing and operating a system to maintain adequate fire flow and redundant capacity is that there are long transit times between the treatment plant and the consumer, which may be detrimental to meeting drinking water MCLs.

## Water Quality in the Distribution System

It is important to maintain the proper water quality in the distribution system until the last customer is served. Water quality deteriorates due to stagnancy, dead ends, cross connections and corrosion.

## Valves

The two types of valves generally utilized in a water distribution system are isolation valves, or shutoff valves, and control valves. **Shut off valves** (typically either gate or butterfly valves) are used to isolate sections for maintenance and repair and are located so that the area is isolated and will cause a minimum of inconvenience to other service areas. Maintenance of the valves is one of the major activities carried out by a utility. Many utilities have a regular valve-turning program in which a percentage of the valves are opened and closed on a regular basis. It is desirable to turn each valve in the system

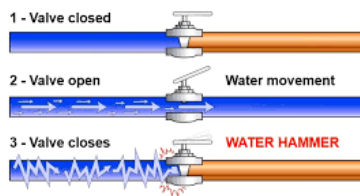
at least once per year. The implementation of such a program ensures that the water can be shut off or diverted when needed, especially during an emergency, and that valves have not been inadvertently closed.

**Control valves** are used to control the flow or pressure in a distribution system. They are normally sized based on the desired maximum and minimum flow rates, the upstream and downstream pressure differentials, and the flow velocities. Typical types of control valves include pressure-reducing, pressure-sustaining, and pressure-relief valves; flow-control valves; throttling valves; float valves; and check valves. Most valves are either steel or cast iron, although those found in premise plumbing to allow for easy shut-off in the event of repairs, are usually brass. They exist throughout the distribution system and are more widely spaced in the transmission mains compared to the smaller-diameter pipes.

Other equipment in a water system include blow-off and air-release/vacuum valves, which are used to flush water mains and release entrained air. On transmission mains, blow-off valves are typically located at every low point, and an air release/vacuum valve at every high point on the main. Blow-off valves are sometimes located near dead ends where water can stagnate or where rust and other debris can accumulate. Care must be taken at these locations to prevent unprotected connections to sanitary or storm sewers.

## Stagnancy

Stagnancy results when water stays too long in the lines. The water loses some of the residual disinfectant and dissolved oxygen. When water is stagnant, microbes such as iron, sulfur, nitrogen, or even coliform bacteria begin to multiply and produce objectionable by-products. Bacteria occur in a thin layer of organic and inorganic deposition, called **biofilm**, on the inner surface of water lines, where they multiply. Part of this film can be eroded by certain hydraulic conditions, such as high velocity and water hammer to replace these bacteria, resulting in high heterotrophic plate counts and even a positive coliform test.



The best remedy to stop the regrowth of microbes, is the adequate unidirectional (in the same direction as the normal flow) flushing of the distribution system and continuously maintaining an appropriate amount of residual disinfectant. Unidirectional flushing is important to maintain proper water quality by removing biofilm, maintaining disinfectant residual, and reducing erosion. If the water pH is low and chloramines are the residual disinfectant, then nitrification bacteria convert ammonia to nitrites, and nitrites to nitrates (nitrification).



Ammonia (NH<sub>4</sub>) → Nitrites (NO<sub>2</sub>) → Nitrates (NO<sub>3</sub>)

*Nitrification*

To stop nitrification, the pH of the water needs to be raised above 9.0. Water should be kept moving and lines should be kept flushed regularly.

## Dead Ends

Dead ends are the endings of the pipes without any movement of the water. There should be a regular flushing of the dead ends and cleaning as required to keep the water fresh.

## Cross Connection

Cross connection is any physical connection between the treated and non-treated water. Examples of cross connections are a direct pipe connection from a private water supply (well water) to the municipal water supply; discharge of the potable water supply below the water level in a swimming pool; and submerged inlets in lavatories, bath tubs, fountains, and spray tanks. When there is a high demand of water and pressure is low in the water lines, the non-

treated water is sucked into the public water supply system, sometimes resulting in serious health problems. Cross connection contaminations of drinking water with pesticides are reported. Sprinkler systems have also caused cross connections. There should always be backflow prevention, such as an air gap or a check valve, to protect the public water supply.

### Corrosion

Corrosion of water lines and plumbing fixtures can cause the leaching of harmful metals such as lead and copper into water, growth of objectionable microbes, and biofilm formation. Water should be noncorrosive. It does not matter how properly the water is treated unless it is delivered as good as it is treated. For proper delivery, proper maintenance of system and pressure are important.

### Distribution System Problems and Possible Solutions

Problems	Possible Causes	Possible Solutions
Water smells like a pesticide.	There is a cross connection. If pesticide is being sprayed in an area, look for the water line in the tank. A hose under the water in the tank is causing the problem.	Remove the hose and flush the area. Check the reservoir for any contamination. If contaminated, flush it, and clean it thoroughly before putting it back in service.
High heterotrophic bacterial count in the distribution system when chloramines are used for postdisinfection.	Nitrification, which is the conversion of ammonia into nitrites and then into nitrates by bacteria. It is indicated by pH around 8, stagnant smell of water, high nitrites and nitrates and red water complaints.	Increase the pH to an appropriate level (about 9) to solve the nitrification problem.
	Dead ends. This is indicated by red and stagnant water complaints and high HPC count. It occurs when chlorine gets low and dissolved oxygen is depleted in the stagnant water. Iron and sulfur bacteria become active and corrosion of pipes starts.	Unidirectional flushing of the area is the solution to this problem.
Pinkish deposits are on faucets.	High calcium carbonate in the water.	The color is due to a fungus growing on calcium carbonate deposits. Adjust the alkalinity and pH to reduce the calcium carbonate deposition potential.
There is a high chlorite content.	Inadequate ferrous treatment. Ferrous should be added before alum or lime.	Determine the needed dose of ferrous to remove the desired amount of chlorite. Apply three parts of ferrous for each part of chlorite.
There is a high chlorate content.	An old sodium hypochlorite solution used for chlorination can have high chlorates. Concentrated sodium hypochlorite has a high amount of chlorates.	Always use a fresh sodium hypochlorite solution. Normally sodium hypochlorite is 15%, dilute it to 7.5%.

### Distribution System Calculations

After water is adequately treated, it must be conveyed or distributed to the customer for domestic, commercial, industrial, and fire-fighting applications. Water distribution systems should be capable of meeting the demands placed on them at all times and at satisfactory pressures. Waterworks operators responsible for water distribution must be able to perform basic calculations for both practical and licensure purposes; such calculations deal with water velocity, rate of water flow, water storage tanks, and water disinfection. We will also look at calculations for pressure and force, head and head loss, horsepower, pump capacity and wire-to-water efficiency. Calculations pertaining to the distribution system also include the amount of water used per day per population.

### Basic Hydraulics

To operate a pump efficiently, the operator and/or maintenance operator must be familiar with several basic principles of hydraulics.

## Weight of Water

Because water must be stored and/or kept moving in water supplies we must consider some basic relationships regarding the weight of water.

- One cubic foot of water weighs 62.4 pounds and contains 7.48 gallons.
  - 1 ft<sup>3</sup>/62.4 lb
  - 1 ft<sup>3</sup>/7.48 gal
- Water 1 foot deep will exert a pressure of 0.433 pounds per square inch (psi) on the bottom area
  - 1 ft water/0.433 psi
- A column of water 2.31 feet high will exert 1.0 psi.
  - 2.31 ft/1 psi

The term **head** is used to designate water pressure in terms of the height of a column of water in feet. For example, how many psi will a 10-foot column of water exert?

$$10 \text{ ft} \times \frac{0.433 \text{ psi}}{1 \text{ ft}} = 4.33 \text{ psi}$$

A 10-foot column of water exerts 4.33 psi.

You can work it with another water weight conversion: 2.31 ft/psi:

$$10 \text{ ft} \times \frac{1 \text{ psi}}{2.31 \text{ ft}} = 4.33 \text{ psi}$$

## Water at Rest

Stevin's law states: "The pressure at any point in a fluid at rest depends on the distance measured vertically to the free surface and the density of the fluid." Wow! So what does that mean, or even matter? It basically means that due to natural physics, water and other fluids will always find their horizontal level. Water at rest is measured in units of volume, such as cubic foot and acre-foot.

- 1 ft<sup>3</sup>/62.4 lb
- 1 ft<sup>3</sup>/7.48 gal
- 1 acre-ft/326,000 gal

*Example:*

**How much does 10.8 gallons of water weigh, in lbs, if it is at rest?**

This will need to be done in two steps:

$$10.8 \text{ gal} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} = 1.44 \text{ ft}^3$$

$$1.44 \text{ ft}^3 \times \frac{62.4 \text{ lb}}{1 \text{ ft}^3} = 89.9 \text{ lb}$$

## Water in Motion

The study of water in motion is much more complicated than that of water at rest. It is important to have an understanding of these principles because the water in a treatment plant and/or distribution/collection system is nearly always in motion. Most of this motion is the result of pumping, but it's still in motion.

Velocity is expressed by indicating the length of travel and how long it takes to cover the distance, and is expressed in almost any distance and time units. Note that water flow that enters the pipe is the same flow that exits the pipe (under steady flow conditions). Water flow is continuous.

At any given flow, velocity is dependent upon the **cross-sectional area** of the pipe or conduit. Velocity (the speed at which the flow is traveling) is an important parameter. Recall that when dealing with velocity of flow

- 1 cfs = 0.646 MGD
- 1 cfs = 449 gpm

### Discharge

Discharge is the quantity of water passing a given point in a pipe or channel during a given period of time. It can be calculated by the formula:

$$Q = V \times A$$

Where:

Q = discharge in cubic feet per second (cfs)

V = water velocity in feet per second (fps or ft/sec)

A = cross-section area of the pipe or channel in square feet (ft<sup>2</sup>)

Discharge can be converted from cfs to other units, such as gallons per minute (gpm) or million gallons per day (MGD) by using the appropriate conversion factors.

*Example:*

**A pipe 8 inches in diameter has water flowing through it at 10 feet per second. What is the discharge in 1) cfs, 2) gpm, and 3) MGD?**

Before we can use the basic formula, we must determine the area (A) of the pipe. The formula for the area of a circle is:

$$\text{Area} = 0.785 \times \text{Diameter}^2$$

Since most conversions will include feet instead of inches, we will need to always convert pipe diameters from inches to feet for later calculations:

$$8 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 0.67 \text{ ft}$$

Now use this measurement for the pipe diameter.

$$\text{Area} = 0.785 \times \text{Diameter}^2$$

$$\text{Area} = 0.785 \times 0.67 \text{ ft} \times 0.67 \text{ ft}$$

$$\text{Area} = 0.35 \text{ ft}^2$$

1) Now we are able to determine the discharge in cubic feet per second (cfs):

$$\text{Discharge (Q)} = V (\text{Flow}) \times A (\text{Area})$$

$$Q = 10 \text{ fps} \times 0.35 \text{ ft}^2$$

$$Q = 3.5 \text{ cfs}$$

You can also solve it by using dimensional analysis:

You have an area of 0.35 ft<sup>2</sup> and a flow of 10 fps through this cross-sectional area. You need to know the flow in cubic feet per second (cfs or ft<sup>3</sup>/sec). Let's start with the area, which is in ft<sup>2</sup> and convert it to ft<sup>3</sup>/sec by adding in the flow given from the problem:

$$0.35 \text{ ft}^2 \times \frac{10 \text{ ft}}{\text{sec}} = 3.5 \text{ ft}^3/\text{sec}$$

We broke 10 fps down so the units could stay individual (ft and sec). Since "ft" is on the top we multiply it by "ft<sup>2</sup>", which gives us ft<sup>3</sup>. The "sec" is left over, so the entire unit would be ft<sup>3</sup>/sec. The units are correct, so now multiply the numbers: 0.35 x 10 = 3.5 ft<sup>3</sup>/sec.

2) To determine the discharge in gpm, we need to know that 1 cubic foot per second (cfs) is equal to 449 gallons per minute (gpm). We already know the flow is 3.5 cfs:

$$3.5 \text{ cfs} \times \frac{449 \text{ gpm}}{1 \text{ cfs}} = 1572 \text{ gpm}$$

3) To determine the discharge in MGD we need to convert the gallons to million gallons and minutes to days from the 1572 gpm flow rate. This is done through dimensional analysis, or unit conversion:

$$\frac{1572 \text{ gal}}{\text{min}} \times \frac{1 \text{ MG}}{1,000,000 \text{ gal}} \times \frac{1440 \text{ min}}{\text{day}} = 2.26 \text{ MGD}$$

To solve, punch (1572 x 1440) ÷ 1,000,000 in your calculator. Don't forget the parenthesis.

### *The Law of Continuity*

The law of continuity states that the discharge at each point in a pipe or channel is the same as the discharge at any other point (provided water does not leave or enter the pipe or channel). This is represented as:

$$Q_1 = Q_2$$

or

$$A_1V_1 = A_2V_2$$

Where A is the area and V is the velocity.

### *Example:*

**A pipe 8 inches in diameter is connected to a 6-inch diameter pipe. The velocity of the water in the 8-inch pipe is 3 fps. What is the velocity in the 6-inch pipe?**

We need to determine the area of each pipe, in ft, first:

*8-inch pipe:*

$$8 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 0.67 \text{ ft}$$

*6-inch pipe:*

$$6 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} = 0.5 \text{ ft}$$

Now you can use the continuity equation:

$$A_1V_1 = A_2V_2$$

$$(0.67 \text{ ft} \times 3 \text{ fps}) = (0.5 \text{ ft} \times V_2)$$

To solve for  $V_2$  you need it on one side by itself. To do this, divide both sides by "0.5 ft". This will cancel it on the right side and move it to the left:

$$\frac{0.67 \text{ ft} \times 3 \text{ fps}}{0.5 \text{ ft}} = V_2$$

$$V_2 = 4.02 \text{ fps}$$

To solve, enter  $(0.67 \times 3) \div 0.5$  in your calculator. Don't forget the parenthesis!

You can also enter it this way:  $0.67 \times 3$ , hit enter. Hit the divided by symbol and 0.5, hit enter.

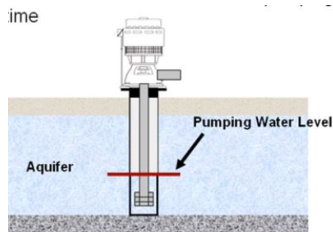
So, the velocity in the 6-inch pipe is 4.02 fps, which is faster than the velocity in the 8-inch pipe, which is only 3 fps. This means, the smaller the pipe, the faster the velocity.

## Basic Pumping

Certain computations used for determining various pumping parameters are important to the water operator. Here we will look at those more relevant.

## Pumping Rates

The rate of flow produced by a pump is expressed as the volume of water pumped during a given period. The mathematical problems most often encountered by water operators when determining pumping rates are often determined by using one of the following equations:



*Example 1:*

**The meter on the discharge side of the pump reads in hundreds of gallons. If the meter shows a reading of 110 at 2:00 p.m. and 320 at 2:30 p.m., what is the pumping rate expressed in gallons per minute (gpm)?**

To solve this problem, we must first find the total gallons pumping (determined from the meter readings):

$$32,000 \text{ gal} - 11,000 \text{ gal} = 21,000 \text{ gal}$$

Next, it says this quantity was pumped between 2:00 p.m. and 2:30 p.m. for a total of 30 minutes. From this information we can calculate the gpm pumping rate:

$$\text{Pumping rate, gpm} = \frac{\text{gallons}}{\text{minutes}}$$

$$\text{Pumping rate, gpm} = \frac{21,000 \text{ gallons}}{30 \text{ minutes}}$$

$$\text{Pumping rate, gpm} = 700 \text{ gpm}$$

Example 2:

**A tank 50 feet in diameter is filled with water to a depth of 4 feet. To conduct a pumping test, the outlet valve to the tank is closed and the pump is allowed to discharge into the tank. After 80 minutes, the water level is 5.5 feet. What is the pumping rate in gallons per minute:**

We must first determine the volume pumped in cubic feet:

$$\begin{aligned}\text{Volume pumped} &= \text{Area of circle} \times \text{Depth} \\ \text{Volume pumped} &= (0.785 \times (\text{Diameter})^2) \times \text{Depth} \\ \text{Volume pumped} &= (0.785 \times (50 \text{ ft})^2) \times 1.5 \text{ ft} && *5.5 \text{ ft} - 4 \text{ ft} = 1.5 \text{ ft} \\ \text{Volume pumped} &= (1,962.5 \text{ ft}^2) \times 1.5 \text{ ft} \\ \text{Volume pumped} &= 2,944 \text{ ft}^3\end{aligned}$$

Next, convert the cubic-foot volume to gallons:

$$2,944 \text{ ft}^3 \times 7.48 \text{ gal/ft}^3 = 22,021 \text{ gallons}$$

The pumping test was conducted over a period of 80 minutes. Calculate the pumping rate in gallons per minute (gpm):

$$\text{Pumping rate, gpm} = \frac{\text{gallons}}{\text{minutes}}$$

$$\text{Pumping rate, gpm} = \frac{22,021 \text{ gallons}}{80 \text{ minutes}}$$

$$\text{Pumping rate, gpm} = 275 \text{ gpm}$$

## Head and Head Loss

As mentioned, head is the vertical distance the water must be lifted from the supply tank or unit process to the discharge. The total head includes the vertical distance the liquid must be lifted (static head), the loss to friction (friction head), and the energy required to maintain the desired velocity (velocity head).

$$\text{Total head} = \text{static head} + \text{friction head} + \text{velocity head}$$

## Static Head

Static head is the actual vertical distance the liquid must be lifted:

$$\text{Static head} = \text{Discharge elevation} - \text{Supply elevation}$$

Example:

**A supply tank is located at an elevation of 108 ft. The discharge point is at an elevation of 205 ft. What is the static head in feet?**

$$\begin{aligned}\text{Static head} &= \text{Discharge elevation} - \text{Supply elevation} \\ \text{Static head} &= 205 \text{ ft} - 108 \text{ ft} \\ \text{Static head} &= 97 \text{ ft}\end{aligned}$$

## Pressure/Head

The pressure exerted by water is directly proportional to its depth or head in the pipe, tank, or channel. If the pressure is known, the equivalent head can be calculated:

$$\text{Head, ft} = \text{Pressure, psi} \times 2.31 \text{ ft/psi}$$

*Example:*

**The pressure gauge on the discharge line from the influent pump reads 75.3 psi. What is the equivalent head in feet?**

$$\text{Head, ft} = \text{Pressure, psi} \times 2.31 \text{ ft/psi}$$

$$\text{Head, ft} = 75.3 \text{ psi} \times 2.31 \text{ ft/psi}$$

$$\text{Head, ft} = 173.9 \text{ ft}$$

## Head/Pressure

If the head is known, the equivalent pressure can be calculated by:

$$\text{Pressure, psi} = \frac{\text{Head, ft}}{2.31 \text{ ft/psi}}$$

*Example:*

**A tank is 15 feet deep. What is the pressure, in psi, at the bottom of the tank when it is filled with water?**

$$\text{Pressure, psi} = \frac{\text{Head, ft}}{2.31 \text{ ft/psi}}$$

$$\text{Pressure, psi} = \frac{15 \text{ ft}}{2.31 \text{ ft/psi}}$$

$$\text{Pressure, psi} = 6.49 \text{ psi}$$

Now, let's combine math principles from above, and others from previous lessons.

*Example 1:*

**A 150-ft diameter cylindrical tank contains 2.0 MG of water. What is the water depth? At what pressure would a gauge at the bottom read in psi?**

First convert MG to cubic feet:

$$2,000,000 \text{ gal} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} = 267,380 \text{ ft}^3$$

Next, using volume, solve for depth:

$$\text{Volume, ft}^3 = 0.785 \times (\text{Diameter})^2 \times \text{Depth}$$

$$267,380 \text{ ft}^3 = 0.785 \times (150 \text{ ft})^2 \times \text{Depth}$$

$$267,380 \text{ ft}^3 = 17,662.5 \text{ ft}^2 \times \text{Depth}$$

$$\frac{267,380 \text{ ft}^3}{17,662.5 \text{ ft}^2} = \text{Depth}$$

$$\text{Depth} = 15.1 \text{ ft}$$

Now that we know the head, or depth, let's determine the psi at that depth:

$$\text{Pressure, psi} = \frac{\text{Head, ft}}{2.31 \text{ ft/psi}}$$

$$\text{Pressure, psi} = \frac{15.1 \text{ ft}}{2.31 \text{ ft/psi}}$$

$$\text{Pressure, psi} = 6.54 \text{ psi}$$

*Example 2:*

**The pressure in a pipe is 70 psi. What is the pressure in feet of water? What is the pressure in pounds per square foot (psf)?**

First convert pressure to feet of water:

$$\text{Head, ft} = \text{Pressure, psi} \times 2.31 \text{ ft/psi}$$

$$\text{Head, ft} = 70 \text{ psi} \times 2.31 \text{ ft/psi}$$

$$\text{Head, ft} = 161.7 \text{ ft of water}$$

Say that you couldn't remember the formula for head. You could solve by dimensional analysis. Start with the known value, 70 psi. You need pressure in feet and pressure in psf. Let's do those conversions:

$$70 \text{ psi} \times \frac{2.31 \text{ ft}}{\text{psi}} = 162 \text{ ft}$$

Now, convert psi to psf:

$$70 \text{ psi} \times 144 \text{ in}^2/\text{ft}^2 = 10,080 \text{ psf}$$

Solve using dimensional analysis:

$$\frac{70 \text{ lbs}}{\text{in}^2} \times \frac{12 \text{ in}}{1 \text{ ft}} \times \frac{12 \text{ in}}{1 \text{ ft}} = 10,080 \text{ lbs/ft}^2 \text{ or psf}$$

*Example 3:*

The pressure in a pipeline is 6476 psf. What is the head on the pipe?

$$\begin{aligned}\text{Head on pipe} &= \text{ft of pressure} \\ \text{Pressure} &= \text{Weight} \times \text{Height} \\ 6476 \text{ psf} &= 62.4 \text{ lb/ft}^3 \times \text{Height} \\ \text{Height} &= 6476 \text{ psf} / 62.4 \text{ lb/ft}^3 \\ \text{Height} &= 104 \text{ ft}\end{aligned}$$

Using dimensional analysis to solve:

$$\frac{6476 \text{ lbs}}{\text{ft}^2} \times \frac{1 \text{ ft}^3}{62.4 \text{ lbs}} = 104 \text{ ft}$$

You are left with 1 ft as the unit because 2 of the "ft" cancel, leaving only 1 "ft".

### Storage Tank Calculations

Water is stored at a waterworks to provide allowance for differences in water production rates and high-lift pump discharge to the distribution system. Water within the distribution system may be stored in elevated tanks, standpipes, covered reservoirs, or underground basins. The waterworks operator should be familiar with the basic storage tank calculation illustrated in the following example:

*Example:*

**A cylindrical tank is 120 ft high by 25 ft in diameter. How many gallons of water will it contain?**

First, find the total gallons of water contained in the tank, by finding the volume in cubic feet:

$$\begin{aligned}\text{Volume} &= 0.785 \times (\text{Diameter})^2 \times \text{Height} \\ \text{Volume} &= 0.785 \times (25 \text{ ft})^2 \times 120 \text{ ft} \\ \text{Volume} &= 0.785 \times 625 \text{ ft}^2 \times 120 \text{ ft} \\ \text{Volume} &= 58,875 \text{ ft}^3\end{aligned}$$

Now find the number of gallons of water the cylindrical tank will contain:

$$\text{No. of gallons} = 58,875 \text{ ft}^3 \times \frac{7.48 \text{ gal}}{1 \text{ ft}^3} = 440,385 \text{ gallons}$$

### Water Use

It is important for an operator to be able to calculate the gallons of water used per capita per day (gpcd). This will help ensure the plant has enough water stored for its population. The gpcd can be calculated by:

$$\text{Water use, gpcd} = \frac{\text{Volume of water produced, gpd}}{\text{Population}}$$

If you have the amount of water produced in liters per day (Lpd), use the following formula:

$$\text{Water use, Lpcd} = \frac{\text{Volume of water produced, Lpd}}{\text{Population}}$$

*Example:*

**The town of Foxville has a population of 1,350. On a typical day the water treatment plant produces 275,000 gallons of water. Calculate the water consumed in gallons per capita per day (gpcd).**

$$\text{Water use, gpcd} = \frac{\text{Volume of water produced, gpd}}{\text{Population}}$$

$$\text{Water use, gpcd} = \frac{275,000 \text{ gpd}}{1,350}$$

$$\text{Water use, gpcd} = 204 \text{ gpcd}$$

## Summary

Water distribution is the delivery of water from the treatment plant to consumers through the distribution system. A distribution system is a network of water lines (pipes) that deliver treated water to consumers. A transmission system consists of the following major components:

- Pipes (transmission lines) for delivering water
- Pumps for pumping and maintaining pressure
- Valves to control water flow
- Reservoirs and elevated tanks for water storage
- Meters to measure the quantity of water supply
- Fire hydrants to provide sufficient pressurized water for fire-fighting

## Assignment

Please complete the [assignment](#) for this lesson. You must be logged into Canvas to complete this assignment.

## Quiz

Answer the questions in [the lesson quiz](#). You will need to log into Canvas to take the quiz. You may take the quiz 3 times, if needed, and an average will be taken from your attempts for final grade calculation.