Math

This chapter is intended to be an aid to the operator in solving everyday operating problems in the operation of a water system. It deals with basic math that would be required for an operator to accomplish his or her everyday work.

Solving math problems requires practice in manipulation and knowledge of what manipulation to make. Listed below is an approach to solving math problems:

1. Decide what the problem asks.
2. List the information given.
3. Decide what units the answer should have.
4. Perform the calculations necessary to solve the problem.
5. Label the answer.

Manipulation of numbers involves many operations, not all of which are covered here.

FRACTIONS

Fractions are used when you want to express a portion of the whole. If you have a pie that is cut into eight pieces and you eat one, you have eaten 1/8th of the pie (1 divided by 8).

The top number (numerator) represents how many parts you have and the bottom number (denominator) represents the number in the whole.

The bar or slash in the fraction separates the two numbers and can be read as “divided by.” This means that the top number (numerator) is divided by the bottom number (denominator). Another way to say 1/8 is to say 1 divided by 8.

Fractions can also be used to represent units of measurement such as miles per hour or gallons per day where the ‘per’ represents “divided by.”

DECIMALS

Another method of representing a fraction is by using decimals of tenths, hundredths, etc. This is a much better method to use with a calculator. If you have a fraction and need to express the fraction as a decimal, you can convert the number by dividing the numerator by the denominator.

RATIOS

This is a comparison of two numbers or units, such as 2: 1,000,000 or 2 parts to one million parts.

EXPONENTS
Indicates how many times a number is to be multiplied by itself.

Example:

23 = 2 x 2 x 2, where 3 is the exponent
42 = 4 x 4, where 2 is the exponent

UNIT CONVERSIONS
This represents a method of converting from one unit to another, such as cubic feet to gallons. This is one of the most difficult tasks for the operator. You must always write the units down with each number. All units must be checked prior to your calculations to make sure your answer will be in correct units. If the units are incorrect, the number that you calculate is incorrect as well.

The following is a method to use when converting one unit to another:

1. Write down the number and units you wish to convert from on the left.
2. Write down the unit you wish to convert to on the right.
3. Draw a line under both of these. This line means "divided by" and allows you to use a conversion factor.
4. Below this line (on the right) write down the same unit as you wrote down on the left.
5. Write the appropriate conversion number associated with the two units you wrote down on the right.
6. Cancel out the same units. This should leave you with the units that you wish to convert to. Perform the appropriate multiplication and division.

Example:

100 cubic feet is ? gallons

$\frac{\text{100 cubic feet x 7.5 gallons}}{\text{1 cubic}}$ = 750 gallons

750 gallons is ? cubic feet

$\frac{\text{750 gallons x 1 cubic foot}}{\text{7.5 gallons}}$ = 100 cubic feet

1. How many gallons are contained in 1,200 cubic feet? (9,000 gal)

2. If the treatment plant you work at has a tank that contains 200 gallons of chemical, how many cubic inches are contained in the tank? (46,200 in^3)

ROUNDING OF NUMBER

Rounding is the process of taking a number and reducing the number to one with fewer digits. If you have a number from your calculation such as 2.346567 and you wanted to round to two significant digits you would look at the third digit to the right of the decimal. If this number is greater than 5 raise the second digit up one, if the number is less than 5 leave the number as is. The answer to the above number would be 2.35.

REARRANGEMENT OF A FORMULA

This procedure allows a formula to be converted to solve for an unknown:

$$\text{Detention time} = \frac{\text{Volume}}{\text{Flow}}$$

$$\text{Flow} = \frac{\text{Volume}}{\text{Detention Time}}$$

The rules for the rearrangement of a formula:

If the unit you do not know is being divided by something you know, then multiply both sides of the equation (on each side of the equal sign) by the units that you know.

Example (you know everything but the volume):

$$\text{Detention time} = \frac{\text{Volume}}{\text{Flow}}$$

$$\text{Flow x Detention time} = \frac{\text{Volume x Flow}}{\text{Flow}}$$

$$\text{Volume} = \text{Detention Time x Flow}$$

If the unit you do not know is divided into something you know, then multiply both sides of the equation by the unit you do not know. After that, divide both the sides of the equation by the unit that you do know.

Example (you know everything but the flow):

$$\text{Detention time} = \frac{\text{Volume}}{\text{Flow}}$$

$$\text{Flow x Detention Time} = \frac{\text{Volume x Flow}}{\text{Flow}}$$

$$\frac{Flow \times Detention\ Time}{Detention\ Time} = \frac{Volume}{Detention\ Time}$$

$$Flow = \frac{Volume}{Detention\ Time}$$

SOLVING WORD PROBLEMS

1. Read the problem.
   a. Underline the given information.
   b. Circle what is being asked for.
   c. Draw a picture and label with the given information.

2. Stop and think about what is being asked for.
   a. Look at the units, many times the units of the item being asked for will tell you how to do the problem.
   b. Do not go on until you understand what is being asked and you know how to proceed.

3. Select the proper formula.
   a. Write down the formula and then start writing down the various information that has been given to you. If you do not have enough information to fill in all but one unit in the formula, you have the wrong formula for the problem.

4. Solve the formula.

5. Ask if the answer is reasonable.
   a. If it is not, you should go back and check your work or possibly you are not using the correct formula.

AREA

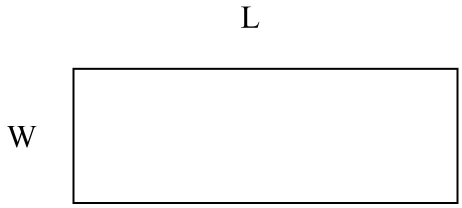
Area of any figure is measured in the second dimension or in square units. In the English system that we normally use in the United States, this would be square inches, square feet, etc. The most common mistake made by operators in working with math is that they do not convert the units so that they are the same. An example of this would be trying to use inches and feet in the same problem. One or the other would have to be converted.

Area conversion factors that are normally used in the water industry are as follows:

1 square foot	= 144 square inches
1 square yard	= 9 square feet
1 acre	= 43,560 square feet
1 square mile	= 640 acres or 1 section

RECTANGLE

The area of any rectangle is equal to the product of the length multiplied by the width of the figure.



Example:

Find the area of a rectangle that has a length of 5 feet and width of 3.6 feet?

A = L x W
= 5 ft x 3.6 ft
=18 ft2

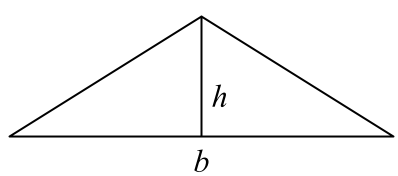
1. How many square feet of tile would it take to finish the lab floor if the room measures 10 feet wide and 15 feet long? (150 ft2)

2. How many yards of sod would you have to buy to repair a water break hole if the measurements are 10 feet wide and 15 feet long? (16 2/3 YDS2)

TRIANGLE

The area of a triangle is equal to one half of the base multiplied by the height of the figure. The height of the triangle is found by drawing a line from the angle opposite the base to the base. The area of the triangle is equal one half the area of a rectangle with the same dimensions.

A = ½ B x H



Example:

1. How many square feet are contained in a triangular room that has a base of 25 feet and height of 10 feet? (125 ft2)

2. How many acres are there in a triangular shaped piece of land that measures 200 feet deep and has a base of 250 feet? (0.57 acres)

CIRCLE

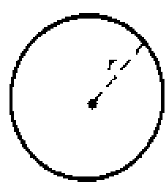
The area of a circle is found in a different manner in that a circle does not have base and height measurements. A circle is defined as a figure that has an arc that is equidistant in all areas from a center point. A line drawn from the center point to any point on the arc is called the radius. A straight line drawn through the center from arc to arc is called the diameter of the circle.

The area of a circle is found by squaring either the radius or the diameter. By doing this operation the units will become squared and at that point the units are right for finding area. If you use the radius of the figure after the units are squared you would multiply the square of the radius times pi or 3.14. Pi is a ratio of the circumference of a circle divided by the diameter, or put another way:

$$\text{Pi} = \frac{\text{Circumference}}{D}$$

This number is always equal to 3.14. If you find it easier to use the diameter when you work the problem, you multiply the square of the diameter times 0.785. No matter which formula you use, the answer will be the same depending on where you round the answers.

Area = $3.14\ r^2$
Area = $0.785d_2$



Example:

What is the area in square feet of a circular tank that has a diameter of 35 feet?

Area = 0.785 x (35ft x 35ft)
= 0.785 x 1225 sq. ft.
= 961.63 sq. ft.

1. How many square feet are there in a circle with a diameter of 45 feet? (1589.63 ft^2)

2. How many gallons of paint would it take to paint a floor in circular pump room that is 25 feet in diameter? A gallon of paint covers 200 square feet. (2.45 gallons)

SURFACE AREA

With the formulas that we have used to this point, it would be a simple matter to find the number of square feet in a room that was to be painted. The area of all of the walls would be calculated and then added together. This would include the ceiling as well as all of the walls in the room.
The area of the top and bottom ends are equal to:

$A = 0.785d^2$
A = 0.785 x (60ft x 60ft) x 2
A = 0.785 x 3,600 sq ft x 2
A = 2826 sq ft x 2
A = 5,652 sq ft

The area of the side wall is equal to the circumference of the tank times the depth. When you find the circumference it is as though you cut the tank depth and unroll the side to make it a rectangular figure.

A = Pi DH
A = 3.14 x 60 ft x 20 ft
A = 188.4 ft x 20 ft
A = 3,768 sq ft

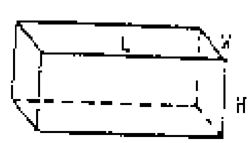
The total surface area of the cylinder is equal to the sum of the two areas or

Surface Area = 5,652 sq ft + 3,768 sq ft
= 9,420 sq ft

VOLUME
Water operators are usually more interested in what a tank will hold or how many gallons will a truck hold, etc. Volume is measured in the third dimension where a depth or height of the figure is known. The units used are generally cubic feet, cubic inches, acre feet, and gallons. In the water field the volume of most tanks are measured in gallons.

Volume is found by taking the area of the base of the figure and multiplying times the height of the figure. All figures that have been discussed to this point can have a volume calculated for them if you know the depth or height of the figure.

VOLUME OF A RECTANGLE
The volume of a tank that has a rectangular shape is found by multiplying the length times the width times the depth of the tank. This will give you the answer in cubic feet.



Volume = L x W x H

Example:

What is the volume in cubic feet of a tank that is 50 feet long, 30 feet wide, and 12 feet deep?

Volume $= L \times W \times H$
$= 50 \text{ ft} \times 30 \text{ ft} \times 12 \text{ ft}$
$= 1{,}500 \text{ ft}^2 \times 12 \text{ ft}$
$= 18{,}000 \text{ ft}^3$

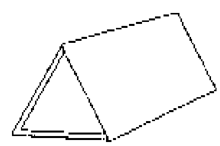
1. What would the volume of a tank be that measures 50 feet long, 24 feet wide and 10 feet deep in gallons? (90,000 gallons)

2. A tank holds 120,000 gallons and is 120 feet long and is 25 feet wide. What is the depth of the tank in feet? (5.3 feet)

VOLUME OF A PRISM

The volume of a prism is equal to the area of the base triangle times the depth or height of the figure.

<u>Volume of Prism</u> = <u>Area of base x height of prism</u>



Example:
Find the volume of a sludge hopper that has a triangle for a base that is 10 square feet and a depth of 6 feet:

Volume = area of base x height
$= 10 \text{ ft}^2 \times 6 \text{ ft}$
$= 60 \text{ ft}^3$

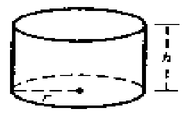
1. Find the volume in cubic feet of a sludge hopper that is triangular in shape that is 3 feet in height and has a base of 2 feet wide and length of 3.5 feet? (10.5 ft^3)

VOLUME OF A CYLINDER

The volume of a cylinder is equal to the area of the base times the height of the figure. The difference in this figure is that when you are working with the area, you must select one of two formulas for finding the area of the base figure. They are as follows:

Volume = $3.14\ R^2 \times H$

Volume = $0.785\ D^2 \times H$



Example:
Find the volume of a cylinder with a diameter of 10 feet and a depth of 10 feet?

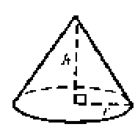
$$
\begin{aligned}
\text{Volume} &= 0.785\ D^2 \times H \\
&= 0.785 \times 10ft^2 \times H \\
&= 0.785 \times 100ft^2 \times 10ft \\
&= 78.5ft^2 \times 10ft \\
&= 785ft^3
\end{aligned}
$$

1. How many gallons does a tank that measures 50 feet in diameter and is 23 feet deep hold? (338,531 gallons)

2. If a cylinder holds 25,000 gallons of liquid what is the depth of the container if the radius is 8 feet? (16.59 feet)

VOLUME OF A CONE
The volume of a cone is equal to one-third the area of the base times the height of the figure. The base figure is a circle.

$$\text{Volume} = \frac{0.785 \times D^2 \times H}{3}$$



Example:
Find the volume of a cone with a diameter of 10 feet with a depth of 5 feet?

$$\text{Volume} = \frac{0.785\ (10\text{ft})^2 \text{ x } 5\text{ft}}{3}$$

$$= \frac{0.785 \text{ x } 100\text{ft}^2 \text{ x } 5\text{ft}}{3}$$

$$= \frac{78.5\text{ft}^2 \text{ x } 5\text{ft}}{3}$$

$$= \frac{392.5\text{ft}^3}{3}$$

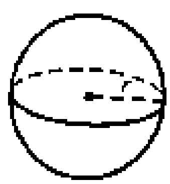
$$= 130.83\ \text{ft}^3$$

1. A sludge hopper is 5 feet in diameter and has a depth of 3 feet. What is the volume in cubic feet? (19.62 ft3)

VOLUME OF A SPHERE

The sphere is a figure in the shape of a ball. The water industry would use this figure in a water tower or a gas holder.

$$\text{Volume} = \frac{3.14 \text{ x } D^3}{6}$$



Example:
Find the volume in cubic feet of a water tower that is in the shape of a sphere that has a diameter of 30 feet.

$$\text{Volume} = \frac{3.14 \text{ x } (30\text{ft x } 30\text{ft x } 30\text{ft})}{6}$$

=3.14 x 4500 ft3

=14,130 ft3

1. What is the volume in gallons of a spheroid water tank that is 24 feet in diameter? (54,289 gallons)

Conversion factors that are used in converting volume to another form are as follows:

1 cubic foot =1,728 cubic inches
1 cubic foot = 7.5 gallons
1 cubic yard = 27 cubic feet
1 acre foot = 43,560 cubic feet
1 quart = .946 liters
1 gallon = 4 quarts
1 gallon = 231 cubic inches
1 liter = 1.06 quarts

The material to this point has been arranged so that you could have a review of the basic skills required to perform your job as a water system operator. There are several other conversions that you must be able to make and they follow the same basic rules as we have used to this point. We will discuss these as they relate to the use that you as an operator will need to know.

TEMPERATURE

The water operator in the United States is used to using the English unit of measurement for temperature, namely Fahrenheit. The water industry in recent years has been converting to the metric system for the measurement of temperature or Celsius.

The formulas for the conversion of temperature are as follows:

Fahrenheit to Celsius

$$°C = \frac{5\ (°F - 32)}{9}$$

$$°F = \frac{(°C \times 9)}{5} + 32$$

1. If the temperature measured in Fahrenheit is 68 degrees, what is the temperature in Celsius? (20 degrees)

2. If you must hold an incubator in the lab at 37 degrees Celsius, what is the temperature in Fahrenheit? (98.6 degrees)

FLOW

The measurement of flow in the water industry is one of the most important calculations that an operator can make in his or her workday. The management of the flow in the water system dictates the operation of the total system from the feeding of chemicals to the collection of bills.

Flow in the treatment plant is a function of the velocity of the water at a given point in the treatment multiplied by the cross sectional area of the pipe or channel. Velocity is the time that it takes an object to travel a given distance. The cross sectional area is equal to the area of the end of the pipe or channel. If the pipe or channel is not flowing full, the area would be calculated using the depth of the water flowing in the pipe.

Flow is generally measured in gallons per minute, gallons per day, or million gallons per day. If you are working with a flow channel or pipe, the cross sectional area multiplied by the velocity will give you the flow in the form of cubic measure per basis of time, such as cubic feet per second.

Velocity is important to the water operator because if the velocity becomes too fast the friction loss in the pipe becomes very high and costs additional money for energy. If you want to calculate the velocity, you need to know the distance traveled and length of time that it took to cover the given distance. The following formulas are used to calculate the velocity of a liquid.

$$\text{Velocity} = \frac{\text{distance traveled}}{\text{time}}$$

$$\text{Velocity} = \frac{\text{flowrate}}{\text{cross-sectional area}}$$

Example:

Find the velocity if an object travels 22 feet in 15 seconds.

$$\text{Velocity} = \frac{22 \text{ feet}}{15 \text{ seconds}}$$

$$= 1.467 \text{ ft/sec}$$

Example:

Find the velocity in a channel with a flow of 20 cubic feet per second. The channel measures 1 foot wide and the depth of water flowing is 0.5 feet.

$$\text{Velocity} = \frac{20\ \text{ft}^3/\text{sec}}{1\ \text{ft} \times 0.5\text{ft}}$$

$$= \frac{20\ \text{ft}^3/\text{sec}}{0.5\text{ft2}}$$

$$= 40\ \text{ft/sec}$$

The water operator may calculate the flow based on the cross sectional area of the pipe or channel where the velocity is known. This is represented by the formula:

Quantity or Flow = Cross sectional Area x Velocity
$Q = AV$

Example:

Find the flow in a 1 foot diameter pipe if the velocity equals 5 feet per second. Express the flow in cubic feet per second.

$$Q = 0.785\ D^2 \times 5\text{ft/sec}$$

$$Q = 0.785\ (1\ \text{ft})^2 \times 5\ \text{ft/sec}$$

$$Q = 0.785\ \text{ft}^2 \times 5\text{ft/sec}$$

$$Q = 3.92\ \text{ft}^3/\text{sec}$$

If the flow in a water system is in cubic feet, the operator can convert the units into any of the other normal units, such as gallons per minute, gallons per hour, or gallons per day. The units of gallons are commonly used by the operators rather than cubic feet. When the flow from a pump or plant is measured in gallons per minute, as an example, the units can be converted to gallons per hour by multiplying by 60 minutes per hour. The units of flow in gallons per hour can be converted to gallons per day by multiplying the gallons per hour times 24 hours per day. A more common method of expressing flow in larger treatment plants is million gallons per day. Million gallons per day is computed by dividing gallons per day by 1,000,000.

If the flow has been expressed as cubic feet per second and you want to convert the flow to gallons per minute, you would use the following method.

$$GPM = ft^3/sec \times 7.5\ gal/ft^3 \times 60\ sec/min$$

Example:

Find the flow in GPM if the flow in cubic feet per second is equal to 10.

$$GPM = 10 ft^3/sec \times 7.5\ gal/ft^3 \times 60\ sec/min$$

$$= 75\ gal/sec \times 60\ sec/min$$

$$= 4{,}500\ GPM$$

1. What is the flow to the treatment plant in gpm when the cfs equals 3.5 cfs? (1,575 gpm)

If the flow is expressed in GPM and you would like it in GPH. You would follow this procedure: GPH = GPM x 60 min/hr.

Example:

Find the flow in GPH when the flow equals 250 GPM?

$$GPH = 250\ GPM \times 60\ min/hr$$

$$= 15{,}000\ GPH$$

1. When the well pumps 400 gpm, what is the flow per hour from the well? (24,000 gph)

If the flow is expressed in GPH and you would like it in GPD you would follow the following procedure: GPD = GPH x 24 hr/day.

Example:

What is the flow in GPD if the GPH equals 15,000?

$$GPD = 15{,}000\ GPH \times 24\ hr/day$$

$$= 360{,}000\ GPD$$

1. What is the flow per day in a plant if the well pumps 20,000 gph? (480,000 gpd)

If the flow is in GPM and you need GPD, you would multiply the GPM times 1,440 min/day.

$$GPD = GPM \times 1{,}440 \text{ min/day}$$

$$\frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = 1{,}440 \text{ min/day}$$

Example:

What is the flow in GPD if it equals 1,000 GPM?

$$GPD = 1{,}000 \text{ GPM} \times 1{,}440 \text{ min/day}$$

$$= 1{,}440{,}000 \text{ GPD}$$

1. A well pumps 150 gpm and runs the total 24 hours of the day. What is the flow from the well in gpd? (216,000 gpd)

When finding the flow in million gallons per day, divide the GPD by 1,000,000

$$MGD = \frac{GPD}{1{,}000{,}000}$$

Example:

What is the MGD if the flow is 500 GPM?

$$MGD = \frac{500 \text{ GPM} \times 1{,}440 \text{ min/day}}{1{,}000{,}000}$$

$$MGD = \frac{720{,}000 \text{ GPD}}{1{,}000{,}000}$$

$$MGD = 0.72 \text{ MGD}$$

FLOW CONVERSION FACTORS

1 cubic foot per second = 450 GPM
1 gallon per second = 0.133 CFS
1 gallon per second = 7.98 cubic feet/min
1 GPM = 0.0022 cubic ft/sec
1 GPM =1,440 GPD

LOADING CALCULATIONS FOR THE OPERATOR

The water operator needs to understand the importance of calculating the amount of chemical that he or she adds to the water of the community. This unit may be expressed as either parts per million (ppm) or milligrams per liter (mg/l). They are for all practical purposes considered to be equal.

The calculation tells the operator the number of pounds of chemical being added to the water per million pounds of water. The loadings are calculated by multiplying the following; the flow expressed in MGD, the weight of one gallon of water (8.34 #/gal), and the amount of chemical being added in parts per million.

Pounds per day = MGD x 8.34 lbs/gal x ppm

Example:

If you are adding 15.01 pounds of chlorine to a flow of 1.5 MGD, what is the ppm feed rate?

Chlorine lbs/per day = 1.5 MGD x 8.34 lbs/gal x ppm

15.01 lbs/day = 1.5 MGD x 8.34 lbs/gal x ppm

15.01 lbs/day = 12.51 million lbs/day x ppm

$$\frac{15.01 \text{ lbs/day}}{12.51\text{Million lbs/day x ppm}} = \frac{12.51 \text{ Million lbs/day x ppm}}{12.51 \text{ Million lbs/day x ppm}}$$

= 1.2 ppm

By dividing each side of the equals sign, the right side is cancelled out. Always insert the number on top of the dividing line first into the calculator. 15.01 lbs/day divided by 12.51 lbs/day x ppm will also cancel out the lbs/day, leaving you with an answer in ppm.

1. If you are adding 20 pounds of chlorine to a flow rate of 350 gallons per minute, what is the ppm feed rate? (4.8 ppm) Remember to convert to MGD.

A positive displacement chemical feed pump has a maximum daily pumping capacity of 24 gallons per day. The pump is set at 50 percent stroke and 50 percent speed, how many gallons of chemical is this pump capable of feeding in a 24 hour period?

Formula for chemical feed pump:

% stroke x % speed x pump capacity (gpd)
Convert % to decimal by dividing by 100.
.50 stroke x .50 speed x 24 hours = 6 gallons per day

1. A positive displacement chemical feed pump has a maximum daily capacity of 6 gallons per day. The pump is set at a 35 percent stroke and 75 percent speed, how many gallons of chemical is this pump capable of feeding in a 24 hour period. (1.6 gallons per day)

Many chemicals that are used in the operation of a water system are not pure elemental chemical, but contain some other chemical in combination with the one that you are interested in. An example of this would be calcium hypochlorite (HTH), which is 70 percent available chlorine.

$$\text{Pounds per day} = \frac{\text{pounds pure chemical}}{\text{percent purity}}$$

Example:

How many pounds of HTH would be required to raise the chlorine residual to 50 ppm if a tank contains 0.5 MGD? HTH is 70 percent pure.

$$\text{Pounds HTH} = \frac{\text{MG x 8.34 \#/gal x PPM}}{\text{percent purity}}$$

$$= \frac{\text{0.5 MGD x 8.34 \#/gal x 50 PPM}}{.70}$$

$$= \frac{\text{208.5 \# HTH}}{.70}$$

$$= \text{297.85 pounds HTH}$$

WEIGHT CONVERSION FACTORS OF WATER

1 gallon = 8.34 pounds per gallon
1 cubic foot = 62.4 pounds per cubic foot
1 foot of water = 0.434 pounds per square inch
1 pound = 0.454 kilograms
1 kilogram = 2.2 pounds
1 kilogram = 1,000 grams
1 psi = 2.31 feet of water
1 liter = 1,000 grams
1 percent by volume = 10,000 ppm

PRESSURE

Pressure in the water system is what makes the system work. Pressure is caused by the weight of water above a given point in the system. Pressure is generally expressed as pounds per square inch (psi), but it can be expressed as feet of head. To convert from feet of head multiply the head times 0.434 psi/foot of head. When you know the pressure on a given point you can calculate the head in feet by multiplying the pressure times 2.31 feet per psi.

Examples:

Find the pressure on a gauge when the water level above a point is 76 feet.

PSI = 76 feet x 0.434 psi/foot
= 32.98 psi

Find the feet of head when a pressure gauge reads 24 psi.

Head = 24 psi x 2.31 feet/psi
= 55.4 feet

1. A pressure gauge at the base of a water tower reads 67 psi. What is the elevation of the water above the gauge? (154.77 feet)

2. The tower in your community is 245 feet high. If the tower is filled to the 222 foot level, what is the pressure at the base? (96.12 psi)

SPECIFIC YIELD

Feet of head to the water operator likely means more than the pressure that it causes. Head is used in the design of all the pumping equipment that makes the water system work. The operator, in order to understand what head is, must understand some of the terms that are used to explain head. The operation of a well involves many types of head. They are as follows:

Static Water Level
Static means that the water is at rest without movement. The static water level of a well is the distance to the water level in a well from the surface with the pump off.

Pumping Water Level
The level of the water in a well after the pump has operated until the well has stabilized. The measurement is taken from the ground level to the water surface with the pump operating.

Drawdown
The distance between the static water level and the pumping water level.

Static Discharge Head
The static discharge head is the difference in elevation the water is being lifted in feet.

Total Static Head
The distance the water has been lifted above the static water level. It is the sum of the static discharge head and the static water level. This is also the total static head that the pump will have to work against when it is turned on.

Total Dynamic Head
The sum of all the heads including static water level, static discharge head, drawdown, and the friction head in the pipeline. It is also the total pressure that the pump will have to work against after the pump has run for a period of time.

Example:

The water line to the elevated tank is 100 feet above the ground. The static water level is 36 feet below the ground elevation. The pump is turned on and after a period of time the pumping level drops to 52 feet.

What is the static discharge head?	100 feet
What is the total static head?	100 feet + 36 feet = 136 feet
What is the drawdown?	52 feet - 36 feet = 16 feet
What is the total dynamic head?	136 feet + 16 feet = 152 feet

When the amount of drawdown is known along with the flow (in GPM) the specific yield of the well can be analyzed. The specific yield of the well is found by dividing the GPM by the drawdown of the well.

Example:
Find the specific yield of a well if the flow is 1,000 GPM and the drawdown is 50 feet?

$$\text{Specific Yield} = \frac{\text{GPM}}{\text{Drawdown}}$$

$$= \frac{1000 \text{ gpm}}{50 \text{ feet}}$$

$$= 20 \text{ gpm/foot}$$

1. The static level in a well is 34 feet. When the pump is pumping 1,500 gpm, the pumping level is 75 feet. What is the specific yield of the well? (36.58 gpm/ft)

2. A well has static level of 100 feet and a pumping level after 4 hours the pumping level is 185 feet. The pump is pumping a rate of 1,500 gpm. What is the specific yield of the well? (17.64 gpm/ft)

When the pump is started, a large amount of energy is required to pump the water, this is normally supplied by electrical power. Power is the rate of doing work and is usually expressed in foot pounds per minute. The water operator is familiar with horsepower, the form of work that is done by lifting water. If the flow from the pump is converted to a weight of water and multiplied by the vertical distance that the water is lifted and then divided by 33,000 foot pounds per minute. This is called water horsepower.

$$\text{Water horsepower} = \frac{\text{gpm x 8.34 lbs/gal x head}}{\text{33,000 ft lbs/min}}$$

or

$$\text{Water horsepower} = \frac{\text{gpm x head}}{3{,}960}$$

Example:
Find the water horsepower if a pump is expected to pump 100 gpm against a head of 100 feet.

$$\text{Water horsepower} = \frac{\text{100 gpm x 100 ft}}{3{,}960}$$

$$= \frac{10{,}000}{3{,}960}$$

$$= 2.52 \text{ HP}$$

When you are calculating the required horsepower for a given pump, you must remember that no pump is 100 percent efficient. Likewise, no motor is 100 percent efficient. The following formulas allow the operator to calculate brake horsepower where the efficiency of the pump is considered, and motor horsepower, where both pump efficiency and motor efficiency is considered.

$$\text{Brake horsepower} = \frac{\text{gpm x head}}{\text{3,960 x pump eff}}$$

$$\text{Motor horsepower} = \frac{\text{gpm x head}}{\text{3,960 x p eff x m eff}}$$

1. What size motor would be required to lift 1,000 gpm against 200 feet of head? The pump is 82 percent efficient and motor is 94 percent efficient. (65.53 HP)

2. A pump in a well is designed to pump 2,000 gpm against 250 feet of head. The pump is designed to have an efficiency of 80 percent and the motor has an efficiency of 92 percent. How many horsepower must the motor produce to meet the demand? (171.55 HP)

NOTE: The formulas above are developed for water and wastewater applications where water is the medium being pumped. If the application is being applied to another medium, the specific gravity of the liquid must be applied to the calculation.

DETENTION TIME

The detention time of a tank or piping system is the time that it would take to fill the system or empty the system. This is a theoretical time in that it will not tell you if the tank is short circuiting or not. The detention time is found by calculating the volume of the vessel and dividing it by the flow to the vessel.

$$\text{Detention Time} = \frac{\text{Volume}}{\text{Flow}}$$

Example:

Find the detention time of a tank that measures 50 feet long, 30 feet wide, and 10 feet deep with a flow to the tank of 1500 gpm.

$$\text{Detention Time} = \frac{\text{50 ft x 30 ft x 10 ft x 7.5 gal/ft}^3}{\text{1,500 gpm}}$$

$$= \frac{\text{112,500 gallons}}{\text{1,500 gpm}}$$

$$= \text{75 minutes}$$

1. A tank measures 50 feet in diameter and is 14 feet deep, if the tank receives a flow of 2,500 gpm, what is the detention time of the tank in minutes? (82.43 minutes)

2. What is the detention time in hours of a settling basin that measures 50 feet long, 20 feet wide, and 10 feet deep when a flow of 1,000 gpm is applied to it? (1.25 hours)

Another example of finding detention time is where you would want to know the time water will remain in the piping system. Here you would find the total volume of the pipe and divide by the flow out of the system to the residents connected.

How many hours would it take to use the water in 120,000 feet of 8 inch pipe with a flow out of the system of 1,000 gpm and a flow into the system of 250 gpm?

$$\text{Detention Time} = \frac{.785 \text{ x } D^2 \text{ x Length}}{1{,}000 \text{ gpm} - 250 \text{ gpm}} \quad (8 \text{ inches} / 12 \text{ inches} = .67 \text{ feet})$$

$$= .785 \text{ x } .67\text{ft x } .67\text{ft x } 120{,}000\text{ft} = 41{,}866 \text{ ft}^3$$

$$= \frac{41{,}866 \text{ ft}^3 \text{ x } 7.5 \text{ gal/ft}^3}{750 \text{ gpm x } 60 \text{ min/hr}}$$

$$= \frac{314{,}000 \text{ gal}}{45{,}000 \text{ gph}}$$

$$= 6.98 \text{ hours}$$

1. A piping system has a length of 22,000 feet of 20 inch pipe. How long will it take to fill the pipe if you can pump 1,000 gpm into the pipe? (358 minutes)

FLUORIDATION

The operation of a fluoridation system requires the operator calculate several different things. One of the most common calculations is the amount of fluoride to add to the system in gallons. One thing that you must know is the weight of one gallon of hydrofluosilicic acid, which is approximately 10.3 pounds per gallon. This gallon of acid is also approximately 25 percent acid and 75 percent water. Also, the 25 percent acid is only 79 percent fluoride.

The following calculation shows how many pounds of pure fluoride are contained in one gallon of hydrofluosilicic acid.

$$\text{Fluoride per gallon} = 10.3 \text{ lbs/gal x } .25 \text{ acid x } .79 \text{ fl/lbs}$$
$$= 2.57 \text{ lbs acid x } .79 \text{ fl/lbs}$$
$$= 2.03 \text{ lbs fl/gal}$$

When you want to know how many gallons are required to raise the fluoride residual to a given level, you must find the amount of pure chemical that is required and divide this by the amount of pure chemical per gallon of acid.

Example:
How many gallons of hydrofluosilicic acid are required to raise the fluoride residual to 1.2 ppm in 1.0 mgd? The weight of the fluoride is 10.3 pounds per gallon with and acid content of 25 percent and 79 percent purity. Natural fluoride level is 0.

$$\text{Gallons fluoride} = \frac{\text{Mgd x 8.34 lbs/gal x ppm}}{\text{pounds per gallon}}$$

$$= \frac{\text{1.0 mgd x 8.34 lbs/gal x 1.2ppm}}{\text{10.3 lbs/gal x .25 x .79}}$$

$$= \frac{\text{10.01 lbs fl/day}}{\text{2.03 lbs/gal}}$$

$$= \text{4.92 gal}$$

1. How many gallons of hydrofluorsilicic acid is required to raise the fluoride residual to 1.3 ppm when the flow to the system is 150 gpm and it runs 24 hours? The hydrofluosilicic acid is 10.3 lbs/g and 25 percent acid and containing 79 percent fluoride. (1.15 gallons)

If you are using sodium silica fluoride, which is a dry powder rather than a liquid, the procedure is the same. First you find the amount of pure chemical needed and divide this by the amount of pure chemical per pound of chemical fed. Sodium silica fluoride is approximately 69 percent pure fluoride for each pound of chemical fed.

Example:
Find the amount of sodium silica fluoride that is required to raise the fluoride residual to 1.3 ppm with a flow of .5 mgd. The sodium silica fluoride is 69 per cent pure fluoride.

$$\text{Pounds per day} = \frac{\text{mgd x 8.34 lbs/g x ppm}}{\text{percent pure}}$$

$$= \frac{\text{0.5 mgd x 8.34 lbs/gal x 1.3 ppm}}{\text{.69 pure}}$$

$$= \frac{\text{5.42 lbs/day}}{\text{.69}}$$

$$= \text{7.85 lbs/day}$$

The percent of purity is used in all calculations where you are feeding a chemical that is less than 100 percent pure. If you are buying chemicals, in some cases they are bought in so many dollars per dry pound of a certain chemical. An example of this would be ferric chloride. Ferric is approximately 35 percent pure. Again you must know the weight of one gallon plus the specific gravity of the solution.

Another area where you may use this calculation is when you want to buy so many gallons of pure fluoride.

Example:

Find the number of gallons of fluoride you must buy to obtain 100 gallons of pure fluoride if the percent of purity is equal to 24 percent.

$$\text{Gallons} = \frac{\text{Gallons needed}}{\text{percent}}$$

$$= \frac{100 \text{ gallons}}{.24}$$

$$= 416.66 \text{ gallons}$$

1. How many gallons of acid must you buy to obtain 1,200 gallons of pure fluoride when the percent purity is 23 percent? (5,217 gallons)

SPECIFIC GRAVITY

Specific gravity is a relationship of the liquid to water. A liquid that is heavier than water will have a specific gravity greater than one. If you know the weight per gallon of the liquid you can find the specific gravity of the material by dividing the weight per gallon by the weight of one gallon of water.

$$\text{Specific Gravity} = \frac{\text{weight per gallon}}{\text{weight of water/gallon}}$$

Example:

Find the specific gravity of a chemical that has weight per gallon of 10.6 pounds per gallon.

$$\text{Specific gravity} = \frac{10.6 \text{ pounds per gallon}}{8.34 \text{ pounds per gallon}}$$

$$= 1.27$$

1. A liquid that you are buying weighs 11.4 pounds per gallon. What is the specific gravity of the liquid? (1.37)

When you have a material and you know the specific gravity of the material, you can easily calculate the weight per gallon of the material. In order to find the weight per gallon, take the weight of one gallon of water times the specific gravity of the material.

Weight per gallon = 8.34 lbs/gal x specific gravity

Example:

Find the weight per gallon of a liquid that has specific gravity of 1.04.

Weight per gallon = 8.34 lbs/gal x 1.04

= 8.67 lbs/gal

1. A material has a specific gravity of 2.5. What is the weight per gallon of the material? (20.85 pounds per gallon)

FILTRATION

The operation of sand filters requires the operator to apply the water at a given rate of generally 2 to 6 gallons per minute per square foot of filter area. The filter is generally designed at a rate by the engineer, but the operator must know the basics of how the engineer designed the plant in order to operate it. If one filter is removed from service, what is going to happen to the efficiency of the filters if the flow is not reduced? The loading of a filter is found by dividing the flow in gpm by the surface area of the filter.

Example:

Find the filter loading in gpm/ft^2 when the flow to a filter equals 500 gpm and the filter measures 10 feet wide by 15 feet long.

$$\text{Filter loading} = \frac{\text{gpm}}{\text{filter area}}$$

$$= \frac{500 \text{ gpm}}{10 \text{ ft} \times 15 \text{ ft}}$$

$$= \frac{500 \text{ gpm}}{150 \text{ ft}^2}$$

$$= 3.33 \text{ gpm/ft}^2$$

1. A filter in a plant measures 15 feet wide and 27 feet long and has flow of 2,000 gpm applied to it. What is the loading in gpm/ft^2? (4.94 gpm/ft^2)

2. A plant has a flow of 2,500 gpm and you want to have a loading of 3 gpm/ft^2. How many square feet of filter are needed to handle the flow to the plant? (833 ft^2)

Another area that is important to the operation of filters is the backwash rate that is used to clean the filter. Generally the design engineer will supply a backwash pump larger than is needed to wash the filter and the operator must select a rate that will clean the filter. Most filters are designed to be washed at a rate 12 - 15 gpm/ft^2. The same formula that is used to load the filter is used to calculate the filter backwash rate.

Example:

Find the backwash rate in gpm/ft^2 if a filter is washed at 2,500 gpm and measures 12 feet by 16 feet.

$$\text{Backwash rate} = \frac{\text{gpm}}{\text{filter area}}$$

$$= \frac{2{,}500 \text{ gpm}}{12 \text{ ft x } 16 \text{ ft}}$$

$$= \frac{2{,}500 \text{ gpm}}{192 \text{ ft}^2}$$

$$= 13.02 \text{ gpm/ft}^2$$

1. A filter that measures 14 feet wide and 15 feet long is backwashed at a flow rate of 3,500 gpm. What is the backwash rate of the filter in gpm/ft^2 ? (16.66 gpm/ft^2)

Another method of calculating the wash rate of filters is in inches of rise per minute. This means that you want to know the upward velocity in the filter per minute. You would calculate this by dividing the gpm of wash water by the number of gallons per inch in the filter.

Example:

Find the inches of rise in a filter that measures 10 feet wide and 12 feet long when the flow from the backwash pump equals 3,000 gpm.

$$\text{Inches of rise} = \frac{\text{gpm}}{\text{gal/in}}$$

$$= \frac{3{,}000 \text{ gpm}}{\frac{10 \text{ ft x } 12 \text{ ft x } 1 \text{ ft x } 7.5 \text{ gal/ft}^3}{12 \text{ in/ft}}}$$

$$= \frac{3{,}000 \text{ gpm}}{\frac{900 \text{ gal/ft}}{12 \text{ in/ft}}}$$

$$= \frac{3{,}000\text{gpm}}{75 \text{ gal/in}}$$

$$= 40 \text{ in per minute}$$

1. A filter in a plant measures 20 feet square and is 4 feet deep. A flow of 6,000 gpm is applied to the filter during the backwash. What are the inches of rise in the filter? (6 inches per minute)

MOLECULAR WEIGHT

In the operation of a water treatment system, the operator must be able to understand the molecular structure that makes up the chemicals that they use in the day to day operation. A chemical is made up of separate elements that are bonded together to form the material that you are using. Very few chemicals, such as liquid chlorine, are fed in their pure form. The molecular weight of a compound is equal to the atomic weights of the elements making up the compound.

Example:

Find the molecular weight of Calcium Oxide (CaO). The atomic weight of calcium is 40.08 and oxygen is 16.0.

$$\text{Molecular weight} = \text{Calcium weight} + \text{Oxygen weight}$$
$$= 40.08 + 16.0$$
$$= 56.08$$

1. Find the molecular weight of $Mg(OH)_2$ when Magnesium has an atomic weight of 24.32, oxygen weight is 16, and hydrogen is 1.008. (58.336)

2. Find the molecular weight of $Ca(OH)_2$ when the weight of calcium is 40.08, oxygen is 16, and hydrogen is 1.008. (74.0960)

SOFTENING CALCULATIONS

The operation of a lime softening treatment plant requires the operator to calculate the amount of lime required to remove a certain amount of hardness from the water.

The first step is to find the amount of lime required (in ppm) to remove the hardness from the water. This is found by subtracting the amount of hardness in the water after softening from the total hardness. Step two is to find the equivalent for the lime that you are using. As an example, if you are removing the hardness using calcium Oxide (CaO) and you are removing calcium bicarbonate $Ca(HCO_3)_2$ you would divide the molecular weight of the CaO by the molecular weight of the $Ca(HCO_3)_2$. After this you would use the basic pounds per day formula.

$$\text{Pounds CaO per day} = \text{MGD} \times \frac{\text{CaO}}{\text{Ca CO}_3} \times 8.34 \text{ lbs/g} \times \text{ppm removed}$$

Example:

Find the amount of lime as CaO that would be needed to remove 200 ppm of calcium bicarbonate from 1 mgd.

$$\text{Pounds CaO} = 1 \text{ mgd} \times \frac{56.01}{100.06} \times 8.34 \text{ lbs/g} \times 200 \text{ ppm}$$

$$= 1 \text{ mgd} \times 0.56 \times 8.34 \text{ lbs/g} \times 200 \text{ ppm}$$

$$= 4.67 \text{ lbs/Million lbs} \times 200 \text{ ppm}$$

$$= 934 \text{ pounds CaO}$$

Another method of softening uses caustic soda or soda ash in place of the calcium oxide. When using something in place of the pebble lime you would substitute that chemical in the place of the calcium oxide in the formula.

1. How many ppm of Hydrate lime ($Ca(OH)_2$ is required to lower the $Ca(HCO_3)^2$ from 450 ppm to 85 ppm? (270 ppm)

2. A treatment plant treats a flow of 140 gpm for a period of 24 hours. The raw water contains 120 ppm of hardness as calcium bicarbonate. The finished water is to be 70 ppm. How many pounds of lime as CaO must be added to obtain this? (47 pounds)

ZEOLITE SOFTENING

This is a process that is generally used as a point of use softening appliance in the home or used in the industrial area where the water must be near zero hardness. It operates by exchanging sodium ions from salt for hardness ions in the water. Zeolite has the ability to remove approximately 35,000 grains of hardness per cubic foot of media. One grain per gallon of hardness equals 17.1 ppm per grain of hardness. If you have the hardness of the water in grains per gallon you can convert the hardness to ppm by multiplying by 17.1 ppm/grain/gallon. If you have the reading in ppm, divide the ppm by the 17.1 grains per gallon.

Example:

Find the grains per gallon of water that contains 230 ppm of hardness as calcium bicarbonate.

$$\text{Grains/gallon} = \frac{230 \text{ ppm}}{17.1 \frac{\text{ppm}}{\text{g/g}}}$$

$$= 13.45 \text{ g/g}$$

What is the hardness in ppm when water contains 21 grains per gallon of hardness?

$$\text{ppm hardness} = 21 \text{ g/g} \times 17.1 \text{ ppm/g/g}$$

$$= 359.1 \text{ ppm}$$

1. A customer has bought a new water softener and the instructions state that you must know the grains per gallon in order to set the control. You have the hardness reading for your water of 130 ppm, what is the reading in grains per gallon? (7.6 grains per gallon)

2. If water contains 18 grains per gallon of hardness. What is the hardness expressed as ppm? (308 ppm)

A zeolite water softener has the ability to exchange the hardness ion for a sodium ion, which will soften the water. A cubic foot of zeolite will remove between 35,000 - 50,000 grains of hardness. If a water contains 20 grains per gallon and you want to know how many gallons the softener will treat before requiring regeneration you must know the volume of zeolite available and the amount of grains that each cubic foot will remove.
Example:

How many gallons will be produced if the softener contains 1,000 cubic feet of zeolite that will remove 45,000 grains per cubic foot? The water being treated contains 15 grains per gallon.

$$\text{Gallons} = \frac{45.000 \text{ g/ft}^3 \text{ x } 1000 \text{ ft}^3}{15 \text{ g/g}}$$

$$= \frac{45{,}000{,}000 \text{ grains}}{15 \text{ grains/gal}}$$

$$= 3{,}000{,}000 \text{ gallons}$$

1. Water contains 22 grains per gallon of hardness. The softener will remove 46,000 grains before requiring regeneration. The tank contains 1,500 cubic feet of zeolite. How many gallons will the softener treat before regeneration? (3,136,363 gal)

SAMPLE PROBLEMS

The following problems are designed to use all of the information that you have learned to this point. Problems may require you to combine formulas to arrive at the answers. Answers are given for each problem. If your answer differs, but is close, it may be in the way the calculation was rounded at some point.

1. What is the area of the water surface in a tank that measures 25 feet wide and 32 feet long? (800 ft^2)

2. What is the area in square inches of a 10 inch ductile iron pipe? (78.5 in^2)

3. What is the circumference of a standpipe that has a radius of 22 feet and a height of 200 feet? (138.16 feet)

4. What is the volume in cubic feet of a tank that measures 50 feet long, 35 feet wide, and is 12 feet deep? (21,000 ft^3)

5. What is the volume in gallons of a circular tank that measures 50 feet in diameter and has 

a sidewall depth of 18 feet? (264,937 gallons)

6. What is the detention time of a tank that measure 45 feet in diameter and has depth of 22 feet? The flow to the tank is 2,300 gpm. (114 min.)

7. How many pounds of chlorine would it take to raise the residual of the above tank to 50 ppm? (109.37 pounds)

8. Calcium hypochlorite is 70 percent available chlorine. How many pounds would be required to raise the residual of 400,000 gallons of water to 50 ppm? (238.28 pounds)

9. Determine the flow in cubic feet per second if the velocity in a 12 inch pipe is 4 feet per second? (3.14 ft^3/sec)

10. Before a pump was started the static level was 48 feet from the surface. After the pump was started the pumping level was lowered to 120 feet. If the pump was pumping 1,200 gpm what is the specific yield in gpm/ft? (16.67 gpm/ft)

11.

12. How many pounds of hydrated lime would be required to treat 5.0 mgd of water to reduce the calcium bicarbonate from 120 ppm to 80 ppm? (1,234 pounds)

13. How many gallons of water will be pumped from a well expressed as mgd if the pump runs for a period of 13 hours at 1,800 gpm? (1.404 mgd)

14. The discharge pressure gauge reads 120 psi at the pump head. How many feet of head will the pump have to produce to overcome the pressure? (277.2 feet)

15. A standpipe measures 25 feet in diameter and stands 80 feet high. How many gallons are contained in the tank when the water level is at the 60 feet? (220,781 gallons)

KMnO4 FEED RATE

1. 24 gallon per day pump output
2. Stroke 40%
3. Speed 40%
4. Flow rate: 320 gpm + 400 gpm = 720 gpm
5. 720 gpm x 60 min. x 24 hrs = 1,036,800 gallons
6. 1,036,800 gallons divided by 1,000,000 = <u>1.04 MGD</u>
7. 3% solution KMnO4
8. .03 x 8.34 lbs/gal = .25 lbs KMnO4 per gallon
9. .40 x .40 x 24 gpd = 3.84 pump output gallons/day
10. 3.84 pump output gallons x .25 = .96 pounds of KMnO4 **Formula: lbs/day = ppm x 8.34 lbs/gal x 1.04 MGD**
11. .96 lbs KMnO4 = ppm x 8.34 lbs/gal x 1.04 MGD
12. .96 lbs KMnO4 = ppm x 8.67 million pounds
13. $\frac{.96 \text{ lbs KMnO4}}{8.67 \text{ million pounds}}$
14. Answer: 0.11 ppm dosage

CALCULATION FOR UNACCOUNTED FOR WATER

The Department of Natural Resources allows for a 10% water loss. Formula to Determine Water Loss: take water pumped or purchased, subtract water metered (sold), then divide by water pumped or purchased. (Convert to % by multiplying answer by 100).

Example:

$$\frac{110{,}000 \text{ gallons pumped (purchased)} - 100{,}000 \text{ gallons metered (sold)}}{110{,}000 \text{ gallons pumped (purchased)}}$$

Water loss is 10 percent

Using a yearly average is the best way to determine your water loss. Remember to track your monthly usage for fire hydrant flushing, fires, water leaks, and ice rinks. Compare the usage from previous days water use to determine the amount of water used for these activities. This is not considered un-accounted for water; you only need to show where the water went when it is not metered. This water will be added to the gallons metered or (sold) in the water loss calculation.

Example:

1. The city pumped 10,000,000 gallons and sold 9,000,000 gallons. What is the % water loss?   (10%)