University Curriculum Development for Decentralized Wastewater Management

Hydraulics I: Fundamentals
Module Text

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Citation of Materials

The educational materials included in this module should be cited as follows:

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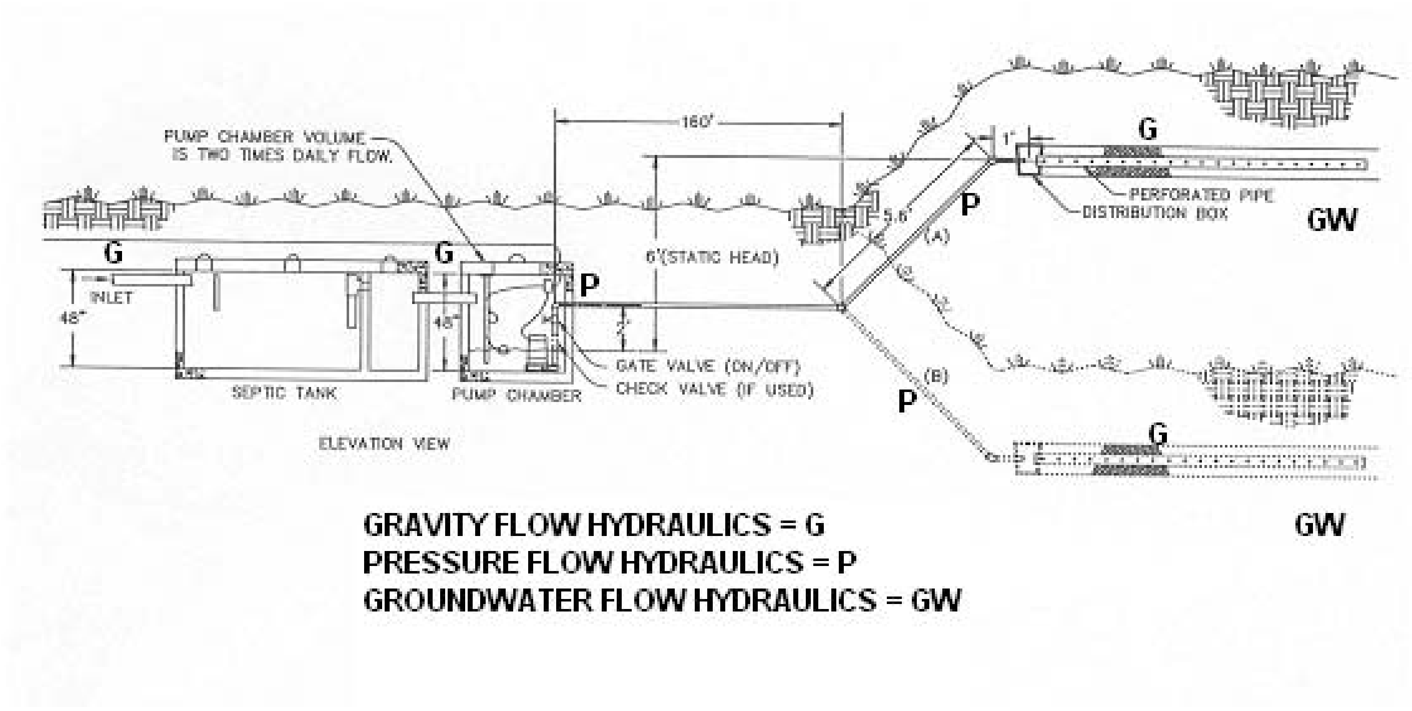
I. Hydraulics Fundamentals

Partially treated and untreated residential wastewater must be transported from its point of generation to and through its treatment and finally to its dispersal back into the environment. The movement of these fluids is governed by the same hydraulic principles that are used throughout the design process for hydraulic systems that move fluids of all sorts (water especially) around our communities. Figure 1 shows the three basic types of water movement that need to be considered in onsite and decentralized systems: Gravity Flow, Pressure Flow, and Groundwater Flow. Each of these types of water movement will be considered separately in the following modules. However, there are many basic principals that pertain to all these types of water movement. The following section is a basic review of the essential hydraulics that need to be understood if one is to successfully design a transport system for onsite and decentralized wastewater systems of any kind.

Figure 1 Types of Water Movement in Onsite and decentralized Systems



A. Fundamental Properties of Water

LEARNING OBJECTIVE: Recognize how the fundamental properties of water affect an onsite wastewater system.

Water as a fluid has all the following important properties:

- Density
- Relative Density or Specific Gravity
- Viscosity
- Surface Tension
- Compressibility
- Vapor Pressure

Water is contaminated with pollutants also exhibits all these properties although the measured value of these properties may vary with the level and type of contamination found in the wastewater or effluent. Each of these properties plays a role in the controlled movement of treated wastewater from its point of origin to its final point of dispersal.

1. Density and Specific Gravity:

On Earth, we experience an object's density when we note how heavy or light it seems to be relative to its size. A piece of lead feels heavy relative to its size because it is dense. Styrofoam feels light relative to its size because it is not very dense.

The density of water is important in onsite and decentralized wastewater engineering both when the water is still (static) and when it is moving (dynamic). The density of water, soil, and concrete are major concerns when one is determining whether a concrete storage tank will float up through the soils when the soils are saturated with water as they might be in some locations in the spring. Density is also very important when the power and size of a pump is being determined to move a certain volume of water from one point to another. All other things remain the same while the energy required to move water from one elevation to another is directly proportional to the water's density.

Density then is the ratio of the mass of a given amount of a substance to the volume occupied. Thus, we have: Density = M/V (M = Mass; V= Volume). The mass of water is formally measured in "slugs" in the English system. One slug of water on earth is about

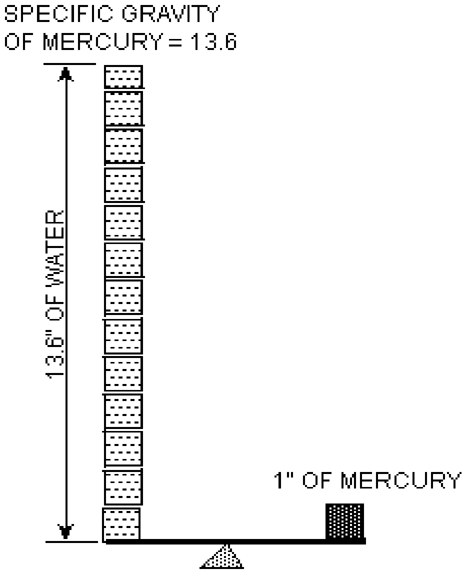
32.2 lbs {14.62 kg} or 0.51 cubic feet {0.014 m^3} or 3.83 gallons {14.5 L}. This makes Sir Isaac Newton happy because he said F= M x A (F= Force, A = Acceleration). So, when we multiply 1 slug {14.6 kg} by the acceleration of gravity on earth (32.2 ft/sec^2) or {9.8 m/s^2}, we get 32.2 lbs {14.6 kg} of water. Divide the weight of one cubic foot of water on Earth, 62.4 lbs {28.3 kg} by the acceleration of gravity, 32.2 ft/sec^2 {9.8 m/s^2},we will get 1.94 slugs {28.3 kg}. So one cubic foot of water has a mass of 1.94 slugs {28.3 kg}. We generally don't use the formal definition of density for water but generally assume that we are on Earth and actually use the weight of water, which is 62.4 lbs/ft^3 {1001 kg/m^3} or 8.34 lbs/gallon {1.0 kg/L}. However, most people are content to refer to the density of water as 62.4 lbs/ft^3 {1001 kg/m^3} even though it isn't formally correct.

Engineers often simplify things by making comparisons. Rather than dealing with the absolute density of materials, they often find it easier to look at a given material in comparison to another more common material. In the case of relative density or specific gravity, the common material used for comparisons is water.

Specific gravity then is the ratio of the density of a substance to some standard density. Typically, we use water (on Earth) as our referential density. If something has a relative density of 2 for example, it would weigh 124.8 lbs/ft^3 {2060 kg/m^3} (2 x 62.4 lbs/ft^3 = 124.8 lbs/ft^3). This term often comes up when we are doing buoyancy computations. The concrete in a concrete tank will have a Specific Gravity of 2.4 while the soil above the tank will have a Specific Gravity of about 2.0.

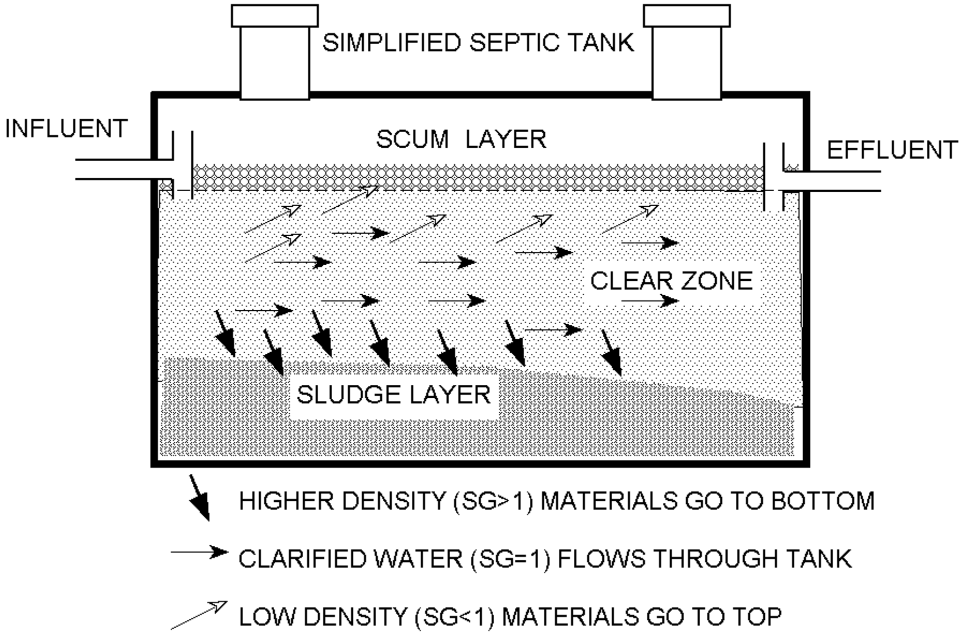
Mercury is a heavy liquid that we often see in thermometers, barometers and sometimes in labs as part of a pressure measuring apparatus. It is used because its specific gravity makes it easier to set up reasonably sized equipment. We hear a weatherman talk about the atmospheric pressure using inches of mercury as the measuring unit. This is done because of the tradition of using mercury in barometric measuring devices rather than water. It is sometimes easier to discuss inches of mercury than to convert to more formal measures of pressure. Figure 2 illustrates the relationship between the specific gravity of mercury and water.

Figure 2 Specific Gravity



A septic tank works in part due to the difference in specific gravity between the various components found in sewage. Typically, settled wastewater is seen to have three components; sludge, clarified effluent, and scum. The sludge consists of the solids and denser components of the wastewater. The scum consists of the floating debris, oils, greases and foams that are found in wastewater. In the middle, the clarified effluent forms a band that the tank will discharge. Figure 3 illustrates these levels. The liquid level is shown below the top surface of the tank's contents due to the presence of floating debris and foams. Below the liquid level, a scum layer is found which may consist of liquids with densities or specific gravities less than that of water. Beneath the scum layer (unlabeled in the figure) is the clarified (and clarifying) layer of sewage from which the lower density materials float up and the denser materials settle out.

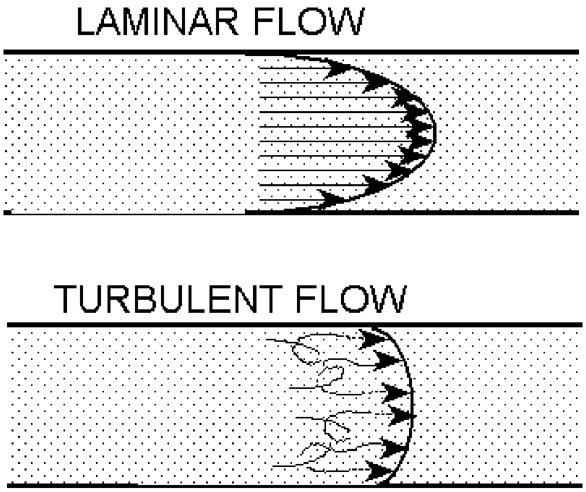
Figure 3 Septic Tank with Density Layers



2. Viscosity

A fluids resistance to flow when acted upon by an external force, such as gravity, is called viscosity. Some fluids such as molasses or grape jelly are very viscous, other fluids such as water or gasoline are not as viscous. Viscosity plays a part in the “frictional head loss” we hear about in pipes. As the fluid moves down the pipe, there is a constant shearing of the fluid along the boundary of the pipe and into the middle. One layer of the fluid is moving relative to another and friction causes a loss of energy. If the fluid is moving relatively smoothly, the flow is set to be laminar and each layer of fluid is shearing over the next like the concentric cylinders of a multiple section telescope being opened up. If the fluid is moving fast, turbulence increases and the flow swirls in all directions as it moves down the pipe. In this case, the shear forces act in many different directions consuming energy more rapidly. Almost all the pressure flow hydraulics seen in onsite and decentralized systems are turbulent although with the very low velocities found in drip irrigation lines, there is the possibility that laminar flow exists within the drip line. Figure 4 illustrates the velocity distribution in laminar and turbulent flow situations.

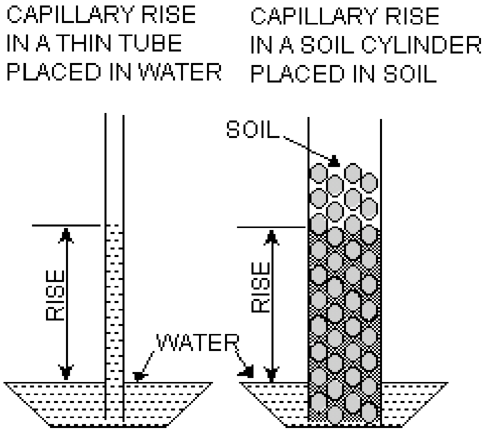
Figure 4 Laminar and Turbulent flow patterns



3. Surface Tension

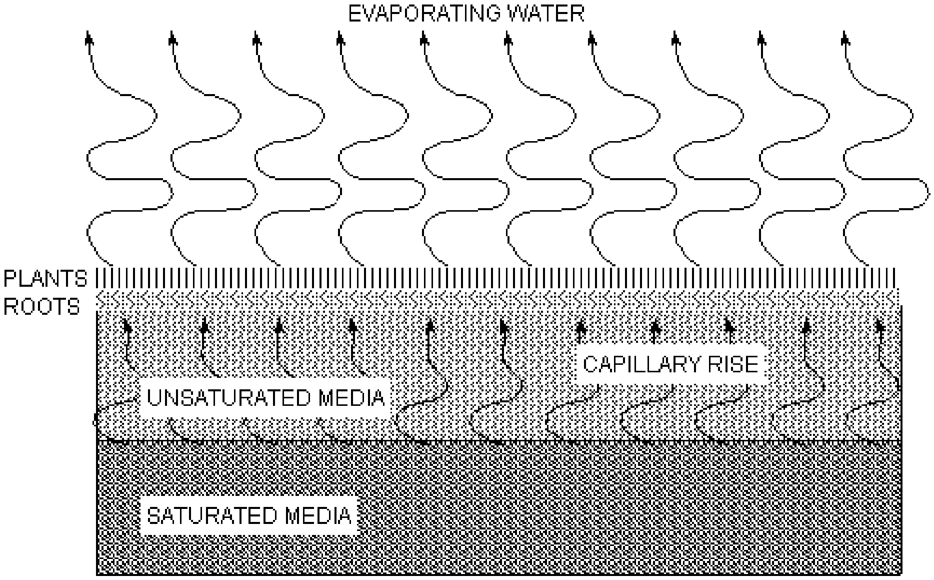
This is the extra force molecules exert towards each other when they are at the boundary of the fluid. They can't share their attraction with particles all around in three dimensions, so they attract their neighbors on a plain of the fluid's boundary with a greater force. This results in a trampoline like the effect that we know as the surface tension. It is a weak force when compared to the forces of gravity or the large forces that result from moving water but, nonetheless, it is important because it gives rise to the capillary movement of fluids in media. Figure 5 illustrates capillary rise in a thin tube and in a tube filled with a sandy media. In the case of the thin tube, the surface tension effect drags the water up due to the surface tension interaction with the sides of the tube while with the sand media the surface tension interaction is with the sand particles, which surround the void spaces, which the water rises through.

Figure 5 Capillary Rise



Evapotranspiration (ET) beds are based on the principal of capillary rise to allow water to evaporate with the help of plants (transpiration) without having the bed saturated to the surface. Capillary movement is also important in soil dispersal of effluent where the "soil matrix potential" is related to capillarity. Figure 6 is an illustration of a cross section through an ET bed.

Figure 6 Evapotranspiration (ET) Bed



4. *Compressibility*

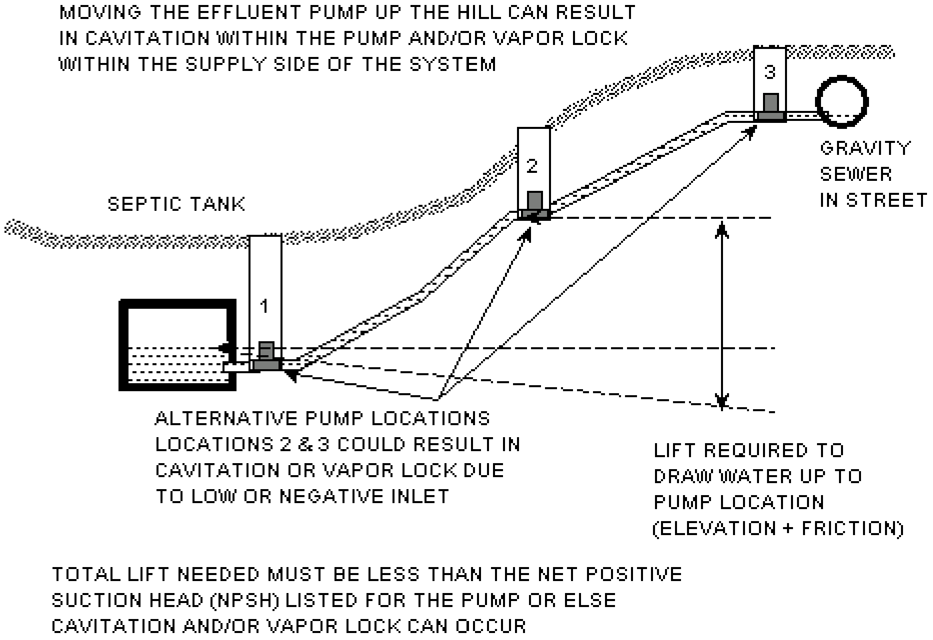
Generally, we don't have to worry about this with water (or most liquids) because water is almost incompressible in the liquid and solid phase. It is a somewhat important fact because it allows us to figure problems out which require keeping track of a given volume of water without having to adjust for its density changing that would result if it were compressible. Air is compressible, that is why you can put more air in a pressure container than the original volume of the container. The mass (and therefore the weight) is still there but it is occupying a smaller space so its density would be greater in the cylinder. Water vapor is a gas and as such it behaves much like air and can be compressed. However, for decentralized wastewater applications, compression of water vapor is not a topic that will enter into this curriculum.

5. *Vapor Pressure*

This is another useful property of water that is worth knowing about. In the onsite and decentralized industry, we consider vapor pressure when we place a pump within a system. If we place the pump higher than the fluid it is pumping, the pump has to suck the water up. This results in a negative pressure that begins to "challenge" the vapor pressure of the liquid. If the negative pressure exceeds the vapor pressure, it will cause the liquid to spontaneously convert to a gas (vaporize or boil), creating a vapor lock that prohibits the pump from lifting the water up the pipe. Vapor pressure is also important inside pumps because behind the impeller are areas which have very low pressure. If not careful, the designer can place a pump in a situation in which the pressure behind the impeller drops below the vapor pressure causing what we call "cavitation". This can also happen behind the propeller of a boat. Pump cavitation can damage or destroy the pump and also requires extra energy without producing additional work.

Consider the use of a pump to move water from an underground tank up hill to a disposal area as illustrated in Figure 7. From the standpoint of overcoming gravity and friction, the pump could theoretically be placed anywhere in the system between the tank and the dispersal area. However, as the pump's location is changed from a position well beneath the elevation of the water in the tank to an elevation well above the elevation of the water in the tank, the inlet pressure that the pump is exposed to go down dramatically and becomes negative. In simple terms, the pump is sucking the water up more than it is pushing the water down and there is a limit (vapor pressure) to the amount of negative pressure (or vacuum) that the water can stand without vaporizing spontaneously. Hydraulic engineers and pump manufacturers refer to the maximum allowable negative pressure which can be present at the inlet of a pump to insure that cavitation does not occur inside the pump as the Net Positive Suction Head (NPSH)

Figure 7 Vapor pressure and NPSH



B. Useful Units and Equivalences

LEARNING OBJECTIVE: See the relationship between the various measurement units which are commonly used in onsite wastewater analysis and design.

- 1 cubic foot of water (1 ft^3) weighs 62.4 lbs {28.3 kg} on Earth, 1 square foot has 144 square inches (12 in x 12 in = 144 in^2 {929 cm^2})
- 1 foot depth of water pushes down with a force of (62.4 lbs/ft^2)/144 in^2/ft^2 = 0.433 lbs/ in^2 {0.03 kg/cm^2}
- 2.3 cubic feet of water covering 1 ft^2 of surface results in 1 lbs/ in^2 (psi)
- 1 psi is equivalent to 2.3 feet of head {0.7 m}
- 1 cubic foot of water is equivalent to 7.48 gallons {28.3 L} anywhere
- 1 lb of water is almost 16 (15.35) fluid ounces or 2 cups
- 1 gallon of water weighs 8.34 lbs {3.79 kg} on Earth
- 1 gallon/minute (gal/min or gpm) = 0.0022 cubic ft /sec or ft^3/sec or cfs
- 1 cfs = 448.8 gpm

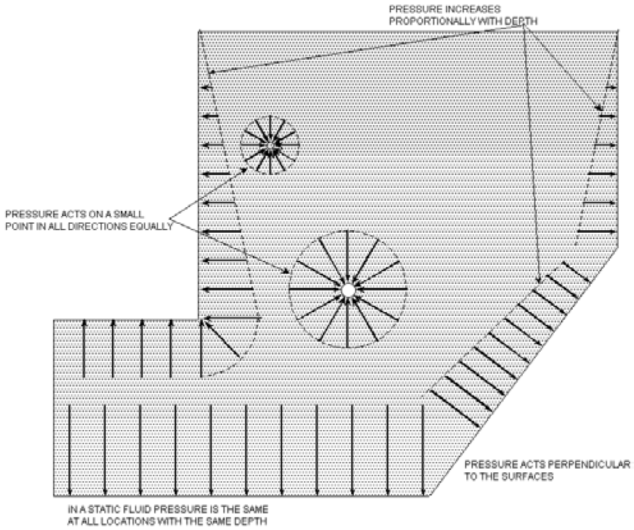
C. Fluid Statics: Pressure and its Measurement

LEARNING OBJECTIVE: Understand pressure consideration.

1. Pressure – Definition

Pressure is the force per unit area that would be exerted on an imaginary small plane area at the point of interest. Your eardrum feels the pressure of the water (until you equalize) regardless of whether your ear is pointing down, up or sideways in the water. The pressure on you ear is the same in any direction as long as it is at the same depth in the water. Pressure is the same at all equal depths (as long as the fluid is static). Figure 8 illustrates the increase of pressure with depth (along the sides of the container), the constant and omni-directional aspect of pressure around a small point, and the upward pressure exerted against the underside of a submerged section of a container.

Figure 8 Pressure Concepts-1

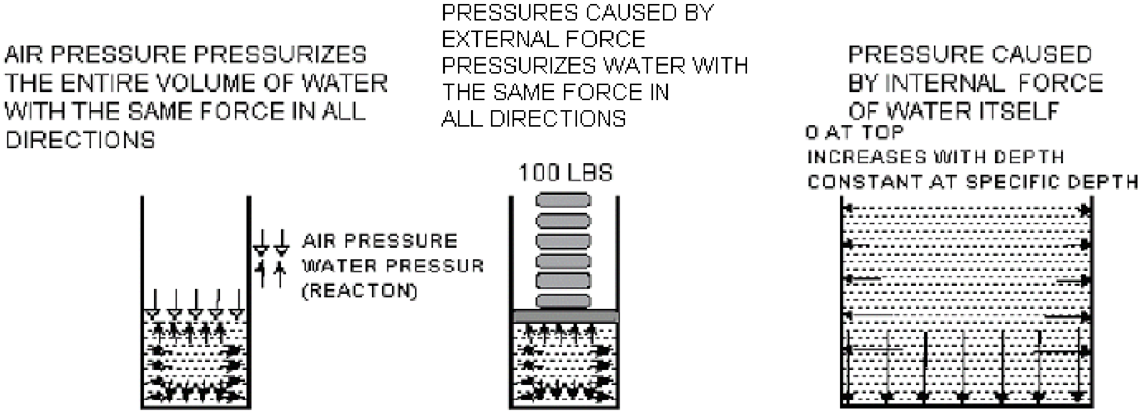


If the fluid is moving, there can be changes of pressure along a given horizon. This concept will be considered a little later when hydraulic energy considerations are discussed. Figure 9 illustrates the effect of air pressure on a fluid, the effect of an external force on a fluid, and the effect of the water itself upon the internal pressure.

Pressure – Measurement

Pressure is measured in two ways: Absolute and Gauge Pressure.

Figure 9 Pressure Concepts-2

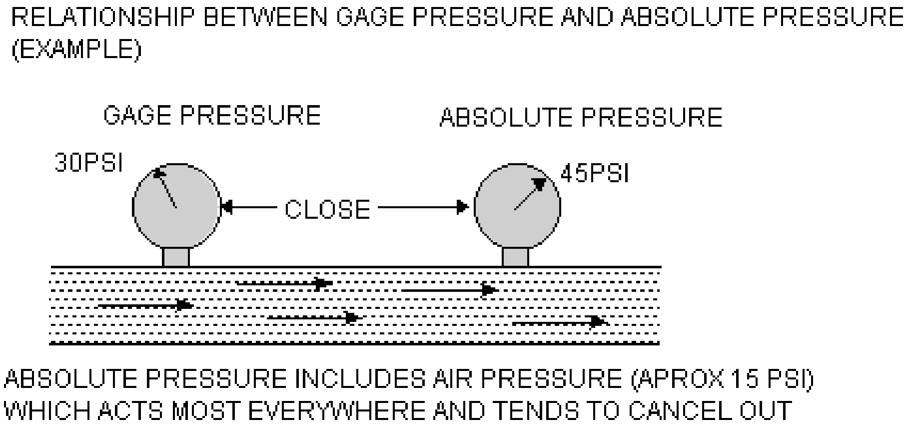


2. *Absolute & Gage Pressure*

Absolute pressure is the formal expression of the total force per unit area. It includes the pressure from the atmosphere (air pressure), the pressure from any external forces applied to the fluid, and the pressure resultant from the weight of the fluid itself. Absolute pressure is generally not the measure of pressure most often encountered in the applied hydraulics related to onsite and decentralized systems. However, as mentioned above in the discussion of vapor pressure, absolute pressure is the pressure evaluated for comparison to the vapor pressure of the liquid at its given temperature. Tables available in most engineering handbooks will provide the vapor pressure of water for different temperatures. If the absolute pressure, in any portion of the system, is below the vapor pressure of the water, problems relating to vapor lock and/or cavitation can occur.

Gauge pressure measures only the difference in pressure between atmospheric pressure and the pressure being measured. Air pressure typically works in all directions and at all locations open to air. As such the air pressure tends to cancel out in our analysis. Therefore if we consider only the pressures relative to atmospheric (positive or negative) then our computations are often simpler. Atmospheric pressure is typically in the range of 15 psi although it depends upon the elevation of the system and atmospheric conditions. An absolute pressure of 25 psi would be equivalent to a gauge pressure of 10 psi. An absolute pressure of 15 psi would be equivalent to a gauge pressure of 0 psi. Typically we use psi (lbs/ in^2) for both absolute and gauge pressures. Figure 10 illustrates the difference in absolute and gage pressure which would be observed between two gages located in close proximity along a pipe.

Figure 10 Gage & Absolute Pressure

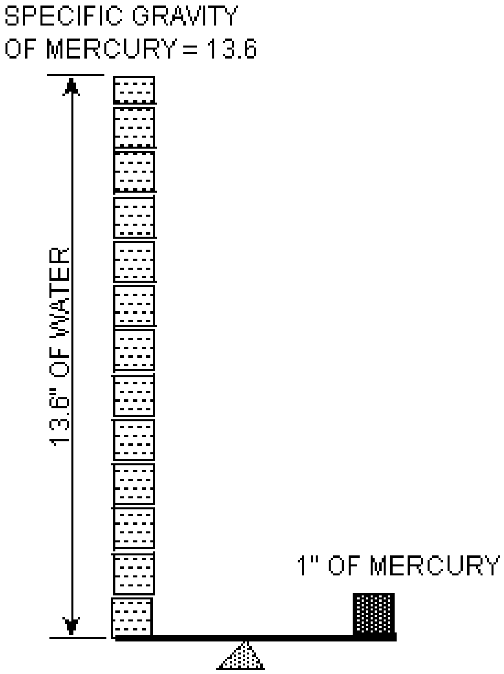


3. *Pressure "Head"*

Other measures of pressure that we need to pay attention to in the onsite and decentralized industry include pressure head expressed as feet of water, inches of water or inches of mercury. Figure 11, repeated from the previous discussion on specific gravity is presented again to reinforce the concept that the pressure from either of these columns of liquid would be exactly the same. These columns of liquid are used as measures of pressure because of their convenience. The change in the surface elevation of a liquid column connected to components that have pressures we want to measure is often used as the measure itself:

a. 1 ft of water exerts a downward force of 62.4 lbs/ft3 / 144 in^2 = 0.433 psi.
b. 1 inch of water would exert a downward force 1/12 of what 1 ft would cause. Therefore, 1 inch of water is equivalent to 0.036 psi
c. Since mercury has a specific gravity of 13.6 we see that 1-inch of mercury would be equivalent to 13.6 inches of water or 13.6 x 0.036 psi or 0.486 psi.

Figure 11 Specific Gravity & Pressure



As anyone who has ever gone swimming underwater knows, water pressure increases with the depth of the dive.

$P_{absolute}$ = P_a + depth (ft) * 0.433 psi /ft where P_a is the atmospheric pressure.
P_a = Atmospheric pressure = 14.7 psi (+/-) at sea level
Atmospheric pressure = 11.5 psi (+/-) at 7000 ft {2134 m} (+/-)

If we are interested in gauge pressure it becomes:

P_{gauge} = depth (ft) * 0.433 psi/ft

Or if you want to use ft (head) as your measure,

P = 1 ft /ft.

For example, 10 feet down in the water
$P_{absolute}$ = 15 psi + 0.433 psi/ft x 10 ft = 19.33 psi
P_{gauge} = 0.433 psi/ft x 10 ft = 4.33 psi
P_{head} = 10 ft

Almost all of the water pressure devices we use are measured in gauge pressure. A gage which is measuring absolute pressure will read about 15 psi in the air.

4. The Manometer

The manometer is a useful device for measuring gauge pressure in the field because all it takes is a clear tube and a measurement. In Figure 12, the height that the fluid rises in the tube above the pipe (pipe is shown in a cross section view) directly relates to the pressure in the pipe. The height should theoretically be measured from the centerline of the pipe but this is not an important difference for pipe sizes used for onsite wastewater systems.

Figure 12 Manometer

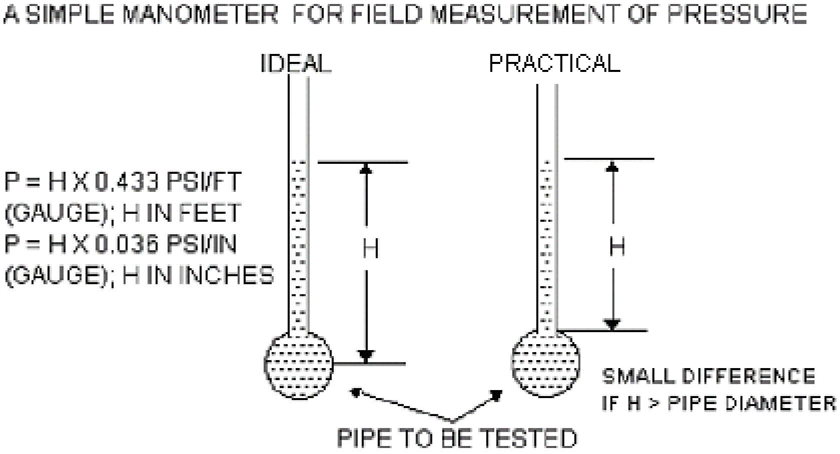
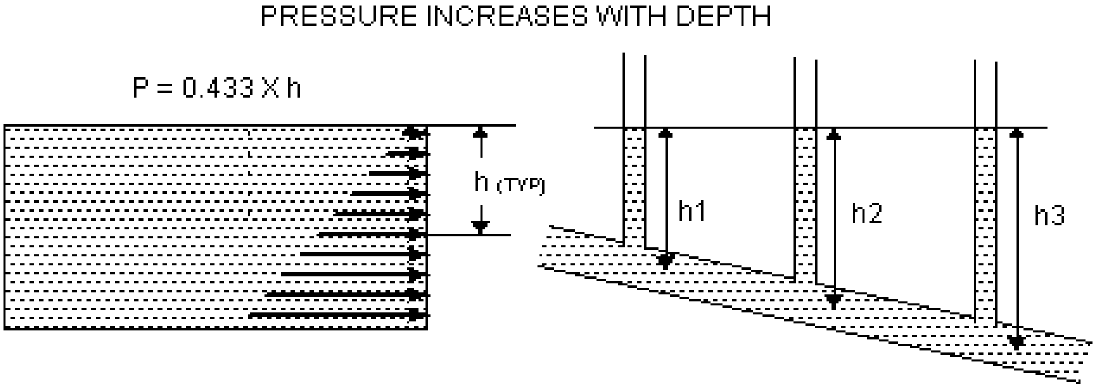


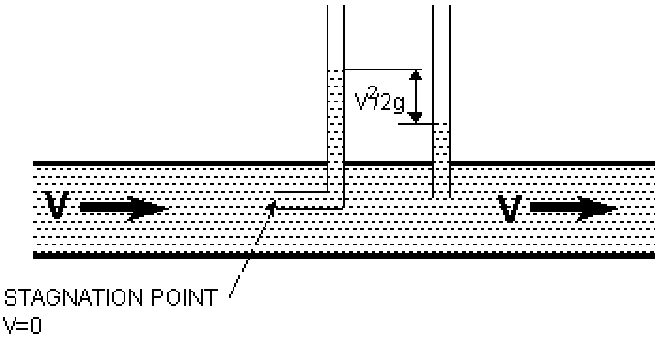
Figure 13 Manometers and Pressure illustrates the relationship between increasing pressure and depth. The height of water recorded in the manometer tubes (measured from the pipe) increases with the pipe's pressure although the absolute height that the water rises (measured from a horizontal datum) is the same.

Figure 13 Manometers and Pressure



The total energy available at the manometer location includes the effect of velocity but this energy is generally not available for increasing the elevation that the water rises in the manometer tube. If, however, the tube's end is turned upstream the result of the dramatic reduction of velocity immediately in front of the tube's end (referred to as a stagnation point) results in the fluid’s kinetic energy momentarily being “captured” and turned into pressure which will cause in increase in the water’s elevation in the manometer tube. Such a configuration is referred to as a Pitot tube. Figure 14, illustrates the use of two tubes to determine the velocity of a fluid in a pipe. The use of a manometer and Pitot tube has been used historically to determine the velocity of ships and airplanes with respect to the water or air that they are traveling in.

Figure 14 Velocity Determination in Fluids

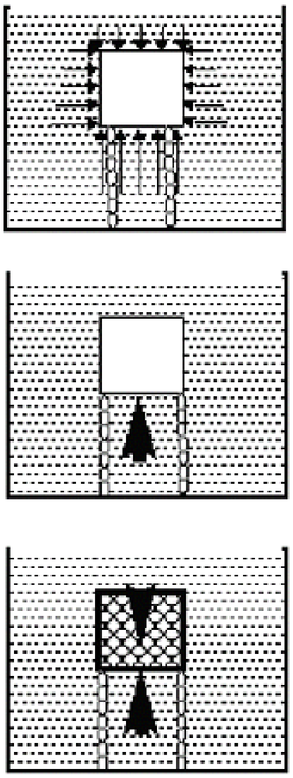


5. Buoyancy

Buoyancy is a direct consequence of pressure considerations. As we learned previously, water’s pressure is proportional to depth and works all around the perimeter of an object either containing the water or suspended within the water. You float in water because you have a specific gravity of about 0.98. If you weigh 135 lbs {61.3 kg} gravity is pulling you down with a force of 135 lbs {601 N} but the water is pushing up with exactly the same force. In water, there is pressure all over your body that increases with depth. The pressure acting on vertical surfaces produces a horizontal force. The pressure acting on horizontal surfaces produces a vertical force. At any given depth, the horizontal forces on one side are cancelled by the horizontal forces acting on the opposite side. Therefore, there is no net horizontal force. The vertical forces acting at the top of the object are smaller than the vertical forces acting at the bottom of the object because the pressure is increasing with depth, thus a net upward force results.

Consider a simple lightweight empty box anchored by a chain to the bottom of a tank as illustrated in Figure 15. The overall force tending to float the box (which is being resisted by the chain) is the net result of the difference between the weight of the box and its contents and the pressure that surrounds the box. The pressure on the sides of the box acts in equal and opposite directions and, therefore, cancels. The pressure’s difference from bottom to top results in the net upward force of buoyancy.

Figure 15 Buoyancy



AN EMPTY BOX OF NEGLIGIBLE WEIGHT IS ANCHORED BY CHAINS TO THE BOTTOM OF A CONTAINER OF WATER.

PRESSURE ON LEFT = PRESSURE ON RIGHT THEREFORE THE HORIZONTAL FORCES CANCEL EACH OTHER

THE PRESSURE ON THE BOTTOM IS GREATER THAN THE PRESSURE ON TOP,THEREFORE THERE IS A NET UPWARD FORCE

THE DIFFERENCE IN PRESSURE FROM TOP TO BOTTOM IS EXACTLY EQUAL TO THE WEIGHT OF WATER WHICH IS DISPLACED

IF THE BOX IS FILLED THEN THE WEIGHT OF THE MATERIAL IN THE BOX WILL ADD TO THE TOTAL DOWNWARD FORCE.

IF THE TOTAL DOWNWARD FORCE REMAINS LESS THAN THE ORIGINAL UPWARD FORCE THE BOX WILL CONTINUE TO BE SUSPENDED.

IF THE TOTAL DOWWARD FORCE BECOMES MORE THAN THE ORIGINAL UPWARD FORCE THE BOX WILL DROP TO THE BOTTOM.

6. Buoyancy Analysis in Onsite

Consider a septic tank set in an area that is subject to seasonal high ground water as illustrated in Figure 16. It is important in a situation like this to determine if the tank is likely to float up. The water surrounds the tank and even though the tank is not in a large body of water the surrounding water exerts the same pressure it would if the tank were submerged to the same depth in a large tank.

Figure 16 Buoyancy Analysis

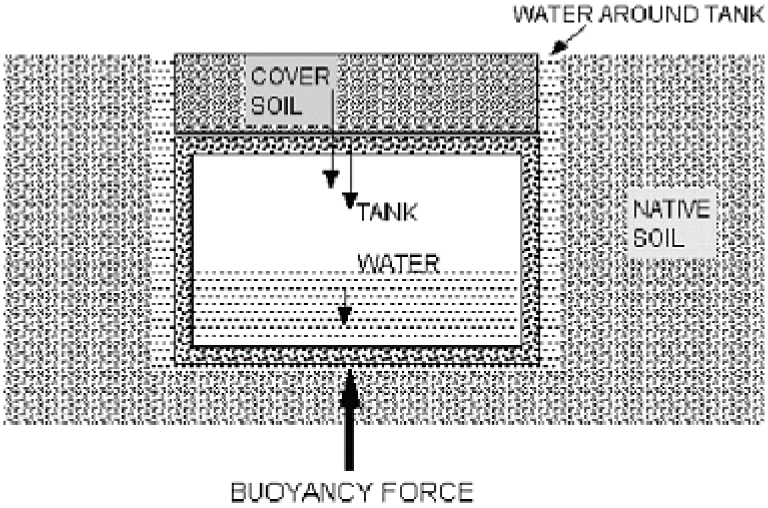


Figure 17 below illustrates what can happen if buoyancy forces are not taken into account. The septic tank shown below has literally floated up from its placed position in the excavation. This event followed a period of rain that saturated the soils in the area. The water in the saturated soil supplied the upward force that dislodged the tank.

Figure 17 Septic Tank Dislodged By Buoyancy Force

To determine if the tank will tend to float up, breaking its inflow and outflow pipes (and possibly contaminating the area with partially treated wastewater, thereby creating a public health problem as well as an environmental problem), it is necessary to do a buoyancy analysis.

To do such a buoyancy analysis the following data are necessary:

a. The weight of the empty tank. (Wt) This force acts downward. This can be computed by calculating the amount of concrete presented from the inside dimensions and outside dimensions. Some concrete tanks have internal concrete baffles that also must be considered. Generally, the gross weight of the tank can be determined by calling the manufacturer. With the volume of the concrete and its specific gravity the total weight of the tank can be computed.

b. The weight of the maximum displaced volume of water that would otherwise fill the place where the tank is (B). This, as discussed above, is the buoyant force that acts upward on the tank.

   Length (ft) x Width (ft) x Height (ft) x 62.4 lbs/ft^3 = Total Buoyant Force (B)

c. The weight of the minimum amount of water that will be in the tank. (Ww) The conservative approach might be to consider this amount of water to be *zero* gallons, pounds, cubic feet, or depth. Example: a homeowner has his septic tank pumped during the spring (when his system is not working because of groundwater) and the effluent pumping company drains the entire tank. With pressure-dosed systems, there is usually a minimum amount of water below the lowest (off) float.

d. The weight of any soil directly over the tank. (Ws) This can be computed by knowing the length and width of the tank, the specific gravity of saturated soil, and the anticipated minimum cover depth. (The shear forces that the soils can withstand at the boundary will be ignored. They will be much less when the soil is wet anyway.)

Putting it all together, if:

(Wt + Ww + Ws) > B the tank will not float

If, however,

(Wt + Ww + Ws) < B the tank will float.

Generally, the tank will not rise up dramatically and partially stick up above ground as was shown in the picture above. Instead, the tank will slowly, gradually move up pulling at its pipes. As it moves up, a fraction of an inch at a time the water level around it will drop as more water comes into the void around the tank. Then it will rise again and the process will repeat until the pipes break. It would likely to happen slowly and would not be noticed for a while. It is unlikely that the tank would rise uniformly. The tank may begin to tip with one edge or corner lifting more than the others. If the intake portion of the tank lifts more, the tank may lose additional content out the discharge line, reducing its weight further thereby resulting in more accelerated dislocation. Furthermore, we have ignored the shear forces between the overburden soil and the surrounding native soil and between the tank and the backfilled material. These shear forces can slow down the process and may even stop it, but eventually as the soils become saturated, these forces tend to get smaller. Tanks lacking flat tops including smooth plastic and fiberglass tanks often have circular, curved, or beveled tops. These tops form wedges that can cause the loose fill on top of the tank to shed toward the sides removing some of the tank's overburden load.

D. Continuity

LEARNING OBJECTIVE: Understand the use of continuity to solve/analyze onsite problems.

The concept of continuity is a simple one. You use it every time you balance your checkbook:

Deposits – Withdrawals = Change in Balance

In hydraulics:

Total Inflow – Total Outflow = Change In Volume

Or seen another equivalent way,

Final Volume = Initial Volume + Total Inflow – Total Outflow

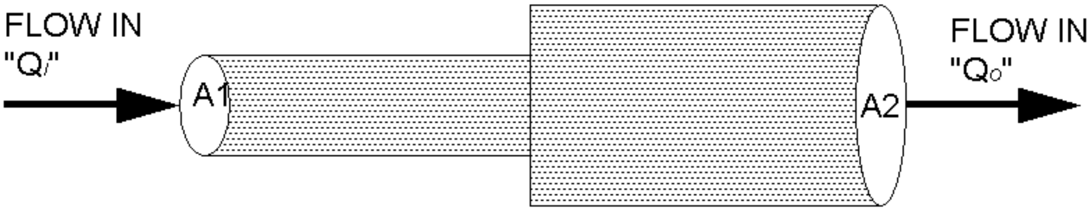
1. Continuity in Closed Systems

In a closed and filled system where there is no place for either additional storage or release of water continuity simplifies to:

Deposits – Withdrawals = 0
Or,
Deposits = Withdrawals

This simpler approach to continuity is useful in closed and filled pipe systems.

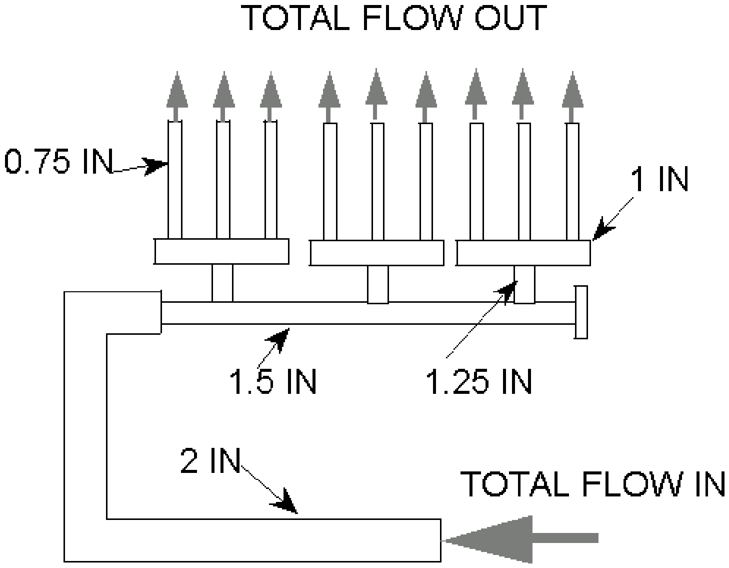
Figure 18 Continuity



The flow in (Q_i) must equal the flow out (Q_0) because there is nowhere for extra water to be stored or released. Where there is space for storage and/or releases, the inflow may not equal the outflow. Consider a simple septic tank with flows both coming in and going out. If they are not equal there must be change in volume:

Other situation where continuity is important is in the computation of the component flows in a branching (or joining) system. In **Figure 19**, it can be seen that the flow from the supply line experiences both a change of diameter as the supply line's diameter is reduced but also there are two stages of flow division. The first state of flow division results in a division by three of the total flow to the three sub assemblies of laterals and the second stage of flow division further divides the flow by another factor of three. A total of nine laterals carry the same flow as the original supply line.

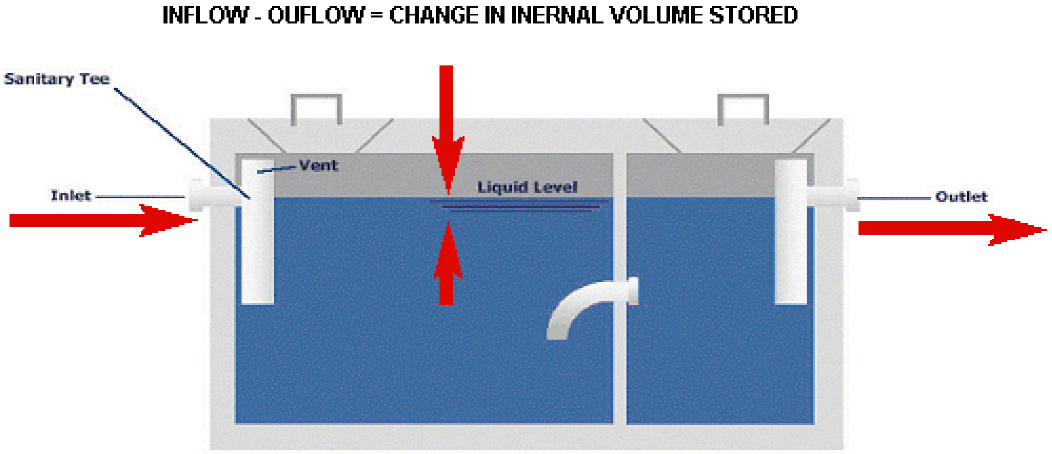
Figure 19 Pipe System with both Diameter Changes and Flow Division



2. *Continuity in Open Systems*

Open systems include systems with tanks or other confinements with at least one liquid surface that is free to move. Such systems are generally not under pressure (except atmospheric) and can hold a varying amount of water within their boundaries. A simple septic tank or a pump chamber is an example of an open system where simple arithmetic is sufficient to keep track of the contents.

Figure 20 A Two-Compartment Septic Tank with Inflows and Outflows



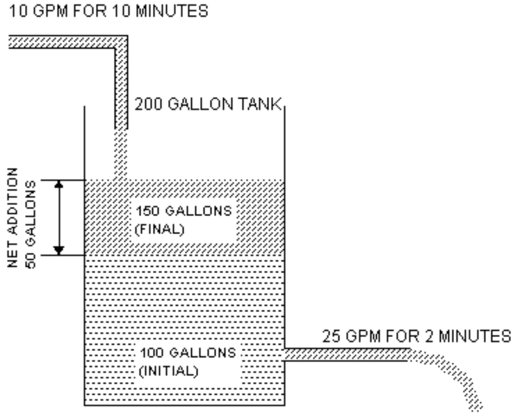
Using flow rates make things a bit more complicated but not much.

Inflow (rate) x Inflow time - Outflow (rate) x Outflow time = Change in Volume

Or seen another way,

Final Volume = Initial Volume +Inflow (rate) x Inflow time - Outflow (rate) x Outflow time

Figure 21 Continuity with Flow Rates (Open System)

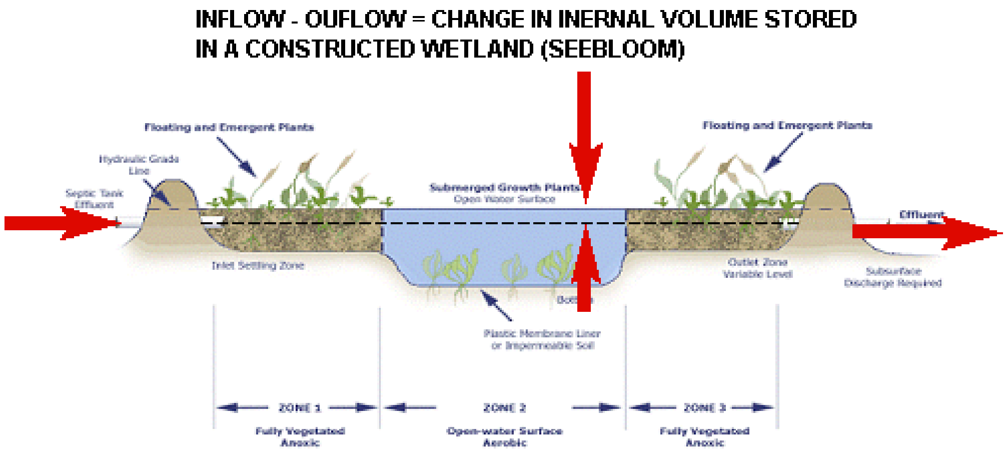


A frequent computation is necessary in the design or review of a storage tank relates the change in water level to the inflow and outflows.

Final Elevation = Initial Elevation + **(**Inflow (rate) x Inflow time - Outflow (rate) x Outflow time**)** / Tank Inside Area

The same principles described above apply equally well to an open surface, lined above ground storage facility such as a constructed wetland. **Figure 22** illustrates this idea. The computation of the change in water level is complicated in this case by the sloping sides of the embankments, the possibly irregular shape of the wetland and the combination of both open surface water where the volume of water stored is easily computed and the saturated soil around the boundary of the wetland where the porosity of the soil influences the amount of water stored per unit volume. Nevertheless, the fundamental idea of continuity applies equally well in this situation as it does to a rectangular concrete tank with vertical walls.

Figure 22 Application of Continuity to a Constructed Wetland



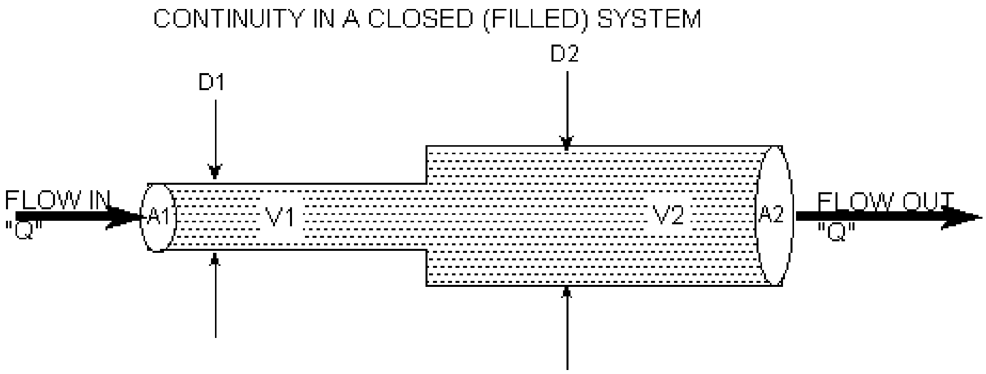
3. *Continuity for Water in Motion*

Continuity for water in motion allows the computation of the average velocity of the water in the conduit. If the average velocity at a point is called V and the area of the conduit is A, the total flow at that point is V x A. This must equal the total flow Q, Therefore Q = V x A

Since the flow must remain constant if there is no place for storage or release this must result in V x A being the same all along the conduit:

$V_1 \times A_1 = V_2 \times A_2 = V_3 \times A_3 = \text{etc.} = Q$

Figure 23 Continuity in Closed Systems



In general;

$$V_1 \times A_1 = V_2 \times A_2 \quad \text{or} \quad V_1/V_2 = A_2/A_1 = (R_2/R_1)^2 = (D_2/D_1)^2$$

"*The ratio of the velocities is inversely related to the square of the ratio of the diameters.*"

Pipe velocities in lines carrying water with solids are important because when effluents are being pumped and piped throughout a system care must be taken to insure that the velocities are high enough (generally above 2.5 ft/sec {0.762 m/s}) that solids being carried in the system will not settle out in the pipe. If this happens the solids will accumulate and eventually contributing to blockage. On the other hand, velocities that are too high (generally above 10 ft/sec {3.048 m/s}not only result in inefficient pump systems but can also lead to the slow erosion of the pipe material due to the abrasion with any solids in the line. In mechanized systems with pump discharges that may be controlled with fast acting solenoid valves which can close quite rapidly a "water hammer" effect is possible in which a long and heavy column of water is moving in one direction down a pressurized water line and the valve closes almost instantaneously. A more detailed discussion of water hammer is available in the Hydraulics II – Energy Module. Under such a condition the water column has to be slowed down to a stop almost immediately and relatively large forces are needed to decelerate the flow to zero. By Newton's second law in which force equals mass times acceleration (F = M x A) when the acceleration (or deceleration) is large the force will also be large. These fast acting water hammer forces can literally tear a system apart by breaking joints.