Aquatic Life Support Operations

AALSO Organization
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**Water**
Water covers more than 70% of the earth’s surface and most of that is contained with the earth’s oceans. As aquatic animal life support operators, the seawater we treat, whether it is directly from the ocean or created artificially is home to the animals we care for. It is for this reason that we must understand some of its basic properties.

**Water, Temperature, and Pressure**
Water exists naturally on earth in all three of its states: Solid (Ice), Liquid (Water) and Gas (Steam/Vapor). At standard temperature and pressure, water exists as a liquid as it is most often observed. At lower temperatures and/or higher pressures, water exists as ice as can be seen on mountain peaks or as glaciers. At higher temperatures and/or lower pressures, water exists as a vapor as can be observed in the form of clouds. Water, under standard atmospheric pressure at sea level, has a freezing/melting point of 32 F (0 C) and a boiling point of 212 F (100 C). As pressures change or substances are dissolved in water, these points will rise or fall. When water or any substance is heated, the molecules begin moving at higher rate. When dissolving solid or liquid substances in water, this increased movement amongst the molecules creates better conditions for the substance to be dissolved. Similarly, at lower atmospheric pressures, fewer air molecules are “pressing” on the water which leaves the water molecules less restricted to move around. When dissolving gases in water, less movement between the molecules is desired. Oxygen or carbon dioxide, for example, stay in solution much better when the temperature of the water is lower.

**Water Composition**
Water is made up of two hydrogen atoms and one oxygen atom, with the chemical formula H2O. The hydrogen atoms form covalent bonds (bonds in which electrons are shared amongst the atom) with the oxygen atom. When molecules of water are in close proximity, the molecules tend to form hydrogen bonds with one another. This unique property is what gives water its surface tension, which enables liquid water to act almost like a solid at the surface at the moment the body of water is struck by another object.
The “Universal Solvent”

Water has been termed the “universal solvent”, which is mostly attributed to its polarity. The oxygen atom, being electrochemically negative is repelled by the hydrogen atoms, which are electrochemically positive. These electrochemical “repulsions” give water its familiar di-pole structure. This relationship is expressed in Figure 1 below:

These forces give the water molecule “poles”, just as the earth has distinct poles. Any substance that demonstrates distinct poles such as water is termed a polar substance which allows these substances to, in varying degrees, dissolve in water. Many substances that exist on earth, whether natural or manufactured, are polar and thus soluble in water: substances such as salts and acids, and even gases like the carbon dioxide dissolved in cola or the oxygen dissolved in our oceans. This makes it quite difficult to come across water in its purest form. Substances that are deemed non-polar, such as vegetable oils and gasoline, are not soluble in water.

Water by Observation

When observing water, whether it is in a laboratory or in our natural environment, it is important to note its cohesive and adhesive properties. Cohesion can loosely be described as the substance’s affinity for “staying together” or staying intact. Adhesion is the substance’s affinity for “breaking off” or sticking to another substance. In the case of water, cohesion can be observed on a tree leaf where the water forms a droplet, or sphere, as it resists breaking apart. Adhesion can be observed between water and glass, where the water level appears higher where it contacts the glass; thus forming a meniscus as can be observed in Figure 2 below.
The graduated cylinder on the left demonstrates the adhesive relationship between water and glass. The cylinder on the right contains mercury, whose cohesive forces are stronger than its adhesive forces with the glass, keeping the mercury together. If one were to pour out the contents of both cylinders, some water would remain in the left cylinder whereas all of the mercury will have left the right cylinder.

**Understanding Water Chemistry**

There are many factors in an aquatic environment that affect the health and well-being of animals in captivity. Through laboratory testing and constant monitoring of seawater, those environments can be made even more stable and enhancing than the conditions that exist in the wild.

**Testing for pH**

The pH of a substance is the measurement of the activity of the hydrogen ions present in the substance (not to be confused with the actual concentration of hydrogen ions). The use of the letter “p” has no known original reference, but is modernly referred to as the “power” or “potential” of hydrogen in the solution. pH can be mathematically expressed as the inverse logarithm of the hydrogen activity in a compound, whose scale runs from 0 – 14.

At the low end of the pH scale are strong acids, whose hydrogen activity is very high. Acids such as hydrochloric and sulfuric acid are strong acids, which references their ability to “donate” hydrogen ions to other substances. At the high of the pH scale are strong bases, whose hydrogen activity is very low. Bases such as sodium hydroxide (lye) and potassium hydroxide are strong bases, which references their ability to “accept” hydrogen ions. Acids when mixed with water will form hydronium ions (H$_3$O$^+$) whereas bases will reduce the level of hydronium in the water. The following figure demonstrates the pH of many well-known substances:

![pH scale diagram](image)
Pure water sits at the middle of the pH scale with a value of 7. At a pH of 7, a substance is considered neither an acid nor a base but rather a neutral substance. Seawater, however, is not pure and ranges in pH from 7.5 to 8.4. Many compounds affect the pH of seawater including minerals in the ocean bed and carbon dioxide in the air above. pH is most often tested in a laboratory setting by use of a probe which uses a glass bulb and low voltage to measure the hydrogen activity at the glass bulb; or by a chemical substance with known reactions to pH, such as litmus or phenolphthalein. The electronic probe method is more accurate and will give definitive pH values whereas litmus can only describe the substance as an acid or a base.

**Testing for Temperature**

Temperature can be described as the kinetic energy (energy of motion) of the molecules of a substance. When water is heated, for example, the molecules become more and more excited. They begin to move more rapidly until which point they begin to change state (into steam) as they escape the vessel containing them. Heat is simply a bi-product of those movements. As the molecules collide and vibrate and rub against one another, the friction causes heat to be released (similar to warmth you obtain by rubbing your hands together on a cold day). When water molecules are moving very rapidly, the distance between molecules is great. This relationship can be viewed in the form of water vapor.

When the molecules are severely slowed, they group together very tightly to form ice. The following figure demonstrates the states of water at the molecular level:

![Figure 4](image)

When temperature is tested in a laboratory setting, it can be done using a standard liquid thermometer which measures the temperature-pressure relation of the liquid inside the thermometer, or by use of a probe. A temperature probe most typically measures the conductivity or resistance value of a known metal or metals and converts those values into temperature units. Both methods are accurate, however an electronic probe can provide a more precise figure.
Testing for Salinity
Salinity is a measurement of salt ion concentration in water and for seawater is typically expressed in parts-per-thousand (ppt), percentage (%) or mS/cm (milli-Siemens per centimeter) when tested by conductivity. The standard method for testing salinity in an aquarium environment is by use of the refractive index (with a refractometer) or by conductivity. Salts are typically composed of a cation (an electropositive ion) and an anion (an electronegative ion). An example of this would be Sodium Chloride, or table salt. Sodium (Na\(^+\)) is a cation and Chlorine (Cl\(^-\)) is an anion. Most commonly when salts are dissolved in water, they readily dissociate into their respective ions. The equation NaCl\(_{\text{s}}\) → Na\(^+\)\(_{\text{aq}}\) + Cl\(^-\)\(_{\text{aq}}\) expresses this relationship. This separation forms electrolytes (substances that conduct electricity in water), which allows us the ability to measure salinity as conductivity. Conductivity (in mV) is then converted by the probe to units of salinity as described above. The USDA regulates that salinity values for marine mammal pools must be maintained between 15-35 ppt.

Figure 5 below displays the major salt ion concentrations of seawater by percentage (figures are approximate).

<table>
<thead>
<tr>
<th>Chloride (Cl(^-))</th>
<th>55.03%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (Na(^+))</td>
<td>30.59%</td>
</tr>
<tr>
<td>Sulfate (SO(_4^{2-}))</td>
<td>7.68%</td>
</tr>
<tr>
<td>Magnesium (Mg(^{2+}))</td>
<td>3.68%</td>
</tr>
<tr>
<td>Calcium (Ca(^{2+}))</td>
<td>1.18%</td>
</tr>
<tr>
<td>Potassium (K(^+))</td>
<td>1.11%</td>
</tr>
<tr>
<td>Bicarbonate (HCO(_3^-))</td>
<td>0.41%</td>
</tr>
<tr>
<td>Bromide (Br(^-))</td>
<td>0.19%</td>
</tr>
<tr>
<td>Borate (BO(_3^{3-}))</td>
<td>0.08%</td>
</tr>
<tr>
<td>Strontium (Sr(^{2+}))</td>
<td>0.04%</td>
</tr>
<tr>
<td>Miscellaneous constituents</td>
<td>0.01%</td>
</tr>
</tbody>
</table>

Testing for Nitrogen Compounds
Nitrogen is an extremely abundant element on earth whose existence extends from its prevalence in our atmosphere to the make-up of animal DNA. Understanding its role in an aquatic environment is integral to the animals’ lives we preserve.

Total Ammonia Nitrogen
Ammonia as it concerns a life support operator, with the chemical formula NH\(_3\), is a result of the microbiological decay of animal and plant proteins. It is most prevalently excreted by mammals through the urine, however in the case of fish, through the gill membranes. The primary concern with ammonia is its toxicity to fish, primarily at higher pH levels. At lower pH levels, ammonia is ionized to Ammonium (NH\(_4^+\)) whose toxicity is less of a concern. Ammonia and Ammonium combine to form Total Ammonia Nitrogen or TAN. TAN is most often tested using a Salicylate reagent set. Controlling ammonia levels in a fish system can present a challenge, however Mother Nature is on our side.
Nitrite and Nitrate
Breaking down ammonia into less toxic compounds of nitrogen is a bacterial process (as illustrated in Figure 6 below). Ammonia in the water is oxidized by Nitrosomonas, Nitrosospira, and other nitrifying bacteria to form the less toxic Nitrite (NO₂). Nitrite is also toxic to fish, but is less harmless than ammonia. Nitrobacter, Nitrospira, and other nitrifying bacteria then oxidize the nitrite into the even less toxic Nitrate (NO₃). Nitrate in the water is much more desirable as it is not harmful to fish at low to moderate levels. Nitrate is then removed from the water by plant matter and phytoplankton (as a fertilizer) and even denitrifying bacteria which reduces nitrate to elemental nitrogen and at which point the cycle begins again.

This process, know as the nitrogen cycle, can be forced in aquaria but it will occur naturally. It is important when starting a new fish system that the water be left to cycle for a several weeks to allow the bacteria to accumulate in the water and system components (such as filters, towers, etc.). Keep in mind that just as fish need oxygen in the water to breath, these bacteria need oxygen to complete these processes as well. Frequent monitoring of these nitrogen levels is fundamental, as ammonia toxicity is one of the biggest predators of fish in captivity.

![Nitrogen Cycle Diagram](image-url)
Testing for Bacteria
In the case of the nitrogen cycle bacteria are beneficial, but we must also consider harmful bacteria. These harmful bacteria most often originate in animal feces at which point they pose a threat as a waterborne pathogen. These bacteria are referred to as Coliform Bacteria which are anaerobic, rod-shaped, gram-negative, non spore-forming bacteria. Coliform bacteria are measured in CFU (Colony Forming Units) or MPN (Most Probable Number), whose results can be attained via membrane filtration or plate count (as is performed by the Quanti-tray method™).

The USDA regulates that pools housing marine mammals in captivity in the United States be tested weekly for coliform bacteria. These coliform values should not exceed 1000CFU/100ml. If levels rise above 1000CFU/100ml, the USDA mandates two additional retests within 48 hours. If the average of the three tests is above 1000CFU/100ml, actions must be taken to eradicate the bacteria. Partial or full water changes and chemical treatment/sterilization are just two examples of such actions.

Testing for Alkalinity
Water described as alkaline is often mistaken as basic, which does not paint the full picture. Alkalinity is a measure of water’s resistance to changes in pH or its buffering capacity. What is tangibly being measured is the carbonate and bicarbonate buffers in the water. These buffer levels can be measured through titration in which an acid (the titrant, such as sulfuric acid) is slowly added to the water (the titrand) until the equivalence point (the point at which the water ceases to contain carbonate and bicarbonate buffers) of pH 4.5 has been reached. Alkalinity can be measured in mg/L (ppm) or mEq/L. Many chemical processes in the water are inhibited by the absence or abundance of alkalinity. Bacteria that are essential to the nitrogen cycle, for example, rely on alkalinity levels between 20 mg/L and 350 mg/L to be truly effective. When adding acid to a pool to drop its pH, one must consider alkalinity levels, as a highly alkaline pool will require a higher volume of acid to achieve the desired pH.

Testing for Other Compounds
Though the USDA only specifically regulates that pH, salinity, and coliform be tested regularly, any chemicals added to the water, such as chlorine based products or copper compounds, must also be tested regularly. To aid in the repression of algae, one might want to test for orthophosphate levels and handle those levels accordingly. One might consider Calcium and Magnesium hardness of the water, as it affects a wide variety of other tests and additions. For facilities using ozone, one might test for Oxidation Reduction Potential (ORP) or ozone carryover into the pool itself. For assigning values to the clarity of a pool, turbidity is considered. Turbidity is measured in NTU (Nephelometric Turbidity Units) and it physically measures anything in the water column that causes refraction of light. Perfect levels in every aspect of water quality are almost never achieved, however, testing for a wide variety of compounds and handling those results accordingly helps us to keep the animals healthy.
Life Support System Components

Every aspect of a life support system plays a specific role in the treatment of the water. These components, whether they serve a mechanical need or a chemical need for the water are the heart of a functional life support system. These components range from the pumps that move water through the system to the valves that control the direction of the water.

Moving Fluids – An Insight into Pump Technologies

Centrifugal Pumps

Centrifugal pumps are common across the industry of life support and they operate under some basic physical auspices. Examine Figure 7 of a centrifugal pump:

![Figure 7](image)

Water enters the impeller of the pump (the component of the pump that transfers energy from the motor to water) through the face of the pump. The impeller uses fins at its face to influence the direction of the water that enters it. As the impeller rotates, the backward swept fins force the water from the center of the face to the outer edge of the impeller where the water is thrown off and out of the pump. This process is constant, which enacts pressure as the water exits the pump. Centrifugal pumps are typically not self priming. Water is required at the level of the impeller for the pump for a prime to be reached (the point at which the pump begins moving water).

Diaphragm, Piston, and Plunger Pumps

A diaphragm pump is a positive displacement pump, which means the pump will produce flow regardless of pressure on its discharge end. Diaphragm pumps use a membrane to pull water into the pump and then, inversely, push it out. A diaphragm pump requires the use of check valves (valves that allow the fluid to move in one direction) to accomplish this. Figure 8 below showcases this action:
As the membrane expands a vacuum is created, which draws water into the chamber. When the membrane collapses, the water is forced out the other end. Plunger pumps and piston pumps operate under a similar principle.

**Peristaltic Pumps**

A peristaltic pump is another example of a positive displacement pump. A peristaltic pump is an ideal solution for pumping corrosive chemicals as the fluid which is being pumped does not contact any of the pump’s mechanical components. Examine Figure 9 below:

As shown in this example, the roller in the middle of the casing is forced against the tubing which contains the fluid. As this roller rotates, the tubing is pinched against the casing of the pump. As the pinched section of tubing moves around the casing, a vacuum is created behind it, which draws fluid forward. As that roller releases the tubing on the other end of the casing, that fluid is discharged out the other end of the pump.

**Removing Particulates – Filter Technologies in Practice**

Particulate removal is important not only to the appearance of the water, but to its quality as well. Filter technologies are used anywhere from a small home aquarium to a large volume municipal water treatment plant. Let’s examine a few common filter technologies.
Media Filters

Media filters, such as sand filters, are common almost across the board where it concerns the field of life support. A sand filter, whether the water be forced through it by a pump or left to gravity, can be a very effective means of filtration. The biggest advantage to using sand is the size of the sand grains themselves and the porous exterior of a sand grain, which allows the water plenty of surface area to contact before it exits the filter. Sand is an inert substance so no sand is “used up” in the filtering process, which allows a single batch of sand to be used for many years. Sand will collect flocculated and macro-particulates, however, and therefore requires it to be cleaned. This cleaning process is known as backwashing. Backwashing is almost self descriptive; the direction of water flow is reversed at pressure, thus “washing” the sand. As water flows backwards through a sand filter the sand grains are fluidized, allowing particulates trapped in the sand to be released. These released particles are then funneled out of a sand filter to be ejected, after which the sand filter can be returned to its normal operation. Figure 10 below displays the anatomy of a common sand filter:

![Figure 10](image)

Many different types of media can be used in place of sand. The use of activated carbon, for example, is fairly common in a media filter. The term “activated” refers to the micro-porosity of the carbon. Its molecular structure allows just one gram of activated carbon to have as much surface area as a baseball diamond. This large amount of surface area aids in the carbon’s adsorption and reaction processes. A microscopic view of activated carbon can be seen in Figure 11 below.

![Figure 11](image)
**Sieve and Screen Filters**

Sieve and screen filters do not operate on the same principles. For a sieve or screen filter, water is pushed through “holes” in the filter while other matter is left behind. Screen filters can be made from paper, threads of cotton/nylon/polyester, or even stainless steel mesh. Screen filters are more commonly used where the amount of water to be filtered is small. Too much pressure through a sieve or screen would force algae and other particles too far into the screen, making it hard to clean.

Screens can be made to filter out particles even smaller than 1 micron, which makes them more effective than most media filters, but a nuisance to maintain or replace in large scale operations.

**Bio-filtration**

Bio-filters are designed for low pressure and contain large amounts of surface area to allow bacteria to colonize and thrive. These types of filters are important in regards to the nitrogen cycle. Examples of media that are typically used in these types of filters can be seen in Figure 12 below. All of these types of media provide sufficient surface area for the bacteria.
Protein Skimmers and Foam Fractionation

Protein skimmers (or foam fractionators) are common components across saltwater aquaria. Protein skimmers use a combination of air and water to free the saltwater of proteins, amino acids, nitrogeneous compounds, detritus, and a variety of other substances. The removal of proteins and these other compounds is beneficial to the water quality as it relieves some load from the bio-filters and other system components.

A protein skimmer is a vessel of water that is injected with gas (most commonly air). The air that enters the vessel does so in the form of bubbles. For more effective protein skimming, smaller bubbles are preferred. Smaller bubbles have the advantage of more surface area for the same volume versus larger bubbles. Surface area is important as it is on the surface of these air bubbles that the organic compounds collect. The air bubbles (with the organic compounds attached) make their way to the surface of the vessel, which has been fitted with a reduced cylindrical or conical lid. These bubbles are forced out the top of the lid in the form of foam, now at higher velocity, where they overflow into a collection vessel and discharge to waste.

Though macro-particles do not adhere to the air bubbles, the rise of bubbles in the skimmer creates a current, which forces these particulates to the surface as well. Protein skimmers come in a wide variety of shapes and sizes, but all perform the same basic function. They have been proven to be an effective means of reducing ammonia and other nitrogen compounds in the water, thus providing a healthier environment for the marine life in the pool and the bacteria involved in the nitrogen cycle. Consider the Figure below of a large-scale protein skimmer for further reference.

![Figure 13](image-url)
Directing the Water – Valve Types and Functions

There are a variety of different valves used in the industry of life support. All of them control the flow of water, but in different ways. Butterfly valves, Ball Valves, Check Valves, Gate Valves, and Globe Valves are most common.

**Butterfly Valves**

A butterfly valve, whose construction can be of plastic or metal, utilizes a disk between its housing to control the flow of water. In the closed position, the broad side of the disk is perpendicular to the water’s flow direction. In the open position, the disk is rotated so that its broad side is parallel to the direction of the water flow. The casing of the valve is most often lined with rubber, so that as the disks edges seat against it in the closed position, the rubber creates a seal and prevents water from leaking by. Butterfly valves have a relatively small footprint compared to other types of valves, which makes them ideal for large-scale operations. Figure 14 below is an example of a butterfly valve.

![Figure 14](image.png)

**Ball Valves**

Ball valves are extremely common and can be found anywhere from the gas line that supplies your furnace at home to chemical processing plants. Ball valves can be constructed of a variety of metals, plastics, and even ceramic. A ball valve controls the flow of water in much the same way as a butterfly valve. The “disk” in the case of a ball valve is a sphere. The sphere has been bored out from one side to the other, like a “tunnel” through the sphere, to allow the fluid to pass through. In the closed position, this “tunnel” is perpendicular to the water flow, thus the fluid contacts the solid side of the sphere and ceases to move. In the open position, the “tunnel” is in line with the inlet and outlet of the valve. The fluid is free to move through the sphere, whose “tunnel” bridges the pipe.
Ball valves are unique for this in that, when fully open, the sphere acts as a section of pipe. This makes ball valves the least restrictive to flow and the least likely valve to aid in friction or head loss when fully open. Figure 15 shows a ball valve in the closed position.

![Figure 15](image-url)

**Gate Valves**

Gate valves, which are usually of brass or steel construction, are not as frequently used as butterfly or ball valves. Gate valves utilize a gate or wedge in the path of the water to restrict or allow flow, as is illustrated in Figure 16 below:

![Figure 16](image-url)

Gate valves should not be used for throttling flow. They are intended for use in the full open or full closed position. Throttling causes tremors at the face of the gate, which can cause the valve and its components to deteriorate and fail.
Globe Valves

Figure 17 above depicts the basic anatomy of a globe valve. Fluid is free to flow from left to right as long as the plug is not contacting the baffle in the center. Globe valves are often used for throttling purposes, as minor changes in the position of the plug create predictable changes in flow. A globe-type valve, because of the baffle and plug in the center, are not ideal for operations where maximum velocity is to be maintained. Water flow through a valve of this type would experience substantial friction due to the changes in water direction through the valve. These types of valves are often used for municipal water applications where water pressure requires frequent adjustment.

Check Valves
Check Valves are valves which allow a fluid to move in one direction, but not the other. These types of valves are beneficial where fluid is being pumped to great heights. If the pump should fail or lose power, the fluid in the pipe would remain at a point beyond the check valve until the pump issue is resolved. Check valves are often placed in line after a centrifugal pump to prevent backwards flow across the impeller when the pump is de-energized. As discussed previously, check valves also allow a diaphragm pump to operate. There are several types of check valves, including ball-type, swing-type, and diaphragm check valves. Examples of these check valves (in the order listed) can be seen in Figures 18-20 below:
Protecting System Components – Cathodic Protection

Cathodic protection is a process by which structural and system components of a life support system can be protected from the corrosive effects of seawater by electrolysis. When pool structures (such as iron reinforced concrete or steel sand filters) are installed, cathodic protection can be implemented to slow the corrosion process of these structures by connecting the easily oxidized iron/steel compounds to an even more oxidative metal. Metals plates such as zinc, magnesium, or aluminum can be inserted into the water to act as sacrificial anodes for the iron. As long as electrons are arriving faster at the iron/steel than oxygen, the iron/steel will not corrode.

The desired level of protection does not always occur naturally. Cathodic protection can be forced through the use of DC power to both the cathode (the structural and system components themselves) and the anode (sacrificial metals such as zinc, magnesium, or aluminum). In the case of most seawater aquaria, the metal of choice for cathodic protection systems is magnesium, as the metal already exists in the make-up of seawater. Zinc anodes, though commonly used for cathodic protection on boat motors and oil rigs, produces zinc oxides during these processes which can be lethal to fish, zooplankton, crustaceans, and amphibians. The diagram in figure 21 below showcases the process of cathodic protection:

Figure 21
**Applied Mathematics for the Life Support Operator**

Basic geometric and algebraic principles can aid an operator in performing everyday tasks. For example, when adding chemicals to a pool to reach a desired concentration, mathematical principles can be applied to figure out exactly how much to add. When an operator is asked to drain a pool or tank, mathematical principles can be applied to figure out just how long such a task would take. The following information can serve as a beginning to understanding these calculations, and how one might apply them.

**Finding Surface Area**

**Rectangles**
The area of a rectangle can simply be calculated by multiplying its length and width. Examine the Figure below:

![Figure 22](image)

The rectangle has a length of 30ft and a width of 10ft. Multiplying these results gives an area of 300ft$^2$. Area is always expressed in squared units.

**Circles**
The area of a circle is a little more complicated. When solving for the area of a circle, one must consider the ratio of a circle’s circumference to its diameter. This relationship is expressed as the symbol “π”, which has an approximate value of 3.14. Examine the circle below in figure 23:

![Figure 23](image)
A circle’s diameter is the length that spans the circle from one side to the other. In the case of the circle above, the diameter is 20ft. When solving for area, the radius of the circle is required. The radius of a circles is exactly half of the circle’s diameter (in the figure above, the radius would be 10ft). The formula for finding area of a circle is:

\[
\text{Area of a Circle} = \pi r^2
\]

For Figure 23, this would be solved by multiplying the square of 10ft (100 ft\(^2\)) by π (3.14), yielding an area of 314 ft\(^2\).

**Triangles**
The area of a triangle is a little less complicated. It helps to think of a triangle as half of a rectangle in which the length X width of the triangle is divided by 2. Consider the following:

The height of the triangle (10ft) can be multiplied by the length of its base (5ft), yielding a result of 50 ft\(^2\). Divide that result by 2, and the area of the triangle is 25 ft\(^2\).
Finding Volume
Finding the volume of a three dimensional structure, such as a pool or tower, is relatively easy when you understand the formulas for area.

Volume of a Rectangular Prism
Consider the figure below:

![Figure 25](image)

As the length and width of this figure is the same as in Figure 22, we know the surface area to be 300 ft². To find the volume of a rectangular prism, simply multiply the surface area by the height of structure (in this case, 10 ft). The end result is 3000 ft³. Units of volume are expressed as cubed units (in this case, ft X ft X ft yields ft³). Cubic feet can then be converted to liquid units of volume, such as U.S. Gallons. The conversion factor for cubic feet to gallons is 7.48 gallons/cubic foot. This means that 7.48 gallons of water would fill a box 1 foot tall by 1 foot wide by 1 ft long. For the figure above, multiply the volume of the cylinder (3000 ft³) by the conversion factor (7.48 gal/ft³). This yields a volume of 24,400 gallons of water.

Volume of a Cylinder
Consider the figure below:

![Figure 26](image)

Finding the volume of a cylinder is done in much the same way as a rectangular prism. The surface area in this example is the same as in Figure 23 (314 ft²). To find volume, multiply the surface area of the circle (314 ft²) by the height of the vessel (in this case, 10ft). The end result gives us a volume of 3140 ft³. To convert to gallons, simply multiply this result by the conversion factor (7.48 gal/ft³) to yield a volume of 23,487 gallons.
Calculating Turnover Rate

We now know how to calculate the volume of water contained in a vessel. Assuming we also know the total flow rate of a system, we can calculate its turnover rate. Assume Figure 26 represents a sea lion pool. The sea lion system consists of a 2 vertical high pressure sand filters, each producing a filter effluent flow of 150 gal/min. This places our total system flow at 300 gal/min. The formula for calculating turnover rate is:

\[
\text{Turnover Rate} = \frac{\text{Volume of Pool (gal)}}{\text{Total System Flow (gpm)}}
\]

So in the case described above, we divide the volume of the pool (23,487 gallons) by the total system flow (300 gpm) to yield a turnover time of approximately 78 minutes. We can convert this into hours by dividing minutes by 60 min/hour to yield a turnover rate of 1.3 hours.

Flow Unit Conversions

Converting units is often required to be able to plug figures into these equations. For example, if total system flow were given in cubic feet per second (ft\(^3\)/sec), we would need to convert that into gallons per minute (gpm) before we could use our turnover formula. Converting units is simple. We know that 1 cubic foot of water is equal to 7.48 gallons. We also know that there are 60 seconds in a minute. To convert, say 3 ft\(^3\)/sec into gpm, start with volume by multiplying cubic feet (3) by our conversion factor (7.48 gal/ft\(^3\)) to yield 22.44 gallons. We are not done yet. This figure represents flow in gallons per second. We must also convert time units. There are 60 seconds in a minute, therefore we multiply our gallons per second (22.44) by 60 seconds per minute to attain an end result of 1346.4 gpm.

Fluid Dynamics – Calculating Head Pressures

Keep in mind that as head is discussed in this article, the center of the impeller of a centrifugal pump is used as a reference point. Head is a term used in fluid dynamics to describe the pressure that a fluid exerts on the reference point. Head is most commonly expressed in linear units of length (i.e. feet or meters). As it pertains to life support, we will be discussing head pressures for water.

Suction Head

Suction head can be described as the height of the water that exists before the reference point. For example, a pump is placed at ground level, and is fed from a reservoir behind it. The water in the reservoir is 10 feet deep. At this instance, the suction head at our point of reference is -10ft. If the reservoir were in the ground, and the suction pipe from the pump extended down to its bottom, at 10 feet, then the suction head at this instance would be 10 feet.

Discharge Head

Discharge head is the height that the water must reach after the reference point. If the pipe that extends from our centrifugal pump reaches a height of 25 feet, the discharge heat at the reference point would be 25 feet.
**Total Static Head**
Total Static Head, or TSH, is the sum of the Suction Head and Discharge Head.

\[ \text{Total Static Head (ft)} = \text{Discharge Head (ft)} + \text{Suction Head (ft)} \]

Consider Figure 27 below:

The suction head at this instance is the sum of vertical rise of the pipe behind the pump (9 ft) and the height of the fluid in the reservoir (6 ft) which is equal to 15 feet. The discharge head at this instance is 32 ft (the vertical rise after the reference point). The suction head in this example is negative due to the fact that the water sits at an altitude above the reference point, thus the sum of the discharge head and the suction head (TSH) is 17 feet.

**Total Dynamic Head**
Total Dynamic Head, or TDH, is a sum of the total static head at the reference point and any losses in energy due to friction (also expressed in feet). For example, if the friction loss of the pipe in Figure 27 was calculated to be the equivalent of 12 feet of head, those 12 feet must be added to the total static head. This would yield a TDH of 29 feet.

**Converting Head to Pressure**
Essentially, head is pressure expressed in distance. Calculating the pressure that a gauge would read is just a matter of conversion:

\[ \text{Convert height of water column (head) to psi} = \text{Head (ft)} \times 0.433 \frac{\text{psi}}{\text{ft}} \]

\[ \text{Convert psi to height of water column (head)} = \text{psi} \times 2.31 \frac{\text{ft}}{\text{psi}} \]

For example, a gauge placed at the bottom of the suction pipe for the system in Figure 27 would read at about 6.5 psi. This figure represents the height of the water (15 ft) multiplied by the conversion factor (0.433 psi/ft). Inversely, if just the gauge pressure were given (say 10psi), we would multiply by the conversion factor (2.31 ft/psi) to get the height of water in the column (23.1 feet).
Conclusion
Most of the mathematical processes that can aid a life support operator are simple. As long as you know which formula you need, and the conversion factors for your units, most mathematical problems (pertaining to life support) can be solved. Included on the following page is Appendix A (Summary of Formulas). Most formulas an operator may need, as well as conversion factors, are covered in the Appendix.
APPENDIX A

Summary of Formulas

**Length (singular units)**

Radius \( r \) of a circle = \( \frac{1}{2} \) Diameter \( D \)

Circumference of a circle = \( \pi D \)

**Area (squared units)**

Rectangle = Length \( \times \) Width

Triangle = \( \frac{1}{2} \) (Base \( \times \) Height)

Circle = \( \pi r^2 \)

**Volume (cubed units)**

Rectangular Prism = Length \( \times \) Width \( \times \) Height

Cylinder = \( \pi r^2 \times \) Height

Sphere = \( \frac{4}{3} \pi r^3 \)

**Flow and Velocity**

Flow = \( \frac{\text{Volume of Water Moved}}{\text{Time}} \) = \( \frac{\text{Total Volume}}{\text{Turnover}} \)

Turnover = \( \frac{\text{Total Volume}}{\text{Flow}} \)

Velocity = \( \frac{\text{Distance Water Travels}}{\text{Time}} \) = \( \frac{\text{Flow}}{\text{Cross Sectional Area of Pipe}} \)
Head (ft)

- Suction Head = The height of the fluid before the pump where the fluid height is higher than the pump. If the fluid reservoir sits below a pump, the vertical height that the pump must lift the fluid is termed the “suction lift.”

- Discharge Head = The maximum height the fluid reaches after the pump

- Total Static Head = The total height that a fluid must be pumped, from the level of one reservoir to another.
  
  \[ \text{Total Static Head} = \text{Suction Lift} + \text{Discharge Head} \]

  \[ \text{Total Static Head} = \text{Discharge Head} - \text{Suction Head} \]

- Total Dynamic Head = The total height that a fluid must be pumped (including the energy lost to friction with the pipe and fittings, converted to feet of head).
  
  \[ \text{Total Dynamic Head} = \text{Total Static Head} + \text{Friction Loss (ft)} \]

Power

Hydraulic Horsepower/Water Horsepower (Whp) = \( \frac{\text{Flow} \times \text{Head}}{3960} \)

Brake Horsepower (Bhp) = \( \frac{\text{Flow} \times \text{Head}}{3960 \times \text{Pump Efficiency}} \)

Motor Horsepower (Mhp) = \( \frac{\text{Flow} \times \text{Head}}{3960 \times \text{Pump Efficiency} \times \text{Motor Efficiency}} \)

Pump Efficiency = \( \frac{\text{Water Horsepower}}{\text{Brake Horsepower}} \times 100\% \)

Temperature

\[ °F = (°C \times \frac{9}{5}) + 32° \]

\[ °C = (°F - 32°) \times \frac{5}{9} \]

\( \frac{\text{BTU}}{\text{Hr}} = \frac{\text{Weight of water} \times \text{Temperature increase (°F)}}{24 \text{ Hrs} \times \text{Efficiency}} \)
Chemical Additions and Dosage

**“Pounds of Chemical” refers to chemical that is 100% pure**

- When looking for pounds of chemical to add to reach a desired level:

  \[
  \text{Pounds of Chemical} = \frac{(\text{Desired PPM}) \times \text{Weight of Pool Water}}{1,000,000}
  \]

  \[
  \text{Pounds of Chemical} = \frac{\text{Volume of Pool (L)} \times \text{Desired mg/L}}{453,592 \text{ mg/ib}}
  \]

- When looking for the PPM result of adding a known quantity of chemical:

  \[
  \text{PPM} = \frac{1,000,000 \times \text{Pounds of Chemical}}{\text{Weight of Pool Water}}
  \]

  \[
  \frac{\text{mg}}{\text{L}} = \frac{\text{Pounds of Chemical} \times 453,592 \text{ mg/ib}}{\text{Volume of Pool (L)}}
  \]

- When working with a diluted chemical, convert:

  \[
  \text{Pounds of Chemical needed (dilute)} = \frac{\text{Pounds of Chemical needed (pure)}}{\% \text{ Solution/Compound}}
  \]

**Equivalents**

- \( \pi = \pi \)
- \( \pi = 3.14 \)
- 12 in = 1 ft
- 3 ft = 1 yd
- 1 lb = 453.59 grams or 453,592 mg
- 1 cu. ft. water = 7.48 gallons
- 1 gal. water = 8.34 lbs
- 1 gal. water = 3.8 liters
- 1 psi = 2.31 ft. of water column (Head)
- 1 ft. of water column (Head) = .433 psi
- PSIA = PSIG + 14.7
- 1 Horsepower = 0.746 Kilowatts
- 1 BTU = 1°F increase in 1 lb. of water in 24 hours