Revised 4/5/05

MOVING WATER WISELY

A GUIDE TO FIRE STREAM AND PUMP OPERATIONS

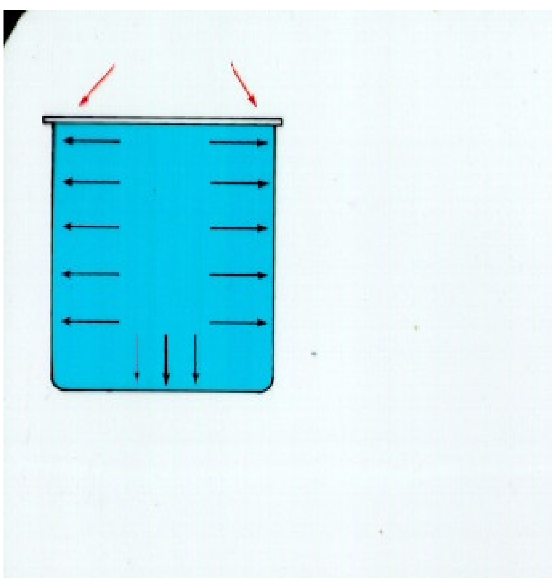
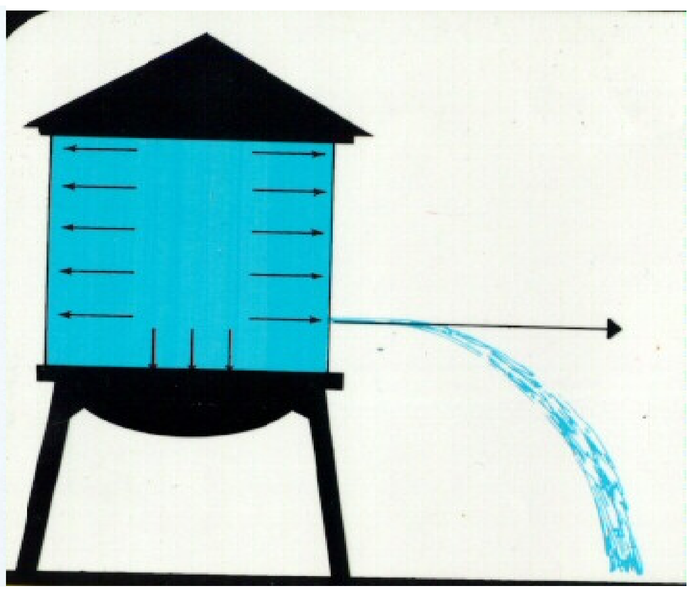
PRODUCED BY

SEMINOLE COUNTY FIRE DEPARTMENT

This information is presented in a format that will hopefully help you understand the limits of your equipment, give you a guide to follow when operating fire streams, and help you best manage your water delivery system.

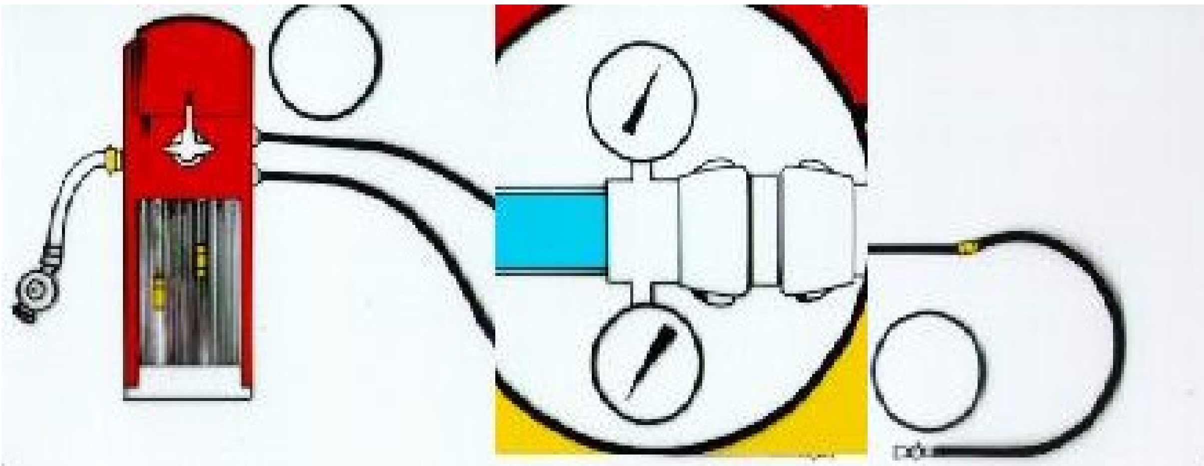
Understanding the principles will help you apply them to practical solutions. The principles of fluid pressure are part of the foundation of understanding and, when coupled with an application, help you to solve some field problems.

1. **Fluid pressure is perpendicular to any surface on which it acts.**

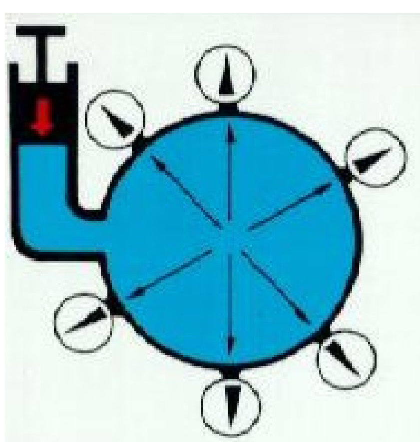
Pressure is at right angles to the surface of the container; the result is that the fluid flow is in the direction illustrated.

2. **Fluid pressure at a point in a fluid at rest is of the same intensity in all directions.**

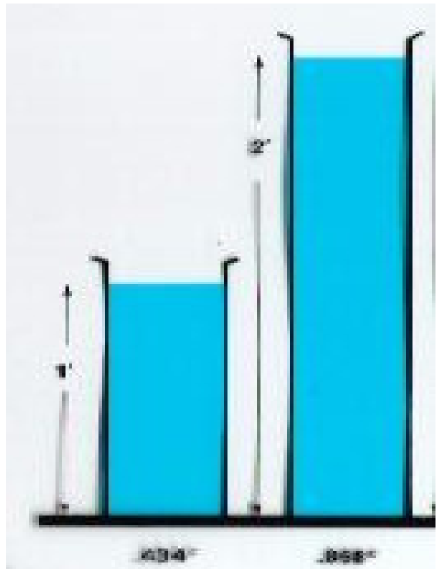


The insert on this figure shows how this principle is used in a practical application. Testing fire hose is the application.

3. **Pressure applied to a confined fluid from without is transmitted equally in all directions.**



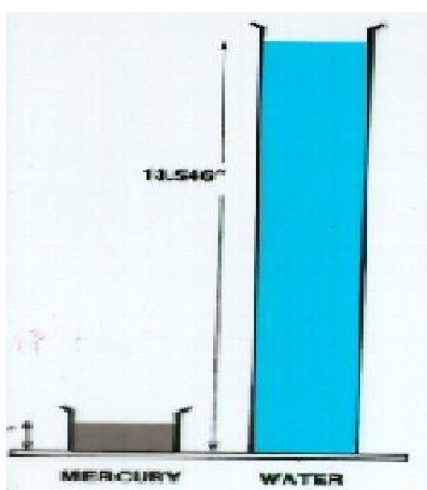
4. The downward pressure of a liquid in an open vessel is proportional to its depth.



.434#   .868#

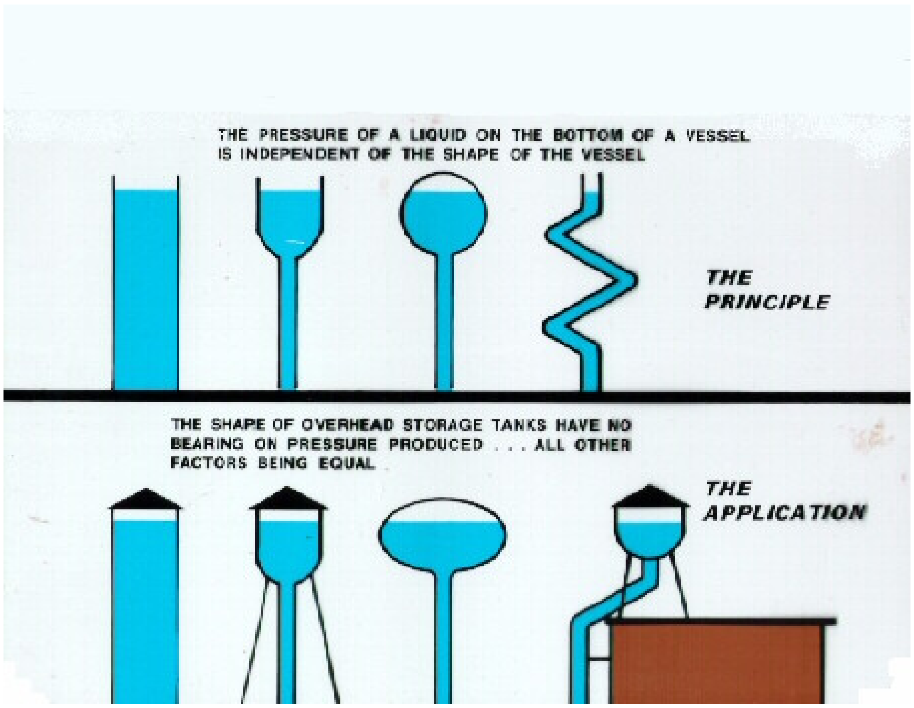
The higher or deeper a fluid, the more downward pressure is created.

5. The downward pressure on a fluid in an open vessel is proportional to the density of the fluid.



In this comparison, you see that the density of mercury is 13.546 times as heavy as water.

6. **The downward pressure of a fluid at the bottom of a vessel is independent of the shape of that vessel.**



Pressure independent of the shape of the vessel is illustrated in this figure. We are measuring pressure per square inch and not by mass or volume.

Moving water through hoses, pipes, fittings, etc.

Just as there are principles of fluid at rest and under pressure, there are principles that apply to moving fluids through hoses, nozzles, pipes and fittings. Energy is necessary to move fluids through whatever means is used. There are conditions where energy losses occur and we must take these into account when moving water. Friction and elevation create two sources of energy loss. There are four principles of friction loss to consider when moving water.

1. **If all other conditions are the same, friction loss varies directly with the length of hose or pipe.** Double the length, double the friction loss.

2. **When hoses, etc., are the same size, friction loss varies approximately with the square of the increase in the velocity of the flow.** Double the speed of the water and increase friction loss by 4 times.

3. **For the same discharge, friction loss varies inversely as the fifth power of the diameter of the hose.** At a given GPM, friction loss is cut by 4 times when you increase the diameter of hose from a 2½" hose to a 5" hose.

4. **For a given velocity, friction loss is approximately the same, regardless of the pressure on the water.** Thus, friction loss is velocity based. The faster you move it, the more friction occurs.

Helpful Information

1. One gallon contains 231 cubic inches.

2. Fresh water weighs 8.35 lbs per gallon approximately.

3. One cubic foot of fresh water weighs 62.5 lbs approximately.

4. A cubic foot contains 1728 cubic inches.

5. A cubic foot of water contains 7.481 gallons. (7.5 gallons approximately)

6. A column of water one inch square and one foot high will create a downward pressure of .434# at the base of the vessel. The symbol # represents pounds per sq. inch.

7. One pound of pressure will raise a column of water 2.304 feet in height.

8. The largest tip size used on a fire stream is one half the diameter of the hose.

9. Class 'A' pumps deliver 100% of their capacity at 150# of discharge pressure, 70% of their capacity at 200#, and 50% of their capacity at 250#, as measured from draft, lifting water no higher than 10 ft. Thus, higher discharge pressures actually reduce the volume of water delivered. Centrifugal pumps are widely used in fire fighting due to their ability to take advantage of incoming pressure. This is most evident when a 1,000 GPM pumper, when connected to a hydrant can deliver 1250 GPM. The pumper can deliver more than its rated capacity up to its critical velocity. Critical velocity is that point where so much turbulence

is created that it makes it impossible to move any more water. You have reached the limits of your equipment.

Managing Your Water

Just like managing your money, you know how much you can spend. On the fire ground there is NO water credit so credit cards are out of the question. You must balance your income with your outgo. To accomplish this, you will need to know how much water you have to spend and how you intend to spend it. If you can get the water to your pump, you can deliver it in some fashion. Remember that someone is dependent on you maintaining his or her fire stream.

Pump operators should have a good understanding of pressure and the different kinds of pressure.

Atmospheric Pressure is the weight of a column of air at a given location on the surface of the earth. Sea level atmospheric pressure is 14.7# on the average.

Static Pressure is pressure on a confined fluid with no water flowing.

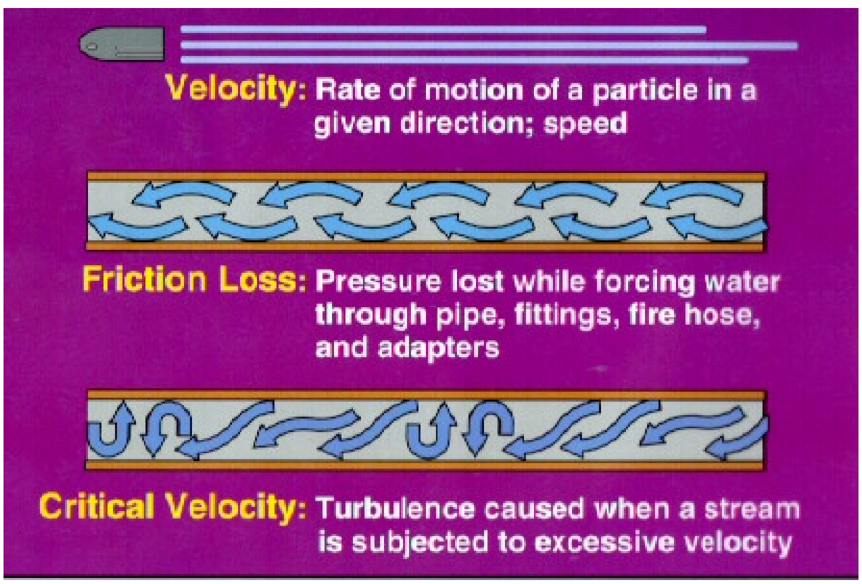
Residual Pressure is pressure remaining on a system when water is flowing.

Discharge Pressure is the pressure of the water at the point of discharge. This can be nozzle pressure, pump discharge pressure or engine pressure.

As a pump operator, you should understand how to calculate engine pump discharge pressures. The standard equation used to calculate this pressure is EP = NP+FL(+/-)ELEV.

EP or engine pressure, sometimes referred to as pump discharge pressure, is the pressure required at the apparatus to deliver the desired fire stream.

Centrifugal pumps are widely used in fire fighting due to their ability to take advantage of incoming pressure. This is most evident when a 1,000 GPM pumper is connected to a hydrant that can deliver 1250 GPM. The pumper can deliver more than its rated capacity up to its critical velocity.



Critical velocity is that point where so much turbulence is created that it makes it impossible to move any more water. You have reached the limits of your equipment.

NP or nozzle pressure, is the pressure at the nozzle tip. Many nozzle tips run standard pressures. It is generally considered that fog nozzles operate at 100# of pressure, no matter if it is on a small booster line or a master stream. Even the AUTOMATIC type fog nozzles operate at 100#. Some manufacturers of automatic nozzles are producing low pressure nozzles. These nozzles can operate efficiently at discharge pressures as low as 75#.

Solid stream handlines are generally operated at 50#. Pressures over 65# makes these hoselines difficult to manage and can be dangerous to the handlers.

Solid master streams generally operate at 80#. These devices flow large volumes of water, 300 GPM and greater, and are supplied by two or more hoselines.

FL or friction loss is calculated based upon hose diameter and GPM discharge. The latest information from IFSTA's Producing Fire Streams, uses a simple way to calculate this loss.

$$\mathbf{FL = CQ^2L}$$

FL = friction loss per 100' of hose
C = coefficient of friction, based upon diameter of hose
Q = quantity, which is the GPM divided by 100
L = lengths of hose, which is the number of 100' lengths divided by 100

Friction Loss Coefficients - Single Line

for common hose diameters

Hose Diameter		Friction Coefficient
¾"	booster	1,100
1"	booster	150
1½"	rubber lined hose	24
1¾"	rubber lined w/1½" couplings	15.5
2½"	hose	2
3"	hose w/2½" couplings	.8
4"	hose	.2
5"	hose	.08

Example: A pumper is delivering water through a 2½" hose 200 ft. long with a 250 GPM nozzle.

Equation $CQ^2L = FL$ substituting into the equation,

C = 2
Q = GPM divided by 100 or 250 divided by 100 = 2.5
L = lengths of hose divided by 100 or 200 divided by 100 = 2

(remember to work squares and square roots first)
$2 \times (2.5)^2 \times 2 = 25$# of friction loss

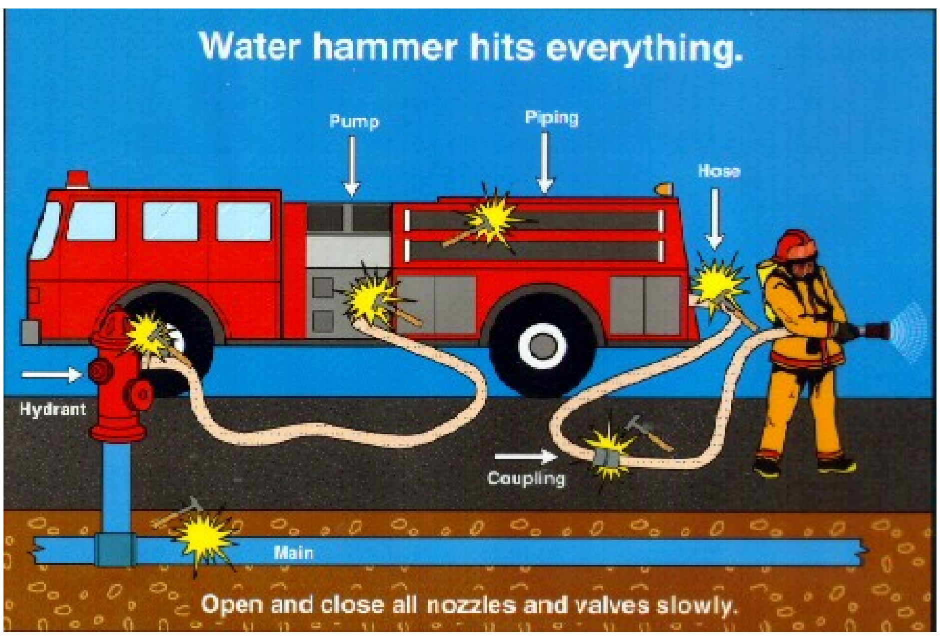
When flowing water from a solid stream tip you can use a flow chart to determine GPM or use the equation: $29.7\ d^2 \sqrt{P}$, where d is the diameter of discharge or tip size, and P is the nozzle pressure.

In the example, 250 GPM was delivered through 2½" hose. This represents about a ton of water a minute flowing through the hose, at a given velocity.

When the nozzle is rapidly closed, the build up of pressure stopping all this energy can be as high as 64 times the original pressure.

This causes what is termed a **water hammer**.

High pressures such as these can damage hoses, pumps, water pipes etc. and render your equipment out of service. Please remember to open and close water flows slowly.



Elev. or changes in the elevation of a fire stream plays a part of the overall equation.

Remember, a 1 ft. column of water creates a downward pressure of .434# or almost ½# per ft.

The height of a building or grade will have an impact on your fire stream.

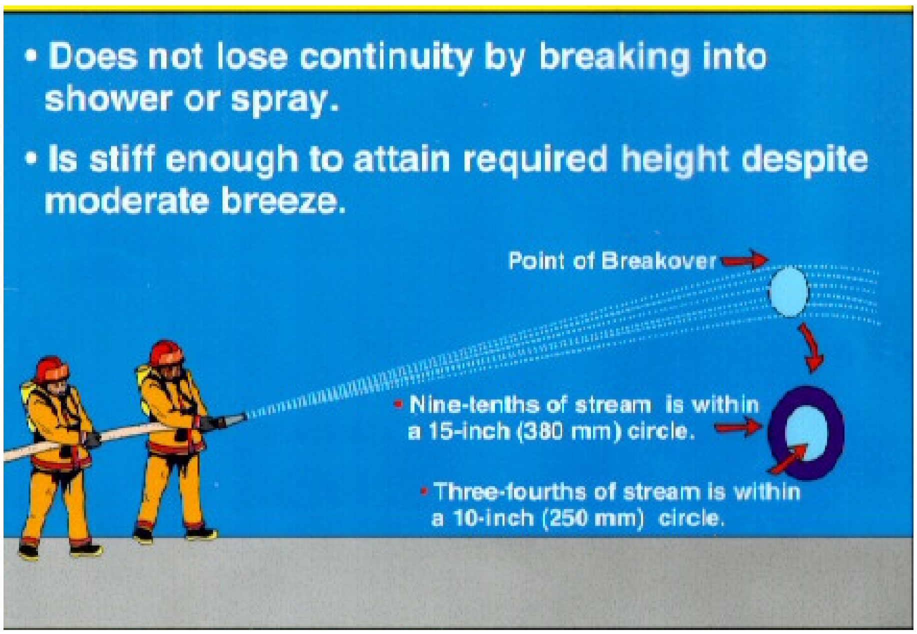
Generally accepted is the figure of 5# of pressure loss for each 10 ft of rise or each story of a building.

This is energy that is needed to push the water column up to the fire floor.

In calculating for elevation, one would add pressure lost due to elevation and subtract pressure gain from below grade applications.

Fire Streams

A fire stream is defined as the stream of water or water solution that leaves a nozzle until it reaches its desired destination. There are three types of fire streams. The solid, fog and broken streams are common fire streams. Each has its application of the fireground.

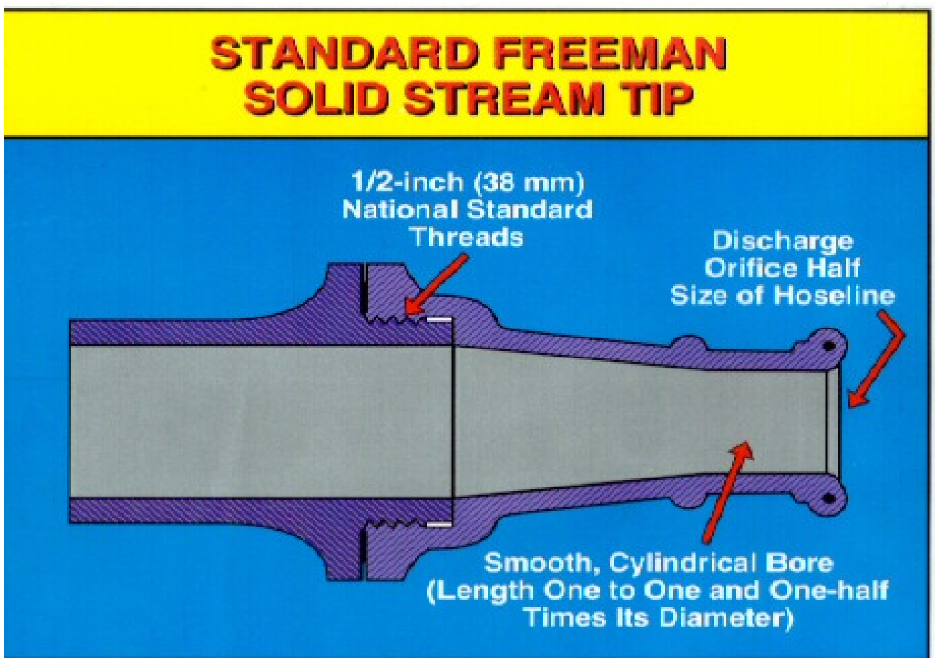


Solid streams provide a solid straight stream of water from an open tip.

These tips vary in size. Common sizes range from ¾" to 2", remembering that the largest tip that can be used on a hoseline is ½ the diameter of the hose.

These streams provide reach into a fire area. As the water moves through a heated atmosphere, the water is evaporated away. The solid stream can provide enough mass to quench the seat of a hot fire, whereas other types of streams would be totally evaporated or converted to steam.

Remember, 50# of nozzle pressure on handlines, and 80# on master stream appliances.



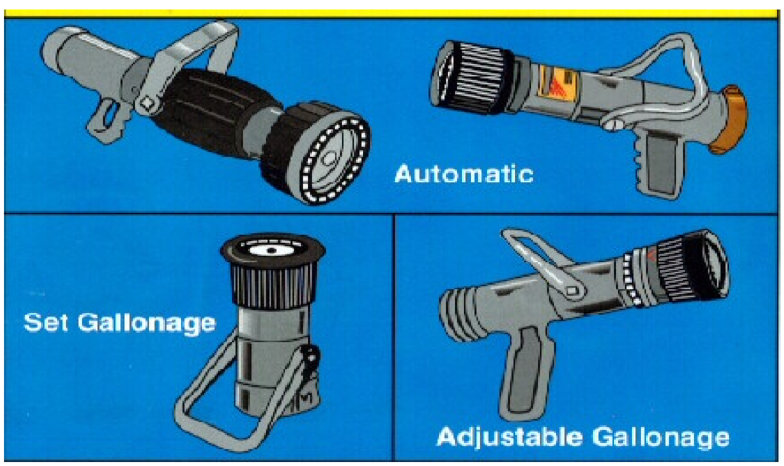
The design of the Freeman tip features a gradual slope and a smooth cylindrical bore. This provides the necessary back pressure to create the desired discharge pressure at the nozzle. The design is configured to help reduce the turbulence of the water moving through the hose, thus the stream attains a greater reach.

Fog streams are the most common fire stream. Spray or fog nozzles are generally in one of four types.

- Automatic fog nozzles
- Variable pattern variable flow
- Variable pattern constant flow
- Fixed pattern nozzles

Each fog nozzle has a rated flow; some are adjustable and some are constant rate and the automatic has a flow range of 50 to 350 GPM.

Most of these nozzles are designed to operate at 100# of discharge pressure. Some manufacturers of automatic style nozzles have low pressure nozzles. Those nozzles can operate at as low as 75#.



Automatic Nozzles perform as any other fog nozzle with a couple of exceptions. First, the more pressure you apply to an automatic, the more water you will discharge (within the limits of the nozzle).

Secondly, the bale or shutoff of an automatic nozzle can be gated back to control the volume of water being discharged.

Knowing how many gallons you are discharging is difficult when you are using an automatic style nozzle in the controlled gate fashion.

Calculating discharge from automatics can be determined. Simply pick the GPM you want to discharge for each hoseline. Example: 250 GPM, 2½" hose with an automatic nozzle. Calculate your friction loss and nozzle pressure for the 250 GPM. The nozzle will deliver the desired flow at the desired pressure.

If you have sufficient supply to increase the GPM, recalculate for the higher flow and pump the line.

Broken streams are nozzles with special purpose applications. They can have the characteristics of both the solid and spray/fog nozzles.

Street Rule Hydraulics

The principles of hydraulics and calculation require math skill. Mathematics is an exact science, however fire stream hydraulics in the field is not that accurate.

There are a number of ways to solve the EP equation. We know nozzle pressures, can determine elevation losses or gains, and can determine our desired GPM discharge. Many agencies use flow charts to help the pump operator determine the Engine Pressure.

Subtract ten method will give you a quick factor of friction in 2½" hose.

Simply subtract 10 from the first two digits of the GPM and that will give you an approximation of friction per 100 ft of hose. Example: 200 GPM in 2½" 20-10 = 10, so 10# of friction per 100 ft of hose. This method is most accurate within the GPM ranges of 180 to 300 GPM.

Five finger hydraulics is a system of counting on your fingers to determine friction loss in a 2½" hose. To use this system some simple math is necessary, along with a basic understanding of how it works. In the equation CQ^2L, the value of Q = the GPM divided by 100. In the five finger system the finger tips represent the Q value in hundreds of gallons and the valleys represent the half hundreds.

Five Finger Hydraulics for 2 1/2"
Hose Per 100'

The base numbers are coefficients used as multipliers to determine friction loss per 100 ft of 2½" hose. To complete the process, remember to add the lengths of hose. This will give you total friction loss for your calculation. This information is put in the engine pressure equation:

$$EP = NP+FL(+/-)ELEV$$

To determine friction loss in 3", 4" and 5" hose, you can use the five finger system.

Replace the finger base numbers with the same number as the finger tip. This will modify your system to reflect Q^2.

Example: 3" hose flowing 300 GPM, tip of 3 (which is the Q value) times the base number of 3 equals 9. That is the friction loss in 100 ft of 3" hose flowing 300 GPM.

Friction loss in large diameter hoses is just one step further than the 3" system.

To determine friction loss in 4" hose, calculate finger tip times finger base as in the 3" system and then divide your answer by 5.

Example: 4" hose flowing 500 GPM, tip of 5 times the base of 5, divided by 5 equals 5# per 100 ft. For higher flows simply count on both hands, i.e., 800 GPM, 8 times 8 equals 64 divided by 5 equals approximately 12 or 13.

To determine friction loss in 5" hose, calculate finger tip times finger base as in the 3" system and then divide your answer by 12.

Example: 5" hose flowing 1000 GPM, tip of 10 times the base of 10, divided by 12 equals 8# per 100 ft. For higher flows simply count on both hands.


3
2
4
5
1
3
2
4
5
1
Five Finger Hydraulics for 3, 4, & 5"
Hose Per 100'

Pumps

Two types of pumps are used in our industry. The centrifugal pumps are generally used to deliver water to the fire, while positive displacement pumps are used as priming pumps for the centrifugal.

These centrifugal pumps lack the ability to prime themselves, that is why the positive displacement pumps are used.

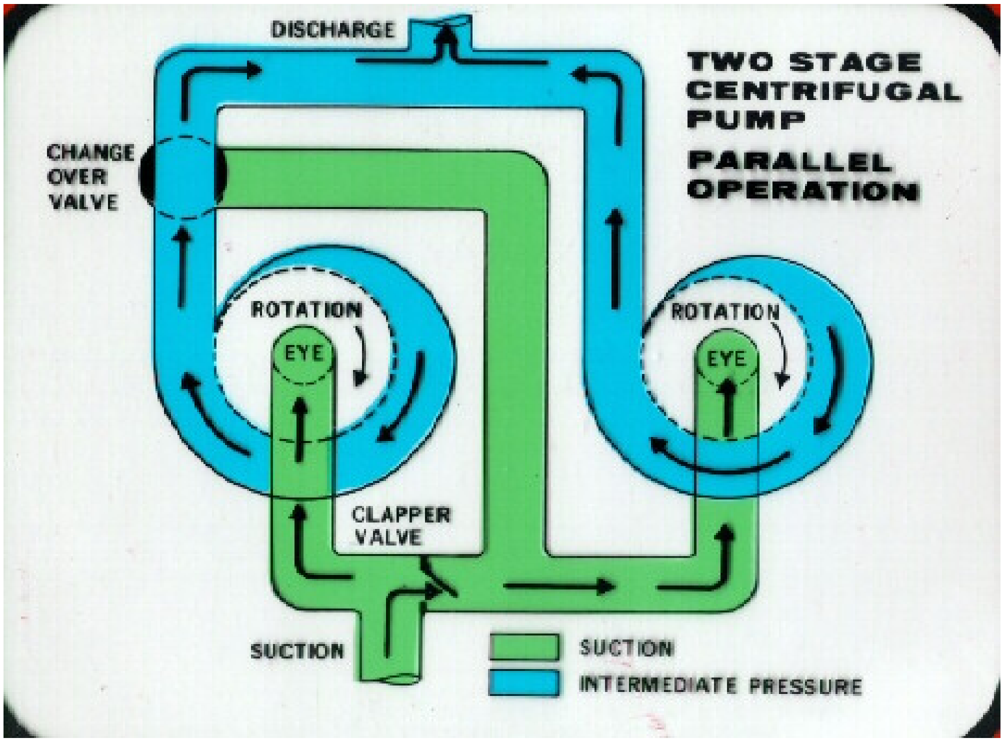
Another method used to prime small centrifugal pumps is with the use of an exhaust primer system.

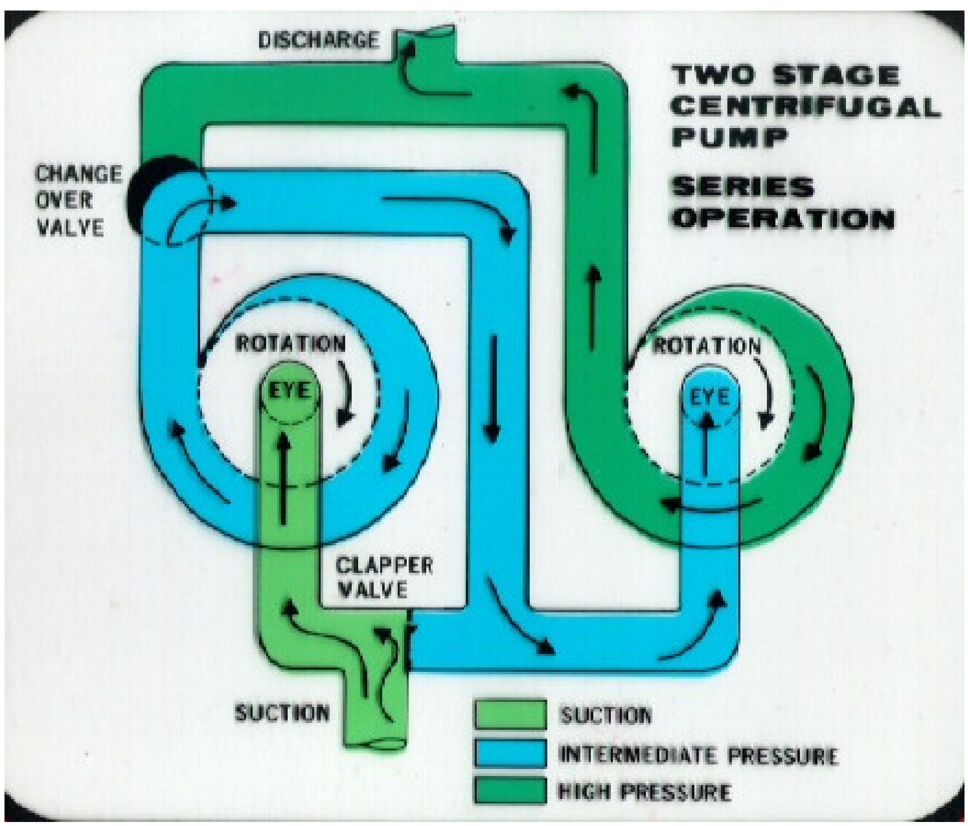
The centrifugal, or non-positive displacement, pumps take advantage of incoming pressure.

These pumps are generally produced in single and two stage configurations.

Single stage pumps are becoming more the norm in the industry, however; some agencies still prefer the pressure building capability of the two stage units.

If you examine the parallel operation of the two-stage system, imagine a single impeller and you get the view of a single stage pump.


DISCHARGE
TWO STAGE CENTRIFUGAL PUMP
PARALLEL OPERATION
CHANGE OVER VALVE
ROTATION
EYE
ROTATION
EYE
CLAPPER VALVE
SUCTION
SUCTION
INTERMEDIATE PRESSURE


DISCHARGE
TWO STAGE CENTRIFUGAL PUMP
SERIES OPERATION
CHANGE OVER VALVE
ROTATION
EYE
ROTATION
EYE
CLAPPER VALVE
SUCTION
SUCTION
INTERMEDIATE PRESSURE
HIGH PRESSURE

Relief Valves & Engine Governors

These are the devices that regulate the overpressure created when a given volume of water is discharged and that flow is stopped.

When flowing a given volume of water, the pump creates the pressure, and the motor of the vehicle produces the energy that drives the pump. That energy level is adjusted by the engine speed.

Complications come into play when we diversify the water delivery by adding more hoselines. Adjustments to the engine speed must be made to compensate for the increased flow.

In reality, the work of the pump has increased. When a nozzle person shuts off their water, the pump is still pumping the same GPM and the result is an increase in pressure to the open hoseline. This can result in injury to personnel.

That is where engine governors and relief valves come into operation. They either divert the excess water back into the suction side of the pump, or slow down the motor RPM to compensate for the change in discharge.

Relief valves should be set with water flowing.

Charge your first hoseline, establish a flow, and set the relief valve at the desired discharge pressure. The indicator light should not be illuminated, as this indicates that the relief valve is closed.

When the hoseline is shut off, the backpressure will open the relief valve and the water flow will be diverted back into the suction side of the pump. The indicator light would now illuminate.

When the hoseline is opened, the relief valve will close and redirect the flow to the hoseline. This is a simple explanation of the operation.

Engine governors operate differently than relief valves. The governor controls pressure by reducing the engine speed.

The governors will increase the engine speed when the hoseline is opened. This is a simple explanation of the operation.