Driver Operator Manual

Chapter 3

Fireground Hydraulics

Revised 04/2014

Introduction

Much of the material contained in this chapter is the result of actual test data that was developed by TFACA personnel on TFACA equipment. Testing our own equipment, fire hose, nozzles, and appliances is beneficial to us in several ways. We can be certain that the flow, force, and/or pressure are safe and practical to what we use here in Tennessee.

In addition to driving the fire apparatus to and from the emergency scene the Driver Operator (DO) is also responsible for operating its fire pump and possessing a thorough knowledge of all of the tools and equipment carried onboard.

To produce effective fire streams, an extensive knowledge of hydraulics is essential. This chapter will help provide you with a system for developing effective fire streams and an understanding of fire stream management. An adequate supply of water delivered properly is essential for successful extinguishment. Any delay or inadequate supply of water will greatly jeopardize fireground operations.

Abbreviations

The following are common abbreviations that are used in hydraulics and throughout this manual:

AL Appliance Loss	d Diameter
EL Elevation Loss/Gain	FDC Fire Department Connection
FL Friction Loss	TPL Total Pressure Loss
gpm Gallons per Minute	NP Nozzle Pressure
NR Nozzle Reaction	psi Pounds per Square Inch
PDP Pump Discharge Pressure	Q Quantity of Water
LDH Large Diameter Hose	

Definitions of Terms

Driver Operators must understand the following definitions as they relate to fire service hydraulics:

- Appliance: Term applied to any wye, siamese, deluge monitor, reducer, adaptor, fitting or other piece of hardware used in conjunction with fire hose for the purpose of delivering water.

- Back Pressure: Also known as “Head Pressure”. Pressure generated by the weight of a column of water above the pump. This is figured at .434 psi per foot of elevation.

- Discharge: The quantity of water issuing from an opening expressed in gallons per minute (gpm).

- Drafting: The process of raising water from a static source to supply an engine.

- Elevation Pressure: Pressure that is gained or lost due to elevation (.434 psi rounded up to .5 psi per foot).

- Engine: Also known as a “Pumper”. The most basic type of fire apparatus consisting of a fire pump, water tank, and fire hose.

- Fire Department Connection: Device to which a pumper connects into to boost or supplement the water flow in a sprinkler or standpipe system.

- Flow Pressure: Pressure created by the rate of flow or velocity of water coming from a discharge opening (measured using a pitot gauge).

- Force: A measurement of weight that is expressed in pounds.

- Friction Loss: Loss of pressure created by the turbulence of water moving against the interior walls of fire hose or appliances.

- Master Stream: A large caliber hose stream capable of flowing 350 gpm or more.

- Normal Operating Pressure: Pressure on a water system during regular domestic consumption.

- Nozzle Pressure: Pressure at which water is discharged from a nozzle.

- Nozzle Reaction: Force directed at a person or device holding a nozzle by the velocity of water being discharged.

- Pitot Gauge: Instrument that is inserted into a stream of water to measure the velocity pressure of a stream.

- Pressure: Force per unit area, measured in pounds per square inch (psi).

- Residual Pressure: That part of the total available pressure not used to overcome friction loss or gravity while forcing water through fire hose and appliances. It is the pressure remaining when water is flowing.

- Siamese: Hose appliance that combines two or more lines into one.

- Static Pressure: Stored potential energy available to force water through fire hose and appliances. Static means at rest or without motion.

- Velocity: Speed at which water travels through fire hose, measured in feet per second (FPS).

- Water Hammer: Force created by the rapid deceleration of water, generally resulting from closing a nozzle or valve too quickly.

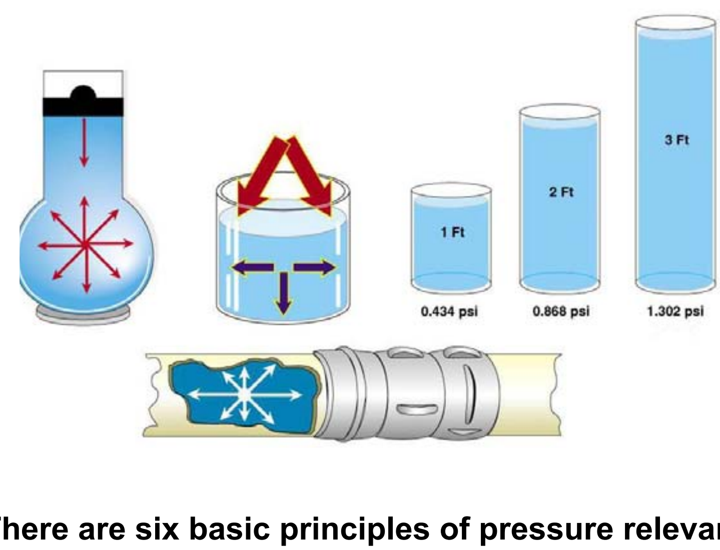
- Wye: Hose appliance with one inlet and two or more outlets that are usually gated.

General Principles and Measurements

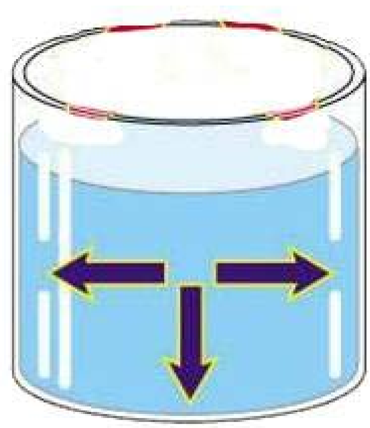
Because water is the most common extinguishing agent a basic understanding of its physical properties is essential. The following principles and measurements are commonly associated with fireground hydraulics:

1 cubic foot contains 1728 cubic inches
1 cubic foot contains 7.48 gallons
1 gallon contains 231 cubic inches
1 gallon of water weighs 8.33 pounds
1 cubic foot of water weighs 62.3 pounds
1 psi will raise a 1 square inch column of water 2.304 feet
A column of water 1 foot high exerts a downward pressure of .434 psi
A column of mercury 1 inch high exerts the same downward pressure as 13.55” of water.
A 50 foot section of 1¾” hose contains 6.3 gallons & weighs 74.5 pounds
A 50 foot section of 2½” hose contains 12.8 gallons & weighs 139.6 pounds
A 50 foot section of 3” hose contains 18.4 gallons & weighs 195.3 pounds

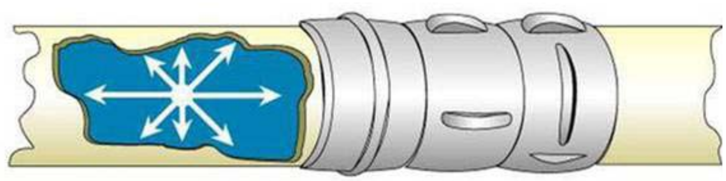
Principles of Pressure



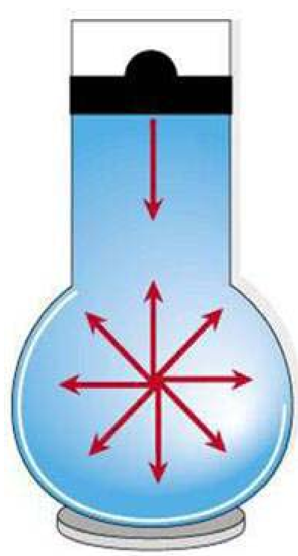
There are six basic principles of pressure relevant to the study of fire service hydraulics.



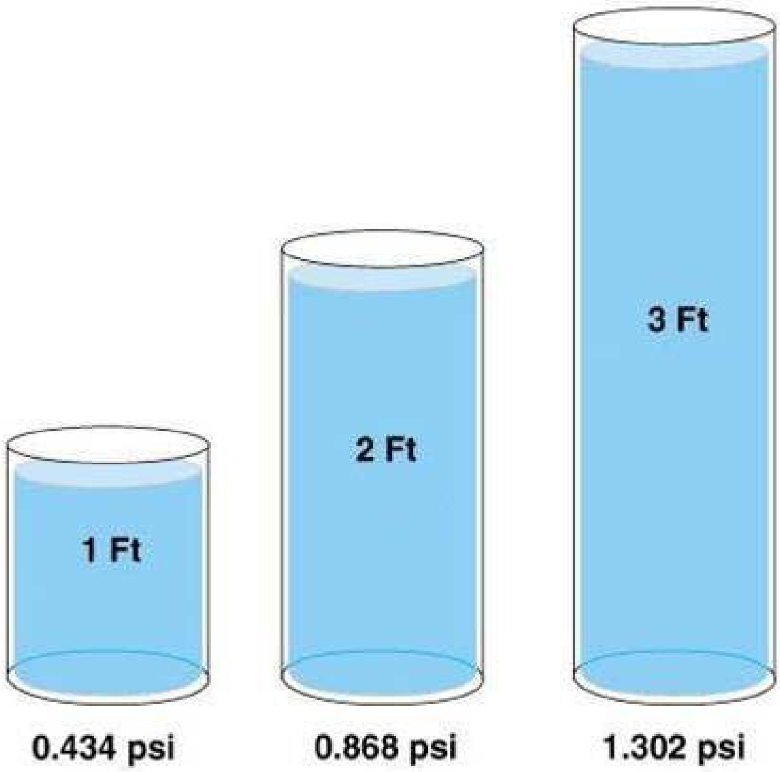
1st Principle: Fluid pressure is perpendicular to any surface on which it acts.



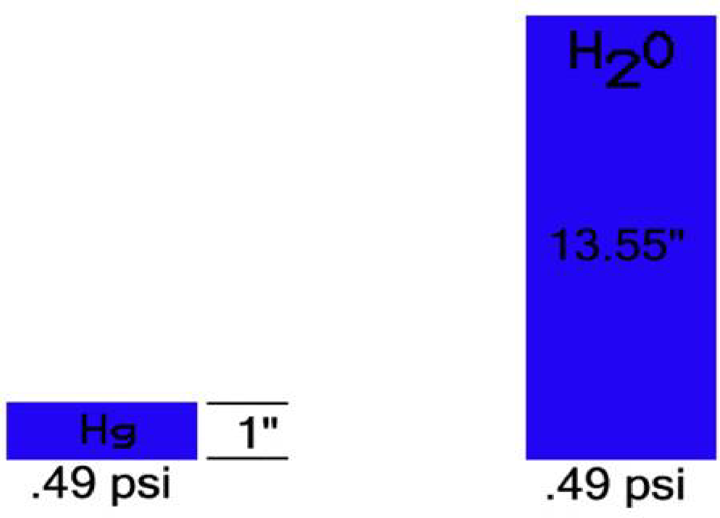
2nd Principle: When a fluid is at rest, fluid pressure is the same in all directions.



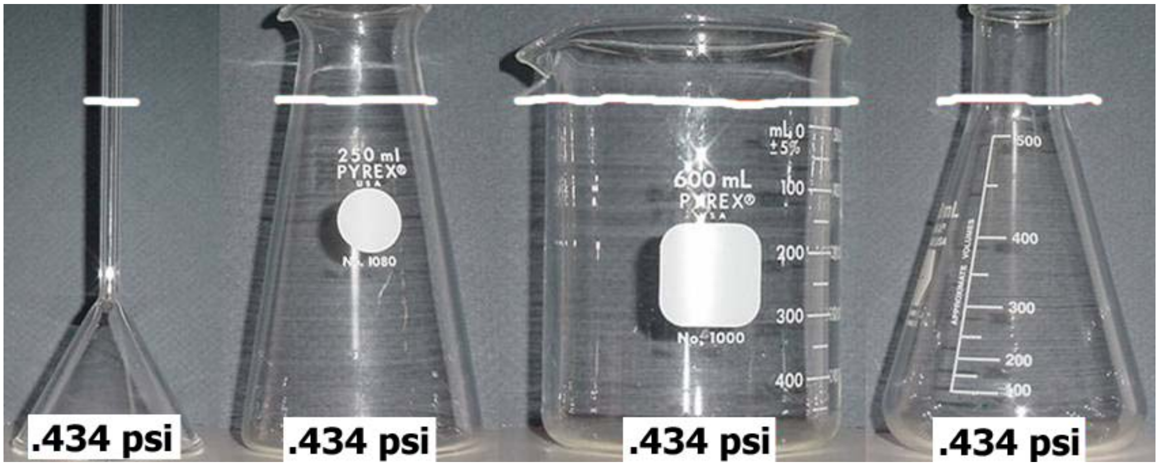
3rd Principle: Pressure that is applied to a confined fluid from without is transmitted equally in all directions.



4th Principle: The pressure at the base of a liquid in an open container is proportional to its depth.



5th Principle: The pressure of a liquid in an open container is proportional to the density of the liquid.



6th Principle: The pressure of a liquid on the bottom of a container is independent of the shape of the vessel.

5 Types of Pressure

Static Pressure: Water at rest or not moving.
Flow Pressure: The velocity of water coming from a discharge opening.
Residual Pressure: Pressure remaining when water is flowing.
Elevation Pressure: Pressure gain or loss due to elevation.
Atmospheric Pressure: Pressure exerted by the air surrounding us.

Finding the Volume of a Box

Sometimes it may be necessary to find the volume of a container such as a pool, drafting tank or even a structure. This can be done by multiplying the length, width, and height of the object (L x W x H). Be sure to convert all measurements to the same units, i.e.; inches, feet, etc.

Q: What is the volume of a box 10" by 14" by 4"?

A: Volume = 10 x 14 x 4 = 560 cubic inches.

To determine how many gallons of water this container will hold, remember there are 231 cubic inches in one gallon. Therefore, we divide 560 by 231 and the answer is 2.42 gallons.

Finding the Volume of a Cylinder

The volume of a cylinder can be found by applying the following formula:

Volume = .7854 x d^2 x Length

Be sure to convert all measurements to the same units, i.e.; inches, feet, etc.

Q: What is the volume of a cylindrical tank that has a 10' diameter and is 5' long?

A: .7854 x 10^2 x 5

.7854 x 100 x 5

.7854 X 500 = 392.7 cubic feet

Friction Loss

Friction loss is pressure used to overcome resistance while forcing water through fire hose, pipes, and appliances. To calculate the friction loss, it is necessary to know the following:

- the volume or quantity of water flowing (expressed in gpm)
- the size of the hose
- the length of the lay

Friction loss is independent of pressure when the gpm remains constant in the same size hose. In other words, if 200 gpm is flowing through a 2½" hoseline at 50 psi, the friction loss will remain the same if the pressure is increased to 100 psi.

Smaller hose will create more friction than larger hose when flowing the same amount of water. This is because in smaller hose, more water comes in contact with the sides of the hose creating friction.

If the length of the hose lay is doubled, then the friction loss will double (when gpm remains constant). For example, 100' of 1¾" flowing 100 gpm has 12 psi friction loss, therefore 200' of 1¾" flowing the same gpm will have 24 psi friction loss.

Other factors that affect friction loss in hose lines are:

- Rough linings inside fire hose
- Sharp bends or kinks
- Improper or protruding gaskets
- Appliances
- Partially closed valves

There are many ways to estimate the friction loss in fire hose. Methods like the old hand, new hand, drop 10, and the condensed "Q" are just a few that you may have learned. Conceivably, the most accurate method to determine friction loss is to conduct your own tests. By doing this you will know, with almost exact certainty, the volume of water flowing at specific pressures. Additionally, this enables us to have consistency in friction loss calculations department wide.

The attack hose (hand lines) used for these calculations were of two sizes: 1¾" and 2½". They were manufactured by Angus called Hi-Combat, and are readily identified by the green and white stripes. Several tests were conducted on this hose to determine the actual friction loss. Here are the findings of those tests:

Friction Loss in 1¾" Hi-Combat Hose
(Average coefficient was determined to be: 10.8)

GPM	Friction Loss in 100'
100	12 psi
150	24 psi
185	36 psi
200	40 psi

Calculating Friction Loss in 3" Hose

An easy way of calculating friction loss is to look at the table below. Take the **1st digit** of the flow (gpm) and multiply it by the **1st digit** of the next number immediately below it. The result is friction loss per 100' of 3" hose. For example, if the flow is 200 gpm, take 2 and multiple it by 2 (the 1st digit of the next number down the column). The answer is 4 which is the friction loss in 100 feet of 3" hose. Let's try a flow of 350 gpm, 3 x 4 equals 12, which is the friction loss in 100 feet of 3" hose. This method is known as Q^2 or condensed Q.

GPM	Friction Loss in 100'
100	1 psi
150	2 psi
200	4 psi
250	6 psi
300	9 psi
350	12 psi
400	16 psi
450	20 psi
500	25 psi
550	30 psi
600	36 psi

Calculating Friction Loss in 2½" Hose

The process of calculating friction loss in 2½" hose is accomplished by figuring the friction loss as you would for 3" hose and then doubling the result. For example, if the flow in 100 feet of 3" hose is 300 gpm, then the friction loss is 9 psi per 100'. Next, double 9 to obtain the answer of 18 psi per 100 feet.

GPM	Friction Loss in 100'
100	2 psi
150	4 psi
200	8 psi
250	12 psi
300	18 psi
350	24 psi
400	32 psi

Friction loss testing of 1 3/4" Hi-Combat hose

Friction Loss in 3" (Yellow) Supply Hose

Flows less than 95 gpm

Friction loss of flows less than 95 gpm in any size hose is negligible and therefore not calculated. Flows at 95 gpm or more can be rounded up to 100 gpm and calculated accordingly.

Friction Loss in 1½" Hose

The only apparatus that utilize 1½" hose are the brush trucks where friction loss is generally not an issue and therefore will not be addressed in this manual.

Rounding

When calculating hydraulic problems, the numbers we work with are either in multiples of 100 or 50. Occasionally you will derive an answer that is neither a multiple of 100 or 50. When this occurs, round to the closest multiple of 50. Example: You derive an answer of 333 gpm. Round it to the closest multiple of

50 which would be 350 gpm. Round down when you derive a number that is exactly in between, for instance 425 gpm would be rounded down to 400 gpm.

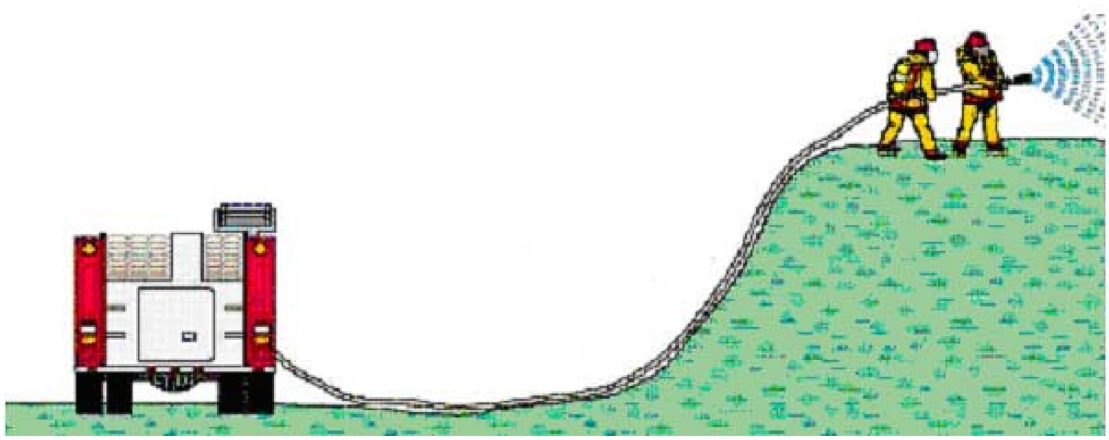
Appliance Loss

Friction loss in small appliances (double males, double females, reducers, wyes, and siamese) is negligible and therefore will not be calculated. Add 25 psi for friction loss for the deck gun when mounted on the engine and 15 psi when used as a ground monitor.

Elevation Gain or Loss

When hose lines are laid to an elevation that is higher or lower than the pump an additional factor known as "Elevation Pressure" (EP) must be considered. In the beginning of this chapter we learned that a column of water 1' high exerts a downward pressure of .434 psi at its base. Therefore, the same column of water at a height of 10' will exert a downward pressure of 4.34 psi. For fireground operations round up 4.34 psi to 5 psi (that is a ½ psi for each foot of elevation above or below the pump). When calculating elevation pressure in multi-story buildings, figure +/- 5 psi for each floor, not including the first floor. A story is estimated to be 10 -12 feet high.

Q: Firefighters are operating on top of a hill where the nozzle is 40' above the pump. What is the elevation gain/loss (EL)?



A: EL = .5 psi x 40' = 20 psi

Tip Sizes and GPM

Hand Line Tip Size	Nozzle Pressure	Approximate GPM
15/16"	50 psi	185
1”	50 psi	200
1 1/8"	50 psi	250
1 1/4"	50 psi	300
Master Stream		
1 3/8"	80 psi	500
1 1/2"	80 psi	600
1 3/4"	80 psi	800
2”	80 psi	1,000

Standard Nozzle Pressures

Nozzle Pressure	Nozzle
50 psi	Smooth Bore Hand Line
50 psi	Combination Nozzle
80 psi	Smooth Bore Master Stream
100 psi	Fog Nozzle

Total Pressure Loss

“Total Pressure Loss” (TPL) is the sum of friction loss, appliance loss, and elevation loss/gain expressed in psi.

TPL = FL + AL +/- EL

Pump Discharge Pressure (PDP)

“Pump Discharge Pressure” (aka pump or engine pressure) is the sum of the following:

- Nozzle Pressure (NP)
- Friction Loss (FL)
- Appliance Loss (AL)
- Elevation Loss/Gain (EL)

PDP = NP + TPL

Discharge Formula

Discharge formula is used to calculate the volume of water flowing from any smooth bore nozzle:

Discharge in gpm = 29.7 x d ^{2} x √P

Q: How much water is discharged from a 1½" tip with 80 psi NP?

A: gpm = 29.7 x $(1.5)^2$ x √80
gpm = 29.7 x (2.25) x 8.9
gpm = 594.7

Nozzle Reaction

Nozzle reaction is the ultimate decider of effective fire flows for handlines. If the nozzle reaction is too great then the nozzle operator will either gate down to control the hoseline or will lose control of it and suffer the corresponding consequences. By definition, nozzle reaction is the force of the water being discharged directed to a person or device holding the nozzle. Realistically a two-person nozzle team can safely and effectively control a nozzle reaction force of about 70 pounds. Nozzle reaction can be calculated for fog and smooth bore nozzles.

Fog Nozzle: NR =.0505 x Volume of Water x √NP

Q: Determine the nozzle reaction from on a 1¾" hose line with a fog nozzle flowing 150 gpm?

A: .0505 x 150 x 10
.0505 x 1500
NR = 75.75 pounds

Smooth Bore Nozzle: NR = 1.57 x d ^{2} x NP

Q: Determine the nozzle reaction on a 2½" hoseline flowing a 1" tip?

A: 1.57 x $(1)^2$ x 50
1.57 x 50
NR = 78.5 pounds

Generally, 3” hose should only be used for supply; do not put a nozzle on 3” hose and use it as a hand line.

Flow Rates & Nozzle Reaction

100 psi Fog Nozzle

gpm	Reaction in pounds
100	51
150	76
200	101
250	127
300	152

Smooth Bore 2½”

gpm	Reaction in pounds
1”	79
1 1/8"	99
1 1/4"	123

Combination Nozzle

gpm	Reaction in pounds
Fog (150)	54
15/16"	69

Reach of Fire Streams

An angle of 25 to 30 degrees works best to achieve maximum horizontal reach. At 50 psi nozzle pressure using a 1” tip on a handline, water travels approximately 115 feet. At 80 psi nozzle pressure using a 1 3/8" tip mounted on the apparatus, the distance that the water travels is approximately 220 feet (approximately 200 feet when mounted on the ground).

Standpipe & Sprinkler Systems

Properly installed and maintained fire sprinkler and standpipe systems have proven to be a dependable first line of defense against fires. These systems are generally hydrostatically tested each year to 175 psi. That is why we should never exceed this pressure when supplying the FDC. When supplying these systems, always connect at least two 3” hose lines to the FDC.

Standpipe systems are the main source of water supply for fighting fires in hi-rise or large buildings. Water is delivered to the fire area via standpipes. There are 3 classes of standpipe systems:

Class I: 2½ inch outlets for fire department use

Class II: 1½ inch hose outlets for occupant use

Class III: Combination standpipe, incorporates both Class I and Class II into a single system.

Note that a "combined" system is different from a "combination" system. Combination refers to a system with both Class I and Class II outlets, whereas a combined system is an integrated standpipe/sprinkler system.

Many fire protection systems in Palm Beach County are "combined" systems. When supplying a combined system, you should pump to the function required, ie; supply either the hose lines via the standpipe or supply the sprinkler system.

For sprinkler operations, build the PDP to 150 psi and maintain it. Once connected to a sprinkler system, be certain to keep the pump cool by means of cracking the tank fill or opening a booster line. As a rule of thumb, a 1250 gpm pumper can supply approximately 60 sprinkler heads.

If you are supplying a standpipe system, PDP can be calculated by the sum of the following:

- Nozzle pressure
- Friction loss in the attack hose
- Appliance loss
- Elevation loss (5 psi per floor)
- Friction loss in the standpipe system (25 psi)
- Friction loss in the hose supplying the FDC

Some alternative methods of supplying a system are to:

- Use a double male when the FDC swivel does not turn.
- Consider using the Quint as an elevated standpipe.
- Consider using interior hose cabinets or outlets when the FDC is not accessible.

Refer to SOGs in this manual for procedures pertaining to supplying sprinkler/standpipe systems.

Starting Operating Pressures

Starting Operating Pressure	Hose/Nozzle	GPM
65 psi	200’ 2½” hose with 1” tip	200
75 psi 85 psi	Hi-Rise Kit (fog) Hi-Rise Kit (15/16")	150 185
100 psi	Relay Pumping	variable
100 psi	Quint Elevated Master Stream with Fog or Smooth Bore Nozzle (plus elevation)	variable
125 psi	200’ 1¾” Pre-Connect	100
150 psi	Sprinkler Systems Only	n/a

The DO should immediately start pumping using the above starting operating pressures and then *“fine tune”* if necessary to the correct pump discharge pressure.

Calculating Available Water

The ability of the DO to calculate the available water from a hydrant is an essential element of the overall role of the driver. Regardless of the size of the fire, Driver Operators should know the amount of water available from a particular hydrant when pumping during an incident. When a pumper is connected to a hydrant and not discharging water, the reading on the intake gauge is called static pressure. Once the pump begins flowing water, the reading on the intake gauge is called residual pressure. The difference between the two readings is called *“pressure drop”.*

1st Digit Method

- Once connected to the hydrant, record the static pressure.
- Multiply the 1st digit of the static reading by 1, 2, and 3.
- Open a line and flow water and record the residual pressure.
- Subtract the difference between the static and residual pressures.

If the pressure drop does not exceed 1 times the first digit, a minimum of 3 lines flowing the same gpm can be added.
If the pressure drop does not exceed 2 times the first digit, 2 lines flowing the same gpm can be added.
If the pressure drop does not exceed 3 times the first digit, 1 line flowing the same gpm can be added.
If the pressure drop exceeds 3 times the first digit, no additional lines flowing the same gpm can be added (although it may be possible that a line flowing fewer gpm may be added).

Q: An engine connects to a hydrant with a static pressure of 84 psi. The DO opens a line flowing 250 gpm and notes the residual pressure drops to 73 psi. How many additional lines can be added?

A: Static Reading was 84. Take the 1st digit, which is 8. Multiply 8 by 1, 2, and 3 respectively:

8 x 1 = 8
8 x 2 = 16
8 x 3 = 24

Now, subtract the residual from the static pressure. 84 -73 = 11.
11 is the pressure drop, and falls between 8 and 16. Therefore, 2 additional lines flowing the same gpm can be added. This hydrant will provide an additional 500 gpm or a total flow of 750 gpm.

Estimating the Static Pressure

We often connect to a hydrant after we are flowing water from our tank. When the hydrant is opened, the pressure reading on the intake gauge is residual pressure. The following method is used to *estimate* the static pressure.

- Note the residual pressure after the first line is in operation.
- Open another nozzle flowing the same gpm as the first line.
- Note the difference in residual pressures on the intake gauge.
- Divide this difference by 2.
- Adding this number to the original residual pressure gives you your estimated static pressure.

Q: A Pre-Connected line flowing 150 gpm is in operation off of tank water. The hydrant is then opened and the intake gauge reads 66 psi (residual pressure). A nozzle flowing the same gpm is opened. The residual pressure is now 58 psi. What is the estimated static pressure?

A: The difference between the two pressures is 66 - 58 = 8 psi. Divide 8 by 2 = 4. Add 4 to the original residual pressure, 66 + 4, and the estimated static pressure is 70 psi. You can now calculate the available flow from the hydrant by using 70 psi as the static pressure.

Calculating Available Water from a Draft

When operating from a static source such as a canal, lake or other abundant source, the DO needs to know how many gpm the pump can provide for firefighting operations. We know that fire pumps receive their rating based on pumping from a draft at 10’ of lift. As an example, a 1250 gpm pumper can supply 1250 gpm at 10’ of lift. At 20’ of lift, the same pump is going to have to work much harder to raise the water the additional 10’. This will result in the pump discharging only 790 gpm. Furthermore, a 1250 pump operating from a 4' lift can discharge 1435 gpm.

Discharge at Various Lifts
(for 1250 gpm pump)

Lift in Feet	Gallons per Minute
4	1435
6	1375
8	1310
10	1250
12	1175
14	1100
16	1020
18	900
20	790
22	660
24	495

Maximum *Efficient* Flow in Fire Hose

The maximum efficient flow, also referred to as critical velocity, is the maximum amount of water that can be put through a fire hose before the fire stream breaks up and becomes ineffective. The table below lists hose sizes with the associated flows. Keep in mind that these flows are conservative in that more water can be supplied if needed but this table should be used as a guideline.

Hose Size	Critical Velocity
1¾"	**200 gpm**
2½"	**300 gpm**
3"	**500 gpm**

Under normal operating conditions, maximum pump discharge pressure should not exceed 225 psi

(175 psi when pumping to the FDC)

Relay Pumping

By using the following table, the DO can determine the distance that a certain flow may be pumped. Built into these figures is the consideration that a 20 psi residual pressure is available at the next pumper in the relay.

GPM	3" Single Line	3" Dual Lines
300	2250'	10,200'
500	800'	3,400'
800	300'	1,250'
1000	n/a	800'
1300	n/a	450'

Fire Flow

As we have already discussed, the DO is required to obtain and deliver adequate water to the fire. A quick, easy to use formula from the National Fire Academy can be used to estimate the amount of water (fire flow in gpm) needed for a structural fire attack:

$$\frac{\text{Length X Width X \% of Area Involved in Fire}}{3} = \text{gpm}$$

Using this formula will give you the needed water flow in gallons per minute to darken the fire in 10 - 30 seconds when applied properly. It can also be adjusted for exposures if necessary by adding 25% for each exposure. Here are some examples:

Example 1:

15' x 20' room, fully (100%) involved, no exposures

$$\frac{15' \times 20' \times 1}{3} \quad \begin{array}{l} = 300 \text{ sq. ft.} \\ = 100 \text{ gpm} \end{array}$$

Example:

If the room in Example 1 is only half involved:

$$\frac{15' \times 20' \times .5}{3} \quad \begin{array}{l} = 300 \times .5 = 150 \text{ SF} \\ = 150/3 = 50 \text{ gpm} \end{array}$$

Example:

A two-car garage that is 24' x 24' that is a third involved with 1 exposure:

$$\frac{24' \times 24' \times .3}{3} = 58 \text{ GPM}$$

Add 15 GPM (25% of the flow rate) for the exposure (58 x .25) = 73 GPM total.