FEDERAL FIRE
SAN DIEGO

HYDRAULICS MANUAL

INTRODUCTION

This Manual is designed to give the driver/operator a quick and fairly easy process for determining fire ground hydraulics. Supplying water is a critical part of fire control, and the efficient use of this water requires maintaining specified pressures and flow rates. Remember, like everything else there is an acceptable margin of error. If pressures are within 5 or 10 PSI of the required PSI, little of the effectiveness is lost. Also, gauges are not precise. They vibrate with the engine and two people reading the same gauge will probably read slightly different pressures.

No exact allowances can be made for friction loss, since factors that influence it vary with condition, design manufacturer and age of the hose and various appliances that may be attached. The NFPA handbook shows five different formulas for calculating friction loss. The formula that greatly simplifies mental computations on the fire ground without seriously affecting nozzle pressures is the Paring/on Formula.

The objective of this Manual is to enable the pump operator to solve any hydraulic problem within one minute with 100% accuracy. This, together with fire ground experience, will enable the operator to supply a continuous flow of water at the desired pressure.

DETERMINING PUMP PRESSURE

PUMP PRESSURE

Pump Pressure is the amount of pressure in pounds per square inch (PSI) indicated on the pressure gauge or any given discharge gauge. Visualize running the pump on a fire engine. You are standing at the pump panel. You are running the throttle out which increases the RPM's of the engine (and thereby the pump) and you notice the pressure gauge at the pump panel increase from 50 PSI to 100 PST. This is energy created by the pump which makes the water move tlu'Ol1gh the plumbing on the fire engine. The pump pressure is telling you the amount of pressure being developed at the discharge side of the pump and up to the discharge outlets on the fire engine. The pressure registering on the pump pressure gauge will not be the same at the nozzle because energy (pressure) is being used up overcoming friction in the hose.

WORKING WITH THE BASIC HYDRAULICS FORMULA

In this Manual, you are going to work with the basic hydraulics formula: PP = NP + (FLR x L) + AL (+/- GG/GL). In determining pump pressure, the first part of the formula to be solved is NP (Nozzle Pressure). Nozzle pressure has to be added in the formula when nozzles are used. This pressure (PSI) is required because it is the pressure which is needed to make the tip (solid stream), or combination nozzle (fog stream), operate effectively. If NP were not added into the formula, you would not have an effective fire stream.

FRICTION LOSS

Friction Loss is determined by recognizing that water, as a non-compressible fluid, exerts pressure equally against its confining material. Therefore, fluid pressure must be determined as a rate of water flow versus the friction index of the substance it is flowing through. Fortunately, in the case of fire hose, the friction loss rate (FLR) is a simple function of the square of the amount of water flowing. Specifically, the total gallons per minute (GPM) divided by 100 and then squared and then doubled, has been found to be an adequate fire ground formula for computing the friction loss rate. Once you have determined the friction loss rate for the length of hose lines, it can be added into the formula to determine pump pressure.

FORMULA TO DETERMINE PUMP PRESSURE:

PP = NP + FLR x L + AL (+/-) GL/GG + SL

PP = Pump pressure

NP = Nozzle Pressure

FLR = Friction loss rate (See formula) L = Length of hose line

AL = Appliance loss (Small or Large Appliance) GL = Gravity loss (+.5 total feet)

GG = Gravity gain (-.5 total feet) SL = System loss

FORMULA USED TO DETERMINE FRICTION LOSS RATE PER LENGTH OF 100 FEET OF HOSE:

$$\text{FLR} = 2\boldsymbol{Q^2} \quad \text{Where Q} = \frac{\boldsymbol{GPM}}{\mathbf{100}}$$

FORMULA USED TO DETERMINE GPM IN A SMOOTH BORE TIP

$$\text{GPM} = 30 \times d^2 \sqrt{\text{NP}}$$

FRICTION LOSS RULED OF THUMB ON THE FIREGROUND

With an understanding of the friction, loss formula an easy mental calculation can be used. The steps for using this are listed below:

1. Take your GPM back to the nearest hundred. Drop the zeros and you have Q. Then compute 2Q squared in your head.
2. Take the remaining number of tens that are left, if any, and multiply the number of tens by half the number of hundreds.
3. Add the figures from Step 1 and 2 together to find your friction loss rate (FLR)

Example: *Compute the friction loss rate for 340 GPM*

1. Drop back to the nearest hundred (300). Drop the zeros and you have Q (3). Compute 2Q squared (3x3=9 then 9+9=18)
2. Take the remaining number of tens (4), multiply them times half the number of hundreds (1½) (4x 1 ½=6)
3. Add you figures from Step 1 and 2 together (18 + 6 = 24). The FLR for 340 GPM is 24.

RULE OF “TWELVE'S"

Another quick way to help remember the friction Joss rates for the majority of GPM flows that we may encounter is informally referred to as the "Rule of 'Twelve's". For 2W' equivalent flows between 180 and 320, GPM can be calculated by subtracting 12 from the first two digits of the GPM flow. For example, the friction Joss rate for 300 GPM is (30 - 12) = 18.

Since the rule of twelve's is only practical between 180 and 320 GPM, be sure to use cautious when using the rule of twelve’s.

PUMP PRESSURE CONSIDERATIONS

Facts which you must have as a pump operator in order to determine pump pressure (PP) are:

1. Amount of hose in lay
2. Diameter of hose
3. Size of tips or GPM flowing
4. Nozzle pressure
5. Gravity loss and gravity gain
6. Appliance loss I system loss

AMOUNT OF HOSE IN THE LAY

In order to solve the amount of friction loss in a hose lay, you must know the entire length of the hose lay. Friction loss factors are computed on J 00' lengths of hose. When hose length is unequal, as in a Siamese or wyed lay, it is necessary to average the lengths.

DIAMETER OF HOSE

The diameter of hose and GPM flowing determines the amount of friction loss for each 100-foot section. With a given flow, the smaller the diameter, the more friction loss involved. This is because a greater proportion of the water pushed through actually comes into contact with the interior surface of the hose than in the case of a larger hose. A larger diameter hose allows a relatively larger percentage of the water pushed through to pass without contacting the interior surface.

The formula for determining FLR is based on GPM through 2 ½” hose. All flow rates through hose other than 2 ½” must be converted to an equivalent flow as if it were flowing through 2 ½” hose.

To calculate friction loss in various hose sizes other than 2 ½”, we have developed factors to convert the larger and smaller hose flows to GPM flow that creates the same amount of friction loss as in 2 W' hose. These factors are based on comparison of friction in hose of other than 2 ½” to that of 2 ½” hose

Conversion Factors to 2 ½" Hose			
Diameter of Hose	**Conversion Factor**	**Diameter of Hose**	**Conversion Factor**
¾"	25	13/4"	2
1"	9	3"	.67 or 2/3
1 ½"	3.6	4"	.25 or 1/4

To use these conversion factors, multiply the GPM times the factor to obtain the equivalent flow through a 2 ½" hose line and compute the friction loss based on this amount. Example: 150 GPM flowing through a 1 ¾" hose line would be multiplied times the conversion factor of 2 to obtain an equivalent flow of 300 GPM.

SIZE OF TIPS OR NOZZLE

The size of the tip or nozzle, plus pressure, determines the gallons per minute of flow. The gallons per minute of flow are the major factor that causes friction loss in fire hose. The larger the tip or nozzle, at a given nozzle pressure, the more friction loss involved. For any size smooth bore nozzle, the discharge can be approximately determined by the formula:

$$GPM = 30 \times d^2 \sqrt{NP}$$

Where d equals diameter of the nozzle and the nozzle pressure will be determined depending upon the type of stream. All handlines up to 1 1/4" tip will use 50 PSI for nozzle pressure. Any tip that is larger than 1 ¼" will be used only as a master stream and 80 PSI will be required at the tip. However, a 1 ¼" tip can be used for either a hand-held line or a master stream.

NOZZLE PRESSURE

The next step in the simplification of fire ground hydraulics is to establish nozzle pressures for all nozzle streams. In general, the following nozzles pressures have been established to determine friction loss.

25	PSI	NP	Sprinkler/standpipe
50	PSI	NP	Hand lines with smooth bore nozzles
80	PSI	NP	Master Streams with smooth bore nozzles
100	PSI	NP	All Fog nozzles
100	PSI	NP	Master streams with fog nozzles

GRAVITY LOSS AND GAIN

When hoselines are laid up or down an elevation, such as inclines, stairways, fire escapes, canyons, or the face of a building, the pressure loss or gain in pounds per square inch which is exerted by the water must be compensated for.

It takes .434 PSI to raise a column of water one foot and for every foot below the level of the pump you gain .434 PST.

For fireground operations, the figure of .434 P.S.I. can be rounded off to .5 or 1/2 PSI per foot of elevation. So, for a ladder pipe elevated 60 feet you would compute 60 x 1/2 = 30 PSI. This 30 PSJ would be added to your pump pressure to overcome gravity loss.

A rule of thumb for standpipe operations is to add 5 PSI per story above the ground floor, assuming each floor is ten feet high. This means that a standpipe connection on the third floor of a building would require l 0 PSI for gravity loss (hose is actually on the bottom of the third floor). However, a sprinkler system on the third floor would require l 5 PSI for gravity loss, since the sprinklers are in the ceiling of the third floor.

APPLIANCE LOSS / SYSTEM LOSS

Water flowing through large or small appliances as well as through standpipe I sprinkler systems will produce a friction loss. The loss will vary with the type of device, amount of water flowing, manufacturer and age of the appliance. For ease of operation the following pressures will be added when an appliance or system is being pumped:

Large appliances, i.e. Ladder Pipes, Deck Guns and Monitors - 15 PSI

Standpipe I Sprinkler System - 25 PSI

ROUNDING OFF

In order to make fire ground calculations easier and more efficient, it may be necessary to round off numbers. This can be accomplished by using the following rules:

¾” and 1” hose, to the nearest 1 GPM

1 ½” and 1 ¾” hose, to the nearest 5 GPM

2 ½” and 3” hose, to the nearest 10 GPM

Once the equivalent flow is computed it is treated as 2 ½” hose, and the equivalent flow is rounded off as 2 ½” hose to the nearest l 0 GPM.

INITIAL STARING PRESSURES

Often the driver/operator will get the request for water before accurate hydraulic calculations can be made. In this situation, the standard operating procedure will be to pump the pressures given below for the following cases:

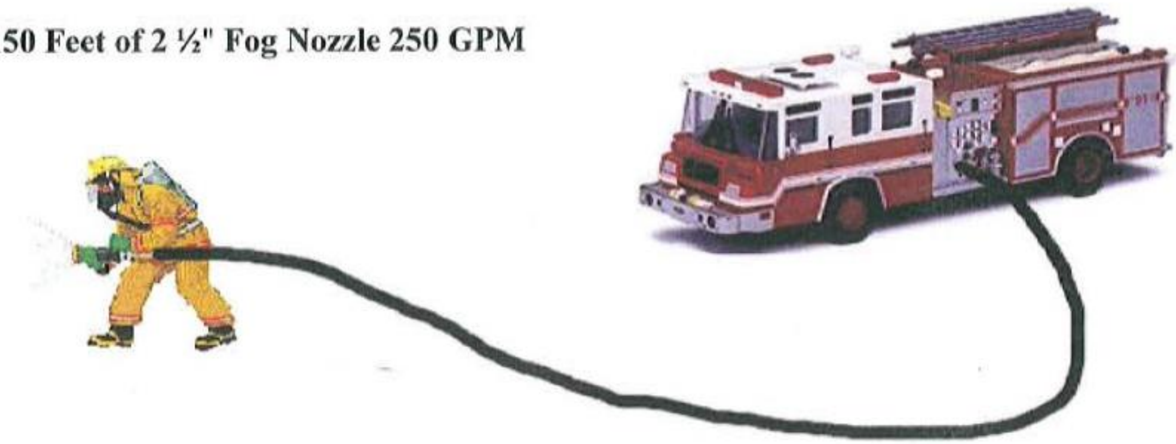
1. For all pre-connected hand lines:
   Initial pressure = 150 PSI

2. Sprinkler Systems:
   Initial pressure = 150 PSI

3. Standpipe Systems:
   Initial pressure = 150 PSI

HYDRAULIC SETUPS AND CALCULATIONS

150 Feet of 2 ½" Fog Nozzle 250 GPM



The firefighter is ordered to pull the standard 150' 2 ½” pre-connect. Since a specific GPM has not been asked for, use 250 GPM (predetermined GPM for 2 1/2" fog nozzle).

To begin this problem, place the known information into the formula. PP= l 00 PST (Nozzle pressure for fog nozzle) +______x 1.5 (150 feet of hose.) To determine FLR, take 250 and divide it by 100, which equals 2.5. Since 2 (2.5) 2 equals 12.5 rounded to 13, 13 equals the FLR per length of 100 foot of hose.

PP=NP + FLR x L
PP=100 + ____x 1.5
PP=100 + 13 x 1.5
PP=100 + 19.5
PP=120 (Rounded Off)

$$FLR=2Q^2$$
$$Q=\frac{GPM}{100}$$
$$Q=\frac{250}{100}$$
$$Q=2.5$$
$$FLR=2(2.5)^2$$
$$FLR=12.5 = 13 \text{ (Rounded Off)}$$

UTILIZING THE CONVERSION FACTORS

200 Feet of 1 ¾" Fog Nozzle 150 GPM

The firefighter is ordered to pull the standard 200” 1 ¾” ore connect. Since specific GPM has not been asked for, assume we will use 150 GPM, the predetermined GPM for 1 ¾” pre-connect. To set this problem up, identify what information you will need to solve the problem. Don’t forget to use the conversion factor to convert the 1 ¾” hose to 2 ½” hose.

PP=NP + FLR x L
FLR= $2Q^2$
Q=GPM divided by 100

To begin this problem, place the known information into the formula.

PP=l 00 PSI (Nozzle pressure for fog nozzle) + FLR x 2 (200 Feet of Hose). To determine FLR, take 150 GPM and convert it to equivalent flow (2 ½”). The conversion factor is 2 for 1 ¾” hose. 150 x 2=300. Divide 300 by l 00, which equals 3.

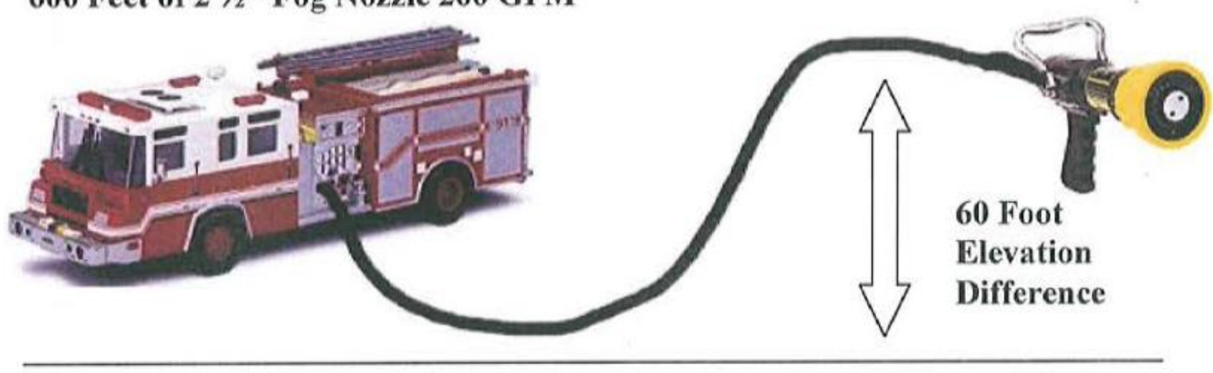
$2(3)^2$ equals 18, 18 equals the FLR per length of 100 foot of hose

PP=NP + FLR x L
PP=100 + ____x 2
PP=100 + 18 x 2
PP=136 PSI

FLR=$2Q^2$
Q=$\frac{GPM}{100}$
Q=$\frac{300}{100}$
Q=3
FLR=$2(3)^2$
FLR=18

GRAVITY LOSS/GAIN

Since we know for fireground operations the figure of .434 P.S.I. can be rounded off to .5 or ½ PSI per foot of elevation, we can now apply this to a problem. We must add more pressure to compensate for going uphill and reduce pump pressure when hose is laid downhill, because of an increase or decrease of head pressure. The following illustrates a problem incorporating gravity loss due to an incline:



The firefighter is ordered to pull 600' of 2 ½" working line un an incline. The company officer requests 200 GMP from a standard fog nozzle. To set this problem up, identify what information you will need to solve the problem. In this case, you will solve for Pump Pressure (PP)

PP=NP + FLR x L + GL

PP=100 + ____x 6 + 30

PP=100 + 8 x 6 + 30

PP=178 PSI

$$FLR=2Q^2$$

$$Q=\frac{GPM}{100}$$

$$Q=\frac{200}{100}$$

$$Q=2$$

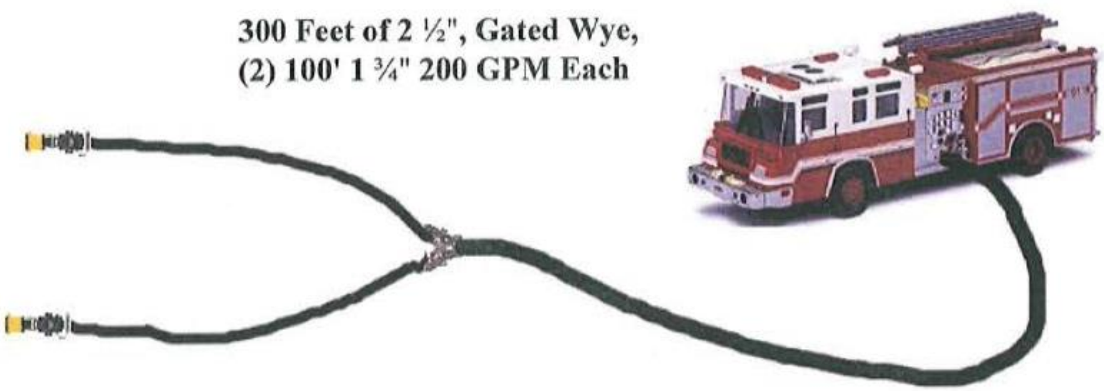
$$FLR=2(2)^2$$

$$FLR=8$$

WYED LINES

There are many different combinations of placing hose on the fireground. Usually a 2 ½" hose is used for a supply line and a gated-wye is attached to the end of the hose for one or two additional lengths of hose as desired. The additional hose is usually smaller in diameter. To figure out the friction loss for the total length of the lay the setup is similar to the previous problems with a few additional steps. To set this problem up, identify what information you will need to determine pump pressure.

300 Feet of 2 ½", Gated Wye,
(2) 100' 1 ¾" 200 GPM Each



PP=NP + FLR x L + FLR x L
PP=100 + ___ x 3 + ___ x 1

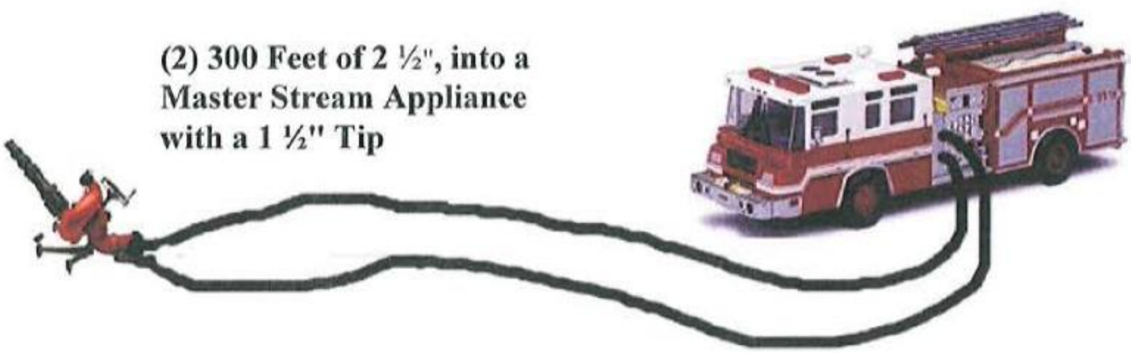
In this problem we need to solve for the FLR rate for 300 feet of 2 ½" hose and the two 100 foot 1 ¾" hoselines. Since all of the water must travel through the 2 ½" hose first, we combine the GPM flowing through both the 100 foot 1 ¾" lines. In this case, since both 1 ¾" lines are identical, add the total GPM for the first half of the problem. 200 + 200=400. Plug 400 into the FLR formula to solve for the FLR for the 2 ½" hose. For the 1 ¾" hoselines since equal water is flowing through both lines and both lines arc alike, we only need to solve for one line. Before you set up the problem don't forget to convert the GPM to 2 ½" equivalent flow. (Times 2)

2 ½" Hose $FLR=2Q^2$	1 ¾" Hose $FLR=2Q^2$
$Q=\frac{400}{100}$	$Q=\frac{400}{100}$
$Q=4$	$Q=4$
$FLR=2(4)^2$	$FLR=2(4)^2$
$FLR=32$	$FLR=32$

PP=100 + 32 x 3 + 32 x 1
PP=228 PSI

SIAMESED LINES

Friction loss in parallel Siamese-lines can be determined by dividing the flow of water (GPM) equally in the hoselines, provided the hoselines are of the same diameter. Then we can calculate the friction loss rate for a single line. For example, if the flow through two 2 ½" lines is 600 GPM, then the flow through each one would be 300 GPM. The friction loss can then be calculated based upon 300 GPM flowing through a single 2 ½" line



PP=NP + FLR x L + AL
PP=80 + ___ x 3 + 15

In this problem we need to solve for the FLR rate for 300 feet of 2 ½" hose. Since there are two lines (both same diameter and length), we can divide the total GPM by 2. When Siamese lines are going to be deployed, they are usually used to supply master streams. Remember the nozzle pressure for a smooth bore tip on a master stream is 80 PSI and 15 PSI is added in for friction loss with a large appliance.

Total GPM = 600 GPM
600 Divided by 2 (Lines)=300
2 ½" Hose

$$Q = \frac{300}{100}$$

$$FLR=2Q^2$$

$$FLR=2(3)^2$$

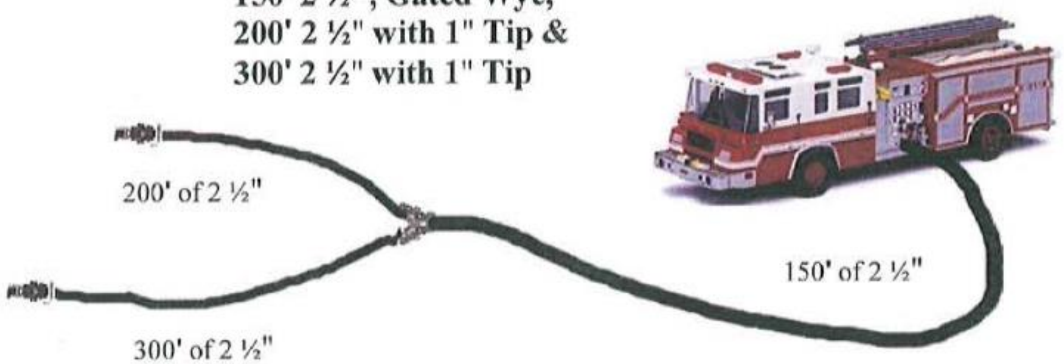
$$FLR=18$$

PP=NP + FLR x L + AL
PP=80 + 18 x 3 + 15
PP=149 PSI

FRICTION LOSS IN UNEQUAL LENGTHS

Sometimes when dual lines are laid, they will be of uneven lengths. When this happens friction Joss calculations can be based on the average length of the hose lay. For example, if one line laid is 200' long and the other is 300' long, the average would be determined by adding both lengths together and dividing by two, which would equal an average of 250'. When the average comes out to a ¼ or ¾ length, round off to the nearest ½ or full length respectively

150' 2 ½", Gated Wye,
200' 2 ½" with 1" Tip &
300' 2 ½" with 1" Tip



PP=NP + FLR x L + FLR x L
PP=50 + ___ x 1.5 + ___ x 2.5 (200' & 300' Averaged)

In this problem we need to solve for the FLR rate for 150 feet of 2 ½" hose and the FLR for the unequal lines. Since one line is 200' long and the other line is 300' long we must average the two lengths to determine friction loss. To average the unequal lengths, add both lines and divide by the number of hoselines. (200+300=500; 500÷2=250) Once we have determined the average for the unequal lines, we solve the problem as in the previous example with a gated wye.

150' 2 ½" Hose $FLR=2Q^2$

$Q = \frac{420}{100}$

$Q = 4.2$

$FLR = 2(4.2)^2$

$FLR = 35.28$ or 35

Unequal Lines of 2 ½" Hose $FLR=2Q^2$

$Q = \frac{210^*}{100}$

$Q = 2.1$

$FLR = 2(2.1)^2$

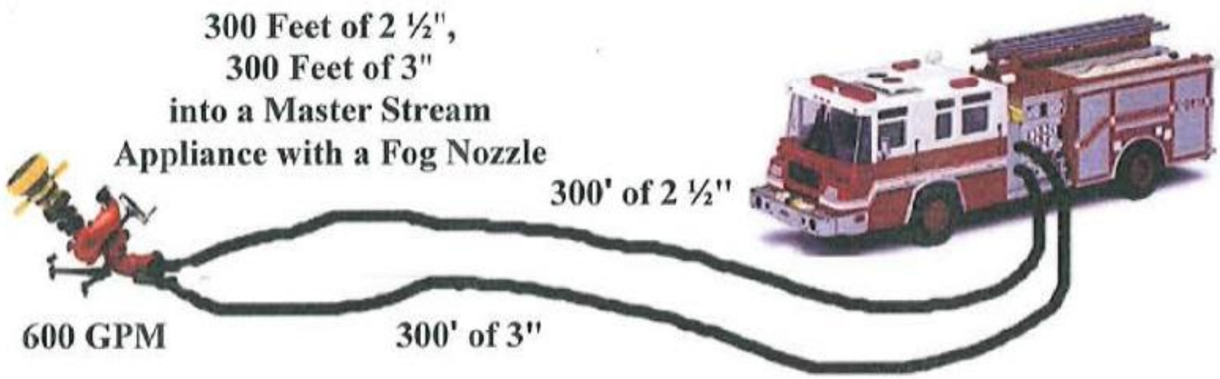
$FLR = 8.82$ or 9

PP=NP + FLR x L + AL + FLR x L
PP=50 + 35 x 1.5 + 9 x 2.5
PP=50 + 52.5 + 22.5
PP=125 PSI

FRICTION LOSS IN UNEQUAL HOSE DIAMETERS

When parallel lines have different hose diameters, they will carry different percentages of the total flow. To compute this percentage and regulate different pressures at each discharge gate would not be practical on the fireground.

However, a practical solution may be obtained by calculating an average engine pressure for the lines. The flow through each hose line would stabilize at a point where the friction losses are the same. To accomplish this, divide the total GPM by the number of hoselines (regardless of sizes), change to equivalent 2 ½" flows for each line using the appropriate conversion factor, compute the friction loss for each line and then average the friction losses. This will be your average friction loss rate per 100 feet of hose.



Divide the total GPM by the number of hose lines (600 GPM divided by 2 = 300 GPM), using the conversion factor for 3" hose, compute the equivalent flow through 2 ½" hose (2/3 x 300 GPM = 200), then compute the friction loss rate for 200 GPM and 300 GPM.

2 ½" Hose $FLR=2Q^2$

$Q=\frac{300}{100}$

$Q=3$

$FLR=2(3)^2$

$FLR=18$

3" Hose $FLR=2Q^2$

$Q=\frac{200}{100}$

$Q=2$

$FLR=2(2)^2$

$FLR=8$

The friction loss rate for 200 GPM is 8 PSI and the friction loss rate for 300 GPM is 18 PSI. Add the friction loss rate for each hose line and average them.

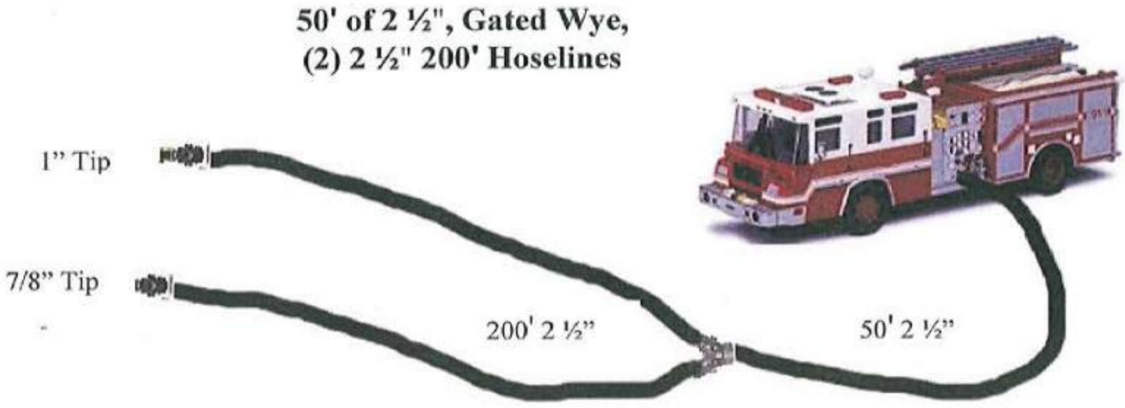
8 + 18 = 26

26 divided by 2 = 13

FLR = 13 PSI per 100'

PP = NP + (FLR x L) + AL
PP = 100 + (13 x 3) + 15
PP = 100 + 39 + 15
PP = 154 PSI

DETERMINING FLOW WITH DIFFERENT SIZE TIPS



This problem is very similar to the previous example. In this problem we have one 2 ½" hose wyed to (2) 2 ½" hoselines with different size tips. Just as in the earlier example with the wyed lines we can break this problem into two problems when solving for the FLR to determine an accurate pump pressure. In this problem, since there are two different size smooth bore nozzles, we will have to dete1mine an average GPM. To determine the average GPM, add the total GPM and divide by the number of hoselines. Let's revisit how to determine the GPM for a smooth bore nozzle:

$30\ d^2\sqrt{NP}$	$30\ d^2\sqrt{NP}$
$30\ (1)^2\sqrt{50}$	$30(.875)^2\sqrt{50}$ (7/8 = .875)
$30 \cdot 1 \cdot 7$	$30 \cdot 0.765 \cdot 7$
210 GPM	160.65 or 160 GPM

Now that we know the total GPM (210 + 160 = 370) we can determine the average by dividing 370 by 2, which equals 185 or 190 GPM per line. To set this problem up, first identify the known information and solve for friction loss to determine pump pressure.

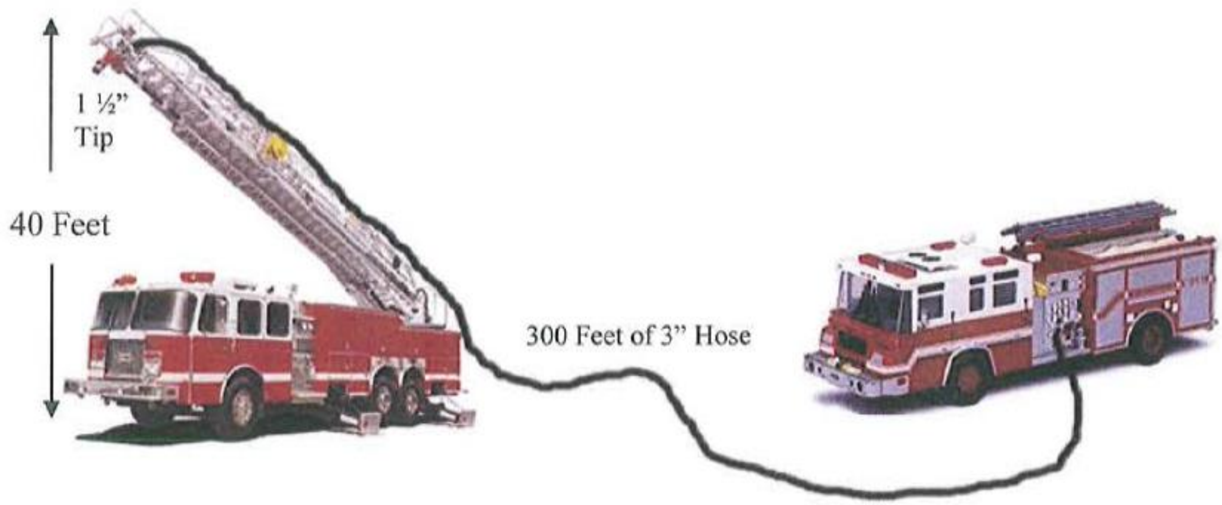
PP=NP + FLR x L + FLR x L
PP=50 + FLR x .5 + FLR x 2

2 ½" Hose $FLR=2Q^2$	Two Lines Hose $FLR=2Q^2$
$Q=\frac{370}{100}$	$Q=\frac{190}{100}$
Q= 3.7	Q= 1.9
$FLR=2(3.7)^2$	$FLR=2(1.9)^2$
FLR=27.38 or 27	FLR=7.22 or 7

PP=50 + 27 x .5 + 7 x 2
PP=50 + 13.5 + 14
PP=77.5 or 78 PSI

SUPPLYING ELEVATED MASTER STREAMS

A driver/operator needs to be familiar with how to supply an elevated master stream. Most newer model truck companies will be pre-plum bed, with a friction loss pre- determined depending upon the unit. Truck companies that are not pre-plumbed will need a hoseline to be extended the length of the ladder and then supplied by an engine company. The following is an example of how to supply a truck company's elevated master stream with a 1 ½" tip:



PP = NP + (FLR x L) + AL + GL
PP = 80 + (32 x 3) + 15 + 20
PP = 80 + 96 + 15 + 20
PP = 211

30 d^2 $\sqrt{NP}$
30 $(1.5)^2$ $\sqrt{80}$
30 (2.25) 9
607.5 or 600
Convert 600 GPM to 3" Hose
2/3's of 600 = 400

Total GPM = 400 GPM (Converted)

$$Q = \frac{400}{100}$$

$$FLR = 2Q^2$$

$$FLR = 2(4)^2$$

$$FLR = 32$$

SUPPLYING ELEVATED PLATFORMS

Elevated platforms are pre-plumbed and can be supplied by an engine company on the scene. There are going to be some differences in the setup of the equation depending on which nozzle is used. 170 PSI pumped to the tailboard is the initial pressure utilized when supplying an elevated stream. Pump pressure will be adjusted to meet fire ground operational needs.

Example 1: 1000 GPM Fog nozzle with the ladder fully extended at 100' being supplied by an engine 100' away using 4" hose.

PP = NP + (FLR X L) + GL
FLR is for the 4" hose, 1000 GPM/4 = 250. 250 converts to a FLR of 13 PSI.
PP=80 + (13 X 1) + 25 + 50
PP= 80 + 32 + 25 + 50
PP = 188 PSI

Example 2: 2"Master Stream nozzle with the ladder 60' elevation being supplied by an engine 200' away using 4"hose.

PP = NP + (FLR X L) + SL GL
FLR is 1100 GPM/4 = 275 or 280 which has a FLR of 16 PSI
PP = 80 + (16 X 2) + 25 + 30
PP = 80 + 32 + 25 + 30
PP = 167 PSI

The examples are showing that the correct way to solve for an elevated platform is to break it down like a standpipe system and figure in all the pieces of the system.

As you can see in this section is that J 70 PSI pumped to the tail board is a close initial pressure until the correct pressure can be determined.

SUPPORTING FIRE PROTECTION SYSTEMS

Standpipes are used to speed fire attack in multi-story buildings or single-story buildings with large open areas. Fire attack teams attach lines to the 2 ½” or 1 ½” connections provided on each floor. Standpipes may be wet or dry, depending upon owner preference or local code requirements. Wet-pipe systems contain water under pressure and are ready to be used as soon as lines can be attached to the outlet. Dry-pipe standpipes must be supplied with water from a pumper that attaches to the standpipe FDC outside the building.

The driver/operator needs to be familiar with high-rise firefighting equipment, like the current nozzles used in the high-rise hose packs. Communication is crucial with the fire attack crew to ensure desired pressures are obtained

When supplying a stand pipe for a multi-story building fire, additional information must be considered when determining pump pressure. The standpipe friction loss, elevation loss due to the height of the building*, the friction loss on the fire floor (attack hose) and

the friction loss for the supply hose into the FDC must all be accounted for, to determine the proper pump pressure.

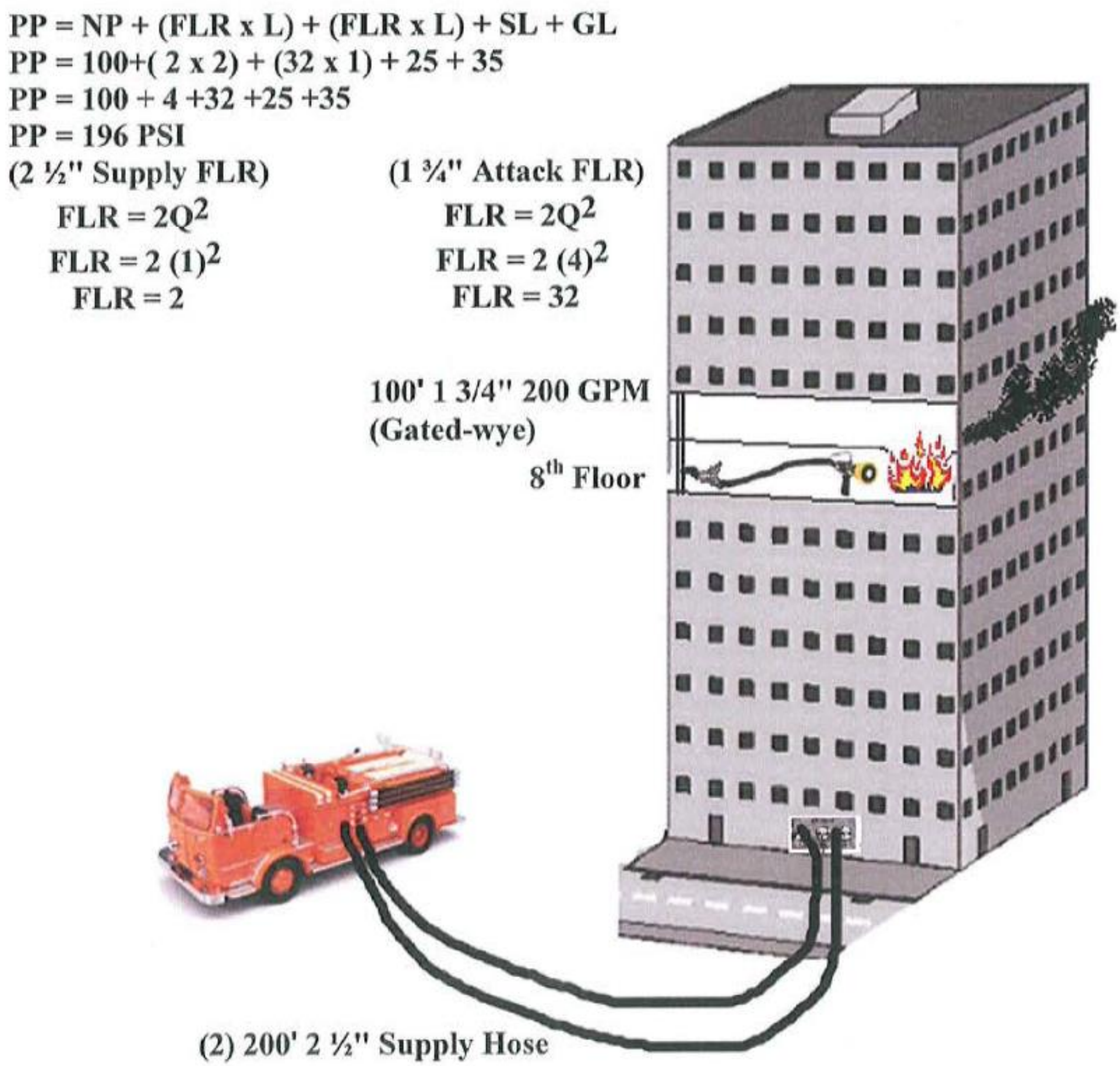
* For below grade floors, remember gravity gain (GG)

STANDPIPES

System loss for a standpipe is 25 PSI. When accounting for gravity loss due to elevation differences, allow 5 PSI gravity loss per floor above ground level. * (Do not count the floor the nozzle is on). For example, a ten-story building would only have 45 PSI added into the pump pressure for gravity loss.

The following is an example of a fire in a high-rise building. The fire is on the eighth floor. The attack crew is flowing one l 00-foot t 3. hi" high-rise pack with the Elkhart Fog Nozzle at 200 GPM. To set this problem up, identify all the information to solve for pump pressure. Total GPM al the nozzle is 200. Since there are two lines supplying the system the total GPM can be divided by 2, which equals l 00. This means Q=1 for the 2 ½" supply hose. One 100 foot 1 ¾" fire attack is attached to the gated-wye. To determine the FLR for this line, first convert it to 2 ½"' (200 GPM x 2) and solve for FLR for 400 GPM. This means Q = 4.

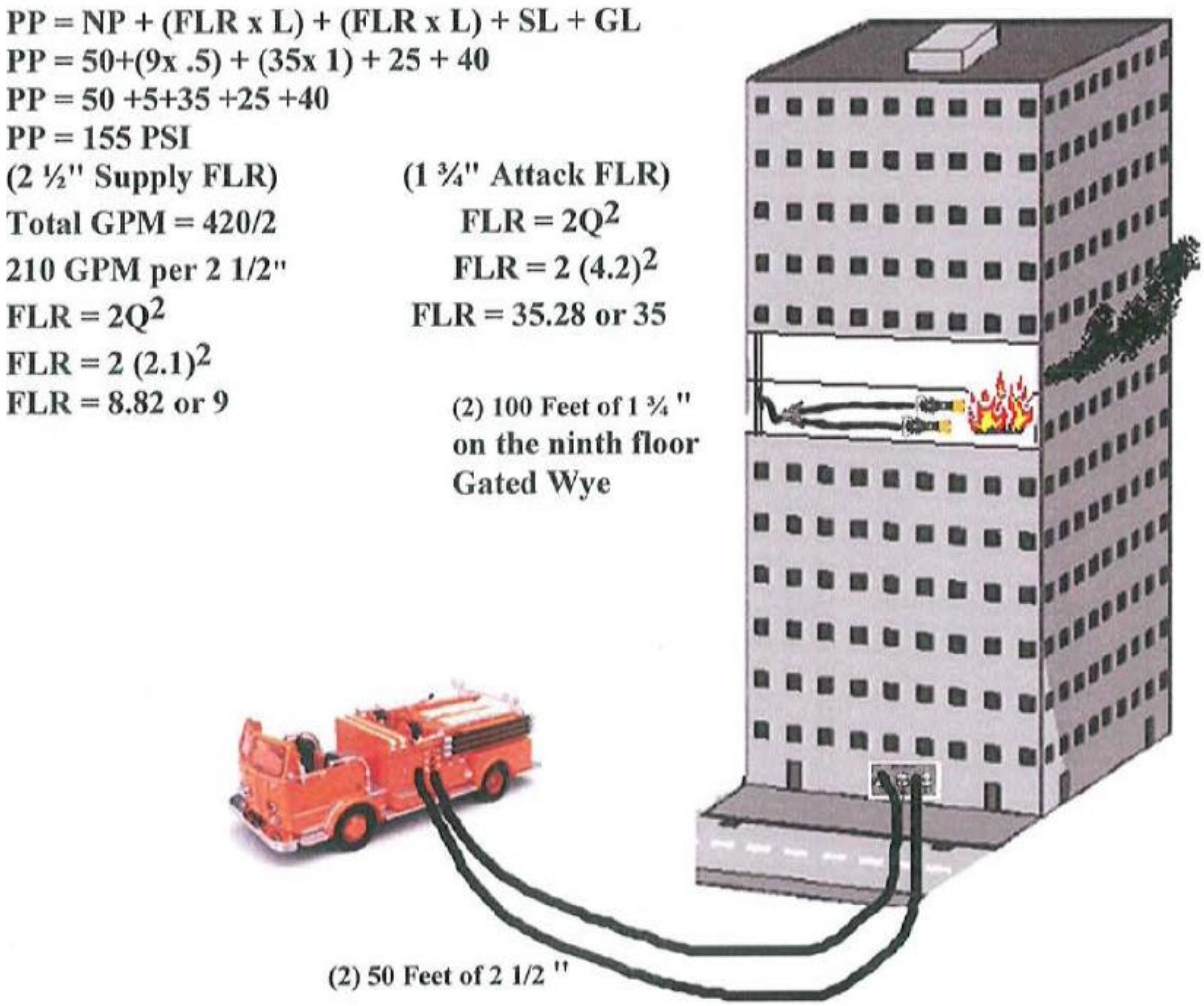
*For below grade floors remember to account for gravity gain (GG). The floor the nozzle is on is counted. Allow for 5 psi gravity gain per floor below the ground level.



PP = NP + (FLR x L) + (FLR x L) + SL + GL
PP = 100+(2 x 2) + (32 x 1) + 25 + 35
PP = 100 + 4 +32 +25 +35
PP = 196 PSI
(2 ½" Supply FLR)
FLR = 2Q2
FLR = 2 (1)2
FLR = 2
(1 ¾" Attack FLR)
FLR = 2Q2
FLR = 2 (4)2
FLR = 32
100' 1 3/4" 200 GPM
(Gated-wye)
8th Floor
(2) 200' 2 ½" Supply Hose

This example is very similar to the previous example with the addition of a second hoseline on the fire floor.

The fire is on the ninth floor. The attack crew is flowing two 100 foot 1 %" high-rise packs with 1 " smoothbore tip nozzles on both lines. To set this problem up, identify all the information to solve for pump pressure. Determine the GPM for the 1 " nozzles. Then use that information to determine the friction loss rate for both the attack lines and the supply lines. Don't forget to use the conversion factor for 1 %" hose. Let's set this problem up.



AUTOMATIC SPRINKLER SYSTEMS

Properly installed and maintained fire sprinklers have a long history of providing reliable, automatic protection to all types of occupancies. The water supply for sprinkler systems is designed to supply only a fraction of the total sprinkler s in a system. If a large fire should occur, or if the pipe breaks, the sprinkler system will need an outside source of water and pressure in order to do its job effectively.

Once on scene of an occupancy equipped with sprinklers and a fire department connection, the driver/operator should locate a hydrant and prepare to support the system if there is any indication of a potential fire. A minimum of two 2 ½" hoselines shall be used to support the FDC.

HERE ARE SOME GENERAL GUIDELINES FOR SUPPLYING SPRINKLER SYSTEMS:

Rapid method hydraulics allows 30 GPM per sprinkler head.

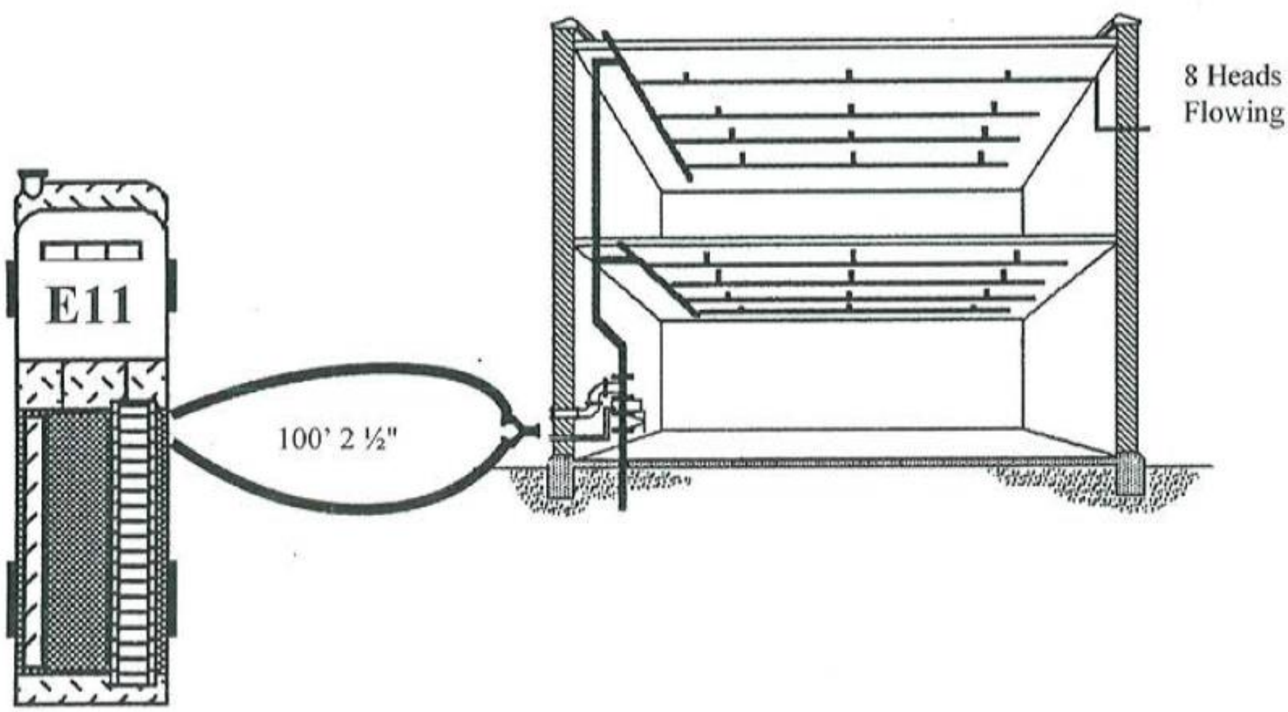
In rapid method hydraulics, 25 PSI can be considered as effective head pressure.

Allow 25 PSI loss for sprinkler system.

Allow 5 PSI per floor gravity loss, including the first floor and fire floor. Do not include the first floor below grade when figuring for gravity gain.

Immediate pump pressure: Maintain 150 PSI at the pump until proper pump pressure can be obtained.

The following example is an illustration of supply to a sprinkler system. In this example there are eight heads flowing. When setting up this problem allow 30 GPM per head to determine total GPM needed to perform the hydraulics calculation. To set this problem, first identify the information needed to solve for pump pressure. Total GPM is 240 (30 x 8), system loss equals 25 PSI, head pressure equals 25 PSI, and since the sprinklers on the second-floor arc discharging, we need to allow I0 PSI for gravity loss. We only need to solve for the friction loss rate for the (2) 100' 2 ½" hose.



PP=NP+ (FLRxL) +SL+GL

PP=25+ (3x1) +25+10

PP=63 PSI

Total GPM = 240/2 (2 ½" Lines)

GPM = 120

$FLR=2Q^2$

$FLR=2(1.2)^2$

FLR=2.88 or 3 PSI

RELAY PUMPING

Relay Pumping Operations Relaying of water can be accomplished when the activities of personnel and equipment involved arc coordinated by the officer in charge, and upon receipt of specific information such as:

a) Amount of water needed to extinguish the fire.
b) Size and length of available hose.
c) Apparatus available for pumping purposes.
d) Time required to set up the relay.
e) Maximum distance one pumper can deliver the GPM.
f) Topography of the area over which relay is to be made.

The quantity of water (GPM) needed to effectively handle the situation must be estimated, because every succeeding phase of the relay will be governed by this estimate.

Since friction loss in hose used for relays will be one of the factors determining the distance between pumper s, the largest hose available should be used to minimize the number of pumpers required in the relay.

The distance from the water supply to the fire is secondary in estimating the amount of hose required for the relay. Primarily, it is the length of hose between individual pumpers that must be determined.

The hoseline or lines leading to the fire from the last pump do not materially affect relay operations, and there is no need for them to enter relay computations. The operator of this pump may assume it is connected to a water supply for the purpose of extinguishing the fire.

The condition of the hose will also have an effect on the length of hose lines between pumps. The pump pressure of the pumps in the relay should not exceed 200 psi. (See Page 5-15 for definition and set up of relay operations.)

When calculating pump pressure to be pumped by a relay pumper, an intake pressure of I 0 PST must be maintained at the next pumper in line. On this basis the pressure which the hose can withstand, minus intake pressure, could be used to overcome friction loss and gravity loss, if it exists.

With the friction loss rate determined, as a result of the GPM flow, the maximum amount of hose between pumps, without exceeding the maximum pump pressure, can be determined.

When distance is not a determining factor, (short relays) a pump pressure Jess than maximum could provide sufficient intake pressure at the next pump in line. It is logical to expect pumpers of varying capacities to be used in each relay operation.

It must be considered that the capacity of a pump diminishes as the pl1mp pressure exceeds a certain amount.

Class A pumps will deliver about one half of capacity at 250 PSI PP. Low discharge capacity compared to those of high discharge capacity should be taken into consideration. The largest capacity pumper should be placed at the source of supply.

More time will be needed to complete a relay than would be necessary to make a regular hose lay. This unavoidable delay should be considered in determining how large the fire will be by the time relayed water is available.

Differences in elevation between water supply and the nozzle will have a decided effect on the placement of pumpers in the relay, and also upon the total number required.

It is now evident several things must be considered to keep within the maximum allowable pump pressure; i.e.

a) Total friction loss developed by the quantity of water flowing, which has to be overcome by the pump.
b) The gravity loss or gravity gain, if it exists.
c) The intake pressure at the next pump in li ne.

After the size and number of hose lines are decided upon, the number of pumps necessary to transport the desired now to the pump engaged in the firefighting can best be determined by the following formula:

$$\text{Number of pumps} = \frac{TFL + GL - GG}{\text{Maximum PP-IP}}$$

EXAMPLE: In a relay operation, 2 - 2-1/2" hose lines, each 500' long, and furnished with 7/8"tips at 50 PSI NP, arc laid from the pump to the fire.

3000' of 2- 1/2" hose will be required to transport water from the source to the pump at the fire scene, which is 200' above the water source. How many pumpers will it require to complete this relay?

7/8" tip @ 50 PSI = 160 GPM

Total GPM = 2 x 160

Total GPM = 320 (FLR = 20 PSI)

$$\text{No. pumps} = \frac{\text{TFL} + \text{GL} - \text{GG}}{\text{Maximum PP} - \text{IP}}$$

TFL = FLR x L
TFL = 20 x 30
TFL = 600 PSI

GL = .5 x H
GL = .5 x 200
GL = 100 PSI

Total pressure = TFL + GL
Total pressure = 20 x 30
Total pressure = 700 PSI

$$\text{No. pumps} = \frac{600 + 100}{250 - 10}$$

$$\text{No. pumps} = \frac{700}{240}$$

No. Pumps = 2.9 or 3 pumps

Using the above formulas, 3 pumps would be required for the relay to keep from pumpingan excessivepressure

ESTIMATE AVAILABLE FLOW FROM A HYDRANT

The ability to calculate the available flow (GPM) remaining in a hydrant can be of great advantage to both the pump operator and the commanding officer, particularly on the fireground, as well as in pre-planning surveys. REMEMBER that to be an efficient engineer you should know as much about the water supply in your district as possible prior to an emergency.

To estimate the available flow from a hydrant the rule is: determine the percentage of drop between static (at rest) and residual (in motion) pressures.

This percentage of drop will indicate the estimated available flow; i.e., I 0 percent drop, 3 more like volumes; 15 percent drop, 2 more like volumes; 25 percent drop, 1 more like volume.

Therefore, to estimate the available flow from a hydrant, the following must be applied:

1. Note the static pressure on the compound gauge after the hydrant has been opened to Jet water into the pump, but before opening any discharge gate.
2. Note the residual pressure on the compound gauge after getting the line into operation at the standard nozzle pressure; and
3. Determine the percentage of drop:

Example: The static pressure on the compound gauge when the hydrant is delivering water into the pump is 60 PSI. When the first line (250 GPM nozzle) is put into operation, the residual pressure is 54 PSI. Estimate the remaining available GPM flow.

Solution: With a decrease from static pressure of 60 PSI to a residual pressure of 54 PSI (a drop of 6 PSI), the percentage of drop is 6/60 or 10 percent; therefore, 3 more like volumes is the estimated available flow, or a total estimated flow of 4 volumes (1000 GPM total).

ESTIMATE STATIC PRESSURE

In the event the static pressure was not noted when the hydrant was opened on the fireground, i t may be necessary to estimate the static pressure to determine available flow from a hydrant. However, if it is deemed necessary, the following procedure may be used:

1. Note the flowing pressure on the compound gauge with the first line in operation.
2. Place another nozzle delivering the same GPM into operation and note the drop-in flow pressure.
3. Divide the drop pressure by 2 and add to the flow pressure that was noted when the first line was in operation. This is the estimated static pressure.

Example: A line delivering 160 GPM is put into operation, and the residual pressure on the compound gauge reads 68 PSI. A second line delivering the same GPM is placed into operation and the residual pressure now reads 44 PSI. Estimate the remaining available now.

Solution: First, to estimate the static pressure with a decrease in residual pressure of 24 PSI (from 68 PSI to 44 PSI), divide the drop in pressure by 2 which equals 12 PSI. This then can be added to the residual pressure that was noted when the first line was put into operation . We now have 68 + 12 which equals an estimated static pressure of 80 PSI. Next, to estimate the remaining available flow with a decrease from static to residual pressure of 12 PSI (80 to 68), the percentage of drop is 12/80 or 1 5 percent; therefore, 2 more like volumes is the estimated available flow, or a total estimated now or 3 like volumes.

Note: When pumping at a fire, the hydrant residual pressure should never drop from positive to negative; an intake pressure of 10 PSI must be maintained.

HOW TO ESTIMATE QUANTITIES OF WATER

To determine the capacity of amount of water in a rectangular container or on a floor of a building if the dimensions are in feet, use the formula:

C = L x W x H x 7.5

C = Capacity in gallons L = Length in feet

W = Width in feet

H = Height in feet

7.5 = Gallons per cubic foot

Example: Determine approximate capacity of rectangular tank 20' x 15' x 5'.

C = L x W x H x 7.5

C = 20 x 15 x 5 x 7.5 C = 11,250 gallons

The rapid method for finding the approximate capacity of water in gallons in a cylindrical tank, when the dimensions are in feet is as follows:

$C = 6\mathbf{d}^2 \text{ x } H$

C = Capacity in gallons 6 = Constant

d = Diameter in feet

H = Height of water in feet

Example: Determine approximate capacity of tank 20' in diameter by 5' deep.

$C = 6\ (\mathbf{20})^2 \text{ x } 5$

C = 12,000 gallons

For greater accuracy, subtract 2 percent of the total, i.e., 12,000 x .02 = 240; thus (12,000 - 240) =1 gallons.

WEIGHT OF VOLUME OF WATER

To determine weight, the number of gallons can be multiplied by 8.35 pounds or the number of cubic feet multiplied by 62.5 pounds.

Example: Determine the weight of water in a cylindrical tank 30' in diameter and 2' deep:

$$\text{Weight} = 6\boldsymbol{d}^{2} \text{ x H x } 8.35$$
$$\text{Weight} = 6\ (\mathbf{30})^{2} \text{ x } 2 \text{ x } 8.35$$
$$\text{Weight} = \frac{\mathbf{90{,}180}}{\mathbf{2{,}000}} \text{ pounds} = 45 \text{ tons}$$

Example: Determine the weight of water in a room 60' by 30' by 6" deep.

$$\text{Weight} = \text{L x W x H x } 62.5$$
$$\text{Weight} = 60 \text{ x } 30 \text{ x } .5 \text{ x } 62.5$$
$$\text{Weight} = \frac{\mathbf{56{,}250}\ \boldsymbol{pounds}}{\mathbf{2{,}000}} = 28\text{-}1/8 \text{ tons}$$

MEASUREMENTS

Atmospheric pressure at sea level is 14.7 PSI = 30 inches of mercury = 33.9 feet of water. Therefore, 1 inch of mercury = 1.13 feet of water.

One gallon of water requires 231 cubic inches and weighs 8.35 pounds.

1 Cubic foot = 1,728 cubic inches

1 Cubic foot of water weighs 62.5 pounds and contains 7.5 gallons

HYDRANT PRESSURE

The rapid method for finding the amount of water flowing from any non-restricted opening such as a hydrant port or the end of a hose (without a nozzle), use the formula:

$$\text{GPM} = 27 \times \boldsymbol{d^2} \times \sqrt{}\,\text{P is used}$$

27 = constant

d = Diameter of opening

P = Pressure per square inch using Pitot gauge

Example: What is the approximate GPM flow from two 2-1/2" hydrant ports flowing simultaneously? Residual pressure of 25 PSI.

$$\text{GPM} = 27 \times \boldsymbol{d^2} \times \sqrt{}\,\text{P} \times 2$$

$$\text{GPM} = 27 \times (\mathbf{2.5})^{\mathbf{2}} \times \sqrt{}\,25 \times 2$$

$$\text{GPM} = 27 \times 6.25 \times 5 \times 2$$

$$\text{GPM} = 1687.5 \text{ or } 1690 \text{ GPM}$$

For pressure (P) go to the nearest number that the square root can be extracted easily from, such as 49 for 50.

WEIGHT OF WATER DELEIVERED

IL is useful to know that a standard fire stream, 250 GPM, represents approximately one ton of water per minute delivered into a building or structure. Consideration should be given to safety of personnel due to the possibility of structural collapse, and provision for the release of water from a building should be a paramount thought of any fire fighter.

Below is a table relating the size of nozzle to the approximate tons of water being delivered per minute.

NOZZLE	PSI	GPM	WATER PER MINUTE
1-1/8”	50	270	1-1/4 ton
1-1/4”	80	400	1-1/2 ton
1-1/2”	80	600	2-1/2 ton
1-3/4”	80	800	3-1/3 ton
2”	80	1100	4-1/2 ton

MASTER STREAM

A large caliber fire stream too heavy for convenient or safe manual operation and therefore discharged through a monitor nozzle, deluge set, ladder pipe, portable monitor or turret. Master Streams may be supplied with single or multiple lines depending on their GPM flow capability and required supply lines.

NOZZLE REACTION

Water being discharged from a nozzle under pressure is not unlike a jet stream from a jet aircraft engine, in that it causes a reaction. The danger of this reaction upon a firefighter handling the nozzle cannot be emphasized enough; especially the reaction encountered from a nozzle on a long lay with high engine pressure to overcome friction. The engine pressure is built up right to the nozzle when the water is static. The reaction is greatest when the nozzle is first opened.

This reaction can be calculated in total force by a formula if the diameter of the orifice is known, and the pressure at the orifice is known. The force will be in pounds.

$$NR = 1.5 \text{ x } \boldsymbol{d^2}$$

1.5 = a constant

$\boldsymbol{d^2}$ = Diameter or orifice squared

NP = Pressure at the orifice when flowing

Example: What is the nozzle reaction from a 2" tip with 80 PSI NP?

$$NR = 1.5 \text{ x } \boldsymbol{d^2} \text{ x } NP$$

$$NR = 1.5 \text{ x } \boldsymbol{2^2} \text{ x } 80$$

NR = 480 lbs. (not PSI)

Another formula that can be used is based on the GPM flow. This formula can be used on fog nozzles as well as solid stream nozzles.

$$N.R. = GPM \text{ x } \sqrt{\ } NP \text{ x } .0505$$

A rule of thumb formula when operating fog nozzles at 100 PSI nozzle pressure is N.R. = ½ GPM.

ROUNDING AND OTHER INFORMATION FOR THE WRITTEN ENGINEER EXAM

SQUARE ROOTS

When determining square roots for the common nozzle pressures of 100, 80 and 50, use the following:

$\sqrt{100} = 10$
$\sqrt{80} = 8.94 = 9$
$\sqrt{50} = 7.07 = 7$

Factors - DO NOT ROUND

Example: Smooth bore tip of 7/8"= 0.875 DO NOT ROUND THIS TO 100th
Example: Elevation loss/gain= 0.434 per 1' DO NOT ROUND THIS TO 100^{th}
Example: Smooth bore tip of 15/16"= 0.9375 DO NOT ROUND THIS TO 100^{th}

GRAVITY GAIN/LOSS

For the written exam only, when calculating gravity gain or loss, use **.434 PSI** per 1 foot for calculations. **DO NOT** round up to 0.5.

ROUNDING GPM

When using 30 x d2x V NP = GPM to determine GPM of a smooth bore tip. Assuming you have converter your GPM to 2 ½" equivalent, round it to the nearest 100th. See example #1 below:

$30 \times \boldsymbol{d^2} \times \sqrt{NP} = GPM$

200' of 2 ½" handline with a 1 ¼" smooth bore tip

$30 \times (\mathbf{1.25})^2 \times 7$

1.25 x 1.25 = 1.5625 rounded to the nearest 100th = 1.56

30 x 1.56 = 46.80 (rounded to the nearest 100th)

46.80 x 7 = 327.60 GPM (rounded to the nearest 100th)

ROUNDING FRICTION LOSS RATE

When determining friction loss rate, round to the nearest 100th as you go.

Q = $\frac{GPM}{100}$

Continuing with example # 1 above:

Q = $\frac{327.60}{100}$ = 3.276 rounded to the nearest 100th = 3.28

FLR = $\mathbf{2(Q)^2}$

FLR = $\mathbf{2\ x\ (3.28)^2}$

3.28 x 3.28 = 10.7584 rounded to the nearest 100th = 10.76

2 x 10.76 = 21.5168 = rounded to the nearest 100th = 21.52

FLR = 21.52

ROUNDING PUMP PRESSURE

Now complete example # 1:

PP = NP (50) + FLR (21.52) x L (2)

PP = 50 + 43.04

PP = 93.04 (now round to the nearest whole number for your final answer)

PP = 93 psi (final answer)

EXAMPLE #2

350' of 2 ½" handline with a 7/8" smooth bore tip

$30 \times d^2 \times \sqrt{NP} = GPM$

$30 \times (0.875)^2 \times 7$

0.875 x 0.875= 0.765625 rounded to the nearest 100th = 0.77

30 x 0.77 = 23.10 (rounded to the nearest 100th)

23.10 x 7 = **161.70 GPM** (rounded to the nearest 100th)

$FLR = 2(Q)^2$ and $Q = \frac{GPM}{100}$

$Q = \frac{161.7}{100}$ = 1.617 rounded to the nearest 100th = 1.62

$FLR = 2 \times (1.62)^2$

1.62 x 1.62 = 2.6244 rounded to the nearest 100th = 2.62

2.62 x 2 = 5.24 (rounded to the nearest 100th)

FLR = 5.24

PP = NP (50) + FLR (5.24) x L (3.5)

PP = 50 + 18.34

PP = 68.34 (now round to the nearest whole number for your final answer)

PP = 68 psi (final answer)

DETERMINING CAPACITY OF WATER IN A CONTAINER

Page 29 of the FFDSD Hydraulics Manual states "for greater accuracy subtract 2 percent of the total." For the written exam, subtract 2 percent of the total gallons for the final answer.

NOZZLE REACTION

Page 32 of this FFDSD Hydraulics Manual shows two formulas for determining nozzle reaction. For the written exam use the following:

SMOOTH BORE TIP

NR = 1.5 X d^2 X NP

FOG NOZZLE

NR = GPM X $\sqrt{NP}$ X .0505

Notes: