Arcadia Fire Department

Hydraulics Manual

ARCADIA FIRE DEPARTMENT

Fireground Hydraulics Manual

Tables

Introduction

A. Purpose: To provide department personnel with a simple and accurate method for determining fireground hydraulics

B. Scope: These calculations will be used as guidelines by department members when determining fireground hydraulics.

Responsibility

All Engineers/ prospective shall study and review this Document in order to gain a working understanding of fireground hydraulics.
Note: All Engineers/ prospective shall also review their station library materials relative to fireground hydraulics, driving practices, aerial apparatus, safety as well as related Arcadia Fire Department and City of Arcadia documents to gain more detailed understanding of hydraulics in the fire service and the duties and responsibilities of the position of Engineer.

Foreword

Equipment operators must be able to compute required engine pressures within + or – 5 psi for any given hose lay. The method of determining calculations contained in this text are based on time tested, nationally recognized formulas. However, some formulas have been simplified and quantities rounded off for easy use. It shall be incumbent upon all Engineers/ prospective to study and review Documents such as Pumping Apparatus, Aerial Apparatus, Fire Stream Practices and water supplies published by the NFPA.

Fireground Hydraulics

The concept of fireground hydraulics has two fundamentally established formulas. Two facts must be obtained to initiate the use of this practice in fireground hydraulics.

1. Gallons of water per minute (GPM), to be used at the scene.
    a. The formula developed to ascertain the gallons per minute through a smooth orifice is $29.7 \times D^2 \times \sqrt{p} =$ GPM, which is the formula used in fireground hydraulics.
2. Friction loss (FL) involved in carrying the water to the desired location through the hose must be established.
    a. The formula used to determine friction loss in psi per hundred feet of 2 ½"is
    $FL= CQ^2L$

    FL= Friction loss
    C= F/L Coefficient
    Q= Flow rate in 100's of GPM
    L= Hose length in 100's of feet

This formula is only used when the gallonage is over 100 GPM.

Fifty pounds has been established as the desired nozzle pressure (NP) for hand line operations with smooth bore nozzles on all hose. There is no logical reason to use any other nozzle pressure on these smooth bore tips unless the officer in charge of a fire wishes to project a fire stream greater or lesser distance. Accepting this fact, the following smooth bore tips and nozzle pressures have been established as the standard for handlines.

Table I

Standard Smooth bore Hand line - Nozzle Pressure

Tip Size	Nozzle Pressure
1"	50
1 ⅛"	50
1 ¼"	50

By using this accepted and established formula for finding gallons per minute flowing through a smooth bore nozzle, take the 1” nozzle at 50 pounds nozzle pressure and established gallons per minute.

Example:

It has been established that 200 GPM is the gallonage for a 1” smooth bore tip at 50 pounds nozzle pressure. In continuing to find the friction loss for 200 gallons per minute, use the $FL = CQ^2L$ formula.
Example: $FL = CQ^2L$ $FL = (2)(2)^2 = 8$ PSI FL, or 8 pounds loss per 100' of 2 ½” hose for 200 gallons per minute.

By using the same pressure, calculate the gallonage and friction loss for 1⅛” and 1 ¼” smooth bore nozzle. Using the gallons per minute formula it is determined that the 1⅛” tip delivers 265 gallons per minute and 50 pounds nozzle pressure. The hydraulics is simplified by rounding off this figure to 250 gallons per minute. Using the friction loss formula, the friction loss per 100' of 2 ½” hose is calculated at 12.5 psi.

$$FL = CQ^2L \quad FL = (2)(2.5)^2 = 12.5 \text{ PSI FL}$$

The 1 ¼” smooth bore nozzle by calculation, delivers 326 gpm at 50 pounds nozzle pressure. Rounding this figure off to 325 gallons, the friction loss of 21 pounds per 100' of 2 ½” hose is calculated. By making additional calculations, 300 gpm equals 18 pounds friction loss, and 400 gpm equals 32 pounds friction loss. Placing these figures on a scale, various gallonage and friction losses can be interpolated.

Table II
Gallonage and friction loss

FL	3	4	5	6	8	12.5	18	21	25	32	50
GPM	120	135	150	175	200	250	300	325	350	400	500

Engine Pressure

When nozzle pressure and the friction loss are known, the pump discharge pressure (PDP) may be determined with the formula: PDP = NP + FL.
Four standard nozzles have been adopted for use on 2 ½” handlines, as shown in the following table.

Table III

Nozzle Size	GPM	NP	FL
1”	200	50	8
1 ⅛	250	50	12.5
1 ¼”	325	50	21
Fog Nozzle	250	100	13

*As long as the GPM remains the same, a fog nozzle which delivers 250 gallons per minute at 100 pounds nozzle pressure would have a related 12.5 pounds friction loss per 100' of 2 ½” hose.

Example:

Using the standard NP, calculate the pump discharge pressure for an engine company pumping through 500' of single 2 ½” hose with a 1 ⅛” tip nozzle at 50 pounds nozzle pressure.

Answer:

PDP =NP+ FL
NP= 50 psi
FL= CQ^2L
FL= $(2)(2.5)^2$ 5
FL= (2) (13) 5
FL= 62.5 (63)
NP + FL = 50 + 63
PDP= 113 psi EP

- For any fog nozzle 1 ½", 1 ¾" or 2 ½" hose lines, use 100 psi NP. Combination fog and straight stream nozzles have a pressure regulated automatically adjustable water flow to maintain effective pressure and constant fire stream.
- Fog nozzles currently used on Wildland hose (1" and 1 ½") use 100 psi NP.
- Handlines with smooth bore use 50psi
- Master Heavy Streams - Smooth Bore Nozzles - 80 Psi
- Master streams fog -100Psi

To be effective, heavy master stream appliances require pressure above those for handlines. Smooth bore nozzles for heavy master stream appliances range from 1 ¼" to 2". 80 psi NP has been established as the standard pressure. The discharge of these tips will be from 400 to 1000 gpm. (See table IV).

Table IV
Master Streams

Nozzle Size	GPM	NP
1 ¼"	400	80
1 ⅜"	500	80
1 ½"	600	80
1 ⅝"	700	80
1 ¾"	800	80
2"	1000	80

Note: The above chart indicates that, at 80 psi NP, each increase of ⅛" nozzle size increases the GPM by 100 gallons.

Heavy Master Stream Appliances

Throughout practical tests, the average friction loss calculation for 25 psi has been established as being the average loss by friction of water pressure entering a heavy master stream appliance, i.e., monitor, deluge set, cellar pipes, and ladder pipes is 25 psi.

Basic Formula for Multiple Lines

When two or more lines are used to supply water to a desired point or appliance, calculations are simplified by considering only the friction loss per 100' of one line. Each hose line will deliver an equal amount of water to the desired point because the pressure applied by the pump will equalize in each line.
When multiple lines are used to supply large volumes of water to heavymaster stream appliances, the engineer must know the total number of lines supplying the appliance, the length of the lines he is pumping into, and the size and/or type of tip being used. By knowing these factors, the engineer is able to determine GPM on the fireground. (see table IV).

Example:

Determine the PDP for an engine pumping 300' of dual 2 ½" hose into a monitor using a 1 ¾" tip.

Answer:

Table IV indicated that the 1 ¾" nozzle discharges 800 GPM at 80 psi NP. Divide the two lines into 800 GPM. Each line will supply 400 GPM. Friction loss for 400 GPM is 32 psi per 100' of 2 ½" hose.

To determine PDP for the problem, add the friction loss in the hose to the desired NP (80) and 25 psi for friction loss in the appliance.

PDP = NP + FL (Hose) FL (Appliance)
NP = 80 PSI
FL = CQ^2L
FL = $(2)(4)^2(3)$
FL = 96
FL = 25 PSI (Appliance)
PDP = 80 + 96 + 25
PDP = 201 EP

Note: Minimum pump capacity for this Example is 350 GPM. A I000 GPM pumper can supply 700 GPM at 200 psi EP. If a third line is added, the friction loss would be reduced to 14 psi per 100' of 2 ½" hose as each line would then supply approximately 266 GPM, instead of 400 GPM. It now would be possible to supply the problem using a 1000 GPM pumper. For fast mental calculations planning hose lays, the addition of a third line will cut the friction loss in half, thus allowing the pumper to supply the problem from twice the distance.

Siamese Or Wye

As previously mentioned, greater volumes of water cause more friction loss (heavy master stream appliance). Friction loss in the case where the total flow through the appliance is less than 350 GPM is generally considered to be insignificant and is not considered in this manual. For this manual, it is assumed that there is a 0 psi loss for flows less than 350 GPM and a 10Psi loss for each appliance (other than a heavy appliance) in a hose assembly when flowing 350 GPM or greater.
To solve for PDP where Siamese lines are used, the same principle used in heavy master stream is applied with one addition: the total gallonage is returned to one line and friction loss FL is calculated on this basis.

Example:

Determine the PDP for an engine pumping through 2 lines of 2 ½" hose, 400' in length connected by a Siamese and continued 100' to a 1 ¼" tip.

Answer:

PDP = NP + FL (Single) + *FL (Siamese) + FL (Dual)
NP = 50 PSI
FL = CQ^2L
FL = $(2)\ (3.25)^2$
FL = 21
FL = 0
FL = $(2)\ (1.625)^2\ (4)$
FL = 21
PDP = 50+21+21
PDP = 92
*Flow less than 350 GPM through an appliance = 0Psi FL

Head Pressure

When vertical distance, either above or below pumping equipment is involved, add or subtract 0.5 psi per foot for head pressure (HP). When water is pumped above or below grade in structures, add or subtract 5 psi for each story above or below the first floor.

Standpipe 25 Psi

While the actual friction loss under ordinary conditions in standpipe risers is almost negligible, there is a loss at the Siamese connection and at the outlet valve flowing to the fittings and reduction in flow area. For calculation purposes, an allowance of 25 psi friction loss in the standpipe is required

Example:

Determine the EP for an engine pumping through a single 2 ½" line, 300' in length, into a standpipe. 100' of 2 ½" hose is connected to the standpipe outlet on the fifth floor and advanced up the stairwell to the sixth floor. A 1 ⅛" tip is being used.
Combining the 300' of hose going into the standpipe with 100' attached to the standpipe outlet, there is a total of 400' of 2 ½" hose using a 1 ⅛" tip.

Referring to Table II, a 1 ⅛" tip nozzle requiring 50 psi NP and delivers 250 GPM and the friction loss is 12.5 psi per 100' of hose.

Next, find the PDP necessary to overcome the friction loss in the hose and provide 50 psi NP. To these figures, add the head pressure (HP = 5 psi per floor), and friction loss allowed for the standpipe connection (25 psi), which gives the PDP necessary to complete the problem.

Answer:

PDP	=	NP + HP + FL (Standpipe)
NP	=	50
FL	=	50(4 X 12.5) (Hose)
HP	=	25(5 X 5)(Head)
FL	=	25 (Standpipe)
PDP	=	50 + 50 + 25 + 25
PDP	=	150 EP

Note; when two or more lines are connected to the standpipe outlet above ground, determine which line requires the highest pressure and pump to that line.

Friction Loss Coefficients for Various Hose

In the previous pages, the simplified method of determining FL in 2 ½" hose using the basic formula has been described. To calculate FL in various sizes of hose using a friction loss Coefficient.

Table V

Friction Loss Coefficient Single Hose Lines	
1" Booster	150
1 ½"	24
1 ¾"	15.5
2 ½"	2
3" with 2 ½" couplings	0.8
4"	0.2

Coefficient for 4" = 0.2

Example:

500 gpm are being delivered through 4" hose.

FL = CQ^2L
FL = $(0.2)\ (5)^2$

Determine the PDP for an engine pumping through 400' of 4" hose wyed into two 2 ½" hose length's, 300' each with 1 ⅛" tips.

Answer:

To solve this problem, first determine the gpm being delivered, 500 gpm. (1 ⅛" tip = 250 gpm times two tips)

Using the basic FL formula, the FL is 5 psi per 100' 4" hose, or a loss of 20 psi in the 400' of 4". The balance of the problem is the same as previous solutions, i.e. 300' of 2 ½" hose with a 1 ⅛" tip = 37.5psi FL. The wye causes a 10 psi FL and the NP is 50 psi, for a total of 97.5 psi in the wyed lines. Adding the 20 psi loss in the 4" hose gives us a total of 117.5 psi.

PDP = FL(4") +FL(2 ½") + FL (Wye)+ NP
FL = $(0.2)\ (5)^2(4)$
20
FL = $(2)(2.5)^2(3)$
37.5
FL = 10 (Wye)
NP = 50

PDP = 20 + 37.5 + 10 + 50
PDP = 117.5 PDP

Wildland Friction Loss and Small Diameter Hose

Friction loss is the reduction of pressure caused by the friction of water moving through a hose. Friction loss is variable. It is influenced by the diameter of the hose, the smoothness of the hose lining, and the length of the hose lay and the volume of water moving through the hose. Friction causes a 24 psi loss in a 100 foot length of 1” and a 8 psi loss in a 100 foot length of 1 ½”hose (when flowing 40 gpm at 70 psi with a nozzle tip of 5/16”). The number and type of fittings and whether you are using foam or wet water will also impact friction loss. A gated wye and other commonly used fittings can add up to a 5 psi loss. General rules on friction loss (if all other factors remain constant) are:
The smaller the diameter of hose, the greater the friction loss will be. The longer the hose lay, the greater the friction loss. The more fittings in the hose lay, the greater the friction loss.

Table VI
Wildland nozzles

Friction loss 1” Hose

Type	GPM	FL Per 100’	Nozzle Pressure
Fog	42	26	100
Bubble Cup	10/40	24	100

Friction loss 1 ½” Hose

Type	GPM	FL Per 100’	Nozzle Pressure
Fog	125	37.5	100
½” Smooth Bore	50	6	50

Appliance

Wye	5 psi
Tee	5 psi

1" Booster Hose

The coefficient of 150 will be used. The same procedure is used as in the previous conversion problems.

Example:

Determine the PDP for an engine pumping through 200' of 1" Booster hose, with a Bubble Cup nozzle at 100 psi NP.

FL = CQ^2L
FL = $(150)(.4)^2(2)$
FL = 48
PDP = 48+100
PDP = 148

Pump Capabilities

A 1500gpm pump is rated on its ability to discharge its rated capacity, operating at draft with vertical lift not over 10 feet, at a net pump discharge pressure of 150 psi. Also, the pump must discharge 70% or the rated capacity at 200 psi and 50% of its rated capacity at 250 psi. In efficient pumper utilization, pump capacities at various pressures is the first factor that a pump operator must understand.
The maximum working pressure of 250 psi has been established by our department and, from a practical standpoint, some reserve capacity should always be maintained on the fireground. A reserve of 50 psi is desirable for changes in elevation or other provisions; therefore, 200 psi should be considered as the maximum working pressure.

Hose Lays -Short, Medium And Long

To determine the maximum length of a hose lay that can be used with any of the three basic smooth bore nozzles for handlines, i.e., I", 1 ⅛" and 1 ¼", start with a net working pressure of 200 psi. Allowing the standard 50 psi for nozzle pressure on handlines, this leaves an available working pressure of 150 psi to overcome FL.

Short Lay

A short lay would be the maximum length of hose that would supply a 1 ¼" nozzle delivering 325 gpm at 50 psi NP. FL of 21 psi per 100' of 2 ½" hose. Deducting 50 psi NP from the net working pressure of 200 psi leaves an available 150 psi which will be used to overcome friction loss in the hose lay. If the available working pressure of 150 psi is divided by the friction loss (21 psi) per 100' for the gallons per minute delivered, we have 150 divided by 21 = 7, or 700'. This is the maximum length of 2 ½" hose for a 1 ¼" nozzle delivering 325 gpm at 50 psi NP.

Medium Lay

A medium lay is the maximum length of hose that will supply a 1 ⅛" nozzle delivering 250 gpm. The available working pressure of 150 psi is divided by the FL (13.5 psi) per 100' for the gpm delivered or 150 divided by 13.5 = .11 or 1100'.

Long Lay

A long lay is the maximum length of hose that would supply a 1" nozzle delivering 200 gpm. The available working pressure of 150 psi is divided by the FL (8 psi) per 100' for the gpm delivered, or 150 divided by 8 = 18.75, or 1875'.

Table VII

EP	Hose	2 ½" hose	Tip	GPM	FL	NP
200	Short	700'	1 ¼"	325	21	50
200	Medium	1100'	1 ⅛"	250	13.5	50
200	Long	1875'	1"	200	8	50

Relay Pumping

When establishing relay operations, unlike maximum hose lays for single pumpers, the following items must be considered in making an efficient relay operation

1. GPM needed at the fire ground
2. The distance water must travel from the source
3. Size of the hose
4. Maximum distance one pumper can deliver the gpm
5. Number of pumpers needed
6. Topography

The largest capacity pumper should be placed at the source of supply and ensuing pumpers should be placed so that the smallest pumper will be at the fire. This arrangement enables you to have the maximum pumping capabilities with the equipment available for any condition that may arise.

The maximum distance water can be delivered is accomplished in three ways

1. Increase the size of the hose
2. Add additional lines
3. Use additional pumpers

The Engineer at the source (hydrant) will complete a full hydrant hook-up using the one of the 4" intakes or if needed a 2 ½" inlet. Any time a pump is connected to a hydrant, and when water is being used from said hydrant, engineers shall pump a minimum of 100 lbs. engine pressure. This will ensure a minimum flow of water to the fire under all situations**.** The source engineer will calculate the required engine pressure based upon the total GPM's known. Once the total GPM's are known the source engineer will calculate the friction loss plus 25 lbs and make the appropriate adjustments.

Example:

250 gpm's are needed to supply a 1 1/8" nozzle 4200' from the source of supply. Using a single 2 ½" hose for relaying, we have a FL of 13 psi per 100', or a total of 546 psi (13 x42). This, plus a NP of 50 psi, equals 596 psi. To determine the number of pumpers, divide 596 by the available working pressure of 175 (200 psi net less 25 psi IP), which equals 3.4, required gpm, or 4 pumpers. Now, the distance between pumpers and the engine pressure required for each pumper can be determined.

Step 1

The distance between pumpers is calculated by dividing the 175 psi of available pressure by 13 psi FL per 100'; 175 divided by 13 = 13.46 or 1350' between pumpers.

Step 2

Pumpers A, B, C			Pumper D		
PDP	=	FL + IP	EP	=	NP + FL
FL	=	175 (13 13.5)	FL	=	20 (13 X1.5)
IP	=	25	NP	=	50
PDP	=	175 + 25	PDP	=	20 + 50
PDP	=	200	PDP	=	70

If elevation had been involved in the above problem, either above or below the pumpers, head pressure would cause a need for an increase or decrease in the EP.

Aerial Ladder Streams

Aerial ladder companies use 100' of 3” hose up the ladder to the appliance. Quick Calculations with the ladder at 75' elevation using a metropolitan valve are shown in Table Vllll.

Note: The table below indicates that for each 100 gpm increase the pressure required at the base of the ladder will increase 5 psi.

Table VIII

Nozzle Size	GPM	Pressure at Base
1 ⅜”	500	145
1 ½ ”	600	150
1 ⅝"	700	155
1 ¾”	800	160
2”	1000	170
Fog	500	165

Fog	700	175
Fog	1000	190

Estimated Available Flow From Hydrants

This method of calculating the flow (GPM) available from a fire hydrant is of value to both the pump operator and the commanding officer.
Available water flow on the fireground is calculated by testing and noting the static pressure (water at rest) and the residual pressure (water in motion) of fire hydrants. To estimate the available flow from a hydrant, the rule is to determine the percentage drop in pressure from static to residual.
This percentage drop indicates the additional flow available. A drop of 10% or less indicates an availability of 3 like volumes. An 11% to 15% drop indicates two more like volumes. A 16% to 25% drop indicates that only one more like volume can be handled.

1% to 10%	=	3 like volumes
11% to 15%	=	2 like volumes
16% to 25%	=	1 like volumes

Example:

The pumper is connected to the hydrant and the suction is charged. Before opening the discharge gate, the operator notes the static pressure is 60 psi the operator then opens the discharge supplying a 250 gpm fog nozzle. The residual pressure now shows on the compound gauge is 51 psi, a drop of nine pounds. This is a 15% drop in pressure and means that the hydrant can supply an additional 500 gpm.

Solution:

With a decrease from static to residual pressure of 9 psi, the percentage of drop is 9/60, or 15%, therefore, two more like volumes is the estimated available flow, or a total estimated flow of three like volumes

Estimated Flow From A Hydrant with a Line In Operation

If the static pressure was not noted when the hydrant was opened, and it is required in order to estimate the available flow, this can be determined as follows;

1. Note the residual pressure on the compound gauge with the first line in operation.
2. Place a test nozzle delivering the same gpm into operation and note the drop in residual pressure.
3. Divide the drop in pressure by 2 and add to the residual pressure which was noted when the first line was in operation. This will enable you to estimate the static pressure.

Example

With the first line in operation, the residual pressure on the compound gauge is 68 psi. A test nozzle delivering the same gpm is placed into operation and the residual pressure on the compound gauge is now 44 psi. Estimate the remaining available flow.

Solution:

To estimate the static pressure with a decrease in residual pressure of 24 psi (68 - 44), divide 24 by 2 which equals 12 psi. This is to be added to the residual pressure which was noted when the first line was in operation. Combining 68 + 12 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 - 68), the percentage of drop is 12/80 or '15%; therefore, two or more like volumes is the estimated available flow, or a total estimated flow of 3 like volumes.

Automatic Sprinkler Systems

When using an automatic sprinkler system, an engine company shall lay a minimum of one 2 ½" hose line to the sprinkler connection inlet and maintain an engine pressure of 150 psi. If one line is not sufficient to obtain this engine pressure, additional lines must be laid into the system until 150 psi engine pressure can be maintained. The minimum gallonage for efficient coverage by a sprinkler head is 15 gpm and most authorities agree that the minimum acceptable efficient range is 15 to 25 gpm.

Weight of Water Delivered

It is necessary to know that a standard fire stream 250 gpm represents approximately one ton of water per minute being delivered into a building Consideration must be given to safety of personnel due to the possibility of structural collapse, and provisions for the release of water from a building is imperative. Below is a table relating the size of nozzle to the appropriate tons of water being delivered per minute.

Table VIIII

Weight of Water Delivered

Nozzle	GPM being delivered
1 1/8”	1 ton
1 3/8”	2 tons
1 5/8	3 tons
2”	4 tons

Capacity of Cylindrical Tanks

During fire or other emergencies, when rapid calculations must be made to find the capacity or amount of water in a cylindrical tank and the dimensions are in feet, the following formula may be used; $Q = 6D^2 \times H$, where Q equals quantity in gallons; D equals diameter in feet; and H equals height of the water in feet.

Example:

A tank 20' in diameter has 5' of water in it. Determine the gallons of water in the tank.

Solution:

$$Q = 6D^2 X H$$
$$Q = 6 (20) X 5$$

$$Q = 6\,(400) \times 5$$
$$Q = 2400 \times 5$$
$$Q = 12{,}000 \text{ gallons}$$

For greater accuracy, subtract 2% (.02) from the above answer, (12,000 x .02 = 240), which equals 11,760 gallons. This answer approximates the NFPA gallonage tables for cylindrical tanks.