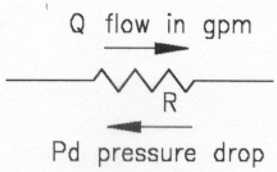
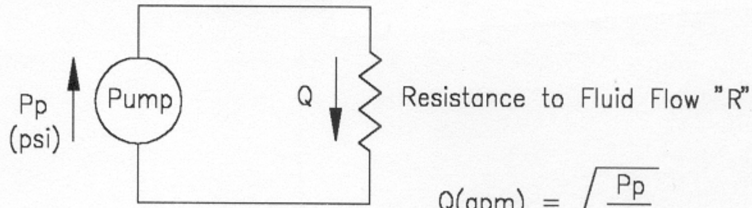
OHM'S LAW FOR FLUIDS

How to calculate flow using Ohm's Law for Water



$$Pd = Q^2 R$$



$$Q(\text{gpm}) = \sqrt{\frac{Pp}{R}}$$

BASIC LAW – Pressure Drop equals the Resistance times the square of the flow (R x gpm x gpm)

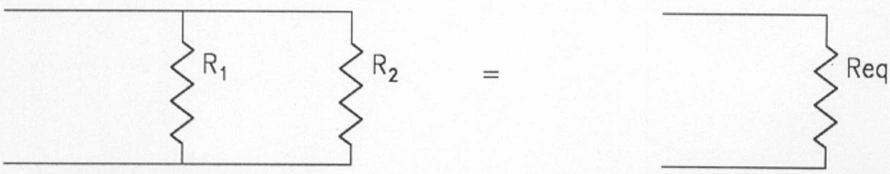
EXAMPLE – Pump supplying water at Pp psi forcing water to flow through a resistance of R fluid ohms. Resistance can be hose friction, a nozzle, or both.

SIMPLIFY all problems into the form shown above – one pressure source and one resistance. Divide the pressure (psi) by the resistance and take the square root to get gallons per minute.

HOW TO SIMPLIFY WATER CIRCUITS – TWO CASES – SERIES AND PARALLEL

RESISTANCES IN SERIES

Add them together $Req = Rh + Rn$



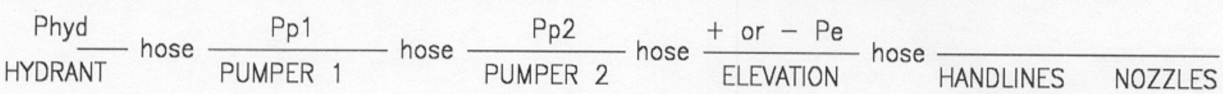
RESISTANCES IN PARALLEL

A little trickier – be careful with your arithmetic

The equivalent fluid resistance $Req = \left(\dfrac{\sqrt{R_1}\,\sqrt{R_2}}{\sqrt{R_1} + \sqrt{R_2}} \right)^2$

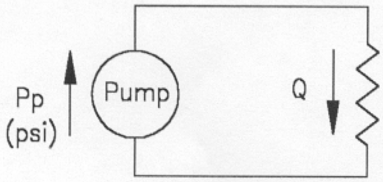
This is similar to electrical resistances in parallel, except that the square root of each resistance is used, and the result is squared.

PUMPS AND PRESSURE SOURCES – If Pumps and other sources of pressure are all part of a single loop, simply add (or subtract) their values to get the equivalent total pressure.
Example: a hydrant supplying a pumper supplying 4 inch lines supplying handlines with nozzles.



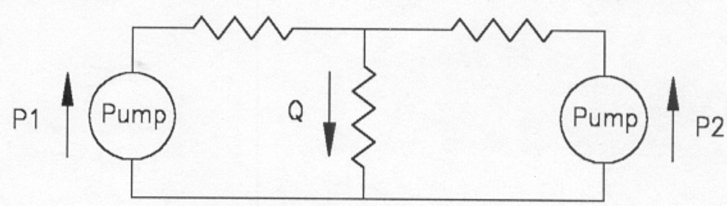
Total pressure sources equals Phyd plus Pp1 plus Pp2 plus or minus Pe (plus if pumping downhill and minus if pumping uphill). Total resistance equals the sum of all the resistances between (and including) the hydrant and the nozzle (hydrant, pumps, hoses, nozzle).

NOTE – Ohm's Law is not as useful working with loops which have individual pressure sources feeding a common resistance. Water equations are non–linear and some common electrical techniques such as the Thevenin / Norton theorems don't work.



EASY TO SOLVE

(After you reduce any series and parallel resistances and add up any series pumps)



DIRECT SOLUTION IS NOT EASY

Use a computer program or set up a trial and error solution on a spreadsheet (This would be an easy electrical problem but squaring the water flow complicates it)

RESISTANCE VALUES FOR 100 FEET OF COMMON HOSE

Hose Diameter (inches)	Hose Resistance Rh (Fluid Ohms)	Hose Diameter (inches)	Hose Resistance Rh (Fluid Ohms)
1-1/2	0.0024	3 (w. 3" cplg)	0.0000667
1-3/4	0.00155	3-1/2	0.000034
2	0.0008	4	0.000020
2-1/2	0.0002	5	0.000008
3 (w. 2.5" cplg)	0.00008	6	0.000005

The Hose Resistance Rh is simply C/10000 where C is the Hose Loss Coefficient given on EK's FRICTION LOSS AND NOZZLE FLOW CALCULATOR

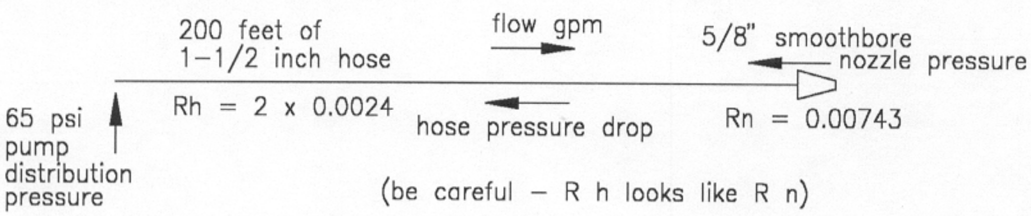
RESISTANCE VALUES FOR COMMON NOZZLES

Nozzle Diameter (inches)	Nozzle Resistance Rn (Fluid Ohms)	Nozzle Diameter (inches)	Nozzle Resistance Rn (Fluid Ohms)
1/2	0.0184	15/16	0.001468
5/8	0.007430	1	0.001134
0.71	0.004461	1-1/8	0.0007078
3/4	0.003583	1-1/4	0.0004644
7/8	0.001934	1-3/8	0.0003172

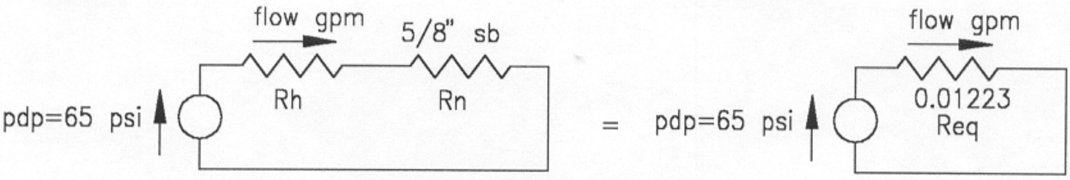
Here is the formula: $Rn = \dfrac{1}{(29.7 * d^2)^2}$ in case you want to calculate other sizes. d is the diameter in inches

There are two different ways to think of nozzle pressure – one way is to picture the nozzle pressure driving the water out of the nozzle, but another way which works is to picture the nozzle pressure as the pressure drop which occurs as water is forced through the nozzle, like hose friction loss. This second view is not completely correct, in that hose friction loss is energy lost and you don't get it back, while the pressure drop in a nozzle represents energy transformed into a different kind (velocity), and it's still in the water leaving the nozzle. For calculating flow, the nozzle "resistance" works like hose resistance. It also works for calculating energy changes, but it's up to you to keep track of what happens to that energy.

EXAMPLE 1 Pump at 65 psi, 200 feet of 1-1/2 inch hose, 5/8 inch smoothbore



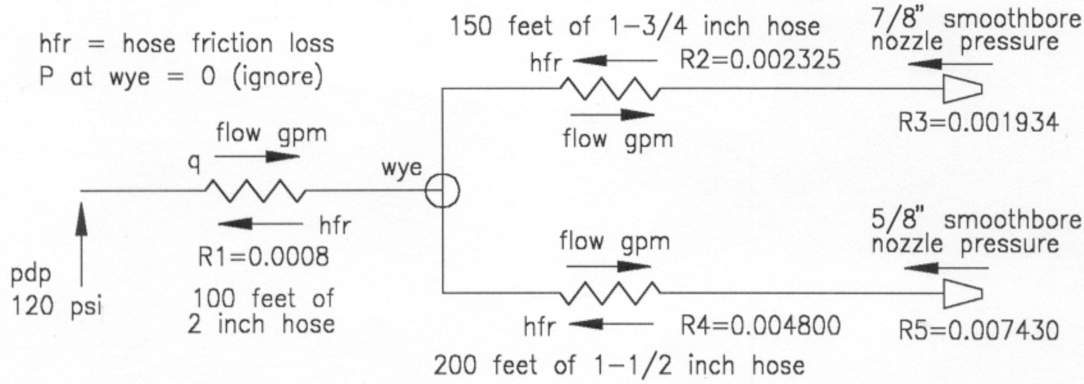
(be careful – R h looks like R n)



SOLUTION Req = Rh + Rn = 2 x 0.0024 + 0.00743 = 0.0048 + 0.00743 = 0.01223

$$Q(gpm) = \sqrt{\frac{pdp}{R}} = \sqrt{\frac{65}{0.01223}} = 72.9 \text{ gpm}$$

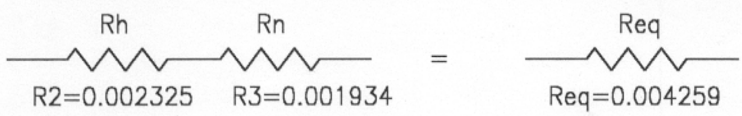
EXAMPLE 2a Calculate flow in gpm for one 2 inch hose feeding two smaller handlines.



Note that two of the hose resistances are already scaled up from their 100 foot values.

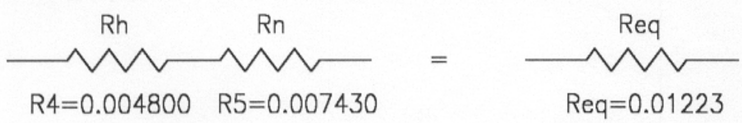
Ohm's Law gives a direct solution which is not difficult once you know how. You need good bookkeeping skills and some practice to make the numbers come out right.

STEP 1 Add the hose resistance and the nozzle resistance together to give an equivlent single resistance for the 1-3/4 inch hose with 7/8 nozzle.



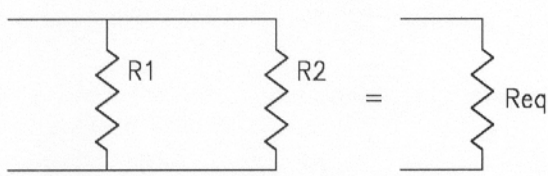
$$Req = Rh + Rn$$

STEP 2 Add the hose resistance and the nozzle resistance together to give an equivalent single resistance for the 1-1/2 inch hose with 5/8 nozzle.



$$Req = Rh + Rn$$

STEP 3 Convert the two equivalent resistances from Step 1 and Step 2 (they are in parallel) into a single equivalent resistance.



RESISTANCES IN PARALLEL

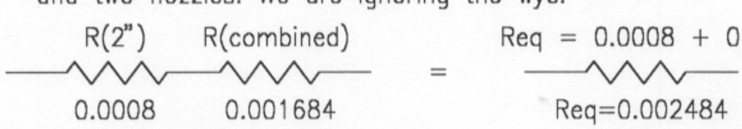
$$Req = \left(\frac{\sqrt{R_1}\,\sqrt{R_2}}{\sqrt{R_1} + \sqrt{R_2}} \right)^2$$

where R1=0.004259
R2=0.01223

Req=0.001684

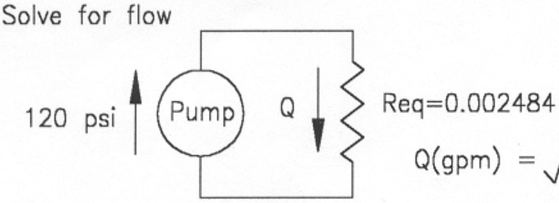
Note – the arithmetic is shown in more detail in Example 2b

STEP 4 Add the resistance calculated in Step 3 to the resistance of the 2 inch hose to give one single equivalent resistance for the combination of the three hoses and two nozzles. We are ignoring the wye.



$$Req = 0.0008 + 0.001684$$

STEP 5 Solve for flow



Req = equivalent resistance of all hoses and nozzles combined

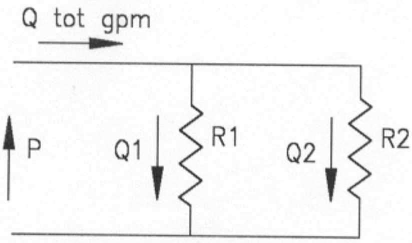
$$Q(\text{gpm}) = \sqrt{\frac{P}{R}} = \sqrt{\frac{120}{0.002484}} = 219.8 \text{ gpm}$$

EXAMPLE 2b Calculate the flow in in the individual hoses.

SOLUTION We have just found the total flow (219.8 gpm) and we know that all of it flows through the 2 inch hose. Now we need to see how it divides up between the 1-3/4 hose and the 1-1/2 hose.

FLOW DIVIDES between two parallel resistances based on how the resistances of the paths compare to each other. The formula uses square roots.

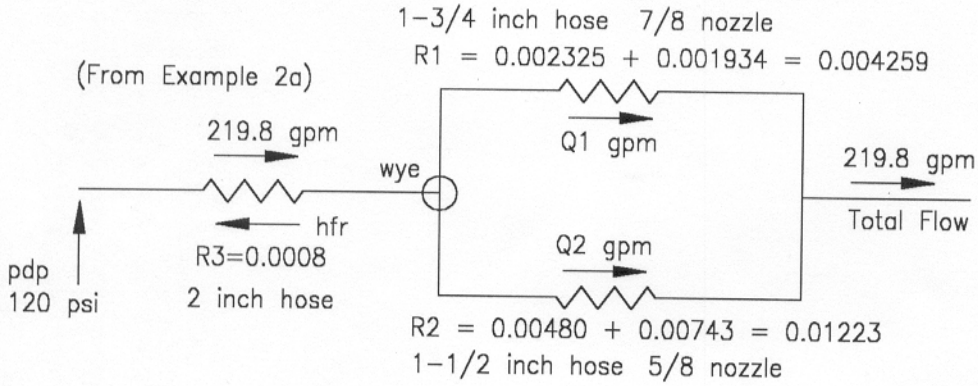
Q tot is the total flow so Q tot = Q1 + Q2



How Flow Divides (General Case)

$$\text{Q1 flowing in R1} = \frac{\sqrt{R2}}{\sqrt{R1} + \sqrt{R2}} \times \text{Q tot}$$

$$\text{Q2 flowing in R2} = \frac{\sqrt{R1}}{\sqrt{R1} + \sqrt{R2}} \times \text{Q tot}$$



$$\text{Q1 in 1-3/4} = \frac{\sqrt{R2}}{\sqrt{R1} + \sqrt{R2}} \times \underset{\text{gpm}}{219.8} = \frac{\sqrt{0.01223}}{\sqrt{0.004259} + \sqrt{0.01223}} \times 219.8$$

and

$$\text{Q2 in 1-1/2} = \frac{\sqrt{R1}}{\sqrt{R1} + \sqrt{R2}} \times \underset{\text{gpm}}{219.8} = \frac{\sqrt{0.004259}}{\sqrt{0.004259} + \sqrt{0.01223}} \times 219.8$$

here's the arithmetic:

$\sqrt{0.01223} = 0.11059$ and $\sqrt{0.004259} = 0.06526$

so $\sqrt{0.004259} + \sqrt{0.01223} = 0.17585$

$$\text{Q1 in 1-3/4} = \frac{0.11059}{0.17585} \times 219.8 = 138.23 \text{ gpm}$$

$$\text{Q2 in 1-1/2} = \frac{0.06526}{0.17585} \times 219.8 = 81.57 \text{ gpm}$$

As a check 138.23 + 81.57 = 219.8 gpm as it should

EXAMPLE 2c Calculate the pressure at each nozzle and at the wye.

SOLUTION We're going to do this three different ways, just for practice. None of them are hard, but the first is the easiest. We already know the flow in each of the three hoses.

THE EASIEST WAY – Use EK's Friction Loss and Nozzle Flow Calculator. We already know the flows, and the chart eliminates almost all the remaining calculations. We're ignoring drop in the wye.

Chart Step 1 – Find the pressure at the wye. Draw a line between the 2 inch hose mark and the 220 gpm line – read off hose friction loss of (say) 39 psi per 100 ft of hose. Our 2 inch is 100 ft long, so its friction loss is 39 psi. Subtract 39 psi from 120 psi to give 81 psi at the wye.

Chart Step 2 – Find the pressure at the 5/8 smoothbore, which we already know is flowing 81.57 (say 82) gpm. Draw a line between the 5/8 nozzle point and the (about) 82 gpm point on the flow rate scale, extending the line out to the nozzle psi scale, and read about 51 psi.

Chart Step 3 – Find the pressure at the 7/8 smoothbore, which we already know is flowing 138.23 (say 138) gpm. Draw a line between the 7/8 nozzle point and the (about) 138 gpm point on the flow rate scale, out to the nozzle psi scale, and read about 36 psi.

NOW – Let's do it with numbers. We know the flow, so it's easy to work out the pressures.

Numbers Step 1 – Find the pressure at the wye. The pressure drop in the 2 inch hose equals the SQUARE of the gpm times the Resistance of the 2 inch.

2 inch hose P drop = 219.8 x 219.8 x 0.0008 = 38.65 psi drop

The pressure at the wye is the pump pressure minus the drop along the hose, so the pressure at the wye is 120 – 38.65 = 81.35 psi

Numbers Step 2 – Find the pressure at the 7/8 nozzle. The pressure outside the nozzle, in the air, is 0 psi, so the pressure drop across the nozzle (outside to inside) is the "nozzle pressure". We know the flow in the 7/8 nozzle is 138.23 gpm, so the square of the flow times the nozzle resistance gives the pressure drop.

7/8 nozzle P drop = 138.23 x 138.23 x 0.001934 = 36.95 psi inside the nozzle

Numbers Step 3 – Find the pressure at the 5/8 nozzle. The pressure outside the nozzle, in the air, is 0 psi, so the pressure drop across the nozzle (outside to inside) is the "nozzle pressure". We know the flow in the 5/8 nozzle is 81.57 gpm, so the square of the flow times the nozzle resistance gives the pressure drop.

5/8 nozzle P drop = 81.57 x 81.57 x 0.00743 = 49.44 psi inside the nozzle

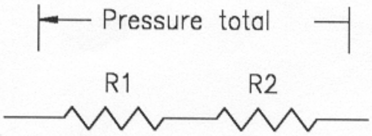
The nozzle pressures could also be found by calculating the friction losses in the hoses and subtracting them from the pressure at the wye. Using the nozzle resistance to calculate nozzle pressure directly has the advantage of possibly surprising you, besides being quicker.

FINALLY – Let's find the pressure at the wye and at the two nozzles without using the flow. We already know the flow, but let's pretend that we don't. Ohm's Law lets us find the three pressures without calculating flow. All we need are resistances and pump pressure.

Ohm's Law Step 1 – Find the pressure at the wye. We need 3 things: the pump pressure, the resistance of the 2 inch line, and the equivalent resistance of the parallel combination of the 1-3/4 with its 7/8 nozzle and the 1-1/2 with its 5/8 nozzle.

This is easier to do than it is to describe. As is so often the case, the best place to begin is to draw a simple diagram.

The pump pressure is 120 psi, and we worked out the resistances in Example 1a. We'll just copy them into our little sketch.



How Pressure Divides (General Case)

The pressure across R1 is $\dfrac{R1}{R1 + R2} \times$ Pressure total

The pressure across R2 is $\dfrac{R2}{R1 + R2} \times$ Pressure total

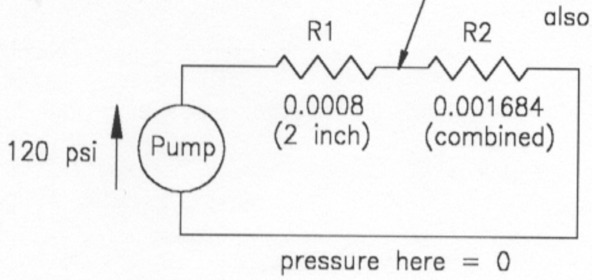
In fact, this same thing works for any number of resistances in series – the pressure across any one of them is the ratio of that one resistance to the total series resistance, multiplied by the total pressure. The ratio of resistances is like working with percentages – the ratio gives you the fraction of the total pressure.

The interesting point is that you don't need to know the flow to see how the pressure divides. Pressure division across series resistances without calculating the flow is analogous to flow division between parallel resistances (Example 2b) without calculating the pressure.

Here are the resistance values worked out in Example 2a, Step 4. The 2 inch hose has a resistance of 0.0008 and the equivalent resistance of the combined two smaller parallel hoses with their nozzles is 0.001684

AT THE WYE

The wye is here. The pressure at the wye is also the pressure across R2.



$$P\ \text{wye} = Pr2 = \frac{R2}{R1 + R2} \times \text{Pressure pump}$$

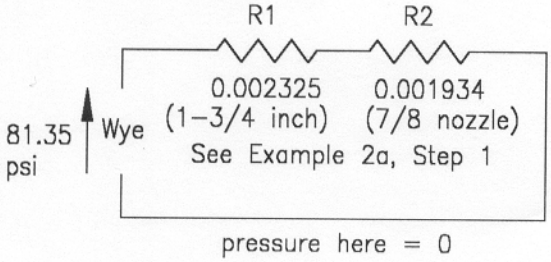
$$= \frac{0.001684}{0.0008 + 0.001684} \times 120 = 81.35\ \text{psi}$$

Note that series pressure division doesn't need square roots. Also, R2 is in the numerator when you want the pressure across R2.

Next, we'll work out nozzle pressures, using the pressure at the wye as our "total pressure"

AT THE 7/8 SMOOTHBORE

The pressure across R2 is the 7/8 inch nozzle pressure.

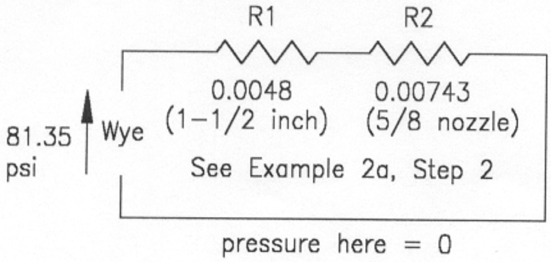


$$Pr2 = \frac{R2}{R1 + R2} \times \text{Pressure wye}$$

$$= \frac{0.001934}{0.002325 + 0.001934} \times 81.35 = 36.94\ \text{psi}$$

AT THE 5/8 SMOOTHBORE

The pressure across R2 is the 5/8 inch nozzle pressure.



$$Pr2 = \frac{R2}{R1 + R2} \times \text{Pressure wye}$$

$$= \frac{0.00743}{0.0048 + 0.00743} \times 81.35 = 49.42\ \text{psi}$$

TALKING ABOUT POWER – A FIRST PASS (Without Numbers)

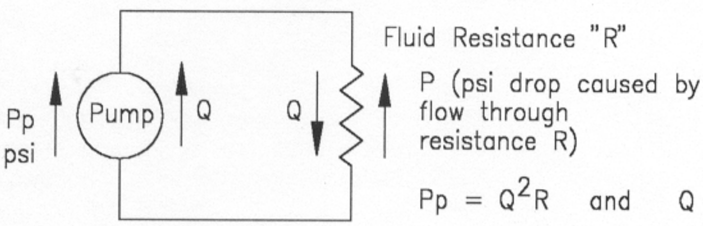
POWER – Power is the rate at which energy is generated or used, in terms of Energy per Unit of Time. Power is to Energy what Speed is to Distance (Foot Pounds per Second, Miles per Hour). Three common ways to describe Power are foot–pounds per second, Horsepower and Watts. You can use whichever term you want. They all describe the same thing – the only difference is the number – but Horsepower is commonly used to describe mechanical power and Watts is commonly used to describe electrical power. You could ask for a 1/10 hp light bulb or a car with a 100 kilowatt gasoline engine. You'd be accurate, but no one would understand you.

When you are working with Water, the units of foot pounds per second or horsepower are commonly used. We will use them too, but we will also borrow the term "Watts" from electrical practice, because in many cases it's a lot easier to calculate with watts, and then convert to horsepower at the end.

Solving water problems using Ohm's Law for Water, lets you do several things. You can solve for flow and pressure, but you can also solve for power. In addition, you can manipulate circuit elements, like adding series resistances or combining parallel resistances, to simplify a problem.

$$HP = \frac{GPM \times PSI}{1714.55}$$

This is the basic formula – if you know the gpm and the psi, just go ahead and calculate the horsepower. The catch is that you don't always know their values, and in these cases it's easier to work with fluid watts.



$$Pp = Q^2R \quad \text{and} \quad Q = \sqrt{\frac{Pp}{R}}$$

We can substitute these terms into the HP expression.

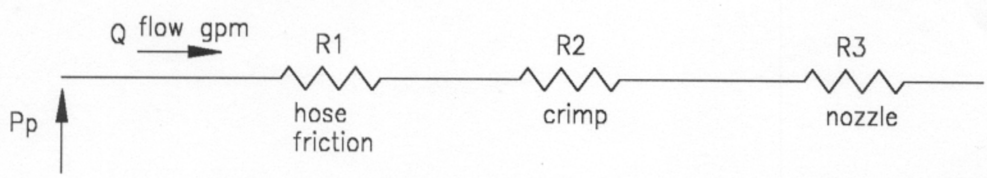
$$HP = \frac{\sqrt{\frac{Pp}{R}} \times PSI}{1714.55} = \frac{\sqrt{\frac{P^3}{R}}}{1714.55}$$

For HP in terms of Pressure and Resistance

$$HP = \frac{GPM \times Q^2R}{1714.55} = \frac{Q^3R}{1714.55}$$

For HP in terms of Flow and Resistance

Let's look at crimps in a hoseline. Do they matter?



Suppose that you are pumping exactly the amount of water you want, using exactly the amount of pump pressure you want, and that there is no crimp. The hose resistance is fixed – it is what it is, and the same goes for the nozzle. If there is no crimp in the hose, the crimp resistance R2 is zero. This means that whatever amount of water is flowing is determined only by the pump pressure and the two resistances R1 and R3.

Here's what is happening. For this amount of flow, the pump must supply a certain amount of pressure which depends on the sum of the two resistances, R1 and R3. It's that simple. Now add a crimp to the hose which increases the total resistance by 20 percent.

If you increase the total resistance by 20 percent, then to maintain the same flow, you also have to increase the pump pressure by 20 percent. But, and this is important, when the pump pressure goes up 20 percent, then for the same flow, the horsepower also goes up 20 percent. Truck mounted pumps usually have pressure and horsepower to spare. But how do things work with a portable pump which is limited in both pressure and horsepower? We'll soon see.

Now lets add some numbers.

HORSEPOWER CALCULATIONS USING FLUID WATTS.

THE BASICS $HP = \frac{GPM \times PSI}{1714.55}$ It takes power to make water flow under pressure. The higher the gallons per minute, the more the power. The higher the pressure, the more the power.

For example, a pump which adds 90 psi to a flow of 125 gpm requires 6.56 horsepower to drive the pump, which then puts that 6.56 horsepower into the water flow. This assumes that the pump has no losses of any kind – in other words that it is 100% efficient. Pumps are not that efficient. In addition, they are normally driven by a motor rated higher than the pump's horsepower, although the motor actually delivers only the power which the pump demands.

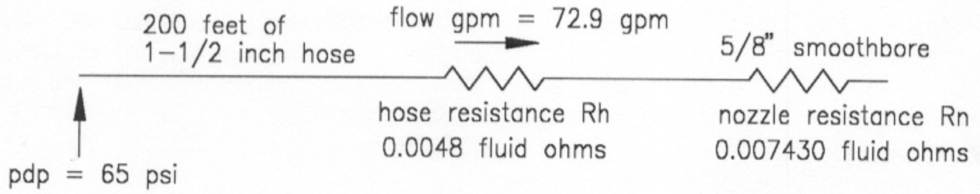
The HP formula given above is basic, but it's not always the easiest formula to use.

We can get the same information from circuit diagrams with very little extra effort beyond that which we have already put into solving the circuit. We can also see at a glance where our power is being used. The trick is to work with what we call fluid watts, where 1 Fluid Watt equals 1 gpm pressurized by 1 psi. 1714.55 fluid watts equals one horsepower.

This lets us work with resistance values, and allows us to work directly with various combinations of pressure (psi), flow (gpm), and resistance (fluid ohms) without having to convert all our units into psi and gpm. Here are some formulas.

$HP = \frac{GPM \times PSI}{1714.55}$	This one is basic – if you know the gpm and the psi, just go ahead and calculate the horsepower.
$Wf = Q \times P$	Fluid Watts = Gpm x Psi
$Wf = Q^3R$	Remember that $P = Q^2R$ where Q is in gpm
$Wf = P\sqrt{\frac{P}{R}} = \sqrt{\frac{P^3}{R}}$	As you see, we can calculate Hp in many different ways.
$HP = Wf/1714.55$	Divide Fluid Watts by 1714.55 to get Horsepower
$Wf = Hp \times 1714.55$	Multiply Hp by 1714.55 to get Fluid Watts

Let's calculate some power, starting with a simple handline fed from a pumper.



$Rt = 0.0048 + 0.00743 = 0.01223$ $\quad$ $Flow = \sqrt{\frac{65}{0.01223}} = 72.9$ gpm

Total Pressure = 65 psi (we'll assume that the pump supplies all this pressure, by pumping from its tank. If we were pumping from a hydrant which was supplying 60 psi, the pump would only have to supply 5 psi, and the horsepower used by (and required by) the pump would be only 5/65 of what we calculate.

Total Fluid Watts = = P x Q = 65 psi x 72.9 gpm = 4739 Fluid Watts
or 4739/1714.55 = 2.76 Hp

The power used by the Nozzle is Q^3R or $(72.9)^3 \times 0.00743 = 2879$ fluid watts
or 2879/1714.55 = 1.68 Hp.

The power used by the Hose is Q^3R or $(72.9)^3 \times 0.0048 = 1860$ fluid watts
or 1860/1714.55 = 1.08 Hp. (Note that 1.68 and 1.08 add up to 2.76 as they should.)

All our examples so far have included nozzles. The next example, though, pumps water through a hose which does not have a nozzle. If we use a hose which has no friction, and a pump which has no internal resistance at all, how much water will flow under a given pressure head?

Let's take 200 feet of 1–1/2 inch hose which has absolutely no friction whatsoever, and pump water with a pump with absolutely no friction in it, and which does not have a nozzle on its end, then how much water flow through the hose? If we try to plug in numbers for the pressure and the resistance, we find that we end up trying to divide by 0 which gives an infinite flow, and is obviously wrong. What should we do? Read on.

THE VIRTUAL NOZZLE

We need to include a resistance to tell our formula that the hose is 1–1/2 inches in diameter. Bernoulli's Equation, which describes the flow of water in great detail, is often introduced with a picture of a tank full of water. There's a hole in the tank and water squirts out the hole. The amount of water coming out the hole is shown to depend on the head of water above the hole and on the size of the hole. We will examine Bernoulli's Equation in another section, but for now here is the important point.

In our model, the pump represents the pressure head, and the virtual nozzle represents the hole in the tank. When connected to a hose, the diameter of the virtual nozzle is exactly the diameter of the hose. The resistance of the virtual nozzle is exactly the resistance of a regular smoothbore nozzle of the same diameter.

The Resistance Values for Common Nozzles are already given in the earlier table, but the table only goes up to 1–3/8 inch. We have to use the formula given below the table to calculate larger diameters. Here are the results for three hose sizes.

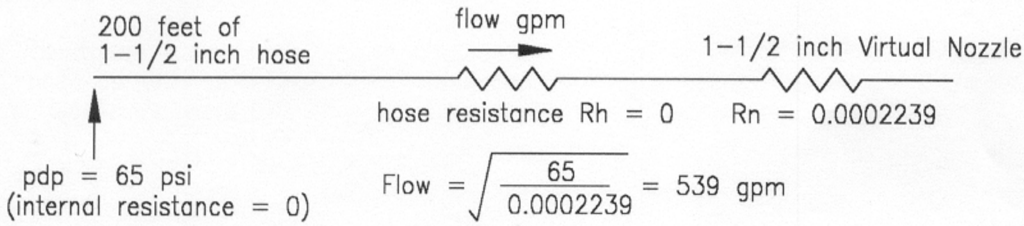
1–1/2 inch diameter hose R = 0.0002239 fluid ohms
2 inch diameter hose R = 0.0000709 fluid ohms
4 inch diameter hose R = 0.0000044 fluid ohms

Here is the formula again (d is the diameter in inches) $\frac{1}{(29.7 * d^2)^2}$

Water in a hose can have two distinct forms of energy. The first is the pressure it exerts on the wall of the hose. This is what the pressure gage measures. The second form of energy is in the motion of the water. We account for it with the nozzle resistance.

The resistance of the virtual nozzle, and in fact for all nozzles, produces a pressure when water flows through it. This pressure has to be provided by something, typically the pump, and it represents the energy that is put into the water to get it moving. The pump has to supply additional energy to keep the water moving against the force of friction in the hose. The energy used up in friction is gone forever. The energy due strictly to the motion of the water stays in the water.

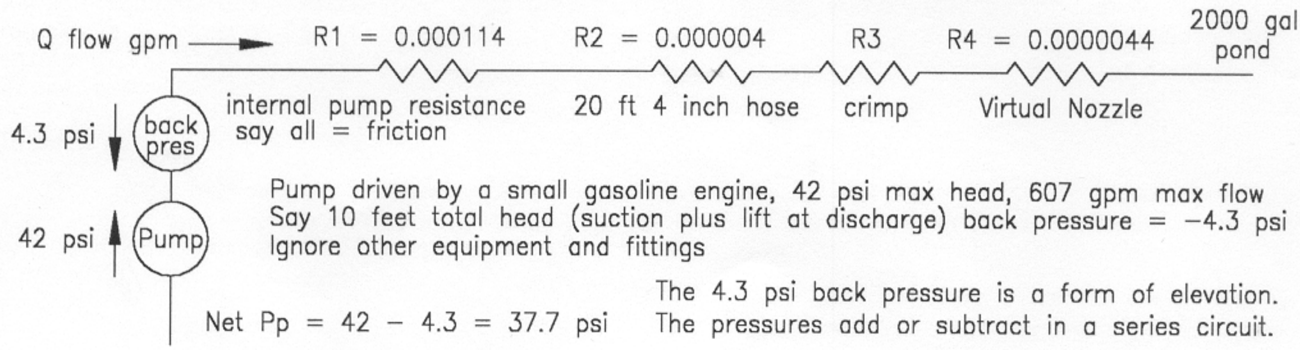
THE FRICTIONLESS PUMP AND HOSE



$$\text{Flow} = \sqrt{\frac{65}{0.0002239}} = 539 \text{ gpm}$$

The flow looks high, but remember we have no friction whatsoever. The 200 feet of hose might as well be 1 inch of hose. In fact, it might almost be a 1–1/2 inch master stream nozzle.

TRASH PUMP Part 1 Let's look at a small pump with 20 feet of 4 inch filling a pond. We'll compare fill times with and without a crimp in the hose.



Case 1 – no crimp (R3 = 0)

Note: The pump is pumping at 42 psi (its rating) but it is working against a head of 10 feet (4.3 psi)

This means that the net pump pressure (37.7 psi) is used to calculate flow but the actual pump pressure (42 psi) is used to calculate pump power consumption.

R total = R1 + R2 + R3 + R4 = 0.000114 + 0.000004 + 0 + 0.0000044 = 0.0001224

Flow = $Q = \sqrt{37.7/0.0001224} = 555$ gpm   which will take 3.6 minutes to fill the 2000 gal pond

Case 2 – Crimp reduces the 4 inch hose to the size of a 2 inch diameter nozzle (R3 = 0.0000709)

R total = R1 + R2 + R3 + R4 = 0.000114 + 0.000004 + 0.0000709 + 0.0000044 = 0.0001933

Flow = $Q = \sqrt{37.7/0.0001933} = 442$ gpm   which will take 4.5 minutes to fill the 2000 gal pond

The fill time increases by a minute. What are the power considerations? Our pump pressure can't adjust upwards – it's running as fast as it can.

Where does the Horsepower Go?

Hp to lift water 10 feet $\frac{\text{gpm x psi}}{1714.55}$ = 555x4.3/1714.55 = 1.39 Hp (no crimp)
= 442x4.3/1714.55 = 1.11 Hp (with crimp)

Hp to get the water up to speed IMPORTANT – Don't add this in when calculating total power below. It is already accounted for in the Virtual Nozzle Pressure

555 gpm in 4 inch hose (no crimp)   1.236 cu ft/sec = 77.16 lbs/sec

Area 4" = 0.087266 sq ft   Velocity = 14.17 ft/sec

Power = lbs/sec x Velocity x Velocity / 2 / 32.2 ft–lbs/sec

so 77.16 x 14.17 x 14.17 / 2 / 32.2 = 240.6 ft–lbs/sec   0.001818 x 240.6 = 0.44 Hp

442 gpm in 4 inch hose (with crimp)   0.985 cu ft/sec = 61.46 lbs/sec

Area 4" = 0.087266 sq ft   Velocity = 11.29 ft/sec

Power = lbs/sec x Velocity x Velocity / 2 / 32.2 ft–lbs/sec

so 61.46 x 11.29 x 11.29 / 2 / 32.2 = 121.65 ft–lbs/sec   0.001818 x 121.65 = 0.22 Hp

Pressure Drop in the Virtual Nozzle

Hp vir noz = Wf/1714.55 = $Q^3R/1714.55$ = 555^3x 0.0000044/1714.55 = 0.44 Hp (no crimp)

Hp vir noz = Wf/1714.55 = $Q^3R/1714.55$ = 442^3x 0.0000044/1714.55 = 0.22 Hp (with crimp)

Friction Losses Internal to the Pump (no crimp)   Hp = Wf/1714.55 = $Q^3R/1714.55$
= 555^3x 0.000114 / 1714.55 = 11.37 Hp

Friction Losses Internal to the Pump (with crimp)   Hp = Wf/1714.55 = $Q^3R/1714.55$
= 442^3x 0.000114 / 1714.55 = 5.74 Hp

Friction Losses 4 inch hose friction (no crimp)   Hp = Wf/1714.55 = $Q^3R/1714.55$
= 555^3x 0.000004 / 1714.55 = 0.40 Hp

Friction Losses 4 inch hose friction (with crimp)   Hp = Wf/1714.55 = $Q^3R/1714.55$
= 442^3x 0.000004 / 1714.55 = 0.20 Hp

Friction Losses Loss in the crimp itself   Hp = Wf/1714.55 = $Q^3R/1714.55$
= 442^3x 0.0000709 / 1714.55 = 3.57 Hp

Total Horsepower (no crimp) = 1.39 + 0.44 + 11.37 + 0.40 = 13.60 Hp

Total Horsepower (with crimp) = 1.11 + 0.22 + 5.74 + 0.2 + 3.57 = 10.84 Hp

Total Hp supplied by the Pump $\frac{\text{gpm x psi}}{1714.55}$ = 555x42/1714.55 = 13.6 Hp (no crimp)
= 442x42/1714.55 = 10.83 Hp (with crimp)