# Understanding the Capacities of the Mark III Pump and how this relates to your wildland S-211 Class Hydraulics Calculations.

Nearly Everyone that goes through the NWCG S-211 course at their local office, or even those in the Contract Fire world may or may not have very good instructors to convey to the new student just what the Mark 3 or similar hi-pressure pump is capable of, and how this fits in with the courses Hydraulics calculations.

As a DIRECT result of either, ill knowledgeable instructors, a lack of adequate material, or anything else, many come away far more confused and thus have a grand resentment of the field of hydraulics or pumps or both altogether. This brief discussion will attempt to change this and allow you the new S-211 Portable Pump and Water use student a much better understanding of this information.

First, we need to get some terms and corresponding definitions out of the way. Let's start with the terms that you're likely to hear from folks in the field first, especially, if you're on an engine crew, a fuels crew, or any other type of crew that will make use of portable pumps.

**Head Pressure:** If you are around engine operators or a seasoned pump operator while on a working fire, you will hear this term. Head Pressure simply means the pressure that is created inside a hose when the line is charged (filled with water) and elevated above the pump's discharge port. This is also called "Back Pressure" because the force of gravity wants to push BACK against the pump.

This has NOTHING to do with pumps. If you have a 1 ½" hose, 300 feet long and up-hill from your pump, with the bottom elevation taken by GPS as 4,625 feet mean sea level, and at the end of the hose, the GPS elevation reads, 4,910 feet mean sea level, then the head is simply the difference between these two elevations. 4,910 feet – 4,625 feet = 285 feet of head.

This "Head" is now measured in pounds per square inch, when filled with water, and it amounts to 0.434 psi for each foot that a column (A hose-line acts like a column) is raised for each foot in elevation above the pump or below the pump. The only difference is that if we are going uphill, we have to add this number to each foot of elevation, and if we are pumping water downhill, we then subtract this number for each foot of decrease.

Before we continue, let us explain WHY we know the pressure is .434psi per foot. A cubic foot of water contains 1,728 $in^3$, and this cubic foot of water weighs 62.4 pounds. If we divide the weight by the cubic inches, we obtain .0361 psi per inch. 0.0361 x 12 inches of height = .433psi. A way to think of how this becomes a square-inch measurement is the horizontal distance is not counted. Head pressures are measured in a vertical plane of a square area ($Psi = \frac{Weight}{Area}$), density and mass are measured in the 3rd dimension (cubic) or volumetric plane.



A 12-inch x 1-inch-wide x 1-inch-deep column turned on its side is now only 1" in height, thus the weight component now generates only .0361 psi due to the vertical height. The actual method used to determine this is to take the *weight*, 62.4 lbs, and divide it by the *area* in square inches. $62.4lbs/144in^2 =$ .433 psi. They both give the same answer. Either way works. For the rule of thumb issues of ½ psi = 1 foot and 1 psi = 2 feet, this is derived from the fact that we simply rounded .434 to .5 to make it easy in the field to do quick calculations. On the next page is a quick explanation of how these figures came about.

We have already shown that .434 psi = 1 foot, and by reason .868 psi = 2 feet. Then where does the 1 psi = 2.304 feet come from and why do I see it in a lot of hydraulics publications? The 2.304 feet is determined by taking 1 psi and dividing by the force to raise water one foot.

$$^{1psi}/_{.434\,psi\ for\ 1\ foot} = 2.304ft$$

And if you had 2.304 feet the pressure would be determined by: $2.304\ x\ .434 = 1\ psi$ and just to complete the picture so you can understand better, .304 feet is a hair over 3 ½". .304*ft* x 12" = 3.64"

These numbers are simply rounded to make math easier and faster in the field but it can cause issues if you do not know when to round and when not to.

Proving this works for our 1 ½" hose when filled with water and what we can expect a gauge to read. We will have 300 feet of hose. Each 100-foot hose is 1,200 inches in length. The inside diameter is determined by $.7854\ D^2 = .7854\ x\ 1.5^2 = 1.7672^{in\,2}$, if we multiply the 1200" x 1.7672 = 2,120.64 cubic inches for each 100 feet of hose. The Capacity of each 100 feet of hose is then determined by dividing 2,120.64 ÷ 231 (cu in) = 9.18 gallons.

Multiply 9.18 by the number of sticks of hose = 9.18 x 3 = 27.54 gallons, and 27.54 x 8.34lb/gal = 229.684 pounds. If you then use the formula from page 3, $Psi = \left(\frac{weight}{area}\right) = \frac{229.684}{1.7672} = 129.97,$ and 300 feet x .434 = 130

**Rounding Numbers**

When working on calculations, you will be most successful in your efforts if you do not round up every single number. Only round the final number. For example, if you have a hose lay that is 5,600 feet long, has an elevation gain of 314 feet, and a 1" kk nozzle with 100 psi nozzle pressure, then you will have 136.6 psi of head pressure, and 4.2 psi friction loss per stick. Do NOT round each FL figure to 5psi and then multiply, do not round the head pressure to 140 psi, sum the entire set of numbers first and then round to the final answer nearest whole number.

$$100 + 136.6 + (4.2x56) = 471.8$$

Take this final 471.8 and round to 472.



**Friction Loss:** This is a term used and is commonly applied to mean a loss in pressure in a fire hose. It is caused by the flow of water acting against the interior surface of the hose. You cannot feel it yourself, but water has a certain roughness to it. This is called "surface tension". Also, the hose lining in standard forestry hose is very rough compared to structure hose because forestry hose is often single-jacketed and single-lined.

The nylon or synthetic fibers on the outside create interior roughness. When the two surfaces make contact due to the forward velocity of the water, as with all other physical objects, friction is created. This then tends to SLOW the flow of water at regular intervals, normally 100 feet apart.

This slowing shows up as a reduction in pressure at this interval because the friction loss pressures are generated as a byproduct of flow velocity only. The Cascade Fire Slide Rule and friction loss calculator you will be using and instructed on how to use shows what these friction loss pressures are and are given for 100-foot intervals of lines of single hose, and also for what is called siamesed or parallel lines of hose.

When you deal with friction losses, on a single hose line and have obtained a final Friction Loss number, if you take the total friction loss figure and divide it by 4, you will have the answer to the friction loss if you were to then lay out a parallel hose lay. Example: 60 GPM through a 1 ½" hose produces 13 psi per 100 feet of hose in friction loss. This is then multiplied by the length of the hose-lays 100ft sections. If the hose lay is 500 feet, then 12.6 x 5 = 63 psi in Friction loss for the entire hose lay. If you take the 63-psi figure and divide it by 4, you will obtain 15.75. If you go back to the 12.6 psi of friction loss per section and divide it by 4, you obtain 3.15, and this 3.15 multiplied by 5 = 15.75. This parallel hose lay now has 1/4$^{th}$ the friction loss compared to the single line. Enough on friction loss.

**Nozzle Pressure:** Nozzle Pressure is a rather elusive term used because there is no "direct" nozzle pressure and Nozzles do NOT create pressure either. Nozzle Pressure is what may be referred to as *Induced Pressure*, as it is a byproduct of another mechanism. That mechanism is the rotating pump impeller that creates the flow through the hose. When this flow of water, that is of a larger volume is then suddenly met with a restricted orifice at the end of the hose, i.e. the Nozzle, a form of pressure is thereby created that is working against the flow. If we were to place a gauge at this nozzle, we would see an indication of pressure. The more water we try to flow through this nozzle, the higher the pressure reading will become and hence we call this Nozzle Pressure. There can be some complex terms for all of these and their various interrelations with other aspects of hydraulics but for portable pumps, and S-211 this is sufficient and accurate.

In Fluid Hydraulics, and dealing with water, we have, like all other forms of science, a formula that we can use to determine the amount of pressure a pump would have to be able to generate to get a certain amount of water to a certain point on a hillside for firefighting.

This formula is given as the following:

$$Ep = Np + Fl \pm Hp$$

Before we explain how this works, first, consider this as an English sentence. Reading left to right and logically. This formula is saying to YOU that the Engine Pressure or Pump used MUST be able to generate the pressure as determined by this formula, and IS the Nozzle pressure induced by the amount of water flowing through it, PLUS, the resistance pressure for the entire hose lay due to friction, PLUS the pressure required to RAISE water from the base elevation to the height we need it, and is the sum of these products.

Here we have Ep = Engine Pressure, Np = Nozzle Pressure, Fl = Friction loss, and Hp = Head Pressure.

**Example 1 hose-lay**

We have a 1,100-foot hose lay, the hose is going uphill and the elevation gain from our pump to the end of the hose is 850 feet. At the end is a 1" kk nozzle, the hose 1 ½".

Remember we showed that Head Pressure would produce .434 psi per foot of elevation? If we take the 850 feet and multiply by .434 we obtain 368.9 psi as the pressure required to raise water to that point. By the same example, if we were at that top, and pumping downhill 850 feet, we would have the same pressure being generated, only by gravity. This means we'd likely have our pump OFF. That is all there is to that.

When figuring Head Pressure, it is recommended to always use the .434 multiplier instead of dividing by 2. The reason is accuracy. Besides, everyone has a calculator in the field these days due to smartphones/watches.

We now move on to the Friction Loss. But before we can determine that, we have to know what nozzle type and size are at the end of our hose. For this discussion, we will say it is a 1" KK Nozzle. Those nozzles are rated for 20 gpm at 100 psi nozzle pressure. Knowing the flow rating of 20gpm we use our Cascade Slide Rule to determine the Friction Loss per 100 feet of hose. It is 1.4psi/100ft. So now you take 1.4 and multiply by the total number of 100-foot sections of hose, which is 11. 1,100 feet / 100 = 11 sections of hose. Thus 1.4 x 11 = 15.4psi of Friction Loss.

And last is the Nozzle Pressure, we know that KK nozzles are rated at 100 psi. So now we just add it all up.

Np = 100

Hp = 368.9

Fl = 15.4

Ep = 484.3

484 psi is a pretty large number.



**Performance Curves**

The performance curves enable us to determine hydraulic feasibility. Looking at the pump curve for 20 gallons per minute, if you draw a line from 20 straight up vertically until you hit the red limit line, then, turn left 90 degrees to the pressure side, you will see that it shows approximately 320 psi.

Based upon this figure you would then use the total PDP from the above example of 484 and divide it by the 320 from the pump curve to determine the number of pumps needed at a minimum.

Example: $Pumps\ Req'd = \frac{484}{320} = 1.513,\ round\ to\ 2\ pumps$ . This also shows that the pressure required exceeds our first pump by 51.3%.

**MARK III PUMP**

878 feet x .434 = 380 psi
878 feet / 2.304 380 psi

**SPECIFICATIONS**

**Flow rate at specified pressure**

Maximum Pressure : 380 PSI (26.2 bar)

Free flow : 98 US gals/min (371 L/min)

Maximum Head: 878' (268 m)

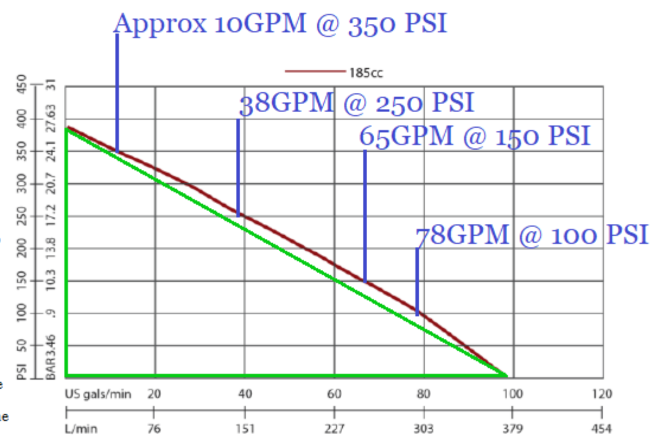
| Flow Rate | | | Pressure | |
|---|---|---|---|---|
| US GPM | (LPM) | | PSI | (BAR) |
| 78 | (295) | @ | 100 | (6.9) |
| 65 | (246) | @ | 150 | (10.3) |
| 38 | (144) | @ | 250 | (17.2) |

Engine: 185cc

Area inside the Green Triangle is what the pump is capable of delivering.

As the pressure increases the flow will Decrease. Likewise, as the flow increases the pressure will decrease.

Think of the green triangle as this pumps "limits". Anything to the right of the RED limit line is not possible!




The image above shows the data from the *waterax.com* website, and on the right is the pump curve. The Green Triangle we drew on the image shows the overall GPM and PSI ranges the pump is capable of operating at. Any flow and/or pressure combination or requirement inside this area can be met. Looking at an enlarged image of the Mark III pump curve on page 6, we can see that for a flow of 60 GPM, the pump will only provide around 175 psi. Out of this pressure you need to be able to supply your friction loss pressure, any head pressure, and nozzle pressure to match the flow demand.

**Determining Distances**

If we have zero elevation (zero head) and want to move 60 GPM, how far can we do so? How do you determine this for your fire ground for the mark 3 pump? Start with what you know will be your constants, i.e. pressures you absolutely must have to do the job at a minimum, these are usually head pressures, nozzle pressures, etc. for the particular scenario you're working on as these will usually change. If you have a scenario with no elevation, then your nozzle pressure becomes the new constant (that is that particular pressure demand can't be reduced). The nozzle requires 100 psi on a combination nozzle so subtract 100 from 175 (shown on the pump curve for 60 gpm) to get 75 psi remaining.

This 75 psi is all you have to work with for Friction loss since you are not dealing with elevation. The flow of 60 GPM requires 13 psi per 100 feet of hose. Take the 75 psi and divide by the 13 to obtain your distance. (*Sh* is the hose-lay distance in feet).

$$Sh = \frac{Psi\ Available}{Fl\ of\ 100\ ft} = \frac{75}{13} = 5.7\ or\ 570\ feet$$

*[You multiply the 5.7 by the length the hose comes in to obtain the distance.]* At this point, you could reduce the 570 feet to 500 feet. The PDP for this one is 165psi. If you use that extra stick of hose and move to 600 feet then the Fl would be 6 x 13 = 78, with Np at 100 totaling 178 psi. Now you're over. Consequently, since the hose is made in 50 and 100-foot lengths, you are limited to those options. (The available distance you can pump water will dramatically decrease once elevation gets factored into the equation).

If you were to now pump uphill, say 100 feet, then to squeeze the most out of our pump, use the figure .434 instead of dividing the elevation by 2. 100ft x .434 psi/ft = 43.4 psi.

Once you determine the elevation pressure required, subtract that from the remaining available psi to determine what you have left over for friction loss and this will determine your allowable pumping distance. (75 psi available – 43.4 psi head) = 31.6 psi remaining. We have 31.6 psi left over for friction loss.

I recommend determining friction loss distances last for the reasons shown below. We did have 75 psi, now after elevation uses 43 of that 75 psi, we only have 31.6 psi left. This radically cuts our distance from 590 feet to 250 feet. Over half.

To determine how far we can run the hose lay, take the 31.6 psi we described previously and divide this figure by the friction loss number you obtain from the slide rule or by a calculator for each 100-foot section. For 60 gpm that is 13.

$$\frac{31.6\ remaining\ psi}{13\ fl\ per\ 100\ ft} = 2.431, \qquad 2.431\ x\ 100 = 243ft$$

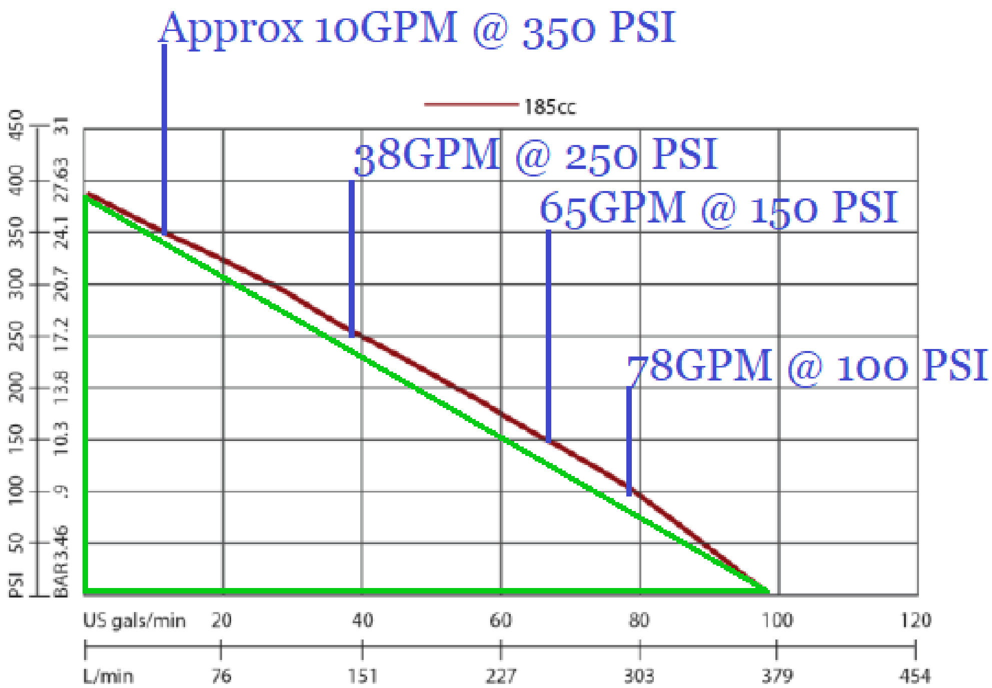
As can be seen, shoving 60 GPM and going up a 100-foot hill with the Mark 3, can only be done for a 240-ft horizontal distance. This figure of 240 feet can now be used to determine the number of pumps needed. If say the distance is 1,200 feet, then dividing this by 240 gives 5. If the terrain is steeper in other parts, then this will mean you may need to add pumps or reduce flow as well. It is tactical objective based.

These figures are then added back up to prove yourself. 100 psi nozzle pressure, 31.6 psi friction loss, and 43.4 psi head pressure equal 175 psi. This process is used regardless of the scenario you encounter or the type of pump you use.



You simply adjust distances, pressures or both to make it work. There are some instances when you can reduce Nozzle pressure to maybe 5 or 10 psi instead of 50 or 100 and these are if you are stage pumping for larger flows to supply pumpkins and NOT using an actual nozzle at the target site. This can have a very serious benefit to your operations in remote areas.



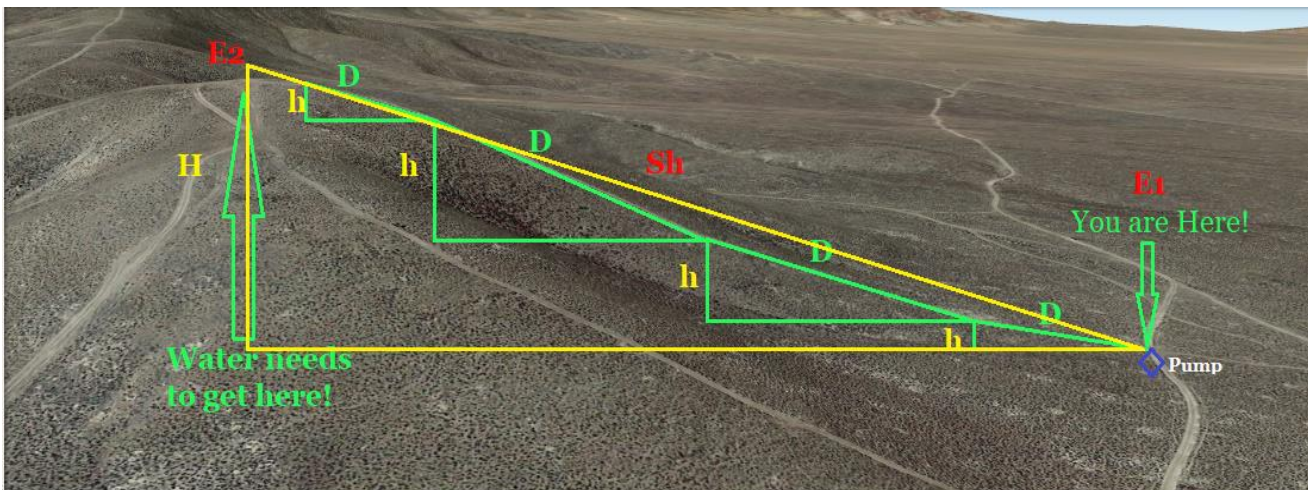

On the Bottom of the pump curve shown above, is the Gallons Per Minute from left to right, ranging from 0 to 120 GPM. On the left side is the pressure ranging from 0 psi on the bottom to 450 psi on the top. The RED Diagonal LINE is best viewed as the pump's LIMIT Line. In other words, obtaining 75 gallons per minute at 250 psi is NOT possible, nor is obtaining 10 gallons per minute at 400 psi!

How to use this pump curve in wildfire scenarios is to **First** perform the Hydraulics Calculations and come up with your Engine Pressure or Pump Discharge Pressures as normal. **Second,** look at the pump curve to see if the pump is capable of providing that calculated flow, at the pressure you calculated for the entire hose lay. **If not**, then you need either a different pump, <u>OR</u> you have to break up the hose lay into "segments" and stage pump the hose lay *This is the most common avenue used and affords some advantages.* Stage Pumping will be covered by your instructor during the S-211 Course, however, again, from page 4, once you obtain the PDP, and you have an idea of how much GPM you need to flow, you can use the pump curve pressure to determine the number of pumps for stage pumping.

These are the only real practical hydraulics calculations you can or should be expected to do with portable pumps. However, you must understand the pumps' performance curves and how to read them to make sure that you can meet the demands required and if NOT, as we showed here, how to provide a workaround. Here we resort to stage pumping, which means we are going to set up our pump, and only run enough hose to the calculated maximum elevation our pump can attain.

Once our pump reaches that point, we again set up another pump to supply water to the next point. And so on.

Most Mark III pumps do not have discharge pressure gauges, in that case, you have no way of knowing what the pump is producing in pressure, however, you can use these examples to determine how far and how high a Mark III can shove water. It is suggested that you obtain a 1 ½" inline pressure gauge and attach it to the discharge port of the mark III and this will work just as well and they are accurate enough. Just keep in mind, that the higher the pressure, the LESS WATER you are getting at the other end!




The Yellow Triangle is a visual of what you need to consider when conducting your Initial Assessment for Hydraulic Feasibility. Can your pump do this job alone?

The E1 and E2 are base elevation and target elevation respectively. The difference is the total Head in Feet.

The Sh = Distance of the Hoselay from E1 to E2.

The Yellow H is the total head. Whereas the Green D's are the segmented distances between each pump platform if you needed to resort to stage pumping and the corresponding h's are the section head in feet. summed together it should be equal to the total Distance and Head overall.

When working with a Mark III or similiar pump, it is HIGHLY suggested you obtain a copy of the Pumps Performance Curve. This curve shows the maximum gallons per minute attainable for a corresponding dischare pressure. One aspect that nearly everyone fails to understand is the maxumum PSI rating on a mark III is also its Least flow rating as well.

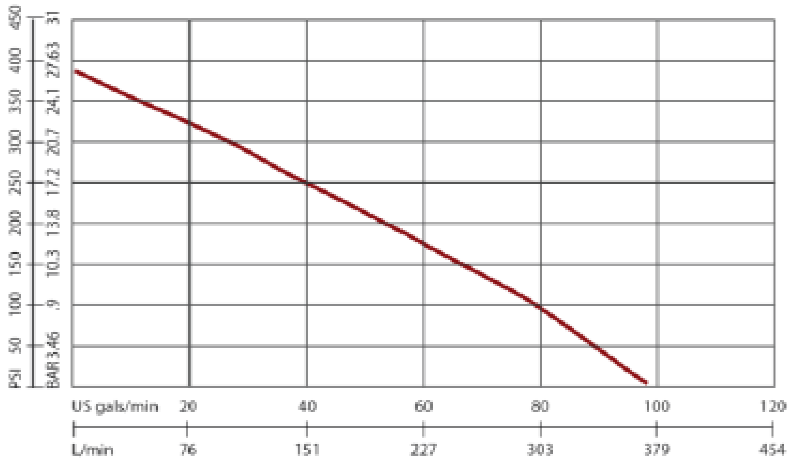
If you have 380 PSI, then your flow is nearly ZERO! you cannot move the water required for 3 20gpm nozzles at 380 psi. According to the Companies Pump Curve, the 380psi corresponds to a flow of: 0 or just barely above zero gallons perminute.

To move the 60 gallons per minute, you would be looking at an attainable 175psi approx. Out of this you have to subtract your head pressure requirement and your friction loss and nozzle pressure.

We will show a visual example on the next slide on how to better think of these situations.






Notice how the pump curve is in the same SHAPE of the hose-lay TRIANGLE on page 8? If you keep this in the back of your mind, providing solutions to head, distance, and GPM will become MUCH easier to grasp. The higher, you go up and the farther away you get, the more pressure you need, the less flow you'll have.

It cannot be stressed enough with the high-pressure portable pumps that you are constantly making adjustments in your calculations and again, your only focus on performing ANY calculation as it relates to the Mark III or any other type of pump is to see where that fits in with your pump's performance curve.

**Last Example**: If you only need 2 gpm to mop up a fire 30,000 feet away with 450 feet of head and need 100 psi of nozzle pressure, the Mark III can do this.

The arithmetic used is the slide rule formula because the flow number, 2 GPM is not shown on the slide rule, so the solution must be computed by hand. However, it is shown below as an example:

1 ½" hose coefficient is 35, Q is GPM, and L is the length of hose-lay.

$$Fl = C\left(\frac{Q}{100}\right)^2 x \left(\frac{L}{100}\right)$$

$$Fl = 35\left(\frac{2gpm}{100}\right)^2 x \left(\frac{30{,}000ft}{100}\right)$$

This then becomes $35\ x\left(\frac{2}{100}\right) = 35\ x.02^2 = .014.\quad \left(\frac{30{,}000}{100}\right) = 300, \quad \therefore\ .014\ x\ 300 = 4.2$

For the entire 30,000-foot hose lay, to move 2 gallons per minute only requires 4.2 psi. Then the head pressure of 450 feet, which is 450 x .434 = 195.3, and the nozzle pressure of 100.

To obtain distance, you are giving up FLOW! To gain flow you give up distance, or possibly distance and head. It's a balancing act.

$100Np$,

$195.3Hp$,

$4.2Fl$

$299.5Ep$ to move 2 GPM 30,000 feet.

However, 20 GPM for this same problem would require a pressure of 715 psi.

Never forget two things. **One** is the importance of obtaining and understanding pump curves for the make and model pump you will have to work with. The performance curves show you what your pump can and cannot do and such will present you with the flow and the psi figures. **Two,** there is a BIG DIFFERENCE between what you think you need, versus what the fire needs. If you think you need only 2 gallons per minute as in the above example, but the fire's HEAT and Rate of Spread require you to supply 20 gallons per minute, then you will be spending a lot of wasted time putting in a hose lay that is woefully undersized for the job. As a new pump operator number Two is NOT your primary concern, your primary and only concern is IF the pump will do the job your supervisor is asking it to do. You should study and ask as many questions as YOU the student need to have a complete understanding of how your pump and hydraulics work together to achieve your tactical objective. Practice!

Fire Order #3, Base **ALL** actions on the current and expected behavior of the fire. Do not put in a hose lay simply for the sake of putting in a hose lay. It never works out well.

There is a "trick of the trade" that I want to explain to you on how to quickly determine the number of Mark III Pumps needed for a hose lay along with determining the Pump spacing, or distance between each pump.

**1st,** calculate as normal, the total head pressure, total friction loss, and nozzle pressure of the entire hose lay. As a rule, if the head pressure exceeds or consumes up to 50% of the rated pressure of a single mark 3, then you'll need more than one pump for the job. Often several pumps.

**2nd**, look at the flow demand on your pump curve that you need for the job (determined from your nozzle(s) in the 1st step.), and then find and select the appropriate pressure on the left side of the pump curve. Once you get this figure you will then divide the total PDP of the hose lay by this pressure for the flow used from the pump curve.

(We chose 20gpm off of our pump curve).

Much of this will largely depend upon your experience, who conducts your training, and the type and quality of your field training you received, however, be mentally flexible on the elements to think of solutions. The more you practice this, the faster you will become!

**3rd,** after you have performed the division step, your answer will tell you the number of pumps needed to do this job.

If we have a pumping operation calling for a PDP of 3,141 psi, for a flow of 20gpm we would use 320 psi from the Mark III pump curve, and the solution is determined as 3,141 / 320 = 9.8 pumps. We need 10 pumps for that task. Always round up to the whole number.

**4th** The total hose lay distance on the incident was 12,000 feet. Then we could determine pump spacing by simply dividing the 12,000 feet by 10 = 1,200 feet apart. This works because we have already accounted for ALL required pressures when we did the initial PDP determination.

For those who desire to know the actual minute details and "need" to know that their figures will work, you can break this down further. Out of the 3,141 psi, subtract the nozzle pressure and friction loss, that is 100 for the nozzle and 168 for the friction loss. 3,141 – 268 = 2,873 psi. So, what is the elevation gain? 2,873 psi x 2.304 = 6,619 feet. And re summing the figures, 6,619 x .434 = 2,873 psi, also 6,619' ÷ 2.304 = 2,873 psi.

The Friction loss based upon the flow of 20gpm is now calculated for the distance of the hose-lay and the 12,000 feet is divided by 100(length of a hose) to obtain the number of sticks as we call them. 12,000 ÷ 100 = 120. The 120 x 1.4 = 168

Summing yields: 10Np + 168Fl + 2873Hp = 3,141. Since we needed 3,141 psi in our original calculation, breaking up the hose lay in this manner provides the working solution.

As can be seen above, we have determined the total number of pumps required to do the job. We have gone back and verified our figures and proven to ourselves that based on the pump performance curve we can achieve the goal. If we had an additional 12,000 feet of hose, we could lay down a parallel line and drop the friction loss, however, considering our head pressure is so high, this would not buy you much.

*Engineers Make it Happen!*



Any Questions or comments or if something stated here should not make sense, then please feel free to contact me with any questions via email or text.

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