

## Rate-of-flow Formulas for larger fires

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Let's return to the beginning, and consider again the question

How much water is needed to fight a given fire?

For one or two family detached dwellings with the fire still confined to the structure, the answer is fairly simple. For confined structure fires involving a room five to ten gallons of water converted to steam will control or extinguish that fire. This can be done with one pumper and three to four firefighters. In fact in the United States 75% of all structure fires are confined to the room of origin by using a single attack line.

However, occasionally fire departments (brigades) encounter a dwelling fire that is not confined. A fully involved house fire that is burning in the open requires more than one pumper and just a few firefighters. Besides this, every community has community or commercial buildings that are much larger than dwellings. Such fires need much more resources in the number of pumpers, the number of fire fighters, and the amount of water needed. So let's shift from house fires to larger fires that occur in larger structures. Our question now becomes:

How much water is needed to fight a larger fire in a larger structure?

For answers to this question we will turn to two books published by the National Fire Protection Association (NFPA) in 1966 and 1968 authored by Warren Y. Kimball. He was then Manager of the NFPA Fire Service Department. The two books are titled: FIRE ATTACK, Command Decisions and Company Operations, and FIRE ATTACK 2, Planning, Assigning, operating. Our concern is primarily with the operations that provide the needed fire flow (NFF) that will control or extinguish the fire. The goal of any fire attack is to control or extinguish the fire with the minimum damage to life and property. In any fire attack there are three operations that firefighters perform.

1. The first is fire attack, that is, the operation of controlling or extinguishing the fire by the application of water from nozzles, or by using other extinguishing agents.
2. The second is the supply of water with needed pressure and volume for the fire streams being used.
3. The third are support operations needed to make a fire attack efficient and effective. Support includes forcible entry, ventilation, laddering, salvage, lighting, and rescue (1<sup>st</sup> priority).

Immediately, before fire attack even begins, the officer in command of the first pumper to arrive on the scene of a structure fire is faced with a dilemma. This dilemma is widely known in the fire service. It is whether to

- proceed directly to the fire and order a fast attack with small preconnected attack lines supplied by water in the tank on the pumper,
- or stop at the nearest hydrant before reaching the fire, and lay out a large supply line to be connected to the pump on the pumper.

The risk in the first operation is that the NFF may be greater than can be supplied using small lines with a limited supply of water. In other words, the officer runs the risk of running out of water before the second pumper arrives on the scene. The risk of the second operation is that the initial fire attack will be delayed long enough for a much larger fire to develop. The number of firefighters responding with the first pumper is critical here. One firefighter has to be left at the hydrant to make the connection and to turn on the hydrant. This firefighter may be needed to stretch the first attack line. So there is a real dilemma here.

There are several things that can be done to get away from this dilemma., but further discussion on the dilemma will take us away from our priority of dealing with NFF.

Standard first alarm response to a house fire for any fire department should be a minimum of two pumpers plus a support truck, that maybe either a ladder, squad, or service truck. Present day pumpers carry a lot of equipment. This includes at least four air packs and spare bottles, a generator, a ventilation fan, a 24 foot extension ladder and a 12 foot roof ladder, assorted tools, flood lights, a variety of nozzles, at least 600 feet of attack hose (1.5 or 1.75 inch), plus at least 1,000 feet of supply hose (3 in or larger diameter). One nozzle maybe a master (heavy) stream nozzle that is fixed and mounted on the truck and capable of flowing at least 400 gpm. A portable master stream nozzle may also be carried. A lot of this equipment is duplicated by equipment carried on the support truck. The pumper may carry 300 gallons of water (city) or more than 1,000 gallons (rural).

The pumper, of course, has a pump that is mounted on the truck and is driven by the truck's motor. Today the pump is usually capable of pumping a volume of 1,000 gpm (or more) at 150 psi. Class A fire pumps are capable of pumping at higher pressures but at lower volumes. Not many years ago fire pumps were either 500 gpm or 750 gpm pumps. In fact, a little more than 100 years ago motorized fire trucks were just being introduced to the fire service. One hundred years prior to that steam fire engines were in use that were pulled by horses. Earlier than that in this country, bucket brigades were used, that required a lot of volunteers.

How many firefighters are needed for a first alarm standard response? Warren Kimball states that standard manning for a low risk area (residential) is a minimum of four firefighters for each of two pumpers including the officer in command for a total of eight. The support company should provide at least four more. However, many fire departments (brigades) shortchange their support trucks with a manning of only two firefighters. This is substandard indeed, and restricts the support firefighters to performing only one task at a time. At least one third of the firefighters should be assigned to support operations.

So standard manning for a first alarm response to a low risk area is twelve firefighters. Kimball strongly recommends that these three trucks be housed at the same station so that they will arrive at the scene of a fire at the same time. This enables the firefighters to be organized into task forces that operate much more efficiently than individual fire companies from different stations. In addition the chief officer will arrive as the 13<sup>th</sup> firefighter on the scene usually driving his or her own vehicle. For high risk areas a minimum of three additional firefighters should be provided, or a total of 16.

What is the fire flow that can be provided by standard manning on first alarm for a low risk area? The answer is 400 to 500 gpm. In the initial fire attack, the first line should be in operation in less than 2 minutes after the fire trucks stop at the scene. Two firefighters should be assigned to the first small attack line (1.5 or 1.75 in), and two firefighters assigned to the second small line. The third line should be a bigger 2.5 inch line manned by three firefighters. The two small attack lines flow 100 gpm to 125 gpm, and the 2.5 in flows 250 at standard pressures and standard length of hose. Thus the NFF is 400 to 500 gpm for initial first alarm attack.

There are two ways that fire flows can be increased by using fewer firefighters. The first way is by using heavy (master) stream nozzles that flow at least 400 gpm. A monitor or deck gun is mounted on the pumper with a pipe leading from the pump. A portable heavy (master) nozzle is operated at a distance from the pumper and is connected to the pump by fire hose. In both cases the heavy stream can be operated by two firefighters. The second way is by using an aerial ladder to apply water to multistory buildings. The ladder is attached to a fire truck and the nozzle is attached to the tip of the ladder. Again this heavy stream can be operated by two firefighters. Much more water can be flowed with heavy streams, 400 gpm each compared to 250 gpm or less for each hand line.

Firefighters assigned to a pumper must perform three basic fire attack tasks:

- Place small attack lines in service for a fast initial attack.

- Operate a standard 250 gpm 2.5 in attack line with pressure supplied by the pumper.
- Operate one heavy stream nozzle flowing at least 400 gpm.

Now let's consider the second operation that firefighters perform at a fire, namely supplying water with needed pressure and volume. The fire department is almost completely dependent upon the capacity of the water system in the urban area. This is the available fire flow that may vary somewhat in different parts of the city. What we are talking about is the amount of water that is available for the fire department over and above the normal supply for the systems customers. The available fire flow is usually several thousand gpm even in small towns. It is the responsibility of the fire officers to know exactly what the available fire flow is in each area of the city.

This knowledge is extremely important because if a fire officer attempts to pump more water than that available, then the entire water supply operation may be disrupted. Exceeding the available fire flow by a small percentage can lower the pressure needed for each fire stream being used. This in turn reduces the volume of flow which could drop below the needed fire flow. Fire officers sometimes blame the water system for "low water pressure", but the fault does not lie with the water system. The cause is almost always the fault of the fire department (brigade) attempting to pump more water than is available.

The second limit on water supply is the available flow from a single fire hydrant. It is the responsibility of the fire department (brigade) to test this hydrant to find out what the maximum flow is. It is also the fire department's responsibility to test the hydrant when other hydrants in the vicinity are flowing. Sometimes this may reduce the available flow well below the maximum flow. Color coding hydrants, and other means, are used to help fire officers determine how much water is available from each fire hydrant. Hydrants that flow around 500 gpm, or less, are not capable of supplying the water needed for larger fires in larger building. Hydrants flowing from 1,000 gpm to 1,500 gpm usually will supply enough water to meet the needed fire flow for a larger fire.

Present day pumpers with capacities ranging from 1,000 gpm on up to 2,000 gpm usually provide more than enough pumping capacity to handle the available fire flow. In fact at multiple alarm fires, each pumper on the average will supply only about 500 gpm. The reason for this is that as hydrants are used farther away from the fire, friction loss becomes so great that less and less water can be supplied to the fire.

The final limiting factor is personnel, the number of firefighters on the fire ground. For most multiple alarm fires, it will turn out to be true that the number of firefighters is the ultimate limiting factor for fire flow. The standard first alarm response provides 13 firefighters producing a flow of 400 gpm to 500 gpm. With one heavy (master) stream this flow can be increased to 1,000 gpm. Doubling this fire flow to 2,000 gpm requires twice as many firefighters, or 30. Increasing to 3,000 gpm requires the same increase in firefighters, 15 more for a total of 45, and so on. Increasing fire flow by 1,000 gpm means an additional 15 firefighters. This is a linear relationship between fire flow and manpower. As shown in the following table.

Fire Flow Applied	Total Personnel
1,000 gpm	15
2,000	30
3,000	45
4,000	60
5,000	75
6,000	90

Of course, flows greater than 3,000 gpm are beyond the capability of most fire departments (brigades). Twelve pumpers would be needed to provide 6,000 gpm at an average flow of 500 gpm per pumper. Only the largest cities can comfortably handle these large fire flows to battle the largest fires.

Now how large a structure can these fire flows provide the needed fire flow?

Warren Kimball looked at data supplied by fire departments (brigades) that reported the actual fire flows at its largest structure fires. The data revealed that the NFF necessary and sufficient to control and extinguish such fires averaged around

$$4 \text{ gpm per } 100 \text{ ft}^3$$

Warren Kimball stated the rate this way so that he could use an integer for the gpm. However, with the availability of hand calculators, it is not necessary to stick to integers. So let's change this rate to "per cubic foot".

$$0.04 \text{ gpm per } 1 \text{ ft}^3$$

This statement is a complex or compound quantified statement. Not only is the gpm quantified, that is, true not just for one minute, but for the second minute, and so on for every minute, but also this number itself is quantified as being true for not just one cubic foot but for every cubic foot. So let's write the rate as

$$(0.04 \text{ gpm}) \text{ per } 1 \text{ ft}^3$$

The formula for calculating the NFF for a given size structure is the rate (r) multiplied by volume (V) equals the NFF.

$$R \times V = \text{NFF}$$

R, of course, is a constant (0.04 gpm).

$$0.04 \times V = \text{NFF}$$

With this equation we can calculate the NFF for any size structure. Let's do this using the data from the preceding table.

Fire Flow Applied	Number Personnel	Number Pumpers	Volume
1,000 gpm	15	2	25,000 ft <sup>3</sup>
2,000	30	4	50,000
3,000	45	6	75,000
4,000	60	8	100,000
5,000	75	10	125,000
6,000	90	12	150,000

The first entry is the volume of a 2,500 ft<sup>2</sup> house one story with a height including attic space of 10 ft. The second entry is the volume of a two story store 25 by 100 feet with a 20 foot height. Each of these entries represents community or commercial building that are commonly found in most communities

Before leaving Warren Kimball's two books, I would like to consider two paragraphs that appear on page 82 of the first volume. They are:

Theoretically, if water is applied in the form of fog with maximum efficiency, one gallon of water will generate 223 cubic feet of steam. And if water could be applied with 90% of its theoretical extinguishing capacity utilized, one gallon of water per 100 cubic feet of fire area might generate sufficient steam to cool a fire within 30 seconds. Possibly the same rate of application evenly applied on material which had been burning, ordinarily might be sufficient to prevent reignition of flaming although in some fires more water is required for complete extinguishment than for blacking out flame.

Such theoretical considerations seldom work out under actual fireground conditions. It is seldom possible, using hose streams, to apply water evenly and efficiently over an extensive fire area without using considerably more water than might be necessary...A desirable factor of safety where extinguishment is to be chiefly by hose streams would appear to be at least three to one and in many cases a factor of four to one would be justified.

Kimball did not present any evidence or research to explain this theory, nor did he give the source. It is more than just a matter of courtesy to cite the source of your information. An author has a professional responsibility to do so. The numbers that Kimball uses are:

One gallon creates 223 ft<sup>3</sup> of steam  
 90% of extinguishing capacity  
 Cool in 30 seconds  
 1 gpm per 100 ft<sup>3</sup>

There is no doubt where these numbers come from. These numbers are the result of the research done by Keith Royer and Bill Nelson at the Fire Service Institute at Iowa State University. The 1 gpm per 100 ft<sup>3</sup> is the r.o.f. of the Iowa r.o.f. formula. The 30 seconds is the discovery made by Keith Royer that all confined structure fires could be controlled within that time. The 90% is the safety factor built into the Royer Nelson formula in case not all the water is converted to steam. Taking 90% of 223 gives 200 that is the constant used in the Royer Nelson formula.

Kimball evaluates this theory by using the following words.

Might generate  
 Possibly or ordinarily generate  
 Seldom work  
 Seldom possible

These are vague and imprecise phrases. There is no evidence or research to validate any of these judgments. In fact all the evidence and research about this theory contradicts Kimball's judgments. Royer and Nelson, beginning in 1953, burned more than 75 structures of all kinds. The structures were instrumented, and the data produced was analyzed very carefully. The conclusions reached were founded solidly upon scientific facts.

The worst statement that Kimball made is that this theory "seldom works" Just the opposite is true. The combination fog attack on a confined structure fire works always provided it is properly done, and that is easy enough in theory as well as in practice. Kimball states that it is seldom possible to apply water evenly and efficiently over an "extensive fire area". This statement is partly true since it is more difficult to distribute water evenly and efficiently in an open fire. However, it is not impossible, and there is nothing to prevent one from trying even though you are only partially successful. In other words, Kimball does not justify the assertion that it is "seldom possible".

There is one more statement that is true. The initial fire attack certainly controls a confined fire but it may not completely extinguish the fire. Thus more water may be needed to overhaul and extinguish the fire. This is ok. Finally Kimball discusses the issue of factor of safety. He ignores the fact that a factor of safety is already built into the Royer Nelson formula. Kimball argues that a factor of three or four to one appears to be justified. Saying that something is apparent is not a very strong argument, since what is apparent to one person may not be apparent to another.

Kimball's statement is not apparent to me because one of the important results of the research at Iowa State University is the following fact. If too much water is applied for a confined fire, this disrupts the fog attack and creates massive thermal imbalance. There is no doubt about this since the research done by the U.S. Naval Research Laboratory produced graphs showing the creation of thermal imbalance and also

showing an effective fog attack that did not. For this reason I do not believe that Kimball's factor of safety is needed to make an effective fog attack on a confined fire.

So Warren Kimball's challenge to the Royer Nelson formula and the combination method of attack that is based upon that formula must be rejected. An initial fire attack using two preconnected small attack lines does control or extinguish 75% of all structure fires in the United States. This r.o.f. of (0.01 gpm) per 1 ft<sup>3</sup> is sufficient to handle these fires with ease. If the fire is larger, the first alarm response can increase the flow to 500 gpm by putting a 2.5 in hand line into operation flowing 250 gpm. This increases the r.o.f. to 500 gpm or (0.02 gpm) per 1 ft<sup>3</sup>.

If this flow is still not enough, then the first alarm crew can place a master (heavy) stream into operation flowing 500 gpm. This raises the flow to 1,000 gpm at a rate of (0.04 gpm) per 1 ft<sup>3</sup>. At this level, the r.o.f. is sufficient to control the largest fire possible in the 25,000 ft<sup>3</sup> structure. For even larger fires, a 50,000 ft<sup>3</sup> building for example, a second alarm response would provide an additional 15 firefighters and an additional 1,000 gpm flow. The total flow of 2,000 gpm provides a r.o.f. of (0.04 gpm) per 1 ft<sup>3</sup> that is sufficient flow for a building of this size.

What is our answer to the question: how much water is needed to fight a larger fire in a larger structure? The answer is 1,000 gpm for each 25,000 ft<sup>3</sup> increase in building size. Another way to answer the question is to say: (0.04 gpm) per 1 ft<sup>3</sup>. As an equation the answer is:

$$0.04 \times \text{Vol} = \text{NFF}$$