Fire Nomograms & Use for Greater Efficiency

PURPOSE

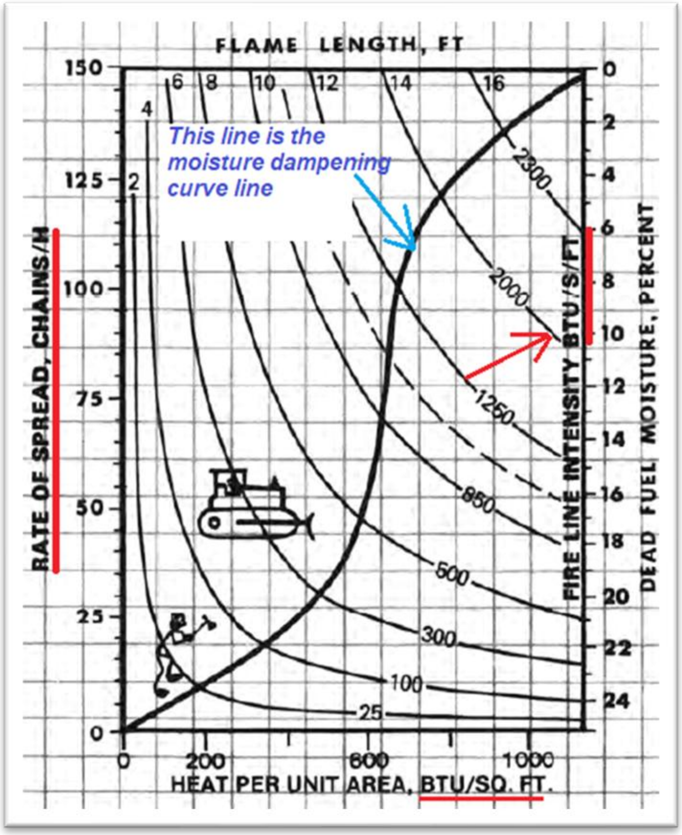
Fire Behavior Nomograms (S390 & S490) or predictive models have existed for a little over 50 years providing valuable information to fire operations and planning personnel so they can better plan, prepare, stage & use resources during an active fire based upon the Nomogram & other Model Outputs. However, some of the information presented in the Nomograms or even the Behave Plus modeling software are cumbersome or of little practical use to the "average" single resource as presented for the firefighter on the ground without extensive classroom instruction and practice, especially if a person is not inclined to such deductions naturally. Another problem arises because even if one is knowledgeable of ascertaining a fires intensity from their use, such personnel are never trained how to properly use that information in determination of resources by their capability. I then ask all who may read this the following question:

What good does knowing the thermal intensity of a fire do oneself, if in one's entire career they are never taught how to use that intensity to determine the amount of cooling required, the amount of fuel to be removed or the number of air and ground resources to be brought against the fire itself?

This is the purpose of this paper.

Our wildland fire industry teaches nothing on how to achieve this.

Inserted on the next page is a "quadrant" of a Fuel Model 3 Nomogram to show what information/elements are used in determining a fires intensity.



On the left (above), the fires rate of spread is in Chains per Hour. Many in fire know what a chain is, 66 feet. Intensity, however, is represented in Btu per foot per second, shown on the right side next to the red arrow. The fires heat is shown in BTU per square foot on the bottom as simply BTU/SQ. FT. To be more useful or successful, the information must be rearranged for operational personnel in the field to readily use. The rate of spread figures must be converted to feet per second. Such is necessary and will make the Nomograms a lot more useful and easier to visualize in being able to determine the right amount and type of Air and Ground resource(s) based upon the estimated thermal intensity of the fire. *(Behave Plus fire modeling software uses this same Arithmetic)*. Neither Nomograms nor Behave Plus, however, will tell you how much cooling capacity or fuel removal is needed. Understand that Fire suppression is a 100% thermodynamic operation; However, it is this type of operational information that is never taught to folks on the ground.

There is a Wildland Apparatus Engineers Quick Reference Guide that was developed for engine operators and pump operators to determine, among a plethora of other things, the *BTU* absorption capacity of water and how to match flow rates to the amount of heat being generated by a fire.

This Document originally was to explain how to better use that Quick Reference Guide (Q-Ref) along with the Fire Nomograms to boost efficiency of air and ground resources. However, it will be used as a stand-alone document for this discussion. I call the process, "FireBridge". That is the Construction of a Mathematical Bridge to fit the fire hydraulics requirements for thermodynamic cooling. We are "Bridging the Gap", between the Planning side of Management Teams, (FBANS, etc.), to the Operational side, (Engines, Dozers, Helicopters, SEATS, etc.), for use at the lowest possible level to assure success and bolster efficiency of every piece of equipment being utilized. Every resource that carries water carries with it a thermal absorption capacity. Every Resource that removes Fuel is a direct equivalent to BTU absorption. Match the capacities & rates to a fires thermal output, and you become instantly more successful. The purpose is to cool such below the ignition temperature. Fire again is 100% a thermodynamic problem. To prove to yourself that we do not teach nor realize such, ask your Local or Federal Wildland Firefighter how much heat their nozzles can absorb, a helicopter pilot how much their bucket can absorb or a SEAT or LAT pilot how much their load can absorb, you'll get the 1,000-yard stare.

But where do you start? The general order in the simplified form is shown below.

- Determine Total Energy generated in Btu/second: ⇨ 250,000,000 Btu/sec
- Mathematically determine the gallons required: ⇨ 26,692 gallons
- Divide the gallons by load capacity of the aircraft: ⇨ 7 Aircraft

(The 7 aircraft shown as required here is based solely on the total fire intensity for the entirety of the active fire line and the intent is to extinguish that entirety in the instant of time (1 second), otherwise it should be determined or referred to as loads required).

Along with a heat exchange issue, we have a life size pump issue to understand. Having all the aircraft in the world will be useless unless you have folks on the ground to design and install the infrastructure to keep this life size pump spinning (Regardless, if it is Helicopters, SEATS, Lats, etc.), otherwise it all ceases. The aircraft act as a pump impeller, the water tenders and engines (in certain special cases), act as the plumbing into that pump. Unless one understands this, it will fall apart, and several days & tens or hundreds of thousands of acres and structures are burned. Nearly every Tender Operator, Engine captain, FMO's, Division Supervisors, etc., are not trained to the caliber required to think in this context. We train them to simply perform specific tasks based upon a task book that is devoid of such information. These Task books contain only rudimentary tasks to be performed repetitiously so we can then label a person as "qualified" simply by doing, it is not by understanding the physics that make up the multiple elements to that specific task. Let us look at an example of how such other tasks can present issues if not understanding the hidden critical details.

Setting up dispatch run cards to send a certain number and type of resources to a reported fire is one such task as well, and often, resources are mismatched to a fire's intensity. Fire Size in acres I submit is irrelevant as I will show in a moment, however, the resources dispatched should be selected principally for their ability to carry and deliver a "Thermal Effect" first. This is often completely omitted, ignored or simply not understood.

If we look at this in logical order, we should be starting with determining the resources required based upon the following:

Fuel type & Fuel Moisture determine the HPA (Heat per Unit Area). These are the only real factors that we need concern ourselves with at this point to be reasonably accurate. (see Rothermel INT-115)

Rate Of Spread (ROS), times the HPA, determine the fires intensity.

To determine the best initial resources (Rothermel INT-GTR-143), Begin determining the fuel type, slope, moisture and intensity with a Nomogram for the appropriate fuel type. This was stated in 1983 (41 years ago), with Rothermel suggesting such on page 3 of his report. There is one aspect to which none of the reports ever discuss and such is never taught to firefighters in the wildland fire service and that is how much heat their apparatus can handle.

In our example we will use a Fuel model 4 as on the next pages. However, it is vital that one considers our current methods of dispatching suppression resources first. Typically, we have a report, then multiple IA resources are dispatched. These resources are not dispatched by the thermodynamic science of their cooling capacity. Often 2 or 3 engines, a water tender, a dozer and a couple of SEATS are the norm on a run card.

Consider this. If the location of the actual fire is typically in an area that engines will not have access to, then that instantly equates to zero thermal effect (cooling) from these resources.

The water tenders are 90% of the time never able to reach the fire directly. This resource also is bringing zero thermal effect (cooling) by two factors. 1.) Unable to reach the fire and 2.) it is rarely used or relied upon to support hose-lay operations. Hence 28,100,000 BTU of cooling, that is routinely never utilized.

The 2 SEATS loaded with retardant bring zero thermal effect (cooling) due to indirect dropping and retardant properties reactivity to heat above 194 degrees F. (see Phos-Check SDS).

Dropping retardant that will have zero cooling effect only allows the fire to maintain its current intensity and acceleration to the point of impact oftentimes being ineffective. Dropping Retardant in such an area while claiming to attempt to slow a fire is not considered a valid argument and is substantiated mathematically when the location is in an area that engines are unable to get into to support the drop, crews are not in place, the mechanized equipment (Dozers) has not even reached the fire should prove that we are consistently ineffective with resources.

(*Also Federal Wildfire agencies currently do not have their own Skidgines that would afford the ability of both fuel removal and thermal cooling simultaneously and better support dozer lines in such terrain than engines and these are non- existent. Skidgines are out now that have 6-way blades and carry 2,000 gallons of water or 18.7 million BTU of thermal cooling*).

Out of 6 total resources dispatched in this example that would comprise of 67.3 million BTU of thermal cooling capacity, only 1 has "direct" potential at instant thermal reduction under our current methods and these resources are chosen arbitrarily and not through fire thermodynamics properties. That is the dozer. The Engines, Dozers and Tenders are in the hundreds of dollars per hour, and the Aircraft in the Thousands per hour. Cost Per acre burned ?

(2) 800 Gallon SEATS with water = 15,000,000 BTU Not Utilized

(3) 860 Gallon Engines with water = 24,161,700 BTU Not Utilized

(1) 3000 Gallon Water Tender = 28,100,000 BTU Not Utilized

(1) Dozer D6T Utilized

These resources will be equally ineffective regardless of whether this is a 100-acre fire or a 100,000-acre fire in this situation. The greatest impact that can be made on a fire are the Aircraft that will 99.99% of the time beat every ground resource and we are dropping NOTHING to reduce the thermal intensity.

Base the dispatches on the fires thermal generation and the field ops can adjust from there providing they're trained to think beyond the standard task book training.

The next few pages will explain the process of how the calculations are determined and performed. A spreadsheet as well as a set of charts (FireBridge - Tons per Acre) were developed to perform/remove these calculations from field personnel for rapid estimation.

numbers Footnotes on page 13

Fire Nomogram Use

Fire Nomogram Model 4 attached pg 12

Mock Fire Example Intensity Estimation

Inputs: (in Blue)

1st Estimate: Fuel Model 4, Chaparral (6Ft) High wind Speed

(Just chosen arbitrarily for illustration)

Slope 60%

20ft wind speed 15mph

Effective Mid flame wind speed estimated at 16mph.

Dead Fuel Moisture 3%, Live fuel moisture 120%

Outputs: (in RED)

ROS ≈ 380 Ch/hr = 25,080 ft/hr = 418 ft/min = 6.97 ft/sec used (round to 7)

HPA ≈ 2,866 $BTUft^2$ (computed) but use 2,800 - 2,900

$BTU/ft/sec =$ HPA x ROS/ft/sec = 2,866 x 6.97 = 19,976

BTU/ft/sec range is between 2,800 x 7 to 2,900 x 7 = 19,600 to 20,300 (700 BTU spread)

For Fuel model 4 in this example, this is how the Aircraft Data in the Q-Ref would be used.

From the outputs again:

ROS ≈ 380 Ch/hr = 25,080 ft/hr = 418 ft/min = 6.97 ft/sec (round to 7)

HPA ≈ 2,866 $BTUft^2$ *(computed) but use 2,800-2,900*

$BTU/ft/sec =$ *HPA x ROS/ft/sec = 2,866 x 6.97 = 19,976*

BTU/ft/sec range is between 2,800 x 7 to 2,900 x 7 = 19,600 to 20,300

The next logical step in the determination & selection of the appropriate number and type of air resources for this discussion is based upon three main factors, all with several sub-factors interwoven.

- The *First* is obtaining the outputs on what the carrier fuels of the fire is generating by using the appropriate fuel model Nomogram (as above), in terms of Rate of Spread then converted to Feet Per Second along with its Intensity in BTU per Square foot. (see nomogram instruction document)
- The *Second* is estimating the dimensions of the active fire line where the Cooling Agent and Retardant will be applied.
- The *Third* is determining the number of aircraft or drops required for each agent used based upon the calculation of the active fire area then using this along with the HPA to get the BTU being generated. (Fuel removal is equivalent to heat absorption, BTU/lb)

First, the ROS is stated in chains per hour as 380. Convert this to Feet/hour by multiplying 380 x 66 = 25,080 feet per hour. Then divide this by 3,600 to get Feet per second. That is your initial first step. You will obtain the ROS of 7 ft/sec. These 7 feet are your fire's "active" width.

Second, you need the fire line length to obtain the area. We'll say for our example it is a mile (5,280ft) long fire line.

The Area is then, 7*ft* x 5,280*ft* = 36,960 square feet.

Next, the BTU per second must be calculated.

Area of 36,960 *sq/ft* x 2,866 BTU/ft^2 = 105,972,360 BTU/sec. Our initial *First* & *Second* steps are complete.

The first step was using the Nomogram to get the final outputs to be used with the second and third factors and that second factor was the estimation of the fire area.

The third factor has 5 parts. 1 part requires you to know the fire's altitude and the water temperature to be used to cool the active fire area. This is important because the heat absorption capacity of water changes with two other factors: Altitude & Water Temperature. We'll say this is at 5,000 feet and then we'll use a water temperature of 50 degrees as in the Q-Ref found on pages 26 & 27(Or on pages 135 & 136 in the Lesson Book). This gives a Thermal Capacity of heat absorption per pound of water of 1,123 *BTU*/lb, once computed as explained on page 25 in the Q-ref (or page 134 in the Lesson Book).

The third factor, 2nd part, requires that you divide the fires estimated BTU generation (determined above), by the thermal capacity of water for the temperature and altitude.

This gives the *Pounds* of water required because the first set of numbers is based upon BTU per pound.

$$\frac{105{,}972{,}360}{1{,}123} = 94{,}325\ lbs\ of\ water.$$

Next, divide the 94,325 *Pounds* by 8.34 (pounds per gallon) to get the gallons required.

$$\frac{94{,}325\ pounds\ required}{8.34\ pounds\ per\ gal} = 11{,}310\ Gallons$$

If you rounded to 106 million BTU, you would have got an answer of 11,318 Gallons.

The third factor, 3rd part. You refer to the Q-Ref and either select a single aircraft if one matches directly or exceeds the Gallon Requirement. As shown on either pages 26 & 27 of the Q-Ref single publication or pages 135 & 136 of the Lesson Book publication, the DC10 fixed-wing tanker holds 11,600 [1]Gallons. Or you could use the approach by taking the 3,000-gallon capacity for the type 1 tankers such as the BAE146, RJ85, MD87, etc., and divide the Gallons Required by the Gallons Carried to obtain the number of loads as shown below.

$$\frac{11{,}310\ Gals\ Req'd}{3{,}000\ Gals\ Capacity} = 3.77, round\ to\ 4 = \ Number\ of\ loads/drops$$

This tells you the number of [2]*Loads or aircraft* you will have to have to achieve good knockdown at a minimum. MAFFS aircraft would be better suited as most of the drop can be placed more closely over the active width. These loads “MUST” be dropped sequentially. Load and Return will not suffice.

Third factor 4th part. Another way to determine the appropriate number of resources is to go back to the originally calculated BTU generated and simply divide this figure by the BTU capacity shown in the Aircraft Data pages. i.e. 3,000 gallons is equal to 28,100,000 BTU.

$$\frac{BTU\ of\ Fire\ Generated}{BTU\ absorption\ of\ Aircraft} = \frac{105{,}972{,}360}{28{,}100{,}000} = 3.7 \text{ Round up to 4.}$$

For an example of this method, let us again take our example fires generated *BTU* output and then divide it by a figure from an aircraft with much smaller capacity and say that we do not have any large aircraft available.

$$\frac{BTU\ of\ Fire\ Generated}{BTU\ Absorption\ of\ Aircraft} = \frac{105{,}972{,}360}{12{,}170{,}000} = 8.7\ Loads\ or\ Aircraft$$

Therefore, if we take the combined *BTU* absorption capacity of say 9, CL215 (scoopers) Type 2 Fixed-wing aircraft that carry 1,300 gallons each, we’d get a *BTU* total of 109,580,094. More than our active fire line is generating. Therefore, the number of aircraft and or aircraft loads will increase or decrease based upon the capacity of each aircraft and the amount of *BTU* being generated. The point is that all aircraft do not have to be the same type and capacity. The idea is to get the combined amount of *BTU* absorption regardless of the different types and models of aircraft being used.

Another such example is if all you have available are 5 seats at 800 gallons each, then, the result would look like this:

$$\frac{105{,}972{,}360}{7{,}500{,}000} = 14.2\ Loads\ \text{(round to 15)}$$

This would further be broken up between the 5 SEATS, so each SEAT needs to drop 3 loads, sequentially. Also to prove our *BTU* absorption capacity of 15 loads of 800 gallons of water works out, we do our math: 800 gallons x 8.34lbs = 6,672 Pounds of water. 6,672 Pounds x 1123 *BTU*/lb = 7,492,656 *BTU* per load x 15 loads = 112,389,840 *BTU* absorption. Why the 15 loads? How else would you carry .2 loads worth in addition to the 14? It must be an extra load.

Third factor 5th part. The Effective Area of Coverage an aircraft can/could provide can be estimated once you know the *BTU* per square foot and the *BTU* Capacity of the resource to be used.

For example: $Fire\ Generated\ BTU/ft^2 = 2{,}866$. Aircraft *BTU* absorption capacity = 28,100,000.

$$\frac{Aircraft\ BTU\ absorption}{Fire\ Heat\ Per\ unit\ Area} = \frac{28{,}100{,}000}{2{,}866} = 9{,}804\ sq/ft$$

If we further take the *known ROS* in feet per second of 7 and then divide the 9,804ft^2 area, by 7*ft* ([5]The active fire width), we'll get an effective run length of:

$$\frac{9{,}804\ sqft}{7\ ft\ sec} = 1{,}400\ feet\ .$$

This is the maximum run length per aircraft and the run length would be a slight percentage less due to an efficiency factor. If we used say .95 for a 95% efficiency factor, then the effective run-length could be estimated at 1,400 x .95 = 1,330 feet. This is since being 100% on target for each aircraft, each drop on every sortie is simply not possible. There are too many variables that can affect drop accuracy. Note: If the terrain is rather steep & jagged, then maybe a .7 efficiency factor would be used. A 1,400-foot run multiplied by a .7 (70% efficiency factor) now is only 980 feet of effective run length. Re computing the number of aircraft/loads is then computed by taking that mile-long line and dividing by the 980 feet, which, you would end up with 5.38, so order up 2 extra aircraft for a total of 6.

Pending the "coverage level", will the 4 aircraft make a mile-long drop then? To be more accurate use a.9 or .95 multiplier to the 1,400. Then re-compute the effective aircraft run to 1,330ft.

1,400 x 4 = 5,600 feet. Yes!

1,330 x 4 = 5,320 feet. Yes!

The ideal coverage to match a HPA of 2,866 $Btuft^2$ would be closer to the following formula:

$$\frac{3{,}000\ \ gals}{9{,}804\ ft^2} = .306 gal/ft^2$$

The .306 gals would be multiplied by the pounds per gallons of 8.34 to determine the total weight, which, comprises 2.552lbs. Then this 2.552lbs would be multiplied by the Btu Absorption capacity of water for the altitude and temperature which is 1,123 Btu/lb.

$$2.552lb\ x\ 1{,}123Btu/lb = 2{,}865.896\ Btu\ per\ square\ foot$$

From this we can derive the gallons per 100 square feet. .306 x 100 = 30.6. Until we can control the drop pattern “Width” and narrow it down so that more of the cooling agent is DIRECTLY over the heat source, we’ll simply have to keep adding aircraft to the mix. MAFFS aircraft would be better on larger fires.

Once the Knockdown of the active flame front is achieved, then you have the [6]LC95 loaded aircraft immediately drop in the same place, to place a CAP of burn inhibitor over the now cooled fuel. The [7]remaining water content in the retardant along with the burn inhibiting characteristics of the retardant should provide a means for crews, Engines, and Dozers to move in to be more effective at control and containment efforts. After all, it is the BTU being generated that keeps such resources at bay and once this knockdown is achieved, due to the large-scale cooling effect, the other resources can move in closer.

Fighting fire in this manner is critical of the timing between aircraft due to the area involved and the amount of residual heat means flare-ups are highly likely.

The aircraft loaded with retardant should be in the air and in the vicinity near the same time as the aircraft with straight water. If you are planning on simply having aircraft load and return with the retardant, you’ll likely find this technique to be sadly ineffective.

After spending the past several months reviewing [3]Rothermel’s & others technical reports, the method described above is believed to offer up the most successful manner to fight large-scale fires with significant *BTU* generation.

Lastly, the $BTU/ft/sec$ figures are the same as the Heat Per unit Area, they are accounting for the ROS. By dividing the $BTU/ft/sec$ figure by the rate of spread in *Ft/sec* gives you the HPA.

The Rate of Spread offers the instant ability to determine where the fire will be in the time frame it will take the aircraft to arrive on the scene to make [4]sequential drops. This should be viewed as that of a nozzle on an engine. If the BTU is too great, the nozzle is ineffective, and you will not be able to engage or get close. Likewise, if there are only intermittent aircraft making drops of random sizes & times then this will have the same effect. The GPM must be matched to the BTU! [5]Wildland Apparatus Engineers Q-Ref pages 26 & 27.

All Fires Generate BTU and Water absorbs $BTU.$ To be truly effective, we have to apply BTU absorption capability equal to or faster than the fire can generate. For example, simply having a 747 Super Tanker on hand loaded to max capacity of 19,000 gallons that takes from 4 to 6 hours to make a round trip, is only delivering an effective gallon per minute capacity of:

$$Egpm(4\ hour\ turn) = \frac{19{,}000gals}{240min} = 79$$

$$Egpm(6\ hour\ turn) = \frac{19{,}000gals}{360min} = 52$$

In this case, 79 Egpm, at the thermal capacity of water of 1,123Btu/lb is only 739,899.78 BTU

On the low side, 52 Egpm thermal capacity, is only 487,022.64 BTU

In this instance, it's not effective if you're dropping LC95 in the trees if the floor is carrying the fire. It (LC95) gets hung up in the canopy and very little to nothing hits the carrier fuels on the forest floor. Further, with LC95, there is less water to absorb the heat (assuming it could absorb heat, it does not). For example, in a full 19,000-gallon load of retardant, there are 3,454 gallons of LC95 and 15,546 gallons of water. Water is your greatest heat-absorbing agent and to be effective, you not only have to drop it directly on the heat source, you also have to have multiple aircraft in the air to drop sequentially. As can be seen above, one aircraft of this size on a *load & return* every four to six hours is simply not effective because there is too much time between loads. This assumes that LC95 would have no toxic side effects and could absorb heat and not pose any toxic dangers. (see the Phos-Chek SDS).

Even though in one drop 19,000 gallons of water absorbs 177.9 million BTU, it will not be effective if you have a fire producing 100 million BTU/Second when there is a 4-hour or 6-hour lag between drops. There is simply too much residual heat to be effective.

15,546 gallons of water absorbs 145,601,037 BTU, whereas 19,000 gallons absorbs 177,950,580 BTU. This is for 5,000-foot altitude & 50-degree water temp.

There is one major problem to the use of this calculation with retardant. It is not dropped on active flame so therefor it effectively has a zero Btu component compared to water. This means if you are not dropping water to cool the area, and then not able to use retardants cooling capacity. You are NOT cooling the fire at all!

Also, I will point out that from 1946 to the present day, not a single technical report reviewed offers up a single method for how to provide suppression of fires or even a possible theory in the suppression of such in all of the reports to which have been reviewed to date. If there are any that state such suppression theories, I would be very interested in seeing their approach.

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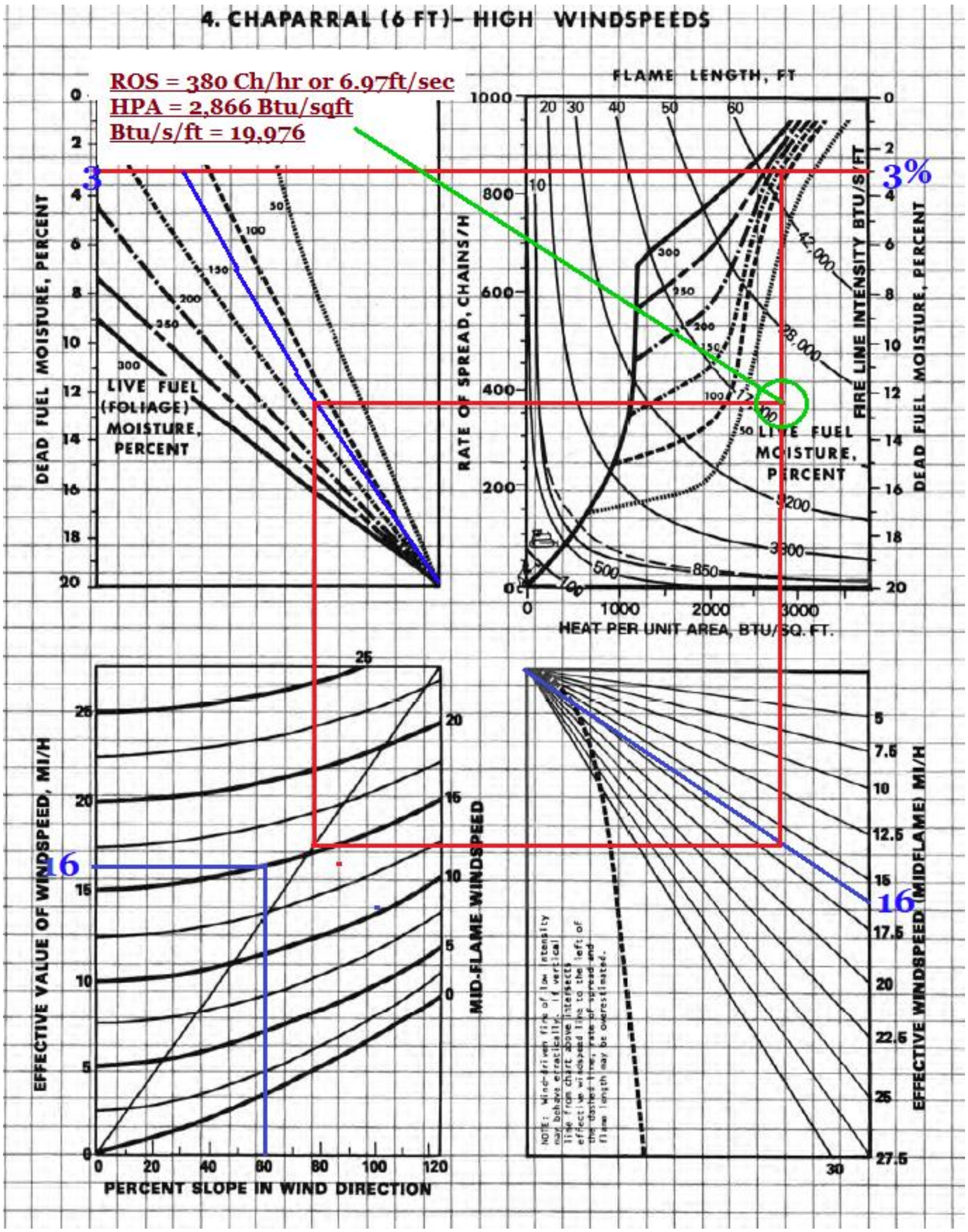


Blue = input figures, RED = output figures

Footnotes

1. The load capacity used herein may not be correct in actual conditions pending density altitude and aircraft load configuration etc.
2. The number of Loads calculated here is NOT for that of LC95 as LC95 does NOT have a calculated or established BTU/lb rating as of date. This only works for Water only loads. Further LC95 & variants produce Phosphoric Acid and Ammonia when exposed to temperatures at 194F.
3. Thanks to Molly Wright (Fire Ecologist) for bringing the awareness of the Rothermel Technical Reports and Other reports & Nomograms to my attention. This was a critical missing element in being able to conceptualize suppression resources and types with estimated fire behavior activity and possible theorized resource arrangement.
4. The Drops must be made in sequential order. Intermittency as normally performed will not provide the required cooling effect by way of the fact that the fire is generating heat continuously, yet if only one aircraft drops an amount of water, then leaves to re-load, in this case only 26% of the amount BTU generated is being absorbed. The adjacent heat radiation will simply re-ignite the fuel before the next drop returns. Sequential dropping is believed to be more akin to that of a constantly flowing nozzle providing exponential cooling capacity more closely matching that of what the fire is producing.
5. The active fire width could be replaced with a known drop width pattern that could be used in place of the fires active width and therefore a better estimate of aircraft run/drop length could be calculated as well as the number of loads required.
6. Once the required cooling has taken place, the LC95 loaded aircraft should drop over the top of the fire to place a burn inhibitor cap over the top of the fuel. This should not present any problems as opposed to higher heats producing the phosphoric acid and ammonia according to phos-chek.
7. Caveat, according to the Phos-Chek Safety Data Sheets, the likelihood of the LC95 retardants and its variants may produce toxic Phosphoric Acid and Ammonia if dropped on active heat above 194 Degrees F. Another reason to ensure the burning fuels are FIRST sufficiently cooled with water first so that the retardant can be made more effective.
8. Aircraft Data from Q-Ref

Aircraft Capacity and Btu per Load

Aircraft Type	Category	Cruise Speed		Capacity indiv?		Cap Total	Btu total Cap?
1,2,3	rotor/fix	Kts	Mph	LC95	Water	Gallons	Million Btu's
1 - RJ85	Fixed	380	437	545	2455	3000	28.1
1- BAE 146	Fixed	380	437	545	2455	3000	28.1
1-C130MAFF	Fixed	238	275	545	2455	3000	28.1
1-MD-87	Fixed	450	517	545	2455	3000	28.1
1-P3A	Fixed	330	380	545	2455	3000	28.1
1-L188	Fixed	310	356	600	2700	3300	30.1
1-C130	Fixed	238	275	727	3273	4000	37.5
1-737-300	Fixed	250	287	727	3273	4000	37.5
1-DC10	Fixed	490	564	2109	9491	11600	108.6
1-747	Fixed	490	564	3454	15546	19000	177.9
1-CH53E	Rotor	150	137	na	na	2000	18.7
1-CH46 sk	Rotor	121	140	na	na	224	2.1
1-CH47D	Rotor	119	137	na	nq	2000	18.7
1-S61	Rotor	133	154	na	na	1000	9.3
1-S64	Rotor	91	105	na	na	2650	24.8
1-S70i	Rotor	159	183	na	na	1000	9.3
1-kmax	Rotor	79	91	na	na	700	6.5
1-AS332L	Rotor	135	156	na	na	2000	18.7
1-B107Vertol	Rotor	121	140	na	na	1000	9.3
1-B234CHnk	Rotor	119	137	na	na	3000	28.1

Use with Fire Behavior Nomograms!

NOTE: The aircraft data sections for pp's 26 & 27, show listings for Maximum Gallon Capacities and may not be reflective of those actually used. The BTU figures are displaying BTU Capacity should those maximum capacities in water be available and utilized.

BAE - 146, MD-87, RJ 85, C130MAFF, ETC

HEAT ABSORPTION CAPACITY OF WATER WORKSHEET

BTU's / Min, per Pound of water

(EXAMPLE)

Desired Flow (GPM)__500____ @ Temp(deg. est)__70____

Flow in GPM __500______ x 8.34 = __4,170________ lbs/minute

Boiling occurs at 212° Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft.

BOILING ____________________ STEAMING ____________________

(Temp to boil @ Alt) – (Tank Temp)

(970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam

5,000 / 1,000 = 5.0
5.0 x 1.84 = 9.2
212.0 - 9.2 = 202.8
Temp to Boil at Alt = 202.8

204° - 70° = 134° each lb of water will be raised 134° to boiling point.

ea. lb will be raised an additional 970btu in the conversion to steam from a boil.

[B]
134 x 4170 lbs/min = 558,780 BTU/Min

[S]
(970) x (4170)lbs/min = 4,044,900 BTU/Lb

S 4,044,900
B 558,780
+
4,603,680 BTU/MIN
x 60
272,220,800 BTU/HR

Desired Flow (GPM)_**3,000**___ @ Temp(deg. est)_**50**___

Flow in GPM _**3,000**___ x 8.34 = _**25,020**___ lbs/minute

Boiling occurs at 212° at Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft. 204° = 4,000ft., 202° = 5,000ft. etc.

BOILING ____________________ STEAMING ____________________

(Temp to boil @ Alt) – (Tank Temp)

(970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam.

202.8 - 50 = btu/lb 152.8

[B]
152.8 ° x 25,020 = 3,823,056
Btu/lb | lbs/min(above) | btu/min
Specific Heat

[S]
(970) x 25,020 = 24,276,906
lbs/min | BTU/min
Latent Heat

[S] + [B] = TOTAL

[S] 24,276,906
+
[B] 3,823,056
=
28,099,962 BTU/~~MIN~~ Total
x 60
= BTU/HR Total

Water Only

Moylan - - Feb 20, 2021

BAE - 146, MD-87, RJ 85, C130MAFF, ETC

HEAT ABSORPTION CAPACITY OF WATER WORKSHEET

BTU's / Min, per Pound of water

(EXAMPLE)
Desired Flow (GPM)__500____ @ Temp(deg. est)__70____

Flow in GPM __500______ x 8.34 = __4,170________ lbs/minute

Boiling occurs at 212° Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft.

BOILING ________________ STEAMING ________________

(Temp to boil @ Alt) – (Tank Temp) | (970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam

204° - 70° = 134° each lb of water will be raised 134° to boiling point. | ea. lb will be raised an additional 970btu in the conversion to steam from a boil.

[B]
134 x 4170 lbs/min = 558,780 BTU/Min

[S]
(970) x (4170)lbs/min = 4,044,900 BTU/Lb

S 4,044,900
B 558,780
\+ ________
4,603,680 BTU/MIN
x 60
____
272,220,800 BTU/HR

5,000 / 1,000 = 5.0
5.0 x 1.84 = 9.2
212.0 - 9.2 = 202.8
Temp to Boil at Alt = 202.8

3,000 / 5.5 = 545.45 (Concentrate = 545.45)

LC95 as of this date has no published btu/lb absorption rating that WAE has been able to ascertain. Thus the BTU absorption capacity MUST be taken off of the water only portion of the entirety of the load.

3,000 - 545.45 = 2,454.55 Gals of water, this is the largest thermal absorbant property of the mixed retardant. The other 545 gals is concentrate and must be considered as a burn inhibitor only. This reduces the total thermal absorbing capability of the entire load.

Desired Flow (GPM) **2,455** ___ @ Temp(deg. est) **50** ___

Flow in GPM **2,455** _____ x 8.34 = **20,474.7** _____ lbs/minute

Boiling occurs at 212° at Sea Level and Boiling occurs at 196.9° at 8,000ft. This works out to 1.84° per 1,000ft. 204° = 4,000ft., 202° = 5,000ft. etc.

BOILING ________________ STEAMING ________________

(Temp to boil @ Alt) – (Tank Temp) | (970)BTU's/lb of water x (lbs/minute flowing) absorption in converting to steam.

202.8 - 50 = btu/lb 152.8

[B]
152.8 ° x **20,474.7** = **3,128,534.16**
Btu/lb | lbs/min(above) | btu/min
Specific Heat

[S]
(970) x **20,474.7** = **19,866,601.41**
lbs/min | BTU/min
Latent Heat

[S] + [B] = TOTAL

[S] **19,866,601.41**
\+
[B] **3,128,534.16**
=
22,995,135.57 BTU/~~MIN~~ Total
x 60
= BTU/HR Total

Mixed LC95

Moylan - - Feb 20, 2021

5.1 million Less Btu than the same amount in 3,000 gallons of straight water "**IF**" it could absorb Heat! In Reality, it is **ZERO!** Phosphoric Acid and Ammonia are/may be produced above 194°*f*

Notes on the procedure used to determine the drop rate in gallons per second for a particular coverage level, Heat Per unit Area and Fire Rate of Spread. Also notes on how to determine proper coverage level for Matching Btu Absorption demands. A coverage level is the number of gallons per 100 square feet. A CL of 3 is 3 gallons per 100 square feet, or .030 gallons per square foot.

1st if we have an air tanker flying at 160 knots. Convert to Feet Per second.

$$160\ Knots\ x\ 1.6878 = 270.1\frac{ft}{sec}$$

2nd Using a Fire active width from the ROS in Feet/sec

$$\frac{100\ ch/hr\ x\ 66ft}{3600} = \frac{6600}{3600} = 1.833ft/\sec$$

3rd Aircraft area covered in square feet per second is then

$$270.1\ x\ 1.833 = 495.1ft^2$$

4th Determine the number of hundreds of square feet

$$\frac{495.1}{100} = 4.951$$

5th Next apply the Selected Coverage Level used to determine gallons per second required for the drop. This is NOT based upon the Btu per square foot factor in this case. We use a CL of 6, 6 gallons per $100ft^2$

$$Gals/square\ foot = \frac{6gals}{100ft^2} = .060$$

$4.951\ x\ 6 = 29.706\ gal/sec$. 29.706 gallons per second divided by the area yields a coverage capacity of 29.706 / 495.1 = .06 gallons per square foot. This only allows for *561 Btu per square foot. If the fire is producing 2,700 Btu per square foot, this would be 4.8 times deficient, or we would need another 5 times the amount of cooling capacity to tackle this. (See #11 for calculating Btu on these figures).

6th Determining aircraft run time is based upon load capacity divided by drop rate.

$$BAE{\sim}146\ Load = \frac{3,000}{29.703} = 101\ seconds\ run\ time$$

7th Aircraft available run length at drop rate is now computed as a function of Aircraft speed in feet per second.

$$101\, \sec x\; 270.1\; ft/\sec\;\; yeilds\; 27{,}280\; feet\; or\; 5.1\; miles$$

This however gives distance but does not take care of the required cooling capacity.

*- see table last page

Focusing now on Fire Btu generation (HPA) plotted against aircraft velocity ($Ft/\sec$) as the new fire line length to determine appropriate coverage level for cooling I obtained the following.

8th Fire parameters, for Fuel model 4; 4% fuel moisture, 125% live moisture. Heat Per unit Area is plotted as 2,700 Btu per square foot. Rate of spread for a 7.5mph wind is 100 ch/hr. The Rate of Spread is plotted at 1.833 feet per second (active width (see #2)). Fire line $Length$ is counted as $270.1ft^{sec}$.

$$Length\; x\;\; ROS = 270.1\; x\; 1.833 = 495.1ft^{2sec}$$

9th The Btu for the area is now taken as the HPA x Area.

$$HPA\; x\; A = \;2700\; x\; 495.1 = 1{,}336{,}770Btu^{sec}$$

10th Determining the drop rate in gallons per second is now calculated using the figure from items 8 & 9.

$$\frac{1{,}336{,}770\;\frac{Btu}{ft}/sec}{1{,}123\;(thermal\; capacity)} = 1{,}190.356\; lbs\; cooling\; agent$$

$$\therefore \frac{1{,}190.356lbs}{8.34\; lbs/gal} = \;142.7gals/sec$$

If we further divide the gals per second required by the area we will arrive at a proper coverage level for cooling effect.

$$142.7\; gals\; per\; second\;\; \div 495.1\; sq\; ft = \;.288\; gal\; per\; square\; foot$$

11th This here shows that a coverage level of 28.8 is actually required. To prove this or "proof" our calculation we then multiply the gal per square foot by the Btu per pound to actually determine if it matches the HPA of 2,700

$$.288\; x\; 8.34 = 2.402\; lbs\; x \frac{1{,}123btu}{lb} = 2{,}697.446Btuft^2$$

Here in #11, we are within 2.554 Btu of complete absorption, and this can be due simply to the precision of the decimal place used. If we round to nearest hundredth, then we have succeeded as .29 gals = $2{,}716Btu$

12th Re calculating to determine the drop rate requires we take the area of the aircraft's rate of speed in feet per second, multiply this by the active width of the fire and multiply by the coverage level computed.

$$(270.1\ x\ 1.833) = \frac{495.1}{100} = 4.951\ x\ CL\ of\ 28.8 = 142.6\ gal/sec$$

13th the Btu absorption of the area covered at the drop rate is thus determined to be.

$$142.6 gals\ x \frac{8.34 lbs}{gal} x \frac{1{,}123 Btu}{lb} = 1{,}335{,}565 Btu^{sec}$$

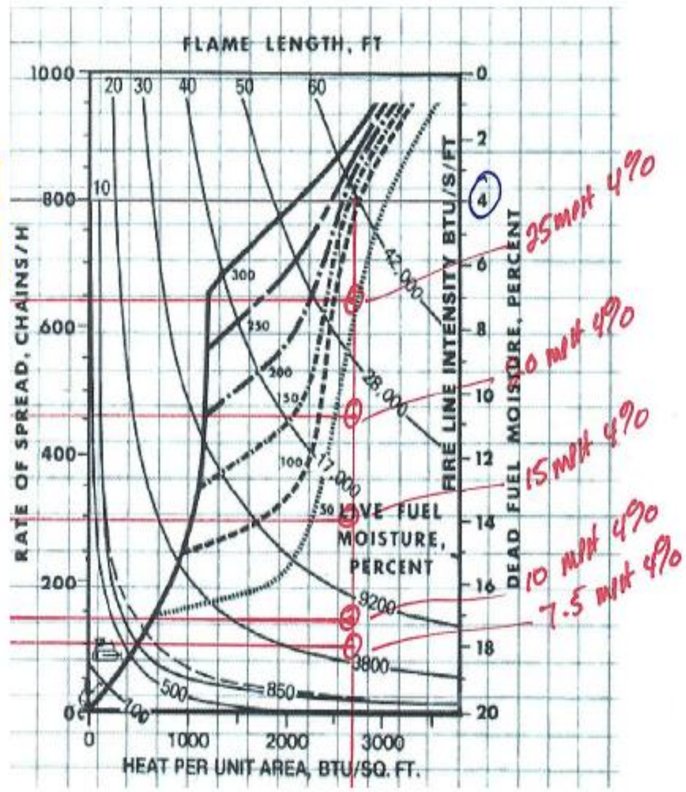
This 1.3 million Btu per second figure is again based upon the distance covered and the amount of cooling agent dropped on a per second basis or rate. The three factors that absolutely need to be remembered are the aircraft speed is converted to feet per second, fire rate needs to be converted to feet per second and drop rate is to be in a per second rate. This has never or is not normally ever done in this manner and is certainly not taught in any of the NWCG courses to which we have reviewed the material for.

Once the amount of water is determined, then the supply infrastructure needs to be setup on the ground to handle this.

Other WAE writings discuss how to facilitate this side of the operation.

Cov Level	Gals/100ft^2	decimal	Gallons	Weight lbs	Btu Cap - per *ft* 5,000*ft* - 50 deg*f*
1	1.00	0.01		0.083	93.209
2	2.00	0.02		0.167	187.541
3	3.00	0.03		0.250	280.75
4	4.00	0.04		0.334	375.082
5	5.00	0.05		0.417	468.291
6	6.00	0.06		0.500	561.5
7	7.00	0.07		0.584	655.832
8	8.00	0.08		0.667	749.041
9	9.00	0.09		0.751	843.373
10	10.00	0.1	1/10	0.834	936.582
11	11.00	0.11		0.917	1,029.79
12	12.00	0.12		1.001	1,124.12
13	13.00	0.13		1.084	1,217.33
14	14.00	0.14		1.168	1,311.66
15	15.00	0.15		1.251	1,404.87
16	16.00	0.16		1.334	1,498.08
17	17.00	0.17		1.418	1,592.41
18	18.00	0.18		1.501	1,685.62
19	19.00	0.19		1.585	1,779.96
20	20.00	0.2	2/10	1.668	1,873.16
25	25.00	0.25		2.085	2,341.46
30	30.00	0.3	3/10	2.502	2,809.75
35	35.00	0.35		2.919	3,278.04
40	40.00	0.4	4/10	3.336	3,746.33

Btu capacity of each coverage level of water at 5,000 feet of altitude and for a useable water temperature of 50 degrees Fahrenheit.



7.5mph wind, 2700 Btu sq ft, 100 ch/hr (1.833ft/sec) x a 1,000ft line length produces 1,833 sqft per second x 2,700btu = 4,949,100 Btu/sec. 1.83ft/s x 2,700 Btu = 4,949.1 Btu/ft/sec.

Explanation sheet. Heat Capacity worksheet on last page.

In order to determine the Btu capacity for a particular gallon per square foot coverage level, the thing to keep in mind, for the most accurate results are to make sure you are using a Btu thermal capacity for the water temperature and altitude where the operations are taking place.

Calculating the Boiling temperature at an altitude.

Altitude we'll state as 4,736 feet MSL. Take the altitude and divide by 1,000 to obtain what WAE calls the Altitude factor. $\frac{4,736}{1,000} = 4.736$. Then this altitude factor is now multiplied by the lapse rate of 1.84 to obtain the total amount subtracted from the Boiling Temperature at Sea Level of $212°f$. To obtain the new boiling temperature at the new altitude.

$$212 - (4.736\ x\ 1.84) = 203.2\ °f$$

Then you need to determine the Specific Heat of a pound of water by subtracting the water temperature from the new boiling temperature. If the water temperature is 48 degrees F, then your specific heat in Btu per pound would be.

$$Sh^{btu/lb} = 203.2 - 48 = 155.2$$

Now you need to factor in the Latent heat of vaporization to this of 970.3 Btu per pound to derive the total Thermal Capacity per pound.

$$Sh + Lh = TC = 155.2 + 970.3 = 1,125.5$$

If there are 8.34 pounds to a gallon of water, then 1,125.5 x 8.34 = 9,386.7 Btu can be absorbed per each gallon of fresh water at this altitude.

Now to determine what .06 gallons per square foot will absorb, first take the gallons and multiply by the pounds per gallon of 8.34 to derive the total weight.

$$.06gal\ x \frac{8.34lbs}{gal} = .5lbs$$

Next multiply this weight by the Thermal Capacity (TC) of the water for the particular water temperature and altitude your fire is at. We'll use the one we already computed as our example. 1,125.5, however, for 5,000 ft and 50 degrees water temperature a Thermal Capacity of 1,123 Btu/lb is obtained.

$$.5lbs\ x\ 1,125.5 = 562.75\ Btuft^2$$

If a Fire Behavior Nomogram (PMS 436-3) projects that you have a Heat Per unit Area of say 1,500 Btu per square foot, then you likely will be short by 937.25 Btu for every square foot of a fire you're trying to suppress.

HEAT ABSORPTION CAPACITY OF WATER WORKSHEET

BTU's / Min, per Pound of water

(EXAMPLE)
Desired Flow (GPM)_____500____@ Temp(deg) Est.____70______.

Flow in GPM ____500____ x 8.34 = ____4,170__lbs/minute

Boiling occurs at 212°ƒ at Sea Level and Boiling occurs at 196.9° ƒ at 8,000ft. This works out to 1.84°ƒ per 1,000ft.

Ex: Altitude of Fire is 5,347ft.

1. Obtain Altitude Factor: Alt ÷ 1,000 = 5.347.
2. Multiply the Altitude Factor by the Lapse Rate: 5.347 x 1.84 = 9.838
3. Subtract 9.838 from Sea Level Boiling Temp to obtain new Boiling temp for New Altitude.
4. 212°ƒ – 9.838 = 202.162°ƒ is new Boiling Temp at 5,347ft msl.

This Specific Heat of Water is calculated from this new Boiling Temperature, NOT sea Level Boiling Temp!

Desired Flow or Amount_______________@ Temperature °ƒ___________(deg est)

Gallons/GPM:____________x 8.34lbs/gal = _______________(lbs/minute)

BOILING _____________________________________ STEAMING _______________________

(Temp to Boil @ Alt) – (Tank Temp)

_______ - ________ = Btu/lb________

970.3 Btu per pound of water is absorbed without an increase in temp in the conversion to steam in the latent heat process.

[B]

_______ X__________ = __________
Btu/lb Lbs/min(above) Btu/min

Specific Heat

[S] + [B] = TOTAL Btu Capacity

Btu/min ÷ 60 = Btu/sec

[S]

(970.3) **X** ________ **=** ____________
Lbs/min BTU/min

Latent Heat

[S] ______________
+
[B]______________
=
______________BTU/MIN Total
rr **x** ____60________
=______________BTU/HR Total

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