Montogue

Quiz SL103

WILDFIRES

Lucas Monteiro Nogueira

PROBLEMS

Conversation Starter

In 2018, a transdisciplinary team of researchers published a concept paper in the journal *Fire* wherein a standard term for large fires was established. What is this term?

A) Extremely large fire.
B) Massive woodland fire.
C) Extreme wildfire event.
D) Standardized megafire.

Problem 2

Regarding various aspects of wildfire science, true or false?

1.( ) There are two basic flame structures depending on when the mixing process of the gaseous reactants takes place: in *premixed flames*, fuel and oxygen are mixed well before combustion, whereas in *diffusion flames*, fuel and oxygen are initially separated and mixed at the flame location at the same instant as the combustion takes place. Wildfires exhibit diffusion flames with negligible presence of premixed flames.

2.( ) Moisture in forest fuels acts to retard the rate of combustion. If the effects of weather are disregarded, one of the most significant factors affecting the amount of water held and transported in woody and vegetative particles is chemical composition. Plant cell wall composition is mainly constituted of cellulose, hemicellulose, lignin, and extraneous or extractive matter (resins, sugars, fatty acids). Of these, lignin has the greatest hygroscopicity or affinity for water.

3.( ) Lighting is the primary natural source of forest fires in the world. Thunderstorm activity in the Pacific Northwest is mild compared to the southeastern United States, but is usually accompanied by lower precipitation. As a result, fire regimes in a typical conifer forest in Washington state are generally more severe than those of, say, Alabama.

4.( ) McGee *et al.* (2015) have reviewed wildfire science in Canada in a recent volume. In their report, Canadian forest cover was divided into four regions: Boreal Forest Region; Montane, Subalpine, and Columbia Forest Region; Deciduous and Coastal Forest Region; and Great Lakes-St. Lawrence Forest Region. Although the Boreal Forest Region encompasses the largest land area, the incidence of fires is actually greatest in the Great Lakes-St. Lawrence portion of the country, which exhibits year-round severe fire episodes in its red and eastern white pine woodlands.

5.( ) Australia houses some of the world’s lushest, most diverse woodlands, which also happen to be quite susceptible to fire. The country’s aggressive fire management policies have minimized the damage of conflagrations such as 2009’s “Black Saturday,” which, in spite of its extensive material damage, came and went without the massive number of casualties of past episodes – including the “Black Friday” of 1939, which killed 71 people.

6.( ) Anglophone research on wildfire behavior began with experimental studies in the United States about a century ago, and was followed by efforts in Canada in the 1930s and in Australia in the 1960s. One important achievement in these early efforts was the development of the first empirical formula for the rate of increase of the fire perimeter as a function of wind velocity and fuel moisture content, devised by researchers of the Canadian Forest Service in 1940.

7.( ) The study of the relationship between fire spread and vegetation structure with the goal of predicting fire danger has a long history in the United States. Standardization attempts converged in 1972, with the creation of the National Fire Danger Rating System (NFDRS). In the same year, Rothermel published his celebrated fire spread paper and defined 11 fuel models based on those used in the NFDRS. Later, Albini extended these models to what are today deemed the 13 stylized fuel models, which were described in detail in a 1982 publication by H.E. Anderson of the USDA Forest Service. Anderson intended to extend the model to the Rothermel model to the widest range of uses, including fire behavior estimates in prescribed fires and simulations of transition to crown fire when using crown fire initiation models.

8.( ) In the 2016 version of the US National Fire Danger Rating System (NFDRS), live fuel moistures are controlled by a simple parameter, the growing season index (GSI). This variable is a simple metric of plant physiological limits to photosynthesis and varies from zero to one according to three determining factors, namely minimum temperature for biochemical processes, vapor pressure deficit, and photoperiod.

9.( ) Since its conception, the Canadian Forest Fire Danger Rating System (CFFDRS) has become the most widely adopted fire danger parameter in fire-prone areas around the world, because it is easy to use and can be adapted to a variety of environments. Indeed, the CFFDRS has been successfully implemented in forest environments as varied as Portugal, Indonesia, and Argentina. More recently, the CFFDRS was found to serve as an excellent fire danger forecasting tool for bushfires in New Zealand and prescribed fires in the British uplands.

10.( ) Boreal conifer forests are some of the most widely studied fire-prone environments in the world. Because these forests are often densely stocked and occur as large monocultures, fires can travel from one tree crown to another above a rapidly moving surface fire; this form of spread is very common in boreal wildfires and is termed an *active* crown fire. In contrast, a *passive* crown fire creeps up from the surface along ladder fuels or by direct scorching. Active crown fires are common in boreal upland forest communities under closed-canopy conditions and passive crown fires are typical in open-canopy lichen woodlands.

11.( ) In the 1980s, Haines developed the Lower Atmosphere Stability Index, or Haines Index, for fire weather use. It is used to indicate the potential for wildfire growth by measuring the stability and dryness of the air over a fire. The Haines Index can vary between 2 and 6; the drier and more unstable the atmosphere is, the greater the index.

12.( ) In the Canadian Fire Weather Index (FWI) system, the FWI is ultimately given as a combination of two dimensionless parameters, namely the initial spread index (ISI) and the build-up index (BUI).

13.( ) In a paper published in the 1970s, van Wagner used statistical distributions to model fire disturbance frequency. Van Wagner's idealized scenario assumes a simple forest on a uniform site, composed of many equal-sized stands, all of equal flammability regardless of age. Climate is uniform, so that lightning, over the study period, causes an equal number of fires per year at random, and each fire burns only one stand. Van Wagner then showed that the frequency of an age class x follows a geometric distribution. If p is the probability of a fire in any single year, and the fire cycle exceeds 20 yr, so that $p < 0.05$, the distribution can be approximated by a negative exponential distribution,

$$f(x) = p \times e^{-px}$$

where $f(x)$ is the frequency of an age class and p is the probability of fire in any one year. The random nature of the fire starts means that some stands may not burn during a fire cycle, whereas other stands may burn more than once. In fact, a Poisson distribution in which the mean is 1 (in other words, the average number of fires per stand in one cycle is 1) fits this situation nicely. Thus, the probability of a stand burning 2 times during one cycle is greater than 20%.

14.( ) In the 1970s, Heinselman defined the concept of *natural fire rotation* (NFR), one of the first approaches to determination of area frequency of fires. If an area of 12,000 ha had a total of 30,000 ha burned in 200 years, its NFR is greater than 75 years.

15.( ) Bark thickness can be a critical factor in determining plant survival. Western larch, Douglas fir, and ponderosa pine all have bark thicker than associated species, and are more likely to survive fires of low to moderate severity. A critical time for cambial kill of a tree exposed to fire can be calculated as a function of bark thickness. One such relationship available in the literature, based on a fire temperature of 500°C, is $t_c = 2.9x^2$, where t_c is the critical time to cambial kill in minutes and x is bark thickness in cm. According to this equation, a tree with bark thickness of 27 mm, independently of other deleterious aspects of the fire, should withstand burning for less than 25 minutes.

16.( ) Realistic crown mortality assessment requires the integration of crown scorch height with crown dimensions of an individual tree. For completely scorched trees, crown morphology may not be relevant, as the entire crown may be killed. For taller trees, the base of the live crown, the shape of the crown, and the height of the tree will influence the proportion of the tree crown that is likely to be killed. Proportion of crown volume killed is a better predictor of postfire tree condition than scorch height because the former is more highly associated with injury to the tree than the latter.

17.( ) In the 1950s, Yih formulated the temperatures reached in a turbulent plume resulting from an idealized source of heat and derived the equation

$$\Delta T = \frac{kI^{2/3}}{z}$$

where ΔT is the temperature increase above ambient at a height z above the line source of intensity I (measured in power output per unit length), and k is a proportionality constant. This equation applies to locations directly above the stationary source, i.e., when $x = 0$. Elsewhere, the temperature distribution, also derived by Yih, is given by

$$\Delta T = \frac{kI^{2/3}}{z}\exp\left(-x^2/\beta^2 z^2\right)$$

where x is the horizontal distance from the source and β is an entrainment constant. Although Yih's results in principle apply only for a stationary line source in a quiescent atmosphere, van Wagner (1973) successfully applied a variation of the model to estimate temperature rise above wildland fires. More recently, Mercer and Weber (2001) successfully applied the model to a set of woodland fire temperature measurements in southern Australia. They concluded that the Yih model accurately describe temperatures from the lowest to highest distances above ground. What's more, they found that the plume constant k had a scale-invariant value of $4.47\ \mathrm{K{\cdot}m^{5/3}{\cdot}kW^{-2/3}}$ that accurately fitted the entire data range.

18.( ) One important development in wildfire characterization was Byram's 1959 definition of *fireline intensity*, which is given by the product of heat of combustion, amount of fuel consumed in the active flaming front, and the linear rate of fire spread. In the English system of units, fireline intensity is expressed as (Btu × sec)/ft.

19.( ) One of the earliest applications of fireline intensity was the correlation between FLI and flame length, for which Byram himself derived the simple power law

$$L = 0.0775 \times I_B^{0.46}$$

where L is fire length in m and I_B is fireline intensity in kW/m. Research conducted since Byram's 1959 paper has revealed, most recently in a 2012 state-of-knowledge review by Alexander and Cruz, that the above relationship between flame length and FLI holds regardless of fuel type.

20.( ) In the 1980s, Catchpole *et al.* employed Byram's fireline intensity concept and first principles of parametric geometry to model the propagation of an elliptical fire. Among their results, it was shown that the total fire flux varies linearly with time.

21.( ) A fire descriptor that is gaining popularity is the so-called fire radiative power (FRP). Usually expressed in watts, FRP is a measure of the rate of radiant heat output from a fire. Its advantages include the availability of continuous, daily observations since the MODIS sensor was launched in 1999 and a strong correlation with fireline intensity.

22.( ) One of the most widely used rate of spread models in Australia is the McArthur set of equations for grassland fires and forest fires. The McArthur model, first published in 1966, is based on Mallard and Le Chaterlier's theory of premixed flames and hence constitutes an important step forward relatively to models published up to its time, which were mostly based on statistical treatments of data.

Statements 23 – 30 refer to the Rothermel fire spread model. Those who have read the review by Andrews (2018) should easily evaluate these statements.

23.( ) The Rothermel fire spread model has enjoyed ample use by wildfire analysts all over the world since it was published in 1972. In the Rothermel fire spread model, the rate of spread of a fire, usually expressed as feet per minute (ft/min), is formulated as the ratio of a heat sink, the numerator, to a heat source, the denominator.

24.( ) The model assumes a linear flame front and calculates spread rate of a head fire with or without wind or slope. The limitations of the Rothermel approach must be recognized: the model is not applicable to crown fire in overstory trees, smoldering ground fire, or post-frontal combustion of fuels after the front has passed.

25.( ) In his formulation of fire spread rate, Rothermel introduced the effects of wind and slope in the form of multiplication factors. Later, in Albini's 1976 introduction to the FIREMOD program, an upper limit was imposed on the effect of slope, which Forest Service fire analysts named the "maximum reliable slope." Rate of spread is modeled as constant for slopes greater than the MRS. This limitation was later incorporated in nomographs and software such as BehavePlus.

26.( ) In the Rothermel fire spread model, optimum reaction velocity is a factor in the calculation of reaction intensity. It is a measure of the rate of fuel consumption. The ORV increases monotonically with surface-area-to-volume ratio and relative packing ratio, especially the latter; the more tightly packed the fuel particles, the greater the reaction velocity.

27.( ) Another crucial parameter in the Rothermel fire spread model is the reaction intensity, which is a measure of the energy release rate per unit area of combustion zone. In general, it is true that reaction intensity increases with

→ Increasing optimum reaction velocity:
→ Increasing heat content;
→ Decreasing fuel moisture;
→ Decreasing mineral content;

28.( ) Yet another quantity required for calculations with the Rothermel fire spread model is the heat of preignition, which is an exponential function of fuel moisture content.

29.( ) In the Rothermel fire spread model, there exists some value of dead fuel moisture content for which the dead fuel can no longer sustain a spreading surface fire. This is the incorporated in the model as the dead fuel "moisture of extinction." The 11 fuel models published in Rothermel's original paper all had a 30 percent moisture of extinction.

30.( ) The Rothermel model, first published in 1972, has been the cornerstone of a number of forecasting and analysis tools produced by the USDA Forest Service in the previous decades. One fundamental example is FARSITE, a GIS-based software that can calculate the spread of a fire perimeter. FARSITE offers insight on the kinematics of wildfire propagation, but, as of versions of the software made available in the early 2010s, the program does not afford physical data such as fireline intensity, flame length, and spotting distance among its output variables.

31.( ) Burned boreal forests can be recolonized by certain animals and become vigorous ecosystems. Species that thrive in fire residual environments are said to be *pyrophilous* or "fire loving." Some of the earliest species to conquer these environments are lepidopterans such as the moth *Melanophila acuminata.*

32.( ) Some species of pyrophilous beetle that inhabit boreal forests reach epidemic levels only when triggered by periodic disturbances such as wildfires, which produce a large supply of ideal hosts in the form of stressed or dead trees. Accordingly, from a biodiversity point of view, the survival of these species is a concern where fire is routinely suppressed and deadwood is in short supply. Researchers have recommended reintroducing fire in areas where wildfires have been suppressed for long periods as a means of conserving the diversity of saproxylic insects.

33.( ) Although pyrophilous insects may thrive in post-fire boreal forest environments, larger animals are not nearly as fortunate. Observations carried out over the years in Canadian woodlands have shown that small mammals such as the deer mouse cannot survive in a nutrient-poor residual forest; they must travel to a living habitat or die.

34.( ) One common forest management practice after wildland fires is salvage logging, the extraction of burned timber or remaining green patches after a conflagration has been extinguished. In boreal forest landscapes, harvesting timber in wildfire footprints has become a routine practice and in some jurisdictions where the occurrence of large wildfires is common policies implemented by government agencies (e.g., in Canada) have encouraged the practice. Since the 1990s, monitoring of salvaged residual forests by ecologists has produced consistently positive results, showing, for instance, that the biodiversity of salvaged residuals is no different from that of untouched post-fire woodlands.

▶ Problem 3

Van Wagner's model for predicting crown fire initiation has been implemented within many fire modeling or decision support systems. His model can be represented by the composite equation

$$I_0 = \left[0.01\times CBH\times\left(460+25.9\times FMC\right)\right]^{1.5}$$

where I_0 is the critical fireline intensity in kW/m, *CBH* is the canopy base height in m and *FMC* is the foliar moisture content in %. The onset of crowning is expected to occur when the surface fireline intensity I_B meets or exceeds I_0. Consider a flame of 1.2-m length burning a generic conifer of 3 m canopy base height and 60% foliar moisture content. Per Van Wagner's criterion, will crowning occur? Use Byram's correlation to compute fireline intensity (see statement 19 of Problem 2).

α) Crowning will occur.
β) Crowning will not occur.
γ) There is not enough information.

▶ Problem 4

Smoldering fires are arguably the most persistent combustion phenomena on Earth. Smoldering megafires in peat and coal deposits occur with some frequency during the dry season in, for example, North America, Siberia, the British Isles, the sub-Arctic, and Southeast Asia. Experience has shown that smoldering fires

A) are easier to ignite and easier to suppress than flaming fires.
B) are easier to ignite and harder to suppress than flaming fires.
C) are harder to ignite and easier to suppress than flaming fires.
D) are harder to ignite and harder to suppress than flaming fires.

SOLUTIONS

P.1 ➡ *Solution*

The term appears in the very title of the paper, *Defining Extreme Wildfire Events: Difficulties, Challenges, and Impacts*. The authors proposed a fire severity scale with seven levels, of which levels 5 to 7 are designated as EWEs.

- The correct answer is **C**.

P.2 ➡ *Solution*

1. True. Indeed, forest fires are primarily diffusion fires.

2. False. In general, hygroscopicity of tree constituents follows the sequence cellulose > hemicellulose > lignin > extractive matter.

3. True. Thunderstorm activity is milder in the Pacific Northwest; places such as Baker, Oregon, and Walla Walla, Washington average between 10 and 15 thunderstorm days per year, while Mobile, Alabama register over 70 such events per year. However, the average annual number of lightning fires is greater in the West because less precipitation accompanies the thunderstorms. The area around Mobile averages no more than 25 lightning fires per million ha per year, compared to 25 – 100 in the Pacific Northwest. Less than 2 percent of annual fire occurrences in the Southeast, Northeast and Midwest are lightning ignited, while in the Pacific states 37 percent of all ignitions are from lightning.

Reference: AGEE, J. (1993). *Fire Ecology of Pacific Northwest Forests.* Washington: Island Press.

4. False. In actuality, most wildfire activity in Canada occurs in the Boreal Forest Region. In their paper, McGee *et al.* (see reference below) state that the area burned by large (> 200 ha) wildfires in the boreal forest accounted for 92% of the total area burned in Canada between 1959 and 2007. Wildfires in Canada's boreal forests are characterized by infrequent, large (> 200 ha), high-intensity crown fires.

Reference: McGee, T., McFarlane, B. and Tymstra, C. (2015). "Wildfire: A Canadian Perspective." In: PATON, D. (Ed.). *Wildfire Hazards, Risks, and Disasters.* Amsterdam: Elsevier.

5. False. In addition to a whopping US$1.3 billion in damages, the fires of Black Saturday claimed the lives of 173 people, becoming Australia's deadliest conflagration to date. The fire burned an area of about 450,000 ha.

6. False. The groundbreaking relationship in question was written by J.R. Curry and W.L. Fons of the US Forest Service in 1938. The authors published their results in the *Journal of Agricultural Research*. Their work was a pioneering effort in that it included physical aspects of fire behavior, but it shared with other contemporary studies an important limitation, namely its purpose: the authors' model was intended for use in fire-danger rating systems. Research purely dedicated to physicochemical dynamics of wildfires had to wait until the second half of the twentieth century.

7. False. In the 1982 publication in question, Anderson (see references below) mentions that the 13 original fuel models were designed to 'make fire behavior estimates for the severe period of the fire season when fires pose greater control problems.' This means that these may not suit other purposes, such as fire behavior estimates in prescribed fire or simulation of the effects of fuel transition to crown fire when using crown fire initiation models. In order to broaden the application of the Rothermel fire model in a greater variety of situations, Scott and Burgan (also at the USDA Forest Service) published a new set of 40 standard fire behavior fuel models in 2005.

References:

→ Anderson, H. (1982). "Aids to determining fuel models for estimating fire behavior." Ogden: USDA Forest Service.

→ Planas, E. and Pastor, E. (2013). "Wildfire behavior and danger ratings." In: BELCHER, C. (Ed.) *Fire phenomena and the Earth System*. Hoboken: John Wiley and Sons.

8. True. Indeed, growing season index is a function of minimum temperature, vapor pressure deficit, and photoperiod. The following table lists the upper (GSI = 1) and lower (GSI = 0) limits used in determination of this parameter.

Input variable	Unconstrained (GSI = 1)	Completely limiting (GSI = 0)
Minimum temperature	5°C/41°F	−2°C/28°F
Vapor pressure deficit	900 Pa	4100 Pa
Photoperiod (daylength)	11 hours	10 hours

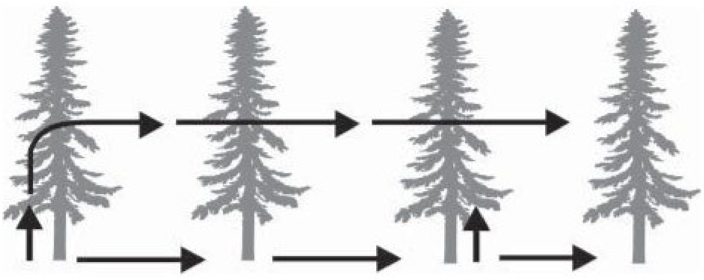
9. False. The two examples cited at the end of the statement are false. Anderson (see reference below) reported that the CFFDRS did not yield reliable results in bushfires in New Zealand. Likewise, Davies (see reference below) found that the Canadian Wildland Fire Information System (CWFIS, a GIS platform that includes fire danger maps based on the CFFDRS) did not accurately predict rate of spread because the moisture content of live or dead *Calluna vulgaris*, the heather that dominates the UK moorlands, was not accurately modelled by any of the moisture codes of the CWFIS.

References:

→ Anderson, S. (2009). Future options for fire behaviour modeling modeling and fire danger rating in New Zealand. *Proceedings of the Royal Society of Queensland*, 115:119 – 127.

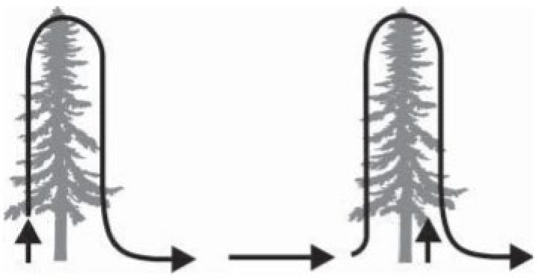
→ Davies, G., Legg, C., Smith, A. and MacDonald, A. (2006). "Developing shrub fire behavior models in an oceanic climate: burning in the British uplands" In: Viegas, D. (Ed.) *Proceedings of the V International Conference of Forest Fire Research.* Figueira da Foz, Nov. 27 – 30, 2006. Amsterdam: Elsevier.

10. True. The two types of fire propagation behavior are schematically illustrated below; illustration (a) refers to active crown fires, while illustration (b) pertains to passive crown fires.



Fire spread

(a)

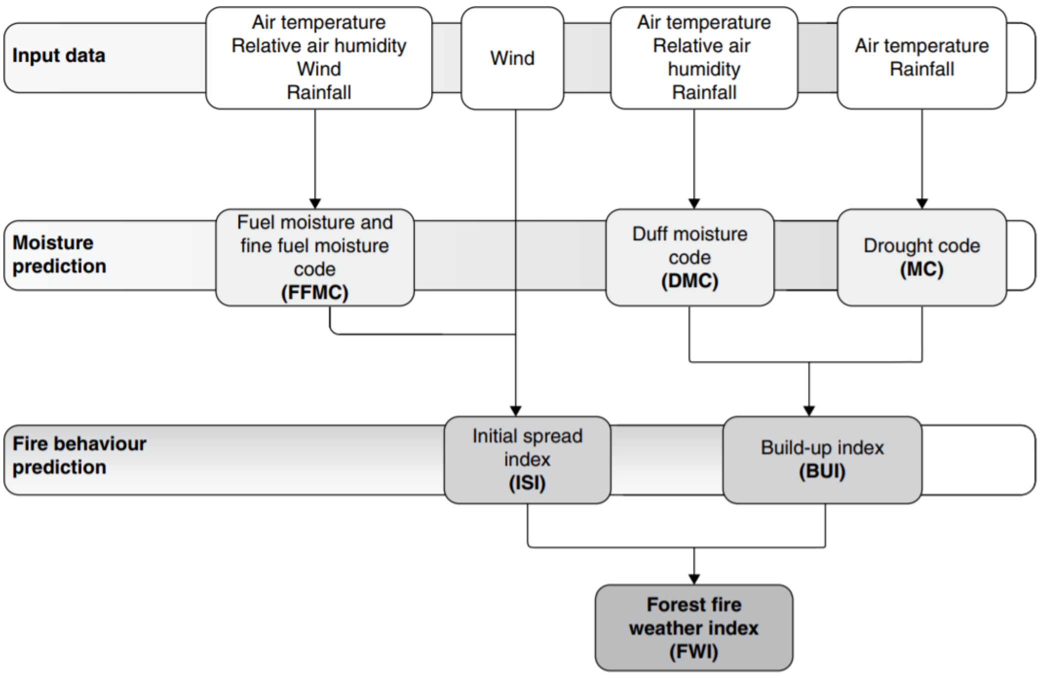


Fire spread

(b)

11. True. As mentioned in the website of the US Wildland Fire Assessment System (WFAS), *the Haines index is a measure of how readily atmospheric conditions roughly 1 to 3 km above the ground would support the development of a large or erratic plume-dominated wildfire.* The Haines index ranges from 2 for very low potential (moist, stable lower atmosphere) to 6 for very high potential (dry, unstable lower atmosphere).

12. True. The FWI is a function of the initial spread index (ISI) and the build-up index (BUI), as illustrated in the next page. The FWI is obtained by combining the initial spread index (ISI), which represents the expected relative fire rate of spread, and the build-up index (BUI), which is an indicator of the availability of coarse woody fuels and layers of organic matter.



13. False. In line with the information provided in the statement, the probability of a stand burning *n* times in one cycle is $e^{-1}/n!$ and the probability of survival throughout an entire cycle would be e^{-1} or 36.8%. With $n = 2$, we get a probability of $e^{-1}/2! = 18.4\%$.

14. True. The NFR is the ratio of the total time period considered to the proportion of area burned in the period. In the present case,

$$\text{NFR} = \frac{\text{Total time period}}{\text{Proportion of area burned in period}}$$

$$\therefore \text{NFR} = \frac{200}{\frac{30{,}000}{12{,}000}} = 80 \text{ yr}$$

15. True. All we have to do is substitute $x = 2.7$ cm in the correlation, giving

$$t_c = 2.9x^2 = 2.9 \times 2.7^2 = 21.1 \text{ min}$$

16. True. Crown scorch volume and scorch height are commonly used to estimate damage to conifers after fire. In a 1985 paper, Peterson (see reference below) compared observed scorch volume for four conifer species of the Rocky Mountains with calculated scorch volume based on scorch height and tree dimensions. Calculated crown volume was significantly greater than observed crown scorch volume for all species. The overestimates are the result of differences among species and trees of varying crown shape. When postfire condition was evaluated from observed crown scorch volume rather than from measured scorch height, crown damage was estimated with greater accuracy. As a result, Peterson concluded that functions that estimate postfire tree mortality based on crown damage should be based on observed crown scorch volume rather than scorch height.

Reference: Peterson, D. (1985). "Crown scorch volume and scorch height: estimates of postfire tree condition." *Canadian Journal of Forest Research*, 15(3): 596 – 598.

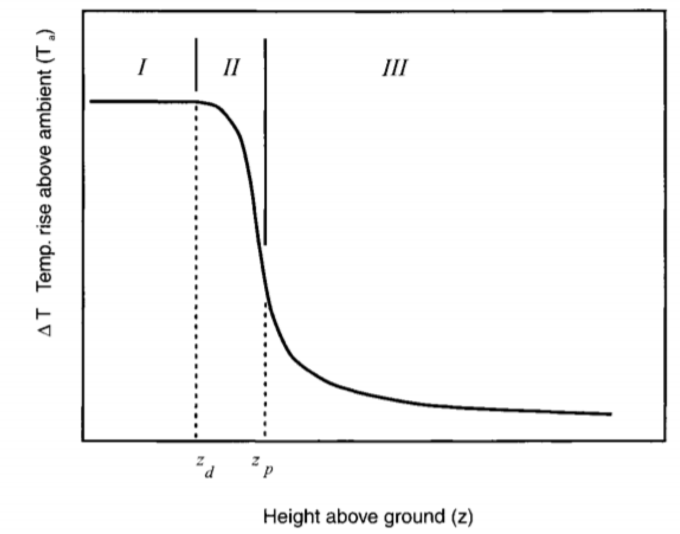
17. False. The reality is a little more complicated. Mercer and Weber (see reference below) found that a three region model for different distances above ground encapsulated the data better than a simple fit to the Yih equation. The equations that describe the three regions are listed below,

$$I.\ \Delta T_I = K \ ;\ 0 \le z \le z_d$$

$$II.\ \Delta T_{II} = K \exp\left[-\alpha\left(z - z_d\right)^2\right] \ ;\ z_d \le z \le z_p$$

$$III.\ \Delta T_{III} = \frac{C}{z} \ ;\ z \ge z_p$$

where K, C, α, z_d, and z_p were constants to be determined. The authors observe that, had they employed Yih's equation as a modeling tool, a key limitation would be the evaluation of plume constant *k;* there is no reason to expect that in such a simple model *k* could be a universal constant. Accordingly, the authors have attempted to shift the emphasis away from finding universal constants, attempting instead to establish a three-region model that could describe the temperature distribution of a fire plume just as well, or likely better, than the Yih equation.



References:

→ Mercer, G. and Weber, R. (2001). “Fire plumes.” In: JOHNSON, E. and MIYANISHI, K. *Forest Fires: Behavior and Ecological Effects*. San Diego: Academic Press.
→ Van Wagner, C. (1973). “Height of crown scorch in forest fires.” *Canadian Journal of Forest Research*. 3:373 – 378.

18. False. Recall that heat of combustion is given in Btu/lb, the amount of fuel consumed in the active flaming front is given in lb/ft^2, and the linear rate of fire spread is given in ft/s. Substituting units in the definition of FLI brings to

$$I_B = HwR = \left[\frac{\text{Btu}}{\text{lb}}\right]\times\left[\frac{\text{lb}}{\text{ft}^2}\right]\times\left[\frac{\text{ft}}{\text{s}}\right] = \frac{[\text{Btu}]}{[\text{ft}]\times[\text{s}]}$$

19. False. The relationship between flame length and fireline intensity is by no means universal; it in fact depends of fuel type. The 2012 paper by Alexander and Cruz (see reference below) compiled 20 such power laws published between 1959 and 2009, including models devised for forest fuels, shrublands, grasslands, and purely laboratorial data.

Reference: Alexander, M. and Cruz, M. (2012). “Interdependencies between flame length and fireline intensity in predicting crown fire initiation and crown scorch height.” *International Journal of Wildland Fire*, 21:95 – 113.

20. True. The equation derived by Catchpole *et al*. (see reference below) is

$$\Phi = 2\pi H w a^2 f h t$$

where H is heat of combustion, w is the mass of fuel consumed per unit area, a is the rate of spread, f and h are parameters associated with wind conditions, and t is time.

Reference: Catchpole, E., De Mestre, N. and Gill, A. (1982). “Intensity of fire at its perimeter.” *Australian Forest Research,* 12:47 – 54.

21. True. At least two recent papers in the *International Journal of Wildland Fire* have shown that the FRP can be in fact correlated to Byram’s fireline intensity; see the first two references below. What’s more, methods for using FRP to quantify intensity differences between fires/regions have been successfully prototyped; see the third reference below.

References:

→ Johnston, J., Wooster, M., Paugam, R., Wang, X., Lynham, T., and Johnston, L. (2017). “Direct estimation of Byram’s fireline intensity from infrared remote sensing imagery.” *International Journal of Wildland Fire*, 26:668 – 684.
→ Kremens, R., Dickinson, M. and Bova, A. (2012). “Radiant flux density, energy density and fuel consumption in mixed-oak forest surface fires.” *International Journal of Wildand Fire*, 21:722 – 730.
→ Kumar, S., Roy, D., Boschetti, L. and Kremens, R. (2011). “Exploiting the power law distribution properties of satellite fire radiative power retrievals: A method to estimate fire radiative energy and biomass burned from sparse satellite observations.” *Journal of Geophysical Research*, 116:D19303.

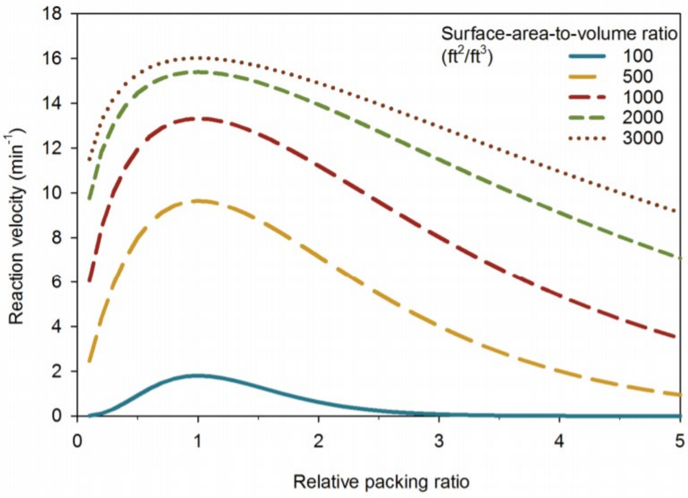
22. False. The McArthur models make no attempt to include any physical mechanisms for fire spread; rather, they are a purely statistical description of test fires. The McArthur models were developed and tested in dry grassland and forest litter in Southeastern Australia during dry winter months.

23. False. In the Rothermel fire spread rate equation, the heat source appears in the numerator and the heat sink appears in the denominator.

24. True. Indeed, the three situations mentioned at the end of the statement are outside the scope of the Rothermel model in its original formulation. The Rothermel model does require significant assumptions and possess recognized limitations; nevertheless, it has important strengths, including the simplicity of input requirements and calculations and the possibility of changing many driving variables.

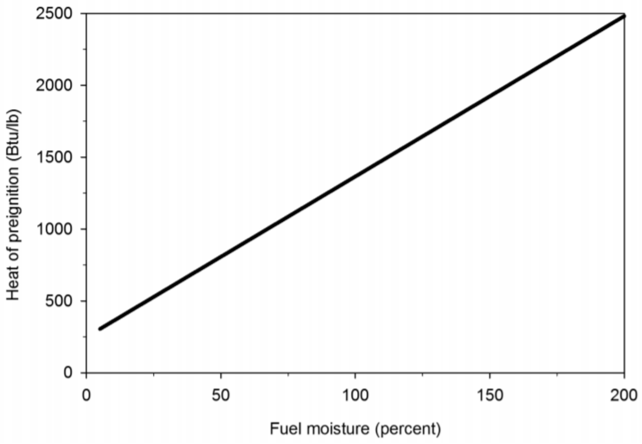
25. False. In actuality, an upper limit was imposed on the wind factor, not the slope factor. This adjustment was present from Rothermel's very first publication and came to be called "maximum reliable wind" by Albini, who established it as 90% of the reaction intensity (I_R); rate of spread is modeled as constant for wind speeds greater than that value. Implementation of this limit was gradual. In FIREMOD, a footnote indicated if the wind limit was reached but the calculated rate of spread was not changed. BehavePlus5 added the option of either imposing the limit or not. More recent software, including FARSITE and FlamMap, always impose the limit. The validity of this adjustment has been debated, with experienced authors advising against it.

26. False. While it is true that optimum reaction velocity increases monotonically with surface-area-to-volume ratio, the relationship of ORV and packing ratio is not so simple. As shown below, experimental data shows that reaction velocity increases as packing ratio increases from 0 to 1, at which point reaction velocity is at a maximum. As packing ratio increases above optimum packing ratio (relative packing ratio increases above 1), reaction velocity decreases as the fuel is more tightly packed. Reaction velocity is generally higher for higher SAV, finer fuels.



27. True. Indeed, the greater the ORV and the fuel's heat content, the greater the reaction intensity. Likewise, the lower the fuel's water and mineral contents, the greater the reaction intensity.

28. False. The heat of ignition varies linearly with fuel moisture content, as illustrated below. As moisture increases, heat of preignition increases and, since it appears in the denominator (heat sink) term of the Rothermel equation, rate of spread decreases.



29. True. Indeed, Rothermel attributed a 30% moisture of extinction to all 11 fuel models published in his initial paper. Later efforts, including the 40 expanded fuel models published in 2005, had variable moistures of extinction. In the Rothermel fire spread model, if the dead fuel is wetter than the moisture of extinction, the model predicts no spread and no reaction intensity, but in reality live fuel alone can propagate a fire. Therefore, the concept of moisture of extinction, although convenient, in fact makes the fire spread model less realistic.

30. False. FARSITE and BehavePlus do include empirical and quasi-empirical mathematical equations to model physical fire properties such as fireline intensity, flame length, and spotting distance, as well as fire effects on the crown scorch height and on tree mortality.

31. False. Beetles, not moths or butterflies, are usually the first insects to invade boreal fire residual environments. *Melanophila acuminata* is the scientific name of the black fire beetle, an exceptional fire-loving organism that can detect smoke plumes from as far as 50 km. Such species, including the genera *Melanophila* and *Oxypteris*, also appear to be attracted by the infrared radiation from wildfires and by volatile compounds that emanate from severely stressed or dying trees.

32. True. Indeed, suppressing fire in some boreal forests has had an impact on the biodiversity of boreal ecosystems. One group of researchers (quoted in the reference below) found aggressive fire suppression to be the reason of the near-extinction of several pyrophilous species in Fennoscandia. Some boreal pyrophilous insects are rare and have been red-listed for potential extinction. Use of controlled burns to provide a habitat for fire-loving insects has been successfully attempted; one group of researchers (also quoted in the reference below) has shown that controlled burns in Norway spruce increased the species diversity of pyrophilous beetles.

Reference: PERERA, A. and BUSE, L. (2014). *Ecology of Wildfire Residuals in Boreal Forests*. Hoboken: John Wiley and Sons.

33. False. Life of higher animals in forest residuals is in fact viable, especially one or two years after the end of a fire. Some small mammals, such as the deer mouse, can take advantage of the burned environment as soon as the conflagration has been stopped, benefitting from the abundant food resources provided by the massive seed bank of dead conifers. Years after a fire, changes in vegetation provide habitat conditions that are attractive for species of mice, voles, and shrews. Other researchers (quoted in the reference below), studying wildfire residual environments in Québecoise boreal forests, found more black bears and moose in recently-burned stands than in older or unburned stands; the increased presence of bears was attributed to a greater supply of berries.

Reference: Nappi, A., Drapeau, P. and Savard, J. (2004). “Salvage logging after wildfire in the boreal forest: is it becoming a hot issue for wildlife?” *The Forestry Chronicle*: 80:67 - 74.

34. False. From a vegetation and wildlife point of view, salvage logging has been shown to have several negative impacts. In a study of the effects of fire and salvage logging on birds, one group of researchers (see reference below) has found that salvage logging had a greater effect on the bird community than fire alone. Species found in salvaged areas were mainly generalists, omnivores or shrub insectivores and ground and shrub nesters. Resident species, insectivores and canopy- and cavity-nesting birds, which are associated with unburned and/or burned forests, were less likely to be found in salvaged areas. Negative effects of salvage logging include the elimination of foraging and nesting habitat for wildlife, reduction of seed sources for regenerating species such as black spruce for several years after fire, unfavorable conditions for understory vegetation and seed establishment/growth, and reduction in nutrients.

Reference: Nappi, A., Drapeau, P. and Savard, J. (2004). “Salvage logging after wildfire in the boreal forest: is it becoming a hot issue for wildlife?” *The Forestry Chronicle*: 80:67 - 74.

P.3 ➡ *Solution*

We were told to use Byram's correlation, namely

$$L = 0.0775 \times I_B^{0.46}$$

Solving for I_B brings to

$$I_B = 259.83 \times L_F^{2.17}$$

so that, with L_F = 1.2 m, we get

$$I_B = 259.83 \times 1.2^{2.17} = 386 \text{ kW/m}$$

Substituting *CBH* = 3 m and *FMC* = 60% in van Wagner's criterion gives

$$I_0 = \left[0.01 \times CBH \times \left(460 + 25.9 \times FMC\right)\right]^{1.5}$$

$$\therefore I_0 = \left[0.01 \times 3 \times \left(460 + 25.9 \times 60\right)\right]^{1.5} = 470 \text{ kW/m}$$

Since $I_B < I_0$, i.e. the FLI is lower than the critical value, we surmise that a crown fire will not occur.

♦ The correct answer is β.

P.4 ➡ *Solution*

Smoldering fires can be initiated by weak sources of ignition; for instance, smoldering ignition of porous synthetic foam occurs with a minimum radiant heat flux of 8 kW/m², while flaming ignition occurs only above 15 kW/m². What's more, smoldering combustion is the most difficult type of combustion to extinguish, requiring much larger amounts of water than flaming fires – in excess of 50% greater mass of H_2O per mass of burning fuel as experimentally measured in a mass of coal heap.

♦ The correct answer is **B**.

REFERENCES

- AGEE, J. (1996). *Fire Ecology of Pacific Northwest Forests*. Washington: Island Press.
- ANDREWS, P. (2018). *The Rothermel Surface Fire Spread Model and Associated Developments: A Comprehensive Explanation*. Fort Collins: US Department of Agriculture.
- BELCHER, C. (Ed.) (2013). *Fire Phenomena and the Earth System.* Hoboken: John Wiley and Sons.
- JOHNSON, E. (1992). *Fire and Vegetation Dynamics: Studies from the North American Boreal Forest.* Cambridge: Cambridge University Press.
- JOHNSON, E. and MIYANISH, K. (2001). *Forest Fires: Behavior and Ecological Effects*. San Diego: Academic Press.
- PATON, D. (Ed.) (2015). *Wildfire Hazards, Risks, and Disasters*. Amsterdam: Elsevier.
- PERERA, A. and BUSE, L. (2014). *Ecology of Wildfire Residuals in Boreal Forests.* Hoboken: John Wiley and Sons.

Got any questions related to this quiz? We can help!
Send a message to contact@montogue.com and we'll
answer your question as soon as possible.