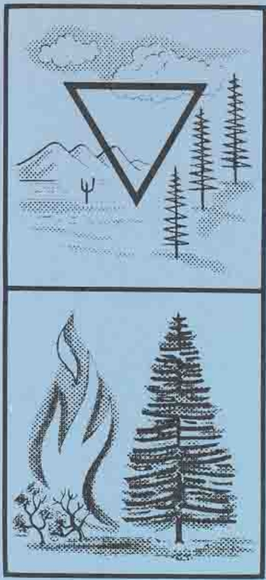
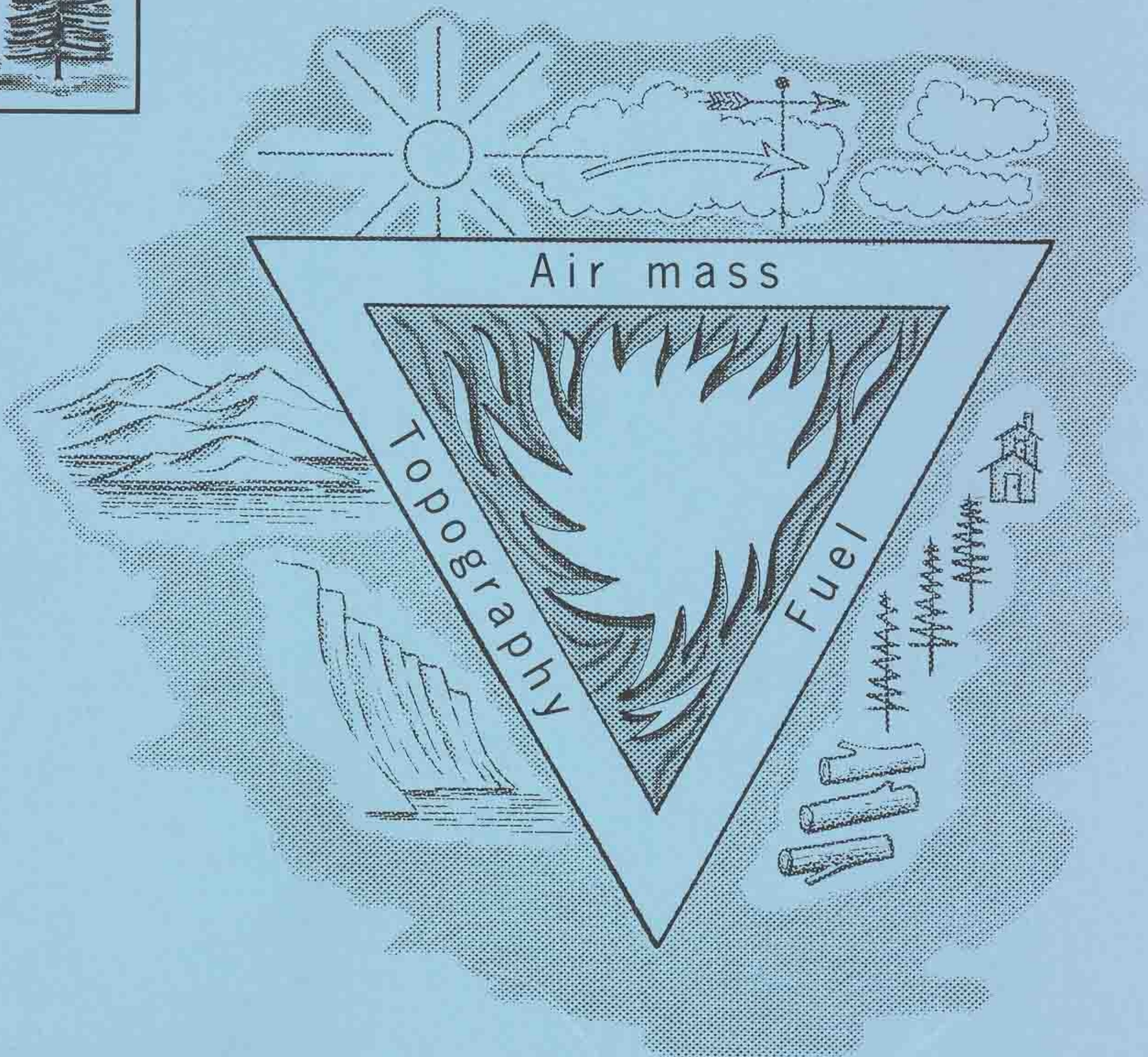


THE FIRE ENVIRONMENT CONCEPT

Clive M. Countryman



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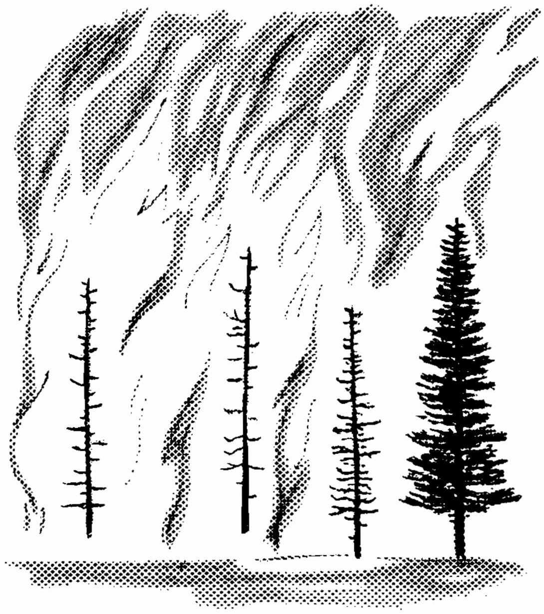


The FIRE ENVIRONMENT concept

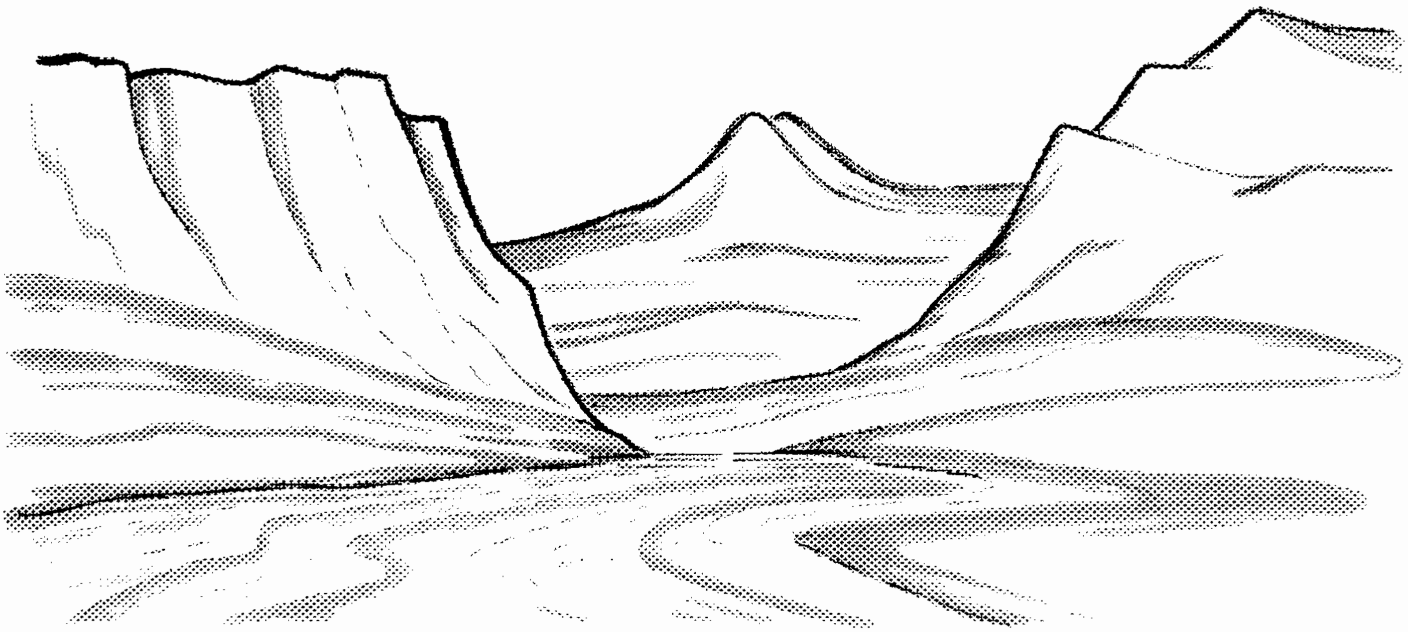
Experience with wildland fires soon teaches that no two are exactly alike. Fire behavior is not an independent phenomenon—it is the product of the environment in which the fire is burning.

Environment has been defined as "surrounding conditions, influences, and forces that influence or modify." In applying this definition to fire, we can then regard *fire environment* as the conditions, influences, and modifying forces that control the fire behavior. Fire behavior must obey physical laws. We consider certain types of fire behavior unusual or unexpected only because we have failed to evaluate properly the conditions, influences, and forces that are in control. To predict fire behavior, and to control and use fire effectively and safely, we must understand and use the interactions of fire with its environment.

In the following discussion we will examine the fire environment—what it is, how it varies and why, and how fire itself alters the total picture.

COMPONENTS OF THE FIRE ENVIRONMENT

Three influences, interacting, compose the fire environment. The first, topography includes such elements as slope, aspect, elevation, and configuration or "lay of the land." In relation to time, topography can be considered static, for the forces that change it generally work very slowly. In horizontal space, however, topography can change quickly, particularly in mountainous country. Variations can cause drastic changes in fire behavior as a fire progresses over the terrain.



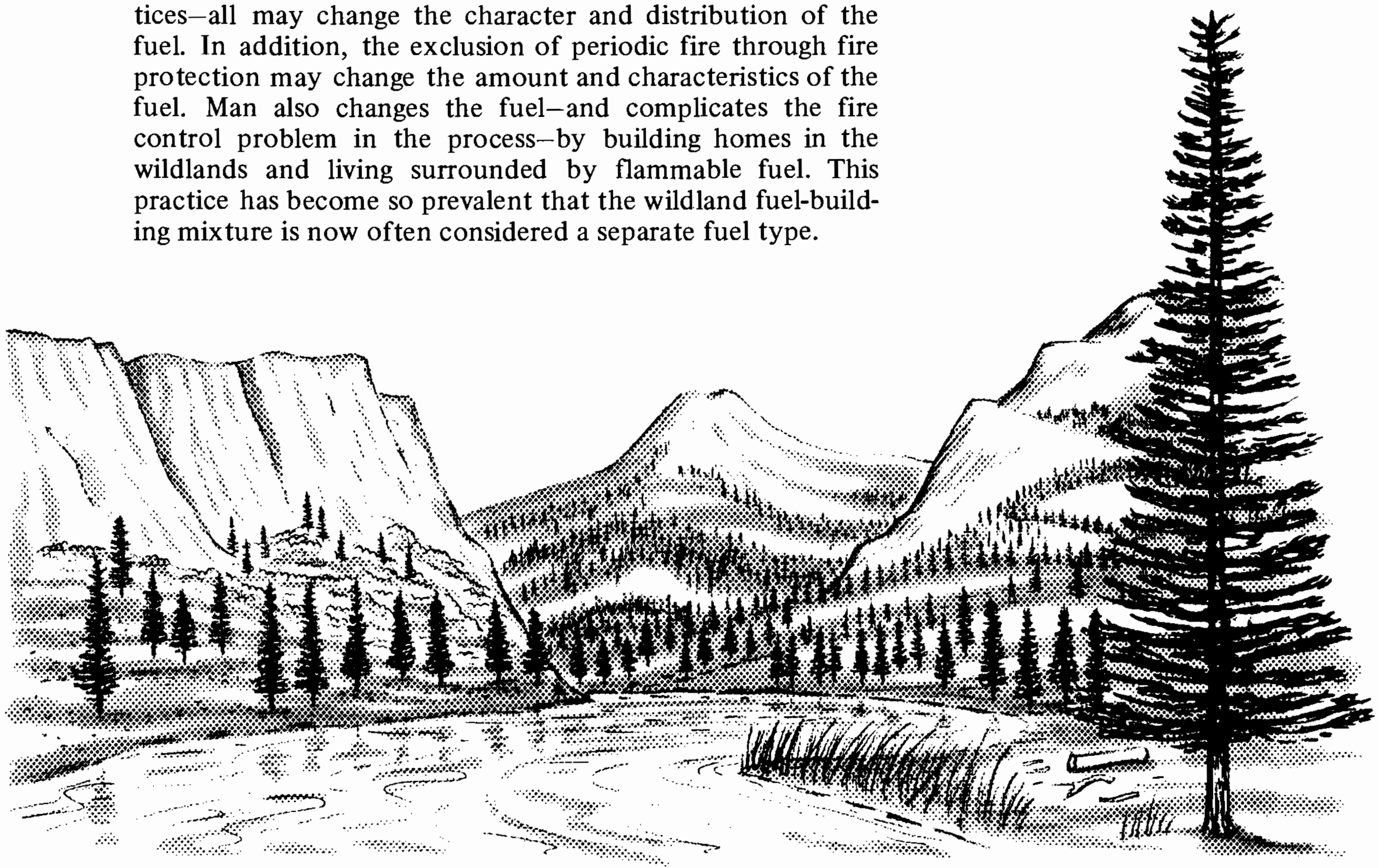
If we imagine a layer of vegetation added to the topography, we have the second influence–the fuel. It is the source of thermal energy and the driving force behind the phenomena of fire behavior. Thus, such characteristics as fuel loading, fuel bed porosity, fuel distribution and continuity, fuel sizes, moisture content, and chemical composition all affect the way the fire behaves. Most of our fire control methods require treatment of the fuel–we scrape it away, or apply water and chemicals to stop the fire from spreading and to extinguish it.

Most fuel characteristics change rather slowly with time. For example, fuel loading and the fuel distribution over the ground surface may not change significantly for years. Some changes in the fuel may take place seasonally, such as variations in the moisture content of living material, the chemical composition, and the proportion of dead fuel. In general, changes in fuel over time take place so slowly that we can consider the fuel static for any one fire. However, the potential fire behavior can change dramatically in a particular fuel type from one part of the fire season to another, or from year to year.

An exception to the slow change of fuel is the moisture content of dead fuels. In a few minutes, rain can change the way the whole fuel complex burns. When there is no precipitation, the moisture content of dead fuel is controlled largely by relative humidity and temperature, and these are changing almost continuously.

Like topography, wildland fuel can change quickly in horizontal space. Large variations in fuel types are obvious, as when timber gives way to brush, or brush to grass. But variations within the same general fuel type can also be great enough to alter fire behavior. For example, fuel loading and the proportion of dead fuel can vary greatly over short distances. Fuel characteristics often change with elevation, and fuels on north slopes are often quite different—and burn differently—from fuels on south slopes.

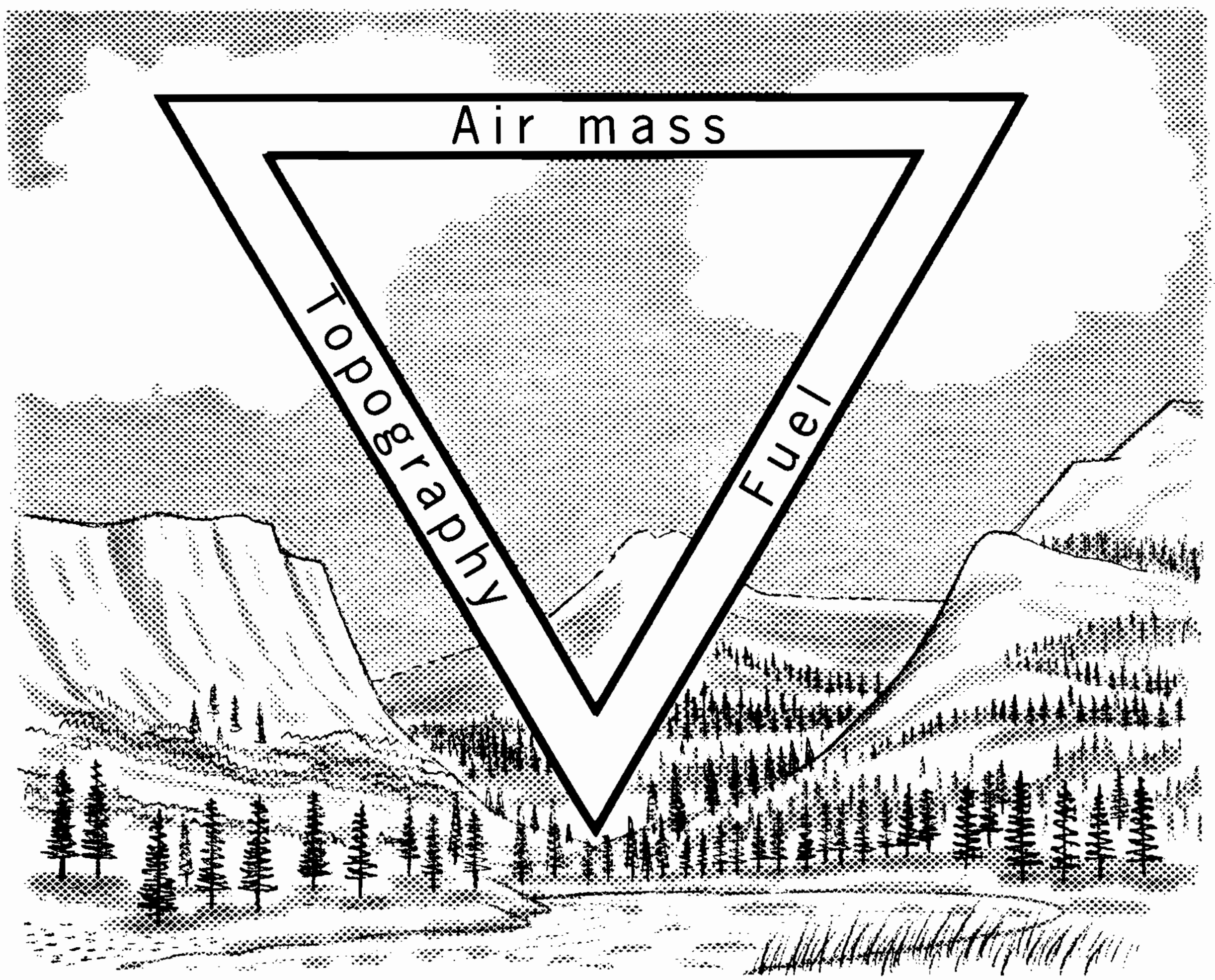
An important source of variation is the tremendous human impact on wildland fuels. Timber harvesting, timber stand improvement, road construction, grazing use, watershed development, recreational use, wildlife management practices—all may change the character and distribution of the fuel. In addition, the exclusion of periodic fire through fire protection may change the amount and characteristics of the fuel. Man also changes the fuel—and complicates the fire control problem in the process—by building homes in the wildlands and living surrounded by flammable fuel. This practice has become so prevalent that the wildland fuel-building mixture is now often considered a separate fuel type.



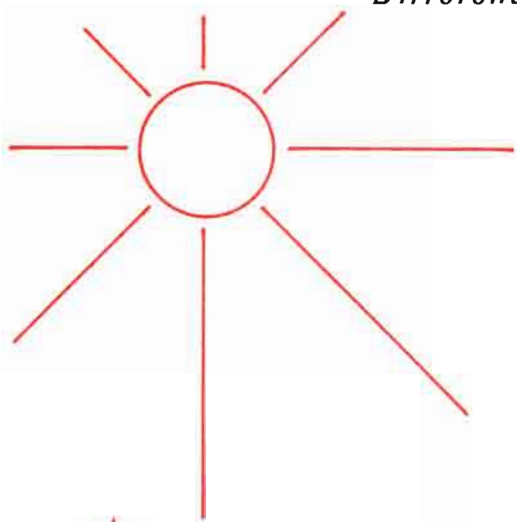
The third component of the fire environment is the air mass. It represents such weather elements as temperature, wind, relative humidity, cloud cover, precipitation, and air stability. The air mass is probably the most variable of all the fire environment components. It can vary greatly over short distances, often in accord with changes in topography and fuel. It is nearly always changing in time—day by day, hour by hour, and frequently minute by minute.

INTERACTION IN THE FIRE ENVIRONMENT

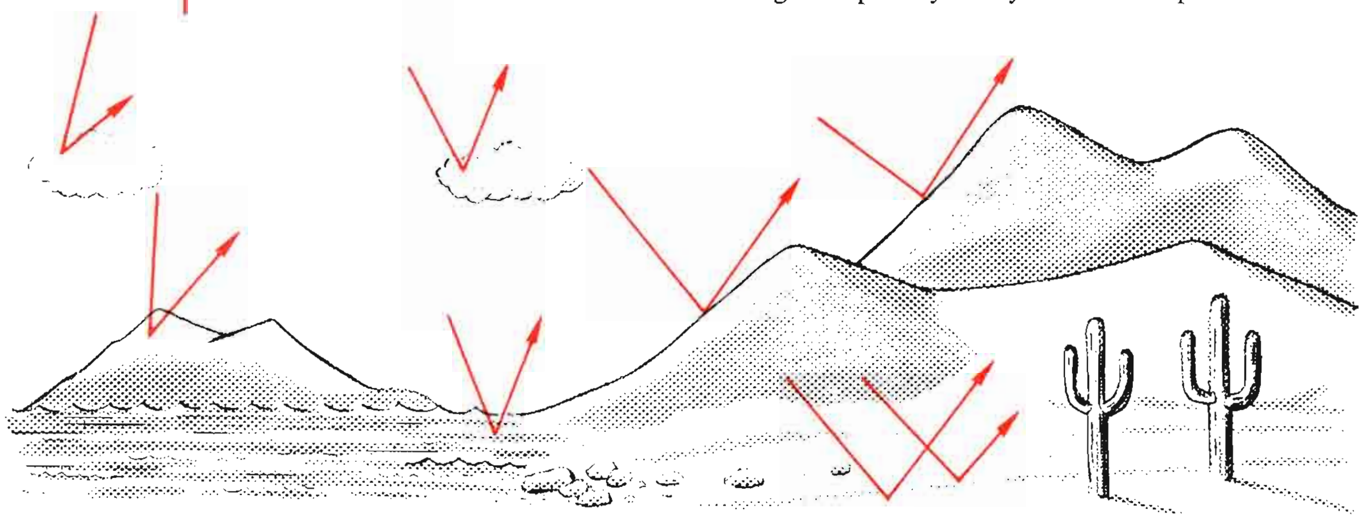
In fire control and fire use operations the air mass component frequently receives more attention than any of the others, possibly because its effect on fire is so often readily apparent and it is so variable. Nevertheless, effective evaluation of the fire behavior potential, requires that all three components be considered. In symbolic form, they are the sides of the fire environment triangle. This symbol implies constant interaction, which takes place primarily through solar energy. The sun's heat evaporates water from oceans, lakes, streams, and other moist surfaces, and thus provides the atmosphere with moisture that is returned to the earth as precipitation—the moisture that is essential to plant growth, and through erosion helps shape the topography. Heat from the sun also provides the energy for photosynthesis, the basic process in plant growth. Finally, the sun is responsible for differential heating, through which topography and vegetation affect the air mass.



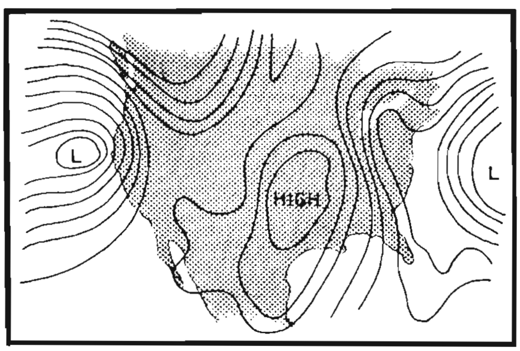
Differential heating



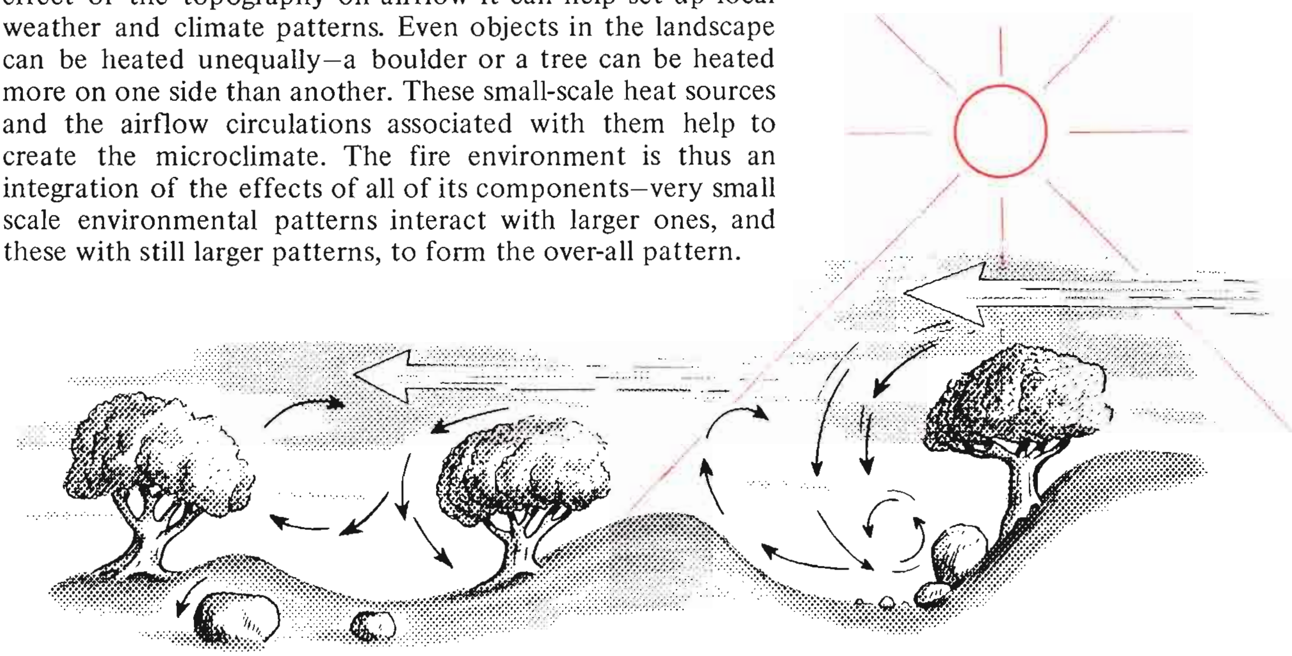
We have seen that the air mass is not static, but varies widely and often quickly, in both space and time. The force behind most of the changes is differential heating. Energy from the sun reaches the earth as electromagnetic radiation. Because of its high temperature, the sun emits short wave radiation, which passes through the earth's atmosphere without warming it much. But when these short waves strike a solid object, such as the earth's surface or something on it, part of their energy is converted to heat, warming the object. The heated object radiates energy too, but because of its relatively low temperature, the radiation is in the form of long waves. This radiation can be absorbed by the water vapor and carbon dioxide in the air, thus raising the temperature of the air. The heated air near the earth's surface is distributed through deeper layers by convective processes.



All materials are not warmed equally by the sun's radiation. Water surfaces are heated much less than land surfaces, and land covered with vegetation is heated less than bare ground. In general, dark or nonreflective materials are heated more than light-colored or reflective materials. The amount of heating is also strongly dependent on the angle of the sun's rays; the more nearly perpendicular to the surface they are, the more intense the heat. Thus, the amount of heating varies with the steepness and aspect of the ground surface, the time of day, the season of the year, and the latitude of an area–its distance from the equator. At night the heating process is reversed, and the earth loses heat to space. Generally, the kinds of materials that absorb heat most readily during the day tend to lose it most rapidly at night.



The differential heating brought about by differences in latitude and between water and land masses sets up circulation by convective and other means and creates large-scale weather and climatic patterns. But this differential heating occurs on a small scale, too, and along with the mechanical effect of the topography on airflow it can help set up local weather and climate patterns. Even objects in the landscape can be heated unequally—a boulder or a tree can be heated more on one side than another. These small-scale heat sources and the airflow circulations associated with them help to create the microclimate. The fire environment is thus an integration of the effects of all of its components—very small scale environmental patterns interact with larger ones, and these with still larger patterns, to form the over-all pattern.

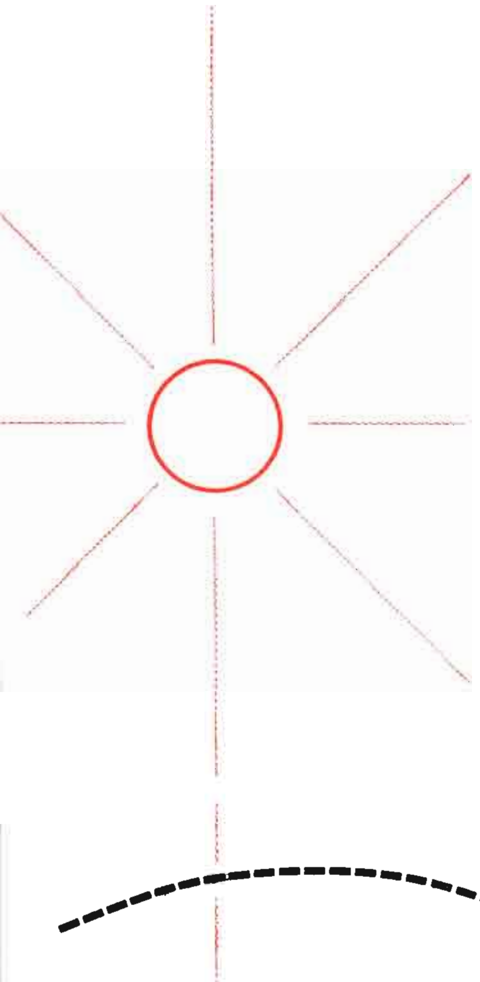


Chain effects

Because the fire environment components are interrelated, changes in one component can set off a chain of reactions that will cause changes in others. For example, cutting a timber stand will change the radiation receiving surface so that it will be heated more strongly, raising the air temperature in a cleared area. Because relative humidity varies with temperature, the relative humidity will be lowered. The moisture content of the dead fuel is dependent on both temperature and humidity; hence the moisture content will also be lowered. Removal of the trees that restrict the airflow, and the more active convection resulting from the higher temperature, can alter the airflow pattern. Thus, the fire environment—and the fire behavior—in the cutover area will probably be much altered, not only because the fuel characteristics are changed, but because the air mass characteristics are also changed.

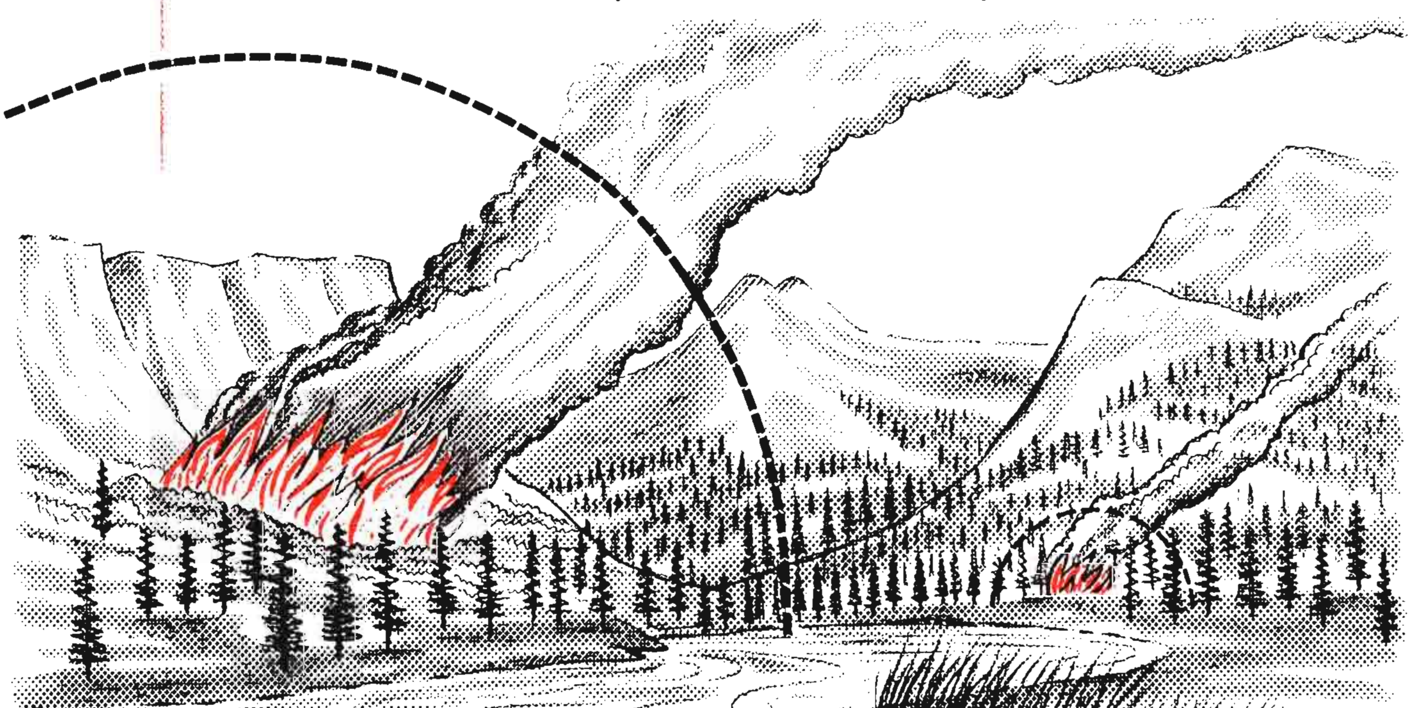
FIRE IN THE ENVIRONMENT

Where does fire itself fit into the environmental picture? As we have seen, in an environment without fire, radiant energy from the sun is almost the only source of heat, and local variation in heating creates variability in local weather and fuel conditions.



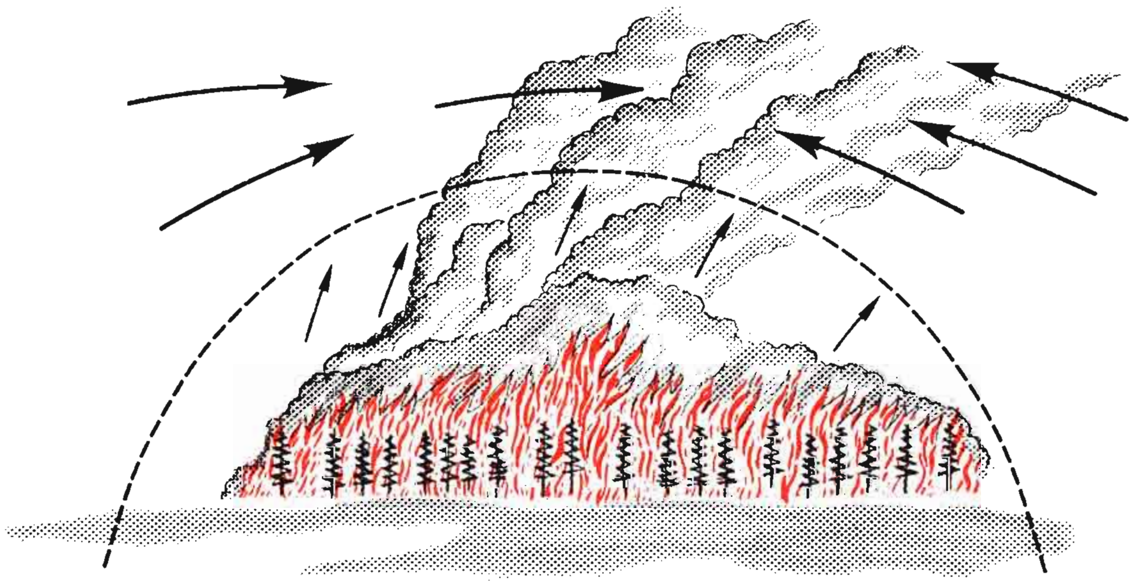
We might consider fire as just another localized heat source. As such, it reacts with its surroundings in the same way sun-created heat sources do, interacting with the air mass to bring about changes in local weather, and with the fuel to modify fuel moisture and temperature. There is an important difference, however. Ground and fuel surfaces heated by the sun do not become extremely hot; surface temperatures over 200° F. seldom occur, and are usually much lower. Temperature differences between adjacent land areas are also not great—a surface temperature difference greater than 100° F. is not likely to occur. But temperatures in a fire can be very high, often exceeding 2,000° F., and the temperature difference between the fire and the adjacent environment can be correspondingly large. Therefore, the reaction of a fire heat source with the environment can be much more violent than that of a sun-created heat source, particularly in its impact on the air mass. A large and intense fire can overwhelm all other heat sources and dominate the local environmental pattern—in effect, the fire creates its own weather.

A wildland fire determines the extent of the environment of concern to its own behavior. For a very small fire the fire environment is limited to a few feet horizontally and vertically. But as the fire grows in size, so does the extent of the environment that will affect it. In a large fire, the fire environment may extend many miles horizontally and thousands of feet vertically. For an intensely burning fire the fire environment usually extends to a much greater distance vertically than in fires of low intensity.



Most of the changes in fire behavior result from changes in environmental patterns as the fire moves over the terrain and as time passes. But sometimes behavior changes can take place very quickly, and almost without horizontal movement. For example, a surface fire burning under a timber stand is burning in an environment different from that existing above the stand. Within the timber, the temperature is usually lower and the humidity and fuel moisture higher during the day, than they are outside the stand. At night the temperature is higher and fuel moisture lower. Wind speeds are almost always lower within the stand than outside or above it.

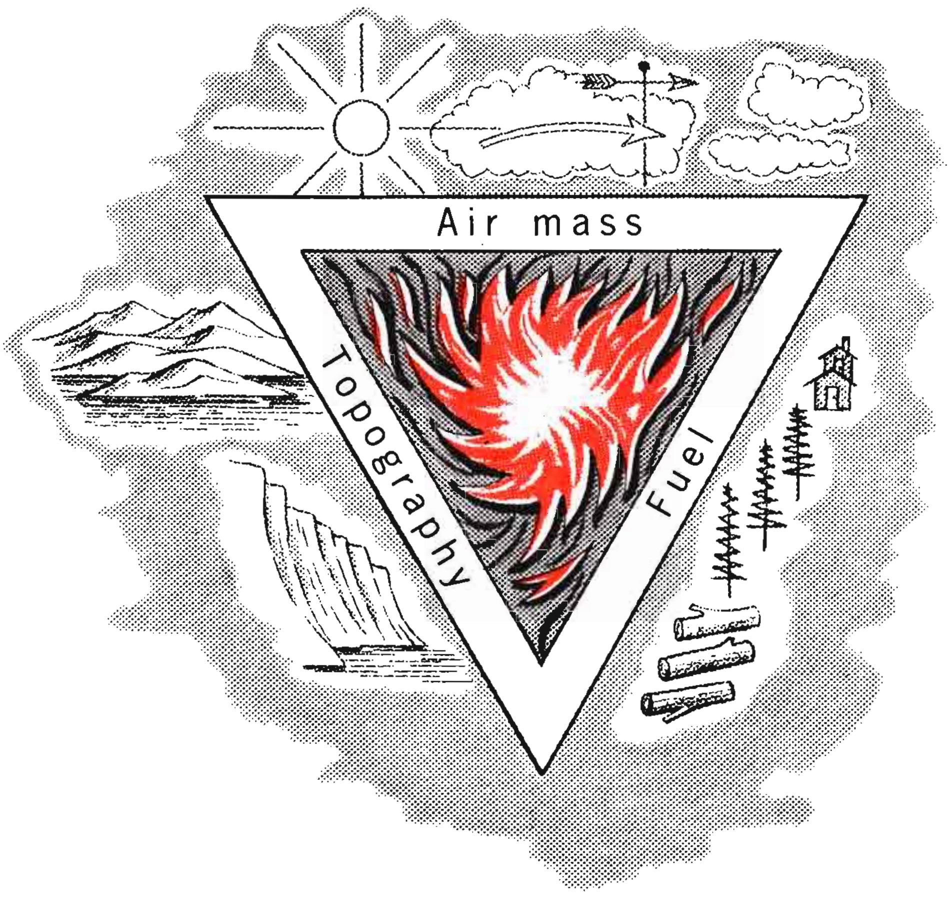
A fire burning under a stand is much like a fire burning inside a building. In the building the air mass, and hence the fuel moisture, is controlled largely by the heating or cooling systems, and the conditions outside the building have relatively little effect. But once the fire breaks out of the building, outside conditions can influence its behavior, and the fire can spread to other fuel and grow in size and intensity. So it is with our fire. Once it increases in intensity enough to crown, it then comes under the influence of the conditions outside of the stand and the fire behavior can change drastically.



The same situation can exist in other fuel types too, such as brush and grass. But because of the lesser vertical extent of such fuels, the environmental difference is not so pronounced, and fires seldom remain long in the more temperate environment.

Earlier it was pointed out that the fire environment is a pattern phenomenon; the effects of small heat sources interact with each other to form larger patterns, which in turn interact to form still larger patterns. The fire heat source is a pattern phenomenon too. Wildland fires seldom burn uniformly. The variations in topography, fuel, and the air mass may cause the fire to build up in one area while it is dying out in another. Thus, there can be hot spots within the fire area, analogous to those in the sun-heated environment. Because of these temperature differences, the behavior of one part of the fire can affect the behavior of another part. The consequences may be disastrous to fire control operations, but the principle can also be used to advantage. For example, it is possible to purposely build up an intense fire in one part of the fire in order to affect the fire favorably for control action at a more dangerous point. Similarly, in slash burning an area of intense heat can be built up near the center of the burn area to draw the fire in from the edges, and in this way lessen the chance of fire escape.

All these observations lead to a single conclusion. The current state of each of the environmental components—topography, fuel, and air mass—and their interactions, one with another and with the fire itself, determine the behavior of a fire at any moment. By adding fire to the environment triangle, we can represent this relationship symbolically with the fire behavior triangle.



PREDICTING FIRE BEHAVIOR

The foregoing discussion suggests that the behavior of a wildland fire is a very highly complicated phenomenon, and so it is. Principles of aerodynamics, chemistry, thermodynamics, and combustion physics—operate in a relation so complex that despite years of work researchers have not been able to develop a satisfactory theoretical or mathematical model. It has been said that we know more about the principles of atomic explosions than we know about the principles governing wildland fire behavior. But the lack of a fire model and the gaps in our knowledge do not mean that we cannot predict fire behavior, at least to an extent adequate for most fire control and fire use operations. Over the years, many wildland firefighters have developed a remarkable skill in predicting the probable behavior of a fire. In particular, this skill is shown by firefighters who have worked in an area long enough to become familiar with the existing fire environment patterns and the fire behavior associated with them.

The ability to predict fire behavior, whether for an entire fire or only a segment of it, required awareness that fire behavior is entirely the result of the interaction of the fire with its environment. To become skillful, we must recognize variations in the fire environment and understand their probable effect on the fire.

In some respects, this is not a difficult task. The beginning firefighter quickly becomes aware that a fire burning upslope behaves differently from one burning downslope under the same weather and fuel conditions, that wind speed and direction can quickly affect the rate and direction of fire spread, and that a fire in logging slash differs from a grassfire.

But many of the variations in the fire environment and their effects on fire are not so obvious, and skill in recognizing them must come from experience and training. A firefighter's ability is often equated with his years of experience with fire. But his real ability to control or use fire safely and effectively is best measured by his skill in predicting fire behavior under prevailing conditions. This ability may represent the difference between ten years of wildland fire experience and one year of experience repeated ten times.

We have been concerned here only with the general nature of the fire environment and its variations. Other publications will describe in more detail the ways of recognizing variations in the fire environment and their effects on the fire, as well as the ways in which the fire itself influences its environment.

SUMMARY

Fire environment is the surrounding conditions, influences, and modifying forces that determine the behavior of a fire. Prediction of fire behavior for safe and effective control and use of fire requires understanding of the interactions of fire with its environment.

The fire environment consists of three major components—topography, fuel, and air mass. From a fire standpoint, topography does not vary significantly with time, but does vary greatly in horizontal space. The fuel component varies in space and also in time; however, fuel characteristics, except for the moisture content of dead fuel, change slowly enough to be considered static for any one fire. The air mass is usually the most variable component, changing rapidly in both space and time.

The thermal energy responsible for most environmental interaction comes from the sun. Because the earth's surface is not heated uniformly, temperature and air circulation patterns are set up that create large scale, local, and microscale climatic and weather patterns. The interaction of these patterns with other conditions determines the fire environment for a particular area.

Fire can be considered as a local heat source. As such, it influences and modifies the fire environment. Because a fire creates high temperatures, it can dominate sun-caused heat sources.

The extent of the environment of concern to fire behavior depends primarily on the size and characteristics of the fire. It ranges from a few feet to many miles horizontally and thousands of feet vertically. The vertical extent of the environment varies with fire intensity.

Most changes in fire behavior occur as the fire moves over the terrain and as time passes. But abrupt changes can occur when a fire moves vertically from one kind of environment to another, as when a surface fire in timber crowns.

Fire behavior is the interactions of the environmental components with each other and with the fire. The current state of each of these influences and their interactions determine the behavior of a fire at any moment.

Fire behavior is the result of complex interrelationships of aerodynamics, chemistry, thermodynamics, and combustion physics. Nevertheless, it is possible for firefighters to acquire sufficient skill in predicting fire behavior to allow safe and efficient control and use of fire. Development of this skill must come from experience, and from training in the fundamentals of fire behavior and fire environment.

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