50 YEARS OF SERVICE: THE MISSOULA FIRE SCIENCES LABORATORY

Jane Kapler Smith, Diane Smith, and Colin Hardy

On September 12, 1960, the brand new Northern Forest Fire Laboratory was dedicated in Missoula, MT. The fire lab's mission was—and is—to improve scientific understanding of wildland fire so it can be managed more safely and effectively in the field. The first scientists to work at the fire lab initiated research that continues to be used, refined, and extended.

The questions studied and the technology used at the fire lab have evolved continually since 1960, and the lab's name has changed more than once. Today, it is the Missoula Fire Sciences Laboratory. But the original focus—developing a greater understanding of wildland fire and using the best technology available to get that knowledge into the hands of fire managers—has been a way of life for fire lab scientists for a half-century.

Fuel Moisture and Fire Danger

In the late 19th and early 20th centuries, severe, life-destroying fires plagued forests in the United States. To help field rangers predict and suppress such fires, the Forest Service initiated a fire research program. In the 1920s, Harry Gisborne—the agency's first full-time fire research scientist—began

Dedication of the Northern Forest Fire Laboratory, now the Missoula Fire Sciences Laboratory, in Missoula, MT, on September 12, 1960. The facility includes a 66-foot-high combustion chamber, inside the tall part of the building, that allows for burn tests in controlled conditions. Photo: Forest Service.

Recent experiments in the fire lab's burn chamber simulate various thresholds and limitations to fire spread on a hillside. Photo: Forest Service.

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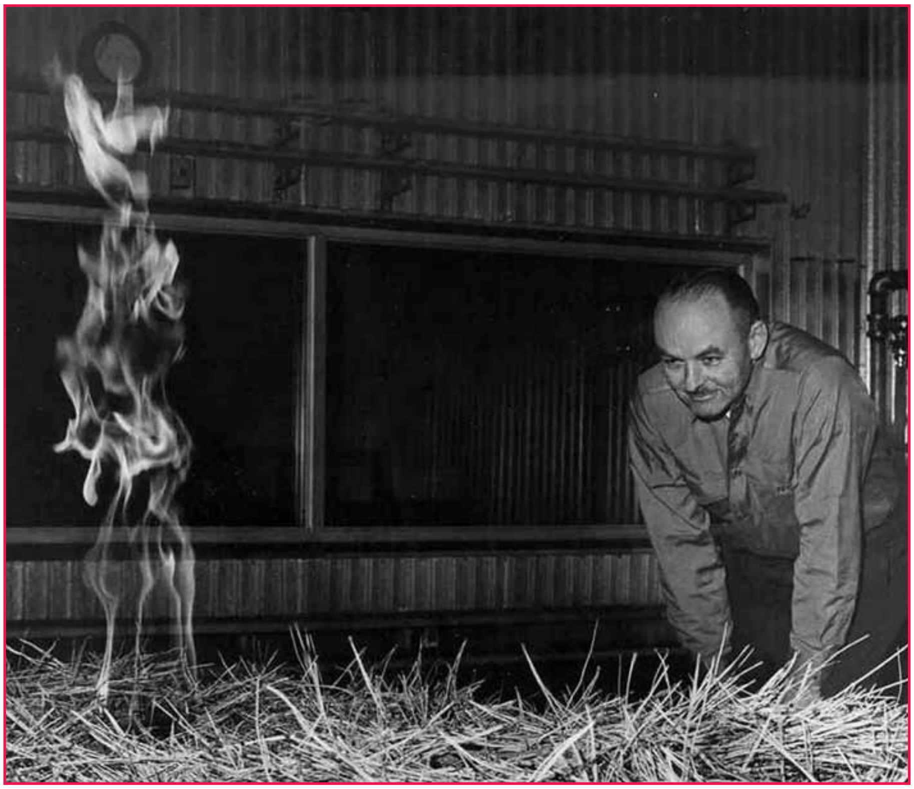
developing a way to predict fire danger. Believing that the moisture content of fuels was key to understanding flammability, Gisborne weighed known amounts of fuel regularly, calculated their moisture content, and related the changes to ambient weather conditions. These results were immediately put to use in the field to assess fire potential, but it was also clear that laboratory experiments were needed. This need was met with the opening of three research laboratories, including the Missoula fire lab in 1960. Jack Barrows was the first director of the lab.

After successfully securing funding for the fire lab, Jack Barrows' next chore was to identify and hire researchers to work in the new facility. Barrows brought in foresters, physicists, and engineers to develop quantitative indicators of fire danger. Within 5 years, these scientists had conducted more than 200 experimental burns and identified thresholds of fuel moisture that could be used to identify "red-flag" conditions when fire danger was increasing rapidly. Continued experiments contributed to release of the National Fire Danger Rating System (NFDRS) in 1972, which provided managers with a standard system for assessing fire danger from local weather observations.

With revisions in 1978 and 1988, the NFDRS still forms the basis for local fire danger rating, which is shared with the public on hundreds of Smokey Bear signs throughout the Nation. In 1994, fire lab scientists developed the Wildland Fire Assessment System (WFAS), which consolidates data from thousands of local weather stations to map fire danger across the country (fig. 1), alerting field managers to regional changes and emerging needs for fire suppression.

Computer Tools for Fire Prediction

A crucial component of the NFDRS was the fire model developed by Richard (Dick) Rothermel and published in 1972. The model predicts the spread and intensity of surface fire based on fuel properties, fuel moisture, wind, and slope. Soon after publication, the model was



Jack Barrows, chief of the fire laboratory in 1960, works in the wind tunnel of the new facility. Photo: Forest Service.

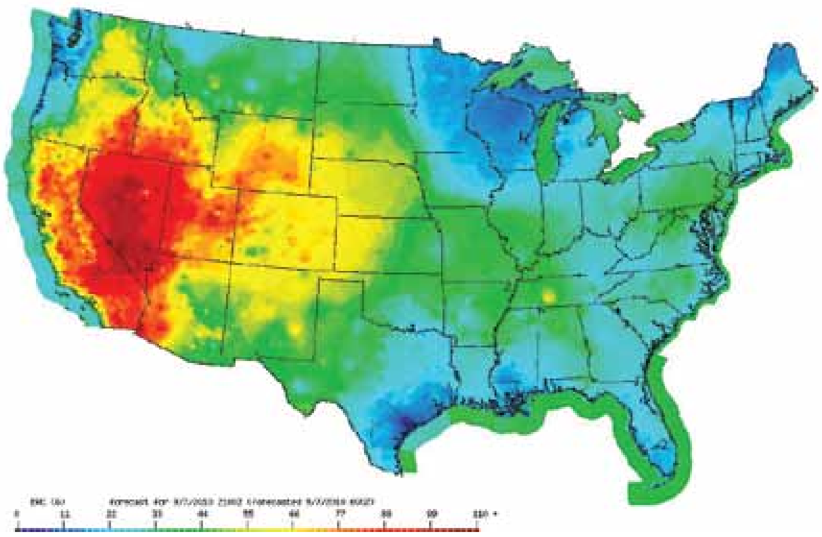


Figure 1—*Fire Danger Class map for conterminous United States, September 9, 2010. Source: Larry Bradshaw, Missoula Fire Sciences Laboratory.*

put to work predicting wildland fire behavior:

- Initially, a system of graphs and charts captured model results. Soon, hand-held calculators were programmed to predict fire spread in the field.
- In the mid-1970s, the Rothermel model was integrated with dozens of supporting models into the BEHAVE system for predicting fire behavior in multiple weather and fuel conditions.
- In the 1990s, the availability of geospatial data on fuels and topography allowed the Rothermel model to be integrated with other models into programs for predicting fire perimeters and spatial fire behavior, including FARSITE (fig. 2).
- In 2007, new systems were initiated for simulating fire growth under thousands of weather scenarios so that managers could estimate the likelihood of fire impacts.

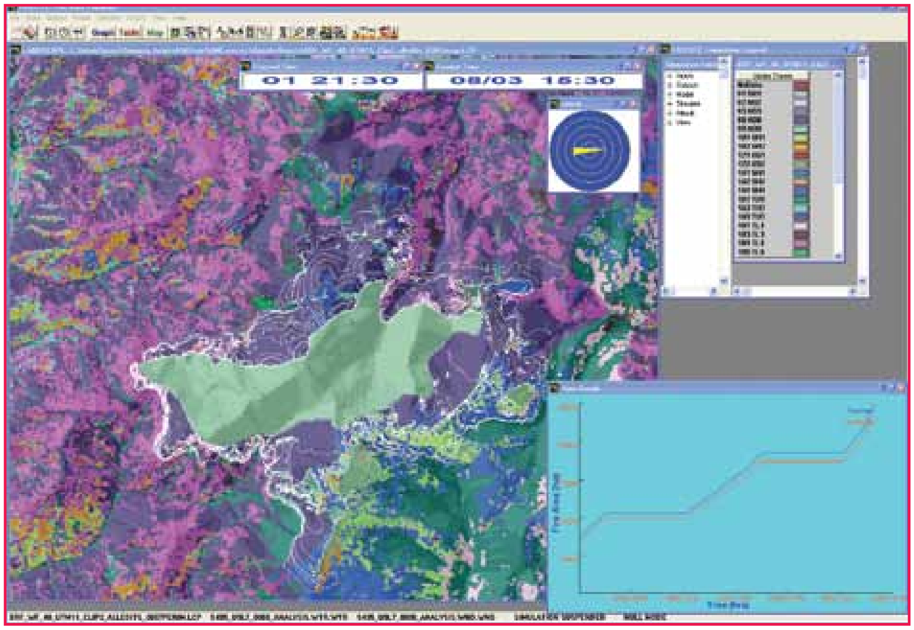


Figure 2—*Computer modeling is used extensively to predict fire spread across landscapes. Here, FARSITE shows fuel types, topography, and potential fire growth on the landscape. Source: Chuck McHugh, Missoula Fire Sciences Laboratory.*

Scientific Measurement of Fuels

How much fuel is available to feed a fire? In the early 1970s, scientist Jim Brown developed methods for measuring the amount of woody, shrub, and herbaceous fuels on the forest floor. Some of these measurements were consolidated into tables of numbers that feed the Rothermel fire model. Today, 40 such quantitative descriptions of fuel complexes are in use throughout the United States. A recent innovation enables managers to match field observations with photographs of known amounts of fuel to improve the accuracy, precision, and efficiency of fuel biomass estimation.

Fire spread in the forest canopy is more complex than on the forest floor. Careful dissection of hundreds of tree crowns in the late 1990s enabled scientists to describe the vertical distribution of crown fuels. Research currently underway uses fractal mathematics to generate three-dimensional models of crown fuels (fig. 3). These models can be used to describe fuel properties that are difficult to measure directly, such as surface area and distribution of particle sizes in tree crowns. This approach will improve managers' ability to predict crown

Scientist Jim Brown measures the fuels on the forest floor to establish fuel loading relationships. This 3- by 3-foot (1- by 1-m) area contained about 10 pounds (4.5 kg) of woody fuel. "Brown's transects" remain the standard for fuel load estimation in the field. Photo: Forest Service, 1972.

Figure 3—*Research currently underway uses fractal mathematics to generate three-dimensional models of crown fuels. Source: Russ Parsons, Missoula Fire Sciences Laboratory.*

fire behavior and estimate fire effects in the complex, discontinuous fuels of the canopy.

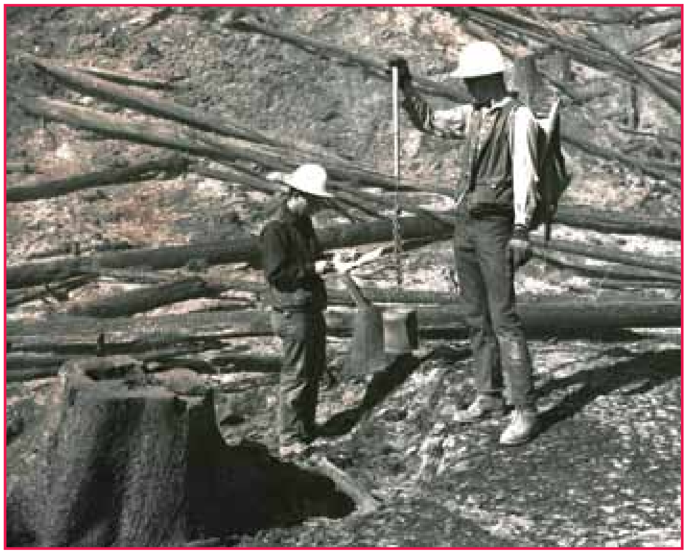
Fire and Forest Ecology

Through the 1960s, managers became increasingly aware of fire as a natural agent of change and renewal. In the early 1970s, scientist Robert (Bob) Mutch helped managers develop area-specific prescriptions for allowing some lightning fires to burn in the Selway-Bitterroot Wilderness. The first such fire occurred in 1972 and covered all of 600 square feet (58 m^2). Since that time, lightning fires have burned more than 500,000 acres (202,000 ha) in the Selway-Bitterroot and Frank Church River of No Return Wilderness areas, producing an intricate mosaic of habitats across the landscape. Managers of natural areas across the country now recognize and welcome the ecological benefits of fire.

Most ecosystems have a specific relationship with fire, known as the fire regime: how often fires occur and their size, season, and severity. Beginning in the 1970s, research forester Steve Arno used fire scars on trees to determine the frequency of surface fires in forests of the northern Rockies. In recent years, research forester Emily Heyerdahl has used fire scars and tree growth rings to determine the climate during years of widespread fires in Idaho and western Montana. She identified 32 years when fires were widespread throughout the region. These years had warm springs followed by warm, dry summers.

In the late 1960s, the fire lab, with multiple collaborators, initiated a rigorous field study addressing the role of fire in forests of spruce, fir, and western larch—the Miller Creek-Newman Ridge project. In more than 30 publications, scientists reported the effects of prescribed fire in clearcut units on tree regeneration, small mammals, physical and chemical properties of soils, hydrology, re-establishment of shrubs and herbs, and smoke production. Since that time, fire lab scientists have studied ecosystem-level fire effects throughout the United States, particularly in forests dominated by ponderosa pine, Douglas-fir, lodgepole pine, and whitebark pine. Research on whitebark pine has led to international collaboration as scientists and managers seek ways to restore this unique ecosystem.

Emily Heyerdahl cuts through a stump to examine tree rings. Dendroecological techniques enable scientists to use dead wood to learn about the history of fire in the area. Photo: Forest Service.



Researchers at the site of the Miller Creek prescribed fire weigh water cans before and after a 1968 broadcast burn to calculate energy release in burning fuels. Photo: Forest Service.

International Connections

The fire lab not only produces new knowledge but also packages knowledge from around the world so it can be readily used by fire managers. From 1978 to 1981, fire lab scientists authored two of the six “Rainbow series” publications that detail how fire affects various ecosystem components. A comprehensive revision of this series began in 2000, with fire lab scientists editing four of the six new volumes.

The First Order Fire Effects Model contains equations from research nationwide that predict tree mortality, fuel consumption, soil heating, and smoke emissions from fire. Ecologists at the fire lab also synthesize knowledge from thousands of studies, packaging the results in the Internet-based Fire Effects Information System (<http://www.fs.fed.us/database/feis>), which currently hosts literature reviews covering more than 1,200 species.

The fire lab’s first smoke measurements were obtained from instruments located at Miller Creek in 1967. But local information is not sufficient: fires on all continents contribute to pollutants and greenhouse gases in the atmosphere. In 1987, the fire lab began studying the chemistry of smoke from burning biomass, whether from wildfires, cooking fires, or charcoal production. Chemists conducted field experiments in Brazil, South Africa, Russia, Mexico, and many other countries to describe the compounds in smoke, how they change over time, and where they go. Chemist Wei Min Hao contributed results to the United Nations’ Intergovernmental Panel on Climate Change, which earned the Nobel Peace Prize in 2007 for increasing understanding of climate change.

Fire lab scientists have contributed to and edited four of the six national syntheses of fire effects research, the Wildland Fire in Ecosystems series. (Not pictured: “Effects of Fire on Cultural Resources and Archaeology.”)

Studies of fire in landscapes in other countries helped broaden the experience and applicability of fire analysis. Here, smoke samples are taken in a 2006 controlled burn in Mexico. Photo: Forest Service.

The Biomechanics of Fire

What kind of fire behavior would kill organisms in the soil? How much heat does it take to kill a tree? In the early 1980s, fire lab scientists conducted experiments measuring the transfer of heat from fire into soil and living organisms. Using the knowledge gained in these experiments, they developed a model to predict soil heating. This model helps managers predict the effects of fires on soil fertility, underground plant parts, and organisms in the soil. Later experiments looked at heat transfer through the bark of trees into living cells. The FireStem model developed jointly between the Missoula Fire Sciences Laboratory and the Forest Service Northern Research Station describes heat transfer through tree bark. FireStem helps managers predict tree mortality based on fire behavior.

Ecosystems are constantly changing. How can the changes associated with fire be predicted? Starting in the 1970s, scientists used state-and-transition diagrams (fig. 4) to illustrate patterns of vegetation change after fire. When probabilities are assigned to these pathways, they can serve as predictive models. However, these models assume that the environment remains unchanged through time. In contrast, the FIRE-BioGeoChemical Succession Model (FIRE-BGC), initially developed in the 1990s, bases predictions on the flow of material and energy through ecosystems as influenced by weather, climate, fire, and many other factors. An updated version of the model is currently being used to explore potential changes in ecosystems due to changes in climate (fig. 5).

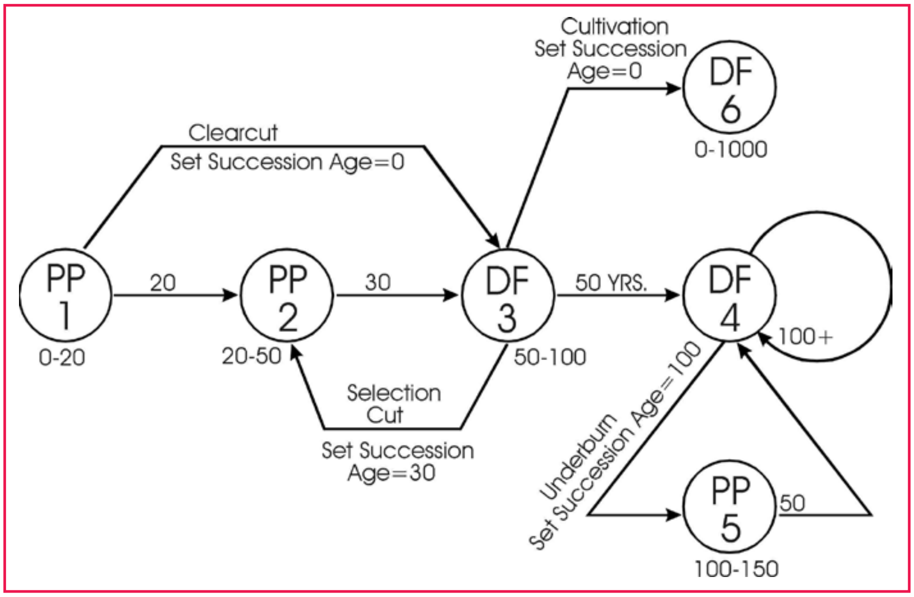


Figure 4—*State-and-transition diagram uses a graphical technique developed in the 1970s to show potential paths of forest change. PP=ponderosa pine; DF=Douglas-fir. Source: Bob Keane, Missoula Fire Sciences Laboratory.*

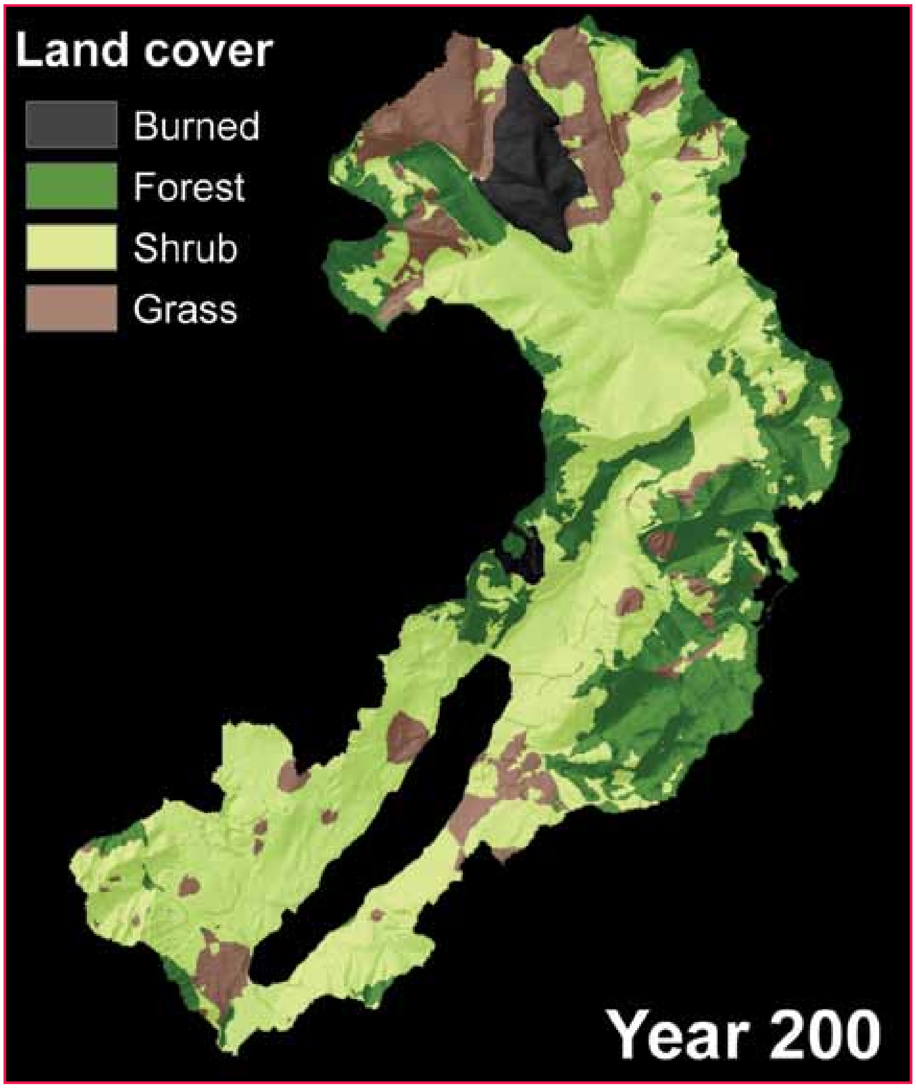


Figure 5—*In a watershed dominated by forest in 2009, FIREBGCv2 predicts shrubs will dominate after 200 years of influence from changed climate and wildfire. Source: Rachel Loehman, Missoula Fire Sciences Laboratory.*

Finding Fires

The sooner a manager knows where a fire is, the better—but it is not easy to locate fires in the vast expanse of America’s wildlands. In 1962, fire lab scientists began using aerial infrared photography to detect and map fires. Within a few years, managers adopted this technology to identify problem areas within fires, establish safety zones for firefighters, and locate spot fires. Infrared flights could map 3,000 square miles (7,770 km^2) in an hour. Today’s moderate resolution imaging spectroradiometer (MODIS) satellite sensor detects “hot spots” across the country several times a day. The fire lab receives this information via a globe-shaped satellite dish on the roof of the facility. Scientists use the data to map the burned area of ongoing fires; this helps predict smoke production, the height of smoke plumes, and smoke dispersion rates—all matters of concern for safety and human health. Smoke data also help scientists estimate the interactions between fire and climate change.

Research at the Missoula Fire Sciences Lab continues to build on what has been learned in the past, and new technology is opening entire new fields of inquiry. A few examples:

- Light Detection and Ranging (LIDAR) imagery describes smoke plumes in ever greater detail.
- Mathematical models are being used to map wind flow (fig. 6). This information improves the accuracy of fire spread predictions.
- Field work increases managers’ ability to predict tree mortality caused by fire and bark beetles.

A satellite receiving dish installed on the roof of the fire lab collects infrared data several times a day to map “hot spots” across the United States. Photo: Forest Service.

- Experimental work contributes to improved guidelines for safety of firefighters and homes.

The Missoula Fire Sciences Laboratory continues to produce new knowledge for safer, more effective, and ecologically appropriate management of wildland fire.

For more information, visit <http://firelab.org>. A history of the Missoula Fire Sciences Laboratory is in press. To receive a copy, email dianemsmith@fs.fed.us.” ■

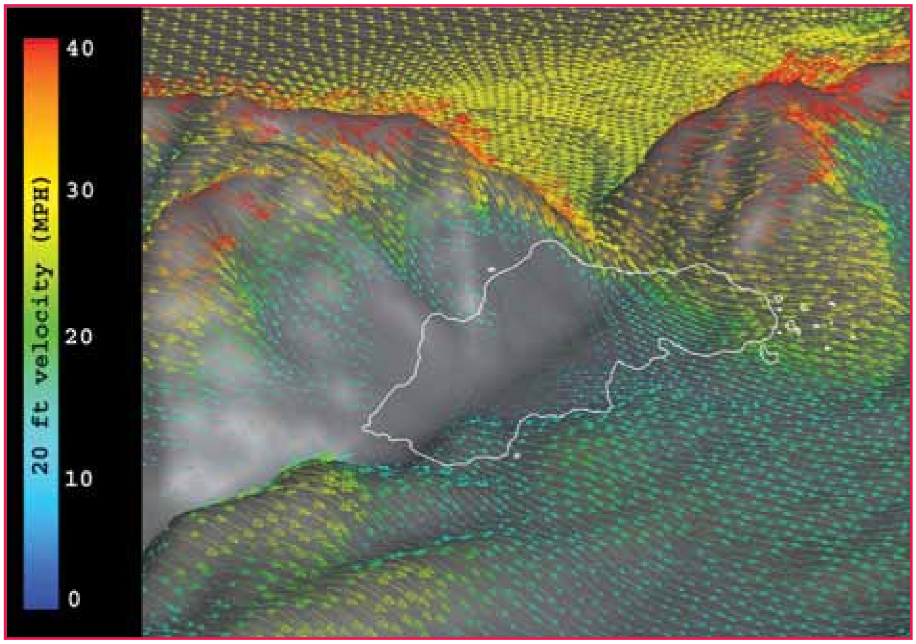


Figure 6—*WindWizard predicts wind patterns across a landscape, 2010. Source: Bret Butler, Missoula Fire Sciences Laboratory.*