

# MODELING

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FIREFIGHTER contemplates  
a Washington State blaze.





# Predicting Wildfires

Fires are burning more acres than ever.  
Where will the next blazes ignite?  
Can we prevent them? Should we?

*By Patricia Andrews, Mark Finney and Mark Fischetti*

## KEY CONCEPTS

- Fuels are building up in forests because for decades agencies that manage these lands have attempted to put out almost all fires. Accumulation of deadwood and debris across large continuous tracts leads to extreme fires that are too expansive and hot to fight.
- Computer models are being used to predict how a current fire will burn and are getting better at forecasting which land areas are most susceptible to wildfire in the weeks, months or years ahead.
- The models are helping land managers better position fire crews and equipment so that they can jump on a blaze as soon as it starts, raising the chances of protecting people, property and natural resources.
- Other software is emerging that can gauge how future fires might be mitigated by thinning forests or allowing some fires to burn. These models can help land managers and agencies craft new policies that will lessen the chance for catastrophic fires and also restore fire as an integral part of natural ecosystems.

—*The Editors*

**T**he number of catastrophic wildfires in the U.S. has been steadily rising. The nation has spent more than \$1 billion annually to suppress such fires in eight of the past 10 years. In 2005 a record 8.7 million acres burned, only to be succeeded by 9.9 million acres in 2006. And this year is off to a furious start.

To a great extent, the increase in fires stems from a buildup of excess fuel, particularly deadwood and underbrush. Forests harbor more fuel than ever in large part because for decades, land management agencies, including the U.S. Forest Service, have followed a policy of trying to quickly put out every fire that starts. Fires, however, can clear out debris, preventing material from accumulating across wide areas and feeding extremely large, intense fires that become impossible to fight. Even in the absence of such a policy, firefighters find themselves compelled to combat many blazes because people continue to build homes further into wildlands, and those structures require protection. Exacerbating the problem, spring snowmelts have been occurring earlier, extending the number of weeks every year when forests are exposed and dangerously dry.

Clearly, the fuel supply needs to be reduced by allowing some naturally occurring fires to burn themselves out and by starting other burns. Fire is also important to the health of ecosystems; plant life has evolved with fire and depends on it. As wildfires skew to the extreme end of the size and intensity range, ecosystems that for millennia had depended on fire are being drastically altered, leaving them vulnerable to full-scale devastation from





**AIR TANKER drops 2,500 gallons of retardant on a fire in Colorado.**

#### [THE AUTHORS]



Patricia Andrews and Mark Finney have developed several of the leading computer models used throughout the U.S. to predict wildfires. Andrews is a research physical scientist at the Fire Sciences Laboratory in Missoula, Mont., run by the U.S. Forest Service. Finney is a research forester at the lab. Mark Fischetti is a staff editor at *Scientific American*.

diseases or insect infestation. Arizona's "sky islands"—small, high-altitude forests protruding from the desert—are already being lost to this very sequence. And wonderful old lodgepole forests in Colorado have been killed by bark beetle infestations that fire usually would have limited.

Unfortunately, it is difficult to know how much fuel must be removed to reduce the chance for extreme fires and how best to effect that removal. When should fires be set purposely to eliminate fuel? When should firefighters allow new fires to burn? To address such questions, policymakers, land managers and firefighting organizations need tools to test possible actions. In the past half a decade researchers have greatly improved computer models that capture how fires behave and provide firefighters with strategies for deciding how to handle them. Fire experts, climatologists and computer scientists are also devising large-scale models that can predict which tracts of land are ripe for fire in the next week, the next fire season and years ahead.

### Fighting a Fire in Progress

Modeling how a fire will burn through a forest might seem to be an impossible task. A daunting number of variables must be considered: types of deadwood, the limb structures of trees, terrain, weather, moisture content of living leaves, mois-

ture content of dead grasses and twigs (which can change hourly), and much more. Figuring out how to control a fire's spread involves even more variables, such as wind speed, ground slope, daily weather and the likely effects of firefighting tactics, among them dropping retardant from the air and bulldozing land to create barren firebreaks that flames have difficulty crossing.

Nevertheless, computer models capable of predicting the spread of a wildfire that has already started are becoming sophisticated. They are helping land managers and fire commanders make decisions that could save the lives of firefighters and area residents, as well as reduce the costs of battling the inevitable blazes. In 2006 some of the new modeling systems were used for the first time to influence where fire crews and equipment should be deployed. And this year they are coming into widespread use, already having helped fight early-season blazes in Florida, Georgia and California.

Technically speaking, a model refers to a set of algorithms that describe a single physical trait of a fire, such as the spread rate of flames. Programmers combine these models to create a fire-modeling system that land managers or fire danger analysts run on a computer to produce forecasts and maps. In daily parlance these systems end up being called models as well, and that is how we will use the term here.

In 1976 fire behavior analysts working on the ground alongside wildfires began consulting tables and graphs called nomograms to predict a fire's intensity, along with the rate and direction of its spread. These predictions were based on the types of fuel in the area (and their moisture content), wind speed and slope steepness (a fire advances up a slope much faster than on level ground). The analysts drew the results as vectors on a big topographic map for firefighters to see. Although expert judgment and manual methods of calculation will continue to be used in the field, computer software is surging.

The FARSITE fire area simulator developed by one of us (Finney) relies on similar inputs but also calculates where a fire might spread and how quickly. A fire behavior analyst enters a blaze's current position along with data on fuels, terrain and weather forecasts into a laptop, and FARSITE produces contoured graphics that depict the conflagration's growth for the next one to three days. This information helps fire managers decide which suppression tactics might be safest and most effective.

Large wildfires often burn for many more

KAREN WATTENMAKER (preceding pages); INMCK MILLAN; Spotfire Images (top, this page); COURTESY OF U.S. FOREST SERVICE (Andrews and Finney)

days, however. Deciding where to position crews and equipment requires longer-term prediction. Another program, FSPro (for fire spread probabilities), was developed by Finney for this task. He intended to run it on a trial basis for a few fires in 2006, but so many broke out during the season that fire managers ended up consulting FSPro on more than 70 blazes. The model calculates the probability of where a fire might spread by running thousands of FARSITE simulations, each with a different weather sequence that is based on historic climatology for the area. Projections can be made for as far out as 30 days. Knowing whether a fire is 20 or 80 percent likely to reach a community influences how fire crews work and whether residents should be evacuated. In general, FSPro predicted well where flames would spread, how quickly they would advance and how hot

they would be; many managers found the model extremely helpful, although some said it tended to predict that fires would spread farther than they actually did.

Because FSPro runs thousands of scenarios, personal computers cannot handle the processing required. During all of 2006 and the spring of 2007, the Fire Sciences Laboratory in Missoula, Mont., overseen by the Research branch of the U.S. Forest Service, ran the model and sent contoured maps to fire crew commanders in the field. But in May, FSPro went online, allowing authorized analysts to enter data directly on the Web and to see the resulting maps there, too.

FSPro will improve as researchers finesse the basic physics-level models. For example, experts are only now creating reasonable models of crown fires—fires that sweep through the canopy of a forest instead of along the ground. Even

## HOW WILL THE BLAZE SPREAD?

On July 23 and 24 of last year, lightning storms ignited multiple wildfires across the Shasta-Trinity National Forest in northern California. Fire crews sprang into action, but Joe Millar, the forest's fire management officer, quickly realized that four or five of the flare-ups could potentially grow large. How likely was that to happen, he wondered? Where should the crews concentrate their efforts?

Millar called Bernie Bahro, a regional liaison to several national agencies. Bahro, in turn, called Mark Finney at the Fire Sciences Laboratory in Missoula, Mont. To prepare for the worrisome blazes, Bahro wanted Finney to run FSPro (for fire spread probabilities)—a new computer model that predicts the probability of where and when a wildfire will spread. "We had 20 years of historical weather data, 10 years of wind data, and the data about how fuels were layered in the

forest," Bahro says—the kinds of information FSPro needed. "We just had to get it all into Mark's machine."

As Finney worked the software, fire crew commanders on the ground began calling in reports of how the fires were advancing. A day later Finney began e-mailing maps to Millar that showed where the fires were most likely to spread. By now six fires had grown large enough to warrant names and were burning just north and west of the forest headquarters in Redding, Calif., where Millar was located. "The simulations helped to orient me," Millar says. "They helped make clear that we needed to put a team on the Bake and Oven fires," which seemed to have the greatest potential to become larger, longer-term burns.

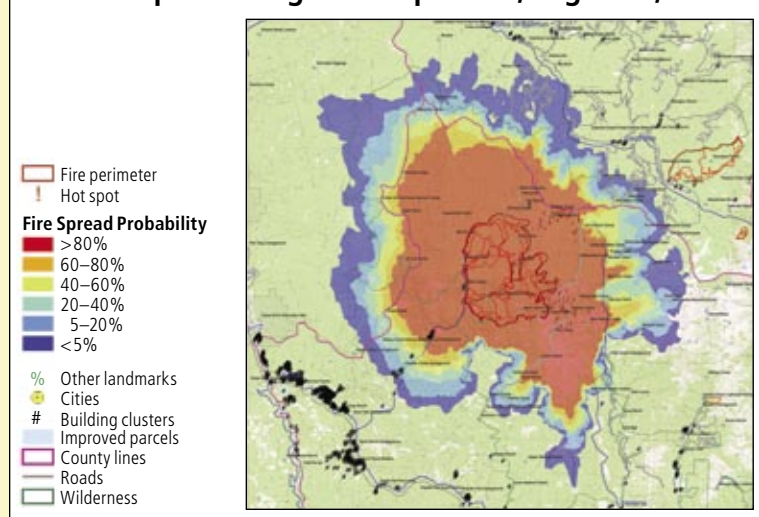
Bahro and Millar had also asked Finney and his colleague Dave Calkin to run another model, called Rapid Assessment of Values at Risk.

This model pinpoints man-made structures as well as critical habitats and estimates their value, clues to which fires could impose the most dollar damage. "Early on we had teams trying to keep the Dog fire off private land," Millar says, "but as the Lakin fire got bigger we moved more resources there because we saw it was going to reach major power lines and a big utility pipeline."

After several weeks, firefighting teams had beaten back some of the blazes, but others stubbornly continued. Finney updated the models as crews submitted fresh information. The runs helped Bahro and Millar decide how to coordinate the teams and share big equipment. By August 29, FSPro showed that the combined conflagrations, now called the Big Bar Complex (left), could consume 286,000 acres, including scenic rivers, salmon habitats and a tribal area, but by moving crews, Millar and Bahro limited the toll to 104,000 acres. Millar emphasizes that the models did not dictate actions: "We still have to base decisions on the reality of what firefighters are seeing. But FSPro did show the tendency of where the fires wanted to go."

—Mark Fischetti

### Potential Spread of Big Bar Complex Fire, August 29, 2006



FSPRO/RAVAR MAP, shown as fire managers saw it, helped to limit fire destruction.

less is understood about how a surface fire can suddenly transform into a crown fire. This switch can happen in minutes and is very dangerous because it can trap crews underneath a fire, making escape difficult. Better modeling of the transition point between the two fire types would help crews know when and where they can effectively operate.

### Forecasting Next Week, Next Month

Firefighters have the best chance of putting out a blaze if they can jump on it as soon as it ignites. Quick response is much more likely if fire managers have a good idea where the next fires will likely arise, allowing them to position crews

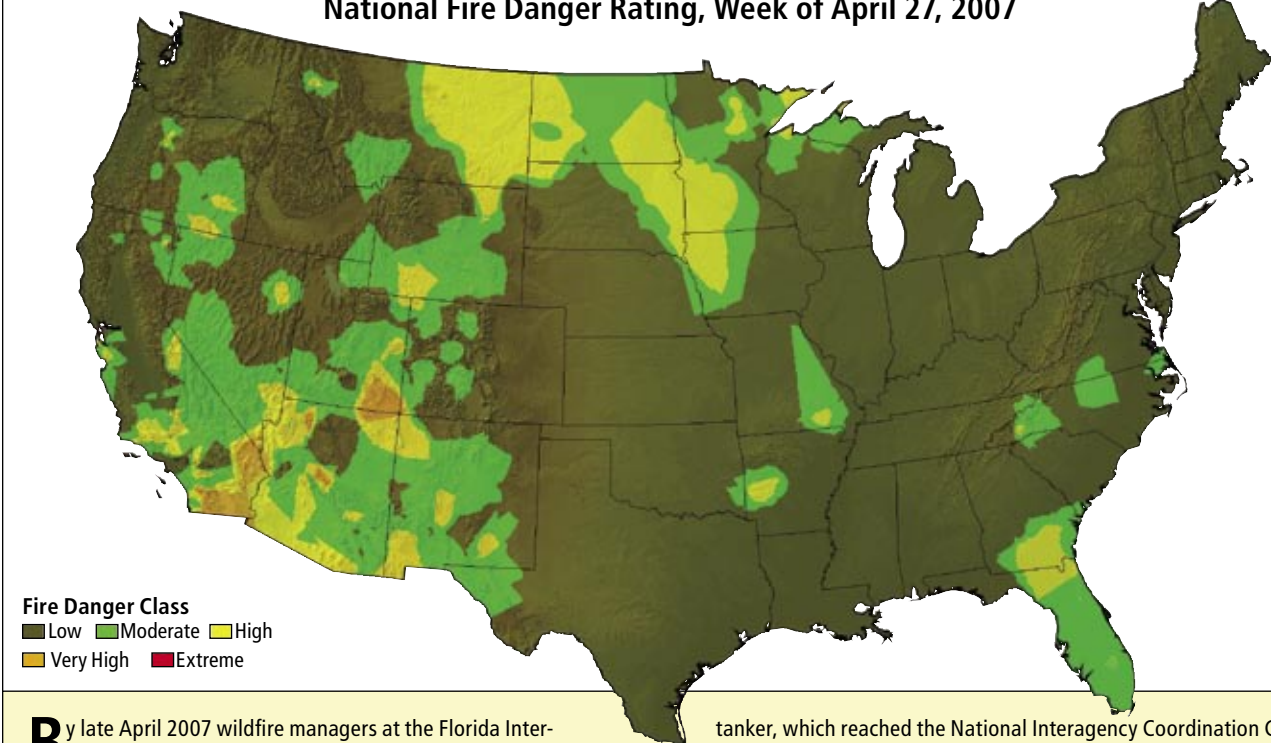
before they do—and to warn the public to be extra cautious about accidentally starting a fire in those areas.

Models that predict fire potential for the upcoming few days or the week in a given forest or grassland look primarily at how damp the fuels are. Moisture levels for grasses and needle litter change daily with the weather, whereas the moisture content of logs and living leaves changes gradually over weeks and months.

U.S. scientists began predicting fire danger as early as 1916, based largely on anecdotal evidence and opinions of experienced fire behavior analysts. Mathematical models led to the National Fire Danger Rating System (NFDRS) in

## WHERE WILL THE NEXT FIRE IGNITE?

National Fire Danger Rating, Week of April 27, 2007



**Fire Danger Class**  
 ■ Low ■ Moderate ■ High  
 ■ Very High ■ Extreme

**B**y late April 2007 wildfire managers at the Florida Inter-agency Coordination Center had become concerned that wildfires would flare up across the northeastern corner of their state. An unusually prolonged drought had left leaves and grasses very dry. And the U.S. Forest Service had just issued a weekly fire danger map from the Wildland Fire Assessment System (WFAS) that indicated a high risk for fires in the region (*above*).

Several small fires were already burning, and the managers determined that if more ignited, firefighters would not have sufficient equipment to battle them. An additional air tanker would help them jump on new fires quickly, but there are only 18 available for nationwide use. None could be borrowed from the southwestern states, where the WFAS showed the risk for wildfires was also high.

On April 25 the Florida managers placed a request for another air

tanker, which reached the National Interagency Coordination Center in Boise, Idaho. The Boise supervisors reviewed the WFAS maps, checked with local experts in California where fire danger was low, and identified an aircraft there. It took off on April 27 and arrived ready for duty in Florida the next day.

The move was well timed; in the following two weeks, 17 new fires ignited in Florida's national forests. Yet none of them became large because firefighters could attack them early, aided by air support, according to Matt Jolly of the Fire Sciences Laboratory in Missoula, Mont., who provided the details for this report. Wildfire managers across the country use models to continuously evaluate regional changes in fire danger and decide where to move crews and gear. Quite often, however, there is not enough of either to go around.

—Mark Fischetti

FIRE BEHAVIOR RESEARCH, MISSOULA, MONT.



1972, which has been gradually improved. Among other applications, forest managers and park rangers use these fire danger ratings to tell the public the risk for fire on a given day, information that is often imparted through the familiar Smokey Bear signs that list the danger from low to extreme.

Today's fire danger ratings from the NFDRS are presented as maps in the Wildland Fire Assessment System (WFAS), developed at the Missoula lab. The WFAS automatically receives daily information from more than 1,800 fire weather stations across the U.S. that record meteorological data germane to fire risk, such as humidity and wind speed. The system calculates the danger indices and produces contoured maps in color for regions nationwide.

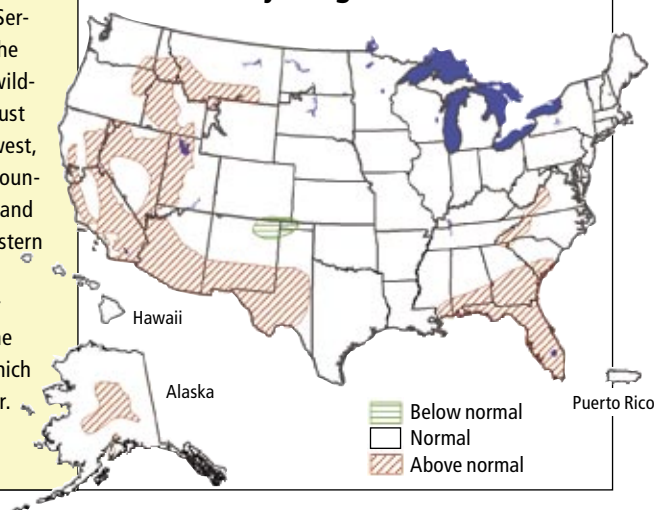
If the risk in a region is extremely high, land managers or local officials may take unusual measures to mitigate it, such as forbidding the public to enter a forest or banning stores from selling fireworks. Local field commanders use the WFAS maps to make decisions such as where to move their fire crews, and whether to keep them on overtime for a weekend so that they will be ready to respond immediately to new ignitions. When fire risk grew extreme in northern Florida this past April, national officials agreed to fly an air tanker there from a low-risk location in northern California; the tanker ended up providing crucial help when fires ignited only days later [see box on opposite page].

Staging crews and gear is expensive. What is more, although the public claims to support fire prevention, eager hunters, fishers and vacationers often become upset if they are forbidden to enter the woods. And local businesses can lose revenues. For these and other reasons, researchers are trying to improve the accuracy of the WFAS. One area of work involves the fire weather stations that provide data. Because these stations are very unevenly distributed across the country, the resulting maps may reflect actual conditions accurately in some areas but be far off the mark in others. This year the WFAS will therefore begin downloading current weather data from the National Oceanic and Atmospheric Administration's National Weather Service reporting stations (typically located at airports) and will also consult NOAA's own weather forecast models. With these inputs, the WFAS will be able to calculate a more reliable fire danger rating every five miles nationwide. The system also uses satellite data to track the moisture levels of live vegetation and will soon be updated

## THREAT FOR 2007

The Significant Fire Potential Outlook map issued by Predictive Services indicates that the greatest chance for wild-fire from May to August 2007 is in the Southwest, parts of the Rocky Mountains, central Alaska and the extreme southeastern U.S. Every July the group issues another map for the rest of the year's fire season, which runs through October.

### Significant Fire Potential, May–August 2007



ed to incorporate information from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellite.

### Assessing the Next Season

Regardless of progress, fires will always happen. The practical question for an upcoming fire season is whether a given region will need more assets than normal to protect natural resources and the public. Will additional funds be needed for fire suppression? Should more crews be hired and trained?

Right now meteorologists and fire behavior analysts in the Predictive Services program, managed by the National Interagency Coordination Center (NICC) in Boise, Idaho, issue maps of weekly, monthly and seasonal outlooks of where the potential for fire is greatest. The maps are based on WFAS projections, but other factors that are hard to pin down must be woven in as well. Long periods of parched soil can result in dry trees, for example. In the western U.S., an arid spring with low snowpack can set the stage for an active summer fire season, whereas if rains come every 10 days far fewer fires than normal will erupt. Ultimately, accurate prediction of a future fire season depends on the ability to forecast the weather months ahead, which is not possible.

Experts at Predictive Services therefore focus on the potential impacts of various climate patterns. They meet with climatologists and other specialists at a workshop in January to devise regional assessments for the eastern, southern and

## WILDFIRE'S TOLL

### U.S. Acres Burned

2006	<b>9.9</b>	million
2005	<b>8.7</b>	million
2004	<b>8.0</b>	million
2003	<b>4.0</b>	million
2002	<b>7.2</b>	million

southwestern areas of the country. The group meets again in early April to assess the western region and Alaska. These assessments take models into consideration as well as anecdotal information about drought, seasonal weather patterns such as El Niño and La Niña (both of which alter the path of prevailing winds) and historic data that show how many large fires occurred during certain climatological conditions. The final result of the workshops is a significant fire potential forecast map that identifies areas where wildfires will likely require resources beyond those typically available. For 2007, much of the Southwest and the extreme Southeast were deemed to face high risk [see box on page 51].

Every year participants also debate how to incorporate new inputs. For example, at the 2007 meetings they discussed findings published in 2006 by Anthony Westerling, then at the Scripps

## BATTLING BLAZES

Firefighters who combat wildfires nationwide move around the U.S. as needed.

**513** 20-PERSON CREWS (10,260 firefighters)

**446** SMOKE JUMPERS

**87** HELICOPTERS

**18** AIR TANKERS

Institution of Oceanography, and his colleagues. Westerling's group compiled data from 1,166 wildfires in the western U.S. that occurred between 1970 and 2003, along with the timing of snowmelts and spring and summer temperatures for those years. Participants of the workshop acknowledged the study's conclusions that an earlier spring snowmelt in mountainous regions is the leading factor in predicting where an above-average number of large wildfires will start.

### Strategy for Years Ahead

Models that predict where fires are most likely during a current season are valuable on many practical levels. But if the country is to adopt policies that can reduce severe blazes, decrease the cost of firefighting and also restore the natural role of fire in ecosystems, then experts must predict the long-term effects of various land

## WISER POLICIES COULD LESSEN CATASTROPHE

Despite ever improving firefighting techniques and technologies, record numbers of acres continue to burn in the U.S. The legacy of past policies is one cause, particularly the charge to put out as many fires as possible.

For decades, scientists and land managers have informed policymakers that extinguishing all fires has the paradoxical effect of making future fires larger and hotter. When fires are not permitted to burn, fuels accumulate across vast contiguous tracts: deadwood piles up, brush and new trees grow in thick, and tree canopies become dense. When a fire does ignite, there is so much fuel across such a wide area that no level of firefighting can contain it, causing severe consequences.

Changing such policies is a difficult proposition, however, because the basic solutions call for more fire, not less. Nevertheless, to avoid the most damaging fires, an enlightened approach should be considered by the many agencies that manage wildlands, including the U.S. Forest Service, National Park Service, U.S. Fish and Wildlife Service, Bureau of Land Management, Bureau of Indian Affairs and their counterparts at the state level. Although the Federal Wildland Fire Management Policy, set in 1995 and updated in 2001, recognizes that full suppression has undesirable consequences, the policy does not provide simple solutions.

Three primary changes would be instrumental. First, certain fires that start naturally—or portions of them—should be allowed to burn. Firefighters would protect important properties such as homes, power lines and watersheds, but in other areas flames would run their course.

Second, more prescribed burning should be pursued. Although this measure is now carried out to some degree, more fires must be set across larger areas, particularly in ecosystems dependent on fire and on lands close to developed areas where wildfires pose heightened risk.



**FIRE CREW starts a prescribed burn in Los Padres National Forest.**

Third, some brush, low-hanging tree limbs and small trees must be thinned, especially in places close to where people live and work. Ironically, one hurdle to accomplishing this is the objection from certain environmental groups suspicious that plans for thinning are veiled attempts to increase logging. Some forest types, once properly thinned, have been proved to survive wildfires that occur under extreme weather conditions.

The susceptibility of homes and private property to destruction must also be reduced. Certain municipalities in fire-prone areas of California, for example, now ban wood siding and require property owners to clear brush within 100 feet of their structures, to lessen the chance that buildings will ignite. Governments might also advise landowners that certain areas may be too remote to expect protection. As Tom Harbour, head of firefighting for the U.S. Forest Service,

told *USA Today* in May, "We need to be telling people with even more clarity that just because you built something here, we're not going to die for it."

Modeling can help fire managers apply these new policies. The simulations can predict the probable impacts of letting certain parts of wildfires burn, as well as the effectiveness of techniques for managing those burns. The models can also help land managers decide where and when to set prescribed fires or how much accumulated fuel to clear. Over time, model makers would track how well the predicted and observed effects match and would adjust the models to improve them, in turn leading to more finely tuned policy changes. — **Mark Finney**

management strategies. Such measures include not suppressing all fires, igniting controlled burns and manually thinning forests.

The Forest Vegetation Simulator is one software project that can demonstrate such long-term effects. It models tree growth, death and regeneration. A Fire and Fuels Extension to the simulator allows analysts to gauge the extent to which thinning trees or setting a prescribed burn would alter the severity of a future fire. The Stand Visualization System can then create images of the results. For example, the software suite can compare how a wildfire in 2065 might affect a stand of trees if no management had taken place there since 2007 or if a prescribed fire had been set. The programs continue to be improved.

Another way to assess the long term is to consider the likely buildup of fuel. The FlamMap model calculates how a fire would behave across a landscape given the present fuel structure, under different weather conditions. Fire managers have applied FlamMap to the Sierra Nevada Mountains in California to help them prioritize which areas might benefit from thinning and prescribed burning. Analysts can also use the BehavePlus model (developed by Andrews and others) to consider whether a prescribed fire might be a viable option in an area analyzed by FlamMap. BehavePlus determines the conditions under which such a fire would not escape the planned burn area, given differing winds and fuel moisture: if fuels are wet, a higher wind speed would be acceptable than that for dry fuels. For contingency planning, the system can indicate how far from the burn wind could carry hot embers and the chances of them starting a spot fire outside the planned area.

Land managers decide to light prescribed fires more often than most people think. In the U.S. in 2006, more than 2.7 million acres were burned by more than 24,000 such fires, according to the NICC. Managers are eager for better models that can help assure that a planned fire is safe and effective. In response, systems are being enhanced so they can better predict such concerns as fire intensity (heat level) and smoke production (too much smoke can make highways impassable or air quality dangerous for a nearby community).

## Better Basics Needed

Scientists, engineers, computer programmers and forestry experts continue to enhance prediction models; we have described only some examples here. Certain models complement one another; some compete. In the end, they will



have to be combined or connected to give fire managers the most helpful, integrated views.

Part of that work will be to further improve the basic physical-level models that underlie all these systems, such as those that calculate flame length or rate of flame spread. A wildfire is a moving combustion reaction with limitless access to oxygen and fuel. The fuel varies in an infinite combination of particle sizes, compactness, dampness and spatial distribution. Weather impacts change continuously. As a result, even the best attempts to quantify variables require simplifying assumptions. Researchers are thus looking to other disciplines to attack the problem. One promising avenue is computational fluid dynamics, an expanding discipline. It is well suited to fire modeling because it can simulate combustion kinetics, chemistry and heat transfer. The technique requires vast computing, however.

Improving models and establishing their scientific credibility also rest on comparing their outputs against observations of actual fires. The difficulty posed to firefighters and researchers attempting to obtain precise field measurements makes this a challenge in itself. Models will also improve as we get a better handle on the most fickle aspects of a wildfire, such as transitions from surface fires to crown fires, as well as spot fires that are ignited ahead of a flame front by windblown embers.

Nevertheless, after decades of modest progress, advancement in fire modeling has surged in the past five years. In perhaps just a few years more, the programs could be integrated into a cohesive set that would help fire analysts and land managers predict the likelihood of fire and advise policymakers on how best to reduce risk while also allowing nature to take its course. ■



To see how experts created the Significant Fire Potential map for May-August 2007, log on to [www.SciAm.com/ontheweb](http://www.SciAm.com/ontheweb)



**SURFACE FIRES (bottom) can quickly transition to crown fires (top), but better models are needed to predict such changes.**

## MORE TO EXPLORE

Current wildland fire information from the National Interagency Fire Center: [www.nifc.gov/information.html](http://www.nifc.gov/information.html)

Fire behavior and fire danger software: [www.firemodels.org](http://www.firemodels.org)

U.S. Federal Fire Policy: [www.nifc.gov/fire\\_policy](http://www.nifc.gov/fire_policy)

Ways to protect homes and communities against wildfires: [www.firewise.org](http://www.firewise.org)