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The Rothermel Fire-Spread Model: Still Running Like a Champ

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The Rothermel Fire-Spread Model: Still Running Like a Champ

In 1972, aeronautical engineer Richard C. Rothermel, of the USDA Fire Sciences Lab at Missoula, Montana, developed a method for modeling the spread of wildfire. The model became widely used, and although the ensuing years have brought many technological innovations, it is still the engine of the predictive tools used by fire behavior officers today. The JFSP is pleased to offer Dick Rothermel's story as a tribute to a significant accomplishment, and also to showcase some of the current work at the Fire Sciences Lab.

It is August of 1979, a hot, dry summer. The Montana woods, spattered by lightning, are erupting in one forest fire after another. One is burning in a remote, rugged corner of the Bitterroot National Forest.

You are a fire behavior analyst on the overhead team assigned to that fire. It is 8 o'clock in the evening. In 2 hours, your plans chief will want a complete briefing on tomorrow's likely events.

Your tools are a sheaf of graphs depicting various fuel types and a Texas Instruments hand-held calculator with a special chip.

You gather the data: wind speed, slope and aspect of the hillsides, types and moisture content of fuel on the ground. You determine which type of fuel this fire is burning in—this requires some judgment and practice. You check the weather forecast.

You feed the information into the calculator. A set of preprogrammed equations crunches the numbers and tells you how fast the fire is likely to spread, how intensely it is likely to burn, and where it is likely to go. You have the critical information in time for the briefing, and your plans chief is pleased.

Now it is August of 2004, another hot, dry season. You have just arrived on a fire in the same rugged area, and your plans chief wants a complete briefing. She hands you her laptop computer, which is linked through a wireless modem to a data library at the Forest Service's Missoula Fire Sciences Laboratory.

You log on and open a sophisticated spatial fire-modeling tool called FARSITE. As you feed in the numbers, you watch the simulated fire blossom in red pixels across the screen. You have the critical information in time for the briefing, and your plans chief is pleased.

The difference between a hardwired calculator and a multi-layered digital map may seem like the difference between a Model T and a Mustang, but these two hypothetical projections are powered by the same engine—a set of mathematical equations developed by Richard C. Rothermel 35 years ago at the Fire Sciences Laboratory in Missoula, Montana.

"It was a big deal to have a quantitative way to calculate fire danger and fire behavior."

Rothermal today. (Courtesy of Richard C. Rothermal.)

Rothermel's model was the Forest Service's first quantitative, systematic tool for predicting the spread and intensity of forest fires, and it is still the main tool being used today. Rothermel, now 78, has been retired for 13 years. He is tall, courteous, reserved, and soft-spoken. He seems a bit surprised that his fire-spread model is still going strong. "It's had a long life," he says, with characteristic understatement.

A model, as the name implies, is a simplified representation of some thing or process that exists in the world. A model is a caricature of reality. A B-17 aircraft can be reduced, simplified, and represented in a structure of plastic and glue. A physical process such as fire can be reduced, simplified, and represented in a structure of mathematics.

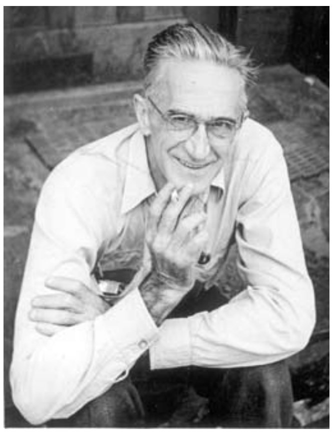
Richard Rothermel's fire-spread model reduces a forest fire to a set of equations operating in a hypothetical universe in which fires burn only small, uniform, dead fuels on the forest floor. The model does not need to know what species of trees or shrubs are growing on a site, except as they are represented as "fuel" of one type or another. The model attempts to describe mathematically the physical and chemical processes of fire.

Rothermel and his team completed development of the model in a hurry, in response to their superiors' demands for a way to reliably predict fire danger over broad landscapes. What it lacks in complexity, it makes up in reliability and ease of use. Even today, despite widely acknowledged limitations—which Rothermel is the first to point out—the Rothermel model of fire spread and intensity is still the most widely used, and it is a component of many fire management tools now in use.

"It was a big deal to have a quantitative way to calculate fire danger and fire behavior," says Patricia Andrews, a research physical scientist and computer programmer whom Rothermel hired in 1973 as a computer programmer to help him implement the model. “Even though there has been a lot of work aimed at improving it, we don’t have a better one yet.”

For most of its 103-year existence, a high priority of the Forest Service has been protecting the forest from fire. The catastrophic fires of 1910, in which more than 3 million acres of forest were burned and at least 85 people lost their lives, focused the attentions of Forest Service officials in the Washington, DC, Branch of Research, notably Assistant Forester Earle H. Clapp.

In 1922, Clapp assigned Harry T. Gisborne, a young forestry graduate from Michigan, to the Priest River Forest Experiment Station then headquartered in Missoula, Montana, and directed him to develop a fire research program.


The hard-driving Harry Gisborne in a relaxed moment.

Gisborne went to work with the vigor of a smokejumper wielding a Pulaski against a fast-moving blaze. It was a time when fire control was a “nearly ceaseless emergency,” according to Gisborne’s biographer Charles E. (Mike) Hardy. Gisborne was impatient and irascible, driving others and himself hard in his quest for practical results, operating at a pitch of stress that would eventually kill him.

Gisborne systematically, and often singlehandedly, collected information about fire and its endlessly varied environment: fuels, winds, slopes, moisture, climate, weather. His 27-year effort produced quantities of basic data on fire that proved a gold mine for later researchers.

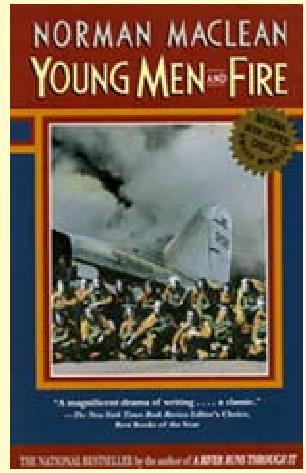
Gisborne also began devising a system for predicting the likelihood and potential severity of forest fires in a given place in a given season. In 1931, he developed what he called a “fire danger meter,” a method for integrating information about fuel moisture, wind speed, relative humidity, and condition of the landscape into an easily understood rating of fire danger.

Gisborne’s 27-year effort produced quantities of basic data on fire that proved a gold mine for later researchers.

Gisborne’s rating system was adopted by the Forest Service and went through several refinements during his time and afterward.

In 1949, the last year of Gisborne’s life, a forest fire in the Gates of the Mountains area in the Missouri River canyon near Helena, Montana, took the lives of 12 smokejumpers and another firefighter. The Mann Gulch fire was assumed at first to be a routine containment job, but it unexpectedly “blew up” and overtook the fleeing firefighters.

Reconstructing the Tragic Race



When Dick Rothermel appeared on national television as a Forest Service spokesman during the 1988 Yellowstone fires, it wasn’t his first brush with fame. Early in the 1980s, a retired University of Chicago English professor named Norman Maclean got in touch with him at the Missoula Fire Sciences Lab. Maclean, author of the well-known memoir *A River Runs Through It*, was writing a book about the Mann Gulch fire. Maclean was raised in Montana and had fought forest fires in his younger days. He wanted to know everything about how the young Mann Gulch firefighters died. In particular, he wanted to know exactly when and where the fire had caught up with them as they fled up the south flank of the gulch on August 4, 1949.

Rothermel agreed to work with Maclean. With information from the Mann Gulch investigation about the timing of certain events, he used his fire model to estimate how fast the fire was going and how much time had elapsed between when the men turned around and headed back upgulch and when the fire overtook them. He published his findings in a 1993 paper called “Mann Gulch: A Race That Couldn’t Be Won.”

Maclean was nearing his 80s when he began work on his book. *Young Men and Fire* was published in 1992, 2 years after Maclean’s death. In it, he draws on Rothermel’s calculations to reconstruct the story of the young men’s race for their lives. He gives generous praise and thanks to the Northern Research Station, the Missoula Fire Sciences Laboratory, and Richard Rothermel and his colleagues.

The Mann Gulch incident quickly became a nationwide story. Some people blamed the Forest Service for the young men's deaths. There was an investigation. Harry Gisborne, who had not been present at the fire, was directed to develop a theory of why it had behaved as it had. He'd gathered copious data on fires, but he realized that there was still no scientific basis on which to build a theory. The Mann Gulch tragedy had made it clear that the Forest Service needed a way not only to predict fire danger generally, but to predict, and also to assess after the fact, the behavior of a fire on a particular site. A couple of months after the fire, Gisborne, intent on his investigation, insisted on walking the rugged gulch, and he collapsed and died of a heart attack. He was 56 years old.

The Mann Gulch fire was assumed at first to be a routine containment job, but it unexpectedly "blew up" and overtook the fleeing firefighters.

The incidence and severity of forest fires waned in the 1950s, and the Forest Service pursued other priorities. Then in the late 1950s, Gisborne's colleague and friend Jack Barrows, determined to continue his mentor's work, pushed the Forest Service to establish laboratories devoted to the study of forest fires. Barrows was the main architect of the lab at Missoula (others were established at Riverside, California, and Macon, Georgia), and he became the first director of the Missoula lab when it opened in 1960.

Barrows went looking for researchers. He learned that General Electric was closing a laboratory in Idaho Falls where engineers had been working on a defense project to develop a nuclear-powered airplane. The government scrapped the program in 1961, and a handful of highly trained engineers and scientists were suddenly up for grabs.

"GE wanted to see that we got as good a placement as we could," Rothermel recalls. "So we all wrote resumes, and Jack got hold of these, and he said it was like a Sears and Roebuck catalog of people." Barrows hired four of the GE scientists: Hal Anderson, a physicist; Stan Hirsh, an electrical engineer; Eric Breuer, a technician; and Dick Rothermel.

Their hiring represented a departure from Forest Service custom. Up until that time, fire research had been pretty much the domain of foresters, who are used to looking at their work through the lenses of biology and silviculture. Gisborne was a forester; Barrows was a forester. But Barrows recognized that fire is a physical process, and that physical scientists and engineers could contribute much to the emerging science of fire behavior.

Rothermel, then barely into his 30s, was glad to join Barrows's staff. He had a bachelor's degree in aeronautical engineering from the University of Washington. During the 8 years since he'd graduated, he had worked in the engineering of nuclear systems in Albuquerque and then in Idaho. (Rothermel later went on for a master's degree in mechanical engineering from Colorado State University.)

"I had the option of staying on [at GE] and working on a lot of programs, but with the cancellation of the atomic-powered airplane, nothing sounded that appealing," he says. "And then I heard about this laboratory, and they said they had two wind tunnels

Jack Barrows examines a fire in the combustion chamber at the Missoula Fire Sciences Lab. Barrows was the main architect of the Missoula laboratory.

Combustion chamber at Missoula Fire Lab; photo taken in the mid-1960s.

and a combustion lab where you could control the atmosphere, temperature, and humidity. I thought, "Wow, that's an opportunity!"

Rothermel worked with Hal Anderson to get the new lab's equipment calibrated and running smoothly. Then they began a set of experiments in the wind tunnel and combustion chamber, testing the effects of wind and moisture on various fuels and determining how fast a fire would spread under different conditions.

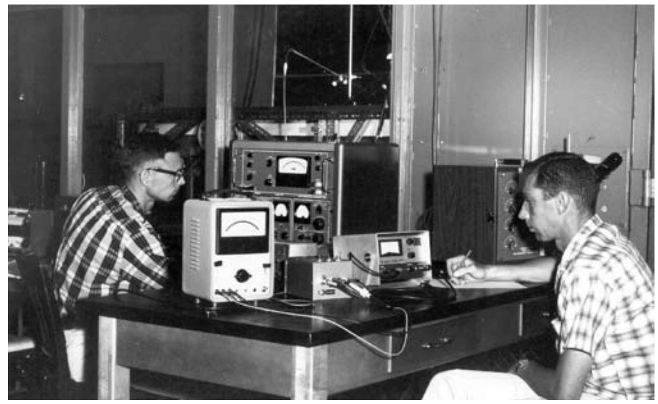
In the meantime, Jack Barrows was transferred to Washington, DC, to become head of Forest Service fire research. Barrows was keen to complete Gisborne's

A young Dick Rothermel watches a fire in the wind tunnel at the Missoula Fire Sciences Lab in the early 1960s.

work on a fire danger rating system. He wanted to develop a system that would cover the whole country, and he wanted to do it fast—within 2 years. A team was assembled from all three fire laboratories. The Missoula Lab's part was to find ways to characterize fire behavior.

Given their training, it made sense to Rothermel and Anderson to approach the task as an engineering problem. Says Rothermel: "The idea was, if we could develop a way of describing the fuels, the weather, the topography, and something about the fire, and be able to put that into what we call a mathematical model, and if we described all these things properly, the model would integrate it and produce answers. It would tell you the resulting fire intensity, rate of spread, flame length, these sorts of things."

Rothermel, Anderson, and Bill Frandsen, another physicist on the project, adapted an approach developed by an early Forest Service fire researcher, Wally Fons, which turned on the concept of conservation of energy. A fire spreads by igniting a series of little fires in the fuel ahead of it. The ignitions are driven by convection, radiation, and conduction. Even if it's unknown which mode is operating in a given instance, the rate of heat transfer can be measured. The researchers reasoned that if they knew how much fuel was ahead of a fire, how big and how densely packed the fuel particles were, and how much moisture the fuel contained, then they could figure out how much energy would be needed to transfer enough heat to bring the fuel up to the ignition point. They

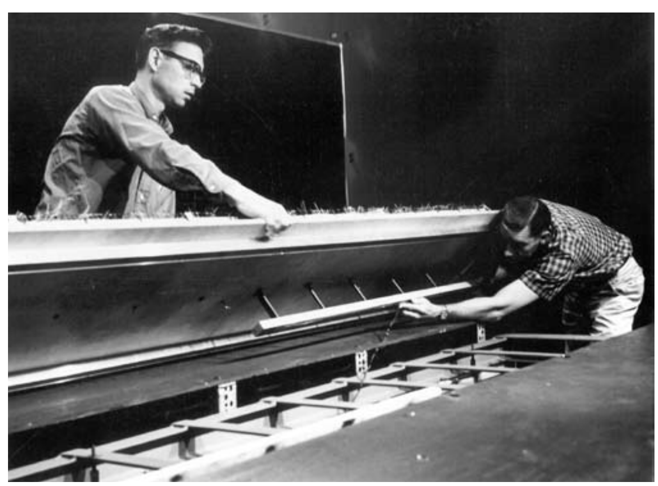


Dick Rothermel (left) and colleague Merlin Brown adjust controls on the wind tunnel at the Fire Sciences Lab, 1963.

could then calculate the rate of ignition that would carry the fire as it spread. The model would also have to account for the critical variables of wind speed and slope of the ground.

Because of the limitations of wind tunnels and combustion chambers, the model is forced to make certain assumptions that don't hold in real life. For example, it assumes that the fuel is continuous and evenly distributed and burns uniformly. It further assumes that the fire is carried primarily by dead plant material and that only moisture will stop it.

The Rothermel model "describes very well a fire burning in a field of wheat," says Bret Butler, a mechanical engineer at the Fire Sciences Lab whom



Rothermel and colleague work with the Lab's fuelbed.

Rothermel hired in 1992. "As you get further away from that uniformity, the less accurate it becomes."

More significantly, the researchers had no basis for modeling the endless spatial variability that actually exists in a forest. So there was no way to simulate a fire's movement through clumpy, discontinuous trees and shrubs. There was also no way to model a crown fire, one that leaves the surface and moves up into the crowns of trees. These were significant and universally acknowledged shortcomings.

Fire research scientists throughout the world are working on developing more accurate surface-fire spread models, but at this point all of them are too complicated to be used in an operational system. The beauty of Rothermel's model, says Butler, "is that it's simple—it can be run quickly with a low-capability computer."

"The beauty of Rothermel's model … is that it's simple—it can be run quickly with a low-capability computer."

It took a little longer than 2 years, but the team accomplished its mission. Rothermel published their findings in 1972 in a paper on the fire spread model. Rothermal's model became the basis for the first national-level fire danger rating system, developed by researchers in Fort Collins, Colorado. The Forest Service and other land management agencies had an updated tool for predicting which seasons might be particularly bad and where fires would have the worst impacts.

Rothermel believed the model could be made even more useful. He had visited many active forest fires in the course of his work, and he saw overhead teams struggling to predict what the fire was going to do, with basically nothing to go on. "They were supposed to calculate the probabilities" of certain patterns of spread or intensity, he says, but "I never saw anybody who had any [basis] for calculating these probabilities. There was really room for developing something for these people to use."

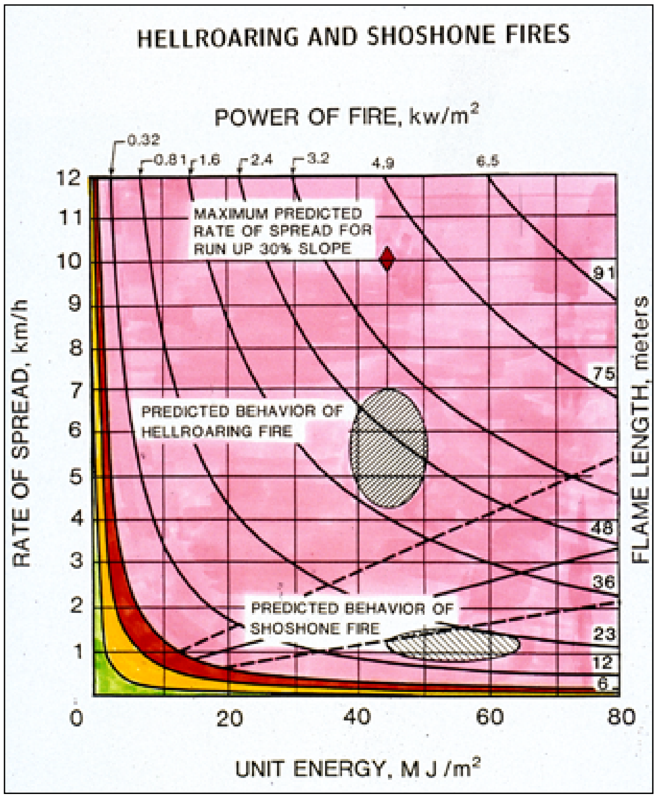
Traditionally, the best predictors of what a forest fire would do were the eyeballs and judgment of the crew chief. A forest fire throws out a lot of information, much of it obscured by smoke and noise. As Norman MacLean writes in *Young Men and Fire*, his book about the Mann Gulch fire: "It is hard to know what to do with all the detail that rises out of a fire. It rises out of a fire as thick as smoke and threatens to blot out everything." How well this information got absorbed, synthesized, and communicated depended on the experience and level-headedness of the crew's leader.

Rothermel and his team thought their model might be able to augment human observation and judgment by distilling sensible data out of the smoke and confusion of an actual forest fire. But first they had to overcome a big obstacle: they needed a shorthand way to describe the large potential array of fuel types, so that a fire behavior analyst could identify quickly what he or she was facing. With that, it might be possible to get the model to produce not just probabilities but actual numbers—feet per minute of spread, length of the flames in feet, fireline intensity in BTUs per second per foot.

Rothermel's 1972 paper included a list of 11 fuel models representing typical field situations. Fuel models are representations of typical fuel profiles and contain a complete set of inputs for the mathematical fire spread model. The team's research engineer, Frank Albini, expanded the number of fuel models to 13 and developed a series of nomograms, or graphs, to give the spread rate, intensity, and flame length under any combination of slope steepness, wind speed, and moisture content. There are two nomograms for each fuel model, one for low wind speeds and one for high wind speeds.

Albini, who died in 2005, was "the closest I've ever seen to a mathematical genius," Rothermel says. Albini's nomograms are mathematically terse. All the data for each fuel type fit onto two notebook pages. A fire behavior analyst can quickly study the graphs, identify the parameters that fit the situation at hand,

Dick Rothermel uses a TI-59 calculator programmed with his fire spread model on a fire site circa 1983.



Nomogram created by Frank Albini.

and draw a series of lines to arrive at a likely rate of spread and intensity. The calculation can be done with pencil and paper and a little know-how.

Another step was taken in 1979 when research forester Bob Burgan turned the spread model into a computer program and had it burned onto a special chip for the Texas Instruments Model 59 hand-held calculator. Now fire behavior analysts had a quick and reliable way to assess their situations and make decisions on where to deploy crews, whether to order in airplanes or bulldozers, when to hold the fire line, and when to get out of the way.

"Those were exciting times … In the evening he [Rothermel] would scribble a new equation on a napkin and the next morning we would include it in our lessons."

Getting his model out into the world was a top priority for Rothermel. "Somehow [technology transfer] was inherent in my makeup," he told Forest Service historian Harold Steen in a 2005 interview. "I felt if I wasn't doing something worthwhile, then why are you doing it? So I guess it's the engineer coming out."

"He worked hard to get it implemented," says Pat Andrews, "and that's to his credit. Some other researchers might have published their findings and moved on, but he worked hard to get it into use."

In 1976, Rothermel began teaching a course at the Fire Training Center in Marana, Arizona. He was part of a group that trained fire analysts from the Forest Service, the Bureau of Land Management, the Bureau of Indian Affairs, and other land management agencies in how to apply his model through use of Albini's nomograms.

"That was a wonderful opportunity to get our stuff into application," he says. "The fun part was going out on a fire and being with the people we'd trained. We'd probably have 35 or 40 in our classes. Then we'd go to a fire and meet these folks: 'Oh, hi! How are you doing?' They'd welcome me in and show me what they were doing. I'd get some feedback as to what was working well and where they were having trouble."

Sometimes he would learn that the model's predictions of a given fire's behavior were nothing like what actually happened. "So every year at Marana, we'd learn what we did poorly the year before and beef it up that winter," he says. "I remember one of the things that we didn't have was a good way of estimating fuel moisture. We didn't have good ways of estimating wind speed at the mid-flame level, and Frank worked on that a lot. We didn't have quick ways of assessing wind speed on a slope, and we worked that out too."

"Those were exciting times," recalls Jan van Wagtendonk, a research forester with the U.S. Geological Survey at Yosemite National Park, who taught with Rothermel at Marana. "In the evening he would scribble a new equation on a napkin and the next morning we would include it in our lessons."

In 1983, Rothermel assembled the training materials into a publication called *How to Predict the Spread and Intensity of Forest and Range Fires*. It came to be known as "the Bible," according to Bob Mutch, a research forester who taught the Marana courses with Rothermel. Rothermel himself was "Mr. Fire Behavior." Says Mutch: "He was user-friendly, and he was practical. He'd say, 'Use the model to the best of your ability, and then use what your eyes are telling you. One without the other is incomplete.'"

In July of 1988, as the forest fires in Yellowstone Park were making national headlines, Rothermel, Burgan, and some others traveled there, assigned to develop a worst-case scenario. During that time,

Tools for Fire Managers [1]

Improving the usefulness of decision support systems for modeling and analyzing wildland fire is an ongoing mission of fire scientists at the Missoula Fire Sciences Laboratory and elsewhere. Some of the decision support systems available to fire managers include:

BehavePlus
A fire modeling system that is an expanded version of the BEHAVE fire behavior prediction and fuel modeling system, which was developed by Pat Andrews and others at the Missoula Fire Sciences Lab in 1986. BehavePlus combines many models, including Rothermel's, that describe fire behavior, fire effects, and the fire environment.

FARSITE
FARSITE incorporates several models of fire behavior in space and time to simulate a fire burning across a variable landscape under changing environmental conditions. FARSITE can help analysts determine the rate and direction of spread of a particular fire and predict when it will reach a given location.

FlamMap
A spatial fire-behvior analysis and mapping program. It is different from FARSITE in that it produces independent calculations of different dynamics of fire, such as intensity at the fire line and length of flames. It lends itself well to comparisons of two different landscapes in terms of their potential fire behavior, and it helps fire analysts identify hazardous combinations of fuels and topography before a fire occurs.

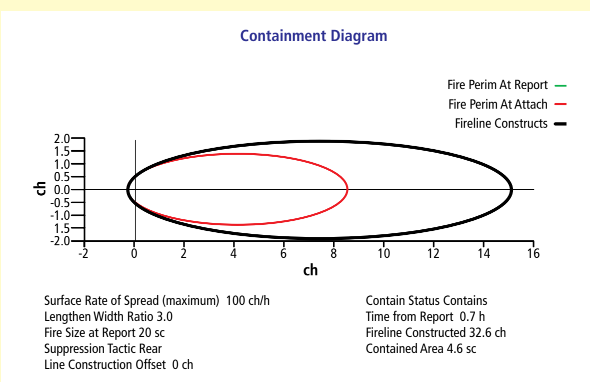
FireFamily Plus
A fire climatology program that allows the user to compute fire danger in a given area and to summarize and analyze historical weather observations in association with local data on fire occurrence.

Rare Event Risk Assessment Process (RERAP)
Estimates the risk that a fire will reach a particular place before it dies. RERAP incorporates Rothermel's surface-fire spread model along with models for weather, fuels, and topography.

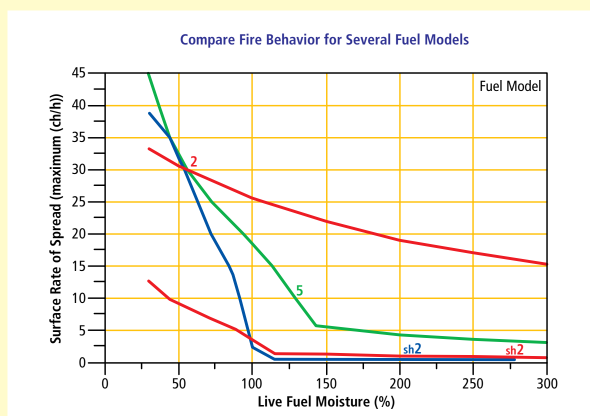
WindWizard
An interface to a computational fluid dynamics model called FLUENT, which simulates the effect of terrain on wind. WindWizard produces wind velocity and direction to a resolution of 100 meters. Output can be imported into FARSITE and FlamMap to improve fire behavior simulations.

FireStem
A computer model designed to aid in predicting tree mortality based on fire behavior and intensity. Eventually, FireStem will be included in BehavePlus to produce improved mortality predictions based on fuel information, moisture, and fire behavior for a specific region and range of tree species.

Wildland Fire Assessment System
An integrated, Web-based resource that provides multi-temporal and multi-spatial views of fire weather and fire potential, including fuel moistures and fire danger classes from the National Fire Danger Rating System, as well as indices of drought, atmospheric stability, and vegetation conditions. WFAS provides short-term fire-potential forecasts, from 24 hours to 30 days.



Behave-Plus diagram of fire containment.



Behave-Plus plot of rate of spread.

[1] From Stratton, Richard D. 2006. *Guidance on Spatial Wildland Fire Analysis: Models, Tools, and Techniques*. General Technical Report RMRS-GTR-183, USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO.; also Andrews, Patricia and Queen, Lloyd. 2001. Fire modeling and information system technology. *International Journal of Wildland Fire* 10:343-352; also Missoula Fire Sciences Laboratory, Fire Models.org, ***http://www.firemodels.org/component/option,com_frontpage/Itemid,1/***, accessed September 10, 2007.

Rothermel (right) and colleague Rod Norum on the Big Salt River fire, Alaska, 1977.

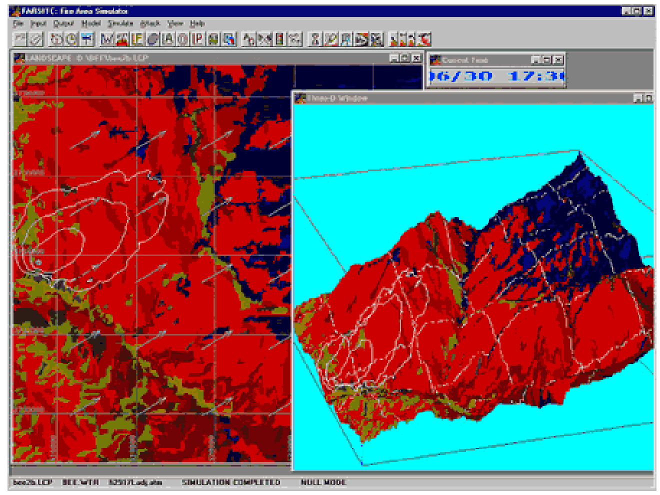
Rothermel was also drafted as a media spokesman for the Forest Service, appearing on national television to explain what was happening in America's favorite national park.

About his primary assignment, he says, "The problem was we couldn't come up with a worst-case scenario because … the winds came again and again and again, and the worst case happened almost weekly." He and his colleagues had assumed that, as in normal years, rain would come in August to dampen the fires. That didn't happen. "It was an amazing season. Nobody had seen this combination of weather and fires before."

He came away from Yellowstone determined to create a model for crown fires before he retired. It still was not possible to model crown fire behavior in the wind tunnel, so he gathered observations of severe real-life fires and categorized them into three basic types. In 1991, he wrote a simple guide on how to predict the spread and intensity of each of these types. "Once again, he stepped up to the plate," says Bret Butler. "He saw a need and filled it."

In the years since Rothermel retired, the Missoula Fire Sciences Lab and others have incorporated his model into many predictive tools used by fire managers today. These are known as "decision support systems" because they are intended to support the experienced judgment of a fire behavior analyst and other fire managers. Fire modeling systems such as BehavePlus, a 2001 update of the original BEHAVE developed by Pat Andrews and her colleagues, and the FARSITE fire area simulator, developed by research forester Mark Finney in 1998, link Rothermel's fire spread model with other models to create increasingly powerful and subtle representations of reality.

"Dick and his team set the stage for the things we're doing today."



A FARSITE simulation of the 1996 Bee Fire in the San Bernardino National Forest. (From the USDA Forest Service Strategic Planning and Resource Assessment Web site, December 3, 2007.)

FARSITE, for example, is a spatially explicit (i.e., map-creating) computer tool that incorporates Rothermel's models for surface and crown fires with several others, including crown-fire models by Canadian researcher C.E. Van Wagner. It also includes models by Albini that describe spotting (ignitions from bits of burning material thrown ahead of a fire), acceleration of a fire from its starting point, and fuel moisture. FARSITE also packs in digital maps of fuels and topography and a 3-day weather forecast. Fed the appropriate information, FARSITE will "grow" a fire in living color on a computer screen even as the actual fire is burning.

Through the years, such tools have been periodically refined as researchers developed more accurate ways to characterize the inputs—fuel moisture, wind speed, and so forth. This refinement will continue, says Mark Finney, but these days the lab's basic research program is departing from Rothermel's footsteps to pursue other conceptual paths.

"Dick and his team set the stage for the things we're doing today," says Finney. "Did he envision the huge consequences of his work? It may have gone well beyond his imagining. It set off a whole field of fire prediction science, and it produced spinoffs that he could not have thought of."

The limitations of the Rothermel model, he believes, are inherent in its empirical, statistical approach—the best possible approach at the time, but adequate no longer. "Now we have a lot of new problems that weren't recognized back in the 1970s," says Finney. "New demands are being placed on those old models. We're asking them to do things they were not designed to do, to answer questions that didn't have a practical context then."

"Dick represents the best that science has to offer. He has a brilliant mind and is able to transfer his knowledge and wisdom to field personnel with humor and humility."

One of these questions is, when is fire a blessing rather than a curse? At the time Rothermel was developing his model, land management agencies were barely beginning to reconsider the policy that the only good fire is a dead fire, and many still clung fiercely to that conviction. In the early 1970s, Bob Mutch was working on a program called Whitecap, investigating what was then called "prescribed natural fire planning" for wilderness areas. (Today it is called "wildland fire use.") The program drew bitter criticism from some long-time agency foresters. "They thought, 'Here are these wild-eyed people, suggesting that fires might actually be doing some good,'" says Mutch with a chuckle. Dick Rothermel was developing his model at a time when suppression was pretty much the only objective.

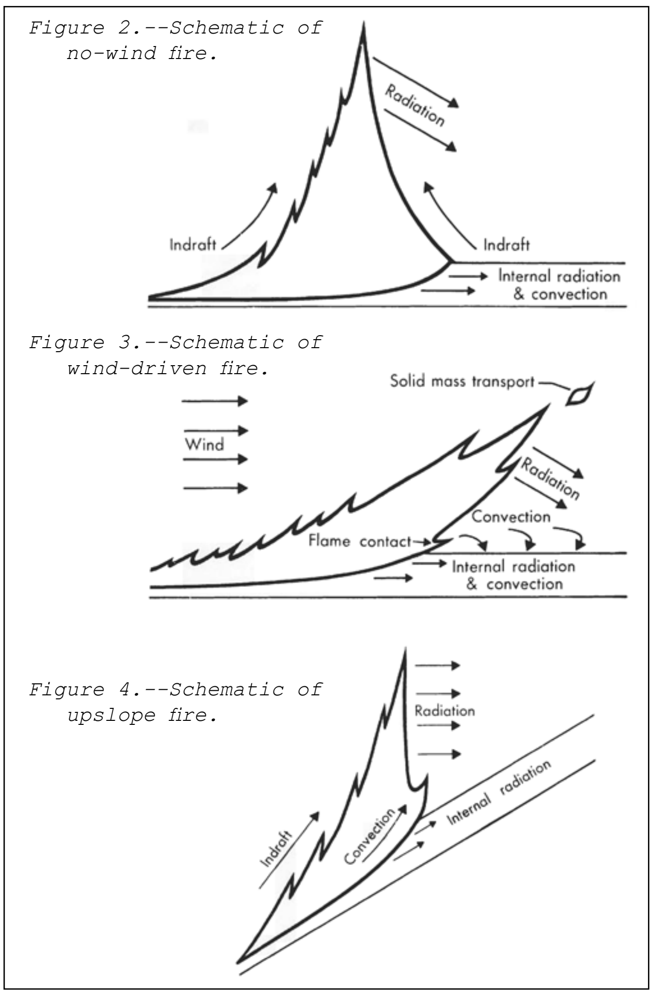


Illustration from page 5 of Rothermel's *A mathematical model for predicting fire spread in wildland fuels*. Research Paper INT-115, January 1972.

Mark Finney and his colleagues represent the next generation of fire researchers. They are questioning old assumptions and trying to describe fire in a new way. Specifically, they are looking more deeply into the three modes of heat transfer—conduction, convection, and radiation—in an attempt to understand the actual mechanisms of fire spread. The Rothermel equation, based on empirical measurements, does not specify *how* a fire spreads, and therefore it can't address questions like, how does convection differ from radiation in how fast it transfers heat energy into a living pine tree? More insight into the basic mechanisms of fire, Finney believes, will lead to better methods for accurately modeling fire in the clumpy, discontinuous real world.

Along with everyone else, Finney acknowledges that any new way to model a complicated physical process like fire will need to strike something like the balance that Rothermel's model achieves: it will need to be detailed enough to be accurate most of the time, yet simple enough to be useful to people who must quickly parse the smoky, noisy chaos of forest fire and come out with accurate and potentially life-saving information.

In 1981, Rothermel received one of the United States Department of Agriculture's highest honors, the Superior Service Award, for "outstanding creativity in developing fire behavior prediction technology and training programs, enhancing the implementation of the Forest Service's revised fire policy." Says his colleague Jan Van Wagtendonk, "Dick represents the best that science has to offer. He has a brilliant mind and is able to transfer his knowledge and wisdom to field personnel with humor and humility."

Rothermel still lives in Missoula and visits the Fire Lab from time to time, shaking hands and talking about old times.

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Many of the preceding USDA Forest Service publications can be accessed at the FireModels.org page at ***http://www.firemodels.org/content/view/34/43/***. However, the possibility exists that these documents could have been modified from those referred to here.

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