The *FARSITE* Fire Area Simulator: Fire Management Applications and Lessons of Summer 1994[1,2]

Mark A. Finney[3]
Patricia L. Andrews[4]

ABSTRACT

The FARSITE Fire Area Simulator has been developed for supporting decision making on wildland fires. It provides the capability for long-term fire growth projections. FARSITE uses a wave-front approach to model fire spread over complex landscapes. This requires spatial data themes from a GIS (elevation, slope, aspect, surface fuel model, canopy cover) along with separate weather and wind data. The simulation runs on a personal computer (80486 processor or better) and incorporates models for surface fire spread, crown fire and transition, and spotting.

Prescribed natural fires at Yosemite and Glacier National Parks during the summer of 1994 afforded an opportunity to field test the FARSITE approach. The primary purpose of the tests was to evaluate the use of this technology during ongoing fires. Our experiences suggest that FARSITE can be a useful tool for management of fires that last for extended periods, provided that the necessary spatial data on fuels and forest structure are available. Reliable output from FARSITE requires accurate data on fuels and winds. Methods need to be developed for obtaining the necessary fuel information for large landscapes. Feedback from fire managers and personnel has been positive. Further extensive validation of FARSITE will be required for better determining the limitations and utility of this approach to fire growth simulation.

INTRODUCTION

The *FARSITE* Fire Area Simulator (Finney 1994) is a fire growth model based on Huygens' principle of wave propagation (Anderson et al. 1982). This technique simulates the growth of a fire front as a 2-dimensional elliptical wave (Richards 1990) using spatial data from a geographic information system (GIS). The fire front is projected over a finite timestep using fire behavior at discrete points along the fire's edge. Fire behavior is computed for those points from local raster information on fuels, weather, and topography using the Rothermel (1972) model. This provides a 1-dimensional rate and direction of fire spread for each point that produces a 2-dimensional fire growth when aggregated for all points around the fire perimeter. This technique is in fact very close to the manual methods employed for the same purpose (Rothermel 1983).

FARSITE has been developed for use on a personal computer (PC) and the Microsoft Windows operating environment (Finney 1995). Version 1.0 was released in January 1995. The PC platform makes the simulation available on inexpensive hardware that is familiar

to fire managers and other users. It also enables portability for field uses. Nevertheless, *FARSITE* requires the support of a geographic information system (GIS) for creating and managing spatial data. Raster files for elevation, slope, aspect, fuel model, and canopy cover, must be imported to *FARSITE* from either GRASS or ARC/INFO. A *FARSITE* simulation can then produce vector and raster data for export back to GRASS or ARC/INFO.

In addition to spatial data on fuels and topography, *FARSITE* requires the user to develop at least one weather and wind stream. Up to 5 weather or wind streams can be imported and designated spatially as to the ground locations to which they apply. The weather stream specifies daily maximum and minimum temperatures and humidities, along with the elevation and time of day that these occur. These data are used to construct a sine-wave model of temperature and humidity fluctuations for computing fuel moistures at any time of the day or night (similar to Rothermel et al. 1986). These are adjusted adiabatically for elevations other than that specified in the weather stream. The wind stream contains wind speed and direction events for particular times. Winds are assumed spatially constant for a particular stream, but vary in time at the interval of the observations.

BETA TESTING DURING SUMMER 1994

The purpose of the testing phase during summer 1994 was primarily to obtain feedback from select users on features of the interface, input procedures, and output options. Summer 1994 was used to evaluate how *FARSITE* might be incorporated into fire management operations during active prescribed natural fires. As a beta release, *FARSITE* was revised throughout the summer as program errors were found. An incidental objective was to observe the general predictive abilities of the simulation, and start making some interpretations as to what is required to make predictions that are useful for fire management operations. These were not intended to be considered "validations" of the simulation model. Validation will require a careful set of procedures to compare observed with predicted fire spread and behavior for a number of fires under a variety of fuel types and burning conditions.

Two opportunities arose during the fire season of 1994 to test the operational use of *FARSITE*. The first event was the Horizon prescribed natural fire at Yosemite National Park. Yosemite National Park, along with Sequoia and Kings Canyon, were original test sites for *FARSITE* because of the Park's well developed GIS

data base, 20 year history of prescribed natural fires, and consequent development of its fire management and research organizations. The second fire event was the Howling prescribed natural fire at Glacier National Park.

Horizon Fire at Yosemite National Park

Yosemite had the necessary digital elevation model (DEM) and fuels and vegetation information. A new fuels map was recently produced for Yosemite from an interpretation of Thematic Mapper (TM) satellite imagery at 30m resolution that made use of the Normalized Difference Vegetation Index (NDVI) (Burgan and Hartford 1993). This map was available before the fire and proved to be an important contribution to the fire growth projections. The Horizon fire was ignited by lightning in late May but did not grow beyond a few acres until mid-June.

Two growth projections using *FARSITE* for 3-weeks into the future were made for the Horizon fire every week or so. The weather and wind streams for the projections were developed subjectively, based on weather patterns experienced during the past week and loosely on weather forecasts. A second weather/wind scenario was developed by punctuating the normal conditions with an interval of extreme fire weather. In Yosemite these conditions are associated with low humidities and an easterly foehn wind, locally known as a "Mono Wind" because Mono Lake is situated approximately due east of the Park.

The first projection was based on a crude reclassification of a vegetation type map. The resulting fuel model map did not adequately reflect spatial variation in fuels at that level. Rocky outcrops and fields of montane chaparral that significantly affect fire spread were underrepresented on this map. Subsequent simulations were run using the new image-based fuels map. Fire growth projections based on the new fuels map and normal weather conditions appeared reasonably accurate. These projections agreed with conventional expectations and had recognizable similarities with the actual fire (Figure 1). Areas of departure were interpreted as resulting from 1) an absence of crown fuels information (height to live crown base, crown bulk density) that prevented initiation of torching or crown fire runs, and 2) limitations of the spatially constant winds in the beta version of *FARSITE* that prevented us from distinguishing valley wind patterns from ridge-top wind patterns.
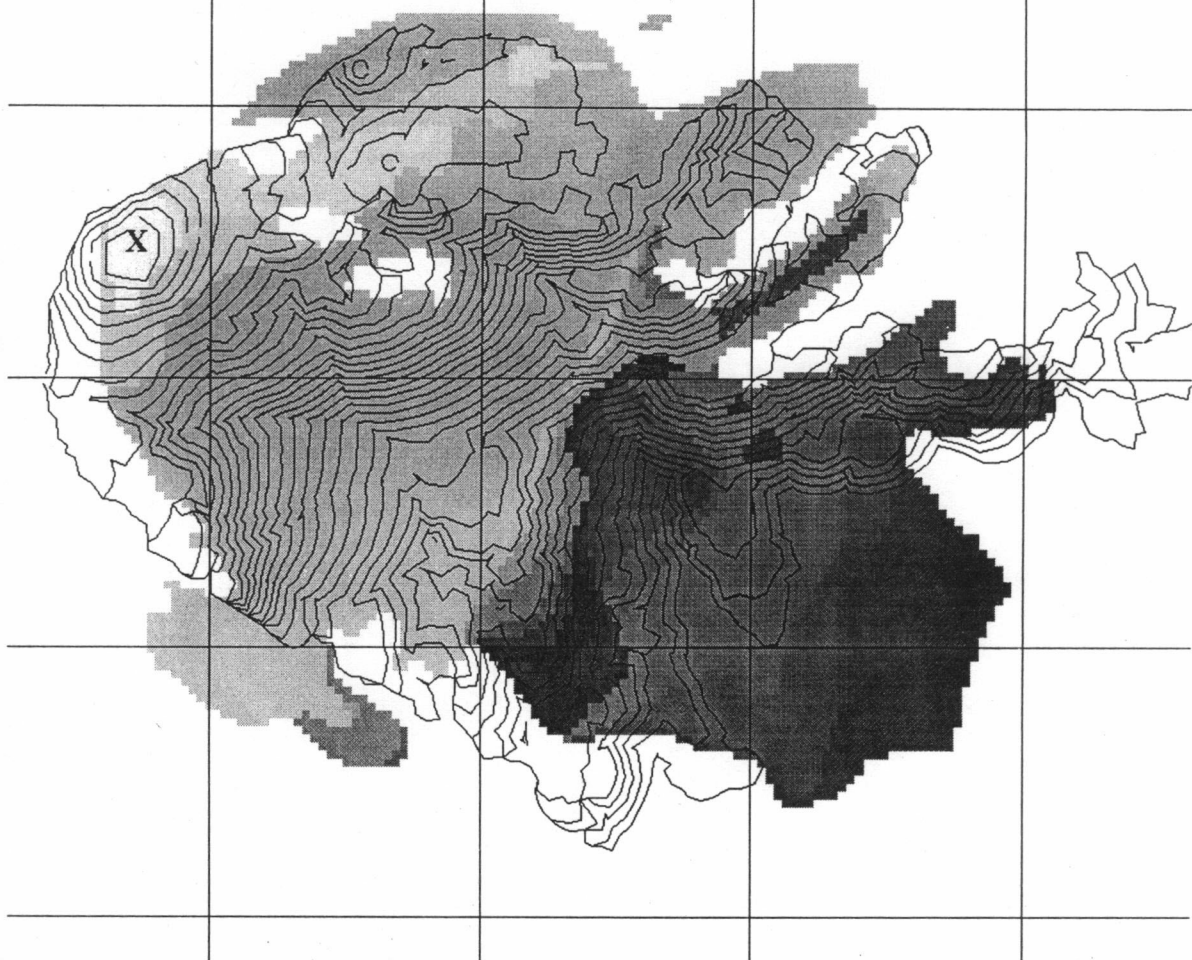
Figure 1. *Fire spread patterns recorded for the Horizon prescribed natural fire at Yosemite National Park, California (shading), compared to daily fire perimeters predicted by the FARSITE model (lines).*

Howling Fire at Glacier National Park

Glacier Park was not originally an established test site for *FARSITE*, given the nascent PNF program there. However, circumstances eventually permitted the Howling fire to be managed as a potentially large PNF. Two fire growth projections were made and used as part of the process of deliberating the decision to designate the fire as a PNF. The first projection used a normal weather/wind stream based on recent weather conditions and typical weather for the season. As with the Horizon fire, a second scenario was the same except with a period of extreme fire weather (strong northwest winds) associated with the passage of a dry cold front.

These projections were run using a fuels map that was a crude reclassification of the existing vegetation type map. As with Yosemite, this map was not considered to have spatial detail on fuels or vegetation structure sufficient to reflect actual variations on the landscape. The fire growth projections were however, considered by fire and Park management staffs to be useful to the decision process. Compared with other methods of projection, *FARSITE* calculations were more objective, and suggested considerably slower fire growth which both agreed with the intuition of local managers and was later verified as the fire progressed (Figure 2).

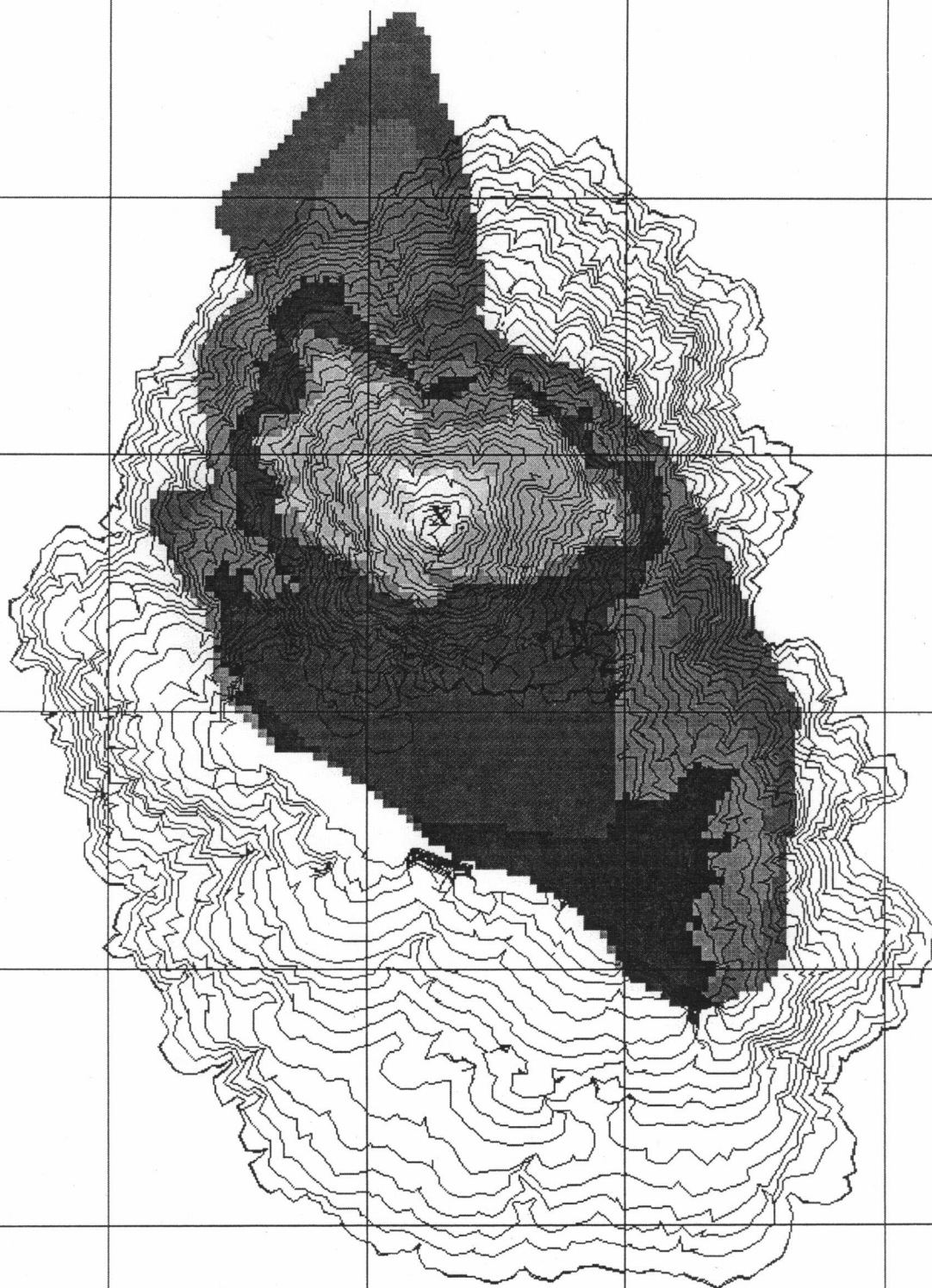Given the limitations of the early fuels map, an attempt

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Figure 2. *Fire spread patterns recorded for the Howling prescribed natural fire at Glacier National Park, Montana (shading), compared to daily fire perimeters predicted by the FARSITE model (lines).*

was made to improvise a fuels map using TM imagery with methods similar to those used at Yosemite Park. This effort, however, did not result in a map that was considered satisfactory for fire behavior or fire growth modeling. Although there was not enough time to thoroughly field-check the fuels map, much of our dissatisfaction with the map resulted because the fuel models assigned to an area weren't producing the correct fire behavior. The fuel models assigned to the landscape were not adequate to model fire behavior because 1) the availability of live herbaceous and shrubby fuels was not predicted by the fire spread model, and 2) the assumptions of flaming spread along a continuous front attending the Rothermel (1972) spread equation were violated (see Lessons below).

The abundance of live understory fuels at Glacier makes fuel "typing" difficult for fire behavior prediction. Live shrubs and herbaceous vegetation may be able to carry the fire if the moisture contents are low and continuity or packing ratio high enough given the wind/slope conditions. However, the availability of the fuels is not a static condition that can be mapped without knowing the burning conditions. Thus, in the simplest case, the fire will burn slowly through the litter and woody surface fuels, or will make the transition to the shrubs and burn much more rapidly, depending on the environmental conditions. Consequently, a single "fuels" map may not be sufficient for fire growth simulation.

LESSONS FROM *FARSITE* TESTS

Experience with *FARSITE* during 1994 made clear the increased effort required to create and organize spatial and temporal data necessary to use the fire growth model. Spatial and temporal data required for *FARSITE* are considerably more detailed than required for other fire prediction tools such as BEHAVE (Andrews 1986) and RERAP (Wiitala and Carlson 1994). This means that all spatial data sets should be completed and available before the fire season begins and the need arises for running a fire growth simulation. For many National Parks and wilderness areas, the use of *FARSITE* will require an investment in creating the necessary GIS data themes. It also means that there must be close cooperation between fire management staffs and GIS specialists in creating, maintaining, and accessing spatial data themes.

An accurate fuels map was found to be critical for achieving reasonable fire growth simulations using the historic weather. The fuels map would be especially important where fuels are more spatially heterogeneous

and where characteristic spread rates differ widely among fuel types. Spread rates for grasses or shrubs can be many times greater than for timber fuels under identical weather conditions. These basic fuel types were defined at 30m resolution on the fuels map for the Horizon Fire at Yosemite. This precision was important to simulating the observed fire growth patterns on that fire. Live fuels in the Sierra Nevada are generally evergreen and schlerophyllous, with typically low moisture contents throughout the summer months. These fuels are typically available to the fire and contribute greatly to fire spread.

Predicting the contribution by live herbaceous or shrub fuels to fire spread was an obvious problem for modeling the growth of the Howling fire. In contrast to the fuels in the Sierra Nevada Mountains, much of the live understory vegetation in Northern Rocky Mountain forests are deciduous. As fuels, these plants have high foliar moisture contents (>200% dry weight) throughout the summer until senescence or frost. Moisture content is probably the primary determinant of live fuel availability for fire spread and behavior in these forests (Brown and Bevins 1986, Brown and Simmerman 1986, Brown et al. 1989). Foliar moisture content will to a large extent determine if fire makes the transition from burning slowly in dead surface fuels to spreading faster through a shrub canopy. This transition, however, is not predicted by the Rothermel (1972) spread equation as used in *FARSITE*. If the transition between vertical fuel layers could be predicted or assumed, the fire spread rate could then be determined using a more appropriate fuel model. Such a transition may be manually inferred based on expert observation of fire behavior trends as the fire season progresses. Fuel models used in *FARSITE* can then be easily converted to models with more realistic fire behavior outputs.

The spatial arrangement of dead surface fuels throughout much of the Howling fire was also problematic for fire modeling. The surface fuels consisted of sparse conifer litter *(Pinus ponderosa, Picea englemannii, Pseudotsuga menziesii, Larix occidentalis)* between a widely spaced network of large downed logs. Given the lack of wind under the dense forest canopy, the fire spread faster by smoldering along the individual logs than between them. Consequently, the fire shape was determined mostly by the spatial arrangement of large woody fuels and the connections between intersecting logs. Occasional and sporadic torching of spruce trees contributed to short-range spotting outside the existing fire perimeter. This produced localized bulges in fire growth patterns that could not be simulated by *FARSITE*.

Independent of the type of fire or fire spread mechanisms, it was necessary to calibrate the modeled spread rates to match observed spread rates. Adjustment is necessary because the Rothermel (1972) spread equation used in *FARSITE* has been observed to consistently overpredict spread rates by several times over large distances and long times (Finney 1994). This may be caused by a number of factors. First, the lack of data on spatial wind variation over complex topography may underestimate sheltering of fuels by both forest canopy and topographic features. Second, the coarse scale of weather and fuel inputs relative to the fine scale of fire behavior processes may cause overprediction by forcing steady state fire spread conditions. The temporal scale of wind vectors in the wind stream (half-hour to hour) is much coarser than the scale of actual wind variations that affect fire spread and appear essentially constant. Similarly, the fuels mapped into the GIS are assumed spatially homogeneous at and below the scale of the GIS raster resolution. Most fuels, however, are homogeneous only at much finer scales. The actual variability in fuels and weather produces fire spread rates that don't reach steady-state conditions predicted from coarse inputs to the Rothermel (1972) spread equation. The fire is continuously accelerating and decelerating in a given spread direction rather than spreading at a constant rate over large distances and times. Calibration is used to adjust the predicted spread rate to approximate the observed spread. The calibration is achieved by trial and error using observed fire growth and changing adjustment factors until predicted spread in homogenous patches of each fuel type approximates the observed spread. Adjustment factors for all fuel types on the Horizon fire were between 0.2 and 0.4 compared to 0.1 to 0.2 on the Howling fire. Preliminary validations from a number of fires seem to suggest that the adjustment factors become less important (approach 1.0) as burning conditions become more extreme. It is therefore possible that the adjustment factors may change for some fuel types throughout the burning season and throughout the duration of a given fire. Many more validations are needed however, before the reasons for needing spread adjustments can be better understood.

Although the fuels map was important to retrospectively simulating the Howling and Horizon PNFs, the accuracy of long-range fire growth projections will always be dependent on long-term weather forecasts. Long-term outlooks on weather (3+ days) will likely remain general and not provide specific information for daily weather patterns. The purpose of long-range fire growth projections will thus be in evaluating the relative sensitivity of fire growth and behavior patterns to potential weather scenarios. This may suggest contingencies for fire management or permit the risks associated with certain weather patterns to be considered. If the actual weather does follow one of the modeled scenarios and the fuels map is accurate, the fire growth associated with that scenario may be useful in anticipating fire activity.

ACKNOWLEDGMENTS

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BIOGRAPHIES

Mark Finney is a fire researcher with Systems for
Environmental Management in Missoula, MT, and is a
cooperator of the Intermountain Fire Sciences Labora-
tory. Before that he was on the research staff of
Sequoia National Park. He received his Ph.D. from
Univ. Cal. Berkeley in 1991, an M.S. from Univ.
Washington, and a B.S. from Colorado State Univ.

Patricia L. Andrews is Project Leader of the Fire
Behavior Research Work Unit at the Intermountain Fire
Sciences Laboratory in Missoula, Montana. She has
been a member of the unit since 1973, She was a
primary developer of the BEHAVE fire behavior
prediction system. Current work includes fire growth
simulation modeling and analysis of historical fire
danger and fire occurrence records