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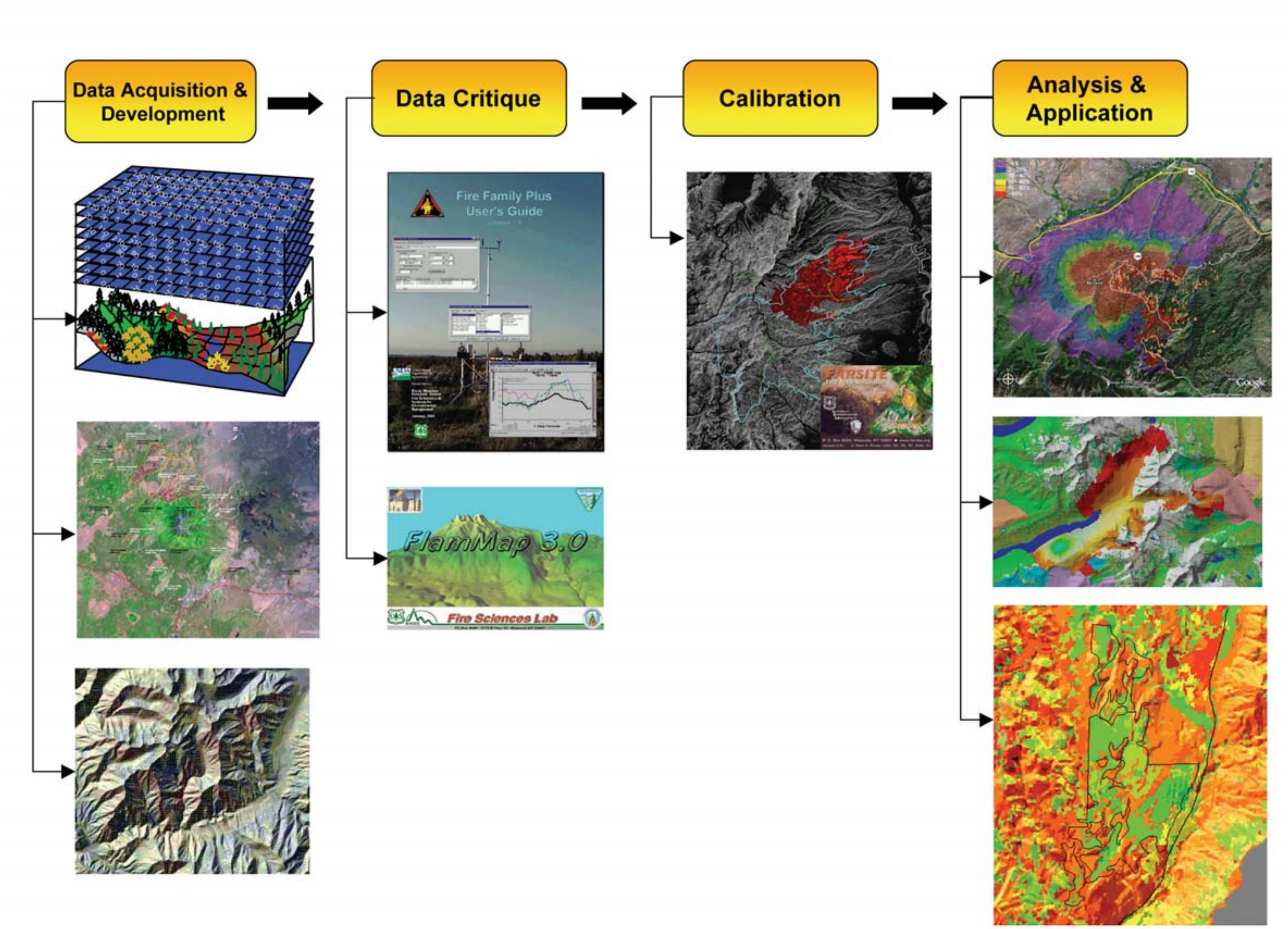
Guidance on Spatial Wildland Fire Analysis:

Models, Tools, and Techniques

Richard D. Stratton



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Abstract

There is an increasing need for spatial wildland fire analysis in support of incident management, fuel treatment planning, wildland-urban assessment, and land management plan development. However, little guidance has been provided to the field in the form of training, support, or research examples. This paper provides guidance to fire managers, planners, specialists, and analysts in the use of “models” (FARSITE, FlamMap, RERAP-Term), tools/programs (KCFAST, RAWS, FireFamily Plus, WindWizard), and procedures for spatial fire analysis. The approach includes a brief discussion about models and their assumptions and limitations, historical fire and weather analysis, landscape file data acquisition and development, landscape file and model output critique, and model calibration.

Keywords: Calibration, FARSITE, FireFamily Plus, Fire History, Fire Modeling, Fire Weather, FlamMap, Fuel Treatment, Gridded Wind, Hazard/Risk Assessment, Landscape Analysis, RAWS, RERAP, WindWizard.

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Introduction

Large fires are a **landscape-level** phenomenon because they affect multiple stands over a large area. They are also a **spatial** phenomenon because the movement and behavior of fire depends on where and what things it encounters and their spatial arrangement to one another. To adequately perform both a landscape-level and spatial fire analysis, one must conduct a mid-scale assessment of expected fire behavior and movement across multiple stands under specific weather and fuel moisture conditions.

Arno and Brown (1989) stated, "An impressive body of scientific evidence…makes it clear that much of North America is a 'fire environment' where wildfire or a substitute recycling mechanism is inevitable." This ecological certainty has been exacerbated by three-quarters of a century of fire exclusion in many parts of the United States, often resulting in uncharacteristic large fire growth, behavior, and its undesirable effects (Arno and Brown 1991).

Policymakers see destructive and costly fire seasons such as 2000 or 2002 and react with legislation and increased scrutiny (for example, National Fire Plan, Healthy Forest Initiative, General Accounting Office Reports). Accordingly, land managers and fire specialists are required to adhere to Federal and state mandates and guidelines. With compliance comes reports, many of which can benefit from or require spatial fire analysis, such as land management plans; wildland fire situation analysis and implementation plans; hazard/risk assessments; community protection plans; and National Environmental Policy Act (NEPA) compliance, documentation, and outreach.

Unfortunately, little training or instruction has been given to the field to adequately conduct spatial wildland fire analyses. Irrespective of the project, plan, or assessment, all landscape-level spatial fire analyses should share a common foundation of procedures and analysis of the **fire environment** (weather, fuel, topography). This paper describes and provides examples of several common models, tools, and methods for spatial fire growth and behavior modeling and weather and fire analysis for use in research, wildland fire decision support, and land management planning.

A Note About Models and Their Assumptions and Limitations

"A model is a simplification or approximation of reality and hence will not reflect all of reality" (Burnham and Anderson 1998). George Box (1979) stated, "All models are wrong, but some are useful." It is the task of the modeler to select the appropriate model, produce usable output, and interpret model findings given model assumptions and limitations. However, it is the client that ultimately determines the usefulness of the model. Modeling is an art as well as a science and one's field experience enables the art of the modeler. Be mindful that a model is a decision support tool, not a tool that makes decisions.

A variety of programs and tools support wildland fire management. For example, there are systems to predict fire growth and behavior, tools and information on fire effects, and smoke models for dispersion and emission estimates. Fire models, such as FARSITE (Finney 1998) and BehavePlus (Andrews and others 2005) are actually **fire modeling systems** that link multiple empirical and deterministic **models** or set(s) of mathematical equations to predict fire growth and behavior. Each model (for example, surface spread model [Rothermel 1972] or spotting model [Albini 1979]) has assumptions and limitations, and can be applied differently in the modeling systems. It is important that users understand model limitations and assumptions and know how these models are used in the fire modeling systems.

For example, among our greatest challenges in fire science is predicting crown fire occurrence and behavior. To do this we use models by Van Wagner (1977, 1993) for crown fire initiation and Rothermel (1991) for rate of spread calculations. However, modeling systems such as NEXUS (Scott 1999), FVS/FFE (Reinhardt and Crookston 2003), BehavePlus, and FARSITE/FlamMap (Finney 2006) are implemented differently and can produce differing results. The different interpretations stem primarily from our poor understanding of crown fire—a field of research still in its infancy. The various models of surface and crown fire spread were developed independently, and the current understanding of crown fire behavior is insufficient to suggest only one way of integrating them. This incongruity is compounded by model assumptions and limitations. A major assumption is that of a uniform tree canopy—which we know is not the case, since a canopy is comprised of crowns of individual trees separated by gaps. Likewise, crown base height is not a uniform value for an area of land, yet the models assume a single value can be applied to an entire stand.

So what then is the analyst left to do? Until an improved crown fire model is developed and it is applied consistently among fire programs, users must (1) know model assumptions, limitations, and design, (2) determine the usefulness of model output through adequate data development and critique, and (3) calibrate the model to be consistent with field observations. Remember models are "…artful applications of existing knowledge. They do not attempt to explain the physics or mechanics… As the science of surface and crown fire behavior advances, so too will our fire management applications" (Scott 2006).

Modeling Systems and Tools for Landscape Wildland Fire Analysis__

FARSITE [1]

FARSITE (Fire Area Simulator) (version 4.1) is a two-dimensional program for spatially and temporally simulating the spread and behavior of fires under heterogeneous conditions. FARSITE incorporates existing fire behavior models of surface fire spread (Albini 1976, Rothermel 1972), crown fire spread (Rothermel 1991, Van Wagner 1977, 1993), spotting (Albini 1979), point-source fire acceleration (Forestry Canada Fire Danger Group 1992), and fuel moisture (Nelson 2000) with spatial information on fuels, weather, and topography (the FARSITE landscape file [LCP]). Simulation output is in tabular, vector, and raster formats. FARSITE is often used to help answer the questions: Where will the fire go? How large will the fire get? When might the fire reach a particular location?

FlamMap [2]

FlamMap (version 3.0) is a spatial fire behavior mapping and analysis program that requires an LCP and fuel moisture and weather data. Unlike FARSITE, FlamMap makes independent fire behavior calculations (for example, fireline intensity, flame length) for each location of the raster landscape (cell), independent of one another. That is, there is no predictor of fire movement across the landscape, and weather and wind information are held constant. FlamMap output lends itself well to landscape comparisons (for example, pre- and post-treatment effectiveness) and to identifying hazardous fuel and topographic combinations, thus aiding in prioritization and assessment (Stratton 2004).

FireFamily Plus [3]

FireFamily Plus (FFP) (Bradshaw and McCormick 2000) (version 3.0.5) is a fire climatology and occurrence program that combines the functionality of the PCFIRDAT (Cohen and others 1994, Main and others 1990), PCSEASON (Cohen and others 1994, Main and others 1990), FIRES (Andrews and Bradshaw 1997), and CLIMATOLOGY (Bradshaw and Fischer 1984) programs into a single package with a graphical user interface. It allows the user to summarize and analyze weather observations, associate weather with local fire occurrence data, and compute fire danger indices based on the National Fire Danger Rating System (NFDRS) (Deeming and others 1977) and the Canadian Forest Fire Danger Rating System (Canadian Forestry Service 1987).

Rare Event Risk Assessment Process [4]

Rare Event Risk Assessment Process (RERAP) (USDA 2000, Wiitala and Carlton 1993) (version 7.0) is a program used to estimate the risk that a fire will reach a particular point of concern before a fire-ending event occurs (Term). It incorporates weather, fuels, topography, and Rothermel's surface spread (1972) and crown fire (1991) models with two waiting-time distributions—one for the fire-ending event and the other for "critical" spread events—to produce probabilities along a straight-line transect. RERAP consists of three modules: Term, Spread, and Risk. For the purpose of this paper, the Term Module is used to develop a Weibull waiting-time distribution for a user defined fire- and season-ending event.

[1/2/3] FARSITE, FlamMap, and FireFamily Plus: www.fire.org

[4] RERAP: www.fs.fed.us/fire/rerap/indexz.htm

WindWizard [5]

WindWizard is an interface to a computational fluid dynamics model (CFD) (FLUENT®) to simulate the effect terrain has on wind (Butler and others 2004). CFD technology was initially developed by the aerospace and automotive industries to simulate fluid flow around and through aircraft, automobiles, pipes, etc. Output is wind velocity and direction in raster and vector format with a default resolution of 100 meters. Gridded wind has two principle functions: visualization and model input. Shapefiles can be plotted to help managers visualize the channeling and checking effect topography has on wind flow for operational, planning, and educational purposes. Output can be imported into FARSITE/ FlamMap and may improve fire growth and behavior simulations, particularly at a finer scale (Butler and others 2004, 2006).

The Spatial Wildland Fire Analysis Process

Above I addressed the need for fire specialists to perform both landscape-level and spatial wildland fire analyses. I defined frequently used terms, briefly discussed model assumptions and limitations, and mentioned a few key modeling systems and tools. This paper will now shift from a purely informational style to an instructional approach. Each subsequent topic is prefaced by a short introduction followed by specific instructions intermingled with a few thought-directing questions.

Project Design and the Management Question

A research or management question(s) should be at the core of any wildland fire analysis. Development, execution, and implementation of the project should be centered on *answering* the question. The formulation of a clear question will guide data *acquisition*, model selection, the *analysis* process, *application* of the results, and reporting and *archival* (the "four As" as taught in S-492 [RERAP]). Sometimes a project can be structured as a series of questions and the findings of the initial inquiry are needed to answer subsequent questions. For example, where are our ecological and socio-economic values? Which of these values are at risk from a wildfire? What can be done to mitigate this risk? It is important that the question be answerable, roles and responsibilities identified, funding secured, and a reasonable timeline prepared.

Historical Fire Analysis: Understanding Fire Occurrence and Movement

Historical fire records can be useful in understanding the size, behavior, frequency, seasonality, and spatial distribution and orientation of fires. They help managers conceptualize the **fireshed**—the possible or expected area influenced by a single fire start as constrained by natural barriers, fuel, terrain, and weather within a given period of time. Fire records are either hardcopy or electronic—in a Geographic Information System (GIS)/spreadsheet format or in a central database (for example, National Interagency Fire Management Integrated Database [NIFMID] [USDA Forest Service 1993]). Information is typically categorized as a fire occurrence or ignition history, or a fire area history (for example, fire atlas). A few areas may contain fire histories reconstructed from cross sections of fire-scarred trees or establishment dates of post-fire tree cohorts [6]. In most cases, the longer the fire record, the easier it is to ascertain the fireshed and see patterns on the landscape.

Fire ignition history—Common among federal and some state agencies are GIS point ignition layers. Federal fire occurrence information is available for download at the National Fire and Aviation Management Web Applications Site (FAMWEB) or Kansas City Fire Access Software (KCFAST) (USDA Forest Service 1996) [7]—Forest Service only (Fire > Standard Extract) (.RAW file). If electronic data are not available, a GIS layer can be generated from local fire reports or associated records—include attribute data such as fire name, date, size, and cause. Create a density grid from fire locations to identify high fire frequency areas (fig. 1). Where do most fires occur? Are they human or natural-caused? Display the fires by size; where do most large fires occur? Display the fires by date; are there any noticeable trends? This information should give a manager an adequate feel for where ignitions could occur and when the fire season begins and ends.

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[5] WindWizard: www.firelab.org

[6] NOAA Paleoclimatology: www.ncdc.noaa.gov/paleo

[7] FAMWEB (KCFAST and US Federal Wildland Fire Management Data): http://famweb.nwcg.gov/

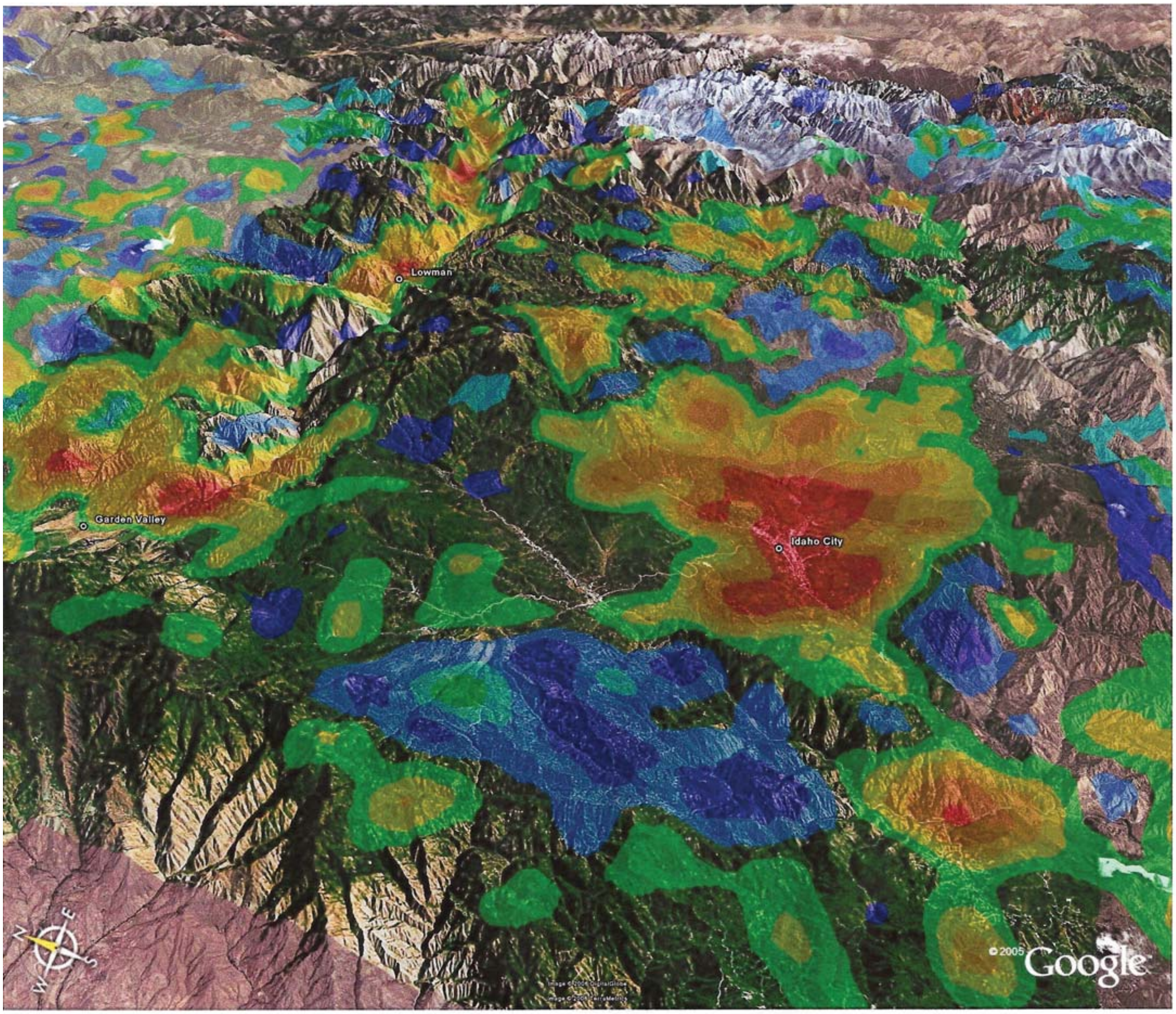

Figure 1—Fire ignition density, both human and lightning caused, on the Boise National Forest (ID) (1955 to 2002). One to three fires within the 1-mile search radius are in blue, 4 to 6 fires (green), 7 fires (yellow), 8 fires (orange), and 9 to 10 fires (red).

An ignition density only indicates where fires have started, not where or under what conditions fires will spread or what impacts will occur. Thus, fire occurrence data alone are of limited value to risk assessment. The components of fire **risk** include the probability of burning and the impacts that fires have when they do burn. This is different than **hazard**—the physical setting (fire environment) adjacent to the value (Bachmann and Allgower 2000). Most area is burned by the rare, large fires (Finney 2005) that are not necessarily related to the locations of frequent ignitions. So use the ignition information cautiously for where a fire *may* originate.

Fire area history—Develop a fire atlas or fire area history using Global Positioning System (GPS) perimeters, remote sensing, aerial photographs, historical documents, fire scars, dates of post-fire tree cohorts, and so forth (fig. 2). Pay particular attention to the large spread events and consider the following: What was the size, behavior, and orientation of these large spread events? What did the fuel complex look like when these large fires occurred? What was the weather, wind, and fuel moisture? What was the energy release component (ERC) or other fire danger indices when the fire made significant advances? To obtain this information, talk

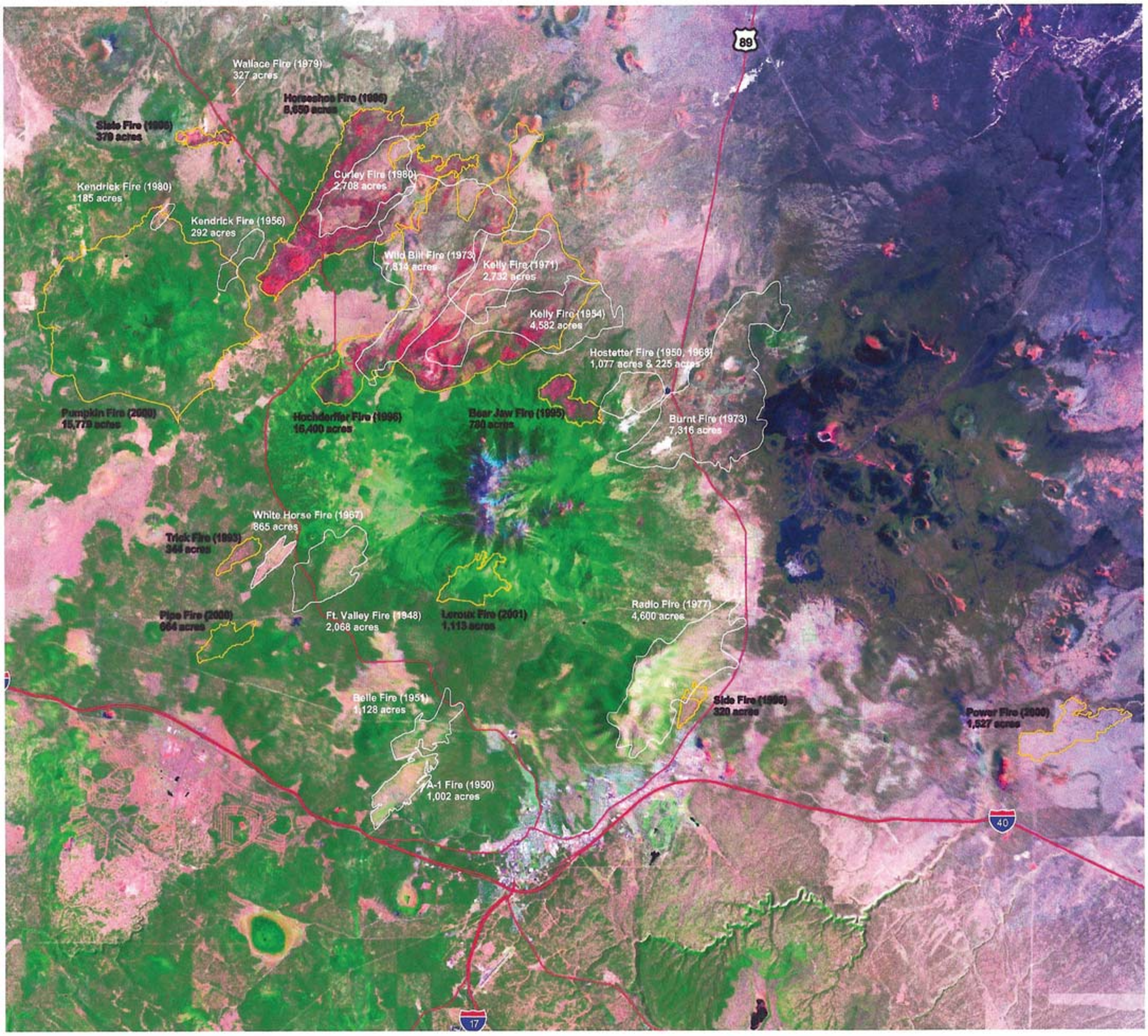

Figure 2—Large fire history (>100 ac) on the Coconino National Forest, north of Flagstaff, AZ (1950 to 2001) (courtesy of Charles W. McHugh).

with past fire managers and obtain fire packages and related materials from the host unit.

Answering the above questions about large fire growth provides the framework for understanding and developing **the problem fire**—a possible fire event, as evidenced by the historical fire record, whose occurrence on the landscape would be undesirable. Information from a thorough historical fire analysis will enable managers to understand the fire threat and visualize the fireshed, resulting in an appropriate management response and improved project development and implementation.

Environmental Analysis: RAWS, FireFamily Plus, RERAP, WRCC, and WindWizard

FARSITE and FlamMap require weather and fuel moisture variables for modeling (Finney 1998). Historical and current weather information—obtained from remote automated weather stations (RAWS) (NWCG 2000; Zachariassen and others 2003)—can be downloaded from NIFMID using KCFAST, and imported into FFP. If RAWS stations are unavailable for your analysis area, consider stations administered by the National Weather

Service, Federal Aviation Administration, and Natural Resource Conservation Service (SNOTEL sites).[8]

Remote Automated Weather Station retrieval—Locate the nearest RAWS(s) for your project area[9]. It is important to select a RAWS at a similar elevation and topographic setting, keeping in mind the influence the terrain and vegetation may have on the station. Occasionally, local topographic influences mask prevailing wind patterns that influence large fire growth. In this case, one station may be used for the wind direction and another for the weather (Stratton 2004).

Use KCFAST Weather Information Retrieval[10] to (1) find the Weather Information Management System (WIMS) station number (KCFAST: Weather > Station Catalog > Station Information), (2) obtain a year count (KCFAST: Weather > Data Extract > Utilities), (3) obtain the station catalog, and (4) retrieve the raw historical weather data file(s). The station year count is important as it shows how long the station has been operable. Generally, the longer the history the better. The station year count also shows the number of observations per year. Years with few observations or large gaps in the data (KCFAST: Weather > Data Extract > Utilities > Missing Data) should be omitted. Region and unit numbers can be obtained using FFP (Fire > Associations).

Climatology and fires analysis in FireFamily Plus—Using FFP, import the station catalog (.TXT), historical fire (.RAW or .FPL), and weather files (1972 data format [.FWX]) (Data > Import). Hourly data are also available from KCFAST (1998 data format [.FW9]), but is only accessible for the previous 18 months. View the import error log(s) after bringing in station and weather information. Errors in these files can significantly affect your analyses. List all weather observations (Weather > View Observations > All). Sort each weather variable in ascending or descending order—right mouse click—looking for errors including missing data and excessive values (for example, precipitation, wind, relative humidity).

Associate fire data with the weather station(s) (Fires > Associations). Determine when fires start, peak, and end (FFP: Fires > Summary). What was the *range* of ERC values or other fire danger indices when the large fires occurred (FFP: Fires > Fire Analysis)? Remember that fire size is associated with the *discovery date*, so be careful when interpreting the data.

To obtain climatology and moisture information, users can generate a daily listing of customized variables (for example, relative humidity, fuel moisture) relative to the number of fires or size of the fire (Weather > Seasonal Reports > Daily Listing). This listing can be imported into a spreadsheet. Or, users can generate a percentile weather report (Weather > Seasonal Reports > Percentile Weather) using an NFDRS index (for example, ERC) to produce the required inputs for modeling. Using the daily listing feature is preferred in some cases because fires resulted from these conditions and agency personnel and the interested public can remember and relate to that particular event.

RERAP—Use RERAP, Term Module, to develop waiting-time distributions for fire- and season-ending events (fig. 3). A **fire-ending** or **fire-stopping** weather event occurs when sufficient moisture results in termination of fire spread. A **season-ending** weather event consists of a fire-ending event followed by a persistent combination of environmental factors that end the fire season (USDA 2000).

Develop Term event criteria by combining local knowledge with climatology and fires data in FFP. A fire-ending event is usually a result of a certain amount

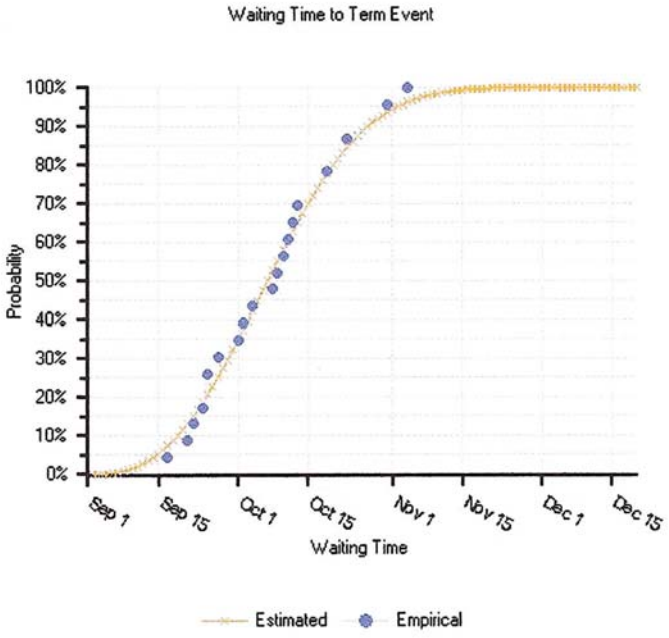

Figure 3—Weibull waiting-time distribution from RERAP given the likelihood of a fire-stopping event (>2 inches of rain over a 3-day period) on the White Mountain National Forest (NH).

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[8] RAWS and other Station Information: http://raws.wrh.noaa.gov/roman/index.html

[9] RAWS Locations: www.raws.dri.edu/index.html

[10] KCFAST/Fire Weather Information Retrieval: http://famweb.nwcg.gov/kcfast/html/wxmenu.htm

of precipitation over a specified timeframe. A season-ending event combines the fire-stopping event with a predictor of fire behavior (for example, ERC). In FFP, graph ERC and overlay a series of years with historical fires to identify a threshold ERC value when fire occurrence and large fires cease and resurgence is no longer a threat. Use the Event Locator in FFP to identify the occurrence of the fire-stopping events and the threshold ERC value. This information, along with the season start date, is used in RERAP to develop the season-ending event. It is not uncommon to have multiple season-ending events—a bimodal fire season. Term information is useful for incident management, risk assessment, planning of prescribed fires, and fine-tuning season start and end dates.

Wind speed and direction from RAWS/FireFamily Plus—Wind is one of the primary environmental variables influencing wildland fire growth and intensity (Catchpole and others 1998, Rothermel 1972). For this reason, it is critical that representative wind speed and direction information are used in any landscape fire analysis. When obtaining and using wind information, consider the following questions: What is the prevailing wind direction during the fire season? Is the wind direction consistent with what fire managers perceive as their predominant wind direction? At what wind speed do fires torch and actively crown? What causes high wind events and how often and when do they occur?

Be cautious when using FWX files for wind speed and direction information. First, most RAWS wind speed and direction information is a 10-minute average prior to data transmission, typically 1300 local standard time. In the case of wind speed, this value is an *average* composed of lulls and gusts. Averaging the gustiness is problematic when modeling fire behavior. Often these gusts or peak winds affect fire growth, intensity, and spotting (Crosby and Chandler 2004). By using the 10-minute average, even at the 99th percentile, the wind speed is often underrepresented. Adjust this value to be more characteristic of target conditions. Consider using the maximum 1-minute wind speed from the "wind gust estimating table" by Crosby and Chandler. Second, because FWX files are only a single snapshot in time, no other wind information is provided. This may be of concern for mid-morning activity, late afternoon runs, and active burning in the evening. In FFP, wind direction information can be obtained by a wind speed vs. wind direction report (Weather > Winds), as specified by analysis period (days) and summarized by direction. Information from FFP can also be exported into FARSITE/FlamMap format.

Wind speed and direction from WRCC—An excellent supplement to the KCFAST database is weather and wind information from the Western Regional Climate Center (WRCC). WRCC stores historical data from all RAWS in the U.S., including the Caribbean Islands [11]. WRCC data is *hourly*, may include gusts, and viewable via their website or downloadable in FW9 or FWX format for import into FFP (Select your RAWS [see 9]/ Data Lister > Data Format). Wind speed and direction information is reported as a 10-minute average. A useful feature is the selection of sub intervals by month, day, and starting and ending hours. This allows the user to get more detailed wind information for the fire season and burning period displayed in a wind rose (fig. 4).

WindWizard—WindWizard requires synoptic (general or upper level) wind speed and direction, and a digital elevation model (DEM) (USGS 1990). This input speed differs from the 20-ft wind speed. Usually, the speed needs to be two to three times that of the observed 20-ft ridgetop wind to produce the desired results. WindWizard is not a forecast; it simulates topographically modified flow for an instant in time. Multiple simulations of wind speed and direction can be created for use in FARSITE/FlamMap.

The DEM must include a buffer area of approximately 20 percent of the horizontal and vertical distance to incorporate surrounding terrain that may influence the area of interest. If DEMs are inaccessible for your area of interest, the United States Geological Survey (USGS) Fire Data Ordering System [12] provides a quick and efficient way to obtain a DEM and other ancillary layers.

Output from the WindWizard is wind velocity and direction in vector (ArcView or ArcMap; one file) (fig. 5) and raster (ASCII/Raster; two files) format. To view vector format, download the instructional briefs from the WindWizard website [see 5]. Import the raster data for fire modeling in FlamMap by selecting New Run > Inputs > Wind Grid. In FARSITE, select Input > Project Inputs > Select Wind File (.ATM). The atmosphere file (ATM) is a text file specifying month, day, hour, wind speed, direction, and cloud cover. It must be precisely formatted to function in FARSITE (refer to FARSITE Help).

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[11] Western Regional Climate Center: www.wrcc.dri.edu/index.html

[12] USGS, Fire Data Ordering System: http://firedata.cr.usgs.gov/

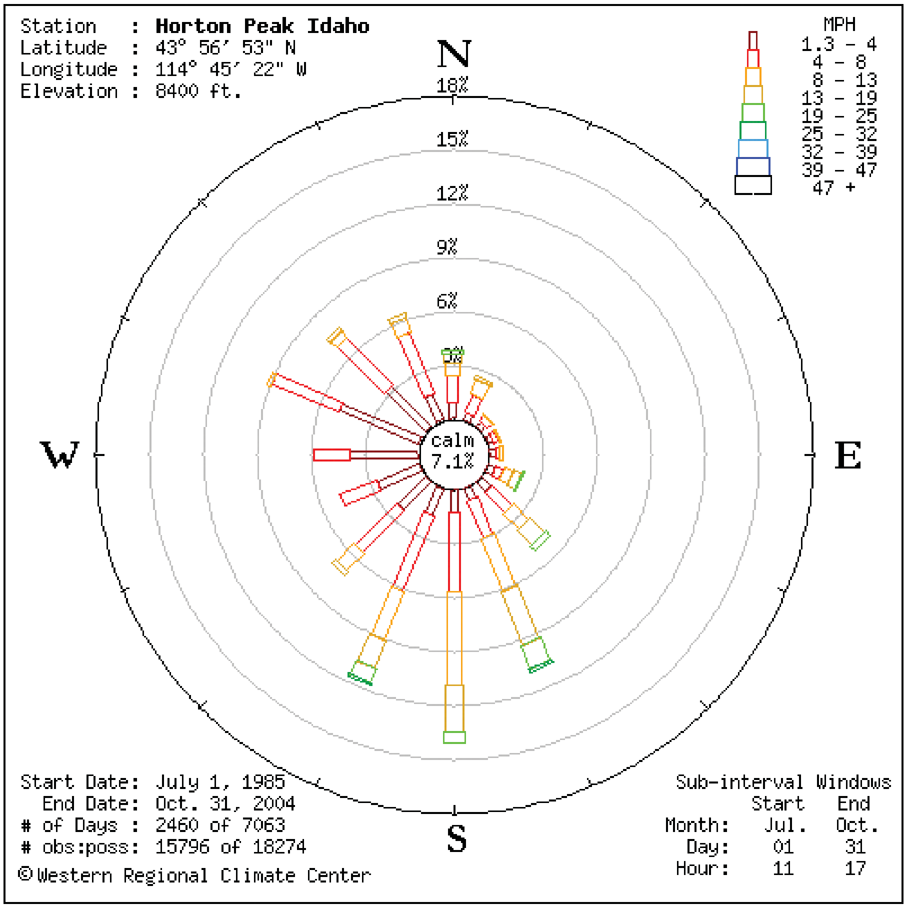

Figure 4—Wind rose from the Western Regional Climate Center for Horton Peak RAWS (ID), July 1 to Oct. 31, 1985 to 2004. Observations are hourly from 1100 to 1800.

Spatial Data Acquisition and Development: The FARSITE Landscape File

At the beginning of any landscape project, one should develop a **spatial needs analysis**—a list of required and ancillary GIS information requisite for completion of the task. Table 1 provides an extensive list of GIS data for landscape wildland fire analysis. Central to this type of work is the accurate parameterization of the fire environment. The most common file structure for spatial fire analysis is the FARSITE/FlamMap landscape file or LCP, a single file consisting of elevation, slope, aspect, fuel model (Anderson 1982, Scott and Burgan 2005), and canopy cover (CC)—required inputs—as well as optional themes of stand height (SH), crown base height (CBH), crown bulk density (CBD), duff loading, and coarse woody debris (Finney 1998). The standard practice is to create an LCP using all of the required files and the three canopy characteristic files. Development of the optional themes may not be necessary in areas where crown fire spread is of little concern (for example, hardwood forests). Each GIS layer needs to be exported as an ASCII Raster to create the LCP file.

Data required to create an LCP come from a DEM (elevation, slope, aspect) and satellite imagery or remotely sensed data that are usually classified by vegetation type and attributed. DEMs are easily obtained from the USGS; fuel model, canopy cover, and canopy characteristic information is more problematic. Presently, several Federal lands have FARSITE data accessible by contacting the host agency. LANDFIRE, a nationwide fire, fuel, and vegetation mapping project, will begin rollout of western products in 2006, including FARSITE data, with final coverage of the United States in 2009 (Alaska). [13] Irrespective of the source of the FARSITE data, LCPs should be *thoroughly* critiqued and mapping assumptions and limitations understood to ensure proper use and to produce realistic results.

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[13] LANDFIRE: www.landfire.gov

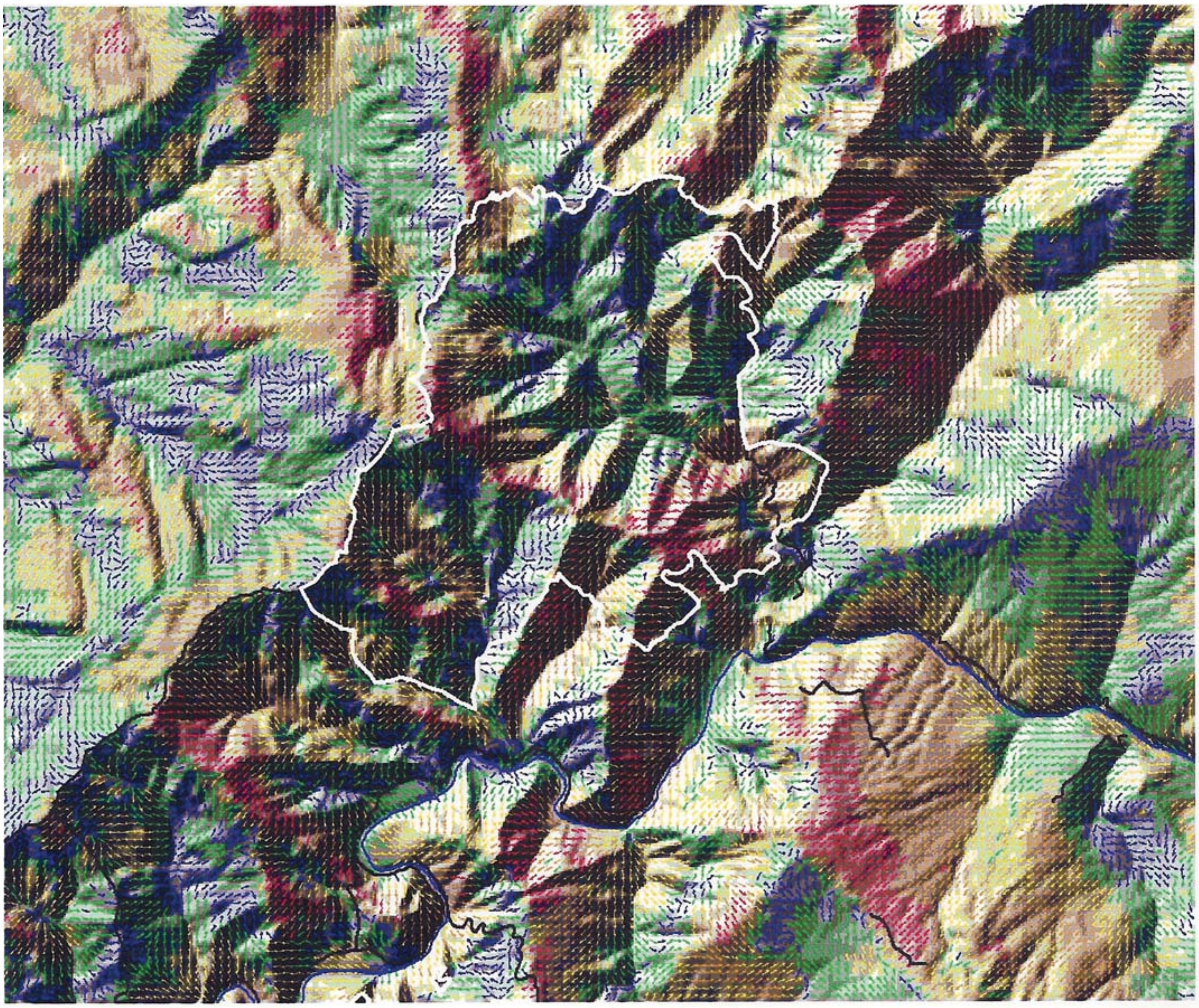

Figure 5—Gridded wind (100 m) derived from WindWizard based on 30+ mph ridgetop winds from the northeast. Wind vectors are colored by speed with 0 to 7 mph (blue), 8 to 14 (green), 15 to 22 (yellow), 23 to 29 (orange), and 30+ (red). The Blossom Fire (14,908 acres) (Aug. 12, 2005; Agness, OR) perimeter is overlaid on a shaded relief with trails (black) and the Rogue River to the south (blue).

Critique of the Landscape File

Errors in creating the LCP file—There are several common errors in the creation of the FARSITE landscape file. To identify these errors, load the LCP in FARSITE or FlamMap. Critique the LCP by querying the landscape and viewing the dialogue box looking for common oversights (listed below). View the LCP file generation box looking for errors including (1) a "0" latitude, (2) the loading of incorrect ASCII Raster data, and (3) distance and ASCII Raster theme units incorrectly specified. If creating the LCP from individual ASCII Raster files, an additional check is done by opening each file in WordPad© and checking the extent, resolution, and grid values.

Common oversights in ASCII Raster data—There are several common missteps in FARSITE layer development. Often, CC values are too high and CBD and CBH are inaccurate. CC rarely exceeds 70 percent even in so-called closed-canopy forests (see Scott and Reinhardt [2005]). If excessive CC values exist within the modeling domain, rate of spread will be reduced due to the sheltering effect of the tree canopy.

Table 1—GIS data requirements and considerations for spatial wildland fire analysis.

FARSITE/FlamMap Landscape File

Canopy cover
Crown base height
Crown bulk density
Digital elevation model (DEM)
Fuel model
Stand height

Wildland Fire History

Fire atlas (perimeters)
Fire occurrence (points)
Fire progression layers
Fuel treatments and other stand modifications
Prescribed fire history

Ecological Considerations

Areas of critical environmental concern (ACEC)
Erosive soils
Fire regime condition class (FRCC)
Historical range of variability (HRV)
Invasive weeds
Old growth
Proper functioning condition (PFC)
Research sites (for example, research natural areas [RNA])
Rivers and streams
Sensitive or critical wildlife habitat (for example, winter range, riparian)
Threatened, endangered, and sensitive (TES) flora and fauna habitat
Timber products
Water bodies
Watersheds of concern (6th code HUC particularly useful)

Socio-economic Considerations

Bridges
Camps
Communication sites
Concentrated use areas (CUA)
Cultural resources
Grazing allotments
Historic and recreational sites
Mine and mineral claims
Municipal water supplies and infrastructure
Primary and secondary residences
Railroads
Remote automated weather stations (RAWS)
Roads
Scenic integrity
Ski areas
Structures - other (for example, highway maintenance buildings, rest areas)
Trails and trailheads
Utility corridors
Wildland-urban interface areas

Other Useful Base Layers

Aerial photos
Coordinate system (for example, UTM, Lat/Long)
Digital orthophoto quads (DOQ) or quarter quads (DOQQ)
Digital raster graph (DRG)
Ownership and jurisdictions (for example, private lands)
Public land survey system (PLSS)
Satellite imagery
Shaded/painted relief
Vegetation or cover-type classification

Field measurements of CBD rarely exceed 0.25 kg m^{-3} (for example, spruce-fir) (Scott and Reinhardt 2005), but to yield realistic crown fire estimates in FARSITE/FlamMap, these upper values often need to be increased to 0.4+ if the default crown fire calculation method (Finney 1998) is used. If CBD values are generated from FVS/FFE or FMA Plus (Carlton 2005), select the Scott and Reinhardt (2001) crown fire calculation method. Particular attention should be given to CBH. If values are too high, particularly when coupled with a modest fuel model (for example, FM 8), crown fires will seldom initiate.

Critique of Fire Behavior Outputs

An excellent way to critique fire behavior outputs is by using FlamMap. Consider simulating low, moderate, and severe conditions using *both* crown fire calculation methods (Finney 1998, Scott and Reinhardt 2001). Compare output from each simulation and perform sensitivity analyses by asking questions such as: Is the flame length, rate of spread, and intensity consistent with field observations? Are areas of crown fire initiation appropriate given fuel and weather conditions? Are passive (torching) and active crown fire areas reasonable? When you see things that are not quite right, remember "Don't Be DUM"—data, user, model. We are often too quick to accuse the model when the data are the source of the problem (as taught in S-493 [FARSITE]). In general, if modifications of the spatial data are needed, adjust the fuel model layer first, followed by CBH and CC. The FARSITE landscape calculator is an excellent way to make changes to an LCP without GIS assistance.

Flame length and fireline intensity—Flame length is calculated from fireline intensity—the product of the rate of spread and heat generated from the available fuel during flaming combustion (Byram 1959). In FARSITE/FlamMap, Byram's equation is used to predict surface fire flame length; Thomas' (1963) equation is used to predict flame length for passive and active crown fire (Rothermel 1991).

Since flame length is defined and measured for shallow surface fires, flame dimensions in crown fires or deep fuel beds may appear to an observer to be *greater* than the calculated values. Flames generated from aerial fuels are viewed relative to the ground but originate well above the surface. So keep in mind that "flame length is an elusive parameter that exists in the eye of the beholder. It is a poor quantity to use in a scientific or engineering sense, but it is so readily apparent to fireline personnel and so readily conveys a sense of fire intensity that it is worth featuring as a primary fire variable" (Rothermel 1991).

Crown fire occurrence—Crown fire initiation is dependent on several factors, including surface fireline intensity, canopy foliar moisture, and CBH (Van Wagner 1977). CBH is used to determine if torching occurs. CBD affects transition to an active crown fire. If modeled output is inconsistent with field observations (for example, an under-prediction of active crown fire) (Cruz and others 2003, Fulé and others 2001), modifications to fuel model, CBH, CBD, or windspeed may be necessary. Also, lowering the foliar moisture content—a landscape wide adjustment in FARSITE/FlamMap—will increase the occurrence of crown fire.

Model Calibration

Calibration is critical to any landscape analysis. To produce fire growth and behavior outputs consistent with observations, model checking, modifications, and comparisons are done with known fire perimeters and weather conditions (Finney 2000). If the model has not been properly calibrated to local fires, how can analysts or managers have any confidence in its output? Conversely, when fire behavior outputs have been critiqued and the model calibrated to previous large fires, one can have a higher degree of confidence in future simulations. For the purposes of this paper, calibration of the FARSITE model is discussed. However, a similar approach can be used to calibrate other modeling systems, such as RERAP (Spread Module) and FSPro (Finney, in preparation).

Rate of spread is the most common fire behavior variable calibrated. Where appropriate, calibration of fire type may be important for fire effects modeling and to accurately differentiate between surface fire spread rate (includes torching) and active crown fire spread. Field observations, still and video photography from aerial reconnaissance, and the National Park Service/USGS National Burn Severity Mapping Project can be used to calibrate fire type [14]. Consider selecting one fire or run to calibrate the model under moderate conditions and another for severe conditions (fig. 6) with and without a high wind event. *In order of importance*, criteria fundamental to any calibration exercise include:

- a carefully developed and critiqued LCP;
- progression layer or detailed field observations that identify the position and time of the fire (for example, field notes, dispatch logs), including a precise starting location;

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[14] Burn Severity Mapping Project: http://burnseverity.cr.usgs.gov

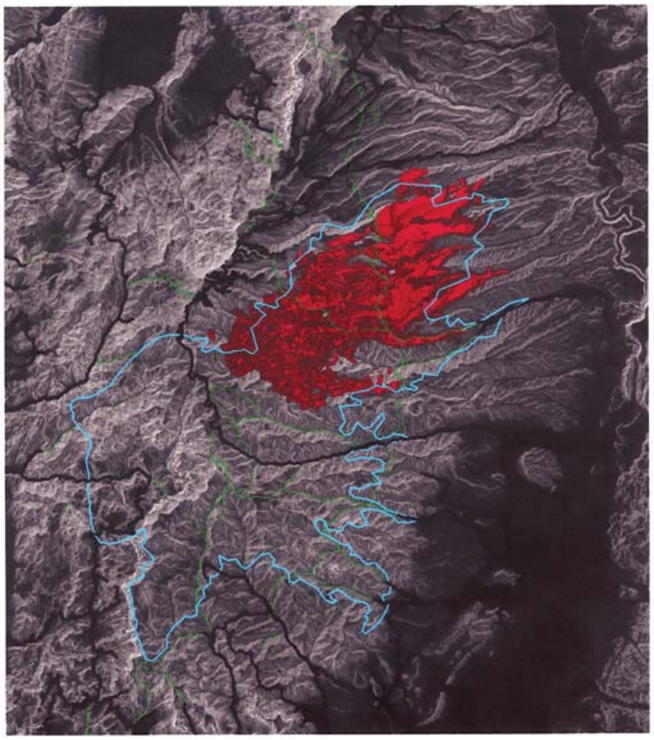

Figure 6—Calibration of the FARSITE model (in red; 16,686 acres) to a 1-day crown fire run on the northeast head of the Sanford Fire (June 8, 2002; Panguitch, UT). Overlaid on slope are trails (green), roads (black), and the fire perimeter (blue).

- a fire of a sufficient size and/or includes several burn periods;
- ample and representative weather and wind information (for example, RAWS[s] nearby);
- a fire that burned in several different fuel models and varying terrain;
- accurate fuel moisture information;
- a fire with minimal suppression or knowledge of suppression tactics;
- a fire that burned under a variety of weather and wind conditions; and
- a fire that resulted in both surface and crown fire runs.

Sufficient calibration takes time and patience. Do not expect perfection given model assumptions and limitations, data inaccuracies, fire suppression, variability in the weather and wind, etc. Sometimes, FARSITE will adequately predict the shape of the fire, but not the timing of fire arrival. Every fire and LCP is different, hence every calibration exercise will vary. The following calibration tips usually hold true:

- Wind, weather, and fuel moisture files are crucial so get these inputs as close to reality as possible. Spending time here will isolate several variables and streamline your calibration process. Make sure the station elevation is within the fire area and fuels are conditioned (if needed).
- Accurately define the burn period by the starting and ending time of daily fire movement.
- Select the appropriate model parameters—usually a coarser resolution at the start of your simulations moving to a finer resolution as you get closer to completion.
- If spotting contributed to the growth of the fire, enable spot fire growth early on, but at a low frequency (0.5 to 1 percent). If fire spread is predominately through spotting, adjustments to CBH will likely be necessary.
- Make one modification at a time and then rerun the simulation.
- Do not try to calibrate the entire fire at once. Start with the first few hours or burn period and then build from there. If the initial progressions are off, it is likely the entire simulation will follow—a result of compounding error.
- For large fires, or where the origin or progressions are lacking, use a reliable perimeter and begin your calibration process there—watch for errors in perimeter dates and times.
- A substantial change (~0.3 to 0.4) in the adjustment file indicates a different fuel model may be needed. Try using a conversion file, or as a last resort, a custom fuel model.
- Adjust for the lack of extinction of the fire perimeter after nightfall or rain. This is important in light fuels, where the fire will resume when the fuel moisture drops.
- Personnel on the fire can be a useful resource as multiple perspectives lead to corroboration of key events.
- Keep a detailed log throughout the calibration process of model settings, parameters, adjustments, etc.

Summary

This paper has been written to provide direction to fire specialists in spatial wildland fire analysis. It is a product of seven years of experience in support of incident management, fuel treatment projects, risk assessments, and reviews/investigations. Figure 7 is a flow chart that ties the tools and programs to the analysis process. Although “applications” are listed on the right (the end), the research or management question should dictate model and tool selection. When a modeler is familiar with model assumptions, limitations, and design; completes a comprehensive fire and weather analyses;

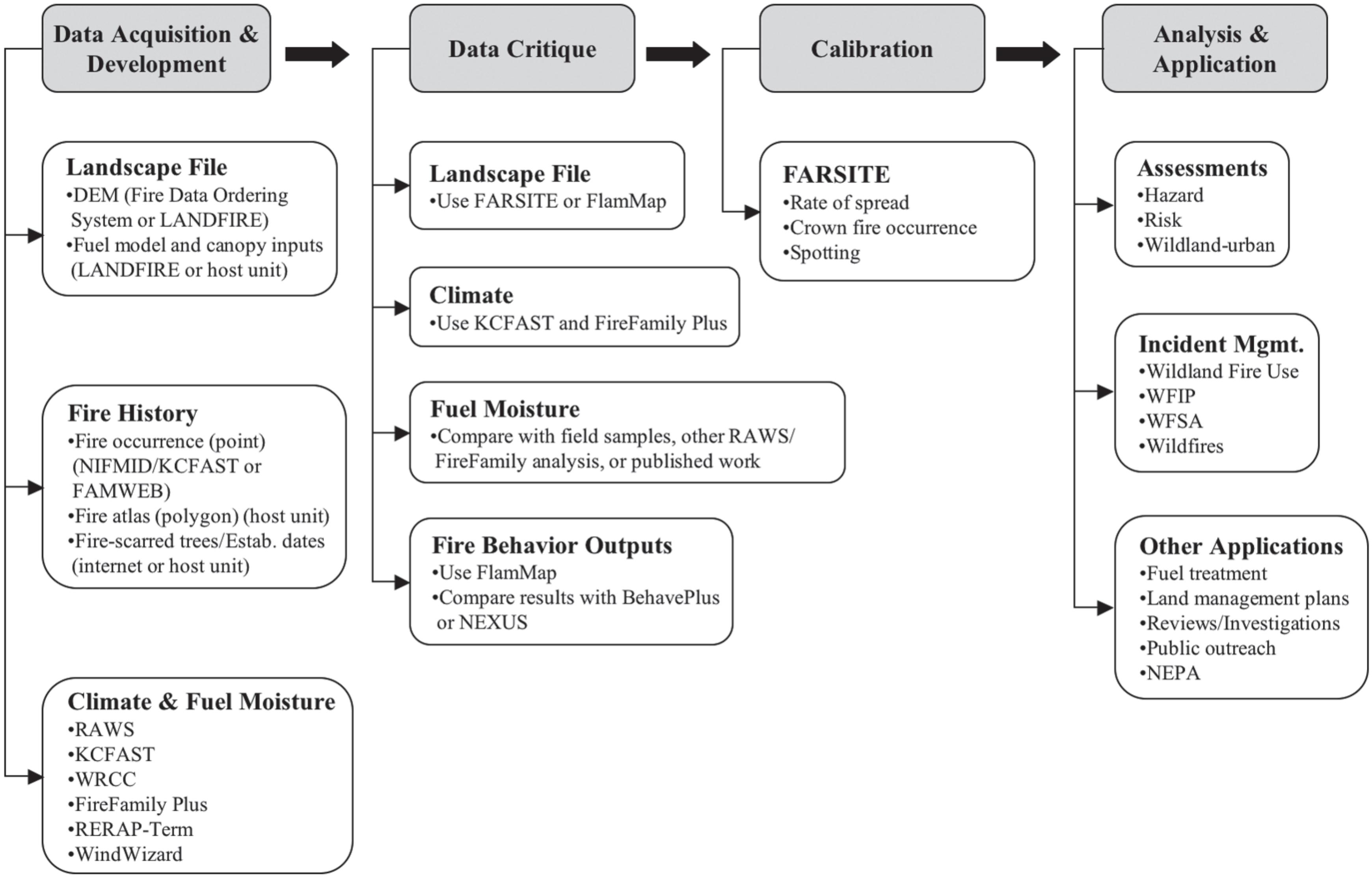

Figure 7—Flow chart for spatial wildland fire analysis: design, tools, and application.

carefully critiques the LCP and resultant fire behavior output; calibrates the model; and performs the necessary analyses, then line officers, incident commanders, and fire specialists have compelling and useful analyses for improved decision making, documentation, and public outreach and education.

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