3 Modeling Interactions Among Wildland Fire, Climate and Society in the Context of Climatic Variability and Change in the Southwest US

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INTRODUCTION

Between 1985 and 2004 wildland fires burned more than 75 million acres across the United States (NIFC 2004a, 2004b). Moreover, in 2002 the direct cost of fighting fires reached a high of more than $1.6 billion (NIFC 2004b). Damage and destruction of homes, infrastructure and ecosystems have likewise been skyrocketing. Indeed, concern about wildland fire has reached the highest levels of government (White House 2002; US Congress 2003) and accounts of dramatic fire events have become a staple of national, regional and local news media. The raging fires that occurred in southern California in early fall 2003, for example, captured sustained attention from reporters and viewers alike. In part, contemporary fire problems stem from almost 100 years of active and aggressive fire suppression. Rapid exurban development of areas near and within the region's forests has exacerbated these problems. The concern expressed at all levels of government, from local to federal, about both the impacts and costs of these fires is providing unprecedented opportunities to combine scientific expertise with on-the-ground knowledge held by fire fighters, forest managers and local communities to improve management of fire-adapted landscapes.

At the same time that fire risk is increasing, our knowledge about fire and its role in wildland ecosystems is also increasing – as is our understanding of the processes influencing geographical and interannual variability in fire regimes. This increase in knowledge has been paralleled by intensified efforts to translate knowledge into decision support tools that decision makers and fire managers can use to anticipate and manage fire risk more effectively. Such tools provide rich sources of information for determining how best to reduce destruction from catastrophic fires while at the same time allowing fire, where appropriate, to play its natural role in ecological processes.

Fire as a natural part of ecological processes is especially prominent in large parts of the western US where some landscapes, such as those dominated by ponderosa pine, are adapted to and require periodic episodes of burning. Much has been learned about the role of fire, although much fundamental and applied scientific work remains to be done. For example, knowledge has been gained as to what factors influence forest health (Covington and Moore 1994a; Covington et al. 2001), the biophysical influences on natural fire regimes and influences of fire on biophysical conditions (Baisan and Swetnam 1990; Covington and Moore 1994b; Yool 2000; Henry and Yool 2002; McHugh et al. 2003). Research has also illuminated the importance of societal factors (Baker 2001; Pyne 1982, 2001; Pyne et al. 1996).

Integrated research that provides new insights into the interactions between fire, biophysical and societal dynamics is one of the areas where new research holds particular promise for aiding decision making (see for example Conard et al. 2001; White 2004). The southwestern US constitutes an important venue for such research; and projects focused on the southwestern region, in turn, hold promise for improving wildland fire management across the US.

Climate patterns in the Southwest, for example, are known to be important factors in fire regime variability at seasonal to interannual and interdecadal time scales (Brown and Comrie 2002; Comrie and Broyles 2002; Crimmins and Comrie 2004; Sheppard et al. 2002; Simard et al. 1985). In addition, tree-ring research indicates a statistical correlation between interannual shifts in precipitation regimes and patterns of widespread fire occurrence at the regional scale across much of the West, including the Southwest (Grissino-Mayer and Swetnam 2000; Swetnam and Betancourt 1990; Baisan and Swetnam 1990). Much of the vegetation is fire-adapted, and indeed, as noted above, some species require fire to propagate. Research into vegetation dynamics (Moran et al. 1994; Running et al.1989; Covington et al. 2001; Covington and Moore 2004a) provides a link between climate and ecological dynamics, while advanced geographic information science (GIS) and remote sensing constitute essential technologies for improving knowledge of vegetation distribution and class, as well as for understanding interactions between climate, weather and fuel conditions (see for example Keane et al. 2001; Reed et al. 1994; Nemani et al. 1993; Morgan et al. 2001). When biophysical information is integrated with socioeconomic data and with geospatially referenced data on human values, possibilities arise to create innovative products useful for decision making in fire-prone landscapes by experts and by the general public as well.

CLIMATE IN THE SOUTHWEST US

Climate is an important factor in seasonal to longer-term patterns of wildland fire occurrence. The climate of the southwestern US, although generally semiarid, is characterized by a bimodal precipitation regime, with rains occurring during summer and winter (Sheppard et al. 2002). Spring tends to be predictably dry, as does fall except for occasional rain associated with passing events such as tropical storms. The El Niño Southern-Oscillation (ENSO) strongly influences interannual variability in the region, and research suggests that the longer-term Pacific Decadal Oscillation (PDO) intensifies ENSO conditions when the positive and negative phases of the two coincide. Winters in the region have a tendency to be wetter when El Niños occur and, more predictably, drier when La Niñas occur. Under certain conditions, the PDO may influence these tendencies. For example, when ENSO and PDO are both in negative phase, winter precipitation in the Southwest trends toward even drier conditions than usual. ENSO-neutral years feature a more scattered pattern of wet and dry winters. An outgrowth in scientific understanding of ENSO influences on regional climatic patterns has led to a marked improvement in winter precipitation forecasts (Hartmann et al. 2002). During years when Pacific Ocean temperatures and air pressure along the equator indicate formation of moderate to strong ENSO conditions, forecasts tend to be relatively accurate for the Southwest and for other areas such as the Pacific Northwest (where the influences of El Niño and La Niña, respectively, are opposite those of the Southwest). Although predicting precipitation during ENSO-neutral conditions tends not to be as well-developed, the knowledge that an ENSO-neutral winter is anticipated can be useful information. For wildland fire management in the Southwest, precipitation conditions over multiple years, especially those where a wet El Niño winter is followed by one or more years of anomalously dry winters, have significant implications for fuel loads, fuel moisture conditions and ultimately fire risk (Swetnam and Betancourt 1990; Grissino-Mayer and Swetnam 2000).

Temperature conditions are also important to understanding the climate of the Southwest, particularly during spring and fall, the major fire seasons. Interannual temperature variability on average may not be as marked as that of precipitation, but early onset of hot weather and/or delayed relief from high temperatures in the fall can have significant impacts on the region and its resources. Furthermore, scientific evidence is strong that temperatures in the region have increased markedly in the last couple of decades, suggesting that longer-term climatic change may be underway (Sheppard et al. 2002;

Overpeck et al. 1990). Long hot spells and the general trend toward an increase in temperatures are particularly important influences on moisture conditions in dead and live fuels and, more generally, the availability of water at times when it is most needed such as forage needed by livestock. For fire management, higher average temperatures can lead to less moisture availability in the atmosphere as well as in soils and fuels, thus exacerbating fire risk even in cases where precipitation patterns remain at or above historical norms.

Research on climate change impacts suggests that the Southwest is already experiencing an elevation in temperatures, and that future change can be expected (Overpeck et al. 1990). However, modeling climatic change in the Southwest remains problematic in no small part because the topography of the region is quite complex, and because even nested regional models do not yet do a good job of representing the North American Monsoon, which is responsible for the area's summer rainfall regime (Sprigg and Hinckley 2000). Output of the Canadian Climate Model, for example, has indicated that in the Southwest US the primary changes would be increased temperatures and increased precipitation. However, as noted above, an increase in precipitation, accompanied as it would be by increased evapotranspiration, would not necessarily result in moister conditions or diminished fire risk. An initiative currently underway to gather more data on climatic processes and conditions associated with the North American Monsoon will certainly contribute to better climate change modeling. Enhanced understanding of the implications of climatic change for ENSO and PDO processes will also be very useful. In the meantime, development of models such the one described in this chapter that focus more specifically on climatic variability at regional or sub-regional scales hold promise for addressing persistent societal and ecological problems, such as wildland fire, that are influenced at least in part by climatic processes.

WILDLAND FIRE CONDITIONS IN THE US AND IN THE SOUTHWEST US

Forty million acres of National Forest lands alone are currently in elevated fire hazard condition; these conditions prevail in much of the forested land in the Southwest US. High fuel load levels, fire suppression policies, human activities and climatic conditions all contribute to the hazard. The cost of fighting wildfires is increasing, as are wildfire-related fatalities. Given existing conditions, experts expect wildfires to last longer, encompass more acres and involve more regions of the US. An assessment issued by the National Interagency Fire Center's Predictive Services Group early in 2004 cited the persistence of long-term drought over much of the interior west, combined with insect infestations, as major reasons to be concerned about the potential for large destructive wildfires in mid and high elevations (NIFC 2004a). Another report suggests that, using data from 1994, 1996, 2000 and 2002, the National Interagency Coordination Center could expect worst-case conditions, on average, to produce 85 000 reported fires, and for more than 6.1 million acres to be burned (NIFC 2004b). The extent of the fire problem in wildland areas shows up in the statistics for acres burned during the recent past:

1. 2000 = 7 383 493 acres
2. 2001 = 3 570 911 acres
3. 2002 = 7 184 712 acres
4. 2003 = 3 959 223 acres.

The five year average for amount of land burned, through 2003, amounts to 5 477 830 acres, and the ten year average is 4 455 593 acres. In the Southwest, years such as 1994 (563 696 acres burned), 2000 (601 670 acres burned) and 2002 (1 117 993 acres burned) stand out. Based on data from 1994, 1996, 2000 and 2002, the worst fire years averaged 656 091 acres burned. At the same time, the cost of suppressing fires has become a matter of political concern. Indeed, the years 2000, 2001 and 2002 registered the three highest expenditure levels for the entire period, topping $1.6 billion in 2002. Injuries, loss of life and property damage add even greater costs to the effort of managing wildland fire.

Fire hazard conditions currently threatening valuable lands and resources in the US exist within a larger context of increasing linkages between urban growth and recreational land use (the urban–wildland interface), and complex institutional factors such as the requirements of the Endangered Species Act, the National Environmental Policy Act (NEPA), the Wilderness Preservation Act, and discussions about the positive and negative effects of prohibiting road construction in wildland areas. Managing fire in natural areas within this context is challenging even under optimal conditions. One of the primary challenges is that gaps persist in scientific knowledge about the interrelationships between human activities, climatic factors and fire frequency, extent and intensity. At the same time, new federal wildfire policy requires fire managers to plan for time periods of up to a century into the future.

Recognition of the positive role played by fire in promoting forest health has grown, reaching the highest levels of decision making and governance (Brown 1985; Baker and Kipfmueller 2001; Covington and Moore 1994a; Kolb et al. 1994; Pyne et al. 1996). Along with this recognition have come stronger efforts to include fire use in fire planning and management. Likewise, interest is growing in bringing the best available scientific knowledge about factors influencing fire regimes, as well as about fire behavior and fire impacts to seasonal and longer-term planning processes. As noted earlier, addressing the need for such information requires innovative approaches that combine the best scientific knowledge available from the biophysical and social sciences into decision support tools that are both useful and usable to the constituencies for which they are designed (Nicholson et al. 2002). FCS-1, developed at the University of Arizona under the interdisciplinary Wildfire Alternatives (WALTER) initiative and funded by the US EPA STAR Program under Grant Number R-82873201-0, is an example of the kinds of decision support research that are currently underway.

FCS-1: AN INTEGRATED MODEL FOR WILDLAND FIRE MANAGEMENT

FCS-1 is a first-generation integrated GIS model for use in *strategic* planning for wildland fire management (Figure 3.1). The name of the model, Fire–climate–society, Version 1, reflects the emphasis that has been placed on including a wider range of factors than is ordinarily included in fire models, such as BEHAVE and FlamMap, that are designed for shorter-term *tactical* use. The 'version 1' tag indicates that this model constitutes a basic framework for representing fire risk, but that it does not have all the components that ideally would be included. For example, a more fully elaborated model would have dynamic components allowing for streaming of real-time climate data and for linkage with a fine-scale vegetation model.

FCS-1 is somewhat unique in emphasizing accessibility, utility and usability for community members as well as for fire managers, fire scientists and decision makers. The model is explicitly designed for use in decision making at time scales of one month to a season, a year or longer. Based on user selection of a climate scenario and user weighting of model layers, the system provides fire hazard and fire risk maps at a grid scale of 1 km. From the beginning, the model has been envisioned as operating via internet interface, and this decision led to dedication of considerable resources and time to building a multifunctional and user-friendly website.[1]

FCS-1 identifies geographically explicit levels of risk of large wildland fire based on research, which indicates that fires growing to 250 acres are most likely to become large, destructive wildfires. The model currently encompasses four well-defined study areas: the sky island ecosystems of the Catalina-Rincon, Huachuca and Chiricahua Mountains in southeastern Arizona and the Madrean ecosystem of the Jemez Mountains in New Mexico (Figure 3.2).

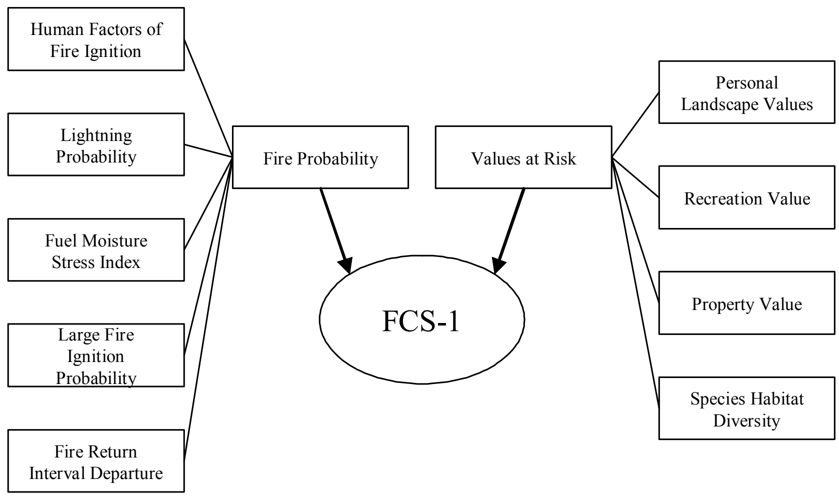

Figure 3.1 Schematic of FCS-1 model

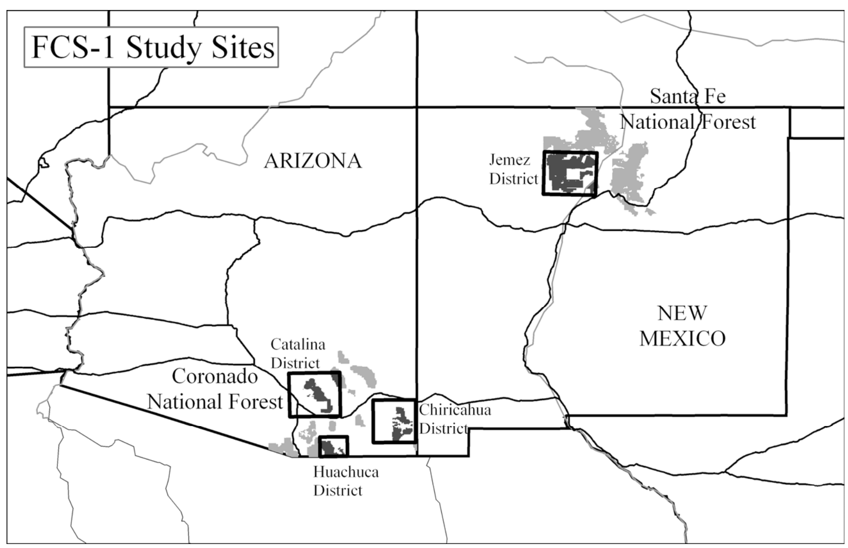

Figure 3.2 FCS-1 study sites

These four study sites were selected for several reasons. First, the principal investigators already had conducted research and had data on the areas that would provide foundations for the modeling effort. Second, each of the sites represented key types of situations faced in wildland fire management. The Catalina-Rincon Mountains border the growing city of Tucson, Arizona, and feature a large urban-wildland interface area. The Huachuca Mountains are located on the fringe of the small city of Sierra Vista, and are partially encompassed by Fort Huachuca Army Base, which is a major US military installation. These mountains also extend to the US–Mexico border and are currently being heavily impacted by illegal migrants. Further, the area is widely famous for its flora and fauna, especially the hummingbirds that are protected in the Nature Conservancy's Ramsey Canyon Preserve. It hosts large numbers of visitors all year round. The Chiricahua Mountains, located just inside the border with New Mexico and just north of the US–Mexico border, constitute the most remote and undeveloped of the study sites. Yet marketing is already underway to convert shrublands at the mountains' base to summer homes. Chiricahua National Monument, a beautiful area that encompasses important geological formations and ecological sites, is located on top of the mountain range. The mountains and surrounding areas support significant ranching activities as well as recreational use. This mountain range is the only one of the study areas that does not have a direct urban–wildland interface. As such, it provides a baseline case for modeling fire–climate–society dynamics in a significantly less impacted area. The fourth study site, the Jemez Mountains in northern New Mexico, being part of the Madrean system, comprises a somewhat different, but analogous landscape. The Los Alamos Nuclear Laboratory and the city of Los Alamos constitute major social imprints on the landscape. A few other communities, such as Espanola, are also scattered around the base of the mountain range. On the ridge of the mountains, Bandelier National Monument encompasses some of the most important Native American ruins in the area. Here again, the urban–wildland intermix is critical to fire management. Also crucial to decision making is the existence of Native American lands belonging to Santa Clara and Jemez Pueblos, and sacred sites important to these pueblos, as well as Cochiti Pueblo and others. The Laboratory is a key player in local forest and fire management activities, not only with regard to the high-security nature of the operation and the need to actively manage the forest on its lands, but also due to its energetic participation in the Interagency Wildfire Management Team, which meets every two weeks to coordinate planning and operational activities. Three of the four study areas have experienced major fires over the past 30 years, with the most recent occurring in June–July 2003 on top of Mount Lemmon in the Santa Catalina Mountains; fire forced evacuation of Los Alamos in 2000.

FCS-1 MODEL DESIGN

FCS-1, while specifically incorporating data for these four study areas, is designed with sufficient flexibility to be transferred to other forest areas in the Southwest, and to other parts of the West where similar conditions prevail. The model comprises two sub-models: the fire probability sub-model combines biophysical data layers to produce a fire hazard map, and the values at risk sub-model combines societal value data layers to produce a map of societal values vulnerable to damage or destruction by wildland fire. FCS-1 combines the layers from both sub-models to produce an integrated fire risk map. Each of the layers incorporated in the model represents the best science and data available at the time they were created. In most cases, data for the past 20 years were used. In some instances, such as lightning data and human values, it was necessary to use shorter time periods.

Fire Probability Sub-model

FCS-1 contains five data layers representing biophysical conditions contributing to fire hazard: human ignition probability, fuel moisture stress index, lightning probability, fire return interval departure, and large fire probability. These layers incorporate, as appropriate, basic characteristics such as topography, slope, aspect, roads, administrative boundaries and other features.

The *fuel moisture stress index* layer is cued by climate scenarios from which the user must make a selection. This is the only layer that allows such user input. The data making up this layer includes vegetation type and fuel moisture conditions calculated at a scale of 1 kilometer using NDVI data (ground-truthed through field research) for each selected study area, in combination with the climate scenario data. The scenario data include precipitation for the previous winter and temperature during the fire season of the scenario year selected. FCS-1 applies the indexed data to each of the pixels on the map of the selected study site.

The *fire return interval departure (FRID)* layer is based on 20 years of fire history data. The layer contains spatially explicit information about vegetation types, fire perimeters, dates of the fires, length of time since last fire, expected fire return interval based on longer-term records and vegetation type. FCS-1 calculates the FRID for each pixel using the following equation: (years since last fire – natural fire return interval) / natural fire return interval. The normalized index derived from this equation is applied to each of the one-kilometer grids to produce the FRID maps for the four study sites.

The *large fire ignition probability* component provides input regarding the likelihood that, based on vegetation type, a fire greater than 250 acres will occur within each pixel. Research that suggests that fires reaching 250 acres in size have an increased probability of growing into fires consuming more than 1,000 acres. Burn statistics and vegetation data constitute the foundational elements in this component.

The relative importance of natural versus human sources of fire ignitions reflects the likelihood of fire in specific areas based on lightning events or human activities. The *lightning ignition probability* layer identifies, by 1 kilometer grid cell, the probability that lightning will occur in that cell. The data for this layer are derived from records of lighting strikes in each of the study sites. These data were purchased from a private firm specifically for use in this model. As good lightning data are only available for the past ten years for all four study sites, only ten years of data are included in this layer.

The *human factors of fire ignitions* component represents the locations of human-set fires that have occurred in the study area. This layer is based on proxies such as distance from roads and assumes that physical factors such as road density and distance to picnic areas are reasonable representations of relationships between fire occurrence and human activities.

Values at Risk Sub-model

There are four societal values layers included in the model: personal landscape values, property values, recreation values and species habitat diversity values. The *recreation value* layer is based on calculations of Euclidean distances from roads and hiking trails to scenic vista points, campground locations, etc., on the assumption that landscape views are of considerable value to those who make the effort to go into these mountain ranges.

The *species habitat richness* layer represents a proxy for values individuals hold with regard to the existence of wildlife in the area. The data reflect the extent to which existing habitat conditions could support mammals, amphibians, reptiles and birds that might be expected to visit or reside in each pixel. This proxy was chosen due to the lack of dependable data about actual existence/distribution of different species in the study areas. Data for this layer were obtained Arizona and New Mexico GAP databases.

The *property value* layer reflects the values of owner-occupied houses within and surrounding each study site. These data were obtained from US Census files. The *personal landscape values* layer represents the results of a series of interviews in the four study areas. A total of 120 individuals were interviewed. Each interviewee was asked to mark, on a large-sized, specially designed topographic map of their study area, their responses to a series of questions. These questions included the areas they most anticipate will burn in the next five years, the area they would most hate to see burn, the areas where they have engaged in recreation over the past year, and the routes they take to get to these places. Digitized versions of these individual maps provide the aggregated base data for this layer.

User Weighting of FCS-1 Layers and Model Outputs

FCS-1, as a decision support tool for strategic planning in the realm of wildland fire, is unique in allowing users to weight the model layers themselves. They may also elect to run the model based on an expert weighting scheme that is provided. The weightings are accomplished using Analytic Hierarchy Process (AHP) (Saaty 1980, 1990; see also Schmoldt and Peterson 2000). AHP is a structured method, based on matrix algebra, that facilitates analysis of complex issues by sorting key factors into a series of pair-wise comparisons. To assign weights for one of the selected mountain ranges, the user first selects a climate scenario from the alternatives provided on the website, then selects the option allowing user assignment of weightings. The model displays the first two layers of the fire probability sub-model. The user begins by designating the relative level of importance (using a scale of 1 to 10) to the fuel moisture hazard layer relative to the FRID layer. If the user assigns, for example, a weight of 6 to this layer, it means that this user considers fuel moisture hazard to be six times more critical to fire probability than the FRID. The user would then go on to assign weights for fuel moisture hazard against vegetation type hazard, lightning hazard and human ignition hazard. Next, the user would weight FRID relative to vegetation type hazard, lightning hazard and so on. This process continues until every possible pair-wise comparison has been made for the fire probability sub-model. The user then repeats the process for all the layers in the values at risk sub-model. After this process is complete, the user assigns weights to the fire probability and values at risk sub-models in a final pair-wise comparison. Once all of the comparisons have been completed, the model calculates the results and displays them as map outputs, gridded at a scale of one square kilometer.

As is evident from the above description, the model produces multiple outputs with a wide range of potential variability. Maps for individual users may be produced, or aggregate maps representing everyone participating in the weighting exercise. The model may be used by a single expert, for example, to assess fire risk for budgeting or preseason planning for fire season staffing. At the same time, its flexibility allows use in a group setting where, for example, the intent might be to identify, discuss and perhaps resolve issues in specific geographical areas where contention exists among different interest groups.

When combined with other information provided on the WALTER website, such as animated AVHRR greenness maps, additional fire history data, fire policy information and climate information, FCS-1 constitutes a forward-looking addition to the array of decision support tools available to fire managers and – relatively unique in this case – to the public as well.

HORIZONTAL AND VERTICAL INTEGRATION: OPPORTUNITIES AND CHALLENGES

Designing decision support tools that foster horizontal integration across different disciplines, interest groups and segments of society is a challenging endeavor, but one that can have high payoffs in terms of return on investment of funds, time and energy (see Courtney 2001; Bonczek et al. 1981). The effort can also have high payoffs in terms of providing access to the best information available to members of society who wish to participate in decision processes and/or who stand to be affected by the decisions of others. Further, such tools afford opportunities for bringing together disparate sectors of society who might not ordinarily have the same access to information. However, in many cases building tools that satisfy the needs of experts and at the same time afford decision support to non-expert members of society – especially those who stand to be most strongly affected by decision making processes – is challenging under even the most ideal circumstances. As described below, the process of developing and testing FCS-1 was strongly focused on bridging the gap between experts and non-experts.

Likewise, vertical integration within modeling efforts can produce both successes and challenges. FCS-1, for example, like many models, is built with the best information that could be obtained; however few datasets and sources of information can fill all of the needs of such modeling efforts. As discussed below, the data used in the model's layers have been assessed in terms of quality assurance, and this information has been made available to the individuals who participated in workshops to evaluate the model.

Horizontal Integration

FCS-1 is explicitly designed for use both by fire management experts and by communities in the four study sites. The primary factor facilitating both public and expert use of the model is AHP: each individual is empowered to weight the model's data layers according to their own knowledge and preferences. The model is designed to allow each individual to see his/her own maps for each data layer, the composite maps for each of the sub-modules and the final combined fire risk map. Making the model accessible in this manner to both experts and non-experts has been an important goal of the project. Holding user evaluation sessions in each study area that explicitly included both expert and community participants provided an invaluable opportunity to obtain constructive feedback about how well the model performed, how well it met user needs and what adjustments – including addition of other or alternative datasets – might make it more accurate and useful. Equally important, these sessions provided an opportunity to assess success toward the goal of building a model that actually served both expert and general public needs in terms of the usefulness of the model outputs and the usability of the model itself.

Creating a model that serves both expert and public needs through horizontal integration has posed a number of challenges. One of the biggest challenges has been building the interfaces required to run the model on the web. While concepts of how the interface would look and function were developed early in the project, the need to spend the first two years developing the underlying data for the model meant that much of the intensive work on combining the various elements and ironing out the interface challenges could not be tackled until relatively late in the project funding period. Another challenge, discussed below under 'Vertical Integration', was determining how to weight the data layers of the model in a way that would produce good fire risk maps. The decision to shift this determination to the users themselves, via AHP, constituted a significant break-through in the model design and construction process. The user evaluation sessions, held at each of the study sites, affirmed that this approach of allowing users to make their own choices about the importance of the layers relative to each other was the best design strategy.

An important element in horizontal integration is the ability to run the model any number of times, and to see how different weightings and climate scenarios affect the patterns appearing on the FCS-1 fire risk maps. Also important is the possibility of integrating use of the model in group contexts. Having alternative risk maps available can facilitate discussion of points of agreement and disagreement about the level and spatial distribution of fire probability, the potential implications for values at risk and overall fire risk in the area. The group setting can also provide a venue for discussion of individual opinions about how the data layers should be weighted relative to each other and how different weightings influence model outputs. As the FCS-1 testing and evaluation sessions with stakeholders have revealed, group sessions provide an opportunity for experts and residents to analyze jointly the final map as well as maps produced by different individuals. This can encourage discussion not only about the type, quantity, quality and sources of the underlying data, but also about individuals' knowledge, fundamental values and concerns. Since the purpose of the system is to facilitate strategic planning for fire management – that is, planning a season to a year or more in advance – group sessions like these can provide opportunities to work toward forest/fire management plans that rest on a broader base of community support, and that reflect more closely the intent of policies such as NEPA, the Air and Water Quality Acts, the Endangered Species Act and so on.

Opportunities and challenges also arose in the narrower world of designing a model that would be accepted and used by forest/fire management experts. WALTER team members recognized from the beginning that expert knowledge of the local areas was a crucial factor in strategic planning. A pivotal strategy in the development of the model was direct interaction with key individuals over the course of the model construction and testing/evaluation processes to obtain the best available scientific data for each of the layers, to build the kinds of professional relationships that would ensure that the model was as useful and usable as possible, and ultimately to facilitate acceptance and use of the model. The devastating fire seasons of 2000, 2001 and 2002, together with heightened interest at federal and state levels in reducing wildland fire risk, provided an excellent opportunity for productive interaction with managers and scientific experts in the development of FCS-1. Through cooperation with these individuals important datasets were obtained, as was early feedback on the model's design and components. The evaluation/testing sessions proved especially useful in discussing the relative merits of the datasets used, the availability of additional or alternative datasets and how key improvements in the model could be made. Horizontal integration across the different agencies, disciplines and job classifications, with regard to consensus on the data used in the model and with regard to using the model, posed surprisingly few problems in the evaluation sessions. It is likely that some operational and/or interpretational issues may arise, however, when the model is actually used in real-world decision situations. Members of the WALTER team are addressing these potential challenges through maintaining interactions with key entities via other projects, meetings, conferences and similar opportunities.

Two key challenges with regard to horizontal integration remain. The first is to provide experts with the ability to modify datasets in the model's layers. The second is to ensure that the model can be adapted to other sites in the region. Work on both of these challenges is anticipated to continue, as funding availability permits.

The WALTER website is an essential component of the project, not only because it provides the platform for access to the model, but also because the website provides an array of ancillary information ranging from descriptions of the main policies implicated in fire management decision making to animated NDVI maps, fire history information and statistical analyses of climate conditions, as well as links to many other websites. Considerable effort has gone into design of the website, particularly with regard to assuring its accessibility and usability for a wide range of individuals. The site is set up to allow different levels of access, from completely open to experts only, and provides a clear path through which users can explore without losing connection with main entry pages. Construction of the WALTER website posed its own set of challenges, not the least of which was employment of a high-caliber team of web designers and content specialists with expertise in building user-friendly and architecturally sound systems. The development process was both time- and labor-intensive and required considerable effort on the part of all researchers on the project to assure that the entire work load did not fall on the team's shoulders at the very end of the project. The effort required building sustained interdisciplinary relationships among the project's researchers, student research assistants and staff members through frequent meetings and other forms of interaction to keep abreast of the state of development of the various components of the project and to harmonize the different elements in a coherent manner.

Vertical Integration

As noted above, the architecture of FCS-1 combines GIS layers embedded in the two sub-models, the fire hazard sub-model and the values at risk sub-model. Each of these sub-models is constructed from a series of data layers representing the critical factors influencing fire risk in the forests of the Southwest US, as well as similar areas elsewhere in the West (see Figure 3.3 for an example of how FCS-1 displays individual GIS layers). Vertical integration involved:

1. assuring that all data were developed at a common grid scale of one kilometer square;
2. using common databases for underlying information such as vegetation type;
3. producing an evaluation of the quality of the data contained in each GIS layer; and
4. assuring that each layer was compatible with use of AHP.

The availability of metadata for each layer was also assured wherever possible. All of these efforts have insured that the model is as transparent as possible, and thus maximally useable and useful, especially to the experts who will be responsible for maintaining the data layers for their geographical area. An additional and absolutely crucial factor in the vertical integration process was the considerable effort expended by research team members to work together across disciplines and areas of expertise to assure that the data each team was creating would harmonize with that produced by the other teams. Another critical quality-control process in the vertical integration phase involved bringing representatives of both the expert and general public user communities in each study area to evaluate the model, its individual layers, and the data and processes used to create each layer. Participants also participated in an AHP exercise to understand how to create their own model outputs, and to assess the specific output arising from their group's AHP activity.

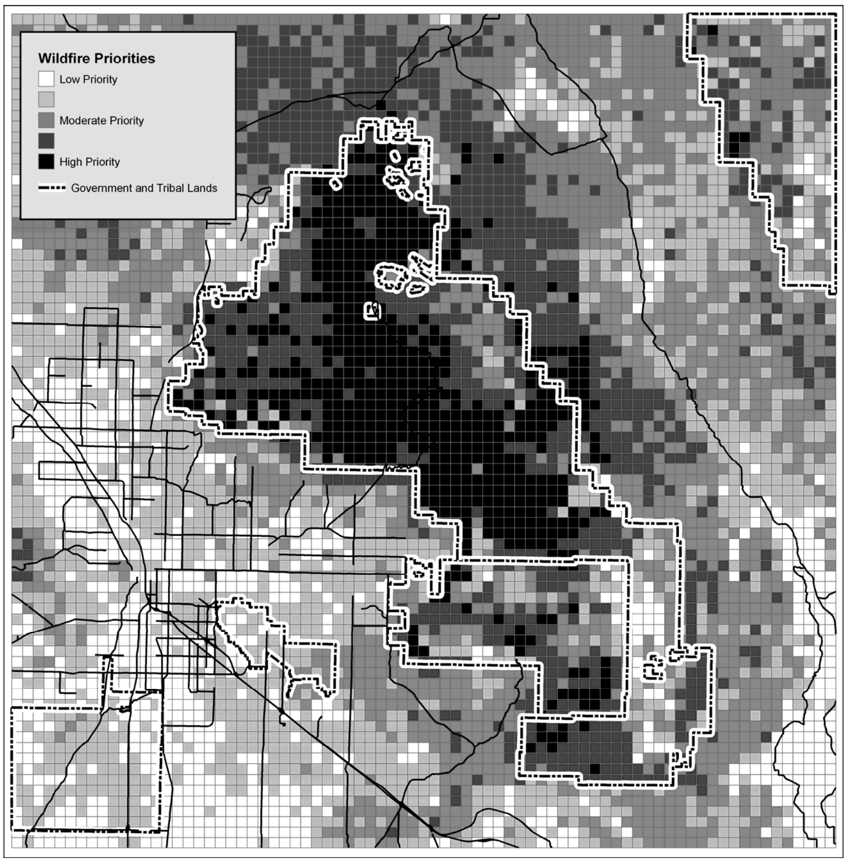

Figure 3.3 Example of FCS-1 data layer: perceived values layer

FCS-1 AS A POTENTIAL COPING MECHANISM IN BUILDING RESILIENCE TO CLIMATE IMPACTS

As recent drought conditions in the Southwest US have shown, climate impacts on the forests of the Southwest can be huge. Likewise, research that looks deep into the past shows strong links between large regional fire years and seasonal to interannual climate patterns, notably variability in precipitation associated with ENSO. Research undertaken in building FCS-1 also shows that the combination of low precipitation levels during the winter preceding fire season and high temperatures during the following spring correlate with a higher probability of occurrence of large fires in the Southwest. Through incorporation of this information into the model, and through requiring users to choose from a range of climate scenarios to run the model, FCS-1 affords a unique opportunity to think through the potential implications of climatic variability on wildland fire regimes. Further, the need to use AHP to assign weights to the model's components means that each user must think through the relationship between his/her choice of climate scenario and the impacts of that scenario in terms of fire probability and of values at risk. The results produced by the model likewise provide considerable information useful for carrying out strategic planning for time periods ranging from a month out to multiple years in the future. The ability to experiment with different climate scenarios and different weighting schemes affords opportunities to ask 'what if' questions, an exercise that can be very valuable in developing the kinds of flexibility in planning and decision making needed to cope with different possible conditions. Combined with the additional information provided on the WALTER website, the system presents valuable opportunities for enhancing resilience to climate impacts among experts and lay people alike who are concerned about the potential for and impacts of large wildland fires.

CONCLUSIONS

Wildland fire will continue to be a serious problem into the indefinite future. Getting a grip on the problem requires attention to the ways in which climate variability and change, ecological variability and change, and societal dynamics and values interact with each other and with fire. FCS-1 is a first-generation fire–climate–society integrated GIS decision support tool that brings together these disparate factors in a manner that allows assessment of conditions and alternatives at the scale of individual mountain ranges. The model maximizes possibilities for user influence over the weights assigned to the various layers, and allows for multiple experiments with different combinations of climate scenarios and weighting schemes. Subsequent versions of the model will include introduction of dynamic vegetation and climate variables, as well as web-based capacity to carry out the survey and cognitive mapping exercise used to develop the personal values layer of the model. In addition, plans call for introducing the model to other areas of the Southwest that are at risk from wildland fire.

The experience of building FCS-1 and introducing it to users in the Southwest through the model evaluation workshops held in each of the study areas has provided opportunities to acquaint key potential users with the system, to identify additional data sources to improve data quality in several of the layers, and to obtain advice on how to improve the model in other ways. The workshops also highlighted the value of the model, when used in group settings, in fostering dialogues that lead to better understanding of the sources of differences, and sometimes disagreement, between individuals and organizational units. Instances where participants in evaluation sessions asked to go back and look at certain model layers to compare weightings as they affect fire hazard and risk revealed the extent to which the flexibility of the model could be turned to creative uses in group dialogues.

FCS-1 represents one of a new generation of fire management models that are breaking new ground in terms of integration across areas of expertise and involvement of constituencies in all phases of research and development. FCS-1 arose from suggestions raised at a climate–fire workshop organized by researchers at the University of Arizona in 2000 and, from the beginning, involved interactions with individuals who would be expected to use the model (or its outputs) when carrying out strategic planning for fire management. The process offered a valuable opportunity to bridge the science–society gap in a manner that opens participation to a wider array of people who are interested in strategic planning aimed at coping with the uncertainties of managing fire in a context of uncertainty about environmental and societal change.

NOTE

1. Information on the WALTER initiative and the FCS-1 model is available at http://walter.arizona.edu.

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Impacts and Responses

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