Incorporating Human Values in a Strategic Wildfire Management Model

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The changing nature of wildfires in recent years and the growing urban wildland interface make it necessary to incorporate human values into both tactical and strategic fire models. These values are both quantitative (e.g., property and timber values) and qualitative (e.g., favored vistas and perceived vulnerability to fire) and impact the ways in which managers plan for and fight wildfire. This paper discusses the creation of spatial datasets in ArcInfo that model both quantitative and qualitative landscape values for strategic wildfire management.

Introduction

This paper represents the current state of the society component for the Wildfire Alternatives (WALTER) project. The WALTER project (http://walter.arizona.edu) is a quantitative model that integrates biotic, climatic, and human factors influencing wildfire mitigation and activity in the Southwestern United States. In particular, the society component has the following objectives: understanding (1) how human values, perceptions, and activities influence wildland fire probability over time and space; (2) why non-spatial institutional and sociocultural factors are important in managing fires affecting natural ecosystems; and (3) how these factors can be combined with each other, and with biophysical factors, to allow integrated representation and assessment of wildland fire prospects?

Wildfire probability has become a major concern in recent years, particularly where humans live in close proximity to forests (Lavin 1997); (Greenberg and Bradley 1997). Historical statistics on fire illustrate the current crisis in Western forests. For a greater part of the 20th century, wildfires in Arizona and New Mexico consumed up to 60,000 acres every year (Swetnam and Betancourt 1997). However, that number soared to more than 180,000 acres in 1997 and reached almost a million acres in 2002. Costs associated with fighting wildfires, defending properties in the wildland-urban interface (WUI), and rehabilitation of burned areas have also risen to unparalleled levels. Arizona's Rodeo-Chedeski fire of 2002 cost nearly $22 million to fight and caused $329 million in damages. Further, fire managers are currently uneasy that the continued drought environment and tree mortality from bark beetle infestations will result in even larger expenses in the current and future fire seasons.

Although the Southwestern United States has a history of large, costly fires, no comprehensive study has been made of the factors in the region that influence wildland fires-uncontrolled, wild, or running fires on forest, marsh, or other nonstructural property. This paper assesses the significance of social factors that influence the presence and number of wildfires of four mountain forest regions in the southwest. Additionally, it identifies areas in these regions that are important to people and worthy of pre-fire treatment if they are to be saved.

The pervasive influence of humans on wildfires across the country is best summarized by Heinselman (1981), who said that human impacts of all kinds have "so greatly lengthened and modified natural fire cycles, that they are no longer relevant". Whereas wildfire origin locations may have once have been determined largely by environmental factors, ample evidence indicates that fire occurrence and size are strongly influenced today by human settlement and activity (Main and Haines 1974; Stocks, Lee, and Martell 1996). Human caused fires account for roughly half of all wildfires in the southwestern United States and in Minnesota, Wisconsin, and Michigan in 1986 they accounted for 93% of all fires greater than 4 hectares (USDA 1997). Active fire suppression, another major human activity influencing fire sizes and patterns, limits the area burned, can change the overall fire frequency (Kronberg, Watt, and Polischuk 1998; Frelich and Lorimer 1991)and may allow species combinations to change (Swain 1980).

In order to bring an increased understanding of how human activities affect wildfire ignition locations, the WALTER project has included a society component to what would otherwise be a traditional wildfire model.

The WALTER Project

Mission of WALTER

WALTER is an EPA Star Grant initiative that seeks to improve our understanding of the consequences of interactions between wildfire, climate and society. WALTER is a multifaceted initiative that aims to facilitate strategic planning for wildland fire management. Combining biophysical and social science with advanced geospatial, decision-support, and interactive web technologies to build integrated decision-support tools for use by experts and by the public. The primary goal of WALTER is to improve understanding of the interactions among climate, fuels, fire history, and human factors that produce different kinds and levels of fire probability, and to devise innovative ways to deliver information to those who need it.

The results of WALTER research will feed into the first phase of an integrated model called Fire, Climate and Society (FCS-1) that links human dimensions and natural science GIS submodels into a comprehensive model that allows assessment of fire hazard consequences for ecosystems and human systems arising from the interactions of climate, human activity, and biophysical processes.

Model Components

For additional information, background on the other components of the FCS-1 model are discussed below but are not within the scope of this paper.

Fire

There are three global questions behind the wildfire research being conducted in support of WALTER project. First, what is the current biogeography of the region (such as soils, vegetation, fuel load factors, elevation, aspect, and many other variables) relative to that of the past twenty years, and what changes have occurred over this time period? Second, what correlations can be found with climatic conditions and events? Third, how do these factors interact to produce particular types and levels of wildfire and of fire hazard?

To help address these questions and contribute to FCS-1, research is being conducted on creating fuel load models appropriate to Southwestern vegetation types and structure, deriving surface moisture from satellite imagery, and assessing the relationships between previous fire occurrence and the probability of fire in similar topographic and ecological conditions. The wildfire research is being conducted in concert with both the climate and fire history components.

Fire History

Fire history has three global questions to answer in support of the WALTER project. First, based on historical information, what are the spatial and temporal patterns of human-caused ignitions and naturally caused fire ignitions? Second, what factors influenced these patterns? Third, how do these factors interact to produce particular types and levels of wildfire and of fire hazard?

In order to answer these questions, archival research is being conducted on documented fire occurrence and extent for the project venues. The hard copy information will be digitized to help formulate a longer fire history record. Lightning strike and human caused ignitions will be evaluated relative to land use patterns in conjunction with the society research component. Tree ring data from a case study in the Rincon Mountains of southern Arizona will be sued to create an extensive, spatially explicit, long-term fire history database. Analysis of these data should shed light on the influence of climate on wildfire patterns, and the influence of previous wildfires on the occurrence of future wildfires.

Climate

There are three underlying questions behind the climate research being conducted in support of the WALTER project. First, what fine-scale information will be needed to assess the relative contribution of climate variability and change, and human land uses to fire regimes and consequences for natural ecosystems? Second, what correlations can be found wildfire patterns and climatic conditions and events? Third, how do these factors interact to produce particular types and levels of wildfire and of fire hazard?

The climate research is focused on understanding the relationship between seasonal climate patterns and fuel moisture so that climate analogs (e.g. a wet winter that increases biomass followed by a dry spring results in higher potential for fire) can help in forecasting fuel productivity. Our efforts to capture seasonal climate variability and inform surface conditions with climate data over complex terrains and varying soils involve the integration historical climate data at a one-kilometer spatial resolution and daily temporal coverage (e.g. DAYMET).

Interannual climate is also taken into account in the fire sensitivity mapping. The influence of longer term, inter-annual climate variability associated with ENSO (El Nino-Southern Oscillation) conditions can help generate synoptic climate patterns so that their influence can be incorporated in the assessment of wildland fire sensitivity. This includes regional climate data (the 1 km climate variable surfaces and the Palmer Drought Severity Index (PDSI) which lags fire probability) as well as low frequency teleconnection patterns (ENSO and PDO). The relationship of fire history data and indices of teleconnection patterns will help us understand how these modulate fire regimes at different sites.

Study Venues

The WALTER project selected study areas that could capture differences in southwestern forest ecology, climate, human influences, and wildland management challenges. They are the: (1) the Santa Catalina-Rincon Mountains, adjacent to Tucson, Arizona; (2) the Huachuca Mountains located in the vicinity of Fort Huachuca Army Base and the nearby city of Sierra Vista, Arizona; (3) the Chiricahua Mountains, located in a still largely rural area of extreme southeastern Arizona; and (4) the Jemez Mountains adjacent to Los Alamos National Laboratory and the community of Los Alamos, New Mexico. In this paper we will address only data related to the Huachuca Mountains. It is the smallest of the four study areas and currently has the most complete data set.

Huachuca Mountains

The Huachuca Mountains are located approximately 60 km south-southeast of Tucson, Arizona and directly west of the city of Sierra Vista, Arizona. These mountains range in elevation from 1,199 meters at the base to 2,882 meters at the top of Miller Peak. Vegetation in the Huachucas varies from Chihuahua Whitethorn Scrub and Semi-desert Mixed Grass/Mixed Scrub, at the lower elevations, to Encinal Mixed Oak, and then transitions into Ponderosa Pine at the highest elevations. Like the Catalinas, the Huachuca Mountain area is owned principally by three entities: the USDA Forest Service (41%), private land (32%), and the U.S. Army (20%). Sierra Vista is the main population center (37,775 inhabitants), but there are a number of smaller communities, including Fort Huachuca, in the region as well.

The Huachuca Mountains provide this study with a location that is experiencing rapid population growth in a formerly rural area. Sierra Vista's expansion is pushing population right up along the eastern base of the mountains. Compared with Tucson, where most of the growth is occurring in areas away from the mountains, Sierra Vista will provide an opportunity to study how growth along the urban-wildland interface affects wildfires.

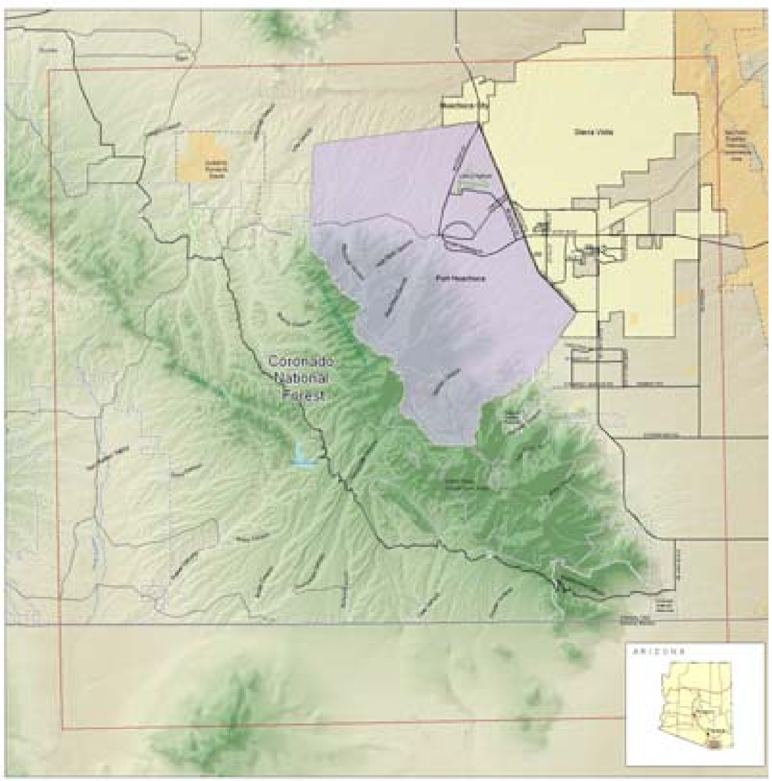

Figure 1 - The Huachuca Mountains

Society Modeling

The society component is the result of an integration of two different aspects relating to people and wildfires in the southwest. The first is a fire probability model that examines what aspects of human activities contribute to ignitions of wildfires. It will use a logistic regression model to determine the impact of four variables that have commonly been used to predict human forest fire ignitions. These variables are distance to roads, distance to urban areas, distance to non-forest areas, and distance to campgrounds and picnic areas. The second model will focus on the combination of landscape that people value. Valued areas in the study areas are indicated by species richness, property values and recreation locations. Additionally, surveys given to key stakeholders in the Huachuca Mountains in order to provided information on areas they personally believed to be at risk form wildfire, areas they value but don't use, areas that they value the most and areas that they use for recreation. These variables are combined with the analytical hierarchy process using the software Expert Choice 2000 2^{nd} Edition for Groups.

Data

Human-caused wildfires are the result of a complex interaction between human sources of ignition and the physical environment of the forest. Six variables used in this study are inherently spatial and are therefore easy to use in GIS analysis. These variables are: (1) distance to roads; (2) distance to urban areas; (3) distance to picnic areas and campgrounds; (4) species richness; (5) property value; and (6) distance to non-forested areas. All data in the final model is converted to a 1 kilometer x 1 kilometer grid for each study area. This format is used in order to align the society component of the WALTER model with both the climate and fire components.

Distance to Roads

Following the historically strong relationship between fire occurrence and railroad sparks (Harrington and Donnelly 1978) and the high proportion of Southwestern wildfires that are caused by humans, it is expected that distance to roads, in absence of nearby rail lines will influence ignition frequency. Distance to roads is expected to strongly affect the probability of a fire being reported by driving the level of human residents and visitors in an area. Since fire suppression equipment is often brought to the scene by road, it expected the accessibility of fire fighting equipment to be related to this factor. Using data from the U.S. Forest Service, a line-based road coverage is produced for the four study areas and converted using the Euclidean distance function to road distance variables.

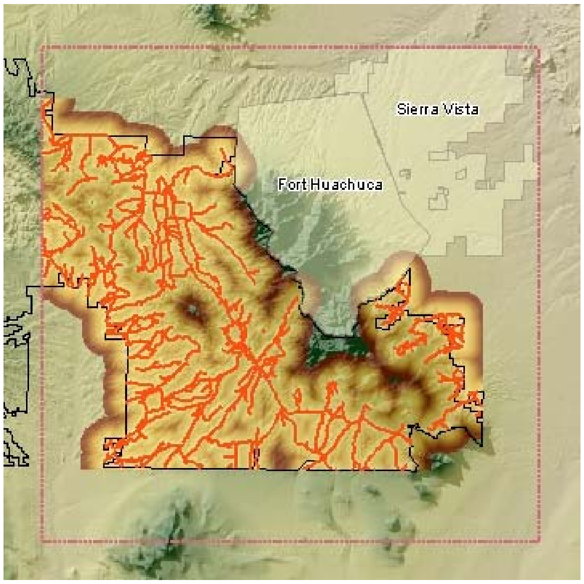

Figure 2 - Distance to Roads

Distance to Urban Areas

Because humans caused a large percentage of wildfires in this region during the last 20 years, a factor expressing the omnipresent effect of population is critical. The influence of human population can be seen in most stages of a reported fire's life-cycle: the population in an area drives the human use of that area and thus the likelihood that part of that area will be ignited; it influences the probability that a fire is reported; and the people and property affect the probability of fire suppression and the methods used. To recreate this factor, incorporated areas, as defined by the 2000 U.S. Census Bureau, are converted into a raster surface and again the Euclidean distance function was used to calculate the distance from each area.

Figure 3 - Distance to Urban Areas

Distance to Non-Forest

It was expected that the distance from a grid cell to the nearest area of non-forest would influence both the likelihood that a fire is discovered and reported as well as the accessibility of a reported fire to the delivery of suppression equipment. Additionally, these areas located at the edge of a forest and thus face the possibility of greater exposure to human activities. Although in a univariate analysis Cardille and Ventura (2001) found that both all the fires and just the large fires were more frequent on unforested areas, it is believed that areas very far from non-forest might, if a fire were to begin there, tend to become larger than fires nearer to non-forest. To simulate this factor areas classified as anything other than a forest were converted into a raster and then a Euclidean distance function was run on them to determine the distance from these areas.

Figure 4 - Distance to Non Forest

Distance to Campgrounds and Picnic Areas

Two major activities of people in the national forests are camping and picnicking. A variable that reflects this is distance to campgrounds and picnic areas in the national forests of southern Arizona and northern New Mexico. Data provided by the United States Geological Survey (USGS) from their Geographic Names Information System (GNIS) gave locations of campgrounds and picnic areas for our study areas. These point locations were then used as inputs ARC/INFO's EUCDISTANCE command, to find the how far away fires were from these locations.

Figure 5 - Distance to Campgrounds and Picnic Areas

Species Richness

The purpose of this variable is to map locations of high animal species diversity in attempt to determine those areas that value the environment. The expectation was that people who place a great deal of importance on environmental issues and concerns will want areas with a high biological diversity to be protected. This variable was created separately from Arizona and New Mexico GAP data. Information on birds, mammals, reptiles and amphibians was obtained and combined to form a single map that counts the number of species from these four classes.

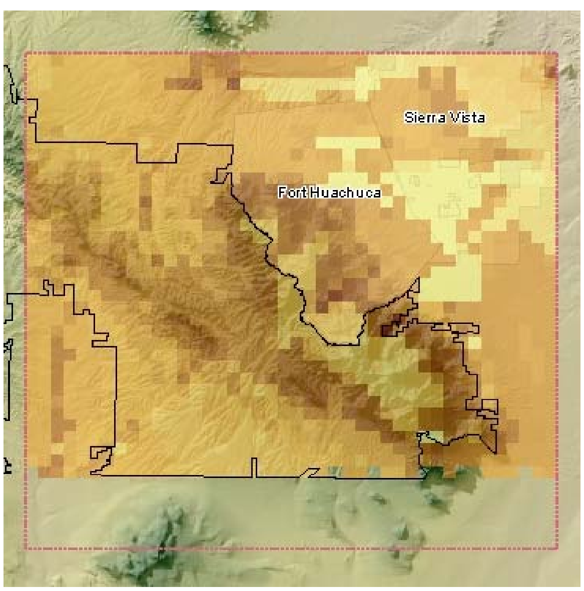

Figure 6 - Species Richness

Property Value

The intent of this variable is to find areas of high land and property values in an attempt to locate those areas where people have a large investment in the land. It is assumed that people who value human structures over the environment and the recreation opportunities will place a higher priority on this variable. This data is available from the 2000 U.S. Census of Housing. Property values from the Census Bureau is available at the block group level and was converted to 1 km grid cells by adding up the value of all the whole block groups in that cell with those that only partially inside that block group. For the partial block groups it was assumed that the property value is evenly spread throughout the polygon and therefore the percentage of the block group that falls inside the 1 km cell is multiplied by the property value and then added to the grid cell. For those block groups that are bigger than a 1 km cell, the percentage of the block group that a 1 km cell occupies is multiplied by the property value and then that value is assigned to the cell.

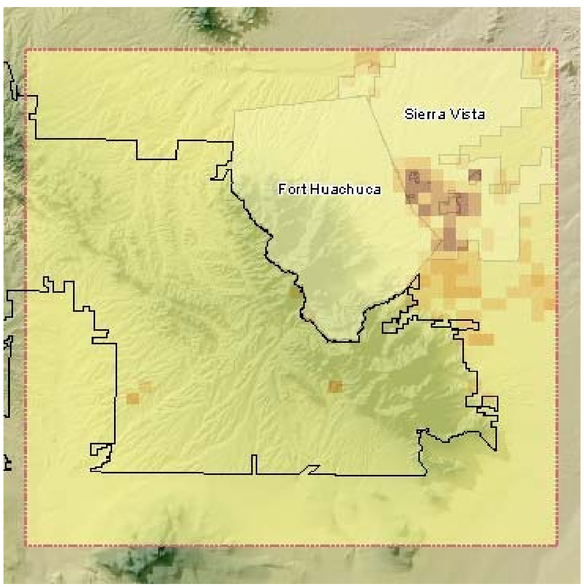

Figure 7 - Property Value

Perceived Landscape Value

While GIS models of environmental risk and value have long taken into account "hard" data such as precipitation levels and property values, they have historically not included intangible values that concerned groups and individuals place on natural areas. In an effort to redress this imbalance in our model, project researchers also conducted map-based interviews in each of the four study areas. The sampling and interview methodology for these were as follows. The sample was stratified and non-random, seeking to identify a breadth of viewpoints. Researchers identified individuals to be interviewed from a variety of sources, including professional contacts previously encountered in the WALTER project, federal agencies, environmental advocacy groups, and homeowners associations, among others. Once the interviews began, many interviewees suggested other individuals for us to contact, resulting in a snowball sampling technique (Bernard 1994). Interviewees answered a series of questions from a

5-page questionnaire and the interviews lasted approximately 30 to 45 minutes. The key questions dealt with having the interviewees mark on a map, and were related to the following four variables: location of perceived fire ignitions, location of areas for personal recreational use, location of areas that the interviewee valued but had never visited, and location of the most important area (in the interviewee's estimation) to protect from damage or destruction by wildfire. Currently, we are in the process of digitizing this spatial data, which will then be attached to an Access database containing the non-spatial survey data, which includes basic demographic data. This will then be overlayed on top of other spatial data for the study areas, and, as we discuss further below, will eventually be incorporated into the WALTER strategic planning model.

Figure 8 - Most Important Area

Recreation Values

From a historical perspective, wildlands have been places to conquer in the name of King and country, untapped riches, or in the name of science. The more contemporary visitor is usually interested in other qualities. Escape from the pressures of everyday life, personal testing, and even a place to socialize are now the prizes sought out by most wildland users. In order to capture this increasingly utilized and valued characteristic of wildlands a variable that maps the locations people visit and the magnitude of that visitation is used.

Visitor use of the national forests is monitored by the U.S. Forest Service. A detailed survey of recreation use for the entire Coronado National Forest, of which the Huachuca Mountains are in, was completed in August of 2002. It contained information on the percentage of visitors that participated in various activities in the forest (See Table 1).

Table 1. Recreation activities and the percentage of visitors who participated in them.	
Activity	**Percent Participation**
Camping in developed sites	5.9
Picnicking and family day gatherings	10.7
Viewing wildlife	36.4
Viewing natural features	63.2
Visiting a visitor information center	12.1
Nature study	8.6
General recreation	36.8
Driving	24.3
Hiking	50.9
Swimming	5.0

Table 1. Recreation activities and the percentage of visitors who participated in them.

Information from the Forest Service provided the magnitude of the various recreation activities. To determine the location of these activities, viewshed and Euclidean distance modeling were used. First a viewshed was constructed that counted the number of times a cell could be seen from known recreation areas of a given type. Table 2 provides information on what GIS data was used for each recreation activity. This was then combined with a Euclidean distance surface that measured the distance from the recreation areas up to 2000 meters. In order for these two very different surfaces to be combined they both had to be rescaled from their current value ranges to a zero to one scale.

Table 2. GIS data used for each recreation activity.	
Recreation Activity	**GIS Data Used**
Camping in developed sites	Developed Campgrounds
Picnicking and family day gatherings	Developed Campgrounds and Picnic Areas
Viewing wildlife	All Roads and Trails
Viewing natural features	All Roads and Trails
Visiting a visitor information center	Visitors Centers
Nature study	All Roads and Trails
General recreation	All Roads and Trails
Driving	All Roads
Hiking	All Trails
Swimming	Lakes

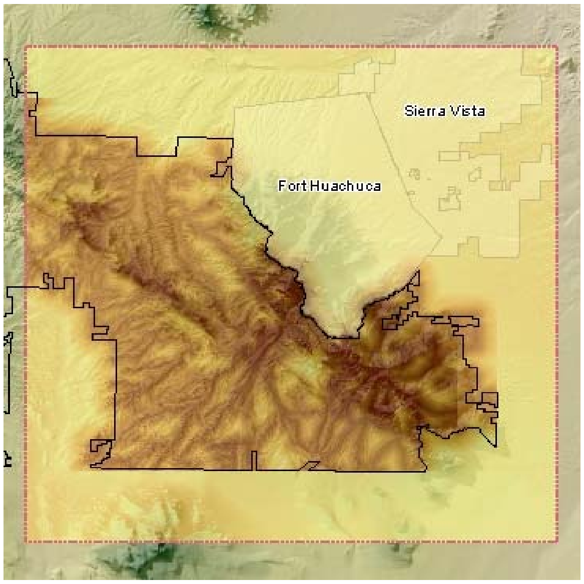

Figure 9 - Recreation Values

Model Integration: The Analytic Hierarchy Process

Numerous decision-making circumstances require preferential selection among some finite set of alternative items, events or courses of action. In the best situations, there would be some intuitive measurement scale that could be used for comparison and the best choice among the available alternatives would then have a high score along that scale. When the selection criterion is “least-cost” for example, the measurement scale is obvious and choosing becomes easy. In most real-world situations, however, there is not a single, simple scale for measuring all competing alternatives. More often, there are at least several scales that must be used and often those scales are related to one another in fairly complex ways. In broad-scale, participatory decision-making, alternative courses of action arise from different stakeholders with different value systems, and yet this diversity must be accommodated and integrated.

The Analytic Hierarchy Process (AHP) (Saaty 1980) is intended to help with these types of decisions. It has been applied to a wide variety of problems (Zahedi 1986). Two important components of the AHP that facilitate the analysis of complex problems are: (1) the structuring of a problem into a hierarchy consisting of a goal and subordinate features of the problem and (2) pairwise comparisons between elements at each level. Subordinate features which are arranged into different levels of the hierarchy, may include such things as objectives, scenarios, events, actors, outcomes, and alternatives. The alternatives, (actions or locations to make a choice from) to be considered are placed at the lowest level in the hierarchy. Pairwise comparisons are made among all elements at a particular level with respect to each element in the level above it. Comparisons can be made according to preference, importance, or likelihood-whichever is most appropriate for the elements considered. Saaty (1980) developed the mathematics necessary to combine pairwise comparisons made at different levels in order to produce a final priority value for each of the alternatives at the bottom of the hierarchy.

In this study, consider the hierarchy in Figure 1, which is designed to enable a stakeholder to prioritize components of the WALTER Society model. The goal, *what component is more important with regards to fire planning*, appears at the top of the hierarchy. The criteria appear on the next level: *fire probability, species richness, property value, recreation, and area of highest value*. The alternatives are the individual cells of a 1 kilometer by 1 kilometer grid generated for the entire Huachuca Mountains, numbering 1,764 cells, and would be on the lowest level. First, the criteria are compared pairwise with respect to their importance to the individual stakeholder. The scales of integers in the range 1-9 are used for comparison (Saaty 1980).

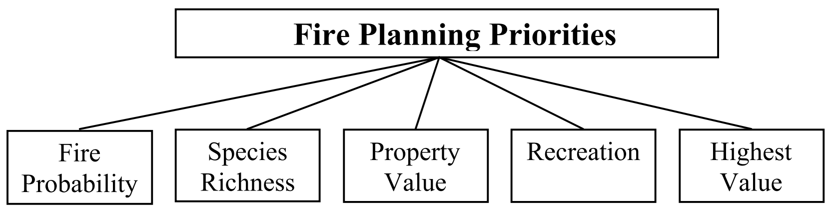

Figure 10. A simple analytic hierarchy for selecting fire planning priorities

After arranging the problem in a hierarchical fashion, the next step is to establish priorities. Each node is evaluated against each of its peers in relation to its parent node; these evaluations are called pairwise comparisons. For example, in Figure 1., *Fire Planning Priorities* is the parent node of *fire probability, species richness, property value, recreation, highest value*, which are themselves peers.

Pairwise comparisons are basic to the AHP methodology. When comparing a pair of "factors", a ratio of relative importance, preference or likelihood of the factors can be established. This ratio need not be based on some standard scale such as feet or meters but merely represent the relationship of the two "factors" being compared. For example, when comparing the heights of two people, we can judge (without any scientific measurements) that one person is taller, or perhaps even twice as tall as the other. This may be a subjective judgment, but the two people can be compared as such.

Most individuals would question the accuracy of any judgment made without using a standard scale. Yet, it has been verified that a number of these pairwise comparisons taken together form a sort of average, the results of which are very accurate. This "average" is calculated through a complex mathematical process using eigenvalues and eigenvectors. The results of this method have been tested experimentally and have been found to be extremely accurate.

For this paper, two of the authors (Johnson and Perin) made comparisons between the five criteria documented in Figure 10. We separately gave our opinions for the comparisons. We then individually then responded to the comparisons assuming the roles of a fire manager, a homeowner and a recreationist. The weights from these comparisons are shown in Table 3.

Table 3. Weights generated by the AHP for eight people.								
	Graduate Student A	Graduate Student B	Fire Manager A	Fire Manager B	Home-owner A	Home-owner B	Recreationist A	Recreationist B
Fire Probability	.394	.175	.476	.450	.175	.167	.417	.387
Species Richness	.119	.155	.074	.125	.077	.103	.111	.087
Property Value	.180	.256	.244	.205	.490	.425	.049	.267
Recreation	.096	.142	.049	.078	.051	.121	.279	.305
Highest Value Area	.211	.271	.156	.178	.206	.245	.145	.158

In a traditional AHP application comparisons between the alternatives would be made to determine how they rank with respect to the criteria. In a case such as this, that would mean 1,554,966 comparisons. To avoid this task we have devised a way to automate alternative comparisons.

In order to facilitate this automation, it is necessary to create a ranking methodology for each 1 km grid cell in the study area. This is accomplished in several different manners. For the fire probability criteria, Euclidean distance surfaces were created for each component (distance to roads, distance to urban areas, distance to non-forest, distance to campgrounds) of this criteria. These four components were then used for a simple logistic regression model to determine weights. These weights were then multiplied with the Euclidean distance surfaces and added together. The creation of the other criteria is described above.

The individual criteria are then multiplied by the weights arrived at from the analytic hierarchy process and added together to arrive at a surface depicting wildfire planning priorities for the Huachuca Mountains. See Figure 11.

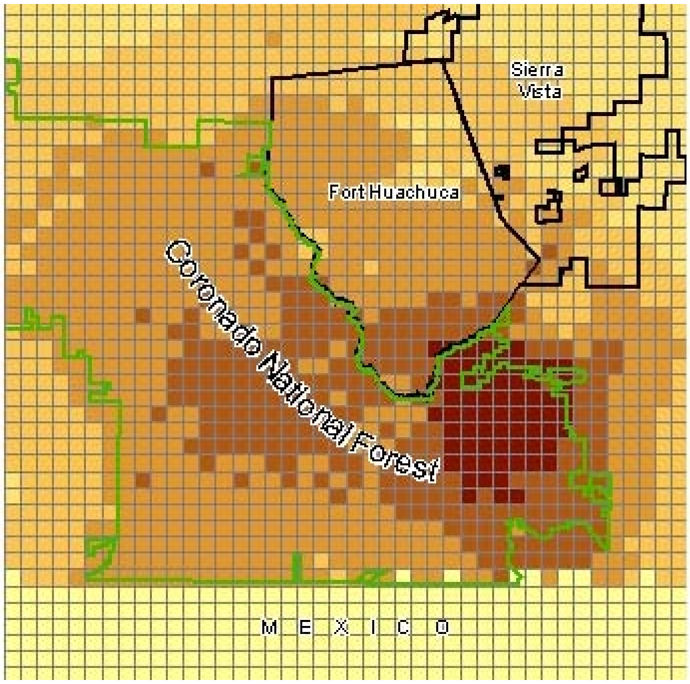

Figure 11 - Priority areas in need of pre-wildfire attention. Darker areas represent high priority areas.

Conclusion

The analytic hierarchy process as shown above has great utility for combining responses to complex problems from a large number of people. It is a powerful and flexible decision making process to help people set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. By reducing complex decisions to a series of one-on-one comparisons, then synthesizing the results, AHP not helps decision makers arrive at the best decision, but also provides a clear rationale that it is the best. When combined with GIS technology it allows people without spatial or technical knowledge to become involved in a decision making process that they would normally be left out of. Eventually, the society component will be merged with the other components of the WALTER model using a process very similar to the one outlined above. See Figure 12 for the complete hierarchy.

In addition to demonstrating geographically to stakeholders and decision-makers, locations of high priority treatment areas, this method also is capable of making comparisons between different stakeholder groups, demonstrating the areas each feel are important. Inputs from the different stakeholder groups will acquired from workshops to be held at each of the four study areas and over the internet for those unable to attend and other interested people.

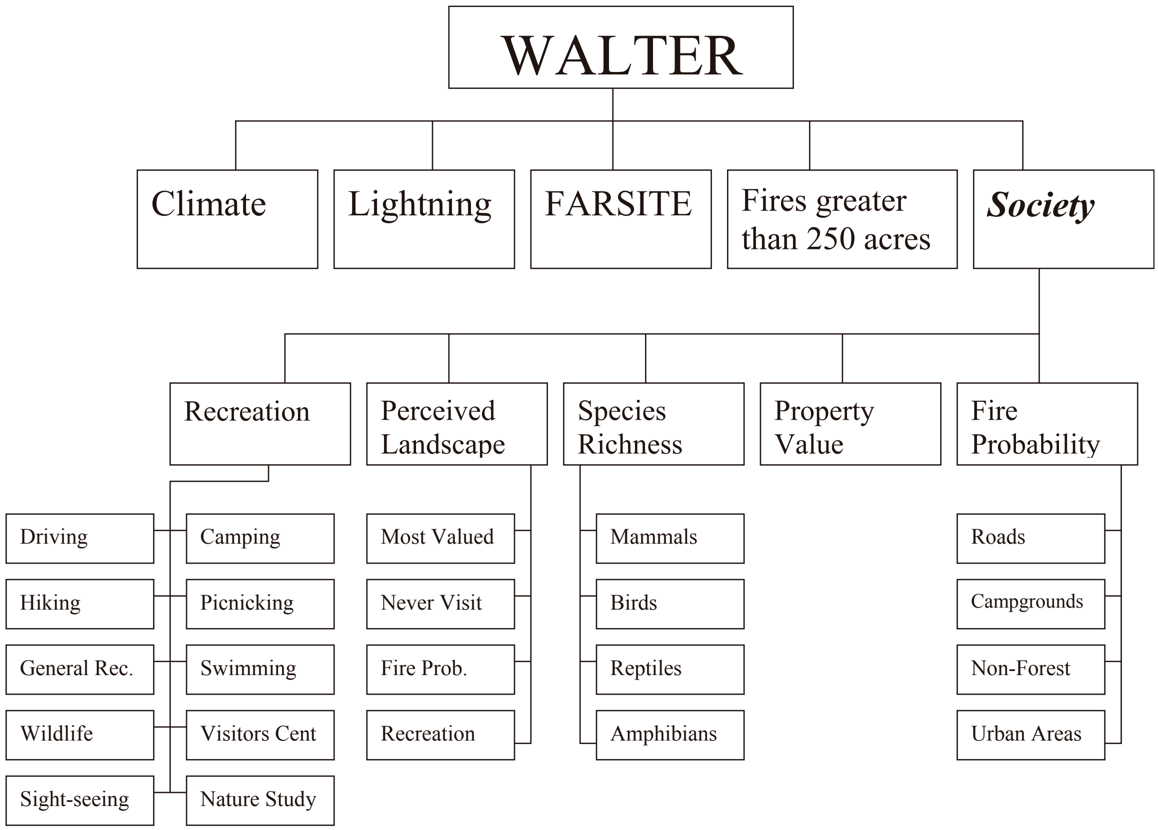

Figure 12 - WALTER Project AHP hierarchy

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