Fuel Model Mapping and Fire Simulation Modeling

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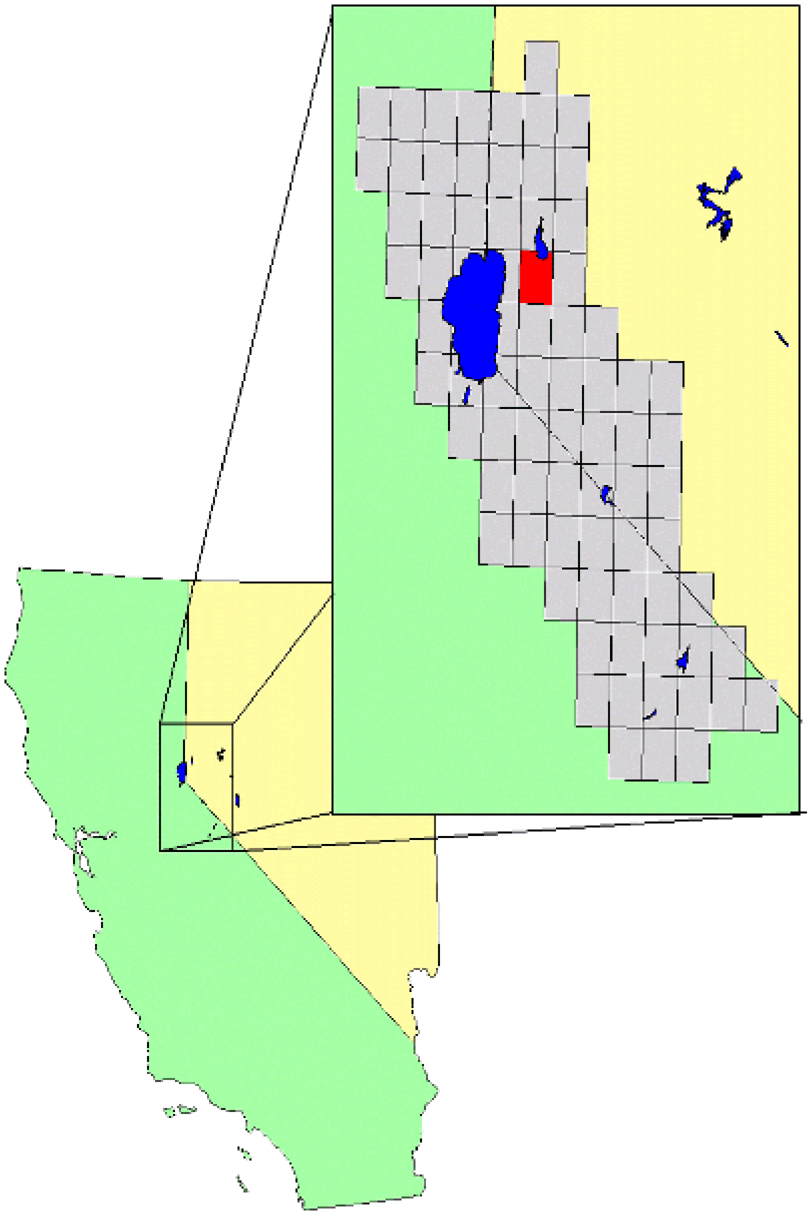
ABSTRACT

IRS 6m satellite images have been used to map the vegetation of range and forest landscapes in western Nevada and the eastern Sierra Nevada, California. Vegetation is being mapped by 7.5 minute topographical quadrangle sheets. These maps are being reinterpreted and new maps prepared of U.S. Forest Service NFFL Fire Fuel Models. A supervised stepwise linear classification algorithm combining three multispectral bands, slope , aspect and one or more vegetation indices and filters give classification accuracies between 50 and 70 percent based on satellite data. A third map of each quad is also being prepared showing fire hazard (high, moderate and extreme) based on three general vegetation classes (grass, shrub and tree) and three slope classes ((0-20 percent, 21-40 percent and >40 percent). The FARSITE fire simulation model is being used to describe wildfire scenarios of interest to fire suppression professionals. Based on the behavior characteristics of the various fuel models determinations were made of potential fire spread rates for selected sites and weather patterns.

1 Introduction

Natural landscapes are covered with soil and vegetation. The soils are relatively permanent unless extreme accelerated erosion takes place. The vegetation, on the other hand, is much less permanent and is influenced by numerous perturbations over time and forms the basis for wildfire fuels. These perturbations include logging, grazing and browsing, flooding, disease and wildfire. This paper briefly describes the vegetation along the eastern Sierra Front in eastern California and western Nevada (Fig. 1)and discusses the vegetation in terms of fire fuel models and their associated fire behavior characteristics. The area includes the east side of the Sierra Nevada from the ridge top down to the east and extends out into the Great Basin to include all areas where urban encroachment makes wildfire and the natural vegetation of concern. The paper also discusses the mapping of the vegetation from the Indian Remote Sensing ((RS) 5 m satellite images, the reinterpretation of these maps into fuel model maps and the preparation of hazard maps for the same areas. Maps of the fuel characteristics provide a valuable tool to fire suppression professionals as they attempt to understand fire behavior and contend with the many wildfires that occur in this part of the world.

Fig. 1 Study site along the boundary between California and Nevada north and south of Lake Tahoe.



2 The Vegetation

The natural and sometimes man-made vegetation along with the topography and the weather define fire behavior in any particular situation. Predicting fire behavior requires relatively accurate descriptions of the vegetation and the topography. The often unknown element is the specific weather characteristics at the time of ignition and throughout the duration of the fire. Here we briefly describe the vegetation of the eastside of the Sierra Nevada extending eastward into the Great Basin. In addition we have attempted to instruct the reader to identify the fuel model that is relevant when a type of vegetation with certain dominant species are present.

A place to begin is at the ridge top. The east side of the Sierra Nevada is essentially in the rain shadow of this auspicious mountain range. As one moves downward into the Great Basin the rainfall decreases substantially. At the ridge line the precipitation amounts may vary from 20- to 25 inches annually, much of it in the form of snow. As we continue downslope we find that the long term average annual precipitation at Reno is only 7.8 inches and even less as one moves further eastward. This, of course, profoundly influences the kind and amount of vegetation and the potential wildfire behavior characteristics.

At the highest elevations the vegetation is rather sparse and is characterized by various species of trees often growing on granite. These are often referred to as subalpine forests or subalpine mixed forests. The plant communities are characterized by dwarf trees sometimes referred to as krummholz by plant ecologists. A prominent tree species is whitebark pine (*Pinus albicaulis*). An additional tree species is Sierra Juniper (*Juniperus occidentalis* var *australis*). A number of dwarf shrubs are also found there and a few grasses and forbs. Normally there is little fuel to carry a fire.

Then just lower in elevation the vegetation can best be described as mixed conifer woodland. The dominant tree species in this mixed conifer woodland area are red fir (*Abies magnifica*), California white fir (*Abies concolor* var. *lowiana*), western white pine (*Pinus monticola*), sugar pine (*Pinus lambertiana*) and incense-cedar (*Calocedrus decurrens).* On drier sites the vegetation is dominated with big or low sagebrush (*Artemisia tridentata* or *A. arbuscula*) and often by stands where bitterbrush (*Purshia tridentata)* becomes important. At elevations above about 6,000 feet mountain big sagebrush (*Artemisia tridentata* var vaseyana) is the common sagebrush taxa. Many of the rocky dry sites are dominated with curlleaf mountain mahogany (*Cercocarpus ledifolius*). This, often highly dissected topography, has dramatic changes in plant species composition over very short distances. This often leads to a spotty fire distribution.

Much of the mixed conifer woodland and the lower elevation forest vegetation has been burned and is now dominated by the eastern Sierra Nevada fire types characterized by the dominance of certain chaparral species. The three most common ones are Tobacco brush (*Ceanothus velutinus*), greenleaf manzanita (*Arctostaphylos patula*) and Squaw Carpet (*Ceanothus prostratus*). Huckleberry oak (*Quercus vaccinifolia)* is also common in certain areas.

At still lower elevations below the mixed conifer vegetation the forest vegetation is dominated by yellow pine. Three species of yellow pine are involved. These are Ponderosa Pine (*Pinus ponderosae*), Jeffrey Pine (Pinus jeffreyi) and in some instances Washoe Pine (*Pinus washoensis*). Washoe pine is usually found at higher elevatons than the other two species. Many of these areas have burned over the years forming areas of chaparral.

At lower elevations still the understory of yellow pine is dominated by big sagebrush and/or bitterbrush. As the pine becomes scarce large areas are found that are dominated by these two shrubs. The bitterbrush is often a large columnar form. On drier areas the big sagebrush is dominant by itself or one of the shorter sagebrush species, sometimes called low sagebrush become dominant. These might be low sagebrush (*Artemisia arbuscula*) or Lahontan sagebrush (*Artemisia arbuscula* ssp.*longicaulis*). Other shrubs such as rabbitbrushes (*Chrysothamnus naseosus* and C. *viscidiflorus)* can add to the fuel load along with cheat grass and a number of perennial grasses and forbs adding to the fine fuel load.

Moving outward farther into the Great Basin to the east the lowest elevations areas and valley bottoms are dominated with salt desert shrub species. The most important species are Bailey's Greasewood (*Sarcobatus baileyi*), black greasewood (*Sarcobatus vermiculatus*), shadscale (*Atriplex confertifolia*) and four-wing salt bush (*Atriplex canescens*). In past years these types have not presented a high hazard for wildfire but with an increasing abundance of cheat grass and other weeds such as Russian thistle or tumble weed (*Salsola tragus*) and the mustards (*Sysimbrium* sp and *Descurainia* sp) the spread of fire after wet years can be significant. In addition urban areas with small ranchettes are spring up all over these areas.

Another important fuel type is the pinyon/juniper woodland. The dominant trees are the single needle pinyon (*Pinus monophylla*) and the Utah juniper (*Juniperus osteosperma*). This vegetation often burns under conditions of low humidity and when there is ample understory cover to provide fine fuels. The common understory species consist of several of the shrubs already mentioned such as big and low sagebrushes, rabbitbrush, horse brushes (*Tetradymia* spp.) and a number of grasses, including the annual cheat grass, and a variety of forbs. When this type has a sparse understory it usually means that the trees are close together occupying the site totally and thus allowing a fire to spread easily from tree to tree after ignition.

Spread throughout the area are the riparian vegetation types including mountain meadows that may be dominated by herbaceous species alone or have an overstory or partial overstory of willows (*Salix* spp.), cottonwoods, e.g. the black cottonwood (*Populus trichocarpa)* and other riparian shrubs. In the fall when the herbaceous and woody material matures these areas can present a fire hazard. Often in the spring they are quite wet and difficult to burn. At higher elevations these sites are dominated by aspen (*Populus tremuloides*), alder (*Alnus* sp.), river hawthorne (*Craetagus* sp.) and a number of willow species.

3 Fuel Models and Fire Behavior

There are certain biological and physical components to a description of fire behavior. These are commonly called fuel models (Anderson 1982). The surface litter layer, the duff, dead woody material, grasses and forbs, living woody shrubs and trees (including the canopies), and tree reproduction are all rather easily discernible components with the fuel complex. Depending on what type of vegetation that dominates the site, the fuel may be divided into five general groups: grasses and grass-like plants, forbs, shrubs, timber and slash. Each cover type is characterized by a particular rate of fire spread, a value loosely determined through field trials, observations and fire reports. Basically two systems are used to define the fuel models, the Northern Forest Fire Laboratory (NFFL) with 13 fuel models and the National Fire danger Rating (NFDR) system with 20 fuel models. This paper uses the NFFL fuel models. Each of these 13 has been defined as a kind of wildland fire fuel situation with specific characteristics of fire behavior. Emphasis is given to how these fuel model descriptions can be applied to the eastside Sierra Nevada. These fuel models are listed in Table 1 where you can find one or more examples of the kind of vegetation that might be placed in each of the fuel models for our area. The first three of the 13 are grass types, models 4, 5, 6 and 7 are shrub dominated, models 8, 9 and 10 are timber types and models 11, 12 and 13 have their fire behavior mostly influenced by timber slash (Anderson 1982). .

It must be remembered that the vegetation and dominant species may suggest one fuel model but given certain weather, fuel moisture and other parameters may act as an entirely different fuel model, one of the 13. For example, just because it is a big sagebrush dominated plant community it may not be a fuel model five. In fact in the study area big sagebrush generally falls into a fuel model #2. In addition it should be noted that the 13 fuel models refer only to ground spread of fire but not for crown fires. Procedures for inventorying surface and biomass in the field are available (Brown et al 1982)

4 MAPPING

To understand a landscape it is necessary to have a vegetation map (Fig. 3). However, even with a high quality accurate vegetation map you are only part way there. Such a map requires complete reinterpretation into fire fuel models. This interpretation requires that each vegetation map must be described in terms of the fuel models they likely represent. There is not a one-to-one relationship between plant communities and fuel models. Several plant communities each with their specific dominant species and species composition make up may all act very similar as to their fire behavior and thus would each be placed into a single fuel model in a fuel model map (Fig. 4). The need is to have a map of fuel models where each polygon accurately represents how a fire will behave given and ignition and specified weather characteristics. Generally we develop maps and weather scenarios that are worst case. Once the fuel models are mapped, where each polygon accurately represents how a fire will behave given specific weather characteristics, this information can assist in fire suppression efforts, land use planning and in other manners.

The importance of assessing the accuracy of Land-use and Land-cover including the vegetation classes derived from remotely sensed data has long been recognized (Stehman 1992). Traditionally, pixels are the fundamental units of satellite images and are used in the analysis of spatial data (Steele et al 1998). Our vegetation mapping was completed using image processing classification procedures on the IRS 6m fuse blend satellite data (Fig.2). A stepwise linear algorithm was used with the following raster files: blue, green, infrared, and slope and aspect from DEMs and the

Transformed Vegetation Index (TVI). Training sites were selected to represent areas for estimating typical spectral values for each class (Verbyla 1995). The vegetation map included 15 classes: lake, snow, barren, crop, alpine, dy meadow, rabbitbrush/sagebrush/bitterbrush, high sierra shrubland, mixed shrubland, riparian shrubland/woodland with wet meadows and aspen forest, mountain mahogany woodland, pinyon/juniper woodland, mixed forest (shaded), mixed forest and ephedra shrubland.

Vegetation classification accuracy was checked with ground mapping portions of the landscapes studied (Congalton 1991). After classification noise or speckling was reduced by using a 7X7 high pass filter. Such a filter allows for the presentation of polygons that have greater homogeneity. Accuracies varied from 50 to 70 percent which is rather common using satellite imagery.

The vegetation maps where then reinterpreted into fuel model maps (Fig. 4) to be used with the FARSITE fire simulation model which we have used to assist in determining the fire behavior to be expected when a fire is ignited and given certain weather and landscape factors such as wind speed and direction, temperature, humidity, slope and aspect.

Prior to a classification for fuel models sub-samples of the study site were used to determine methodology that would produce the most accurate results over the entire study area. We determine that Thematic Mapper (TM) data produce slightly more accurate fuel model classifications (Fig.4) than the IRS images, although there was no statistical difference when comparing percent accuracy and that results in a t-test at alpha is equal to 0.05. We decided with these results to use TM imagery in our classification of the study area because TM as a higher spectral resolution than the IRS data. The TM scene also had covered the entire study area were as with the IRS imagery we had complete coverage but full coverage was an assembly of 7.5' quadrangles with 2 different dates. We also found in our sub-sample results that using all of the TM bands, linearly stretched NDVI, and categorized slope and aspect produced the highest percent accuracy values when using the stepwise linear classification algorithm. In our final fuel model classification of the study area we include the aforementioned data layers plus an annual precipitation layer. We found that with the annual precipitation layer included we could more accurately decipher pinyon-juniper woodlands (generally a fuel model 5) from adjacent mountain ranges which were dominated by yellow pine species (considered one of the 3 forest fuel models).

Once the final classification was completed a 3x3 window modal noise-reducing filter was applied to the results to remove pixel clusters that were smaller than our 1 hectare minimum mapping unit. Accuracy assessment on portions of our final results ranged from 60 – 75%.

4.1 Creation of FARSITE data layers

Five landscape layers are necessary to run the fire simulation program Farsite, slope, aspect, elevation, fuel model, and forest canopy cover. In Arc/Info we derived slope and aspect from a USGS DEMs (digital elevation model)and the converted them to Arc/Info ASCII grid file formats. The fuels layers is also converted to a asci grid format. To create the forest canopy we manually digitize forested areas delineating them into 4 cover classes (i.e., 0-25, 25-50, etc..) and then conveted the vector coverage to a ASCII grid file. Farsite is a public domain software and can be obtained from http://www.montana.com/sem/

4.2 Fuel Hazard map creation

The fuel hazard rating criteria we used (Table 1) were developed by the Sierra Front Wildfire Cooperators a group of fire agencies based in Minden Nevada. The hazard rating was completed by grouping the fuel models into there appropriate classes (i.e., fuel models 1-3 are grouped into the grass fuel class, etc…) and reclassify the slope layer into the 3 slope categories as depicted in table 1. A simple GIS analysis of multiplying the fuel class grid by the slope category raster resulted in a fuel hazard rating map for the study area (Fig. 5).

Table 1

	----------------------- % Slope ------------------------		
Fuel Class	0-20	21-40	> 40
Grass	Moderate	High	High
Shrub	High	Extreme	Extreme
Forest	Moderate	High	Extreme

5 Ecological Response to Wildfire

What happens to the ecology of the area when a wildfire occurs? The ecological effects of fire can be extremely complex. This is often a function of the time of year the fire occurs, the intensity of the fire and the duration of the fire. In many cases the fire may be catastrophic relative to the vegetation and most of the vegetation is removed. Root sprouting shrubs are often the first species to return. In some cases grasses and perennial forbs that are not killed in the fire are the first to reoccupy the burned site. Most of the non-sprouting species will be killed in wildfire and must return to the site only from a seed source. Some species are resistant to fire and others are very susceptible to damage. Because of the relative dry conditions of the ecosystems found on the eastside of the Sierra Nevada recovery vegetation recovery after wildfire can be very slow.

The influence of fire on the vegetation can be long-lasting even though the disturbance itself passes very rapidly. This is especially true of the shrubs which after resprouting on a burned site will maintain themselves for long periods of time. For example, the east side chaparral may last for decades before the yellow pine or mixed conifer forest trees begin to reoccupy the site and a century or more may pass before the trees once again become dominant on the site. Successive fires may be especially detrimental and cause populations of plants and their seed sources to be lost from the ecosystem. So in many situations after a wildfire several generations may pass before a similar prefire vegetation returns.

Of concern on many sites in the shrub dominated vegetation at the lower elevations along the eastern Sierra is the introduced annual cheat grass (*Bromus tectorum*). This grass now occupies many acres at the lower elevations around Reno and other urban areas where wildfires have been rather common. This grass competes with the perennial grasses for spring moisture and tends to preclude their return to the burned sites. At some locations, e.g., the Belli Ranch fire, the annual grass medusa head rye (Taeniatherum caput-medusae) is dominant.

Low intensity fire facilitates cycling of some nutrients, may help control certain plant pathogens, and generally will not increase soil erosion. However, intense fire tends to volatilize excessive amounts of nitrogen and other essential nutrients, destroy organic matter and can disrupt soil structure and may induce water repellancy. The intensity of a fire, its duration and the time of year all govern whether a fire has positive or negative effects. Generally, low and moderate-intensity fires have good effects and high-intensity fires have bad effects. A high-intensity wildfire burning in dry weather and with heavy fuels can remove nearly all the ground cover exposing bare mineral soil to the pounding force of raindrops. This can lead to increased runoff and soil erosion and is why many wildfires are seeded as soon after the fire a possible often with an annual grain seeds to protect the soil surface from fire-induced accelerated erosion. Damage to animal, bird and reptiles is usually related to changes in habitat brought about by the fire. In some instances the alteration of the vegetation will profoundly affect the status of specific populations of mammals, birds and insects.

One way to control wildfire or ameliorate the effects is to modify the fuels. This can be done in various ways but usually always involves some involvement with vegetation. One way is the idea, so prominently promoted, to create defensible space by removing or altering the vegetation near land improvements. Other ways include the ecological manipulation of the fire fuels on the landscapes of interest by removing or altering the vegetation over larger land areas. Grasses and forbs can be removed in various ways, e.g, by grazing or prescribed fire to remove fine fuels. Most other ways are prohibitively expensive.

The reader should be aware of the Fire Effects Information System (FEIS) which is an up-to-date information on fire effects on plant and animals. It was developed at the USDA Forest Service Intermountain Research Station's Fire Sciences Laboratory (IFSL) in Missoula, Montana. The web site (http://www.fs.fed.us/database/feis/) provides a wealth on information for those interested in fire effects and can be easily and frequently accessed to determine the fire effects on your organisms of interest. For example, for a large number of plant species you will find information listed under a number of topics: introductory, distribution and occurrence, value and use, botanical and ecological characteristics, fire ecology, fire effects, fire case studies and a list of reference.

6 Conclusions and Concerns

As fire suppression folks and planners work on plans for land use and management the question of fire behavior is one that is always of concern. An understanding of the natural vegetation and the dominant species and how the vegetation, topography and weather influence fire behavior in those areas with wildfire potential will allow fire suppression professionals and land use planners to better plan for wildfire problems. A knowledge of the kind of vegetation and the associated fuel model and potential fire behavior along with a knowledge of fire hazard and fire risks will allow these professionals to better understand how to plan for the advent of wildfire on their areas of interest. The improvement of maps depicting fuels and their fire behavior along with a landscape representation of areas with different degrees of wildfire hazard is an important part of this process. In addition, when a wildfire occurs there can be a better understanding of what both the long term and short-term environmental consequences will be if the fuel models and associated ecosystem effects are understood.

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Table 2. The thirteen Northern Forest Fire Laboratory fuel models and with examples of eastside Sierra Nevada vegetation corresponding to these fire fuel models (Adapted from Anderson, H. 1982. Aids in determining fuel Models For Estimating Fire Behavior. USDA Forest Service, Intermountain Research Station General Technical Report INT-122)

Fuel Model	Description	Common Species	Fire Behavior

#1 Short Grass	Fire spreads by fine herbaceous fuels that have cured; very few trees and shrubs; fuel bed depth 1 foot or less	Cheat grass or dry meadow	Surface fires that can burn very rapidly but are short lived
#2 Timber (grass and understory)	Fire spread is primarily through fine herbaceous fuels. Litter from shrubs or timber overstory contributes to fire intensity; up to two-thirds cover can be timber or shrub	Open yellow pine with grass or shrub understory; some open growth pinyon/juniper stands and often sagebrush stands	Surface fires can spread rapidly; fuels clumps can produce firebrands and uneven burning
#3 Tall Grass (2.5 feet or higher)	Fire spreads in tall stands of grass usually over 3 feet constituting fine fuels	Stands of perennial grasses; possibly bluebunch wheatgrass or great Basin wildrye; cattails and tules when dry in wetlands	Can have high rates of spread under the influence of wind; most intense fires in the grass group
#4 Chaparral (to 6 feet)	Intense fast spreading fires, involving the foliage and live and dead fine woody material in the crowns of a nearly continuous shrub layer; dead woody material and often a deep litter layer contributes significantly to the fire intensity.	Stands of eastside chaparral species or sagebrush and bitterbrush 6 feet or more in height; this fule type is found in the foothills and alluvial fans on the east side of the Sierras; makes up much of the critical urban interface	Very high to extreme rates of spread may be experienced. Control effort may be difficult
#5 Brush (2 feet or less)	Fire generally carried in the surface fuels of litter from shrubs, grasses and forbs; shrubs usually not tall but have high cover	Eastside chaparral and possibly Mountain Mahogany and big sagebrush	Low intensity fires with low fuel loads; shrubs are young with little dead or low volatile materials in the foliage

#6 Intermediate Brush - Hardwood Slash	Brush is taller than in #5, but less height and fuel than #4. Foliage generally flammable although moderate to strong winds may be required to carry fire in the crowns	Chaparral, some big sagebrush and bitterbrush and stands of mountain mahogany; pinyon and juniper woodlands	Fire carries through the shrub layer with moderate winds, but drops to the ground at low wind speeds or openings in the stand
#7 Southern rough	Not found in the eastside Sierra Nevada	Usually burns under conditions of high humidity not often found on the eastside	Fire in other vegetation types may act like #7 under certain conditions.
#8 Closed timber litter	Closed canopy stands of healthy, short-needled conifers that support fire in the compact litter layer of mainly needles, leaves and twigs	Primarily stands of lodgepole pine, white pine, and red fir; also mixed stands of yellow pine and fir	Slow burning surface fires with low flame heights are typical although thickets can cause flareups.
#9 Hardwood Litter	In our area primarily long-needle conifers with faster burning fires with longer flame lengths than for fuel model #8	Stands of yellow pine	Fires run through the surface litter and possibly torch out trees, spot and crown where concentration of dead-down woody materials are encountered.
#10 Timber (litter)	Fire spreads through high loadings of dead and down woody fuels beneath overmature timber stands	Heavy amounts of slash under a good tree overstory; often these may be beetle killed stands; these could be yellow pine or mixed conifer depending upon the amount of slash	Torching of individual trees and spotting is frequent; fire intensity is highest of the timber models;

#11 Light Logging Slash	Slash and herbaceous material carry an active fire; fuel spacing rather than light fuel can contribute to lowering fire potential. The >3-inch material is less that 12 tons/acre. The greater than 3-inch material is represented by not more than 10 pieces, 4-inches in diameter along a 50 foot transect	May be very similar to #10 under pine; but usually references logged areas.	Surface fires of moderate rates of spread and moderate to high intensities can be expected where fuels are continuous.
#12 Medium Logging Slash	Slash loadings where the less than 3-inch material is less than 35 tons/acre; most needles have fallen and the slash is somewhat compact. The greater than 3-inch material is represented by 11 or more pieces, 6 inches in diameter along a 50-foot diameter transect	After logging of mixed conifer or yellow pine; may also include drainage bottom sites of aspen	Rapidly spreading fire with high intensities capable of generating firebrands; when fire starts, it generally sustains itself until a fuel break or change in fuel model occurs
#13 Heavy Logging Slash	Found in avalanche deposition zones and areas that have been recently logged; loading is dominated by greater than 3-inch diameter material. The total load may exceed 200 tons/acre but the 3-inch material is generally 30 percent or less of total load	If found they would be either mixed conifer or yellow pine stands	Fires spread quickly through the fine fuels, but intesity builds up more slowl as thelarger fuels start; active flaming can be sustained for longer periods and spotting can occur

Fig. 2 IRS image of the 7.5" USGS topographical quadrangle named Carson City one of 74 mapped in our study area.

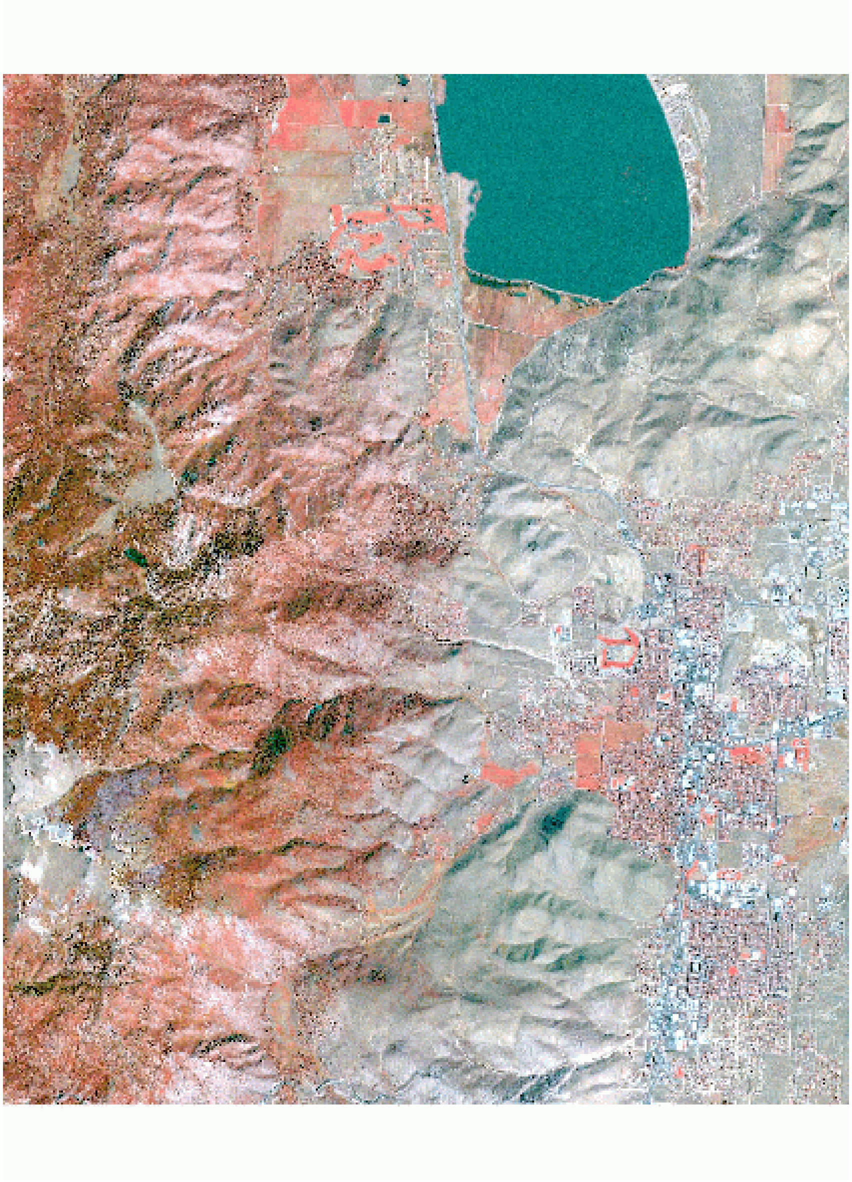

Fig. 3 Vegetation map of the Carson City Quad

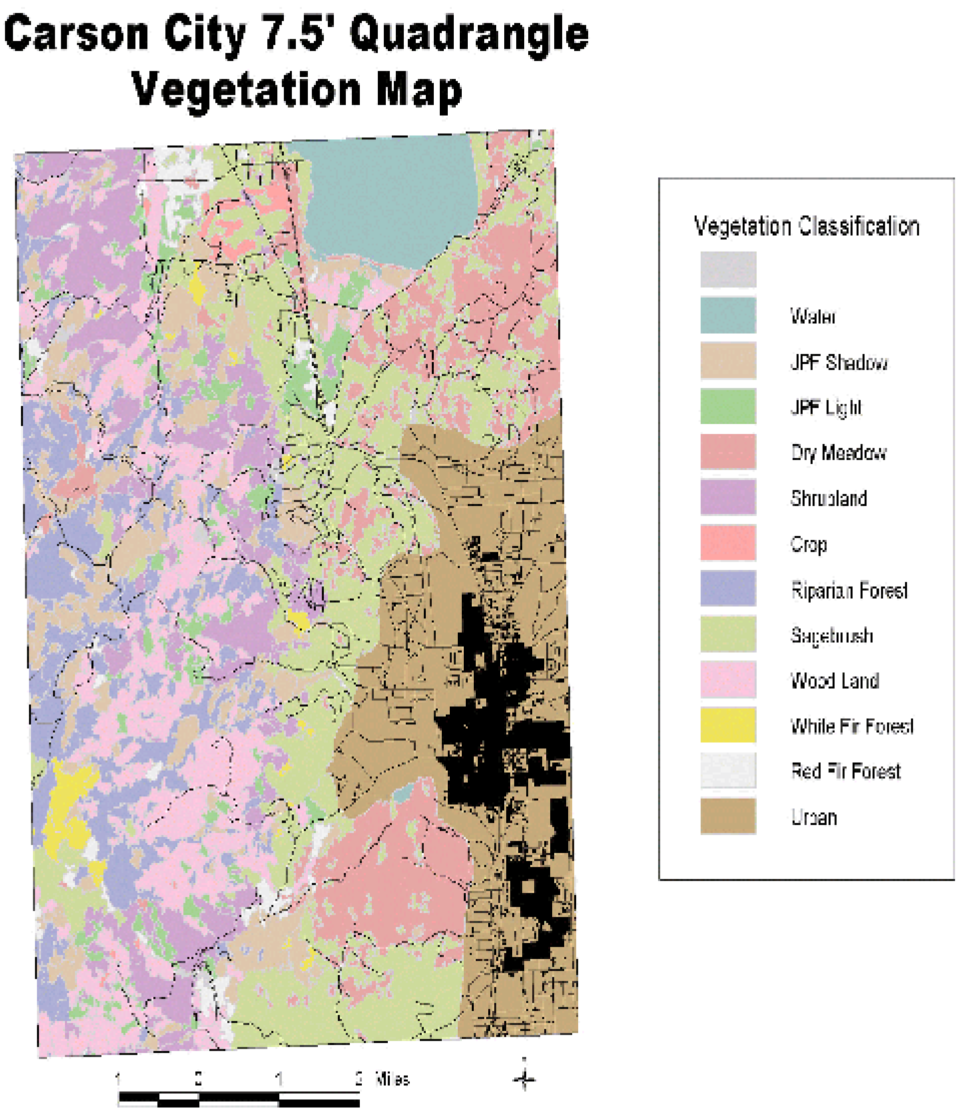

Fig. 4 Fuel Model map of the Carson City Quad

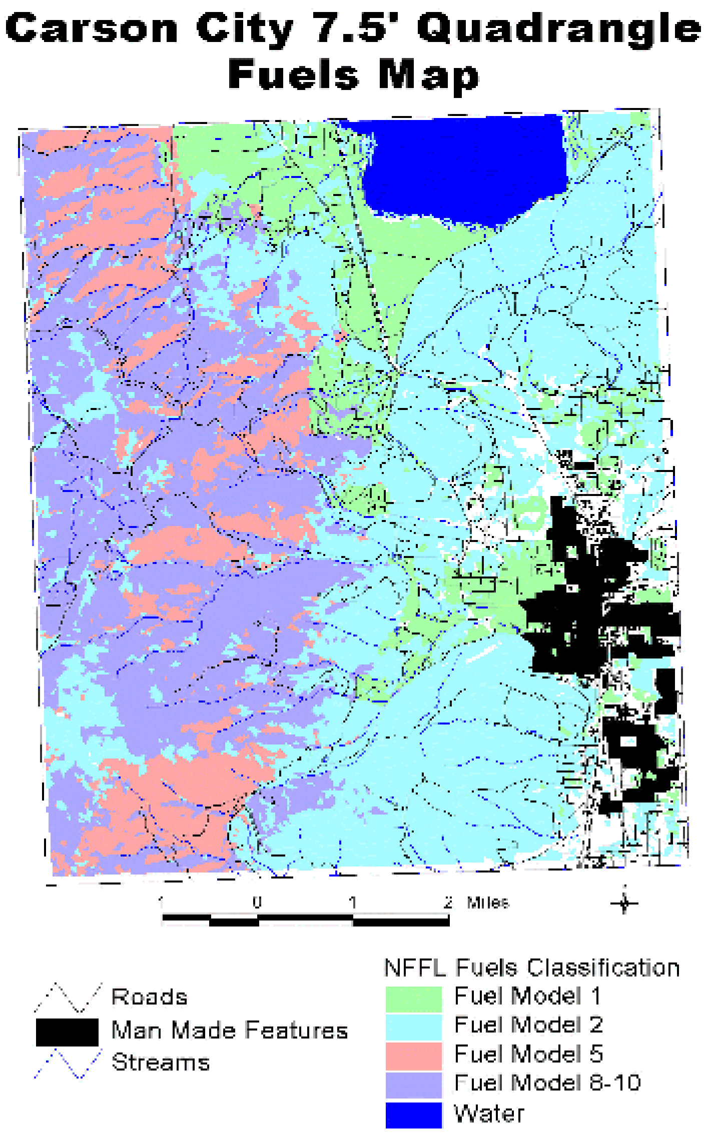

Fig. 5 Fire Hazard map of the Carson City Quad.