USE OF REMOTELY SENSED DATA FOR FIRE DANGER ESTIMATION

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INTRODUCTION

The fire danger rating system currently being used in the United States was developed in 1978 (Deeming and others, 1977) and revised in 1988 (Burgan, 1988). Practical application of the current National Fire Danger Rating System (NFDRS) results in point estimates of fire potential at each of some 1,400 fire weather stations scattered across the United States. Fire danger calculated for the location of each weather station is then assumed to apply to some vaguely defined surrounding area of several thousand hectares. This permits only crude mapping of average fire potential for large geographic areas (Burgan and Hartford, 1988).

The work reported on here is part of a team effort to improve fire danger and fire behaviour technology. The work includes development of improved mathematical fire models, better fuels maps, improved terrain and weather data, and use of spatial analysis and display technology to provide improved fire potential mapping capability.

This paper describes progress on use of Advanced Very High Resolution Radiometer (AVHRR) data from National Oceanic and Atmospheric Administration weather satellites to help assess fire potential at 1 km spatial resolution over large areas, the role of satellite-derived vegetation greenness information in the next generation fire danger/fire behaviour system, and development and use of a high resolution fuels map derived from Thematic Mapper data for fire growth simulation.

Vegetation Greenness Indexes

As living vegetation undergoes seasonal greening and curing, its quantity and moisture content strongly affect fire potential and fire spread. Therefore, the status of living vegetation must be accounted for along with other fire environment factors such as dead fuel moisture and wind speed, when assessing fire potential.

The remote sensing community has used AVHRR data to develop a Normalized Difference Vegetation Index (NDVI) (Goward et al., 1990) that is sensitive to the quantity of actively photosynthesising biomass. AVHRR data have a spatial resolution of about 1 km and are collected daily for the entire conterminous United States. The daily images are composited to reduce the effects of snow, cloudiness, haze, and off-nadir view angles, all of which reduce NDVI values. The composited images are being made available through the U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota.

Because NDVI values for vegetated areas theoretically range from 0 to 1, they are difficult for fire managers to interpret in this "raw" form. Therefore we developed two new indexes that are much more easily interpreted: a Visual Greenness Index (VGI) and a Relative Greenness Index (RGI) (Burgan and Hartford 1993).

Visual Greenness Index

The Visual Greenness Index (VGI) indicates how green each 1 km pixel is in relation to a very green reference such as tropical forest or a lush grassland. Because the maximum NDVI observed for such vegetation is about 0.66, this is the value chosen as a standard reference. Then the VGI is calculated as:

$$VGI = ND_0/0.66*100.$$

where

ND_0 = observed NDVI

Performing this calculation on each pixel produces a map with values ranging from 0 to 100. The interpretation is intuitive in that values near 0 indicate areas having little live vegetation, while values near 100 indicate large amounts of live vegetation. If the resulting image is properly coloured, it portrays vegetation greenness as you would expect to see it if you were flying over the landscape. Normally dry areas will usually appear cured, but normally wet areas will usually appear green. However, this image also has a limitation. Areas that are consistently quite arid or quite wet show little seasonal change in the VGI, so a second measure of vegetative greenness is useful.

Relative Greenness Index

The Relative Greenness Index (RGI) indicates how green each pixel is in relation to the historical range of NDVI observations since January 1, 1989. It is calculated for each pixel as:

$$RGI = (ND_o - ND_{mn})/(ND_{mx} - ND_{mn}) * 100.$$

where

ND_o = observed NDVI value

ND_{mn} = minimum NDVI value

ND_{mx} = maximum NDVI value

This equation implies existence of maximum and minimum NDVI maps as well as a map for the current composite period. The maximum and minimum maps were prepared by retaining only the maximum (or minimum) NDVI value observed for each pixel for all images, from 1989 to the present.

The RGI map calculation results in values ranging from 0 (cured) to 100 (as green as it gets). The interpretation is that green- appearing areas are at or near their historical maximum greenness, while cured-appearing areas are near their minimum greenness. When you look at an RGI map and a VGI map together, you can see, for example, that while a normally dry area may appear cured in the VGI map, it may appear very green in the RGI map. The interpretation is that the area is sparsely vegetated, but even so it is about as green as it can be expected to get. Conversely, a normally wet area may look quite green in a VGI map, but very dry in an RGI map. In this case there is a relatively large amount of green vegetation, but not nearly as much as the site is capable of producing. When both maps show a cured condition, fire potential may be high, depending on current weather conditions. Plate 1 illustrates the difference in the way the two maps portray vegetation greenness for a portion of the Western United States.

Figure 1 shows the difference between the visual and relative greenness calculations. The left vertical bar, labelled "Raw NDVI Scale," represents the maximum realistic NDVI range (0.00 to 0.66) that will be encountered in any vegetation type. The next vertical bar to the right, labelled "Visual Greenness Scale," is the NDVI range converted to a percentage scale.

The next two vertical bars to the right represent the relative greenness concept. Two examples are given, one labelled "Dry Site" and one "Wet Site." The historical dry site NDVI data range is 0.05 to 0.30, while the wet site ranges from 0.20 to 0.60. An example current NDVI value of 0.25 produces a VGI of 38 percent: 0.25/0.66*100. This indicates only a modest amount of green vegetation. If this pixel were the dry site example, then the RGI would be 80 percent: (0.25 - 0.05)/(0.30 - 0.05) * 100. That is, while the area represented by the pixel has modest green vegetative cover, it is getting close to as green as can be expected. But if the example pixel occurred on a normally wet site having an NDVI range from 0.20 to 0.60, then the RGI value would be about 12 percent: (0.25 - 0.20)/(0.60 - 0.20) * 100. This indicates a potential for much additional green vegetation.

Updated Visual and Relative Greenness Index maps of the United States are made available weekly through the U.S. Department of Agriculture's Weather Information Management System (WIMS). Because data files for maps of the entire United States are large (about 13 megabytes), the country has been divided into 42 subregions so fire managers can access data for just their area of interest. The images can be displayed on a personal computer using the Image Display and Analysis program (Pfirman, 1991). Because it is inevitable that it will be necessary to view greenness across subregion boundaries, provisions have been made to easily display one, two, three, or four subregions at a time. Line data such as state, county, or forest boundaries, and streams, can be overlaid on the greenness images.

Broad Scale Vegetation/Fuels Map

While NDVI data can be used to monitor seasonal changes in vegetation greenness, it can also be used to map vegetation patterns. The EROS Data Center has used a time series of 1990 NDVI data to produce a vegetation map of the conterminous United States (Loveland and others, 1991). The basis for this map is that different vegetation types produce different seasonal NDVI profiles. Thus, a series of eight monthly NDVI composites were analysed through a clustering algorithm to produce a 70 class map. Visual inspection of this map indicated the need for additional classes, that were derived by consulting ancillary data sources to guide lumping and splitting

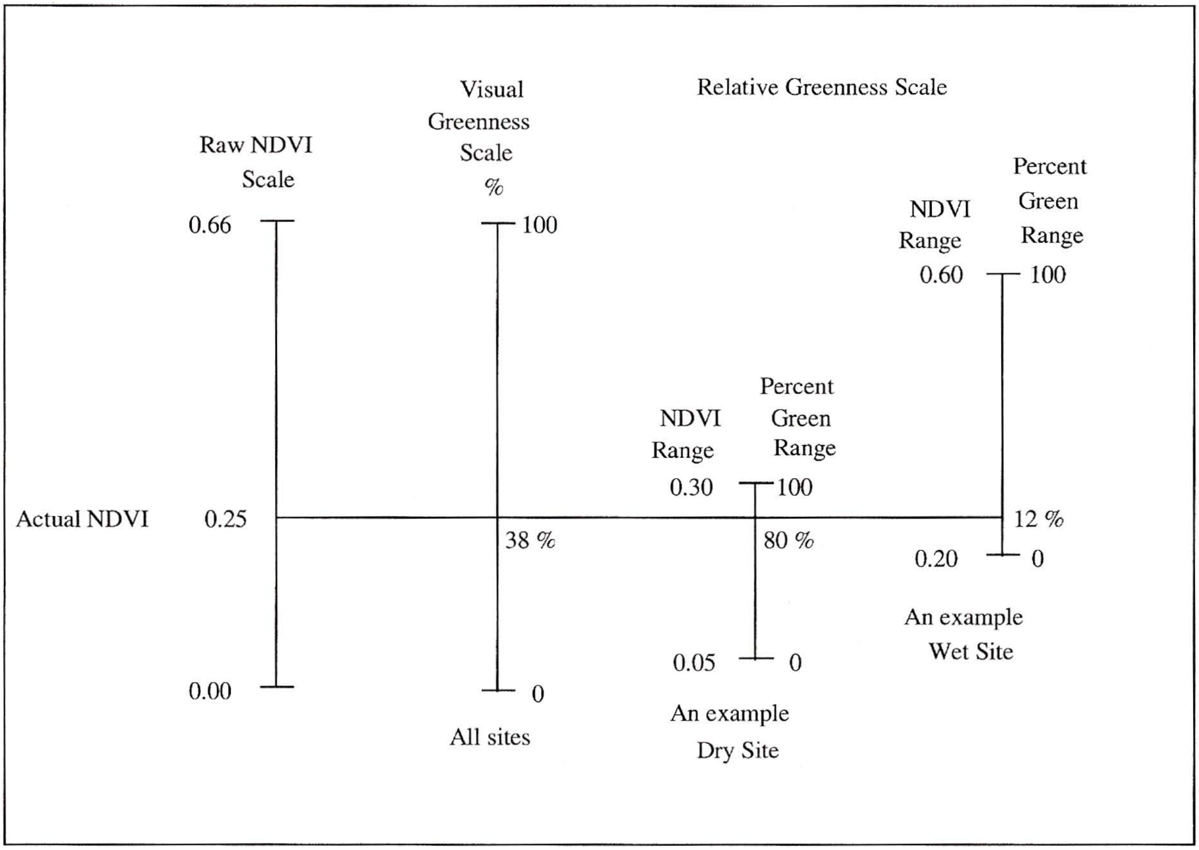

Figure 1 - Visual greenness values are referenced to a common base. Relative greenness values depend on the historial NDVI range of each pixel

of the original 70 class map into a final 159 class map. This land cover map provides the basis for creation of a national 1 km resolution fire danger rating fuels map.

Although a national fuels map has not yet been developed, a map consisting of five fuel models was prepared for Oklahoma. The map was prepared through consultation with fire managers and ecologists in Oklahoma to reclassify the 159 class vegetation map into a fuel model map that represents the major vegetation types of the state (Plate 2). The reclassification was accomplished by grouping the 69 vegetation classes defined for Oklahoma into five broad types, and assigning a fire danger fuel model to each.

Use Of Greenness In Rating Fire Danger

Estimating Live Fuel Moisture and Load

The greenness indexes provide useful assessments of which areas have flammable vegetation, but they would be more useful if they could be directly incorporated into a fire danger rating computer program. It appears this is the case for the RGI, which can be used to provide estimates of live fuel moisture and quantity. Because a large variation exists in live vegetation moisture and quantity across the landscape, it is not reasonable to track it in detail. All that is required for fire danger purposes is to obtain reasonable estimates.

Two additional pieces of information are required to estimate live vegetation moisture and quantity as a function of the RGI: (1) an estimate of the maximum and minimum moistures for major fuel types and (2) an estimate of the maximum quantity of live vegetation by fuel type. In the United States, fuel types are represented by "fuel models" that are a set of numbers describing various fuel bed properties such as quantity of live and dead vegetation by size class, fuel bed depth, fuel particle size, etc. A set of 20 fuel models is used to represent major fuel types of the United States for the current fire danger rating system. These fuel models already have defined loads for live herbaceous and shrub vegetation, thus providing the required input of live vegetation quantity.

Live fuel moisture ranges must be defined by fuel model for both live herbaceous and live shrubby vegetation. This effort is not yet complete. In the meantime, a first approximation is that live herbaceous vegetation moisture ranges from 30 to 230 percent of dry weight. The first approximation for live shrubby moisture ranges is derived as a function of four climate classes, with shrub moisture ranges of 60 to 210 percent for the driest climate class, and from 90 to 240 percent for the wettest climate.

Live fuel moisture is then calculated for each 1 km pixel as a function of the Relative Greenness value for that pixel, such that when the RGI is 0 the live moisture is at a minimum, and when the RGI is 100, the live moisture is at a maximum, with a straight-line interpolation of intermediate values.

The proportion of the live herbaceous and live shrub load that is assigned to the live and dead fuel categories is also a straight-line function. When the RGI is 0, all the live fuel load may be assigned to the dead fuel category, and when the RGI is 100 all of the live load is assigned to the live fuel category. Shrubby vegetation is defined as either deciduous or evergreen to prevent load transfer for evergreen shrubs.

This procedure greatly simplifies the current method for calculating live fuel loads and moisture as a function of 1,000- hour timelag dead fuel (about 6.6 to 20.3 cm in diameter). The computer code is reduced from about three pages to a half page.

Calculating a Fire Danger Map

The primary inputs to a mathematical model for calculating fire danger are fuels, weather, and topography. A high resolution weather network is rare, but one is being operated for the state of Oklahoma by the University of Oklahoma (Crawford, 1993). Cooperative work is under way with the university to use weather observations from their mesonet to calculate fire danger for the state. We have selected one weather station in each county to represent the weather for that county (Plate 2). We have verified the topography in Oklahoma is flat enough that all slopes are of class 1 in the fire danger rating system, so the effect of topography is ignored for this exercise. Definition and geographic distribution of fuels are represented by a fuel model map derived from the EROS produced land cover class map (Plate 2).

The process of calculating fire danger maps is done on a pixel by pixel basis. First weather data from the mesonet stations are used to calculate all the dead fuel moistures (1, 10, 100, and 1,000 hour) associated with each weather station. These moistures are saved in a separate data file. Three input map layers are then referenced for the fire danger calculations

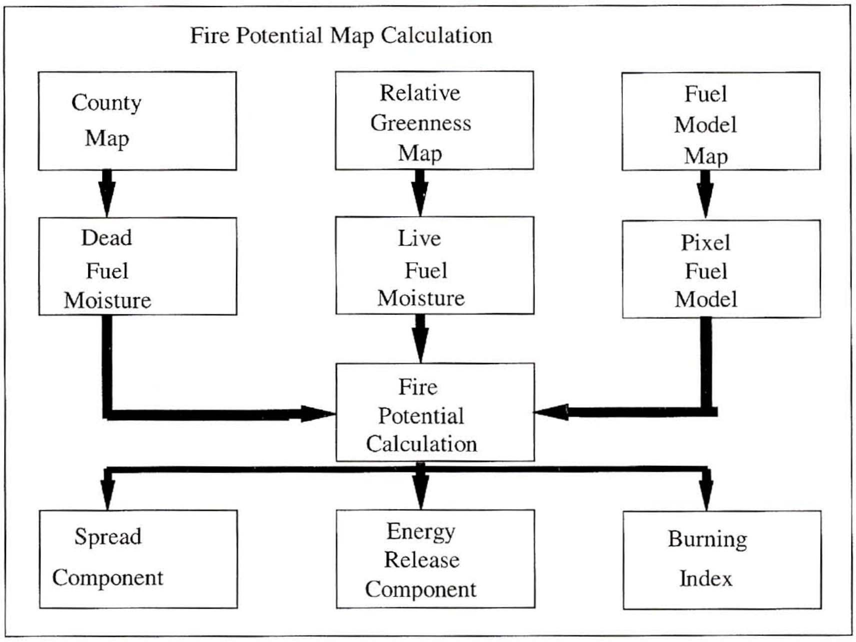

Figure 2 - Input and output fire danger map layers

(Figure 2): (1) a map that identifies the county each pixel is in, (2) a Relative Greenness map for calculating live fuel moistures, and (3) a fuel model map consisting of a fuel model number for each pixel. For each pixel, the county map layer is used to determine the weather station representing that pixel (to access dead fuel moistures), the fuels map layer is used to identify the fuel model, and the Relative Greenness map layer is used to calculate live fuel moisture as described above. The rest of the calculations proceed as in the current fire danger rating system. However, rather than the outputs being a table of fire danger indexes printed on paper for individual weather stations, they are multicoloured maps of fire danger (spread component) at 1 km resolution for the state (Plate 3).

While this process works for Oklahoma, extending the process to mountainous terrain will require additional research. Methods are under development to adjust temperature, relative humidity, and fuel moistures for the effects of slope, elevation, and aspect.

High Resolution Vegetation/Fuels Map

Although low resolution (1 km) fuel maps derived from AVHRR data are ideal for general fire danger estimates across broad areas, high resolution fuel maps are required for modelling the growth and intensity of specific fires. The Thematic Mapper (TM) provides the necessary data with its 30 m resolution.

We selected Yosemite National Park in California for development of a high resolution fuels map for three reasons: (1) the TM data had been purchased for a prior research effort, (2) the National Park Service had already established a large number of "monitoring" plots that could be used for ground truth, and (3) a fuels map that was manually interpreted from TM data was already in existence (Steve Botti, personal communication) and could serve as a basis for comparison with a new map derived from spectral classification.

The process of deriving the spectral classification began with merging TM bands 3, 4, 5, and 7 for an entire TM scene, (dated July 29, 1992) into a single four-band image, then extracting the Yosemite Park area. The existing manually derived fuels map was also registered so that it would overlay the four-band TM scene. This was done because the existing map accurately defined the location of water within the park, and this "water mask" could be applied to the newly derived fuels map.

The Land Analysis System (LAS) was used to calculate NDVI from TM bands 3 and 4, and the water mask was added to the resultant image. Rocky outcrops provided another challenge. Yosemite National Park has many large rocky outcrops that were easily identified by thresholding TM band 5 to identify pixels with values ranging from 125 to 250. Because rock/vegetation mixtures can cause much confusion in the classification algorithms, the areas thus identified as rock were assigned a single value so they would come out of the classification as a specific class. Then the LAS "isoclass" function was run using the NDVI image and TM band 5 to create a 36 class vegetation map. There were 28 vegetation classes in the manually derived map, so the isoclass function was set up to produce a similar number of classes for the new map. Finally, Yosemite Park personnel assigned vegetation names and fire behaviour fuel models to produce the final fuel model map (Plate 4)

The final map provided fuels information for the FARSITE fire simulation program (Finney and Andrews, 1994). FARSITE is a PC-based fire growth model that spatially projects fire perimeters and behaviour over complex landscapes.

A unique opportunity to test the usefulness of the newly derived fuel model map occurred in summer 1994. A natural prescribed fire (Horizon Fire) occurred within the 1,500 to 2,500 m elevation range in the mountains south of Yosemite Valley. Manzanita chaparral (*Arctostaphyllos manzanita*), Jeffery pine (*Pinus Jeffreyii*), red fir (*Abies magnifica*), white fir (*Abies concolor*), and lodgepole pine (*Pinus contorta*) were the primary vegetation types. Finney and Andrews report that fire growth and behaviour was simulated to a useful degree of accuracy and that the new fuels map was an important contributor to this accuracy. Comparative simulations run with the older fuels map that was manually interpreted from TM data were less accurate (Mark Finney, personal communication).

CONCLUSION

Field testing has shown that vegetation greenness maps are useful in themselves for assessing fire potential across large landscapes. These maps can be updated weekly and made available to fire managers at the local level.

In addition, even though simplifications were used to produce a fire danger map of Oklahoma, the process is complete enough to prove that satellite-derived vegetation greenness indexes can be incorporated directly in fire danger calculations to provide improved portrayal of fire danger across broad landscapes. Additional work needs to be done to refine the process and extend it to the conterminous United States.

Accurate high resolution (30 m) fuels maps are required for useful simulations of individual fires. Such maps can be derived from classification of Thematic Mapper data, followed by field checking and assignment of fire behaviour fuel models to the satellite-derived vegetation classes.

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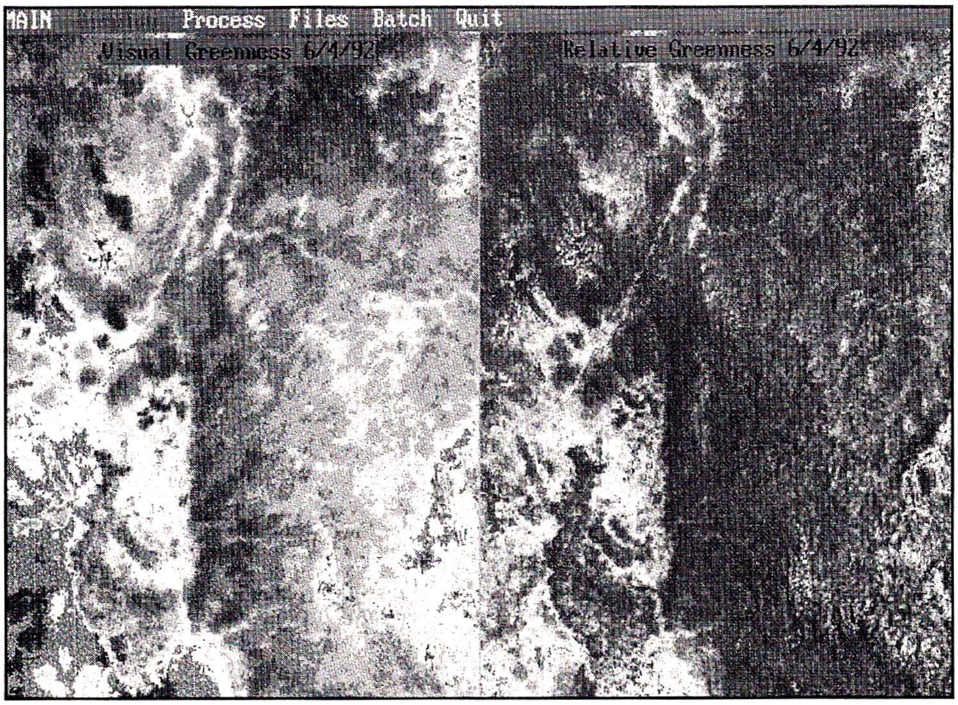

Figure 1 - Areas that look dry in the visual in the Visual Greenness map (left) are shown to be near their maximum greenness in the Relative Greenness map (right)

See plate I at end of volume

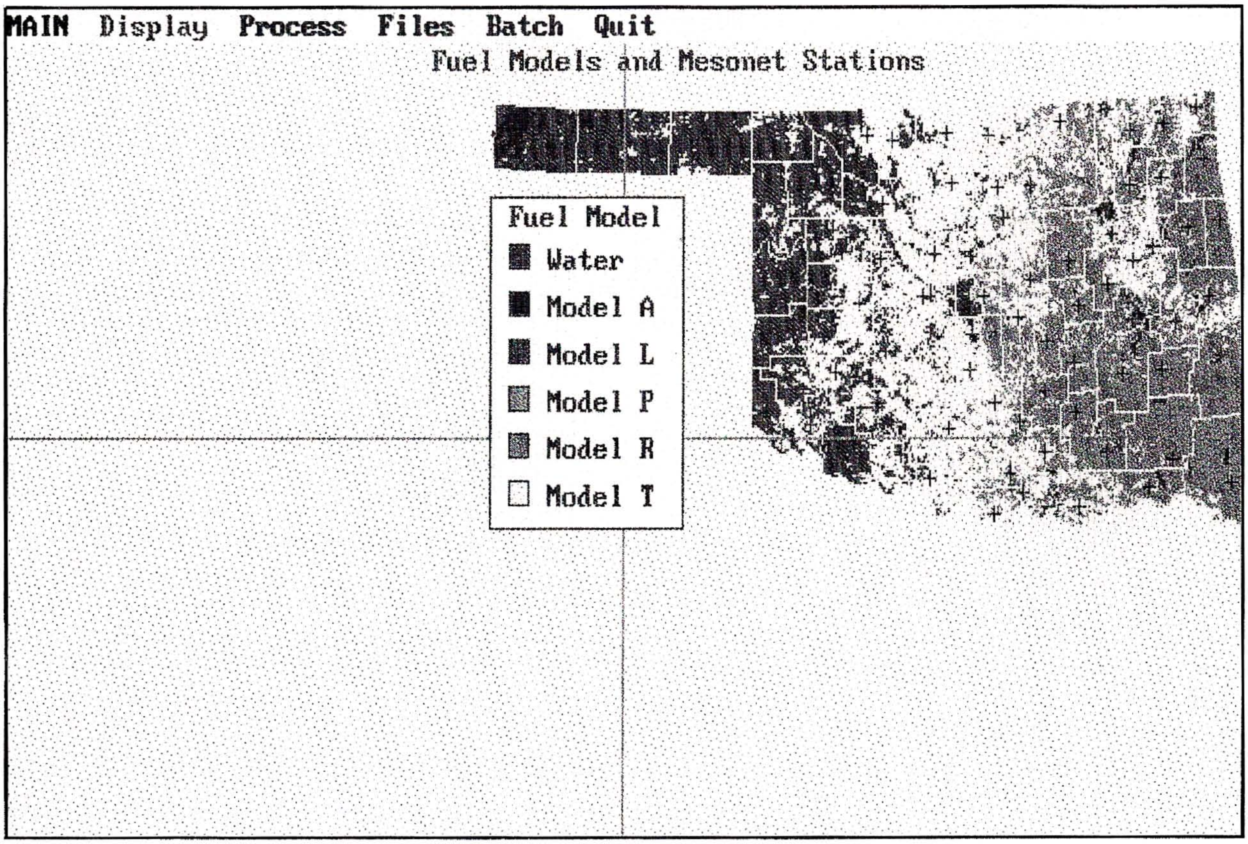

Figure 2 - Fire danger fuel model map and weather station network for Oklahoma

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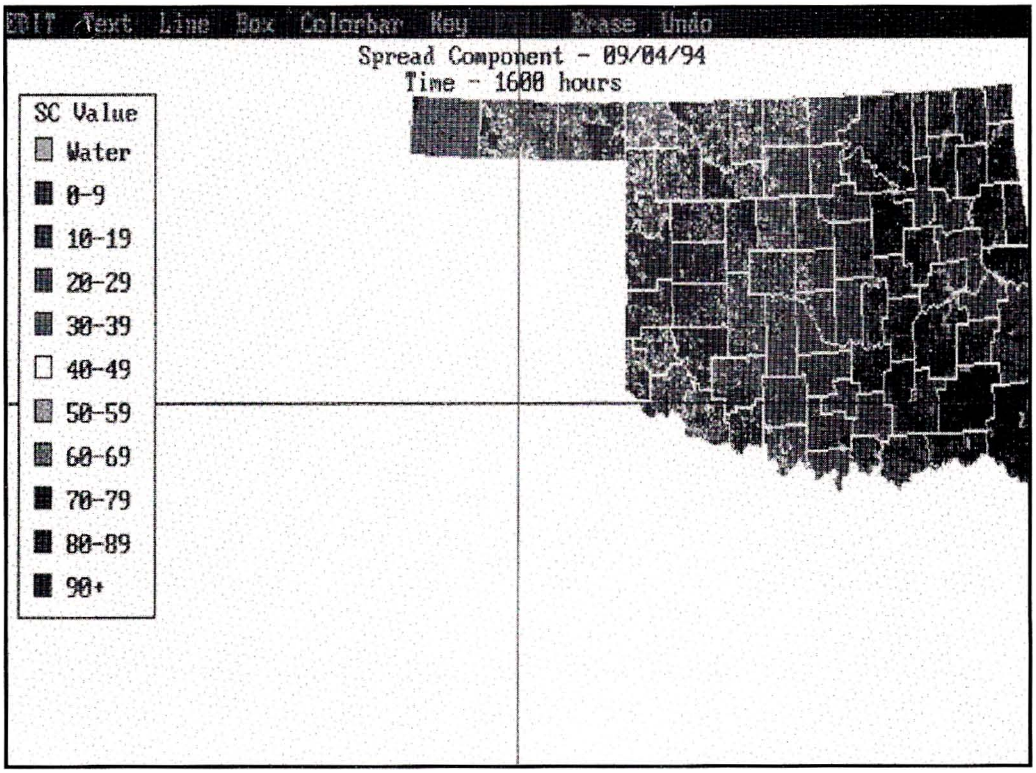

Figure 3 - Spread component is presented as an example fire danger map

See plate II at end of volume

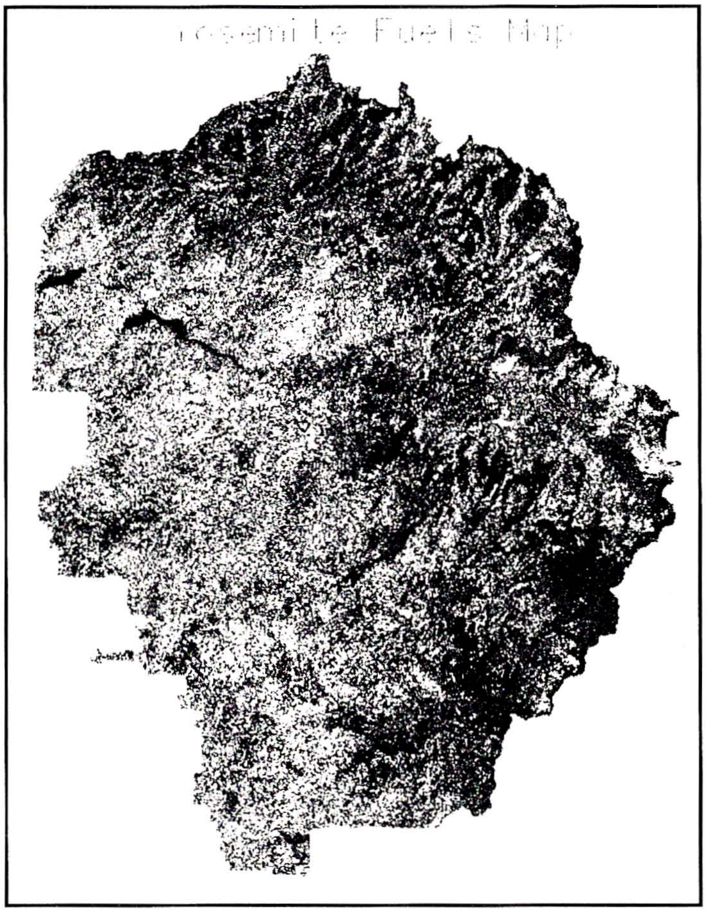

Figure 4 - Fuels map for Yosemite National Park

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