FIRE PROTECTION PLAN

For

Trails at Aspen Ridge
Filing No. 4

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EXISTING CONDITIONS

General Location

Trails at Aspen Ridge Filing No. 4 consists of 124 single family lots on 17.90-acres. The site lies in Section 9 of Township 15 South, Range 65 West. The proposed development is south of Bradley Rd, east of Powers Boulevard.

Land Use

The property was recently rezoned from RS-5000 to PUD and will remain as PUD to allow for a variety of lot sizes.

Topography and Floodplains

The topography of the site and surrounding area is typical of a high desert; short prairie grass and weeds with slopes generally ranging from 1% to 9%. The area generally drains to the south and east with a smaller portion draining west.

All of the flow from the development will be conveyed to two new proposed detention ponds on the west and southeast portions of the proposed development.

The Flood Insurance Rate Map indicates that there is no floodplain adjacent to or on the site.

Geology

The site is comprised of several different soil types. From the Soil Survey of El Paso County, the site falls into the following soil types:

1. "8" Blakeland loamy sand, 1 to 9 percent slopes; Type A Soil

2. "52" Manzanst clay loam, 3 to 8 percent slopes; Type C Soil

3. "56" Nelson Tassel fine sandy loam, 3 to 19 percent slopes; Type B and D Soil

4. "86" Stoneham sandy loam, 3 to 8 percent slopes; Type B Soil

5. "108" Wiley silt loam, 3 to 9 percent slopes; Type B Soil

Note: "#" indicates Soil Conservation Survey soil classification number.

Climate

Mild summers and winter, light precipitation; high evaporation and moderately high wind velocities characterize the climate of the study area.

The average annual monthly temperature is 48.4 F with an average monthly low of 30.3 F in the winter and an average monthly high of 68.1 F in the summer. Two years in ten will have a maximum temperature higher than 98 F and a minimum temperature lower than –16 F. Precipitation averages 15.73 inches annually, with 80% of this occurring during the months of April through September. The average annual Class A pan evaporation is 45 inches.

FIRE PROTECTION

Fire protection is provided by the Security Fire Protection District. The proposed development is located within the Widefield Water and Sanitation District service area. The Widefield Water and Sanitation District operates a central water system to meet domestic demand as well as fire demand. Fire hydrants will be placed to ensure proper coverage and locations for access by fire trucks. With this water system the Security Fire Protection District operates with an ISO Rating of 4. All roadways to the development will meet criteria to ensure fire trucks are not hindered in reaching any portion of the site (slopes of road are less than 10%, width of road is adequate for trucks, etc.). Street signs will be clearly visible as well as address markers on all buildings, per appropriate codes. The proposed development will conform to the requirements of the Security Fire Protection District Code; 2003 ISC Fire Code including Local Amendments. Trails at Aspen Ridge will be served by the Security Protection District as outlined in the Court Order annexing the entire Waterview East into the Security Fire Protection District.

GENERAL FIRE DEPARTMENT INFORMATION

The Trails at Aspen Ridge is located within the Security Fire Protection District. The proposed development is 1.9 miles from the nearest fire station.

The average response time including dispatch, turn out and travel for the first arriving engine company is 5 minutes. At this time, the average response time within the District is 4 to 5 minutes.

The District's average response time includes assignment per NFPA standards consisting of two engines, one ladder and one incident commander.

The Security Fire Protection District has assets to equip the three current fire stations including the following:

- 5 Fire Engines
- 1 Ladder Truck
- 1 Brush Truck
- 1 Utility Truck
- 1 Chief Vehicle
- 2 Ambulance Vehicles equipped with ALS (Advanced Life Support)

There are no plans for any additional equipment purchases at this time.

Security Fire Protection District consists of 15 career firefighters on shifts 24/7 and 35 volunteer firefighters. These firefighters respond from three 24/7 staffed stations.

WILDFIRE HAZARDS ANALYSIS

From the included NFDR fuel model, it is estimated that the proposed site falls within the "L" and "T" models, which represent western perennial grass and sagebrush-grass mixture,

respectively. (See Appendix A) Fire can spread relatively quickly through grasses, due to large exposed surface areas. Low intensity fires can burn out quickly. Effects of wind on a grass fire are significant, resulting in fast rates of spreading.

In order to determine the potential fire hazard at a particular time, there are several considerations. The essay included in Appendix A, "Fuel Models and Fire Potential from Satellite and Surface Observations," by Robert Burgan, Robert Klaver and Jacqueline Klaver describes the procedure to determine relative wildland fire-danger at a particular time, and where up-to-date information is available. For example, as the Experimental Fire Potential Index shows for October 4, 2006, the observed fire potential is roughly in the 20% for the area and the forecasted fire potential is approximately 30%. The fire danger map shows a "moderate" danger, along with the forecasted danger also in the "moderate" range. In general, this area is going to be subject to more fire hazards potential during summer months and drought years.

As development has been occurring in this area, wildfire potential has decreased with urbanization and removal of "prairie" type lands. However, homes and other structures could be potential fuel for any fire which may start. The structure owners will need to address their own fire hazard issues, but protection measures such as maintaining minimum distances from roofs to low-lying limbs and using fire retardant landscaping are recommended. Due to high erosion possibilities in this area, measures should be taken to avoid or minimize barren areas and the destruction of vegetation.

This development will be part of a central water system. Hydrants will be located on-site to provide an adequate minimum 500-foot radius, which will ensure proper coverage for proposed buildings. The location of the hydrants will be coordinated with the Security Fire Protection District.

Although precautions may be taken to prevent the spread of possible fires, there is always the chance of accident, carelessness or lightning causing a fire. When vegetation is dry and winds are strong, fire potential is at its highest.

APPENDIX A: Fuel Model and Fire Potential Essay and Maps

Fuel Models and Fire Potential from Satellite and Surface Observations

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Abstract

A national 1-km resolution fire danger fuel model map was derived through use of previously mapped land cover classes and Eco regions, and extensive ground sample data, then refined through review by fire managers familiar with various portions of the U.S. The fuel model map will be used in the next generation fire danger rating system for the U.S., but it also made possible immediate development of a satellite and ground based fire potential index map. The inputs and algorithm of the fire potential index are presented, along with a case study of the correlation between the fire potential index and fire occurrence in California and Nevada. Application of the fire potential index in the Mediterranean ecosystems of Spain, Chile, and Mexico will be tested.

Keywords

Fire potential; Fire danger; Fuels; Fire model; Satellite data

Introduction

The need for a method to rate wildland fire-danger was recognized at least as far back as 1940, in fire control conferences called by the Forest Service, U.S. Department of Agriculture, in Ogden, Utah. By 1954 several fire-danger rating systems were in use across the United States. In 1958 John Keetch, Washington Office, Aviation and Fire Management, headed a team to develop a national system. By 1964 most fire control organizations in the United States were using a "spread index" system. In 1968 another research effort was established in Fort Collins, Colorado to develop an analytical system based on the physics of moisture exchange, heat transfer and other known aspects of the problem (Bradshaw et al. 1983). The resulting fire spread model (Rothermel 1972) was used in the first truly National Fire Danger Rating System (NFDRS), introduced in 1972 (Deeming et al. 1972, revised in 1974). This system has since been revised twice, in 1978 (Deeming et al. 1977) and in 1988 (Burgan 1988).

Decisions fire managers must make depend on the temporal and spatial scales involved as well as management objectives. Presuppression decisions are often aimed at allocation of firefighting funds, personnel, and equipment. Such decisions usually have a large spatial context, encompassing millions of hectares, and a time scale of 1 to 3 days. Once a fire occurs

initial attack and suppression decisions are directed at attaining cost-effective management of the fire. This may include a decision to not suppress the fire if it is burning within predefined constraints. These decisions have a spatial scale of a few thousand hectares and a temporal scale of 24 hours or less. Once a decision has been made to extinguish a fire, decisions are required on a spatial scale of several hundred hectares or less and a temporal scale of a few minutes to a few hours. The attitude toward wildland fire in the United States is changing from that of simply extinguishment to realization that fire must play a role in maintaining forest health, thus the need for prescribed fires is being recognized (Mutch 1994). Methods to assess fire potential both strategically and tactically must also evolve.

Assessment of fire potential at any scale requires basically the same information about the fuels, topography, and weather conditions that combine to produce the potential fire environment. These factors have traditionally been measured for specific sites, with the resulting fire potential estimates produced as alpha-numeric text, and the results applied to vaguely defined geographic areas and temporal periods, with the knowledge that the further one is displaced (in time or space) from the point where such measurements have been taken, the less applicable the fire potential estimate is. This situation is rapidly changing because Geographic Information Systems (GIS) and space-borne observations are greatly improving the capability to assess fire potential at much finer spatial and temporal resolution.

Recent improvements to fire potential assessment technology include both broad scale fire-danger maps and local scale fire behavior simulations. In the context of local scale fire behavior, FARSITE (Finney 1994) and BEHAVE (Burgan and Rothermel 1984, Andrews 1986, Andrews and Chase 1989), provide methods to simulate fire behavior for areas up to several thousand hectares. In the broad area fire danger context, spot measurements of fire danger, calculated using the NFDRS at specific weather stations, are being interpolated and mapped on a national basis (Figure 1) through the Wildland Fire Assessment System (Burgan et al. 1997) (*http://www.fs.fed.us/land/wfas/welcome.html*).

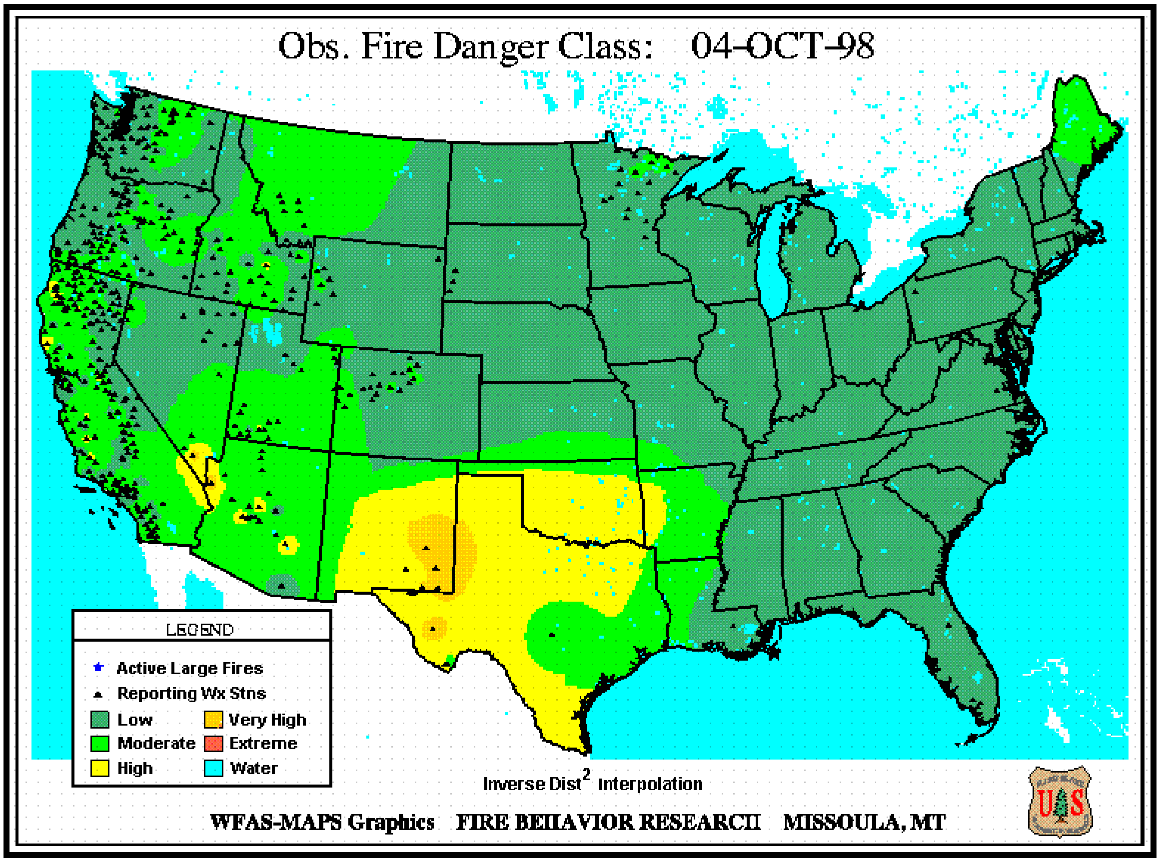

Figure 1. National Fire Danger Rating System indexes are calculated for each weather station, then the indicated staffing levels are interpolated and mapped on a national basis (*http://www.fs.fed.us/land/wfas/fd_class.gif*)

The Canadians publish similar maps for their fire danger system on the internet (*http://www.nofc.forestry.ca/fire/cwfis*) (Lee 1995) (Stocks et al. 1989). The U.S. maps are produced using an inverse distance squared weighting of staffing levels. Staffing level defines the readiness status of the suppression organization. It is based on comparison of current fire danger index values with historical values. The staffing (or readiness) level increases as the current index approaches historically high values. Because fire managers across the United States have not been consistent in their selection of an NFDR index on which to base staffing levels, staffing level itself is the only common parameter with which to map fire danger. Staffing level normalizes all indexes against their historical values so it does not matter which of the several fire danger indexes a fire manager selected. However this method neither addresses the effect of topography on fire potential, nor provides fire potential estimates for specific locations or landscape resolutions.

An operational process that does provide 1 km^2 landscape resolution is the Oklahoma Fire Danger Rating System (Carlson et al. 1996) (*http://radar.metr.ou.edu/agwx/fire/intro.html*), although it still does not recognize the effect of topography. The Oklahoma Fire Danger Rating System represents the direction of future fire-danger systems research for the United States, but the intensive weather network it relies upon could make this type of system difficult for others to apply.

A wildland fuel map, terrain data, and a reasonable sampling of weather are inputs to most fire danger systems. This paper discusses development of a national 1 km^2 fuel model map for the United States and describes a Fire Potential Index (FPI) model that can be used to assess fire hazard at 1 km^2 resolution.

The NFDR Fuel Model Map

Traditionally 1 to 4 fire danger fuel models (Deeming et al. 1977) have been assigned to each fire weather station. These fuel models represent the most common or most hazardous vegetation types occurring in the vicinity of the weather station. The exact geographic location represented by each fuel model has not been well defined. Progress in assessing fire potential across the landscape obviously requires much better fuels information.

In 1991, the U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota, prepared a 159 class, 1 km^2 resolution, land cover characteristics database (Loveland et al. 1991) that portrayed vegetation patterns across the conterminous United States. The initial vegetation map was produced by unsupervised clustering of eight monthly composites of Normalized Difference Vegetation Index (NDVI) (Goward et al. 1990) data for 1990. A post classification refinement was accomplished through use of several ancillary data layers, however ground truth data was not used. It was obvious this map could provide the basis for a national fire danger fuel model map for the next generation National Fire Danger Rating System. However, because the vegetation map was designed to satisfy a wide range of applications, it was necessary to obtain ground sample data specifically for the purpose of developing an NFDRS fuel model map.

The first author and Colin Hardy of the Intermountain Fire Sciences Laboratory collaborated with the EROS Data Center to collect ground sample data for numerous locations across the U.S. Help was enlisted from numerous federal and state land management agencies to collect the ground data. (Burgan et al.1999). A total of 3500 1 km^2 ground sample plots were located on seven hundred 7½ minute USGS quadrangle maps (1:24000) (Figure 2).

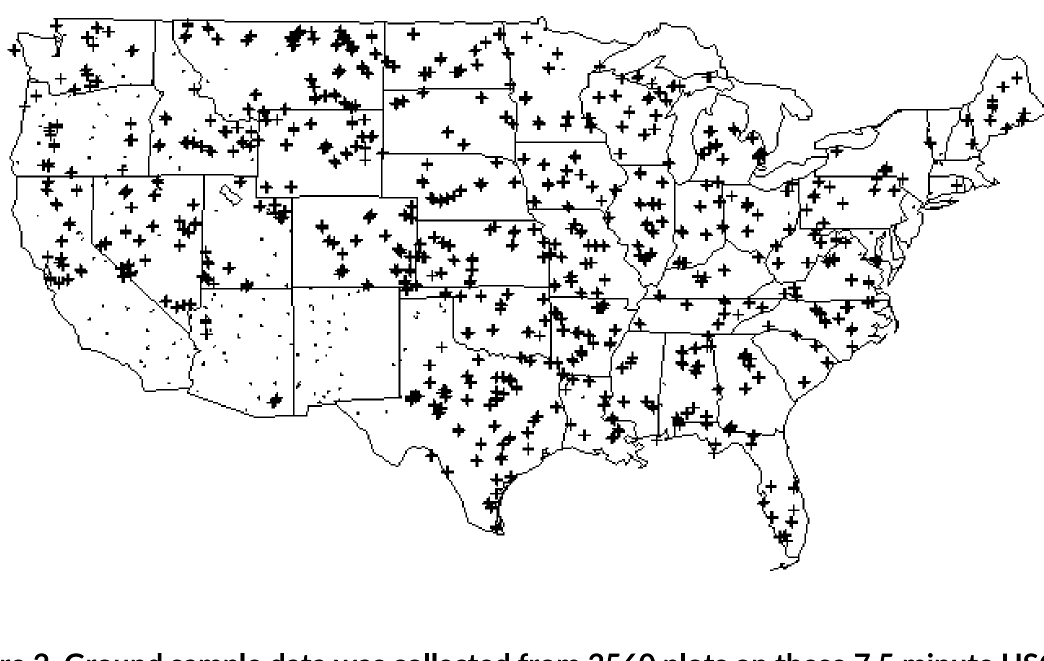

Figure 2. Ground sample data was collected from 2560 plots on these 7.5 minute USGS quadrangle maps. There were up to 5 plots per quadrangle map.

Data was obtained from 2560 of these plots. Percent cover, height, and diameter data were recorded on the four major tree and shrub species, and percent cover and depth were recorded for subshrubs, forbs, mosses and grass. Shrub and grass morphology and density classes were also recorded. Up to four 35 mm slides were taken for many of the plots. All data were entered into a database for analysis, and the slides and graphical analysis summaries were recorded on a CDROM and are available for viewing with a standard browser (Burgan et al. 1997).

Because a major objective of the ground sampling was to relate fire danger fuel models to the EROS Land Cover Classes, a fuel model assignment was required for each plot. The fuel model assignments were not made in the field however, because it was felt the diversity of people involved would produce large inconsistencies in making these assignments. Instead, one knowledgeable person was asked to review the data sheets and plot photographs to make the fuel model assignments, which were then added to the database. The Land Cover Characteristics Database also contained a map of Omernick Eco-regions (Figure 3) of the conterminous U.S. (Omernick 1987), so the eco-region for each plot was also recorded. With this data, a frequency count of fuel model by Omernick Eco-region and Land Cover Class was obtained through a contract with Statistical Sciences Incorporated, 1700 Westlake Ave. N., Seattle, WA 98109. The purpose of including eco-region data was to permit regionalizing fuel model assignments. The fuel model/eco-region/landcover associations were manually inspected and entered into a computer program that produced a 1 km^2 resolution fuel model map for the conterminous U.S. The program built the NFDR fuel model map by using the eco-region and landcover class values read from separate binary data files. With these inputs a table lookup method was used to determine the fuel model assignment for each 1 km square pixel. This became the "first draft" NFDR fuel model map.

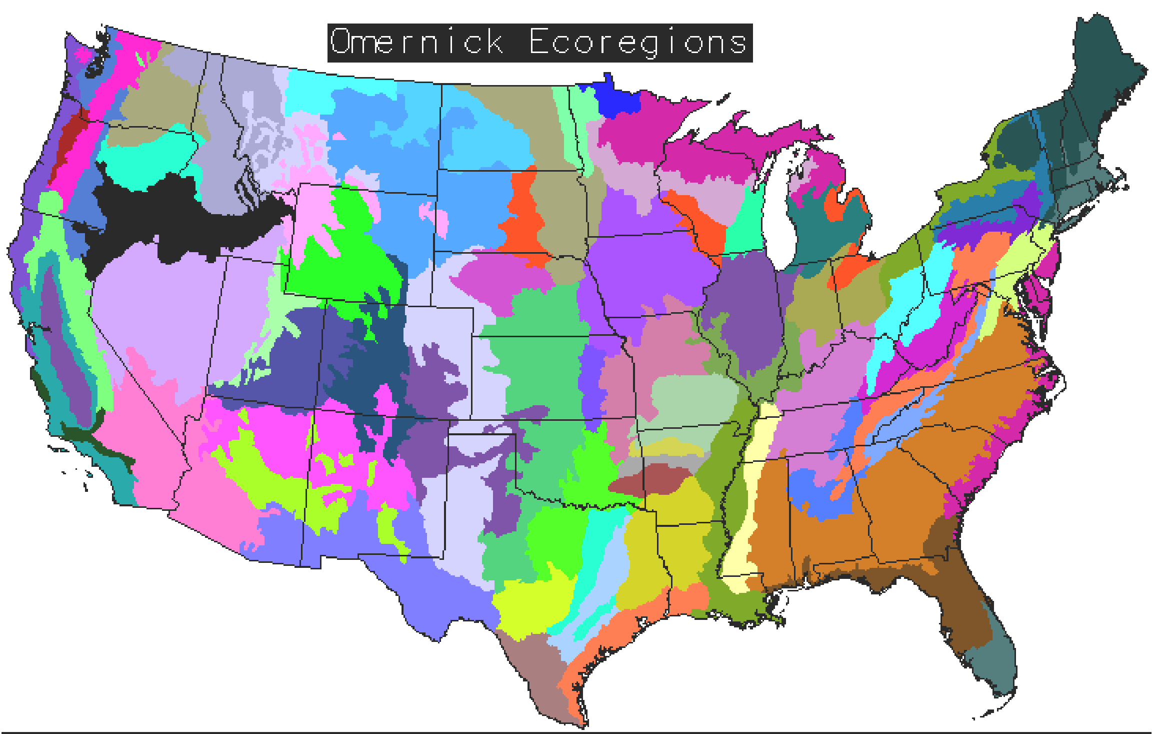

Figure3. Omernick eco-regions were used to localize refinements to the NFDRS fuel model map.

Because the ground data sample size was small for many fuel model/eco-region/landcover combinations, some fuel model assignments were made with inadequate data, thus it was felt that review by fire managers from throughout the U.S. was necessary. This was accomplished by having individual fire managers come to the Intermountain Fire Sciences Laboratory to use the GRASS (U.S. Army Construction Engineering Research Laboratory 1988) GIS software for detailed review of the fuel model map within their area of knowledge. This process permitted alteration of fuel models by Land Cover Class within individual eco-regions by modifying the lookup table based on eco-regions and landcover class. Although there were changes, they were surprisingly limited considering the sparseness of the ground sample data. Fire danger fuel models E, I, J, and K (Deeming et al. 1977) were not used. Satellite observation of seasonal changes in vegetation greenness eliminates the need for using model E as a winter season substitute for model R, and the slash models I, J, and K don't cover sufficient area to be considered. The NFDR Fuel Model map (Figure 4) may undergo future revisions, but the most current version is on the Forest Service home page (*http://www.fs.fed.us/land/wfas/welcome.html*). The EROS Data Center has completed a 1-km resolution land cover database for the world (Belward 1996) (Loveland et al. In press). These data will provide the key to development of fuel model maps for many countries.

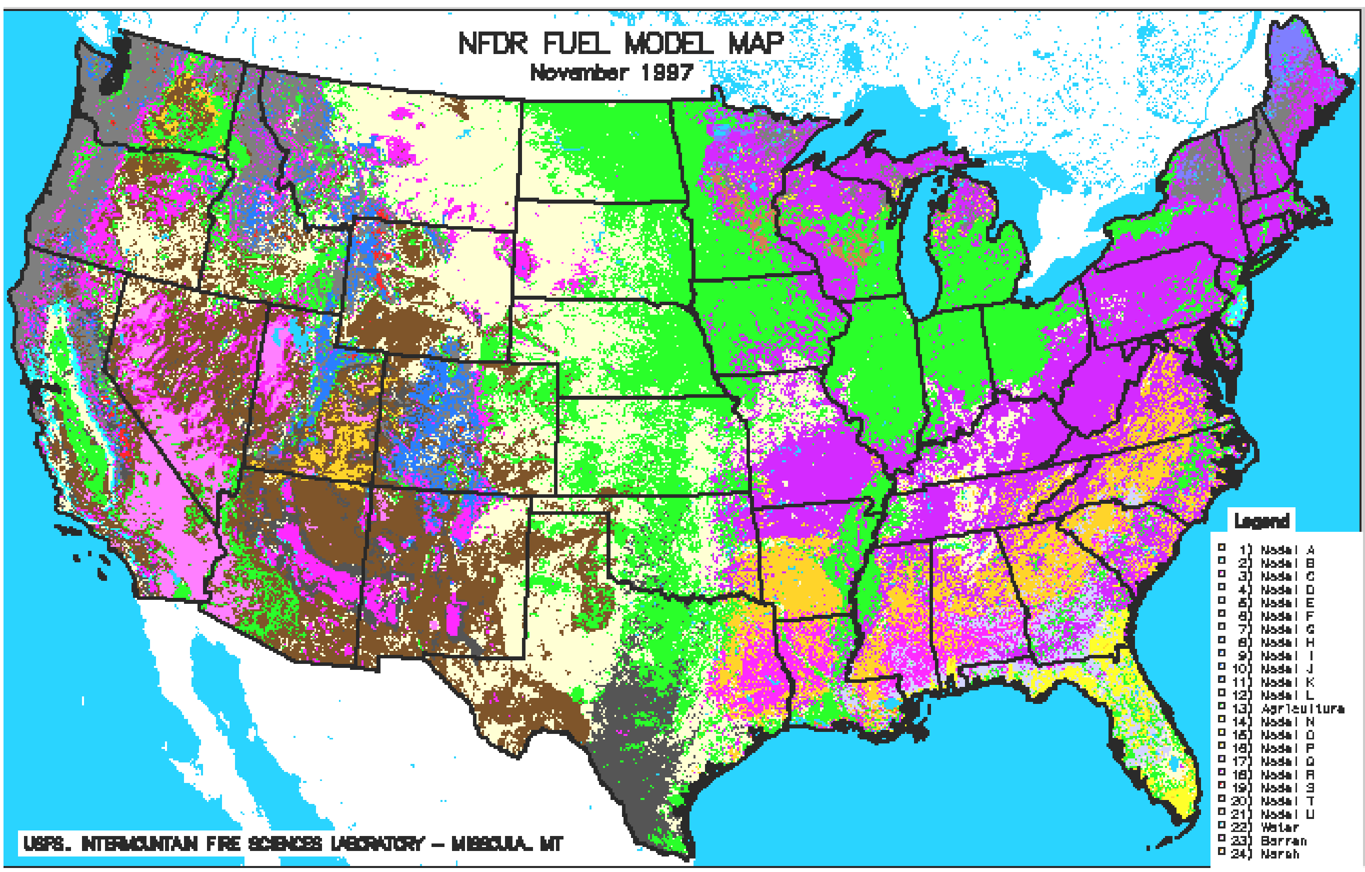

Figure4. The 1-km resolution fire danger fuel model map will be used in the next generation fire danger rating system (*http://www.fs.fed.us/land wfas/nfdr_map.htm*)

The Fire Potential Index Model

Justification and Inputs

The Fire Potential Index (FPI) model was developed to incorporate both satellite and surface observations in an index that correlates well with fire occurrence and can be used to map fire potential from national to local scales through use of a GIS. The primary reasons for developing the model were: 1) to produce a method to depict fire potential at continental scale and at 1 km resolution, 2) provide a method of estimating fire potential that was simpler to operate than the current U.S. National Fire Danger Rating System.

The assumptions of the FPI model are: 1) fire potential can be assessed if the proportion of live vegetation is defined, and it is known how close the dead fine fuel moisture is to the moisture of extinction, 2) vegetation greenness provides a useful parameterization of the quantity of high moisture content live vegetation, 3) ten hour time lag fuel moisture should be used to represent the dead vegetation because the moisture content of small dead fuels is critical to determination of fire spread, and 4) wind should not be included because it is so transitory. Thus the inputs to the FPI model are a 1-km resolution fuel model map, a Relative Greenness (RG) map (Burgan and Hartford 1993) that indicates current vegetation greenness compared to historical maximum and minimum values, a maximum vegetation greenness map, and 10 hour time lag dead fuel moisture (Fosberg and Deeming 1971) . Ten hour time lag fuels are defined as dead woody vegetation in the size range of 0.6 to 2.5 cm in diameter. These inputs must be in raster format and provided as byte data representing 1-km pixels. The output is a national scale,1-km resolution map that presents FPI values ranging from 1 to 100.

Fuel Models

In the traditional sense, fuel models are a set of numbers that describe vegetation in terms that are required by the Rothermel fire model. Thus fuel models used in the U.S. National Fire Danger Rating System have numerous parameters that define live and dead fuel loads by size class, surface area to volume ratios of the various size classes, heat content, dead fuel moisture of extinction, wind reduction factors, and mineral and moisture damping coefficients. The FPI algorithm uses just the dead fuel extinction moisture parameter for the mapped NFDR fuel models (Table 1). Dead fuel moisture of extinction is defined as the fine dead fuel (0.6 to 2.5 cm dia) moisture content at which fires will no longer spread.

NFDR Model	Ext Moist (%)	Vegetation Represented
A	15	Western annual grasses
B	15	California mixed chaparral
C	20	Pine grass savanna
D	30	Southern rough
E	----	Hardwoods (winter)
F	15	Intermediate brush
G	25	Short needle conifers with heavy dead load
H	20	Short needle conifers with normal

		dead load
I	----	Heavy logging slash[1]
J	----	Intermediate logging slash[1]
K	----	Light logging slash[1]
L	15	Western perennial grasses
M	----	Agricultural land
N	25	Sawgrass or other thick stemmed grasses
O	30	High pocosin
P	30	Southern pine plantation
Q	25	Alaskan black spruce
R	25	Hardwoods (summer)
S	25	Alpine tundra
T	15	Sagebrush-grass mixture
U	20	Western long-needle conifer
V	----	Water[1]
W	----	Barren[1]
X	----	Water[1]

[1] Fire Potential Index not calculated for this case.
Table 1. Extinction moistures used in calculating the Fire Potential Index.

Maximum Live Ratio Map

In the original formulation of the FPI algorithm, maximum live ratios were determined as a function of the live and dead loads assigned to each fuel model. However, this resulted in similar live ratios for fuel models that represent very different vegetation types - not a realistic situation. The effect was to overestimate the FPI in the eastern U.S. during summer, when the vegetation is normally very green. This dilemma was resolved by deriving a maximum live ratio map from the maximum NDVI map of the conterminous United States, under the assumption of a direct relationship between the two. The algorithm used is:

$$LR_{mx} = 35 + 40 * (ND_{mx} - 100)/ 80$$

where

LR_{mx} ***= Live ratio for a given pixel when the vegetation is at maximum greenness***
$ND_{mx} =$ ***historical maximum NDVI for a given pixel.***

NDVI values were scaled to range from a minimum of 100 by multiplying the standard fractional NDVI data values by 100, then adding 100. This keeps NDVI within the range of binary byte data (0-255), making for efficient data compression. The value 35 is used as a the lowest maximum percent green, even for arid areas of the west. That is, whatever amount of vegetation does exist, will be at least 35 percent green at its greenest, the remainder being dead vegetation from previous years

growth. The value 40 scales the maximum live ratio from 35% to 75% as the maximum NDVI ranges from 100 to 180, the highest value recorded for the conterminous U.S.

Figure 5. Maximum live ratio map for the conterminous U.S.

The live ratios for the current date are determined as a function of the current Relative Greenness for each pixel, thus seasonally modifying the live/dead ratio. The 1-km fuel model map of the U.S. provides a key to the dead fuel extinction moisture value for each pixel.

Relative Greenness

Relative greenness is derived from the Normalized Difference Vegetation Index (NDVI) (Goward et al. 1990) which is calculated from data obtained by the Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration's TIROS-N series of polar-orbiting weather satellites. The basis for calculating RG is historical NDVI data (1989 to present) that defines the maximum and minimum NDVI values observed for each pixel. Thus RG indicates how green each pixel currently is in relation to the range of historical NDVI observations for it. RG values are scaled from 0 to 100, with low values indicating the vegetation is at or near its minimum greenness. Specifically the algorithm is:

$$RG = (ND_o - ND_{mn}) / (ND_{mx} - Nd_{mn}) * 100$$

where

ND_o = highest observed NDVI value for the 1 week composite period
ND_{mn} = historical minimum NDVI value for a given pixel
ND_{mx} = historical maximum NDVI value for a given pixel

The purpose of using relative greenness in the FPI model is to define the proportion of live and dead vegetation. The RG map has a 1-km resolution and is registered with the fuels map.

Ten Hour Time lag Fuel Moisture

Given an ignition source, the probability that a wildland fire will ignite and spread is strongly dependent on the moisture content of small dead vegetation. The U.S. National Fire Danger Rating System separates dead fuel moisture response into time lag classes of 1, 10, 100, and 1000 hours (Deeming et al. 1977), meaning that their moisture content will change about 2/3 of the difference between initial and final conditions in one time lag period. Anderson (Anderson 1985) has shown that most dead wildland vegetation primarily involved in determining fire spread rate is in the 1 to 10 hour time lag response category, with only very fine fuels such as cheatgrass having response times of 1 hour or less. On this basis 10 hour time lag fuel moisture was selected to represent the moisture content of all dead vegetation in the 1 to 10 hour time lag size classes.

Ten hour fuel moisture is calculated from temperature, relative humidity, and state of the weather (cloudiness and occurrence of precipitation). These data are measured at surface weather stations and must be extrapolated across the landscape to meet the FPI model input requirement of 1-km resolution byte data. The process currently used to extrapolate this point data to a 1-km grid is an inverse distance squared algorithm. The advantage of this process is that it is convenient and simple to perform. The disadvantage is that it does not account for the influence of topography on fuel moisture. If the weather station network is reasonably dense, with weather stations at both high and low elevations, the resulting interpolations are quite

useable. But if the weather station network is too sparse or all the weather stations are at low elevations, the interpolations are not adequate. Improvement of the process for calculating 10-h TLFM is the subject of further work.

The Model

The FPI model uses the proportion of the vegetation that is live, and the ratio of ten hour time lag dead fuel moisture to the moisture of extinction, for estimating relative fire potential. The fuel model map is used to reference the dead fuel extinction moisture for each pixel, and Relative Greenness is used to determine the proportion of the surface vegetation that is live (Fig 6a).

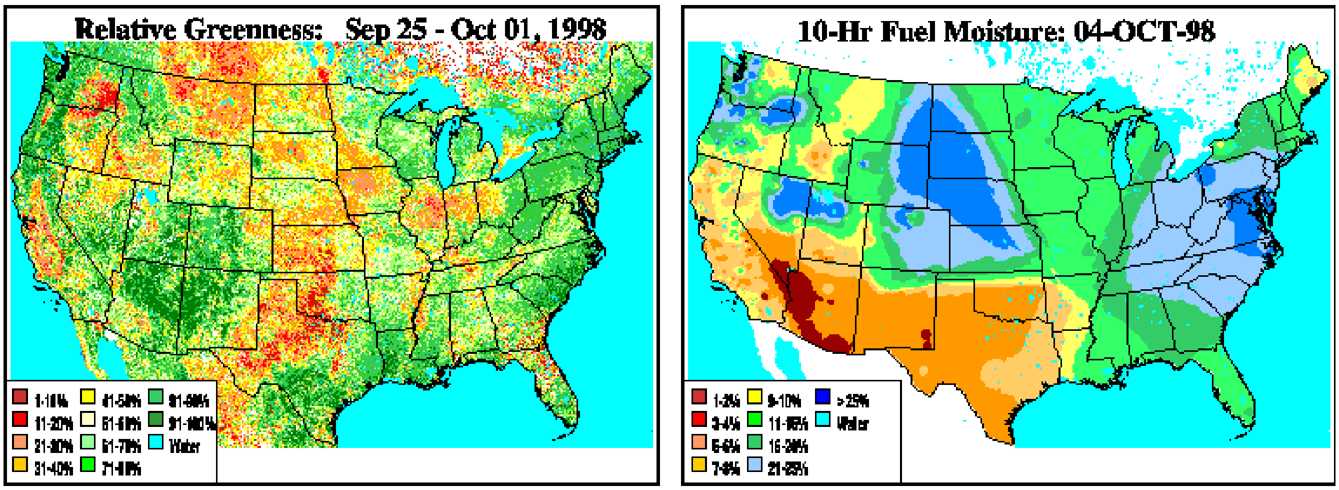

Figure 6a. Relative greenness, 10-hour fuel moisture maps, and NFDR fuel model (fig. 4) and the maximum live ratio (fig.5) maps are inputs to the FPI map calculation.

The FPI index is scaled from 1-100. The specific process for each pixel is to obtain the inputs from the 1-km fuel model, Relative Greenness, 10-h TLFM, and maximum live ratio maps, then perform the following calculations:

Set the FPI to a "no data" value greater than 100

- (1) FPI = 105

Convert RG to a fractional value

- (2) $RG_f = RG/100$

Relative greenness fraction is used to determine the current live fuel ratio (LR) for the pixel.

(3) $LR = RG_f * LR_{mx} / 100$

Fractional 10-h TLFM is normalized on dead fuel moisture of extinction (MX_d) for the fuel model, expressed as a percent (Table 1). Dead fuel moisture of extinction is defined as the dead fuel moisture at which a fire will not spread (Rothermel 1972). It varies from one vegetation or fuel type to another and is generally higher for moist climates such as the southeastern U.S. Ten hour fuel moisture (percent of dry weight) is normalized to the moisture of extinction to produce a fractional ten hour moisture scaled the same as fractional relative greenness (0-1). Ten hour fuel moisture is limited to a minimum of 2 percent, thus subtracting 2 from both the 10 hour moisture and the extinction moisture allows TN_f to reach zero when the ten hour moisture is at its minimum value and provides a convenient method of scaling the FPI from 0 to 100. The fractional ten hour moisture is smoothed near its minimum and maximum limits (0 and 1) to avoid discontinuities.

(4) $TN_f = (FM_{10} - 2)/(MX_d - 2)$

where

TN_f = fractional ten hour fuel moisture
FM_{10} = ten hour moisture (percent)
MX_d = dead fuel extinction moisture (percent)

The FPI calculation is performed only if the this pixel represents a valid fuel model, i.e. not agriculture, barren, etc. The live ratio (LR) defines the proportion of live vegetation, and inversely the proportion of dead vegetation (proportion dead equals 1 minus proportion live). Because live vegetation is green, it is assumed to have a high moisture content, thus reducing fire potential. The dead vegetation, as calculated from current weather data, has a relatively low moisture content -- less than 30%. Thus the FPI can be thought of as a "dryness" fraction times a "deadness" fraction.

(5) $FPI = (1 - TN_f) * (1 - LR) * 100$

where

FPI = fire potential index

Equation (5) produces FPI values that can range from 0 to 100. The FPI will equal 0 when the TN_f is 1 (the dead fuel moisture equals the moisture of extinction) or the LR value is 1 (the vegetation is fully green). These circumstances do occur, but the FPI is limited to a minimum value of 1 so that areas outside the United States can be identified as the value 0 (no data). The FPI will attain a value of 100 if the LRis 0 (all the vegetation is cured) and the 10 hour time lag fuel moisture is at its minimum value of 2 percent.

Fuel model map pixels that indicate agricultural lands are assigned an FPI value of 101. The RG image for the current composite period is processed by the EROS Data Center in a manner to indicate clouds, so pixels appearing cloudy in the RG map can be mapped as cloudy (102) in the FPI map. Pixels indicated as barren lands in the fuel model map are assigned an FPI value of 103, and marsh land pixels are assigned a value of 104. Water pixels are assigned a value of 255. A "C" program to perform these calculations is available from the author. The resulting output is a gridded raster file that can be displayed and analyzed using a GIS, or from which a graphics image can be prepared. Figure 6b illustrates the relationship between the FPI map and the standard NFDR map for October 4, 1998.

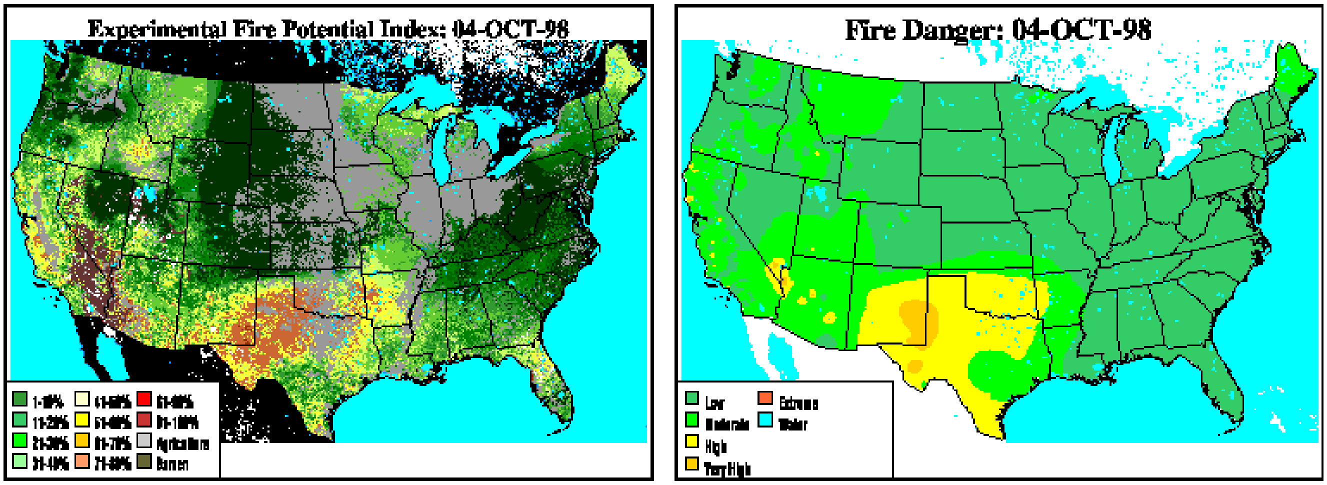

Figure 6b. The standard NFDRS map is provided for comparison with the fire potential index map (*http://www.fs.fed.us/land/wfas/exp_fp_4.gif*).

Model Application

Fire Potential Maps derived from this model were first introduced to fire managers in California and Nevada in 1996. Their response was very favorable, but anecdotal. In the fall of 1996 we required a simple method to assess fire potential in Mediterranean environments as part of a project sponsored by The Pan American Institute for Geography and History (PAIGH) (Klaver et al. 1997). PAIGH, in cooperation with the U.S. Geological Survey EROS Data Center, the Institute Geografico Nacional, Spain, the Instituto Geografico Militar de Chile, and the Instituto Nacional De Estatistica Geografia e Informatica, Mexico is supporting the project "Digital Imagery for Forest Fire Hazard Assessment for the Mediterranean Regions of Chile, Mexico, Spain, and the U.S." In support of this effort we calculated daily FPI maps for mid-March to late October for the years 1990-1995, and performed statistical analyses of the correlation between fire occurrence and the FPI. The California Division of Forestry supplied the required weather data and the fire location data. We looked at the distribution of FPI values for 1990 -1994 in two contexts: 1) FPI for only those pixels in which a fire occurred (Fig. 7), and 2) FPI for all the pixels within the study area (Fig 8), which was basically California and Nevada.

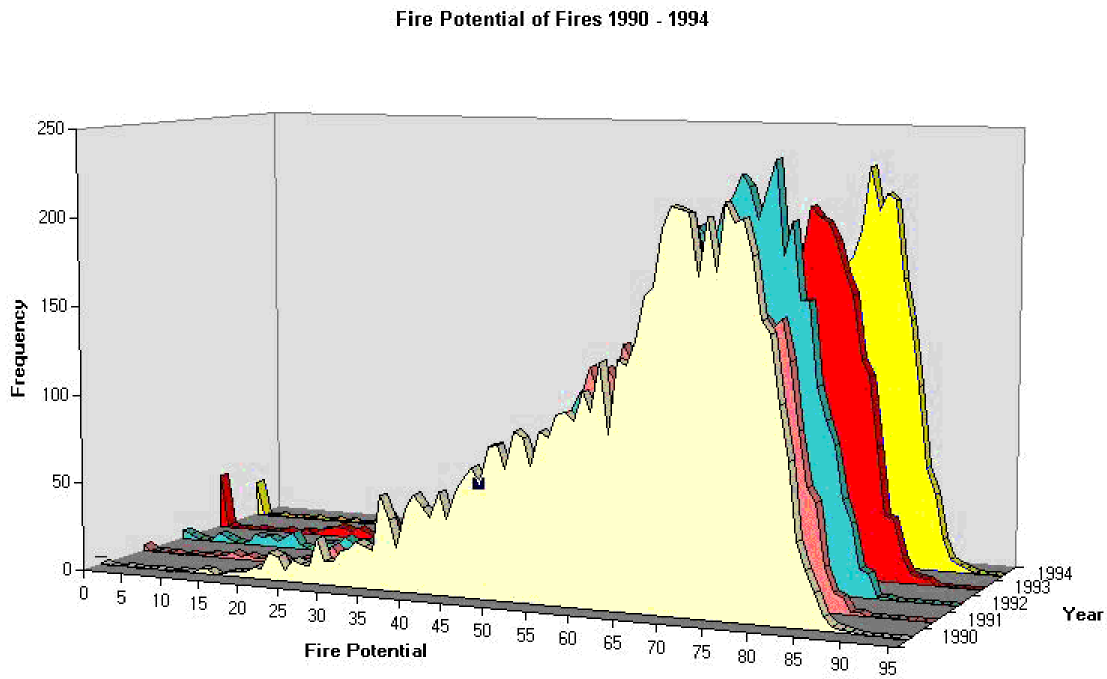

Figure 7. For only those pixels in which fires occurred, in the years 1990 to 1994, the frequency of FPI index values is shown.

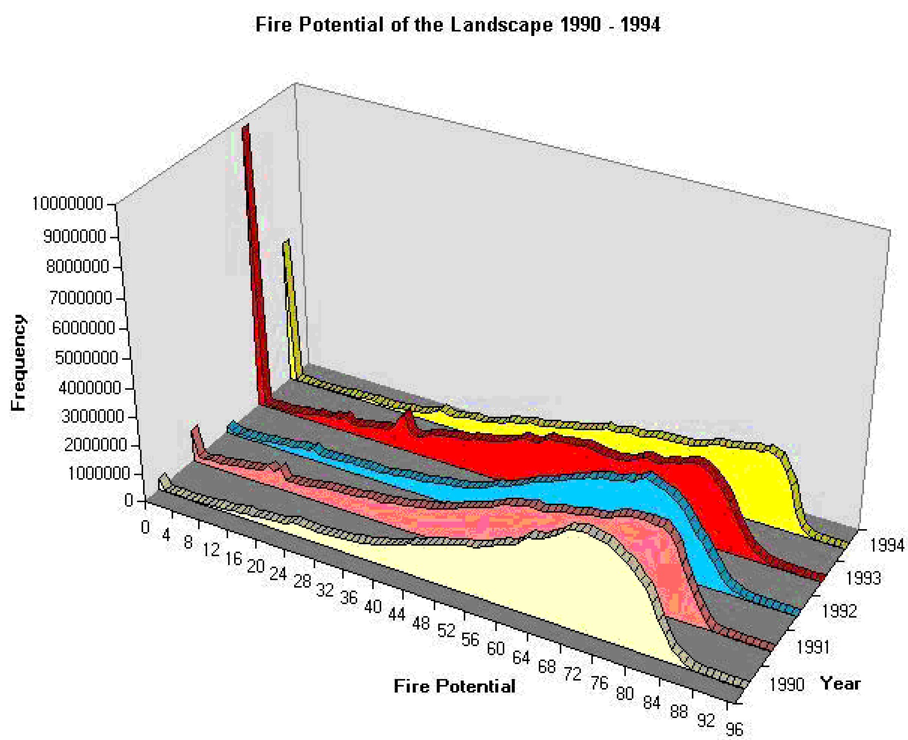

Figure 8. The frequency of pixels in the entire study area is shown for Fire Potential Index values calculated for 1990 to 1994.

For the first case the frequency distribution of FPI values was very similar for all years, indicating that in spite of fire season variability the relationship between fire occurrence and the FPI remains relatively constant. For the second case the frequency distribution of FPI values for all pixels varied between years, indicating that the FPI can discriminate fire season severity in the broad geographical sense. Correlation between the FPI and fire occurrence was very high, with r^2 values by year of: 1990, 0.44; 1991, 0.85; 1992, 0.87; 1993, 0.90; and 1994, 0.88. The r^2 value for all years combined was 0.72. The reason for the low correlation for 1990 is unknown, but could be due to changes in calibration of the AVHRR sensor, accuracy of fire location, or the two week rather than one week compositing period.

Annual comparisons show that the linear equations for the FPI and fire density were statistically identical for 1991, 1993, and 1994 ($r2=0.825$, $df=1$ and 318, $F=375.05$, $p=0.0$). The linear equation for 1990 was different from these years in both slope and intercept. The linear equation for 1992 had a greater intercept than the other years but the same slope (Figure 9). That is, fire occurrence was greater for a given FPI value in 1992 than for 1991, 1993, and 1994.

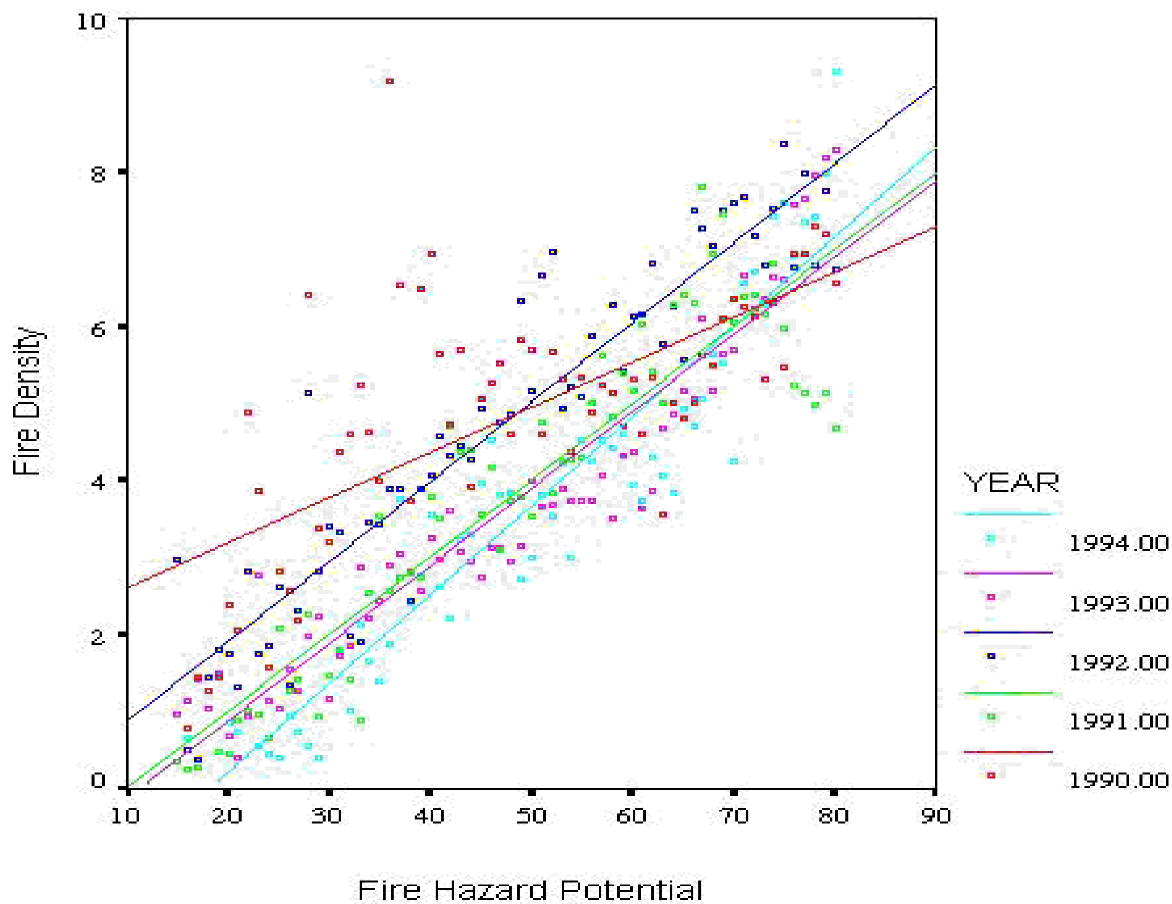

Figure 9. The slopes of the regression lines are very similar for all years except 1990.

The FPI map is also being tested, along with several NFDR indexes, for application to the problem of assessing seasonal fire severity for the United States. This is an important and difficult problem for which there is no standard procedure at this time. The problem is important because millions of dollars are made available to those Forest Service Regions that can show they expect to experience a fire season that is considerably more severe than average, and difficult because the decision of where to place the additional funds must be made 2-4 weeks in advance of the expected fire problems. The accuracy of these decisions depends on the accuracy of long range weather forecasting, so making the process simple in terms of weather requirements is important.

Conclusions

The FPI appears to be strongly correlated with fire occurrence and is well adapted to portraying fire potential across both large geographic areas and for local areas down to a few square kilometers. It is not a physically based model and thus requires enough historical data to develop the statistical relationships that can provide fire probability given a specific FPI value. Use of the FPI requires a fuel model map, a maximum live ratio map, access to current RG maps as calculated from AVHRR/NDVI data, and a reasonably dense network of surface weather stations. The 10-h time lag fuel moistures must be calculated from the weather station data and interpolated for all 1-km pixels. Efforts are underway to improve the interpolation procedure. The results of FPI tests for California and Nevada indicate that it may be a valuable tool for fire managers in other countries. This will be determined by future tests in the Mediterranean ecosystems of Spain, Chile, Argentina and Mexico.

Acknowledgements.

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Update (5/2000).

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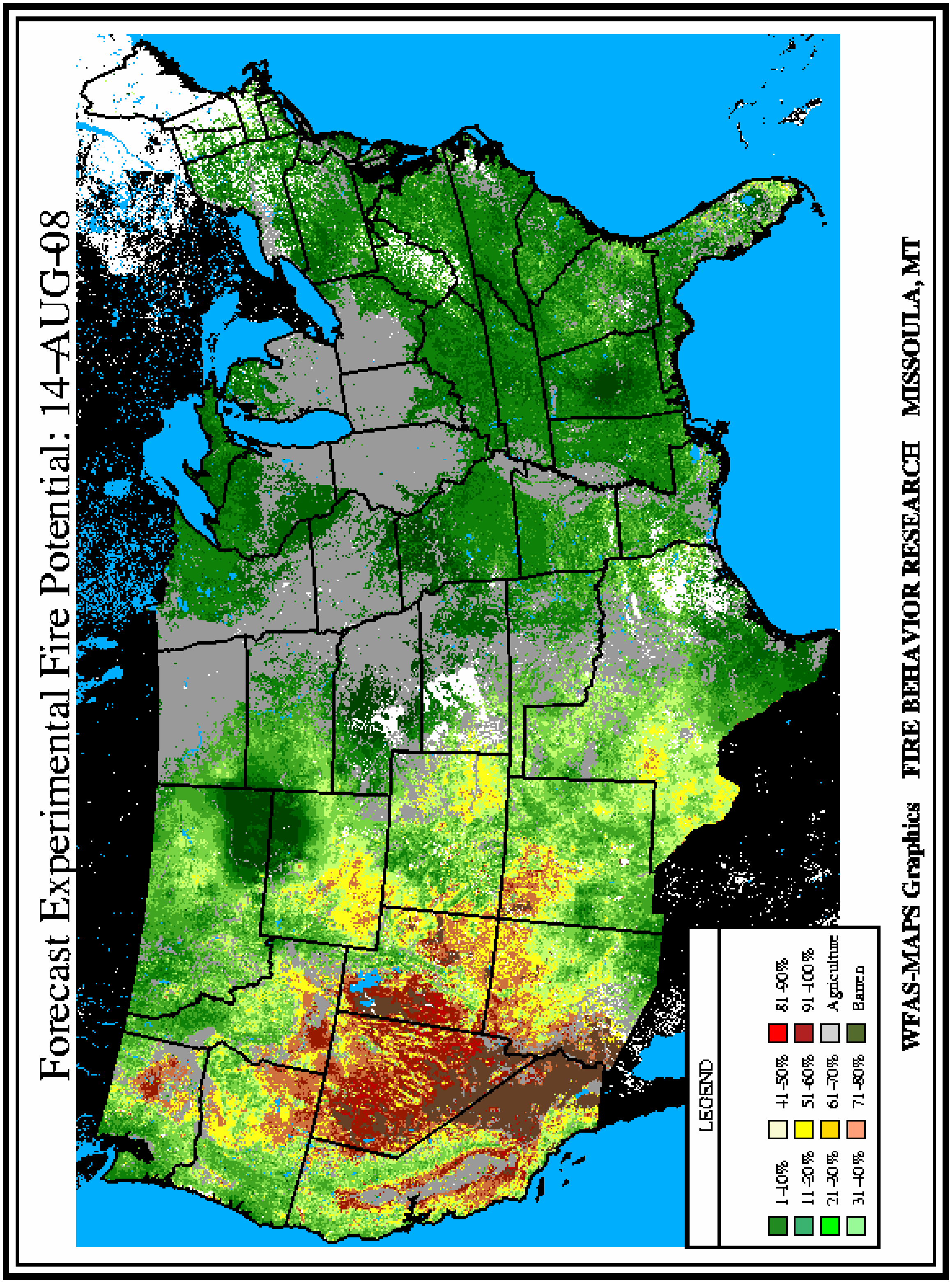
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LEGEND
1-10%
11-20%
21-30%
31-40%
41-50%
51-60%
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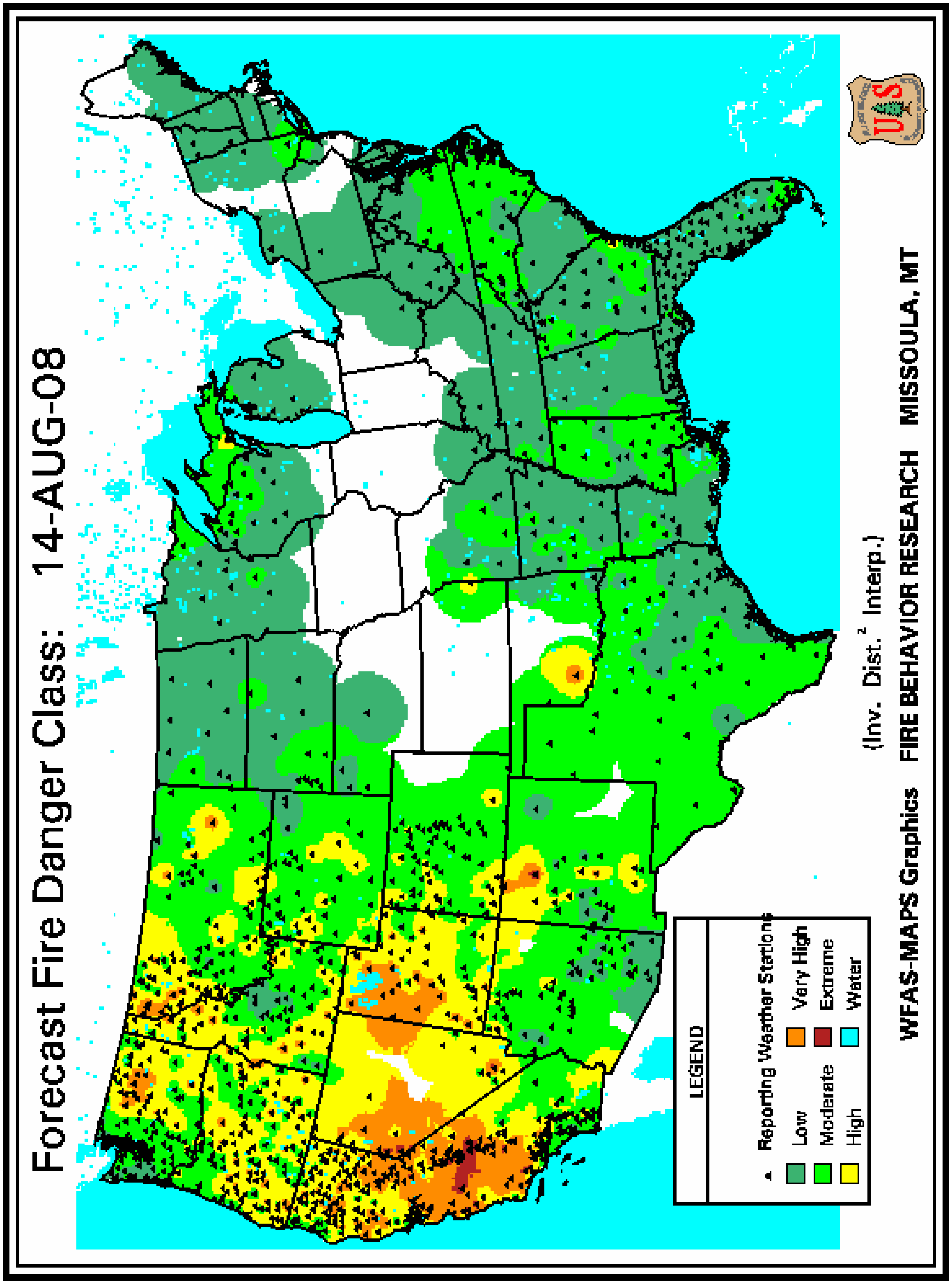
71-80%
81-90%
91-100%
Agriculture
Barren
WFAS-MAPS Graphics
FIRE BEHAVIOR RESEARCH
MISSOULA, MT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LEGEND
Reporting Weather Stations
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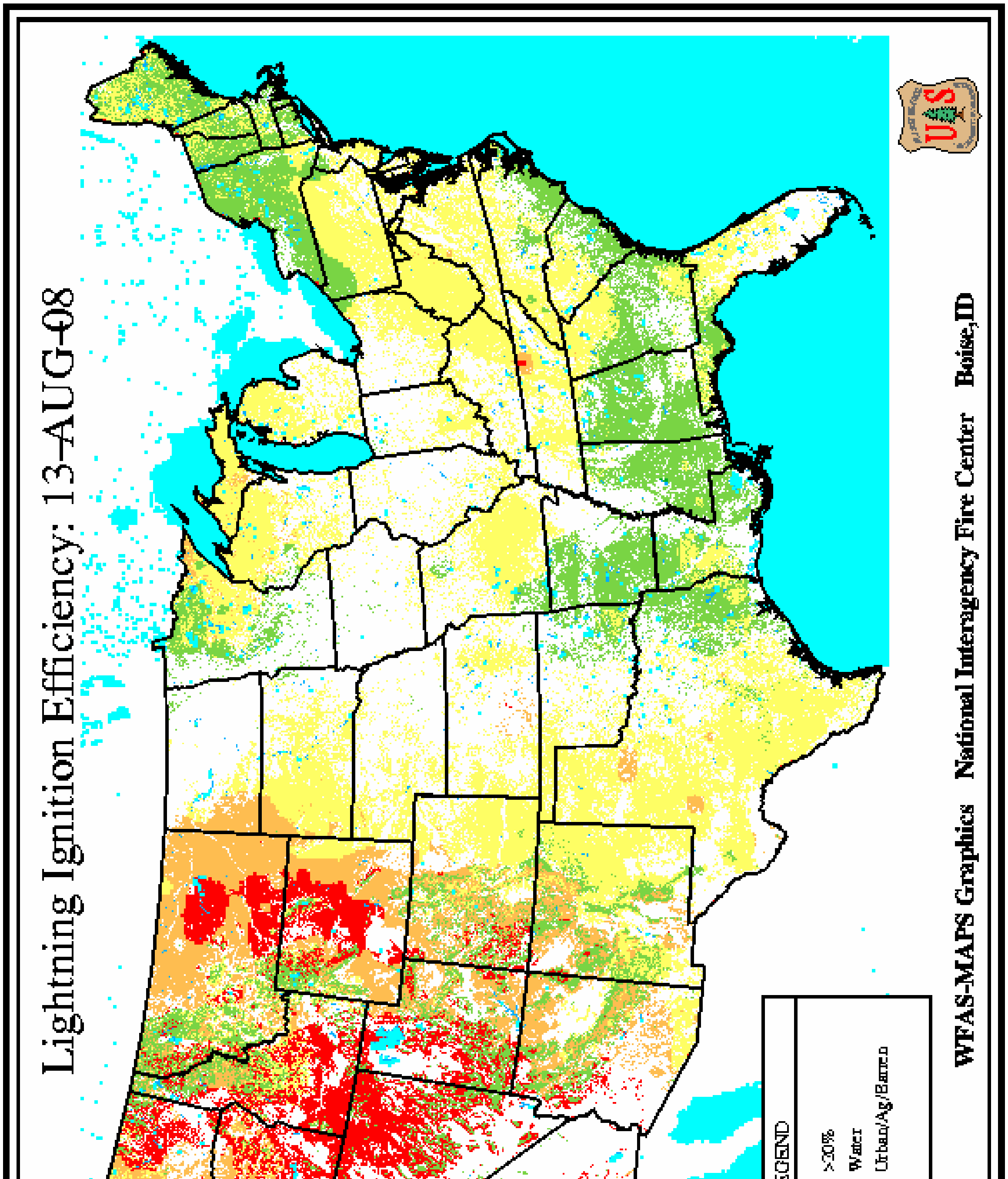
Moderate
High
Very High
Extreme
Water
(Inv. Dist.² Interp.)
WFAS-MAPS Graphics
FIRE BEHAVIOR RESEARCH MISSOULA, MT


Lightning Ignition Efficiency: 13-AUG-08
LEGEND
1-4%
5-10%
11-15%
16-20%
>20%
Water
Urban/Ag/Barren
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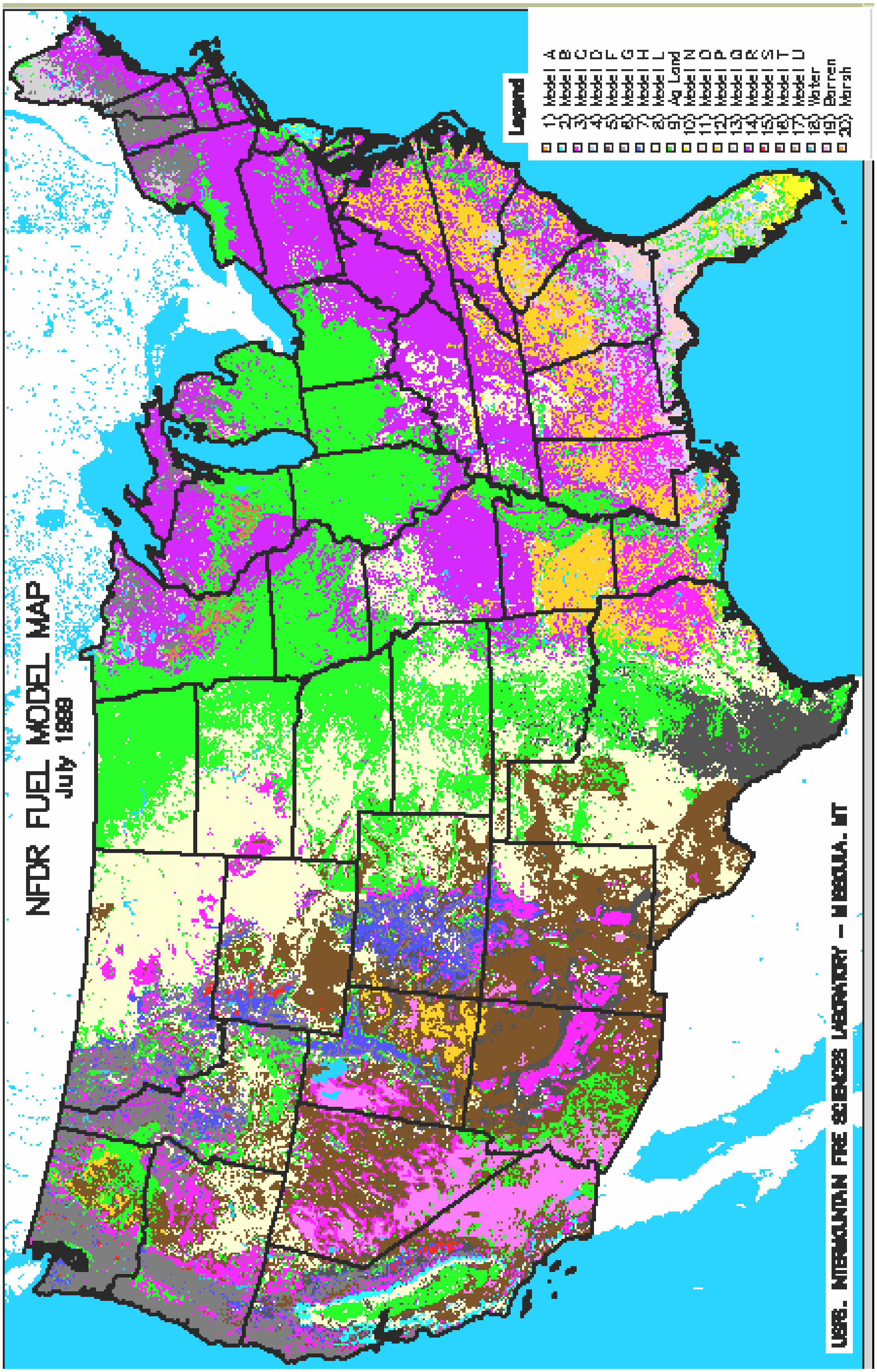
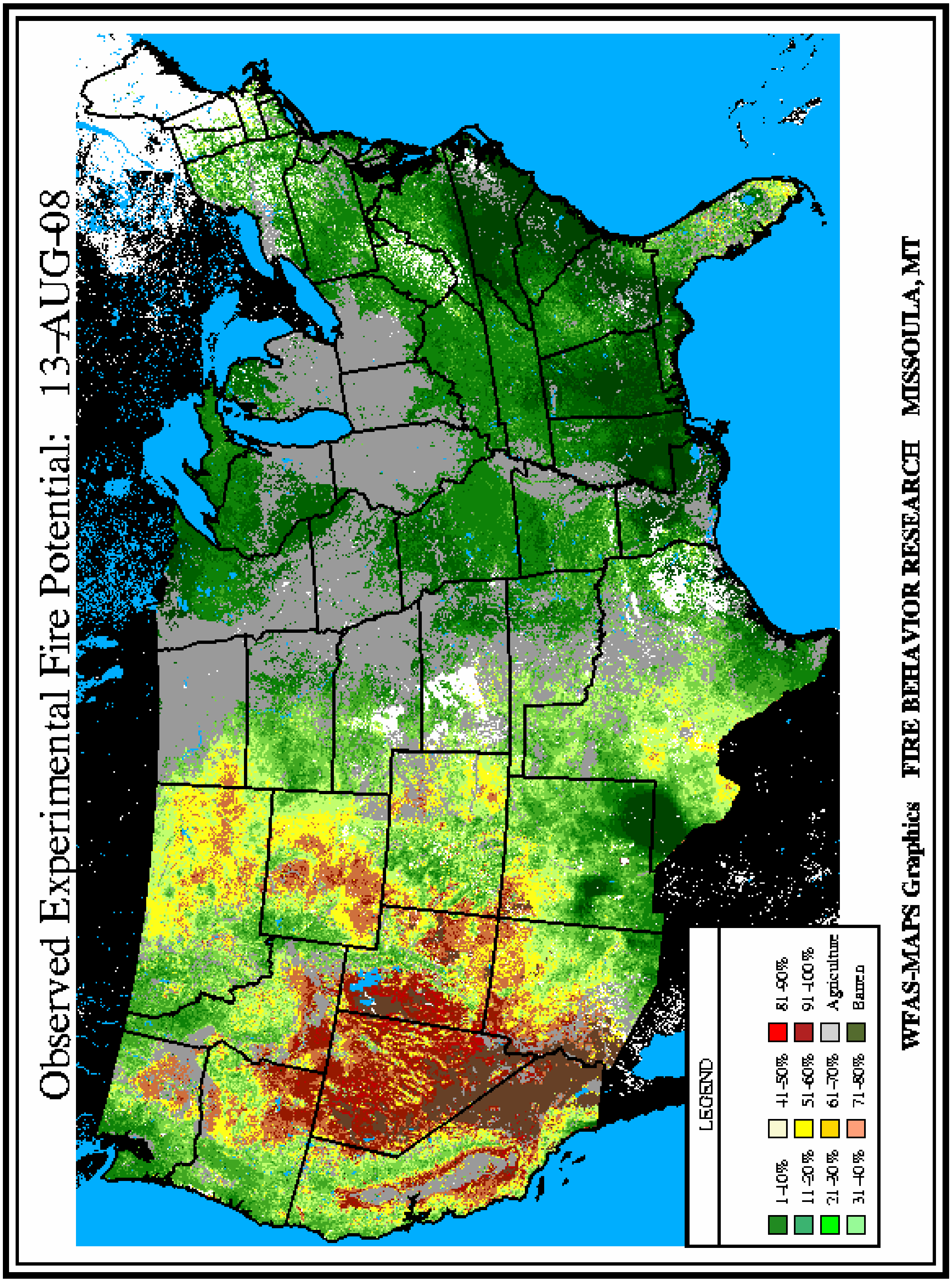
Boise, ID


NFDR FUEL MODEL MAP
July 1988
Legend
1) Model A
2) Model B
3) Model C
4) Model D
5) Model F
6) Model G
7) Model H
8) Model L
9) Ag Land
10) Model N
11) Model O
12) Model P
13) Model Q
14) Model R
15) Model S
16) Model T
17) Model U
18) Water
19) Barren
20) Marsh
USFS, INTERMOUNTAIN FIRE SCIENCES LABORATORY – MISSOULA, MT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1-10%
11-20%
21-30%
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41-50%
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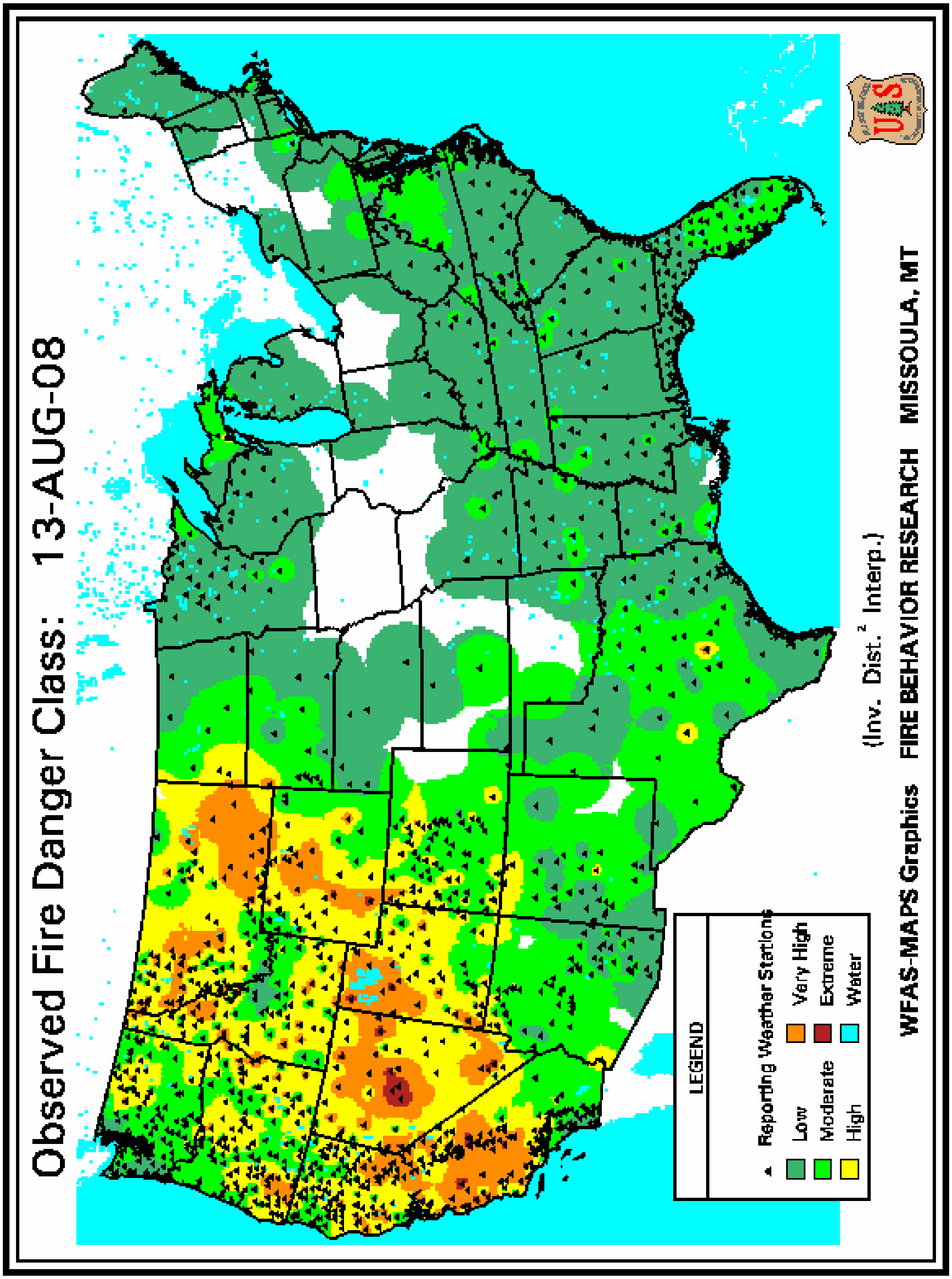
MISSOULA, MT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LEGEND
Reporting Weather Stations
Low
Moderate
High
Very High
Extreme
Water
(Inv. Dist. 2 Interp.)
WFAS-MAPS Graphics
FIRE BEHAVIOR RESEARCH
MISSOULA, MT