United States
Department of
Agriculture

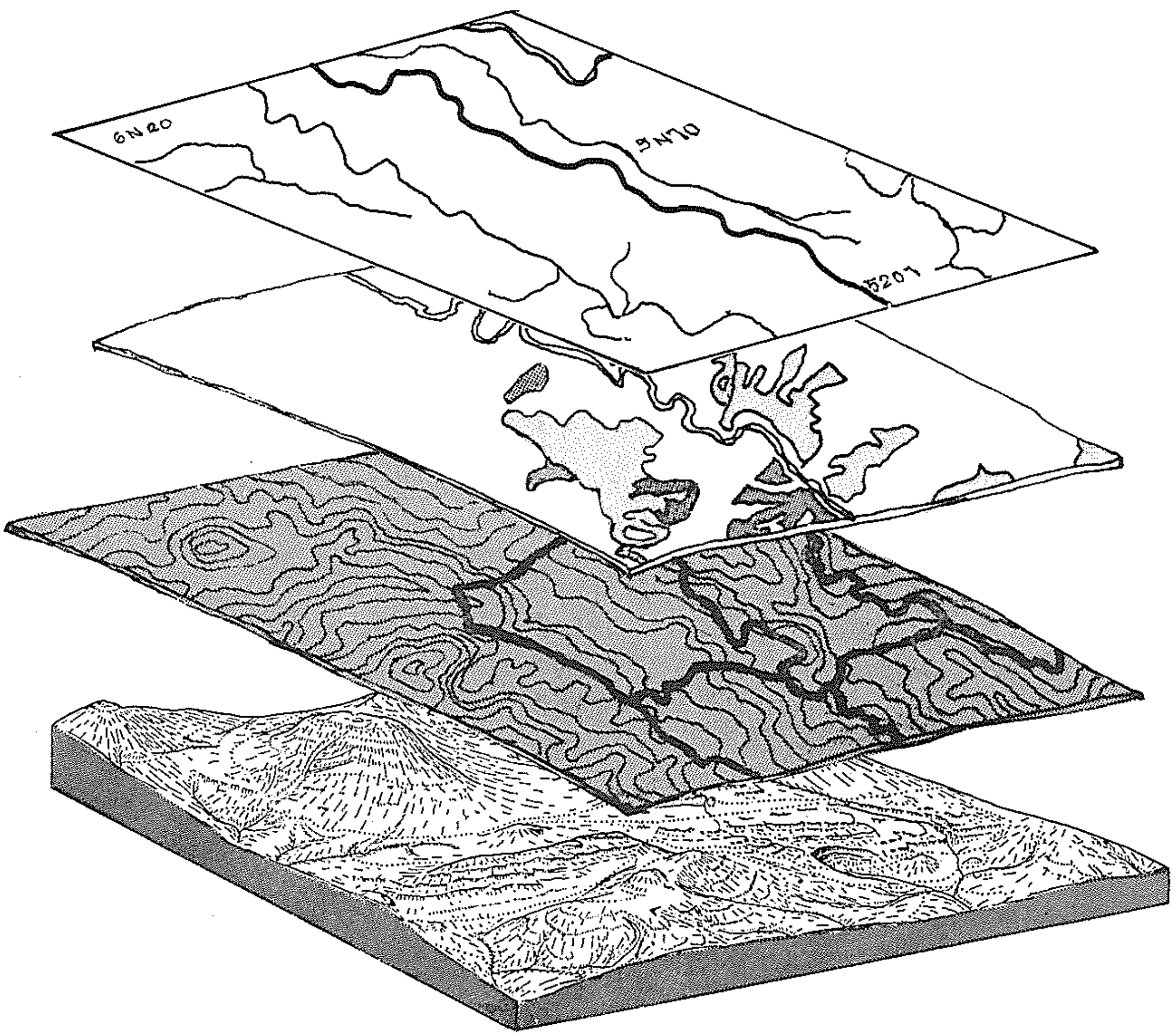
Forest Service

**United States
Department of
Agriculture**

Research Paper
PSW-162

Remote Sensing Techniques Aid in Preattack Planning for Fire Management

Lucy Anne Salazar



The Author:

LUCY ANNE SALAZAR is a research forester assigned to the Station's Fire Management Planning and Economics Research Unit, headquartered at the Forest Fire Laboratory, Riverside, California. She earned a bachelor's degree in mathematics from the University of California, Irvine (1976), and a master's degree in natural resources, with an emphasis in forestry, at Humboldt State University, Arcata (1980). She joined the Station staff in 1980.

Acknowledgments:

This study was done while I was a graduate student at Humboldt State University, and through a cooperative agreement with the Station. I thank the following members of the Six Rivers National Forest for their technical assistance in the field work: Malvan G. Ellison, assistant fire management officer; John Coburn, timber management planner; and Robert McClelland, fuel management technician, Lower Trinity Ranger District.

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

September 1982

Remote Sensing Techniques Aid in Preattack Planning for Fire Management

Lucy Anne Salazar

CONTENTS

IN BRIEF...

Salazar, Lucy Anne. **Remote sensing techniques aid in preattack planning for fire management.** Res. Paper PSW-162. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 19 p.

Retrieval Terms: remote sensing, preattack planning, fire management, presuppression planning

Current methods used to document preattack planning information involve a tedious process of interpreting low altitude photography followed by extensive ground checking. Maps often include both existing and planned preattack measures, usually resulting in a map so detailed that, upon completion, requires almost total revision. As an alternative to current methods, remote sensing techniques were investigated as a means of improving methods of documenting preattack planning information for fire management. Remote sensing techniques were used to develop a basic preattack plan that included fuel types, road systems, and water sources.

The study site was 25,288 acres (10,234 ha) of the Six Rivers National Forest in northwestern California. It was chosen to demonstrate a technique rather than to suggest a preattack plan was absolutely vital. Digital data recorded by the unmanned earth-orbiting Landsat satellite were computer analyzed through unsupervised and guided clustering classification techniques to produce a preattack fuel type map of the area. The two fuel type systems used were based on fuel models from the 1978 National Fire Danger Rating System (NFDRS) and the Northern Forest Fire Laboratory (NFFL). Both fuel model groups, when used along with environmental variables, such as fuel moisture and slope, and their respective computer software, provide the information necessary to determine rates of spread, fireline intensity, and flame length. Aerial photography and ground truth data were used to support the satellite information. Other preattack characteristics, for example, access routes and water sources were delineated through visual interpretation of small- (1:130,000) and medium-scale (1:31,284) color-infrared (CIR) photography taken from U-2 jet aircraft. The final product was a series of mylar overlays with a 7½-minute topographic quad used as a base map. The series consisted of a 1.1-acre grid cell map of NFDRS fuel models by appropriate symbol, a 1.1-acre grid cell map of NFFL fuel models by appropriate symbol, and a line map of numbered access routes, according to size, and water sources of significantly large volume for suppression uses.

A cluster sampling method evaluated Landsat classification accuracy. Photointerpretation determined the true land cover category. Landsat classification accuracies were moderate, 71 percent, mainly because of incompatibilities found between remote sensing capabilities and the NFDRS and the NFFL fuel model descriptions. The Landsat Multispectral Scanner registers spectral reflectance data and, therefore, only "sees" cover types without any indication of understory conditions. Fuel models, however, describe the understory fuels that will carry the fire. Preattack characteristics of roads and water sources were easily documented from the CIR photography. Various overlay combinations can provide fire dispatchers and fire managers with data that is vital in planning strategies for initial attack, prevention, and fuel treatments. Potentially hazardous areas along roadsides or private lands, for example, can be determined from the overlays.

The use of remote sensing techniques was shown to provide basic preattack planning information that is moderately reliable and easily updated. In future studies, more extensive ground truth should be acquired and incorporated into the system. If available for a study area, digitized slope, aspect, and elevation data should be combined with the Landsat imagery to aid in classification decisions.

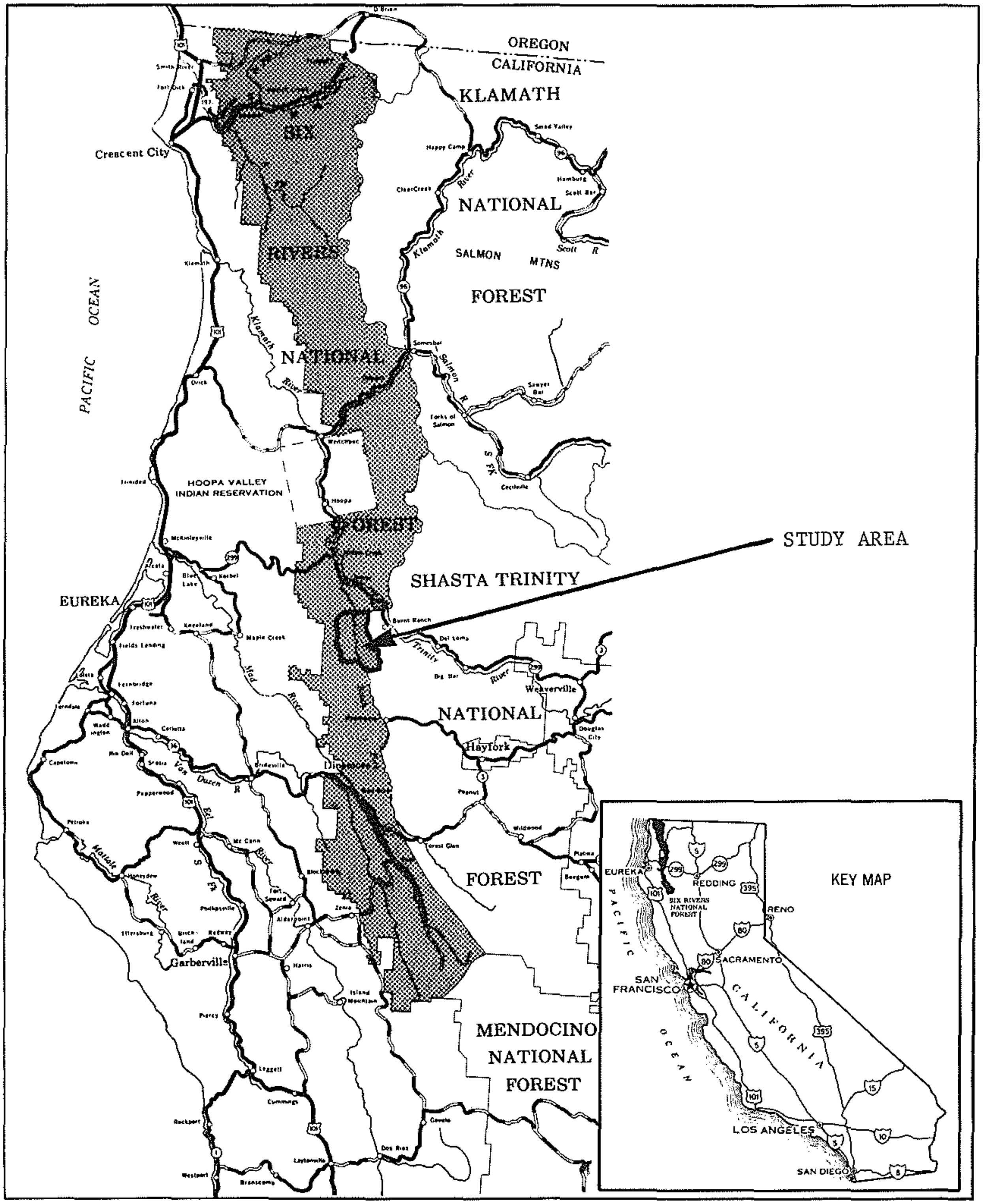


Figure 1—The study area contains 25,288 acres (10,234 ha) within Six Rivers National Forest in northwestern California.

Figure 3—Soil units of Willow Creek SE quad with fire related soil characteristics of high susceptibility to burning damage, high compaction hazard, or both, are mapped separately.

Table 1—*Soil characteristics and erosion-hazard rating, soil mapping units, Six Rivers National Forest, California*[1]

Map symbol and mapping unit components	Erosion-hazard rating[2] (Percent cover) 0-30	30-70	70-100	Hydrologic soil group[3]	Compaction hazard[4]	Susceptibility to burning damage[5]
261: Holland family, deep, 40 percent	High	Moderate	Moderate	C	High	Low
Goldridge family, deep, 40 percent	High	Moderate	Moderate	C	High	Low
Inclusions: 20 percent						
Skalan family, deep	High	Moderate	Moderate	B	Moderate	Moderate
Melbourne family, deep	High	Moderate	Moderate	C	High	Low
Grout family, deep	High	Moderate	Moderate	C	High	High
265: Everett family, deep, dry, 35 percent	High	Low	Low	B	Moderate	High
Hugo family, deep, dry, 20 percent	High	Low	Low	B	High	High
Holland family, deep, dry, 20 percent	High	Low	Low	C	Moderate High	High
Inclusions: 25 percent						
Deadwood family	High	Moderate	Moderate	C	Moderate	High
Grout family, deep	High	Moderate	Moderate	C	High	High
281: Everett family, deep, extremely gravelly, 45 percent	Moderate	Low	Low	C	Moderate	High
Deadwood family, 30 percent	High	Moderate	Moderate	C	Low	High
Inclusions: 25 percent						
Holland family, deep	High	Moderate	Moderate	C	Moderate to Moderate High	Moderate
Skalan family, mod. deep	High	Moderate	Moderate	B	Moderate	Moderate
412: Madden family, mod. deep, 60 percent	High	Moderate	Moderate	C	High	High
Inclusions: 40 percent						
Soils similar to Madden family, mod. deep except skeletal	High	Moderate	Moderate	C	Moderate to High	High
Grondo family	High	Moderate	Moderate	C	Moderate High	High

[1]Source: Parsons and Knox 1980.

[2]Based on such soil characteristics as texture, structure, permeability of surface and subsurface horizons, and the depth at which a reduction in permeability begins and such environmental variables as percent and configuration of slope, distribution, and form of precipitation, and percent vegetative cover.

[3]Indicates potential for runoff: B—low potential; C—moderate potential.

[4]Based on texture, organic matter content, and coarse fragment content of the top 10 inches (25 cm) of soil.

[5]Based on amount of organic matter, coarse fragments, and texture of the top 4 inches (10 cm) of soil and the type of parent rock.

MATERIALS AND METHODS

Preattack Block Layout

Because preattack maps were not available for the study area, the preattack block was chosen on the basis of these criteria:

- It should preferably be a watershed that reflects the attempted containment area of large fires.
- It should be of manageable size—20,000 to 50,000 acres (Dell 1972).
- It should have a diversity of fuel types to test fuel model classification.
- It should consist of large areas of homogeneous fuel types to develop Landsat training sets.
- It should be accessible for acquiring ground truth information.

The last three criteria were added specifically for this study and do not pertain universally to the selection of all preattack blocks. Topographic maps, relief maps, and Forest

Service, U.S. Department of Agriculture, administrative unit boundaries were used in this determination. The four selected timber compartments composing the study area fit these criteria.

Image Interpretation

Color infrared (CIR) photography was selected for interpretation because of the following advantages over black-and-white or true-color film:

- Increased haze penetration.
- Greater contrast between vegetation and bare soil.
- Greater total brightness of vegetation (Colwell 1960).
- Definite color contrast between water and living vegetation, especially in areas of very shallow water or dense vegetation (Chismon 1977).

The CIR transparencies, 9 by 18 inches (22.5 by 45 cm) at 1:31,284 scale and 9 by 9 inches (22.5 by 22.5 cm) at 1:130,000 scale, taken on May 8, 1978, by U-2 aircraft were used for two purposes. They were used to locate ground truth plots for training fields in the Landsat computer analysis. Homogeneous fuel areas were outlined on mylar overlays and assigned an NFDRS and an NFFL fuel model. The Forest Service's Wildland Resource Inventory System (WRIS) maps and compartment vegetation maps were used to find additional training areas that were not evident from the CIR photography. Both map systems were updated through aerial photointerpretation and, therefore, could be included in our remote sensing system.

The photography was also used to delineate these preattack characteristics:

- All visible access routes within the study area and the immediate vicinity, according to size—major and minor arteries.
- Water sources of significant volume to be used by water tankers (greater than 250 gal [945 *l*] minimum).

Access routes and water sources were traced on the same mylar overlays as those that were used to outline the homogeneous fuel areas. Road numbers were found on the Six Rivers National Forest road maps. Any roads not numbered and longer than ½ mile (0.8 km) were given a number and marked with an asterisk.

Fuel models of the NFFL system corresponded to those of the NFDRS (see *table 2* for a more detailed description):

NFFL	*NFDRS*	*Description*
1	A	Short grass
2	C	Open conifer stand
3	N	Agriculture
4	B	Dense shrubs
5	F	Young shrubs
8	H	Healthy short-needle conifer stand
9	R	Hardwoods and mixed hardwood–conifers
10	G	Decadent short-needle conifer stand

When used along with environmental variables such as fuel moisture, slope class, windspeed, the fuel models provide information necessary to determine rates of spread, fireline intensity, and flame length from both the NFDRS and the NFFL or fire behavior system computer software. Both fuel model groups were included in this study to satisfy the planning and operational needs of the Six Rivers National Forest (NFDRS) and the Lower Trinity Ranger District (NFFL). Two nonvegetative classes—bare soil and wet gravel—were included.

Field Data Collection

Recorded ground truth information consisted of percent vegetation cover by species, topographic characteristics, and soil parameters. The vegetation information was used to pick the appropriate fuel model described by Albini (1976) for the NFFL fuel models and by Deeming and others (1977) for the NFDRS models. The fuel models were then designated on the data collection sheet and on the mylar overlays. A minimum of 100 acres total for Landsat ground truth plots were identified for each fuel model. Because acquiring ground truth data is the most expensive and time-consuming step in Landsat classification (Poulton and Welch 1979), the lowest possible number of ground plots were sampled to adequately represent each category and achieve this minimum acreage. Plots were chosen near each other whenever possible, but a representative sample of the entire area was attempted. Plot locations were selected that encompassed variations in slope, aspect, and topographic position.

Landsat Classification

Fuel model mapping was accomplished through computer analysis of Landsat MSS data. The Earth Resources Technology Satellite (ERTS) Data Interpretation and TENEX (PDP-10 computer operating system) Operation Recorder (EDITOR) computer software system, accessed through the National Aeronautics and Space Administration's (NASA) Ames Research Center, was used for this analysis.

An April 12, 1977, Landsat scene 2811-17593 was chosen because of its accessibility and data quality. The scene was preprocessed to correct inherent geometric errors in the Landsat digital data. This preprocessing included geometric and radiometric correction, mosaicking, resampling, and formatting (Mayer 1979). Units of resolution on Landsat imagery are called pixels or picture elements. A pixel is equal to approximately 187 by 259 ft (57 by 79 m) on the ground. A total block of 81,171 pixels was chosen for classification, which included the study area and the immediate vicinity. The additional area was included to add to classification accuracy by providing a larger database.

Table 2—*Detailed description of all fuel models used*[1]

Fuel model	Description
1	Grasslands and savanna represented along with stubble, grass-tundra, and grass-shrub combinations with the shrubs occupying ≤1/3 of area. Annual and perennial grasses included. Fine herbaceous fuels, cured or nearly cured determine fire spread. Fires are surface fires that move rapidly through cured grass and associated vegetation.
A	Western grasslands vegetated by annual grasses and forbs. Brush or trees, if present, are sparse, occupying ≤1/3 of area. Examples of grass types: cheatgrass and medusahead. Sagebrush-grass associations qualify if woody plants meet density criteria.
2	Best fits open pine/grassy understory, wiregrass/scrub oak associations. Also used for timber/sagebrush/grass associations. Fires are primarily surface fires spreading through the fine herbaceous fuels, either curing or dead; herbaceous vegetation, litter and dead-down stemwood from the open shrub or timber overstory contribute to the fire intensity.
C	Open pine stands (open conifer stands used in this study). Perennial grasses and forbs primary ground fuel, but enough litter and branchwood present to contribute significantly to fuel loading. Some brush and shrubs present but insignificant.
3	Best fits tall sawgrasses, eastern marshes, and other grasses such as bluebunch wheatgrass, bluestems, broomsedge, and panicgrass. Wild or unharvested cultivated grains included. Most intense of the grass group and when windy displays high rates of spread. Fire may be driven into upper heights of the grass stand by wind. Stands tall, average about 3 ft, but may vary considerably. One-third or more of stand considered dead or cured and maintains the fire.
N	Constructed specifically for sawgrass prairies of south Florida; may be useful in marsh situations with coarse and reedlike fuel. Model assumes that 1/3 of aerial portion of plants dead. (Model seems best fit for agriculture.)
4	Stands of mature shrubs, ≥6 ft tall, such as California mixed chaparral. Fire intensity and fast-spreading fires involve flammable foliage and live and dead fine woody material in the crowns of a nearly continuous secondary overstory.
B	Mature, dense fields of shrubs ≥6 ft tall. One-fourth or more of aerial fuel is dead. Foliage burns readily. Potentially very dangerous fuels, fostering intense, fast-spreading fires. Mainly designed for California mixed chaparral, generally ≥30 years. Woody plants occupy ≥2/3 of site.
5	Generally nonflammable shrubs including young, green stands of chaparral and manzanita. Shrubs mostly ≤2 ft tall and almost cover entire area. Fire usually carried in surface fuels of litter cast by shrubs and grasses or forbs in understory. Fires generally not intense because surface fuel loads light; shrubs young with few dead branches, and foliage contains little volatile fuel.

Table 2 (continued)

Fuel model	Description
F	Young, closed stands and mature, open stands of California mixed chaparral.
8	Best fits compact litter in closed, short-needle conifer stands. Used also for hardwood litter during spring and summer when compacted (not so in this study—hardwoods included in model 9). Stands closed, healthy, with suppressed undergrowth. Ground fires usually with low flame heights, but fire may flare up if fuel concentration heavy. Only under severe weather conditions—high temperatures, low humidities, and high winds—fuels pose fire hazards.
H	Short-needled, healthy conifers with sparse undergrowth and thin layer of ground fuels. Fires typically slow spreading and dangerous only in scattered areas where downed woody fuel is concentrated.
9	Hardwood stands, especially oak-hickory types typical. Concentrations of dead-down woody material contribute to possible torching-out of trees, spotting, and crowning activity. Acceptable for hardwood and mixed hardwood-conifer stands after leaf fall. (To separate hardwoods from conifers [so not to include both in the healthy timber category], this fuel model used though imagery not taken after leaf fall.)
R	Hardwoods after canopies leaf out in spring. Use during summer in all hardwood and mixed conifer-hardwood stands where ≥½ of overstory deciduous.
10	Overmature conifer stands with high loadings of dead-down woody fuel, including shrub understory or conifer reproduction. Dead-down fuels include large quantities of limb wood ≥3 inches resulting from overmaturity or natural events that create large load of dead fuel on forest floor. Fires burn in surface and ground fuels with greater intensity than other timber litter models. Crowning out, spotting, and torching of individual trees more frequent in this fuel type, leading to potential fire control difficulties. Any forest type considered if heavy down fuels present. Examples: insect or disease-ridden stands, wind-thrown stands, overmature stands with deadfall, and aged, light thinning or partial cut slash.
G	Dense conifer stands with heavy accumulation of litter and downed woody branches. Typically overmature, stands may also suffer insect, disease, wind, or ice damage—natural events that create heavy buildup of dead fuel on forest floor. Duff and litter deep; much of woody fuel >3 inches in diameter. Undergrowth variable, but shrubs usually restricted to openings.

[1]Sources: Albini 1976; Deeming and others 1977; Rothermel 1982.

The MSS records spectral reflectance data in four bands of the electromagnetic spectrum. These bands consist of two visible bands (band 4, 0.5-0.6 μm, green and band 5, 0.6-0.7 μm, red) and two near infrared bands (band 6, 0.7-0.8 μm and band 7, 0.8-1.1 μm). Unsupervised and guided clustering[1] classification techniques were used for the computer analysis (Fleming and others 1975). The spectral correlation between an object on the ground and its signature (that is, a characteristic or series of characteristics by which a material may be recognized) is established before pixel classification in guided clustering, and after classification in unsupervised techniques (*fig. 4*).

Field data and image interpretation provided 59 training areas that were digitized to provide raw data for the guided clustering classification. Pixels from ground truth areas of the same resource type were grouped together for analysis. Spectral variations within each group were displayed through single band histograms. Visual interpretation of the histogram shapes (that is, nodes indicating a different class) suggested the probable number of spectral classes within each category.

The computer then clustered pixels into the specified number of classes on the basis of a Swain-Fu minimum distance clustering algorithm (Swain 1973). A minimum spectral distance of 0.45 was chosen as a decision rule. This was based on a theoretical analysis which showed that this minimum distance resulted in a 95 percent probability of correct classification (Fox and Mayer 1979). The separability of all spectral classes was displayed in a matrix with distance values less than the chosen minimum of 0.45 specifically marked. Means and variances for each class were displayed in all four bands. As a result of this information, three modes of action were taken to arrive at a file of distinct classes:

- Classes that were spectrally unique (that is, with no spectral distance value less than 0.45) were retained.
- All pairs of classes that were spectrally similar (that is, with spectral distance values less than 0.45) were pooled. This low separability indicated that the pair represented the same class.
- Classes that were spectrally similar with two or more classes were deleted. This indicated an ill-defined class that probably would be reassigned to the proper class after pooling had been completed.

The unsupervised technique uses the spectral properties of each pixel to determine whether it is spectrally similar to any other pixel. It was estimated that 35 classes were sufficient to define all possible categories.

The spectral classes resulting from both the guided clustering and the unsupervised classification were joined and edited, resulting in a final set of classes. This was done by the same three procedural modes as previously defined for the supervised method.

Spectral curves were generated for each class by plotting their respective means in all four bands. Classes were aggregated on the basis of the general shape of the curves with special consideration given to the slope between the green (band 4) and the red (band 5) parts of the spectrum (4/5 slope). This slope was found to be the most significant factor in determining the resource identity (Mayer and Fox 1981). The 7/5 ratio (that is, two times the mean cluster value in the IR band [band 7] divided by the mean cluster value in the red band [band 5]) was also calculated to help in aggregation. This value is an indicator of general vegetation condition and can be used to establish the spectral line that distinguishes soil from vegetation (Benson and Beck 1979). A two-band graph was also produced to detect any obvious errors in classification not readily visible in the other two methods.

A 1:24,000-scale computer printout of the final grouped categories was generated with the appropriate symbols for both fuel model groups. Resource labels were assigned to the aggregated spectral classes based on ground truth data and photointerpretation.

Landsat Evaluation

A cluster sampling method was used to evaluate Landsat classification accuracy. The classified Landsat scene was divided into 8- by 8-pixel clusters. With a grid system, 30 clusters were selected at random and without replacement throughout the classified scene (*fig. 5*). It was assumed that Landsat's accuracy, evaluated on these 30 primary sampling units (PSU's), was an unbiased estimate of its accuracy throughout the entire classified scene. A matching 8- by 8-pixel cluster grid was drawn on clear acetate at the CIR photography scale (1:31,284). Each cluster was locally fit to the photograph to compensate for relief displacement, which is a shift in position of the optical image of an object caused by the depth of the object below a datum plane. Photointerpretation was used to determine the true land cover category. Because of limitations of time and accessibility of cluster samples on the ground, the acquisition of ground truth data was not possible during the evaluation.

Errors of omission (that is, omitting a pixel from its correct category) and commission (that is, committing a pixel to an incorrect category) and point estimates of the mean probability of correct classification were calculated.

Probabilities of correct pixel classification, considering errors of omission, were determined by the binomial ratio method described by Cochran (1977). A simple binomial approximation for proportions is not valid because of the cluster sampling method used.

[1]This clustering refers to the act of grouping pixels on the basis of spectral characteristics rather than on the locational proximity definition used in the Landsat Evaluation Section.

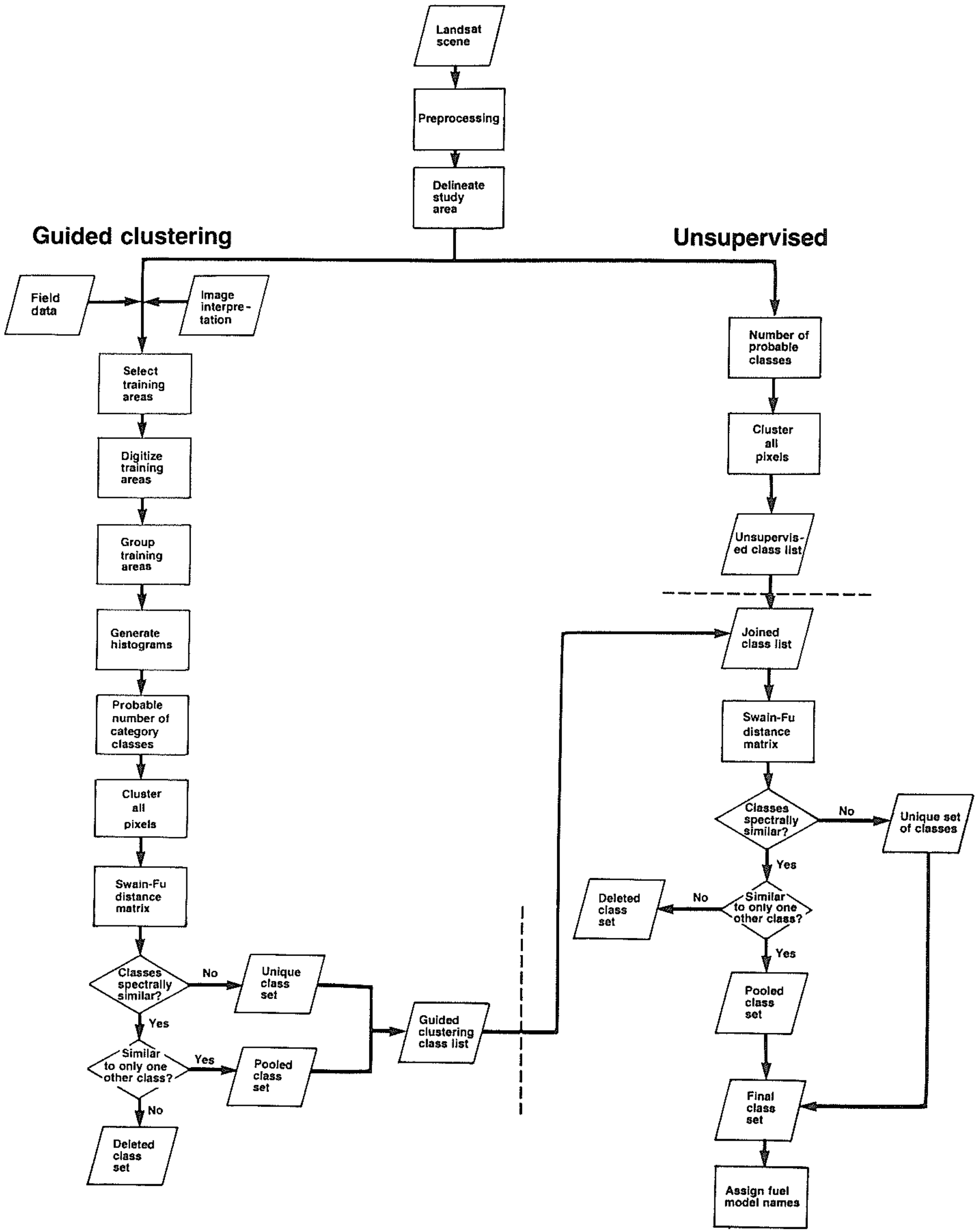


Figure 4—Flow chart of guided clustering and unsupervised classification techniques.

The estimated variance formula for each fuel model category as defined by Landsat is:

$$V(p_j) = \frac{\sum_{i=1}^{n_j} a_i^2 - 2p_j \sum_{i=1}^{n_j} a_i m_i + p_j^2 \sum_{i=1}^{n_j} m_i^2}{n_j \, (n_j - 1) \, \bar{m}_j^2}$$

in which

j = fuel model category
i = 1,2,...,n_j
n_j = no. of PSU's that included representative pixels for each category, ≤30
a_i = no. of correct pixels/PSU
m_i = no. of true (photointerpreted) pixels per PSU

$$\bar{m}_j = \frac{\sum_{i=1}^{n_j} m_i}{n_j} = \text{average no. of true pixels per PSU}$$

$$p_j = \frac{\sum_{i=1}^{n_j} a_i}{\sum_{i=1}^{n_j} m_i} = \text{proportion of correct pixels}$$

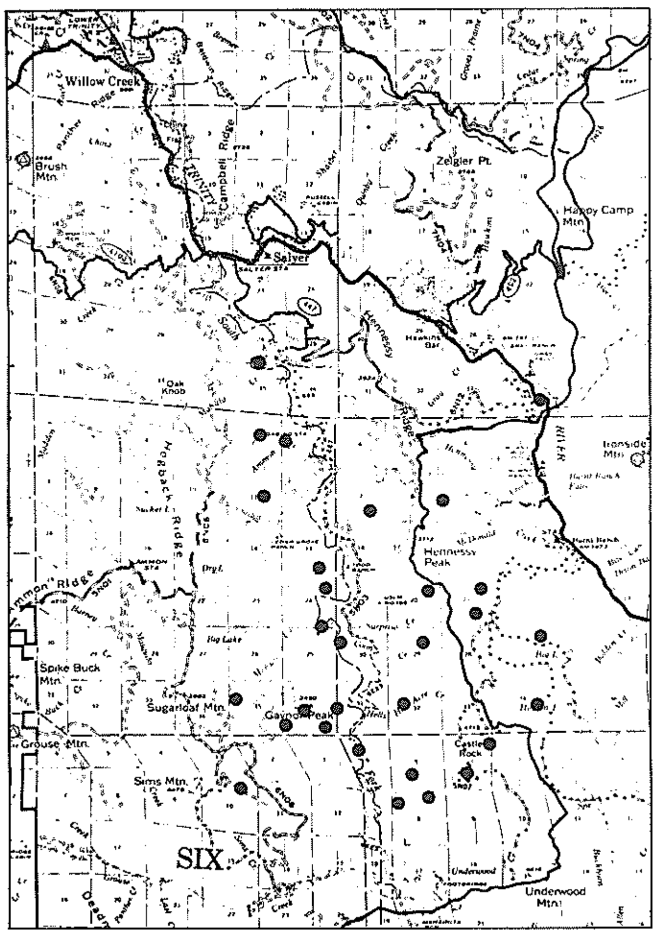


Figure 5—Landsat's accuracy was assessed on 30 primary sampling units (PSU's), selected at random and without replacement throughout the classified scene.

A finite population correction factor (1-f) was ignored because the sampling fraction (2 percent) was well below the minimum of 5 percent specified by Cochran (1977).

Subsequently, standard deviations and confidence intervals at the 95 percent level were calculated considering omission errors. For each identified category, confidence intervals were calculated based on an approximation to a true binomial confidence interval (Snedecor and Cochran 1967).

$$C.I._j = p_j \pm 1.96 \sqrt{\frac{p_j q_j}{N_j}} + 1/2N_j$$

$$p_j = \frac{\sum_{i=1}^{n_j} a_i}{\sum_{i=1}^{n_j} m_i}$$

$$q_j = 1 - p_j$$

$$N_j = \sum_{i=1}^{n_j} m_i$$

a_i, m_i, n_j as in variance formula

Probabilities of correct classification considering errors of commission were calculated from the simple formula:

$$\text{probability correct per category} = \frac{\text{no. ground truth pixels seen by Landsat} - \text{no. incorrect}}{\text{no. ground truth pixels seen by Landsat}}$$

Mylar Overlay Generation

The base map for the overlays was a 7½-minute topographic quad (*fig. 6*). Preattack features were transferred from the photography mylar to the large mylar overlays by a Map-O-Graph and Stereo Zoom Transferscope.[2] Relief displacement was significant enough to require the use of a local fit on steep slopes. Roads and ponds found on both the photo and the topographic map were used to adjust the location of the preattack features.

After completing the Landsat classification, fuel model symbols were printed on mylar overlays at a scale of 1:24,000. Separate overlays were printed for both the NFDRS and the NFFL fuel models.

[2]Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

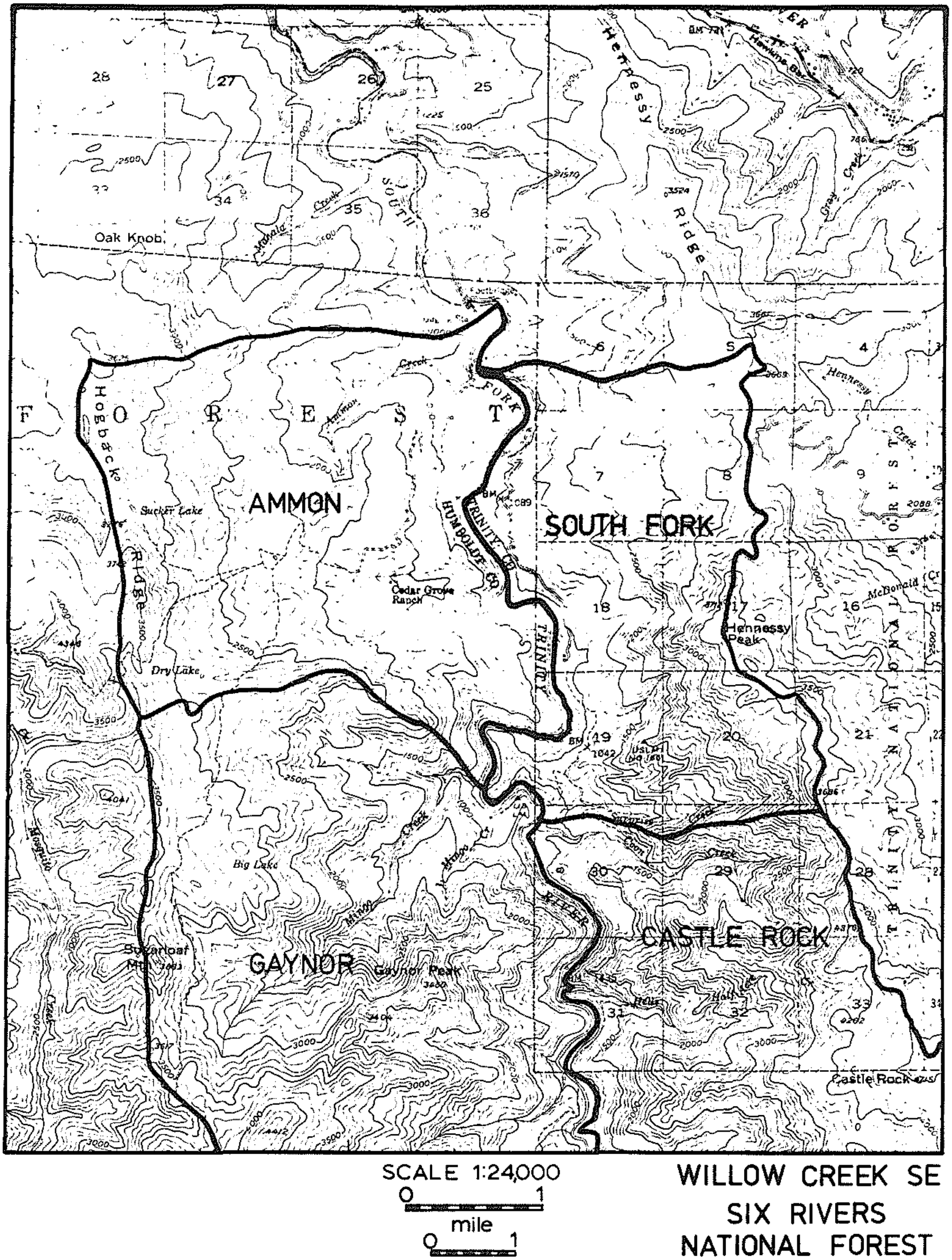


Figure 6—A 7½-min topographic quad, Willow Creek SE, was used as a base map for the overlays.

RESULTS AND DISCUSSION

Landsat Classification

Merging and editing of the spectral classes from the guided clustering (39) and the unsupervised (35) classifications resulted in a final statistics file of 41 distinct classes. The classes resulting from guided clustering were based on previously pooled training fields that had fuel model names associated with them. A running list of resource type names was kept all through the pooling and merging sequences of the guided clustering.

A certain amount of heterogeneity was expected in all "homogeneous" training fields. Spectral curve values for each class, therefore, were reevaluated to determine whether a different category label was necessary. A two-band graph compared band 6 and band 5 digital values (*fig. 7*). This combination was chosen because it spread out the data enough to be useful in class aggregation. In some instances, groups of 10 to 20 pixels of a certain class were located on the CIR photos to aid in fuel model labeling. These same methods were used to define the additional five classes that resulted from pooling the unsupervised with the guided clustering spectral classes. The 41 classes were grouped into a final list of eight fuel models and two land categories (*fig. 7*).

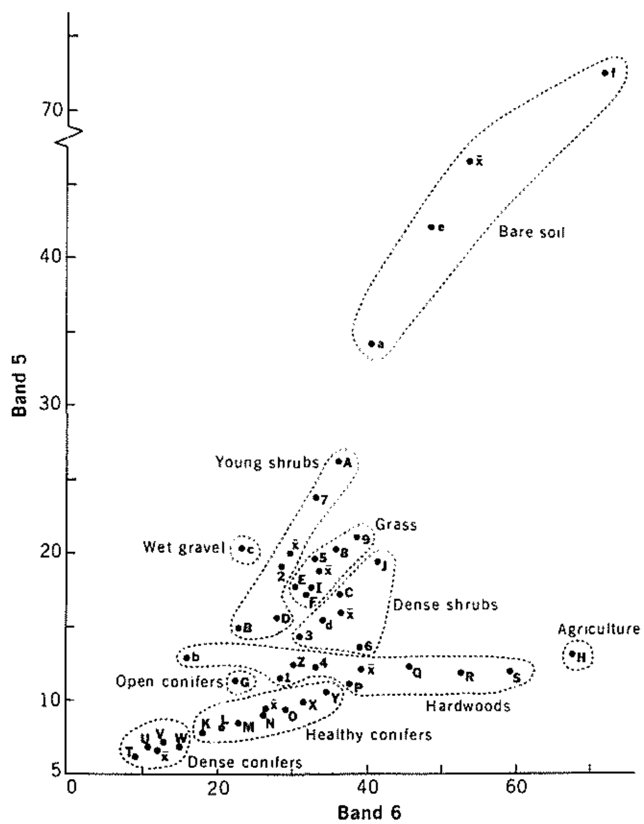


Figure 7—A two-band graph compared digital values for all 41 spectral classes and showed their final grouping.

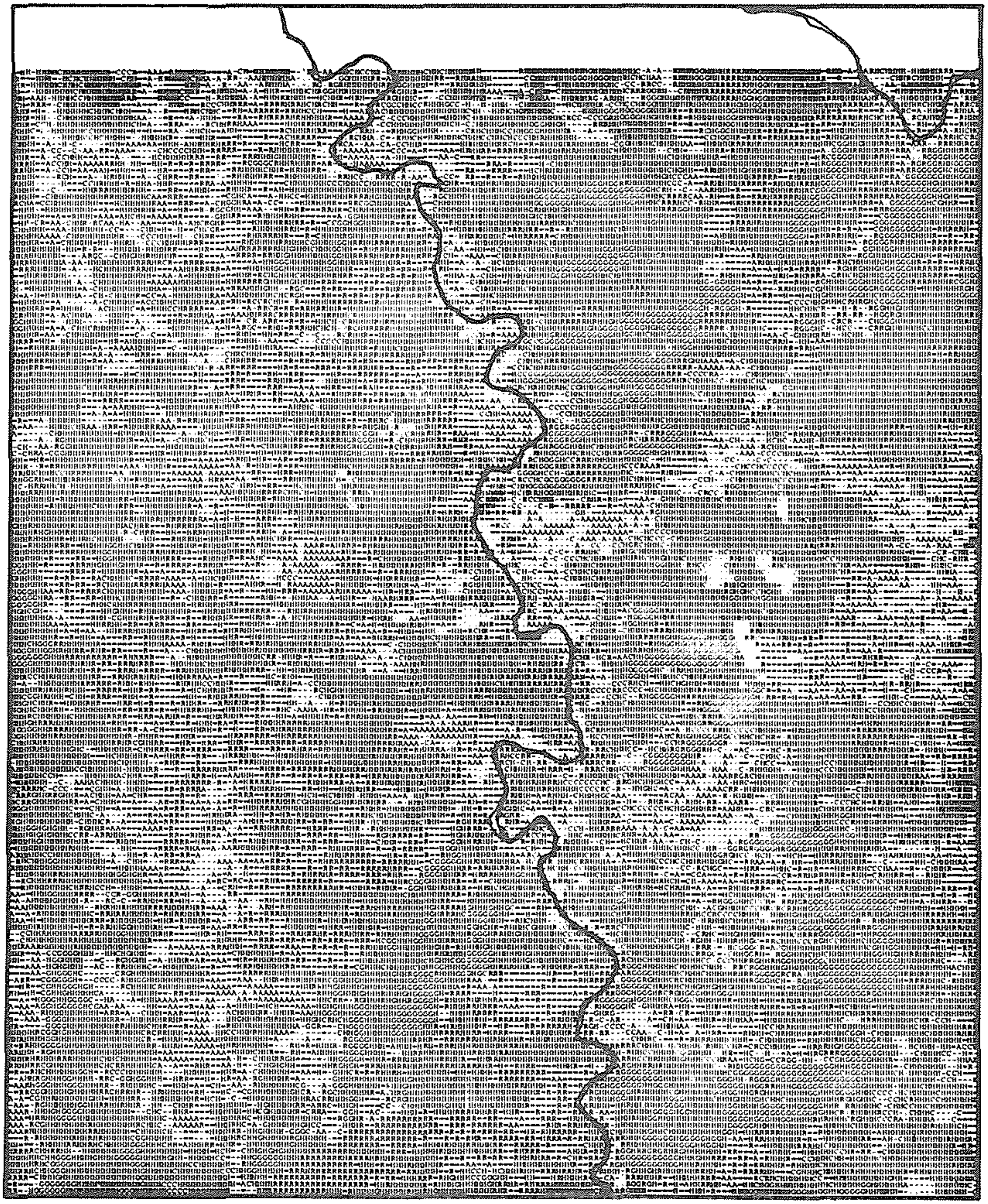
Percentages of pixels varied from 0.06 for agriculture to 47.64 for healthy short-needle conifer stands (*table 3*). The area value assigned a pixel was 1.1 acres (0.45 ha), although the actual value may have varied by 2 to 4 percent (Benson and Katibah 1978). This is because of the mean ground elevation of the area, the fluctuation of attitude, pitch, and roll of the spacecraft, or both. The final Landsat classifications are shown for the NFDRS fuel models (*fig. 8*), and the NFFL fuel models (*fig. 9*). Symbols used on the Landsat overlays are these:

Symbols		
NFFL	*NFDRS*	*Description*
1	A	Short grass
2	C	Open conifer stand
3	N	Agriculture
=	=	Dense shrubs
-	-	Young shrubs
8	H	Healthy short-needle conifer stand
9	R	Hardwoods and mixed hardwood-conifers
0	G	Decadent short-needle conifer stand
.	.	Wet gravel
,	,	Bare soil

The averaged spectral curves corresponded to the final 10 categories (*fig. 10*). Three general land surface features significantly affect the reflected energy measured by the MSS: vegetation cover (for example, species, condition, density), nonvegetated land cover (for example, sand bars, rock outcrops), and topography (for example, slope and

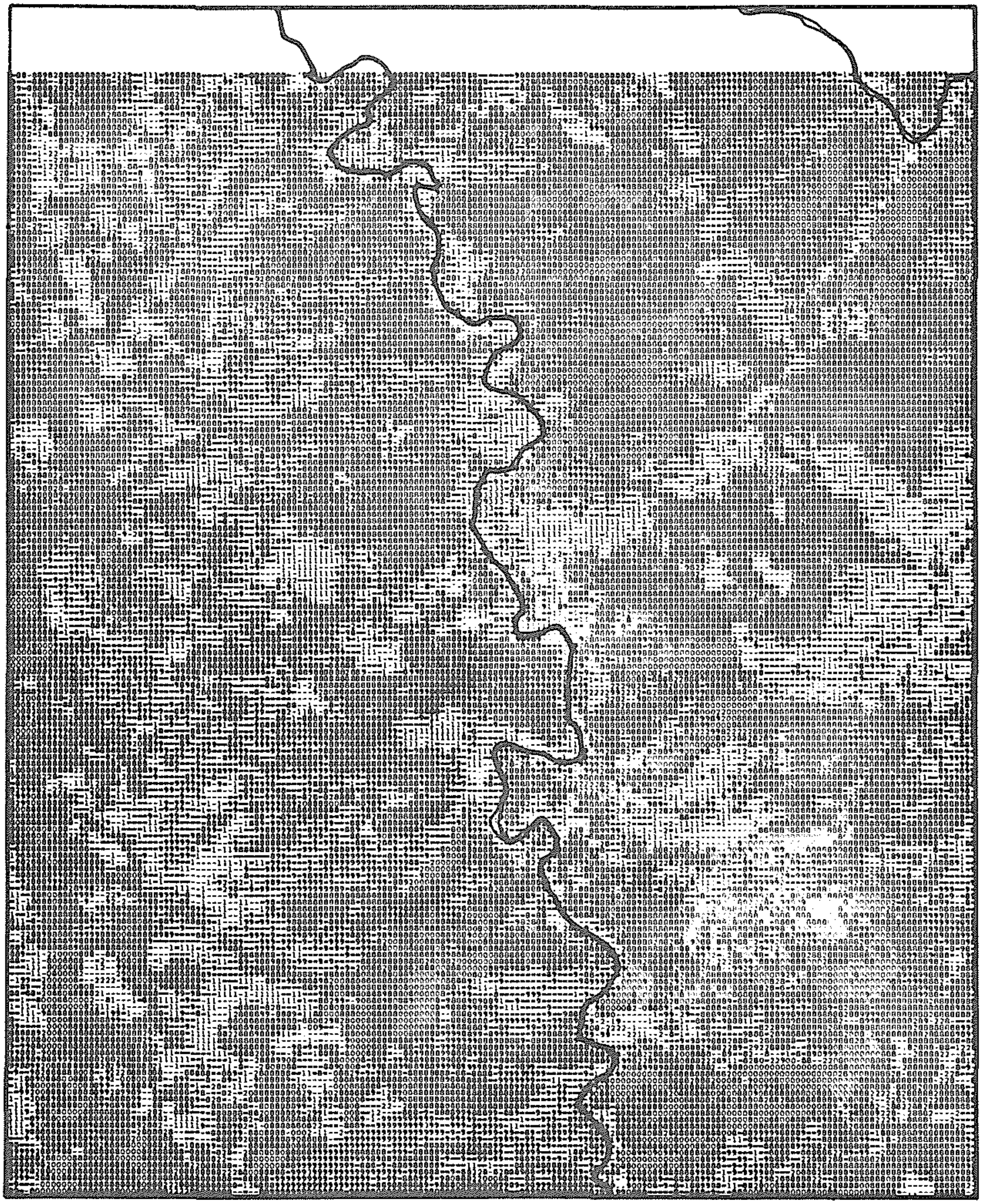
Table 3—*Total number of pixels and area counts for all categories*

Category	Pixels	Total area	Acres	Hectares
		Percent		
Short grass	3,874	4.77	4,261.4	1,724.6
Open conifer stand	3,758	4.63	4,133.8	1,672.9
Agriculture	48	0.06	52.8	21.4
Dense shrubs	11,788	14.52	12,966.8	5,247.7
Young shrubs	6,415	7.90	7,056.5	2,855.8
Healthy short-needle conifer stand	38,670	47.64	42,537.0	17,214.8
Hardwoods and mixed hard-wood-conifers	11,058	13.62	12,163.8	4,922.7
Decadent short-needle conifer stand	4,856	5.99	5,341.6	2,161.8
Wet gravel	512	0.63	563.2	227.9
Bare soil	192	0.24	211.2	85.5
Total	81,171	100	89,288.1	36,135.1



LANDSAT CLASSIFICATION
1978 NFDRS FUEL MODELS

Figure 8—The final Landsat classification of Willow Creek SE quad is shown with National Fire Danger Rating System (NFDRS) fuel model symbols.



LANDSAT CLASSIFICATION
NFFL FUEL MODELS

Figure 9—The final Landsat classification of Willow Creek SE quad is shown with Northern Forest Fire Laboratory (NFFL) fuel model symbols.

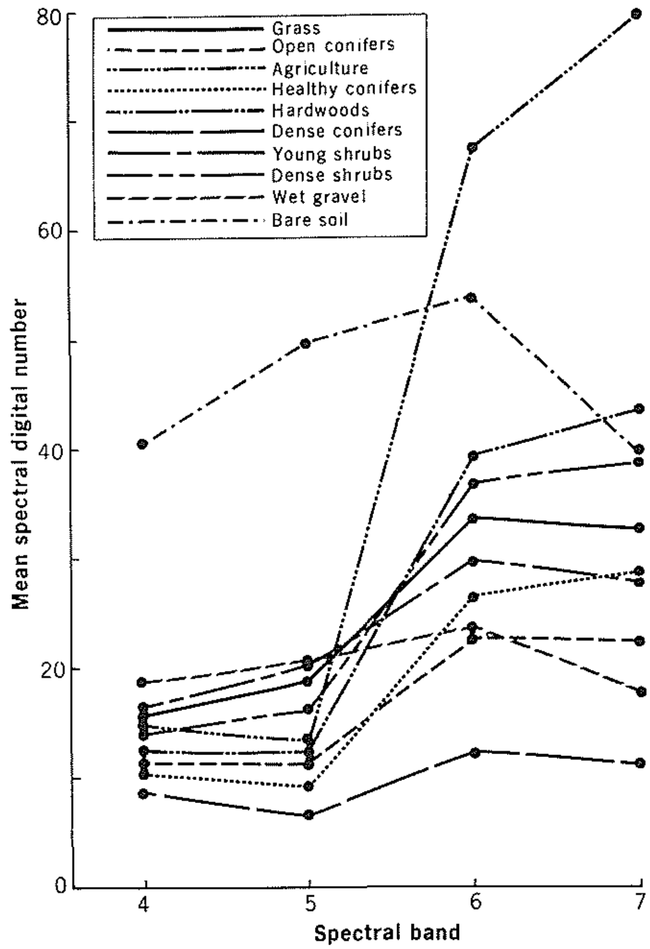


Figure 10—Spectral curves were averaged for all 10 categories of land cover.

aspect) (Joyce 1978). The curves for bare soil and wet gravel are distinctly different from all the vegetation classes. The band 7 value for bare soil was abnormally low, which could indicate wet bare soil because water absorbs electromagnetic energy in the middle infrared (IR) range (Hoffer 1976). This possibility was substantiated by vicinity precipitation records, which indicate that 0.23 inch (0.58 cm) of rain fell within the 4 days before the Landsat imagery data were taken (National Oceanic and Atmospheric Administration 1977). Accompanying maximum temperatures between 58° and 75° F (14° and 24° C) indicate that the soil could have still been wet on the date the imagery was taken. The vegetation curves were much more separable in the IR range (bands 6 and 7) than in the visible range (bands 4 and 5) where much overlapping was observed. The decadent short-needle conifer category was separated from all other fuel types in all bands.

The mean 4/5 slope and the mean 7/5 ratio were derived from grouping the spectral curves for all 41 classes:

Category	*Mean 4/5 slope*	*Mean 7/5 ratio*
Short grass	2.997	1.7
Open conifer stand	−0.14	1.96
Agriculture	−1.5	5.98
Dense shrubs	1.668	2.388
Young shrubs	3.606	1.4
Healthy short-needle conifer stand	−1.0425	3.0325
Hardwoods and mixed hardwood-conifers	−0.26	3.63
Decadent short-needle conifer stand	−2.2375	1.655
Wet gravel	1.5	0.88
Bare soil	9.55	0.83

Negative 4/5 slopes were observed for open conifers, hardwoods, decadent conifers, healthy conifers, and agriculture. Positive values corresponded to grass, both shrub categories, wet gravel, and bare soil. Within the electromagnetic spectrum, a high red reflectance (band 5) means an absence or a small amount of healthy vegetation because leaves with chlorophyll absorb energy in that band. Soil and forest litter increase the red reflectance and when coupled with a low band 4 value result in a positive 4/5 slope. Among all categories, the minimum difference between mean 4/5 slopes was 0.12, corresponding to the difference between hardwoods and open conifer stands. The relative positions of the categories in all four bands, rather than only the slopes between bands, need to be considered when trying to achieve separation of categories.

The mean 7/5 ratios for grass and decadent conifer stands were the closest with a difference of 0.045. A threshold 7/5 ratio value of 1.09 was given by Benson and Beck (1979) as the spectral line that separates vegetation from soil. Both wet gravel (0.88 value) and bare soil (0.83 value) fell substantially below this line. The next closest value was for young shrubs (1.4), which could have bare soil associated with it. Relative rankings of the cover types were consistent with Benson and Beck's (1979) rankings for the 7/5 ratios (that is, in increasing order: barren, grass, shrubs, conifers, hardwoods, agriculture).

Landsat Accuracy

The cluster sampling technique resulted in the evaluation of 1920 pixels. A minimum of 50 pixels to be collected for each Landsat-classified category that is being evaluated for accuracy estimates has been suggested (Hay 1979). The decadent conifer category pixel total (45) fell below this minimum, but was retained in the evaluation. This category accounts for only 6 percent of the population but is considered a significant category in presuppression planning. Insufficient numbers of pixels were available to evaluate agriculture (0), bare soil (2), and wet gravel (25) and,

Table 4—*Confusion matrix for evaluated pixels comparing Landsat classification and ground truth information for all categories*

Ground truth	Landsat classification										
	Grass	Dense shrubs	Young shrubs	Open conifer stand	Hard-woods	Short-needle conifer stand: Decadent	Short-needle conifer stand: Healthy	Agri-culture	Wet gravel	Bare soil	Total
Grass	*43*	5	2	0	1	0	0	0	1	0	52
Dense shrubs	9	*190*	20	2	37	0	16	0	0	0	274
Young shrubs	17	40	*71*	0	8	0	8	0	3	1	148
Open conifer stand	4	14	4	*49*	3	0	21	0	0	0	95
Hardwoods	3	35	19	6	*186*	0	82	0	1	0	332
Decadent short-needle conifer	0	0	0	1	0	*33*	11	0	0	0	45
Healthy short-needle conifer	0	28	8	37	68	28	*777*	0	0	0	947
Agriculture	0	0	0	0	0	0	0	*0*	0	0	0
Wet gravel	1	0	3	0	4	0	1	0	*15*	1	25
Bare soil	0	0	1	0	0	0	0	0	0	*1*	2
Totals	77	312	128	95	307	61	917	0	20	3	1920

therefore, these categories were not included in any accuracy calculations. Their areas were also small in overall size—each was estimated to be less than 1 percent of the total area—and are of little consequence to fire managers, except when used as fire suppression control lines.

A confusion matrix compares pixel identification as reported by ground truth and Landsat and shows where errors in classification were made (*table 4*). All 1920 pixels were evaluated by Landsat and by ground truth, with dissimilarity (that is, values off the diagonal) indicating an error. The confusion matrix data are summarized and evaluated to determine errors of omission (*table 5*) and commission (*table 6*). For errors of omission, probabilities of correct classification ranged from 0.48 for young shrubs to 0.83 for grass. Commission mean probabilities of correct classification ranged from 0.52 for open conifers to 0.85 for healthy conifers. An overall mean probability of correct classification (0.71) was found for errors of both omission and commission.

These data, in part, determine the feasibility of using remote sensing techniques to document preattack parameters. One study suggested 85 to 90 percent as the permissible accuracy range in image interpretation of remote sensor data for levels I and II of land-use studies (Anderson and others 1972). This analysis was a combination of classification levels II and III.

Table 5—*Statistical values of correct classification, considering errors of omission for all fuel models*

Fuel model	Mean probability of correct classi-fication	Standard deviation	Clusters	95 Percent confidence interval
Grass	0.83	0.0658	10	±0.11
Dense shrubs	.69	.0566	27	± .06
Young shrubs	.48	.0595	19	± .08
Open conifer stand	.52	.0613	26	± .11
Hardwoods	.56	.0805	29	± .05
Decadent short-needle conifer stand	.73	.134	8	± .14
Healthy short-needle conifer stand	.82	.0246	30	± .02
Overall	0.71	0.022	30	± .08

Table 6—*Mean probabilities of correct classification, considering commission errors, for all fuel models and their corresponding cluster sample size*

Fuel model	Mean probability of correct classification	Cluster sample size
Grass	0.56	16
Dense shrubs	.61	25
Young shrubs	.55	21
Open conifer stand	.52	23
Hardwoods	.61	28
Decadent short-needle conifer stand	.54	8
Healthy short-needle conifer stand	.85	30
Overall	0.71	30

The use of NFDRS and NFFL fuel models to describe the vegetation could explain a major portion of these low accuracy values. Fuel models were initially constructed to organize fuels data for input into Rothermel's mathematical fire spread model (Rothermel 1972). The underlying idea in their formulation was that certain fuel characteristics (for example, fuel loadings, surface-area-to-volume ratios, heat values, fuel bed compactness) are inherent and, once defined, do not need to be remeasured. To comply with the Rothermel model constraints, the fuel array was assumed to be continuous and contiguous to the ground. Variations of environmental factors, such as fuel moisture, slope, and windspeed, account for ranges of fire behavior—rates of spread, fireline intensity, and flame length—for fires occurring in each fuel model.

The NFDRS was designed to provide information for regional presuppression planning at a scale of 1000 to tens of thousands of acres. One or two fuel models, out of a choice of 20, were assigned to an area based on the typical most severe fuel situation within each protection unit. This decision is not based solely on cover types but on how much fuel, by classes, is present and how it is arranged (Gaylor 1974).

The NFFL or fire behavior system has operational fire behavior estimation as its goal. Its overall design is more site-specific than that of the NFDRS. A total of 13 NFFL fuel models are available. They emphasize the fine fuels that carry the fire, and large fuel components are subsequently left out of the fire behavior fuel models. It should be possible, with increased fire behavior experience, to select the appropriate fuel model not only by its description of the physical vegetation but also by the known fire behavior characteristics of the fuel components that would carry the fire. In nonuniform fuel arrays, two NFFL fuel models can be applied, one to represent the most continuous cover over the area and the second to represent the accumulation of fuels that will burn differently from the first (Rothermel 1982).

The Landsat MSS registers spectral reflectance data in four bands of the electromagnetic spectrum. Therefore, it only "sees" cover types and is not capable of discerning understory conditions unless implications can be made from the overstory about the underlying vegetation or fuel conditions. The same is true for aerial photointerpretation. Unless openings in the canopy are found, conclusions cannot validly be made about other fuel layers besides the uppermost one. Landsat also averages the spectral response for each 1.1-acre pixel. Within a forest, much variation can be observed within an area of 1.1 acres.

These capability factors result in an incompatibility between the fuel model descriptions and the interpretation of "on-the-ground" conditions. Most fuel models will apply to more than one situation and "best fits" and "can also be used for" descriptions are valid (Albini 1976). For example, NFFL fuel model 2, labeled "Timber (Grass and Understory)" best fits open pine–grassy understory, wiregrass–scrub oak association but can also be used for timber–sagebrush–grass associations. Three distinct fuel types are possible in this fuel model—timber, grass, and brush. The description of fuel model 2's NFDRS counterpart (C) indicated that some shrubs may be present, but are of little consequence (Deeming and others 1977). When averaging the spectral responses for each pixel, the inclusion of some shrubs could result in a different fuel model being chosen. This could partially explain the calling of 18 (19 percent) open conifer stand pixels, shrub pixels.

Confusion was also found between decadent conifer and healthy conifer stands. Twenty-four percent of the decadent conifer pixels were misclassified as healthy conifer pixels. Because photointerpretation was the sole source for acquiring ground truth data, only obvious signs of unhealthy conifer stands were discernible (for example, dead trees). The primary factor that differentiated decadent from healthy conifer stands is the amount of ground fuels and understory, both of which are indistinguishable from above a closed canopy.

Hardwoods were confused with healthy conifers 25 percent of the time. On simulated CIR Landsat composites where hardwoods and conifers are mixed in stands, Earth Information Services (1975) found the hardwood color predominated and the stand was usually classified as hardwood. Fuel model R (NFDRS) allows for the presence of 50 percent or less of conifers within a stand. Fuel model 9 (NFFLS) also includes in its description mixed hardwood–conifer stands after leaf fall. Amounts for the maximum level of conifers were not indicated.

The two shrub fuel models are separated within the NFDRS by age, height, and area covered. Age could not be determined with available data. Shrub height determinations of greater than or less than 6 ft (1.83 m) were deemed too difficult with the scale of the photos and the cover conditions encountered. Shrub categories, therefore, were chosen during photointerpretation solely on the basis of the amount of area covered. Forty (13 percent) pixels were committed to the young shrub category (that is, shrubs covering less than two-thirds of the site) that Landsat saw as dense shrubs and 20 (15 percent) dense shrub pixels that Landsat called young shrubs. Locally fitting the cluster samples during photointerpretation could be a major factor in misclassifying young and dense shrub pixels. On the 1:31,284 CIR photography, each 1.1-acre pixel corresponds to a rectangle 0.099 by 0.070 inch (0.25 by 0.175 cm). A minor locational error could result in a different fuel model. In definite boundary areas (for example, clearcuts), the location of each PSU was deemed relatively accurate. In areas where no definite vegetation change was visible, location was more difficult.

Shrub types, when occupying two-thirds of the site or reaching 6 ft in height, can be spectrally similar to hardwoods. This may account for 13.5 percent of the dense shrub pixels misclassified by Landsat as hardwoods or the 10.5 percent of hardwoods misclassified as dense shrubs. When evaluating the NFDRS shrub fuel model (F), 28 percent of the shrub pixels were classified as woodland (Benson and Beck 1979). Woodland was not specifically described in the text, but it was assumed to be a hardwood or hardwood–conifer category.

Locational error could again have been a reason for the sizable misclassification of healthy conifer stands as open conifer stands (39 percent).

Timeliness in acquiring ground truth for the training plots may also account for some of the misclassifications. Landsat imagery was taken in 1977 and the CIR photos were taken in 1978. Ground truth was acquired between March and May 1980. From 2 to 3 years were found to be the maximum useful timespan in a Landsat-based forest inventory (Peterson and Card 1978). Originally, this study was going to include the three slash fuel models, but it was not possible to evaluate what was on the ground in clearcuts 3 years ago. Areas of heavy slash are usually cleared, burned, or both, soon after harvesting, before an additional fuel hazard develops. The Ranger Station's fuel inventory figures were calculated from an averaging of plots throughout the clearcuts. Checking each 1.1 acre (0.45 ha) against an averaged value would definitely have resulted in invalid percent correct figures. These training plots were instead called either young or dense shrubs because shrubs were found to appear quickly after clearcutting or burning.

Another problem associated with using the Landsat imagery chosen was that 1977 was the second year of California's 2-year drought. Vegetation and other ground conditions, therefore, would appear abnormal in that year (Benson and Katibah 1978).

Photointerpretation

Photointerpretation of the CIR photos resulted in 71 roads for the entire study area, with 6 designated as major arteries and 65 designated as minor (*fig. 11*). Twelve of these were not located or identified on Forest Service road maps. The conditions of previously undocumented roads (for example, passability) and their exact locations would need to be ground checked before they were incorporated into a dispatching plan.

A significant advantage of using aerial photos for documenting purposes is that the method does not respect property lines, and private roads are also registered. Use of private roads could improve the accessibility of vital areas to suppression forces.

Fifteen water sources were located on the photos. The smallest was about ½ acre (0.2 ha). The average ¼-acre (0.1 ha) pond with a 7-ft (2.13 m) maximum depth represents about 0.18 acre ft (220.23 m^3) or 57,000 gallons (215,460 *l*) of water (Marcot 1978).

CONCLUSIONS

Remote sensing techniques can provide an abundance of information suitable for use in a preattack plan. Although Landsat's overall accuracy level was 71 percent, the bulk of the inaccuracies are attributed to incompatibilities found between fuel model descriptions and remote sensing capabilities. Each NFDRS and NFFL fuel model can represent more than one vegetation type, whereas Landsat registers the existing vegetation for each 1.1 acres (0.45 ha). For preattack purposes, however, the moderate accuracies found are an improvement over the present method of assigning one fuel model to 1000-plus acres.

For preattack planning maps, however, Landsat's resolution might be considered too precise. The systematic grouping of pixels could be an alternative which would smooth the data to a lower resolution. This could either be done visually by a fire manager or by a computer-assisted pixel clustering technique (for example, one that compares each pixel to the eight surrounding it and then assigns it to the category that appears most often).

Clearcuts are well defined on the Landsat fuel map, and this knowledge alone can be useful in suppression planning. The slash and shrubs associated with clearcuts often correspond to high resistance to control and high intensities that require specific suppression tactics.

Real-time fire planning also necessitates a more detailed and up-to-date fuel map than is presently available to the Forest Service. Once this system is operational, updates could be incorporated regularly into the existing preattack plan at minimal cost.

To be useful, preattack plans need to be attained quickly and updated easily. One so detailed that, upon completion, requires almost total revision, defeats its intended purpose.

Considering only topographic features, some indication of rates of spread, pattern of burn, and potential for a change in fire behavior is evident. When topographic features are coupled with a fuel type map, even accuracies of 60 percent will aid in the decisionmaking process. This degree of accuracy may result in over- or underestimating fire conditions, but even a limited preattack plan is better than none (Dell 1972). The addition of the road and water system can provide a base from which future planning needs could be directed. Potentially hazardous areas along roadsides or on private lands, for example, could be determined from the overlays. All water sources could be inventoried for future suppression use. As was shown by the soil parameter figure (*fig. 3*), the use of an overlay system makes possible the addition of other information that is also significant in planning.

The techniques used in this study provide a basic preattack plan that is moderately reliable and easily updated. Future studies should direct their efforts toward coordinating Landsat imagery, aerial photography, and ground truth at approximately the same time. More extensive ground truth should be acquired and incorporated into the system. If available for a study area, digitized slope, aspect, and elevation data should be combined with the Landsat imagery to aid in classification decisions. All future studies should also include cost analysis as part of their design.

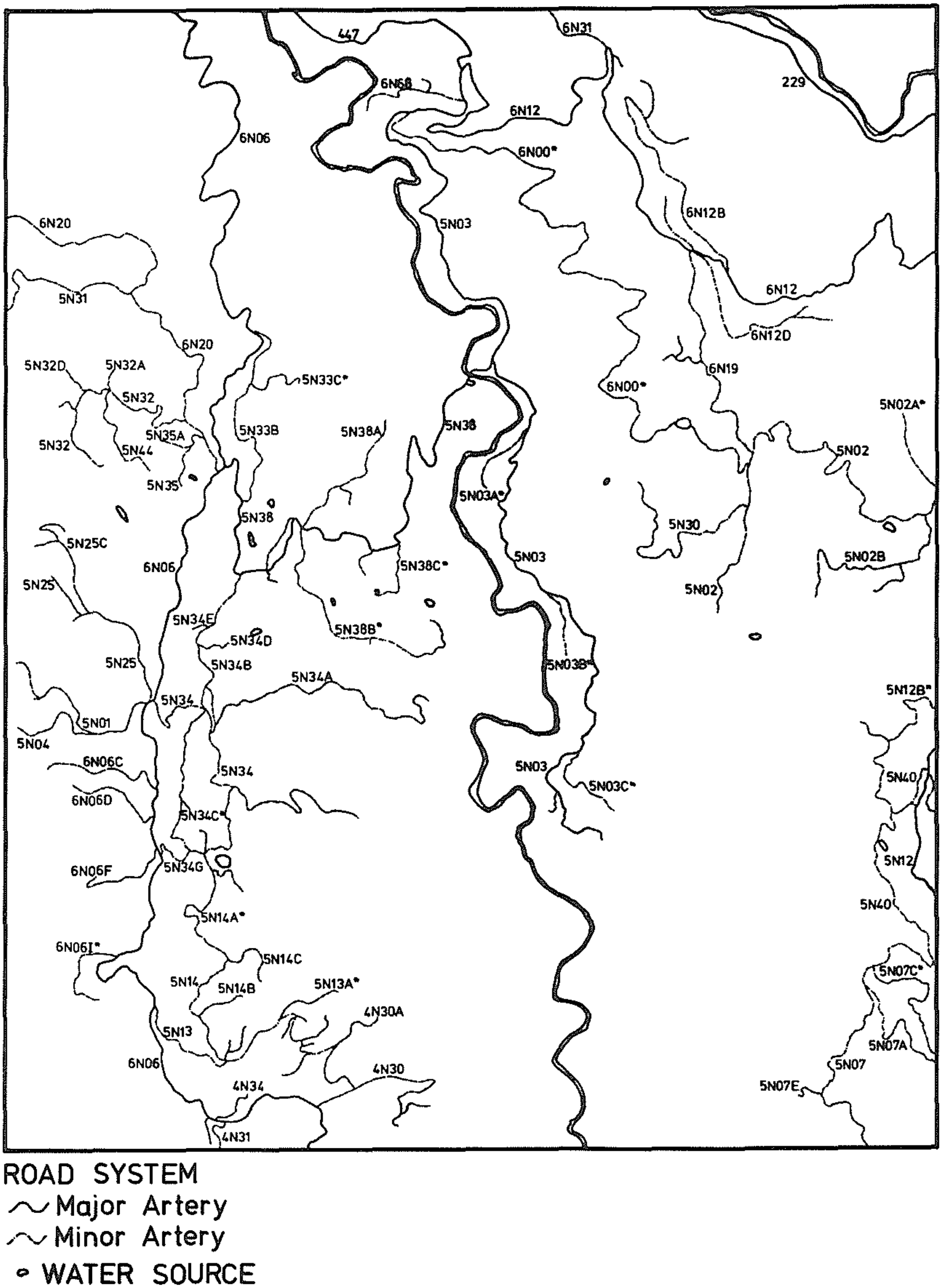


Figure 11—Major and minor road arteries and water sources were identified for the Willow Creek SE quad. Roads not found on Forest Service maps are marked with an asterisk.

REFERENCES

Albini, Frank A. **Estimating wildfire behavior and effects.** Gen. Tech. Rep. INT-30. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1976. 92 p.

Anderson, J. R.; Hardy, E. E.; Roach, J. T. **A land-use classification system for use with remote sensor data.** Circ. 671. Washington, DC: Geol. Surv., U.S. Dep. Inter. 1972. 16 p.

Benson, A. S.; Beck, L. H. **An investigation of the uses of digitally mosaicked Landsat data for mapping wildland fuel hazards in Mendocino County, California.** Ser. 21, Issue 2. Berkeley, CA: Space Sci. Lab., Univ. Calif., NASA Ames Remote Sensing Res. Program; 1979. 78 p.

Benson, A. S.; Beck, L. H.; Henderson, C. **Fuel mapping in relation to the management of brushlands and timberlands in California. Ch. 2 in Applications of remote sensing to selected problems in California.** Ser. 21, Issue 14. Berkeley, CA: Space Sci. Lab., Univ. Calif., NASA Ames Remote Sensing Res. Program; 1979.

Benson, A. S.; Katibah, E. F. **Fuel mapping in relation to the management of brushlands and timberlands in Mendocino County, California.** Ser. 19, Issue 64. Berkeley, CA: Space Sci. Lab., Univ. Calif., NASA Ames Remote Sensing Res. Program; 1978. 54 p.

Chismon, H. **The use of remote sensing data in cartography.** In: Environmental remote sensing 2: practices and problems. Second Bristol symposium on remote sensing; 1974 October 2; Bristol, England. New York: Crane, Russak, and Co., Inc.; 1977; 82-100.

Cochran, W. G. **Sampling techniques.** 3d ed. New York: John Wiley and Sons, Inc.; 1977; 64-68.

Colwell, R. N., ed. **Manual of photographic interpretation.** Menasha, WI: Am. Soc. Photogramm., George Banta Co.; 1960. 868 p.

Cosentino, M. J.; Woodcock, C. E.; Franklin, J. **Scene analysis for wildland fire-fuel characteristics in a Mediterranean ecosystem.** Proceedings of the 15th international symposium on remote sensing of environment; 1981 May 18-25; Ann Arbor, MI: Environmental Res. Inst. of Michigan; (In press).

Deeming, J. E.; Burgan, R. E.; Cohen, J. D. **The national fire danger rating system—1978.** Gen. Tech. Rep. INT-39. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1977. 63 p.

Dell, J. D. **R-6 preattack guide—area planning and development for forest fire protection in the PNW Region.** Portland, OR: Forest Protection Research, Pacific Northwest Region, Forest Service, U.S. Department of Agriculture; 1972. 67 p.

Earth Information Services. **Multispectral analysis and mapping of southern California fuel types.** Final report. Huntington Beach, CA: McDonnell Douglas Corp. 1975; 59 p.

Fleming, M. D.; Berkebile, J. S.; Hoffer, R. M. **Computer-aided analysis of Landsat-1 MSS data: a comparison of three approaches, including a "modified clustering" approach.** Inf. Note 072475. West Lafayette, IN: Purdue Univ., Lab. for Appl. Remote Sensing; 1975. 8 p.

Fox, L.; Mayer, K. E. **Using guided clustering techniques to analyze Landsat data for mapping land cover in northern California.** Machine processing of remotely sensed data symposium; Fifth annual symp.; 1979 June 27-29; West Lafayette, IN. Piscataway, NJ: Institute of Electrical and Electronics Engineers; 1979; 364-367.

Gaylor, H. P. **Wildfires—prevention and control.** Bowie, MD: Robert J. Brady Co.; 1974. 319 p.

Hay, A. M. **Sampling designs to test land use map accuracy.** Photogramm. Eng. and Remote Sensing 45(4):529-533; 1979.

Hoffer, R. M. **Spectral reflectance characteristics of earth surface features.** West Lafayette, IN: Purdue Res. Found.; 1976. 9 p.

Joyce, A. T. **Procedures for gathering ground truth information for a supervised approach to a computer-implemented land cover classification of Landsat acquired multispectral scanner data.** Ref. Publ. 1015. Houston, TX: Lyndon B. Johnson Space Cen. Natl. Aeronaut. and Space Adm.; 1978. 43 p.

Kourtz, P. H. **An application of Landsat digital technology to forest fire fuel type mapping.** Proceedings of the 11th international symposium on remote sensing of environment, volume II; 1977 April 25-29; Ann Arbor, MI. Ann Arbor, MI: Environmental Res. Inst. of Michigan; 1977; 1111-1115.

Marcot, B. G. **Flora and fauna of existing and potential slump pond sites in Six Rivers National Forest with recommendations for management.** Arcata, CA: Humboldt State Univ.; 1978. 87 p. Dissertation.

Mayer, K. E. **Watershed condition inventory of the Hoopa Valley Indian Reservation utilizing Landsat digital data.** Arcata, CA: Humboldt State Univ.; 1979. 48 p. Dissertation.

Mayer, K. E.; Fox, L. **Identification of conifer species groupings from Landsat digital classifications.** Photogramm. Eng. and Remote Sensing 47(11):1607-1614; 1981.

National Oceanic and Atmospheric Administration. **Climatological data—California,** volume 81(4). 1977; 38 p. Available from: Environ. Data Serv., Nat. Clim. Cent., Asheville, NC.

Oakeshott, Gordon B. **California's changing landscape: a guide to the geology of the State.** New York: McGraw-Hill Book Co.; 1971. 388 p.

Parsons, A. M.; Knox, E. G. **Soils of the Six Rivers National Forest.** Tech. Rep. 53-9A47-62. Columbia, MD: SaLUT-Soil and Land Use; 1980. 289 p.

Peterson, D. L.; Card, D. H. **Issues arising from the demonstration of Landsat-based technologies to inventories and mapping of the forest resources of the Pacific Northwest States.** NASA Ames Res. Center. Presented at the 7th annual conference on remote sensing of earth resources; 1978 March 27-28; Tullahoma, TN. Tullahoma, TN: Univ. of Tenn. Space Inst.; 1978. 35 p.

Poulton, C. E.; Welch, R. J. **"Ground data verification methods laboratory exercise" treating one element of an integrated remote sensing system for earth resources inventory and monitoring.** Mountain View, CA: Airview Spec. Corp.; 1979. 26 p.

Rothermel, R. C. **A mathematical model for predicting fire spread in wildland fuels.** Res. Paper INT-115. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972. 40 p.

Rothermel, R. C. **How to predict the spread and intensity of forest and range fires.** 1982. Review draft, Intermountain Forest and Range Experiment Station, Ogden, UT.

Shasby, M. B.; Burgan, R. E.; Johnson, G. R. **Broad area forest fuels and topography mapping using digital Landsat and terrain data.** Draft of EROS Data Center report on work performed under USGS contract #14-08-0001-16439; 1981. 35 p.

Snedecor, G. W.; Cochran, W. G. **Statistical methods.** 6th ed. Ames, IA: Iowa State Univ. Press; 1967: 210-211.

Swain, P. H. **Pattern recognition: a basis for remote sensing data analysis.** Inf. Note 111572. West Lafayette, IN: Purdue Univ., Lab. for Appl. Remote Sensing; 1973. 41 p.

The Forest Service of the U.S. Department of Agriculture

...Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

...Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

...Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

...Represents the research branch of the Forest Service in California, Hawaii, and the western Pacific.

Salazar, Lucy Anne. **Remote sensing techniques aid in preattack planning for fire management.** Res. Paper PSW-162. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 19 p.

Remote sensing techniques were investigated as an alternative for documenting selected preattack fire planning information. Locations of fuel models, road systems, and water sources were recorded by Landsat satellite imagery and aerial photography for a portion of the Six Rivers National Forest in northwestern California. The two fuel model groups used were from the 1978 National Fire Danger Rating System and the Northern Forest Fire Laboratory. Landsat-derived fuel model data were digitized and computer analyzed by unsupervised and guided clustering techniques to produce a fuel model map of the area. Overall Landsat classification accuracies of fuel models were moderate—71 percent. This was mainly due to the incompatibilities found between fuel model descriptions and remote sensing capabilities. The results suggest, however, that a basic preattack plan that is moderately reliable, quickly attainable, and easily updated is feasible by applying remote sensing techniques.

Retrieval Terms: remote sensing, preattack planning, fire management, presuppression planning