FUELS INVENTORIES AND SPATIAL MODELING OF FIRE HAZARDS IN THE LOS ALAMOS REGION

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ABSTRACT

Several land management agencies, including Los Alamos National Laboratory, Los Alamos County, Santa Fe National Forest, and Bandelier National Monument, are working collaboratively toward reducing the fire hazard in the Los Alamos wildland-urban interface. As part of this multi-year project, we have been inventorying fuels, determining the spatial patterns of the fuel levels, assessing the values at risk in the wildland-urban interface, and designing optimal mitigation action strategies. Here we review the preliminary results of the initial two years of fuels inventories and related analyses.

The first year, 1997, was a preliminary survey of fuel levels along the elevation gradient from piñon-juniper woodlands, to ponderosa pine forests, and mixed conifer forests, and on selected topographic positions: canyons, mesas and mountains. The surface fuels were greatest in mixed conifer forests, while the overstory fuels were greatest in mixed conifer forests and in ponderosa pine forests on mesas. These results provided direction for the surveys conducted during the second year, 1998. A random sample of sites above 2100 m in elevation was selected in order to emphasize the portion of the study region that supported the highest fuel loads.

During 1998, it was found that the surface fuels and overstory fuels are greatest at higher elevations in the study region and on north-facing aspects or on relatively steep slopes. Conversely, the variability among the overstory fuels is the greatest at lower elevations in the ponderosa pine zone.

The results of this preliminary survey have several consequences. First, the surveyed fuel loads are consistent with predicted and actual patterns of fire behavior in the study region. Second, the highly variable fuels at lower elevations presents a dilemma to land managers who wish to protect federal facilities and residential areas in the wildland-urban interface. Third, these results are useful for mapping the fuels loads in the Los Alamos wildland-urban interface. Fourth, the data generated by this project are being used as inputs to predictive wildfire behavior models and as the basis for optimal mitigation action strategies.

Keywords: forest fuels, fuels inventories, fire hazard analysis, geographic information systems, spatial modeling

INTRODUCTION

The Los Alamos National Laboratory (LANL) and its neighboring land management agencies have been working together to reduce the regional threats from wildfire (Figure 1). LANL, through its operating contractor, the University of California, manages 111 km^2 of land on the eastern flank of the Jemez Mountains for the Department of Energy (DOE). Adjacent or

Figure 1. Location of the Los Alamos Region and selected major landowners.

nearby land holdings are managed by a variety of administrative units that represent several federal agencies, as well as state, tribal and local governments. These include the Bandelier National Monument, Santa Fe National Forest, Los Alamos County, and the San Ildefonso Pueblo, among others. The County of Los Alamos, including Santa Fe National Forest lands, and Bandelier National Monument cover approximately 415 km^2 of land. Approximately 55% of this land is vegetated by ponderosa pine forests and mixed conifer forests (Figure 2). These forests are overstocked and present a wildfire hazard during the annual fire season.

The forests of the Los Alamos region were not always this dense (Allen, C. D. 1989). Before 1880, forest densities were low, and the groundcover consisted mostly of grasses and sedges. Shrubs and small trees were relatively rare. In this environmental setting, wildfires were common and performed important ecological functions. Although frequent, these wildfires

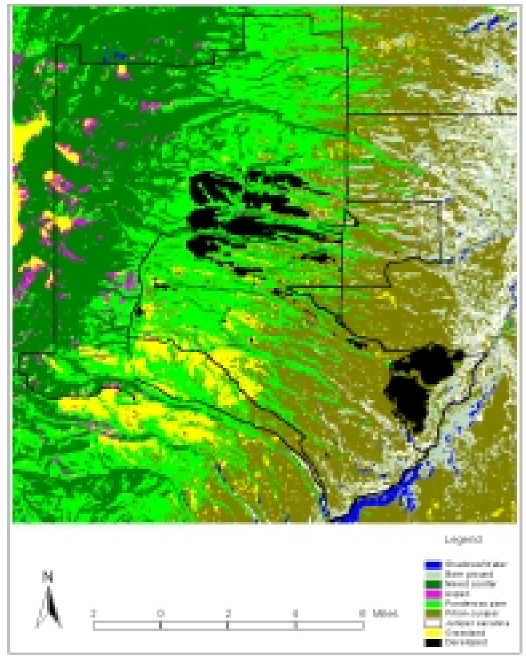


Figure 2. Selected land cover types in the Los Alamos region.

were low-intensity ground fires that did little damage to the forest canopies.

Since that time, the natural fire cycle of frequent, low-intensity fires has been interrupted by human activities, particularly grazing and logging (Allen, C. D. 1989). This interruption of the natural fire cycle, followed by effective fire suppression, produced some unexpected results. The forest vegetation, consisting of a few, widely spaced trees, was replaced by a dense canopy of smaller trees with interlocking crowns. As a result of this unchecked vegetational growth, forests at LANL have become susceptible to severe wildfires that destroy the forests, rather than perpetuate them.

Wildfires in the Los Alamos region potentially threaten more than the forests themselves (Balice R. G. 1997). First, they can destroy federal facilities and residential areas. In the case of the Lab, many of these federal facilities house operations of importance to our national security. Second, they can disrupt operations at LANL and Bandelier National Monument.

In 1996, the land management agencies of the Los Alamos region formed the Interagency Wildfire Management Team (IWMT) (Balice, R. G. 1997). The IWMT consists of representatives from each of the major landowners in the Los Alamos region and its primary purpose is to promote collaboration and cooperation amongst these landowners to reduce the threat from wildfire in the region's forests. This is done by establishing responsibilities for fire suppression under different scenarios, evaluating fire hazards and values at risk, developing and implementing mitigation actions, and informing the public. The IWMT has adopted a research approach to defining and assessing the wildfire hazard problem and for developing mitigation action strategies in the wildland-urban interface that complement actions taken by neighboring landowners, are cost effective, and address the values at risk.

This report presents and summarizes preliminary results of the first two years of this multi-year project. Details of the first year, 1997, can be found in Balice, R. G. et al. (1999). Many of the details for the second year, 1998, can be found in Balice, R. G. (1998). Fuel levels, topographic setting, soil characteristics, and vegetational structures were sampled at selected sites in 1997 and 1998. These data were analyzed for within-plot and between-plot fuel levels and for the spatial patterns of these fuel loads. Since this is an exploratory study, the results of the field sampling in any given year were and will continue to be used to modify the scope of the sampling design for the subsequent year. Ultimately, the combined results of this project will form the basis for designing optimal mitigation action strategies.

METHODS

Scope of the Study

The Los Alamos study region includes lands administered by four agencies. These include 1) LANL, 2) Santa Fe National Forest, extending to the crest of the Sierra de los Valles and north to the Guaje Canyon area, 3) the northern and western portions of Bandelier National Monument, and 4) the Los Alamos townsite and its surroundings that are administered by the County of Los Alamos. In 1997, sampling emphasized LANL and Forest Service property. Based on these results, the eastern portions of the Lab were not sampled in 1998. Instead, greater emphasis was placed on the western portions of the Lab and National Forest lands. In addition, the western portions of Los Alamos County and the Bandelier National Monument were added to the sampling system.

Development of the Sampling Frame

During 1997, one of the objectives of the sample design was to cover the full range of dominant topographic and upland vegetation types within the middle elevations of the Los Alamos region. These types included canyons, mesas, and mountains, and piñon-juniper woodlands, ponderosa pine forests, and mixed conifer forests, respectively. As such, potential sample sites were subjectively chosen from all possible sites that are accessible by road, represent combinations of these major vegetation-topographic conditions, and are homogeneous with respect to vegetation, soils, and topography in an area at least 60 m by 60 m in size.

During 1998, the second year of the study, emphasis was placed on portions of the Los Alamos region that were above 2100 m in elevation, without regard to accessibility. As such, most of the sampled sites were in mixed conifer forests and on mountainous topography. The resulting region for 1998 is approximately 18.3 km long and 13.7 km wide: a total of 250.7 km^2. Having established this study area, we selected potential sample sites according to the following procedure.

Several geographic information system (GIS) data layers, including soils, geology, vegetation cover types, elevations, digital elevation models (DEMS), land ownerships, roads, and buildings and facilities, were assembled for the study area. A recent Landsat Thematic Mapper (TM) image of the study area was also obtained. The DEMS were mosaicked into a single DEM basemap consistent with National Map Accuracy Standards (Crippen, R.E. 1989). The TM and other datasets were registered to the DEM basemap. Selected TM, DEM, and other GIS data layers that are known to be consistent with vegetation characteristics were clustered into 11 groups (Davis, F. W. and S. Goetz 1990). These groups formed strata of spectral and spatial structures from which sample sites were randomly selected, 100 in each group. Each selected sample site was constrained to be spectrally and spatially homogeneous and at least 60 m by 60 m in size. This is equivalent to four 30-m by 30-m TM pixels.

Individual sites on the randomized list were selected and located on the ground with the assistance of a global positioning system (GPS) receiver. Then, each site was checked for homogeneity with respect to vegetation, soils, and topography in an area at least 60 m by 60 m in size.

Plot Layout

In 1997, data were collected in circular plots under a total enumeration design. In 1998, square plots were used with a randomized, nested sampling design. In addition, randomized within-plot subsampling was incorporated into this nested design. For the purposes of this report, the data collection procedures for 1998 will be described. Regardless of the differences in plot shapes, the actual on-the-ground sampling procedures were very similar from 1997 to 1998. Detailed descriptions of the field methods for 1997 and 1998 can be found in Balice, R. G. et al. (1999) and Balice, R. G. (1998), respectively.

In 1998, the sample plot consisted of four square subplots that were each 30 m by 30 m in size (Figure 3). These were arranged in a 2 by 2 matrix of 60 m by 60 m. The lower and upper margins of the plots were parallel to the slope contours. The center of the plot was recorded with a GPS unit. Then, the four outer corners and center of the plot were permanently monumented for later relocation.

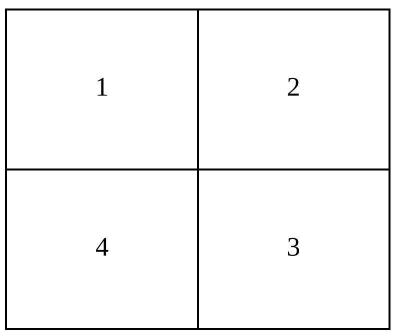


Figure 3. Site layout and subplot numbering scheme. Subplot scale is 30 m.

Field Sampling Methods

By convention, metric units were used for constructing the plot and for measurements made on the ground surface, such as intercept distances. English units were used for above-ground measurements related to vegetation and other parameters and for measurements of depths below the ground. These conventions will be followed throughout this report.

Within each plot, a randomized nested design was used to collect data representing the general site conditions, soil characteristics, ground fuels, understory vegetation, and overstory vegetation. General site conditions included slope, aspect, elevation, and topographic setting. Observations of disturbance, disease, silvicultural treatments, and previous fire were also noted. The fuel model was recorded (Anderson, H.E. 1982). The habitat type was also recorded according to previous classifications (Balice, R. G. et al. 1997, DeVelice, R. L. et al. 1986). Finally, 35-mm photographs were obtained to portray the general site conditions.

To characterize the soil at the sample site, we dug a soil pit in the center of the plot. The horizons were described and sampled for later analyses of nutrient levels. The overall soil depth was also recorded.

Two of the four subplots were selected at random for further sampling. One of these subplots was set aside for complete overstory sampling while the second was reserved for partial overstory sampling. Each of these subplots was further subdivided into four quarters or quads. In the subplot established for complete sampling, all four of the quads were sampled for overstory structures. In one randomly selected quad, all trees and shrubs greater than 10 ft tall were sampled for species, diameter at breast height (DBH), live or dead status, total height, height to live crown, crown width, crown shape, and mistletoe infestation levels. All trees in the remaining three quads were sampled for species, DBH, and live or dead status only. The procedure was the same in the subplot selected for partial sampling except all trees greater than 10 ft tall in one randomly selected quad were fully sampled, while all trees in a second randomly selected quad were sampled for species, DBH, and live or dead status only. Finally, the percent canopy cover was measured with a mirror densiometer at the center and at the corners of the plot.

In each of the quads that had been randomly selected for detailed tree sampling, a random start was established along the lower boundary. From this random start, a 30-m line transect was constructed so that it was perpendicular to the lower boundary and extended 15 m in both directions from the boundary. A second 30-m line transect was constructed parallel to the first, but located at a distance of 2 m from the first transect, as measured along the lower boundary. This formed two 30-m line transects and one 30-m by 2-m strip transect. Forbs and small shrubs were sampled along the first transect. Down woody fuels, duff, and fuels biomass were sampled along the second transect. Shrubs and small trees were sampled in the strip transect.

Along the first transect, the line intercept method was used to sample the canopy cover of each graminoid, herbaceous, and shrubby species. The amount of intercept by litter, bare soil, moss, gravel, cobbles, stones, boulders, and bedrock was also recorded. Finally, a complete census of species present in the quad, and not previously recorded by the line intercept sample, was compiled.

Down woody fuels and related parameters were sampled along the second transect (Brown, J. K. 1974, Brown, J. K. et al. 1982). From the initial point along the lower boundary, 1-hr fuels and 10-hr fuels were measured along the first 4 m of the fuels line transect. Similarly 100-hr fuels and 1000-hr fuels, sound and rotten, were measured for the first 6 m and the entire 30 m, respectively. In addition, duff depth was measured to the nearest tenth of an inch at four locations along the line transect. Finally, litter biomass and ground vegetation biomass were collected along this transect for later weighing, drying, and re-weighing.

Shrubs greater than 2 ft tall, and trees less than 10 ft tall were sampled in the strip transects. They were sampled by species, by basal diameter live or dead status, total height, height to the base of the live crown, crown width, and overall crown shape. For multiple-stemmed individuals, the number of stems by size class was also recorded.

Office Methods

All of the field data were entered into spreadsheet files. The soil nutrient analyses and fuel biomass analyses were also completed, and these results were added to the spreadsheet files. The fuel loads (kg) and numbers of trees in each size class were transformed to a per-hectare basis. Then, summary statistics were computed for each plot.

In 1997, these summary data were analyzed for differences between vegetation-topographic classes using multivariate analysis of variance, followed by Duncan's multiple range test. In 1998, most of the plots were vegetated by mixed conifer forests and were in mountainous topographic positions. Therefore, since most of the sample sites were in a single vegetation-topographic class, analysis of variance was not used for this exploratory investigation. Instead the data were graphed against elevation and exposure (Ex), where exposure is related to the slope (slp) and aspect (asp), as follows:

$$Ex = slp * \cos(\pi * (asp - 190) / 180) \quad \textbf{(1)}$$

In addition to graphical analysis, the summary statistics were tested for significant correlations with elevation and exposure. The results of this graphical and correlation analyses allowed for a preliminary evaluation of topographic influences on the fuel levels in the study region.

RESULTS

The results of the 1997 fuels inventory and data analyses are shown in Table 1. In most of the fuel classes, the fuel levels are significantly higher in the mixed conifer forests, including both canyons and mountains. In addition, densities of trees that are 8 inches DBH and greater are also significantly greater in the ponderosa pine forests on mesas. These results suggest that most of the forested areas supporting high levels of fuels are above 2100 m in elevation.

Veg-Topo Class	N	1 hr	10 hr	100 hr	1000 hr S	1000 hr R	Duff	Litter	Veg	Trees <8	Trees >8
PJ-Canyon	8	587^a	2751^a	1556^a	1078^a	6409^a	7624^a	1847^a	69^a	115^a	64^a
PJ-Mesa	7	738^a	3645^a	2009^a	3542^a	6483^a	8153^a	3788^a	67^a	170^a	82^a
PP-Canyon	5	558^a	4194^b	1531^a	818^a	9949^a	21681^a	1394^a	16^b	84^a	105^a
PP-Mesa	23	388^a	5230^b	2038^a	2898^a	14914^a	18998^a	2013^a	25^b	130^a	225^b
MC-Canyon	6	2100^b	6945^b	5642^b	2739^a	31917^b	27963^b	3150^a	16^b	563^b	194^b
MC-Mountain	5	1367^b	4456^b	7593^b	7261^b	64143^b	20460^a	1596^a	9^b	549^b	301^b

Table 1. Fuels inventory summary for 1997 and results of multivariate analysis. The vegetation types are as follows: PJ = piñon-juniper woodland, PP = ponderosa pine forest, and MC = mixed conifer forest. N = within-group sample size. The dependent variables are in kg/ha, except for trees < 8 inches DBH and trees >= 8 inches DBH which are in number of stems per hectare. Similar superscript letters within each column indicate differences that are not significant at the 0.05 level.

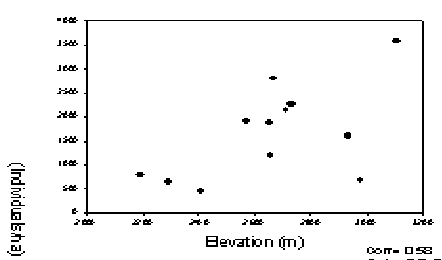
The results from 1997 were incorporated into the sampling design that was implemented in 1998. Since most of the overstocked and fuel laden forests in the study region are above 2100 m in elevation, it was decided to focus on these higher elevation areas during the second year of sampling. This effectively eliminated piñon-juniper woodlands and ponderosa pine forests in canyons from the sample but allowed us to sample higher elevation vegetation types in more detail. In addition to detailed sampling of ponderosa pine forests and mixed conifer forests, two additional forest series, aspen forests and spruce-fir forests, were sampled in 1998 (Table 2). The topographic relationships were also altered by this decision. Since most of the sample sites were located in mountain terrain, the distinction between canyons, mesas, and mountains became less useful, and was abandoned for the purposes of analysis. Instead, the exploratory analyses of these data were conducted by plot or by community type (Table 2).

Forest series	Forest community type	Avg. elev (m)
Ponderosa pine	Ponderosa pine/Gambel oak	2288
	Ponderosa pine/Muhlenbergia montana	2408
Mixed conifer	Douglas fir/Muhlenbergia montana	2192
	Douglas fir/Kinnikinnik	2574
	White fir/Gambel oak	2654
	White fir/Kinnikinnik	2667
	White fir/Mountain maple	2660
	White fir/Forest fleabane	2714
	White fir/New Mexico locust	2732
Aspen	Aspen/Thurber fescue	2978
Spruce-fir	Subalpine fir/Forest fleabane	2932
	Subalpine fir/Whortleberry	3106

Table 2. Forest series and community types sampled in 1998. Average elevations are used as independent variables for plotting in Figures 4 and 5.

The results from 1998 showed a strong relationship to elevation and exposure. This is consistent with, and supplemental to, the results from 1997. Fuel levels, in all fuel classes, tended to increase with elevation. For instance, by evaluating data that were aggregated by community type, it was found that trees in all size classes were significantly correlated with elevation (Figure 4). However, the importance of this trend was diluted somewhat by the inverse relationship between coefficients of variation of the data and elevation (Figure 5). Most of the variability in the data was from lower elevation sample sites. Thus, although the tree densities at higher elevations were high, they were consistently high. Conversely, the tree densities at lower elevations were relatively lower, but more variable and less predictable from place to place.

(a)



(b)

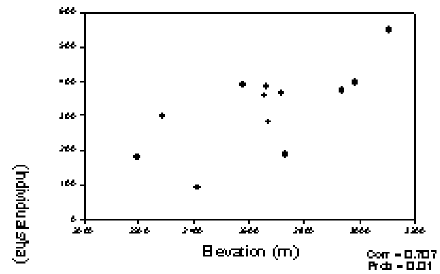
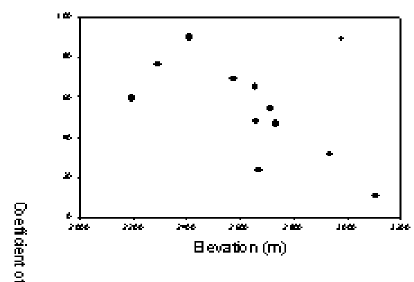


Figure 4. Tree densities versus elevation, by community type. Graphs show trees and shrubs from 2 inches to 8 inches DBH (a) and trees 8 inches DBH and greater (b). Correlation coefficients and significance levels are also shown.

(a)



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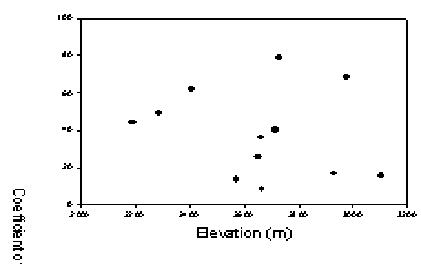

Figure 5. Coefficients of variation for tree densities versus elevation, by community type. Graphs show trees and shrubs from 2 inches to 8 inches DBH (a) and trees 8 inches DBH and greater (b).

In a similar manner, the ground fuels and surface fuels were analyzed by plot against elevation and exposure (Figure 6). The combined 1-hr to 100-hr surface fuels were significantly correlated with exposure. Thus, they tended to be greater on north-facing aspects. In addition, closer inspection of Figure 6a also indicates that these down woody fuels are positively related to elevation and show a slight tendency to increase on south-facing exposures, as well as north-facing exposures. Both of these relationships were not significant at the 0.05 level, although this may in part be caused by nonlinearities in the data. Duff is also significantly correlated with elevation (Figure 6b). Although not significant from the standpoint of linear correlation, duff also appears to be greater on both north-facing and south-facing slopes than on flat topographic positions.

(a) **(b)**

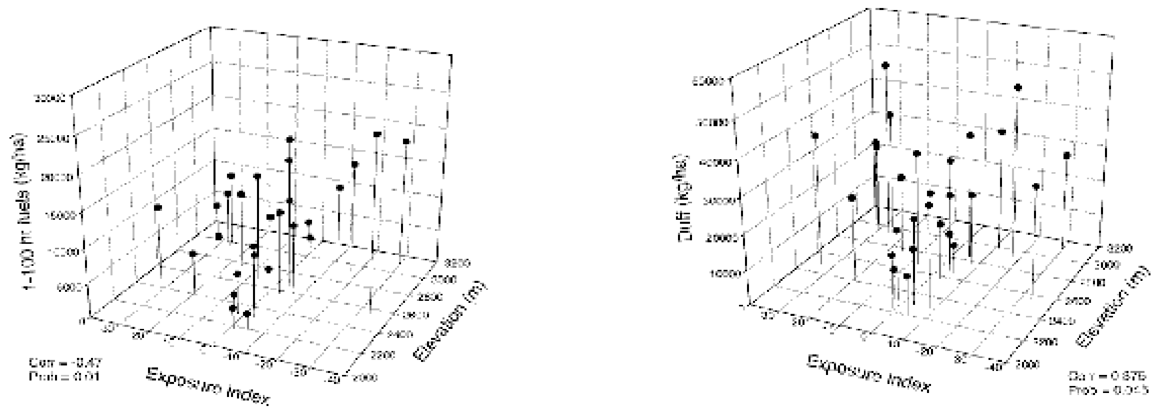

Figure 6. Surface and ground fuels versus elevation and exposure, by sample site. Graphs show combined 1-hr to 100-hr down woody fuels (a) and duff (b). Correlation coeficients and significance levels are also shown if P<0.05.

DISCUSSION

The results of this preliminary survey have several consequences. First, the surveyed fuel loads are consistent with predicted and actual patterns of fire behavior in the study region. The spatial distribution of the fuel structures in high-elevation forests suggests the following general wildfire scenario that one could expect to occur with increasing probability as fuels desiccate during the peak of the fire season, April through June.

1. Ignitions could occur in the forests above 2400 m and to the west of LANL or the Los Alamos townsite. These ignitions would be caused by lightning or from human activities. In either case, the litter, duff and other fuels on the ground would be ignited.

2. Because of the presence of large amounts of surface fuels on the forest floor and because of hot, dry, weather conditions, the fire would maintain itself at low intensities for days.

3. As the air temperatures rise, atmospheric humidity decreases, and wind speeds increase, the ground fire would intensify and move from the ground to the ladder fuels. From there, the fire would easily ignite the overstory canopies.

4. Once the fire is in the upper canopy of the forest, its behavior would be dictated by the current wind conditions. Since the prevailiing winds during the April-June time frame are from the southwest to the northeast, the crown fire would spread from the mountains toward the western perimeter of LANL and the Los Alamos townsite.

5. At this stage, the fire would be raging through the forest canopy. All attempts by fire fighters to suppress the fire would be ineffective. Land managers would be reduced to observers who must merely watch the fire from a safe distance. The Lab would be closed and the townsite population would be evacuated. Destruction of residential areas and Lab facilities would be highly likely under these conditions.

6. The weather conditions moderate. As a result of the decreased air temperatures and wind speeds, the intensity of the wildfire would be reduced to levels that would allow safe and effective suppression activities to resume. Full suppression and mop-up activities would continue for another week.

This general wildfire scenario is not unique to the Los Alamos region. Many regions of the western United

States and Canada have similar fuel levels and ignition probabilities and face these kinds of weather patterns during some time periods of the year. What makes this scenario of particular interest to land managers in the Los Alamos region is the direction of the prevailing winds and the geographic relationships of the mountains to the townsite and Lab facilities. This set of conditions suggests that a wildfire will almost certainly destroy portions of the townsite or the Lab at sometime in the future.

Although this wildfire scenario is based on the data that was collected during the fuels inventory survey, it is consistent with the recent history of wildfires in the Los Alamos region. Since 1954, four major wildfires have occurred on the east slopes of the Jemez Mountains. Two of these fires have occurred since 1996. Each of these fires was ignited in the 2500-m elevation level and was started by human activities. Each fire elevated from the ground to the crown under hot, dry, and windy weather conditions. Each burned dangerously and erratically in the forest canopies for two to four days. During this time period, active fire suppression was impossible because of the danger to fire fighters. Lab operations were interrupted by three of these fires, and, during one wildfire, evacuation of the Lab was considered. Finally, suppression was possible in each of these fires only after moderating weather conditions provided safe opportunities for an initial attack.

Second, the highly variable fuels at lower elevations presents a dilemma to land managers who wish to protect federal facilities and residential areas in the wildland-urban interface. Reconnaissance at these elevations suggests that some of these areas are extremely dense with fuels, while some other areas are relatively free of fuels. This is extremely important to land managers who wish to thin the forests and reduce the fire hazard in a cost-effective manner. For instance, financial resources could be conserved by manipulating forest structures so that they isolate hazard fuels, and connect thinned forests with non-forested areas. The results of this project are helping identify such areas.

Third, these results are being generalized to fuel load maps for the Los Alamos wildland-urban interface (Yool, S. R. and J. D. Miller, 1999). A preliminary understory fuels map of major fuel types, grass, ponderosa pine, mixed conifer and aspen, was created from the fuels data and other sources. This is a preliminary tool for management. The accuracy of the fuels map will be assessed from the fieldwork conducted in 1999. The map will be continually upgraded and ultimately become part of a library for management decision-making.

Fourth, the data generated by this project are being used as inputs to predictive wildfire behavior models. The fuels and topographic data generated for this project are serving as data layers for FARSITE (Finney, M. A. 1998, Keane, R. E. et al. 1998). We are also adopting a wildfire-induced soil erosion risk model to our site conditions (MacDonald, L. H. et al. 1999). These will be used to predict the long-term expected loss to LANL from wildfire. These simulations will be performed under a variety of wildfire scenarios and fuel reduction strategies. In this way, we will be able to suggest optimal mitigation action strategies to the land managers of the Los Alamos region.

Finally, the results of the 1998 fuels inventory suggest several areas that should be investigated in more detail during the 1999 field season. First, the sample is not uniform across the range of elevations and exposures (Figure 6). At lower elevations, relatively steep north-facing and south-facing topographic positions were not well represented in the 1998 data set. Many of these areas are heavily fueled and near critical facilities and residential areas in the Los Alamos wildland-urban interface. With respect to community types, aspen forests and spruce-fir forests were also under sampled. These gaps in the sample will be addressed in 1999 and in the future.

CONCLUSIONS

LANL and neighboring land management agencies have undertaken a multi-year study to assess the fuel levels in the Los Alamos region, model the expected fire behavior in the presence of these fuels, develop and implement optimal mitigation action strategies, and monitor the effectiveness of these actions. This report documents selected aspects of the first two years of the fuels assessment. The knowledge gained from these fuels analyses has already been put to practical use. For instance, emergency fuel reductions were performed in 1998, during a particularly dry winter and spring. These activities were designed in part through interactions with the fuels assessment team.

In recent years, the existence of a severe threat from wildfire to the Los Alamos wildland-urban interface has been increasingly noted in the news media and in official documents. For instance, the Sitewide Environmental Impact Statement for the Los Alamos National Lab concluded that wildfire is the most significant threat, in terms of probability of occurrence and potential to cause serious consequences to the Lab and its surroundings (DOE 1999a). In addition, the draft environmental impact statement for the conveyance and transfer of DOE lands to the general public in the Los Alamos region has also recognized wildfire as potentially a serious hazard to the land tracts in question (DOE 1999b). In addition to LANL, the County of Los Alamos, Bandelier National Monument, and Santa Fe National Forest have all mobilized resources to protect the forests from wildfire. However, the most effective protection from wildfire is the reduction of fuel loads in the forest through thinning and burning. As a result of this ongoing study and increased use of optimal mitigation action strategies, these fuel hazards will be reduced to safe levels in a cost-effective manner.

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