A WILDFIRE HAZARD ASSESSMENT AND MAP FOR LA PLATA COUNTY, COLORADO, USA

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ABSTRACT

In response to the needs of local fire managers, we developed a map of wildfire hazard for La Plata County in southwestern Colorado, USA. Our measure of fire hazard had two components: (i) the probability, should fire occur under dry weather conditions, that fire behavior will be extreme, and (ii) the human values that may be lost or damaged if extreme fire behavior occurs. Using a classification approach in a GIS environment, we developed quantitative indices of potential heat release, flame length, and rate of spread for each vegetation type in the County. This is based on output of the Behave fire behavior system and adjusted for effects of slope and aspect. We then overlaid a map of residential developments to identify locations where homes are most vulnerable to wildfire damage. Results revealed a zone in the central part of the county where extensive exurban development is occurring within pine, juniper, and oak vegetation, leading to a high potential for extreme fire behavior. This assessment is notable in that (1) it treats a wide range of land ownership types including public lands, private lands, and American Indian reservations; (2) it encompasses substantial variability in vegetation/fuel types, from low-elevation semi-arid grasslands and woodlands to alpine forests and meadows to cultivated and residential lands; and (3) it maps wildfire hazard at relatively fine resolution (1 ha) for a large area (ca 4,500 km^2) based on quantitative indices of wildfire behavior. Formal validation of this kind of map is nearly impossible, but we tested the final product by asking local experts to evaluate our interpretations for specific locations with which they were familiar. Feedback from the experts led us to revise some of our initial fire behavior indices, by developing custom fuel models. The same experts concluded that the final product was very accurate. By developing a relatively simple mapping algorithm, and drawing upon spatial data sources readily available to local land managers, our wildfire hazard map for La Plata County provides a template for more extensive fire hazard mapping throughout southwestern Colorado and portions of adjacent states, for use in prioritization of fire mitigation treatments and public education.

Keywords: *fire hazard map, exurban development, Colorado, Behave, fire behavior modeling, GIS*

INTRODUCTION

A spate of large, destructive wildfires during the last decade has raised public awareness of the threat of uncontrollable fires in forest ecosystems throughout the western United States. Annual acreage burned in several western states has been substantially greater during the last two decades than in previous decades. In addition, the 2000, 2002, and 2003 fire years were among the worst in the last 100 years in terms of area burned and economic damage sustained (National Interagency Fire Center: http://www.nifc.gov). The increased fire activity of recent decades is due in part to severe fire weather conditions that have occurred during the last several years, e.g., in 1987, 1988, 1994, 1996, 2000, 2002, and 2003. However, it also is a result of nearly a century of fire exclusion and fuel accumulation in forest ecosystems that burned every 10-20 years prior to the twentieth century (e.g., Dahms and Geils 1997, Arno and Allison-Bunnell 2002). The growing economic losses and social concerns related to wildfire are a consequence not only of changes in the fires themselves, but also of recent social changes in the United States -- notably the dramatic increase in the building of homes and other structures within fire-prone forest ecosystems (e.g., Babbitt 1996, Romme 1997, Riebesame et al. 1997, Theobald 2000, 2001, Cova et al. 2004).

In response to the increasing threat of wildfire damage to human life, property, and natural resources, especially in the western U.S., the federal government released the National Fire Plan in 2000 which authorized wildfire-related expenditures in the billions of dollars (USDA Forest Service and USDI 2000, Hill 2001). More recently, the Healthy Forest Restoration Act of 2003 directed communities to actively participate with the agencies in developing wildfire protection plans (http://www.safnet.org/policyandpress/cwpphandbook.pdf). The state of Colorado also passed legislation (H.B. 1283), which enables counties to actively plan and participate in wildland fire management (Hodgson 2001). A major issue today is how to most efficiently and effectively assess and map wildfire hazards and risks for purposes of planning and prioritizing mitigation treatments (Gollberg et al. 2001).

The objective of the present study was to assess wildfire hazard within a representative portion of southwestern Colorado and to depict the results of this assessment in the form of a relatively high-resolution map. The terms "hazard" and "risk" are sometimes used interchangeably, but have distinct meanings in the field of occupational and environmental epidemiology. Hazard is "the potential to cause harm" whereas risk is "the likelihood of harm" (http://www.agius.com/hew/resource/hazard.htm). Our measure of fire hazard has two components. First is the probability, should fire occur under dry weather conditions, that fire behavior will exhibit high heat release, high rate of spread, or high flame length. The second component of fire hazard relates to the human values that may be lost or damaged if intense or rapidly spreading fire occurs. For this study, we treated only home sites as areas of high value, but we also identify additional components of value that should be addressed in future work. Thus, our fire hazard map does not represent fire "risk" per se, because we do not include any estimate of the likelihood of fire actually occurring at any particular point. Rather, should fire occur, our map indicates the potential for damage to structures (i.e., "hazard").

Similar wildfire hazard and risk assessments have been conducted or are in progress around the country. However, many previous wildfire hazard assessments either have been restricted to a single ecological and land-ownership type, e.g., a portion of a national forest, or have had very low spatial resolution. Burgan et al. (1998) mapped fuel model types and a fire potential index at 1-km^2 resolution across the entire continental United States. Schmidt et al. (2002) developed a similarly extensive but coarse-scale assessment of fire regime condition classes. Broad-scale fire hazard maps also have been developed for portions of Spain (Chuvieco and

Congalton 1989), Greece (Gouma and Chronopoulou-Sereli 1998), and the European Mediterranean Basin (Chuvieco et al. 1999). A group of fire, resource, and GIS experts developed a coarse-scale assessment of wildfire hazard throughout western Colorado in 1996 (Sampson et al. 2000). The Colorado State Forest Service also has produced a more detailed assessment for the Front Range "red zone" – a 1.2 million acre wildland-urban interface zone near Denver, Colorado (Skip Edel, personal communication). A similar effort has recently been completed for Florida and thirteen southeastern states (http://www.fl-dof.com/wildfire/wf_fras.html, http://www.spaceimaging.com/newsroom/2003_swfra.htm). Broad-scale, wildfire hazard maps have been developed for parts of the northern Rockies (Burgan and Shasby 1984, Idaho Panhandle National Forests 1999, Landres et al. 1999), southwestern U.S. (Swantek et al. 1997, Keane et al. 2000), and Sierra Nevada Range (Caprio et al. 1997). Finer-scale analyses also have been conducted in the immediate vicinity of communities known to be at risk, e.g., the East Bay Hills near Oakland, California (Radke 1995), and Colorado Springs, Colorado (Mills 2000).

Our assessment of La Plata County is notable in that (1) it treats a wide range of land ownership types, including public lands, private lands, and American Indian reservations; (2) it encompasses substantial variability in vegetation/fuel types, from low-elevation semi-arid grasslands and woodlands, to alpine forests and meadows, to cultivated and residential lands; and (3) it maps wildfire hazard at relatively fine resolution (1 ha) for a large area (ca 4,500 km^2). Our approach also is distinctive in that it develops quantitative indices of potential fire behavior based on the output of mechanistic fire behavior models. Quantitative validation of a map of this kind is nearly impossible, but we made a qualitative test of the map by asking local experts to evaluate our interpretations for specific areas with which they were familiar. The experts identified two vegetation types for which we initially under-estimated the potential for severe fire behavior, so we developed custom fuel models for these types and revised the map accordingly. The same experts concluded that our final map was very accurate.

The wildfire hazard maps that we produced are already being applied for two major purposes. First, wildland fire managers and local fire districts are using the maps to help identify the areas of highest priority for mitigation treatments designed to reduce local fire hazard. Appropriate mitigation techniques might include mechanical thinning and prescribed burning (e.g., Kalabokidis and Omi 1998, Fule et al. 2001, Hollenstein et al. 2001, Pollett and Omi 2002, Friederici 2003, Martinson and Omi 2003, Scott 2003, Fiedler and Keegan 2003, Stratton 2004, http://www.firewise.org/fw_index.htm). The second application is for educational purposes, for example, to better inform the public and land use planners about the hazards of wildfire in general, and also to highlight specific geographic locations where fire hazard is most acute.

We developed our wildfire hazard maps using a relatively simple classification approach (Keane et al. 2003). We did not attempt to model fire spread, ignition probability, or historical fire regimes, but simply to predict where in the county there is the potential for serious damage should a fire occur under severe fire weather conditions. More sophisticated modeling methods might produce more robust maps, but our product is adequate for the strategic planning and educational purposes for which it is intended, and it meets an urgent local need. In its recent coarse-scale assessment of wildfire hazard throughout Colorado, the Colorado State Forest Service (*undated*) identified southwestern Colorado as one of three regions in the state that may be at greatest risk of wildfire damage (the others being northwestern Colorado and the Front Range). Therefore, local fire managers requested our assistance in developing wildfire hazard maps that would be easily understandable by managers and the public, and that employ a straightforward methodology that can be duplicated in surrounding counties and parts of adjacent states, to provide seamless fire hazard maps for the entire region.

METHODS

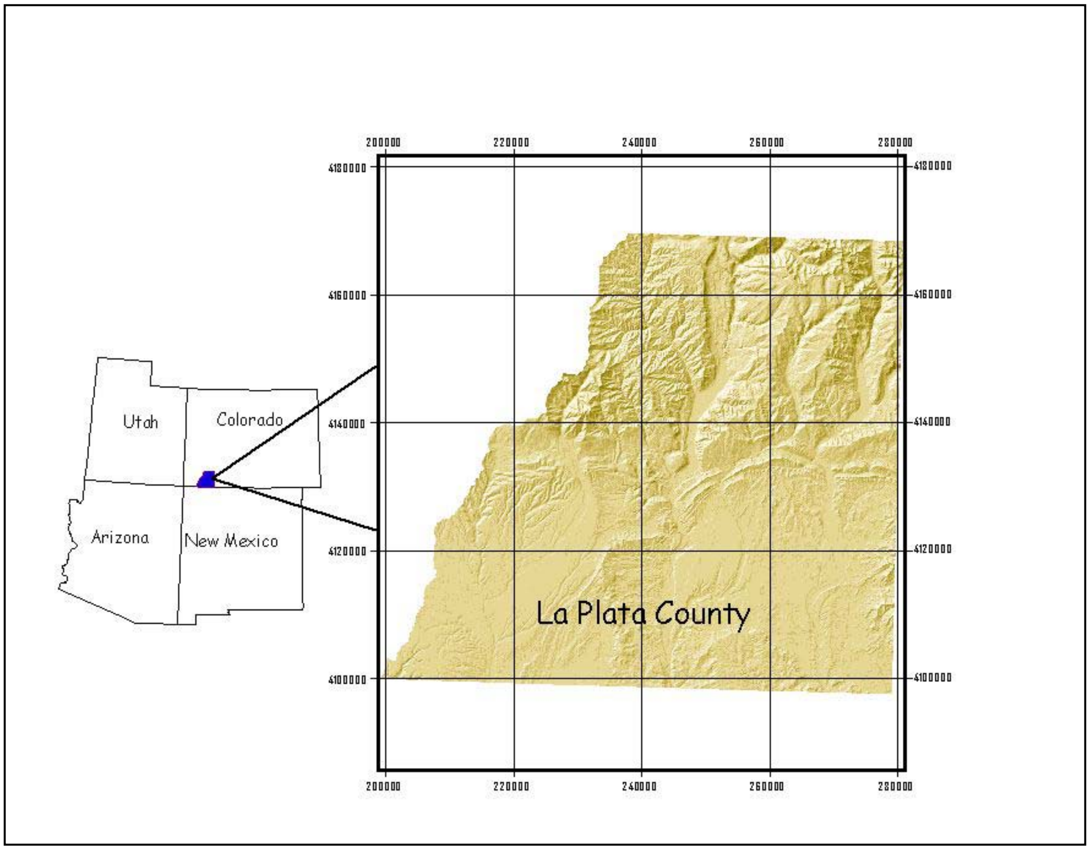
Study Area

La Plata County encompasses 4,500 km^2 in southwestern Colorado (Figure 1). It is a region of striking physical and socio-economic-political contrasts (Romme 1997). The northern portion of the county lies within the rugged terrain of the San Juan Mountains with alpine peaks exceeding 3,900 meters in elevation, whereas the southern part of the county is mostly foothills, plateaus, and river valleys at lower elevations of 1,500 – 2,100 m. Most of the northern county is publicly owned as part of the San Juan National Forest, with a sprinkling of private inholdings, especially along the highway corridor north of Durango. In contrast, the southern county is a mosaic of public land (Bureau of Land Management, state school sections, and Colorado Division of Wildlife), tribal land (Southern Ute Reservation), and private land. Agriculture is still a major land use in the southern part of the county, although much of the former agricultural land is rapidly being converted into low-density exurban housing (Romme 1997). Private residential development is found in and near the incorporated urban areas of Durango, Bayfield and Ignacio; but development is increasingly occurring along the major river valleys, across broad mesa tops, and in the forested foothills of the San Juan Mountains. Over half of the residential population now resides in the rural, unincorporated areas of the county.

Overview of the Mapping Process

All mapping was done in a GIS environment, primarily using ESRI ArcView 3.2a software with Spatial Analyst extension. All datasets were co-registered to the Universal Transverse Mercator Projection, NAD27, zone 13. This is a common format for the federal resource management agencies. In the interest of enabling adjacent counties to repeat the process for their areas of concern, we emphasized the use of data that are easy to obtain, are available at no cost, and require minimal pre-processing. We first obtained a vegetation map for the entire county from the Colorado GAP Analysis Project (Colorado GAP 1998), which is the basic vegetation layer for most of the wildfire hazard mapping work being done in Colorado (Skip Edel, Colorado State Forest Service, personal communication). We supplemented the GAP data layer with the vegetation map of the San Juan National Forest, as described below. We then developed a topographic map using 30-meter digital elevation model (DEM) data from the U. S. Geological Survey. The vegetation and topography data layers were combined to produce a raster base map of vegetation/slope/aspect units for the entire county. Each vegetation type was

Figure 1: Location map of La Plata County, Colorado.



reclassified as the appropriate fuel model, and then potential fire behavior under severe weather conditions was simulated for each fuel model using Behave (details below). Output from Behave was adjusted to reflect the effects of aspect and slope, and the resulting values from the Behave simulations were assigned to each polygon in the vegetation/slope data layer to produce a map of expected fire behavior under severe weather conditions. Finally, we obtained a GIS layer of built parcels from the La Plata County Planning Department, and superimposed this map on the simulated fire behavior map to identify locations where damaging fire behavior could occur in proximity to homes and other vulnerable structures. Details of our methodology are provided in the following sections.

Vegetation

Two sources of vegetation data were available in digital form: the Colorado GAP Analysis Project (Colorado GAP 1998) and the San Juan National Forest vegetation map. Both maps were created from Landsat TM imagery, but differed in coverage and resolution. The GAP data covered the entire county but with coarse resolution (minimum map unit of 100 ha for upland areas or 40 ha for riparian zones). The San Juan National Forest map had a minimum map unit of 30 m, but covered only a portion of northern La Plata County. The Forest Service map also provided a more detailed classification of vegetation types.

We had no choice but to use the GAP map for areas not covered by the National

Forest map, but where the two maps overlapped we combined them to take advantage of the finer spatial resolution and more precise vegetation classification of the Forest map. The GAP vegetation classification includes a coarse category called "aspen/mixed conifer." This was an unsatisfactory unit for our purposes, because aspen and mixed conifer forests exhibit very different fire behavior. Aspen forests do not burn readily, and may even stop the spread of wildfire, whereas mixed conifer forests may exhibit extreme fire behavior. Therefore, we separated aspen from mixed conifer forest in the GAP coverage as follows: First, we intersected Forest Service aspen polygons with the GAP aspen/mixed conifer polygons. All intersecting polygons then were re-classified as aspen in our final vegetation map. Portions of the GAP aspen/mixed conifer polygons that did not intersect Forest Service aspen polygons were re-classified as mixed conifer in our final map.

A second major deficiency in the GAP vegetation layer had to do with riparian areas. The GAP map contained only a coarse-scale (40 ha resolution) riparian vegetation class, which was not adequate for our purposes since even small riparian and wetland areas can strongly influence fire behavior. Creating a high-resolution riparian layer was not straightforward. After trying several different approaches that gave unsatisfactory results (based on visual inspection of the resulting maps, in particular those specific locations with which we had personal familiarity), we obtained an extension from ESRI's ArcScripts web site (http://gis.esri.com/arcscripts/scripts.cfm). The Buffer by Elevation Change extension ("buffbyrise1.avx" file, authored by Damon Holzer, Texas A&M University) creates a buffer zone around a line feature based on an elevation change away from that feature. This script, applied to our DEM layer (described below) and a line shapefile of the stream network produced reasonable-appearing riparian polygons. We decided that these polygons were accurate enough for this first phase of mapping, and they were added to our final vegetation map. However, we note that we were unable to conduct any quantitative validation of our modeled riparian zones (though we tested our results qualitatively by visually assessing the resulting polygons), and we emphasize that riparian and wetland delineation is a topic needing improvement in future work (see Discussion below for directions of future model refinement).

Topography

We created a base map of elevation through the acquisition and manipulation of 30- meter resolution USGS 7.5 minute DEMs . The process to create the base topographic map involved downloading 40 individual DEMs covering all of La Plata county plus an adjacent area beyond its borders. The individual DEMs were mosaicked in five to six piece portions using the Grid Analyst extension from ESRI. All DEMs west of 108d longitude required re-projection from UTM Zone 12 to Zone 13 in order to achieve correct spatial orientation with the remaining DEMs. This was achieved by using the Reproject Grids extension downloaded from ESRI's ArcScripts web site ("reproject.avx" file, authored by William Huber, Quantitative Decisions). The re-projected DEMs were then mosaicked, and merged as a group to the UTM Zone 13

Table 1. Aspect classes and weighting multipliers used in fire hazard assessment for La Plata County, Colorado. The adjustment factor in the table was multiplied by the output from Behave to produce final predictions for fire behavior.

Aspect Range	Aspect Class	Multiplier
292.5d – 67.5d	1	1
67.5d – 157.5d	2	1.33
247.5d – 292.5d	2	1.33
157.5d – 247.5d	3	1.66

Table 2. Vegetation types (Colorado GAP Analysis Project 1998, augmented with San Juan National Forest vegetation map as described in the text) and associated fuel models (Albini 1976) used in the analysis of wildfire hazard in La Plata County, Colorado.

VEGETATION TYPE	FUEL MODEL
Urban / Built-up land	0
Dryland crops	1
Irrigated crops	1
Foothills / mountain grassland	2
Deciduous oak	4
Big sagebrush	4
Aspen	5
Spruce-fir	10
Douglas fir	10
Ponderosa pine	9/4
Juniper woodland	6
Pinyon-juniper woodland	6/4
Mixed conifer	10
Mixed forestland	10
Open water	0
Riparian vegetation	1
Prostrate shrub / tundra	0
Subalpine meadow	1
Bare ground tundra	0
Mixed tundra	0

mosaic to create a complete a countywide DEM. This layer was then clipped to the county boundary shapefile using the Clip Grid(s) script (clipgrid.ave file, authored by Tom Van Niel, CSIRO) available from the ESRI ArcScripts web site. The clipped countywide DEM was then manipulated using Spatial Analyst to derive slope and aspect layers. Slope was classified into three classes: low (0-20%), moderate (20-40%), and steep (>40%) to coincide with classes used in public information documents (USDA 2000). The slope coverage was merged with the vegetation coverage to create a map of all combinations of slope and vegetation.

Initially we did not incorporate topographic aspect in our simulations, because Behave does not directly simulate the effects of aspect. Nevertheless, we recognized that aspect is an important modifier of fire behavior because of its effects on fuel moisture, fuel pre-heating, vegetation mix, and exposure to prevailing wind. When we asked local fire managers to review our initial simulation results (details on this process below), they urged us to include the effects of aspect. The National Fire Danger Rating System incorporates a southwestern aspect in its calculations to represent worst-case conditions (Bradshaw et al. 1978), and other studies have treated aspect by assigning subjective or weighted values to the various azimuth directions (e.g., Caprio et al. 1997, Colorado State Forest Service 1997, Morandini et al. 2002, Nelson 2002). Therefore, we divided aspect into three classes (Table 1) and assigned a multiplier value to each class. Behave output then was adjusted with the multiplier for each aspect class to give a final value for the three fire behavior parameters used in our hazard assessment. Note that these multiplier values were derived subjectively, based on our prior experience with fire and vegetation in this area. The coefficients could be revised to reflect local experience in other areas.

Fuel Models

Two systems of fuel classification are frequently used in fire management: the 13 FBFM models (Albini 1976) and the 20 NFDRS models (Burgan and Rothermel 1984, Burgan 1988). The FBFM fuel models were used in this project to facilitate incorporation into Behave modeling, and to coincide with fire line fire behavior handbooks (NWCG 1993). We subjectively assigned a fuel model to each vegetation type in our vegetation map, based on descriptions provided by fuel models documentation (Anderson 1982) as well as our knowledge of local vegetation characteristics (Table 2). The assigned fuel models were then added to the vegetation grid attribute table to enable querying by fuel model.

Simulating Fire Behavior with Behave

Behave is a widely used system for simulating wildland fire behavior, based on Rothermel's (1972) mechanistic fire behavior model (e.g., Andrews 1986, Rothermel et al. 1986, Andrews and Chase 1989, Radke 1995, Gardner et al. 1999, Mills 2000), and is available free on-line at www.fire.org. Our combined vegetation/slope grid, with fuel models assigned to each vegetation type, provided the necessary matrix to spatially display our Behave results.

From the six fire behavior outputs available in Behave, we selected heat release, spread rate, and flame length as the parameters most pertinent to our analysis (Albini 1976, Bradshaw et al. 1983, Andrews 1986). *Heat release* (btu/ft^2), an indicator of the total potential damage from a fire, varies with fuel model type and fuel moisture, but is independent of slope and wind. *Rate of spread* (chains/hour, a chain is 66 feet) is affected by fuel model, fuel moisture, slope, and wind. *Flame length* (ft) is influenced by fuel model, fuel moisture, slope, and wind. Flame length is often used as a general descriptor of fire intensity and difficulty of suppression; e.g., a flame length of four feet is considered the upper limit for hand crews (NWCG 1993). Flame length also is one determinant (along with crown base height and sub-canopy ladder fuels) of whether a fire will spread from surface fuels into the canopy.

Fuel moisture, atmospheric humidity, temperature and wind all have powerful influences on fire behavior, and one could simulate an almost endless array of potential fire behaviors under all combinations of vegetation type, slope, and ambient weather conditions. However, our focus in this study was on fire behavior and fire damage that could occur under severe fire weather conditions. In much of western North America, most of the fires are small, while a few fires burning under severe conditions account for most of the area burned during any given time period (e.g., Renkin and Despain 1992, Johnson 1992, Moritz et al. 2004). Therefore, to identify areas of fire hazard in La Plata County based on a worst-case scenario, we used extreme but realistic weather conditions rather than average conditions in our Behave simulations (Table 3). Live woody fuel and live herbaceous fuel were both assigned 50% fuel moisture, which is at or near the threshold to be considered as potentially dead fuel. We did not incorporate wind in the Behave simulations, however, because wind speed and direction are highly variable and unpredictable. Moreover, nearly all output parameters from Behave are simply increased by wind, and our objective was to compare potential fire behavior among different geographic areas within the county under a given severe fire weather scenario, not to predict specific behavior of any particular fire event.

We began our fire behavior analysis by simply running Behave for each fuel model in the study area under extreme weather conditions. Each polygon in the fuel model map was then reclassified to depict the simulated heat release, spread, rate, and flame length. Inspection of the initial output by local fire managers revealed one serious problem: both the ponderosa pine and the pinyon-juniper types showed relatively low values for all three parameters. Yet, from experience with recent fires in this region, it was clear to all of us that these two vegetation types actually are capable of exhibiting extreme fire behavior. The reason for the discrepancy was that the fuel models we had assigned to these two vegetation types assumed light surface fuels composed mainly of litter. In La Plata County, however, both ponderosa pine and pinyon-juniper forests almost always have a well-developed understory of Gambel oak or big sagebrush – both of which can produce extreme fire behavior. It was therefore necessary to revise our ponderosa pine and pinyon-juniper fuel models to reflect this potential for severe fire behavior.

Behave allows the use of two fuel models in combination, as long as one model is a majority. The two understory components contributing to extreme fire behavior in ponderosa pine and pinyon-juniper forests (fuel models 9 and 6 respectively) were Gambel oak and big sagebrush, both of which were assigned fuel model 4 (Table 2). To determine appropriate mix percentages in our mixed

Table 3. Environmental conditions used in Behave simulations of extreme fire behavior in La Plata County, Colorado.

1-Hr Fuel Moisture	2.0%
10-Hour Fuel Moisture	5.0%
100-Hour Fuel Moisture	10.0%
Live Woody Moisture	50.0%
Live Herbaceous Moisture	50.0%
Midflame Windspeed	0.0 MPH

fuel models, we used an attribute of the GAP vegetation called primary crown, which describes the percent coverage of the primary vegetation crown in each polygon. Thus, in our mixed models the relative importance of fuel model 9 or 6, vs. fuel model 4, reflected the primary crown cover of Ponderosa or Pinyon-Juniper in the GAP coverage. In the resulting combined fuel models, spread rate was calculated for fuel combinations, heat release was determined as the percentage mix of btu/ft^2 values for the two fuel models, and flame length was determined as the greater of the two values produced by the two fuel models (Andrews and Chase 1989).

Cultural Values

People may value an enormous variety of characteristics of the natural and built environment (Hodgson 2001), and it was beyond the scope of this project to identify and adequately incorporate all potential cultural values in La Plata County. Community-wide discussions are now under way to address this issue of values (Sam Burns, Office of Community Services, Fort Lewis College, personal communication), and future hazard assessments should incorporate a richer treatment of values as a result of those discussions. Nevertheless, because one important and urgent objective of fire managers is to identify specific areas where residential property is threatened by wildfire, and because pertinent spatial data were already available, we focused this analysis on residential parcel values only.

A parcel shapefile was acquired on-line from the La Plata County GIS Department (http://co.laplata.co.us/gis.html). This shapefile was queried by the property use attribute (prop_use) to identify residential parcels only. These parcels were then queried for development status (built/un-built) based on the year built attribute (yr_built) -- a method suggested by Alan Andrews, manager of the La Plata County GIS Department (personal communication). This query produced a GIS map of residential areas containing homes or other structures throughout the county. The residential parcel data did not precisely locate individual structures within a given parcel. This is a problem for large parcels that may contain only one or a few structures, since fire on the un-built portion of the parcel really does not threaten structures. Despite a number of attempts, we were unable to find a satisfactory way to deal with this problem (see Discussion). The residential parcel data also excluded agricultural parcels, although conversion from agricultural to residential use is an on-going process. The La Plata County GIS office routinely updates parcel information as it receives records of changes in land use, so the fire behavior output maps that we developed here can be overlaid on updated parcel maps at any time in the future to depict current hazards.

RESULTS

Vegetation and Fuels Map

The final vegetation map that we produced for La Plata County (Figure 2) illustrates the striking environmental differences that exist between the northern and southern portions of the county. The northern part of the county is rugged and mountainous, and contains several vegetation types that are absent in the southern part, e.g., tundra, spruce-fir, Douglas-fir, and aspen. In contrast, the southern part of the county is comprised of gentler topography and a preponderance of grassland, shrubland, woodland, and agricultural vegetation types.

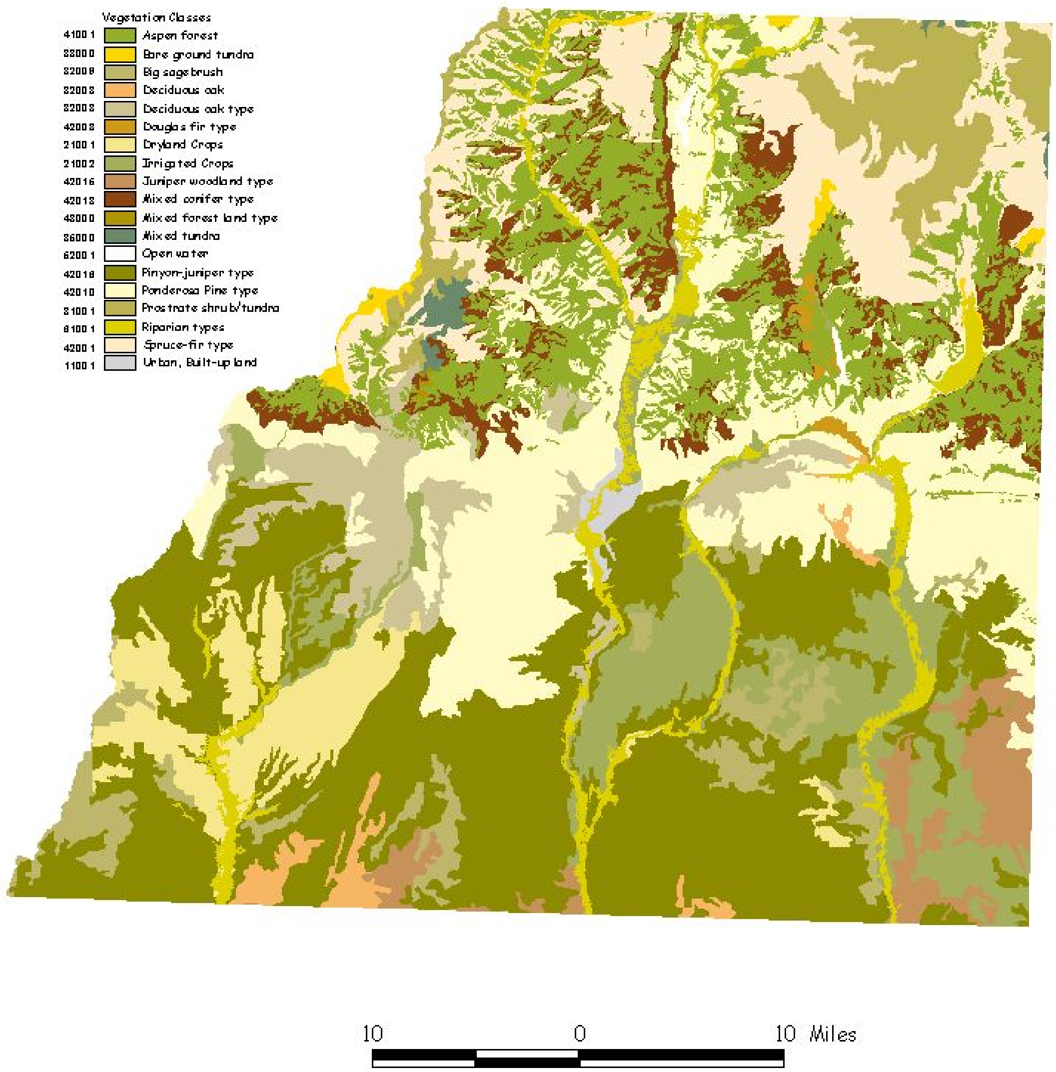
Potential Fire Behavior

Simulated heat release (Figure 3) ranges from < 500 Btu/ft^2 in tundra, riparian vegetation, and irrigated agriculture, to > 5000 Btu/ft^2 in oak, ponderosa pine/oak, and pinyon-juniper/sagebrush on steep southerly slopes. Intermediate values of heat release are predicted in aspen, grasslands, and some of the other, less widespread vegetation types in the county. The overlaid map of built residential parcels (Figure 3) reveals a concentration of homes along an east-west band in the central part of La Plata County, in the foothills of the San Juan Mountains, as well as patches of exurban development elsewhere throughout the county. A wide variety of housing is represented, from multi-million dollar homes on large lots, to medium-scale homes in tract subdivisions, to low-rent trailer parks. This central zone of extensive residential development coincides with some of the highest predicted heat release values (Figure 3).

Simulated flame length under severe fire weather conditions (Figure 4) ranges from < 3 feet in tundra and wetlands, to > 15 feet in ponderosa pine / oak and pinyon-juniper / sagebrush on steep southerly slopes. Aspen and some less common vegetation types have simulated flame lengths of 3 – 8 feet. The greatest simulated flame lengths tend to be in the southern and central portions of the county including the central zone where exurban development is highly concentrated (Figure 4).

Simulated spread rates under severe fire weather conditions (Figure 5) are relatively low (< 14 chains/hour) in most of the county. However, moderate to high rates of spread (25 – 75 chains/hour) are seen in some grasslands and oak shrublands on steep southerly slopes. The greatest occurrence of moderate and high spread rates is in the central zone of the county where exurban development is concentrated,
although most of the built parcels lie in close proximity to areas having high spread rates rather than directly within such areas (Figure 5).

Figure 2. Vegetation map for La Plata County, Colorado. See Table 2 for descriptions of vegetation types and assigned fuel models.



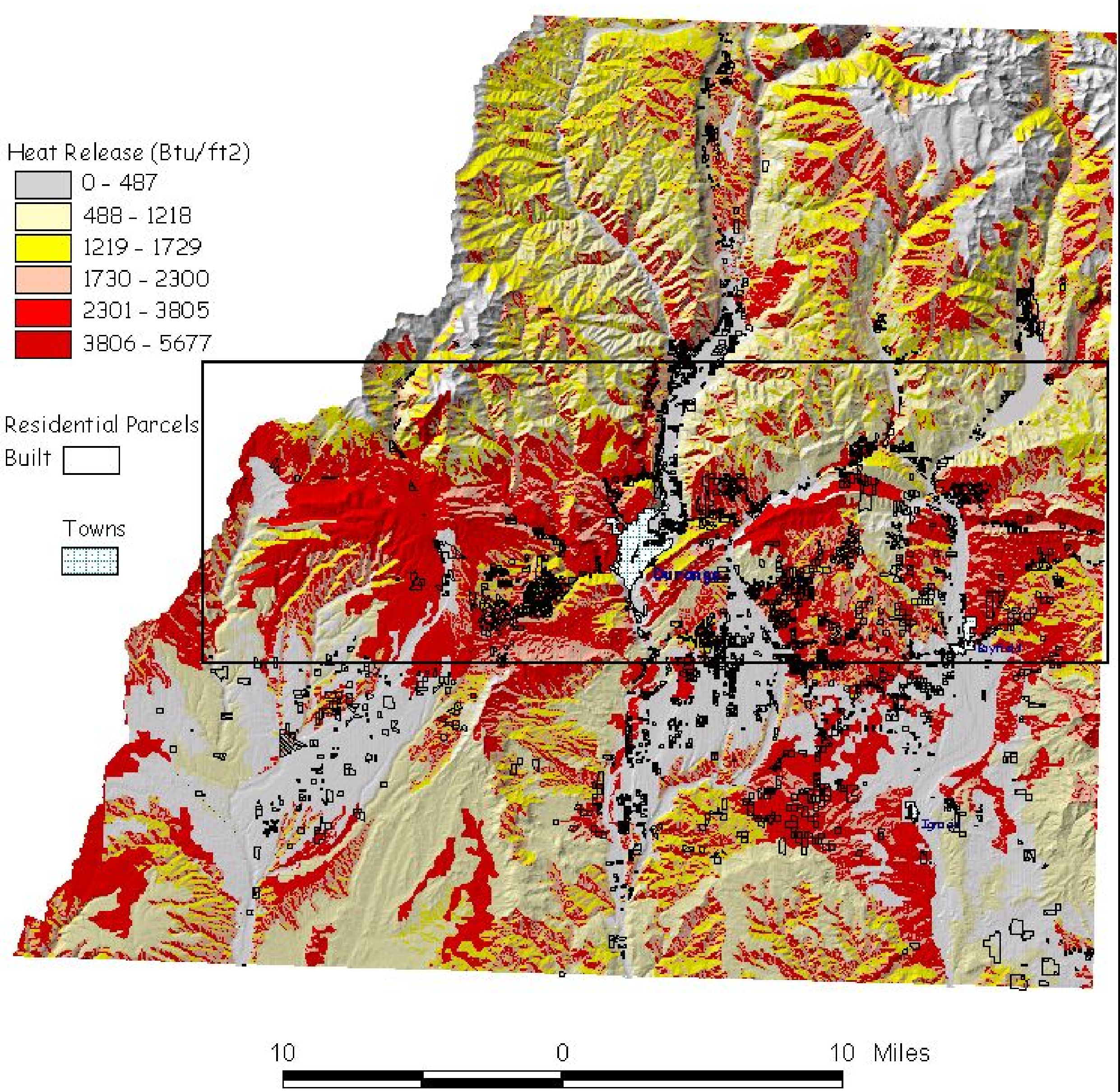


Figure 3. Map of simulated heat release overlaid with built residential parcels in La Plata County, Colorado. The rectangle indicates the central portion of the county where the greatest hazard to homes is found (see text).

Figure 4. Map of simulated flame length overlaid with built residential parcels in La Plata County, Colorado. The rectangle indicates the central portion of the county where the greatest hazard to homes is found (see text).

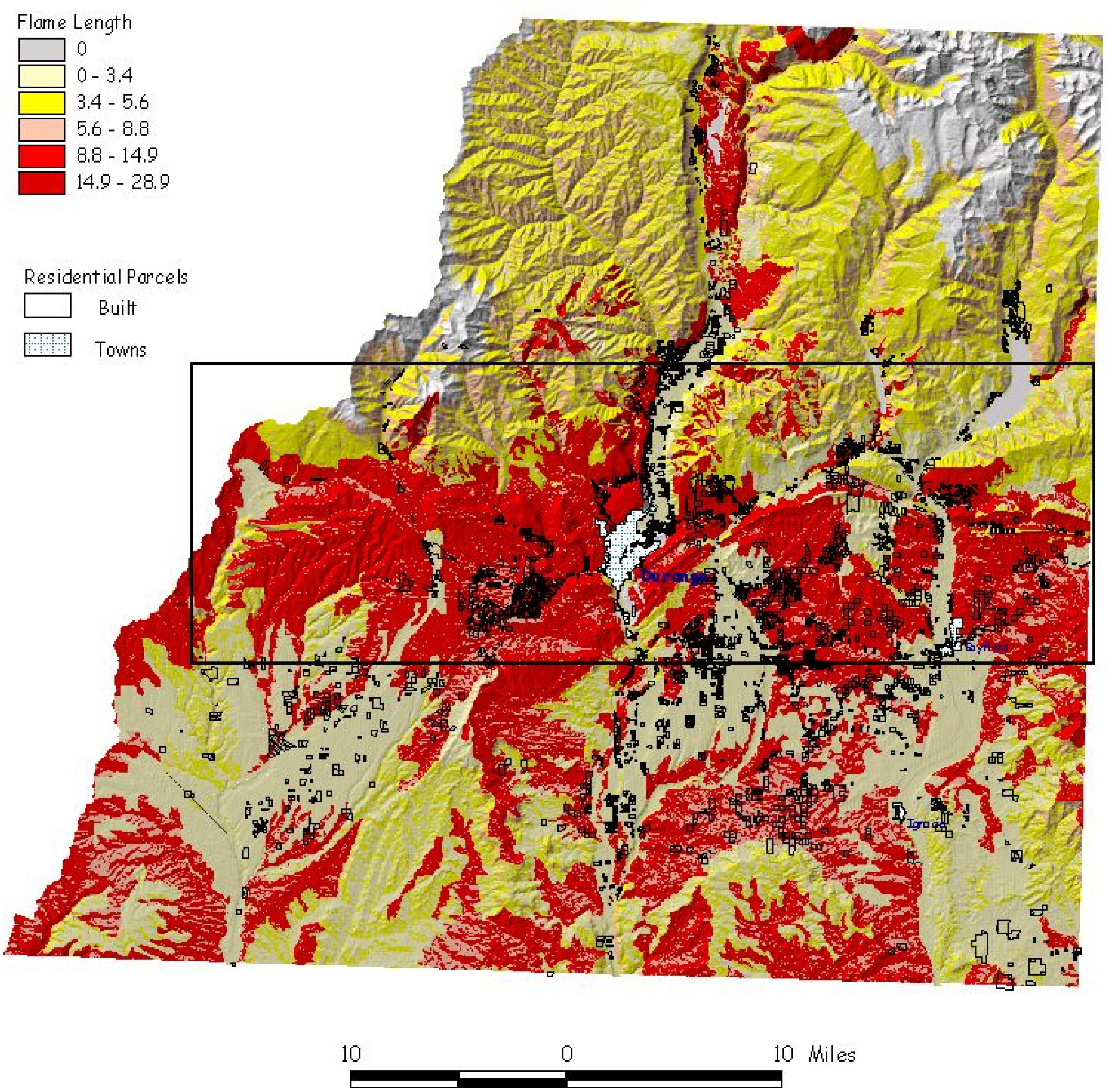


Figure 5. Map of simulated spread rate overlaid with built residential parcels in La Plata County, Colorado. The rectangle indicates the central portion of the county where the greatest hazard to homes is found (see text).

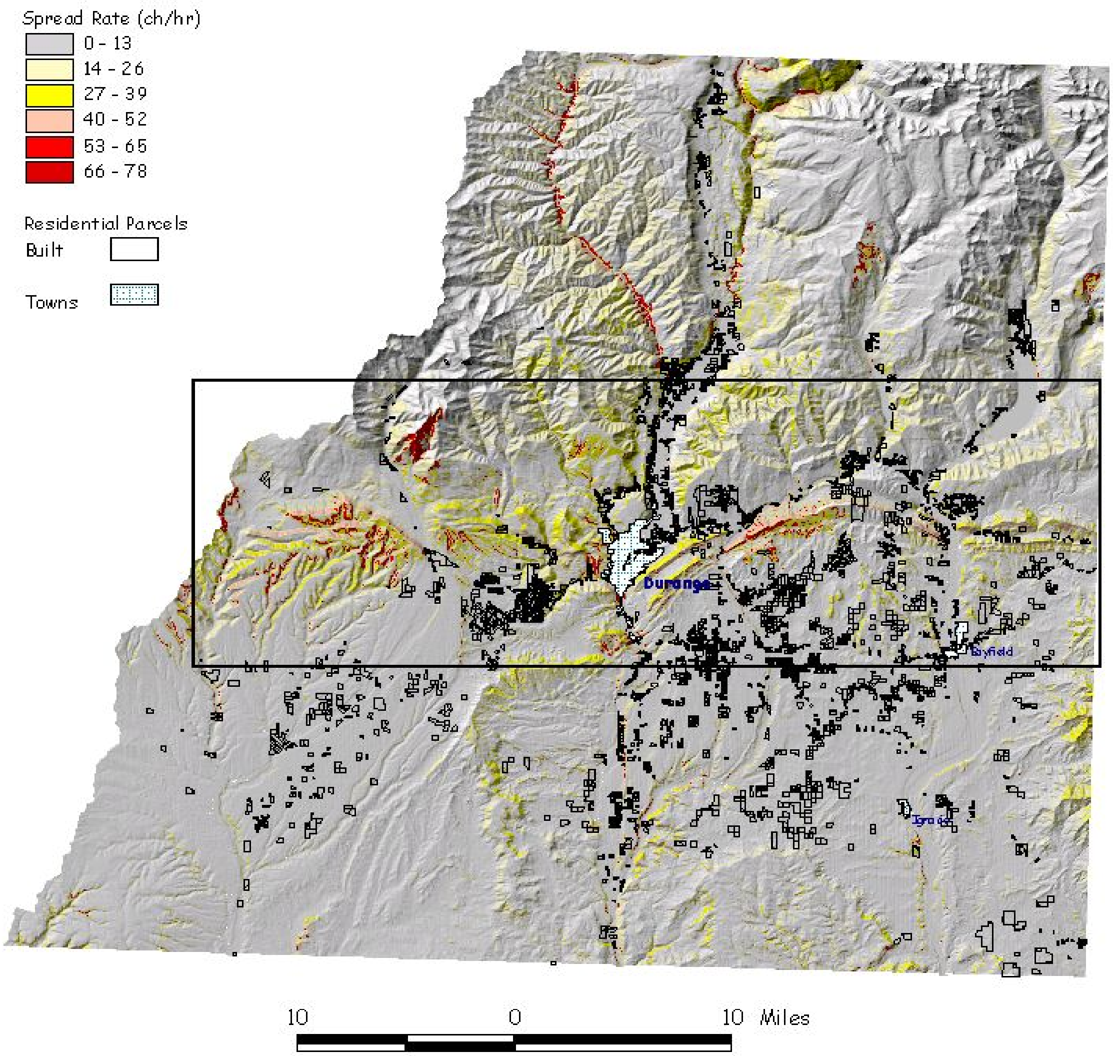
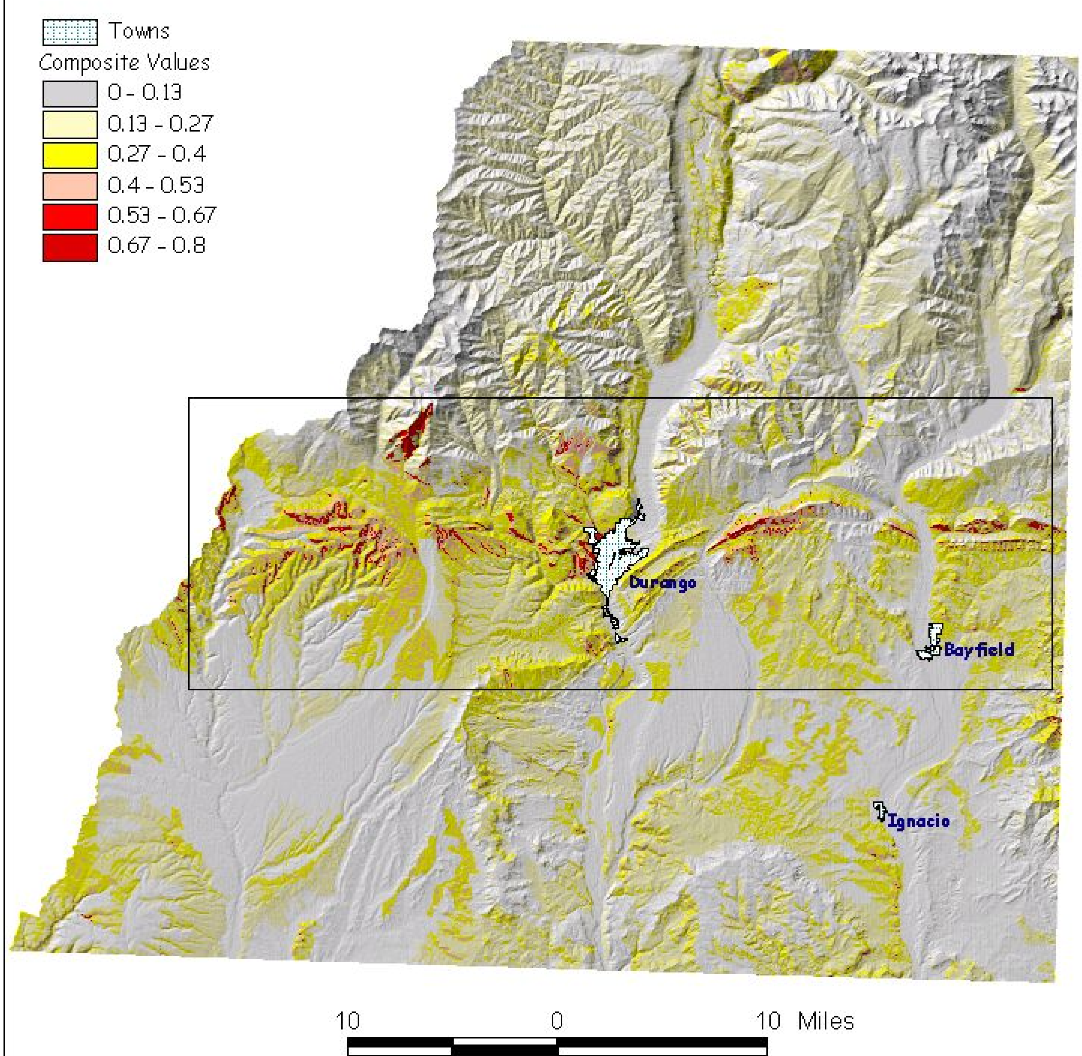


Figure 6. A composite map of wildfire hazard, produced by equally weighting the three individual parameters of heat release, flame length, and rate of spread, and normalizing the combined values to a scale of 0 –1, in combination with a synthetic normalized parcel density index. The rectangle indicates the central portion of the county where the greatest hazard to homes is found (see text).



DISCUSSION

Validating the Model

Formal model validation is difficult in an analysis of this kind, because no rigorous independent data set is available. However, we tested our model output using a less rigorous, but nevertheless informative, approach based on expert opinion.

First, we developed a draft version of the model independently of input from local fire managers, using single fuel models for each vegetation type and disregarding topographic aspect because we had no quantitative data on effects of aspect on fire behavior. We then held a meeting with federal and state fire managers who have worked for many years in La Plata County, as well as fire control personnel from the local fire protection districts. At the meeting we presented our preliminary results and asked for critical feedback – which was freely given! Overall, the practicing fire managers thought our modeling approach was sound, and thought that most of the predictions of fire behavior under severe fire weather conditions were consistent with their previous experience. However, they identified two areas where our predictions were inconsistent with their experiences. The first was in ponderosa pine and pinyon-juniper forests, where our simulations – based on single fuel models—predicted relatively benign fire behavior. The managers' experience was that these vegetation types could produce extreme fire behavior because of the highly flammable shrub component. In response, we developed the combined fuel models, described above in the Methods section. The managers' second criticism of our preliminary model was that aspect in fact makes a big difference in fire behavior in La Plata County. Specifically, in their experience, southerly aspects tend to burn more severely than northerly aspects. Therefore, we added the weighting factors for aspect, as described in the Methods section.

The second test of our model involved a written survey given to the same local fire managers and fire control personnel. The survey asked participants to (1) identify specific locations within the county where they perceived the greatest wildfire threat to homes, and (2) to rate each vegetation type for its potential to exhibit extreme fire behavior and for the difficulty of controlling fire under severe weather conditions. The rural subdivisions identified by managers as at greatest risk, largely coincided with the areas that we identified as having potentially high values for heat release, flame length, and/or rate of spread. Similarly, the experts identified oak shrublands, ponderosa pine / oak forests, and pinyon-juniper / sagebrush forests as the vegetation types with the greatest potential for extreme and uncontrollable fire behavior. Overall, the survey results indicated that our predictions of fire hazard were generally congruent with the experience of local fire experts.

Another validation of sorts was the Missionary Ridge fire, which burned nearly 30,000 ha in La Plata County under extreme weather conditions in June, 2002. Most of the burned area was in uninhabited lands in the San Juan National Forest, in the northern part of the county, but the southern portion of the fire was within the central zone of La Plata County that we identified as an area of special concern. The fire destroyed 83 homes and outbuildings, and caused the evacuation of 2300 homes (http://co.laplata.co.us/fire_slideshow/intro.html).

Where in La Plata County is Wildfire Hazard the Greatest?

Our Behave simulations and fuels map indicated that the environments likely to produce the most damaging and uncontrollable fire behavior are those with (1) steep southerly slopes and (2) oak, ponderosa pine, or pinyon-juniper vegetation. Unfortunately, these also are some of the most popular locations for building homes, because of the views and greenery that they afford (Figures 3-5). A composite map of wildfire hazard clearly shows the potential for extreme fire behavior in the central part of the county (Figure 6). According to local fire control personnel, some of the subdivisions within this zone also have serious problems related to access of emergency vehicles in the event of a fire. In addition to the central band of high wildfire hazard, a number of smaller areas throughout La Plata County appear in Figures 3-6 as places of concern. All such places contain numerous houses within flammable mixed conifer, pinyon-juniper, or sagebrush vegetation, often on steep south-facing slopes.

Further Refinements of the Wildfire Hazard Model

We believe that the analysis and maps presented above are adequate for initial strategic planning and educational purposes in La Plata County. For more precise and accurate assessments, however, we identified three potential improvements to our model that should be addressed in future work. The most serious shortcoming of our product is the coarse resolution of our basic fuels / vegetation map. In similar hazard mapping efforts around the country, inadequate spatial fuels data have been identified as one of the most serious limitations (e.g., Caprio et al. 1997, Keane et al. 2000, 2001). We recommend that a finer-scale fuels map be developed for the ponderosa pine and pinyon-juniper forests located in the central zone that we identified as the general area of highest fire hazard, perhaps by means of aerial photo interpretation (e.g., Oswald et al. 1999). It is not economically feasible to map the entire county in this way, but the results of our initial hazard assessment indicate that this central zone is where additional detailed fuels mapping would be most cost-effective. Even greater understanding could be gained by coupling a more detailed fuels map for the central portion of the county with a spatially explicit database of historic fire starts (e.g., Avalos and Alvarado 1998, Vasquez and Moreno 1998) and simulating fire spread with a model such as Farsite (e.g., Meyer 1996, Finney 1998, 1999, Stratton 2004).

A second shortcoming of our current model is the lack of precision as to locations of homes and other structures. We simply mapped all of the built parcels in the county, but were not able to specify exactly where individual structures were situated within each parcel. This is a minor problem with small parcels, but a potentially serious problem with large parcels. We made a preliminary attempt to use coordinates of electric meters (data provided by La Plata Electric Association) to pinpoint locations of homes, but the meter locations failed to identify numerous significant structures other than homes. A related shortcoming of our current map is that it does not distinguish between parcels that have been treated to create defensible space (e.g., Cohen 2000) and parcels that have not been so treated. Both of these problems could be addressed with additional aerial photo interpretation for the central zone of greatest fire hazard (described above).

The third major limitation of this completed phase of our wildfire hazard assessment is its restricted definition of cultural values. We have identified wildfire hazards only for homes and other structures. Future work should expand our treatment of cultural values to watersheds, viewsheds, critical habitats for sensitive species, and other aspects of the landscape that people value (e.g., Fried et al. 1999, Hodgson 2001).

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