Comparison of Areas Burned in Developed and Wildland Areas in the Northwestern Sierra Nevada Foothills

Vegetation, Wildland/Developed Strata

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Jim Spero, Fire Economics Analyst
Fire and Resource Assessment Program
California Department of Forestry and Fire Protection
1920 20th Street, Sacramento, CA 95814
(916) 227-2686 FAX (916) 227-2672
james_spero@fire.ca.gov

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Andrea E. Tuttle
Director
California Department of Forestry and Fire Protection

Mary D. Nichols
Secretary for Resources
The Resources Agency

Gray Davis
Governor
State of California

This analysis is a work in progress by the author and FRAP. Conclusions, data, and discussion are those of the author and FRAP.

California has a long history of wildfires throughout the state with damage reaching into the billions of dollars. Understanding wildfire in the context of developing rural areas is necessary for effective fire protection planning efforts. In this report, the California Department of Forestry and Fire Protection (CDF) Fire and Resource Assessment Program (FRAP) estimates the probability of vegetation burning due to wildfires on privately owned lands in the foothill areas of the Northwestern Sierra Nevada, so as to better understand how development affects fire occurrence rates.

The study area comprises about 3.5 million acres of CDF Direct Protection Area (DPA) under the administration of the Amador-El Dorado, Butte, Nevada-Yuba-Placer, and Tuolomne-Calaveras Units. This area consists of mostly privately owned lands within the State Responsibility Area (SRA), where the state pays to protect natural resources from damage by fire. A model for estimating the probability of fires in western El Dorado County comes from several different datasets; including vegetation types, historical wildfire perimeters and development density covering five decades.

These data suggest that wildfire protection has made a difference in areas developed at a density of one house per twenty acres or more. Developed areas tend to have more wildfire starts due to human presence. However, the actual area burned by wildfires in these areas, for most vegetation types, is less than in the surrounding less developed *wildland* areas. Faster detection, greater accessibility, roads, other non-flammable infrastructure, ornamental vegetation and other factors play a part in reducing the amount of wildfire. This study highlights the need to maintain the combined efforts of all fire agencies to address the growing risk posed by wildfires to people and property.

FRAP explored two methods of fire prediction: logistic regression and fire rotation analysis. FRAP researchers discarded the logistic regression approach after we found that we could not use a long enough historical data period to capture the variability of wildfire in conifer lands. For best results, researchers divided the landscape into "strata" based on vegetation and housing density class and calculated the number of years it would take to burn an area equivalent each stratum (fire rotation periods) using a 48-year data set.

Existing fire risk maps created for adjacent USDA Forest Service (USFS) National Forest lands may overstate the risk on private lands. In their analysis of USFS DPA, McKelvey and Busse (1996) state "we might reasonably expect 40 percent to 60 percent of the foothills zone to see fire at least once in the next 100 years." In contrast, FRAP data suggests that within the study area it would take wildfires:

- 262 years to burn all the grassland
- 233 years to burn all the hardwood land
- 126 years to burn all the shrub land
- 825 years to burn all the conifer lands

The FRAP study examines current and near future fire risk within the northwestern Sierran foothills study area, and the results are only applicable to that area. These methods, however, could be applied anywhere in California to develop additional fire occurrence information.

Background

FRAP required this analysis in order to generate fire probability inputs for a model (Greenwood & Saving, 1999) that will calculate expected annual housing value losses from wildfires for western El Dorado County.[1] Because fire suppression has shaped fire regimes across the Sierra Nevada (McKelvey and Johnston, 1992; McKelvey and Busse, 1996; Erman and Jones, 1996), and because fire suppression is in large part a response to housing values at risk, FRAP researchers chose to develop a fire risk map tailored specifically to account for the presence of human development.

In the study area, fire is a persistent, if erratic, influence. Despite the increasing potential for human-caused fires because of significant population growth, ignition rates are relatively flat (Figure 1). The number of acres burned in a year is highly variable, however. This illustrates both the generally consistent success of initial attack efforts and the potential for large "escaped" fires.

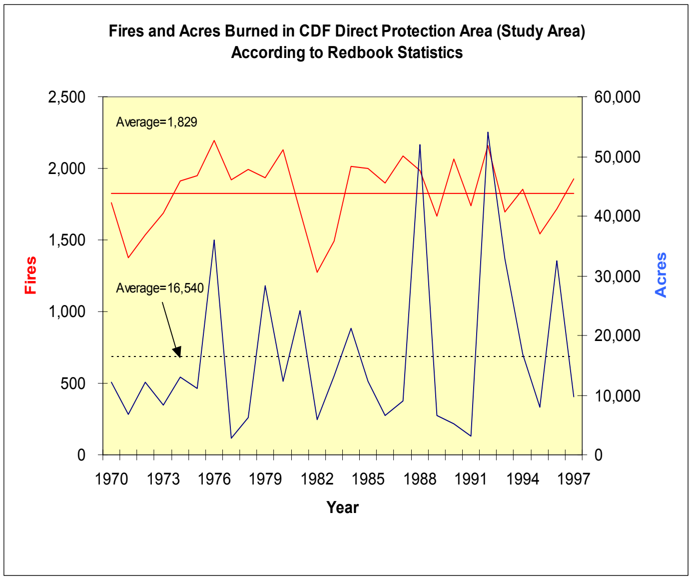


Figure 1. Annual ignitions (red) and acres burned (blue).

A fire risk map prepared by McKelvey & Busse (1996) for USFS lands in the Sierra Nevada defines "risk zones" within which fire locations are essentially random. However, that analysis did not include the lower foothills zone – the largest area of concern because of ongoing development and because the land is mostly privately owned. Also, their model determined fire risk primarily as a function of elevation, and elevation differences are far less in the study area than they are in their Sierra analysis.

An obvious fundamental difference between public and private lands is the presence of urban development. On private lands, widespread urban development (which we define as having a density of at least one house per 20 acres) includes houses and infrastructure that break up the natural vegetation that carries fire. Roads function as pre-built fire containment lines and facilitate the arrival of fire suppression resources. Green lawns, greenbelts, and ornamental plants reduce flammability. Fires are detected quickly and fire service providers respond with aggressive fire suppression augmented by local government and volunteer engines. Because of the exposure of people, houses and property (assets) to wildfire, ground and air fire suppression resources often make heroic efforts to prevent loss of life and property. Because of those efforts, generally, fewer than 5 percent of all fires escape initial firefighting efforts on private lands.

[1]This model multiplies the annual probability of burning by the conditional probability of house loss and the estimated housing value to calculate an expected annual housing value loss due to wildfire

As a result of these fundamental differences between public and private lands, researchers chose to develop a fire risk map tailored specifically to account for the impact of human development, which occurs at all elevations within the study area. Researchers believe that human development affects fire regimes significantly, mostly because of increased fire suppression to protect lives and property, and because of changes in the flammable landscape (fuels matrix).

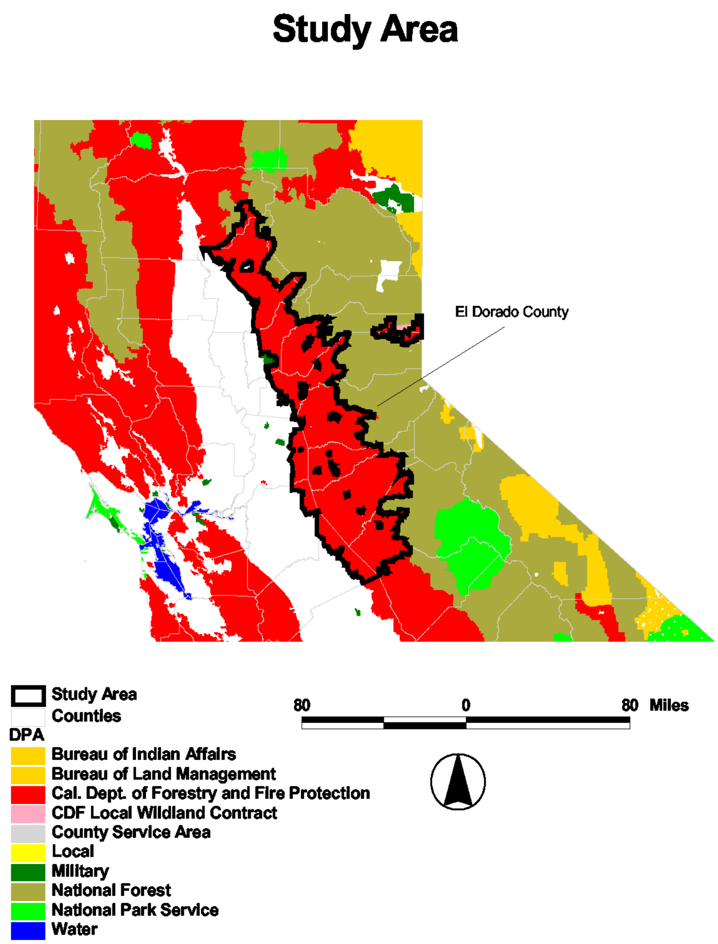


Figure 1. Study Area

Methodology

Because a single county appears too small for statistical purposes, researchers chose an initial study area consisting of 3,511,343 acres in a western portion of the Sierra Bioregion consisting of foothills and surrounding lowlands. This area includes lands in the CDF Direct Protection Area (CDF DPA) and administered by the Amador-El Dorado, Nevada-Yuba-Placer, Butte and Tuolomne-Calaveras Ranger Units (Figure 2). Because some of the eastern edges of this area are not yet mapped for vegetation, the actual analysis area is 3,223,173 acres.

Overall, the study area represents private lands across a region that is broadly homogeneous with respect to weather, topography, fire history, development, and fire suppression policy. Its boundaries include national forest lands to the east and local jurisdictions on the valley floor to the west.

There were few really big fires in the data period (1950-97) so the three million acre study area allows us to attribute the 49er Fire of 1988 in Nevada County (the single largest fire in that period) to the fire history of the entire northwestern Sierra foothills belt and not just to Nevada County.

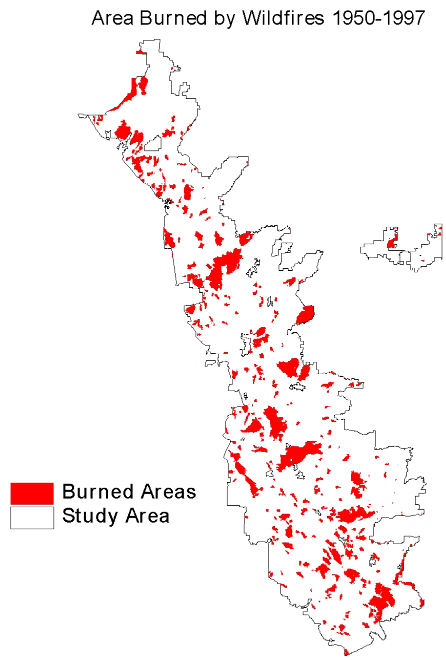
We develop a model of fire probability that includes aspects of landscapes linked to burned areas, including both vegetation types and housing density (we only calculate areas that actually burned). We look at all of these aspects as they occur over a 48-year period of time.

For a more technical analysis, please see the Methodology Appendix.

Data

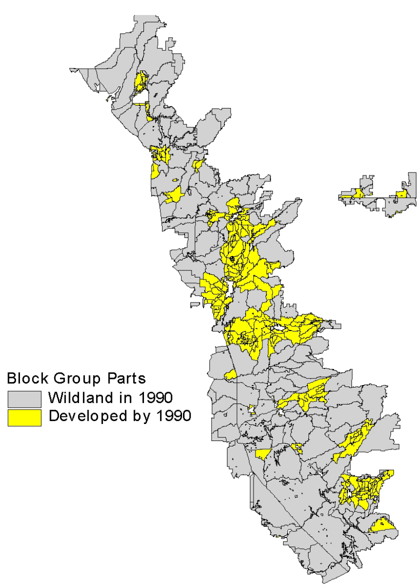
The California Fire History Database (Figure 3) is a data set that combines fire perimeters from CDF, the USFS, and other agencies that collect spatial data on wildland fire. Much of the older data was incorporated into the digital domain by digitizing fire maps from fire reports. Prior to 1989, CDF did not require mapped fire perimeters for fires less than 300 acres. Although these data are subject to inaccuracy and perhaps missing fires, the data used in this study account for most of the area burned by wildfires.

Figure 3. Area burned by wildfires 1950-1997



Historical housing density (Figure 4) for each decade from 1950 to 1990 are contained in datasets using methods developed for the Sierra Nevada Ecosystem Project (SNEP) (Duane, 1996) and based on data from the sample portion (long form) of the 1990 Census of Population ("Year Structure Built"—Summary Tape File 3A). Researchers used this information in the assignment of fires to the two "developed" or "Wildland" data components (strata).

Figure 4. Census block groups



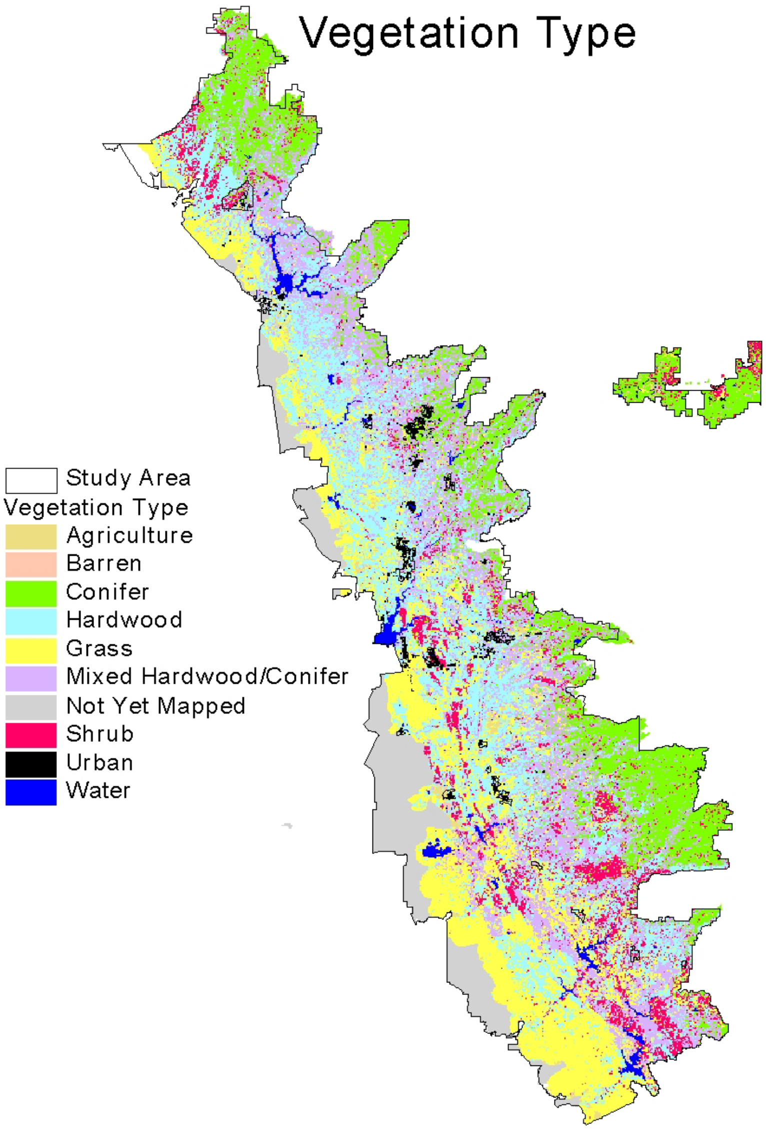
The geographic unit researchers use is the census Block Group part, which FRAP refers to as a "split block group" (SBG). SBG's represent the smallest units of geography for which US Census demographics are generally available.[2]

The sample data could underestimate the degree of development in early years because some residences no longer exist.

[2]A census Block Group that crosses city or county subdivision boundaries divides into two or more parts along those boundaries.

Vegetation Type attributes come from detailed vegetation data in the FRAP GIS Library. We cross-referenced the census Block Groups with the vegetation data. [3]

Figure 5. Vegetation type



[3]These data are intersected with the SBG coverage to assign historical housing density to vegetation polygons. Areas labeled "NYM" are not yet mapped. We exclude NYM, Agriculture, Urban and Water from this analysis.

Computing Fire Rotation Period (FR) by Strata

The concept of Natural Fire Rotation was first proposed in the Boundary Waters Canoe Area of Minnesota, which was concerned with natural fire barriers such as swamps, lakes, and streams (Heinselman, 1973). The **fire rotation method** (**FR**) *calculates the average number of years required to burn an area equal to the total burnable area.* This usually involves dividing the land into areas where the factors affecting fire regimes are relatively homogeneous. Researchers call these areas *strata.* The study area can be thought of as a three-layer cake with fire perimeters making up the top layer, and with vegetation type and development status layers below. Researchers cut the cake into pieces (strata) representing unique combinations of vegetation type and development status. The formula is usually stated:

$$\mathbf{FR} = \frac{Total\ time\ period}{\mathrm{Pr}oportion\ of\ area\ burned\ in\ period}$$

This is equivalent to

$$\mathbf{FR} = \frac{Total\ Area\ of\ Stratum}{Average\ Annual\ Acres\ Burned}$$

FRAP researchers examined fire perimeters from the CDF Fire History Database for the period of 1950-97 against types of vegetation in burned areas. Then US Census housing density estimates for each decade (1949, 1959,1969, 1979 and 1990) were reviewed to approximate housing density for the year that the fire occurred. Then the SBG's crossover fire perimeters were examined. Raw housing density was labeled as **Developed** with 32 or more houses per square mile and as **Wildland** with less than 32 or more houses per square mile**.**

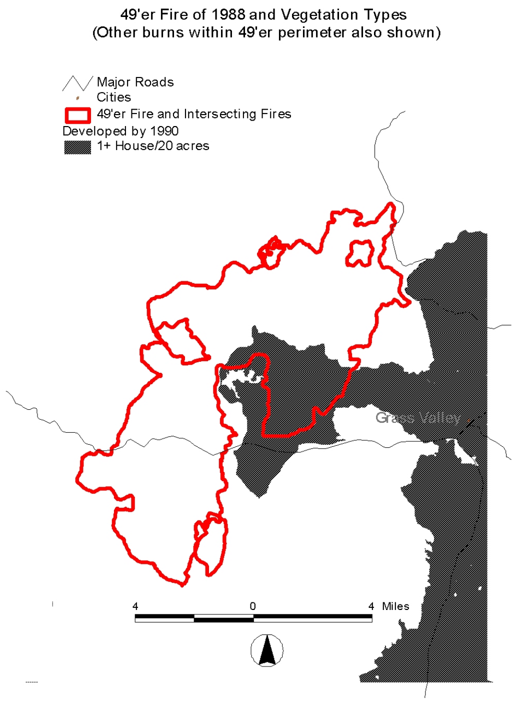
Because historical US Census housing densities was reviewed once a decade, several burn years were included under the umbrella of one decade's housing density information (Table 1) in order to give a best estimate of housing density in burn areas.

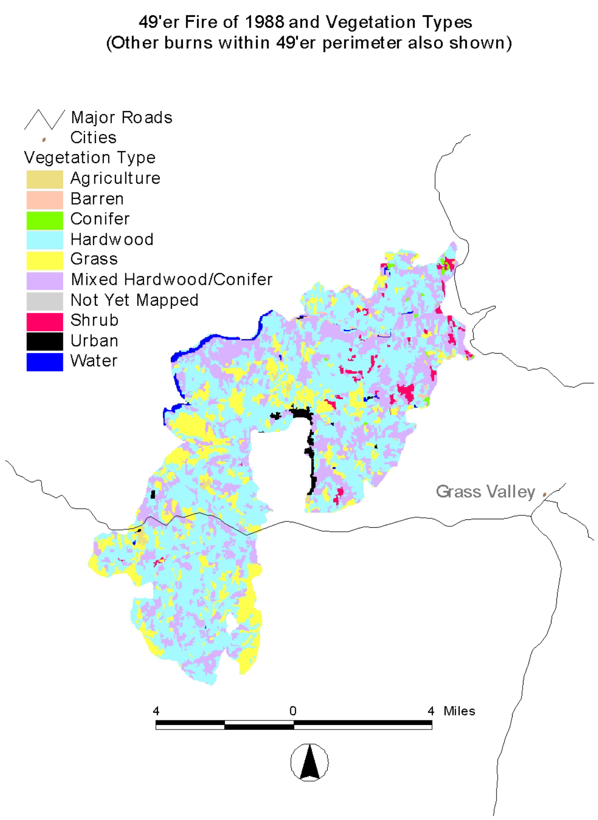
Table 1. Fire start years and corresponding US Census Housing density decade used

If fire started in this period…	Use housing density for this year…
1950-54	1949
1955-64	1959
1965-74	1969
1975-84	1979
1985-97	1990

Figures 6a and 6b illustrate how burned acres are allocated to both Vegetation Type and Housing Density Class. The perimeter of the "49er" fire of 1988 is shown. The area of development (as of 1990) appears in Figure 6a as a hatched area and the underlying vegetation data receive the **Developed** label, while the remainder receives the **Wildland** label. The vegetation datasets (polygons) are shown in Figure 6b. Unburned areas are also labeled for calculation of total strata area.

Figures 4a and 4b. Area of 49er Fire showing overlapping development (top), vegetation polygons (bottom).





The analysis then calculates the total number of acres in each stratum and the number of acres burned by 1) Vegetation Type (Grass, Shrub, Hardwood, Mixed Hardwood/Conifer, and Conifer), 2) Housing Density Class (Wildland, Developed) and 3) Vegetation Type and Housing Density Class combined. Combining Vegetation Type and Housing Density Class results in ten strata (Table 2):

Table 2. Ten strata based on Vegetation Type and Developed/Wildland status

Vegetation Type	Developed	Wildland
Conifer	1	2
Mixed Hardwood/Conifer	3	4
Hardwood	5	6
Shrub	7	8
Grass	9	10

Calculations for each stratum include:

- *Total Area* — Area* of stratum (Acres)
- *Acres Burned/Year* — Average annual acres burned (Ac Burned/48)
- *FR* — Fire Rotation (Total Area /(Acres Burned/Year))
- *1/FR (%)* — Probability of an acre burning in any given year expressed as a percent

*Reduced by 5 percent to account for non-flammable surfaces, such as lakes and streams, roads, etc. This amount is arbitrary, but generous enough to ensure that FR is not inadvertently understated.

Table 3 shows the total area of each Vegetation stratum for Developed and Wildland over time. The average per decade minus 5 percent is the *Total Area* of each stratum for the purposes of calculating FR.

Table 3. Acres of Vegetation Type and Housing Density Class for years 1949, 1959, 1969, 1979 and 1990, and averages

Vegetation	1949	1959	1969	1979	1990	Average	Avg. less 5%
Conifer (Developed)	5,031	10,850	27,272	64,288	98,504	41,189	39,129
Mixed (Developed)	13,710	24,791	52,056	113,663	188,846	78,613	74,682
Hardwood (Developed)	14,506	27,983	60,369	122,283	215,506	88,129	83,723
Shrub (Developed)	5,469	7,236	11,434	25,225	49,205	19,714	18,728
Grass (Developed)	6,202	11,007	21,102	48,214	90,069	35,319	33,553
All Developed	44,919	81,867	172,232	373,674	642,130	262,964	249,816
Conifer (Wildland)	591,698	585,879	569,456	532,441	498,225	555,540	527,763
Mixed (Wildland)	751,079	739,998	712,733	651,126	575,943	686,176	651,867
Hardwood (Wildland)	865,500	852,023	819,638	757,723	664,500	791,877	752,283
Shrub (Developed)	254,358	252,591	248,393	234,602	210,623	240,113	228,108
Grass (Wildland)	715,620	710,815	700,720	673,608	631,752	686,503	652,178
All Wildland	3,178,255	3,141,307	3,050,941	2,849,499	2,581,044	2,960,209	2,812,199
Developed+Wildland	3,223,173	3,223,173	3,223,173	3,223,173	3,223,173	3,223,173	3,062,015

FR was not calculated by decade and results averaged because it would involve very small sample sizes.

Results

A total of 529,824 acres burned in the study area over the 48-year period, or 11,038 acres per year on the average (about 0.4 percent per year). Table 4 shows the FR results for various strata. Total Area is reduced by 5 percent to account somewhat for non-flammability. The last column is the percent of area burned annually, calculated as the probability of burning (1/FR) expressed as a percent.

For Vegetation strata alone (Table 4, Middle), Shrub had the most fire occurrence (0.8%/year), followed by Hardwood and Grass (0.4 percent), Mixed Hardwood/Conifer (0.3 percent) and Conifer (0.1 percent). For Housing Density strata alone (Table 4, Bottom), Developed areas burned at 0.2 percent per year, half the 0.4 percent/year rate of burning in Wildland areas.

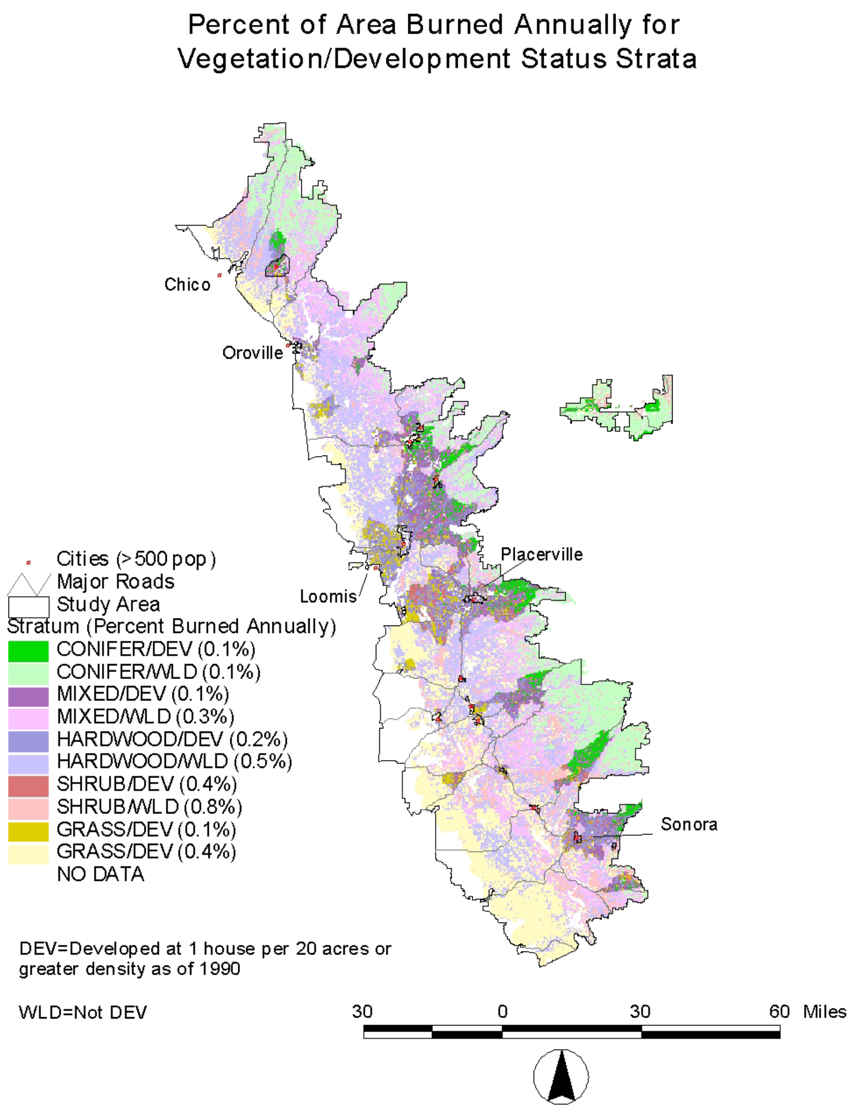
Together, the combined Vegetation Type and Housing Density strata appear at the top of Table 4. Note that although FR differs in the Conifer strata, 1/FR (%) is identical (no density effect detected).

Table 4. Fire Rotation (FR) and the percent of acres burned annually (1/FR(%)) for Vegetation Type only strata (Middle), Housing Density strata only (Bottom), and Combined Vegetation Type and Housing Density Class (Top).

STRATUM	Acres Burned/Year	Total Area -5%	Fire Rotation	1/Fire Rotation (%)
Conifer/Developed	45	39,129	868	0.1%
Conifer/Wildland	642	527,763	821	0.1%
Mixed/Developed	93	74,682	802	0.1%
Mixed/Wildland	2,090	651,867	312	0.3%
Hardwood/Developed	127	83,723	658	0.2%
Hardwood/Wildland	3,458	752,283	218	0.5%
Shrub/Developed	73	18,728	258	0.4%
Shrub/Wildland	1,894	228,108	120	0.8%
Grass/Developed	47	33,553	712	0.1%
Grass/Wildland	2,568	652,178	254	0.4%
Conifer	688	566,892	825	0.1%
Mixed	2,184	726,550	333	0.3%
Hardwood	3,585	836,006	233	0.4%
Shrub	1,966	246,836	126	0.8%
Grass	2,615	685,731	262	0.4%
Developed	385	249,816	649	0.2%
Wildland	10,653	2,812,199	264	0.4%
ALL	11,038	3,062,015	277	0.4%

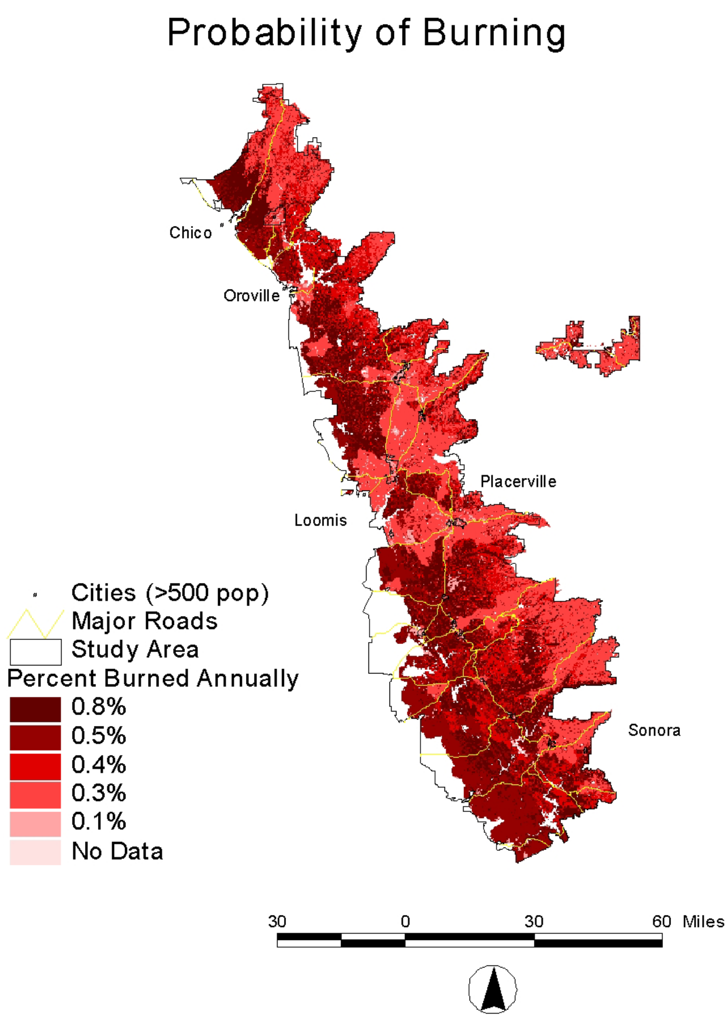
Figure 5 illustrates these results spatially.

Figure 7. Percent of area burned annually in private lands in the foothills of the Northwestern Sierra.



In contrast to the fire occurrence patterns on public lands in the Sierra bioregion, where McKelvey and Busse (1996) found elevation to be a strong influence on fire risk (fire risk decreases as one moves upslope), our map shows less burning (lighter colors) on populated lowlands as well as on eastern uplands (Figure 8). McKelvey and Busse did not find their model of fire risk well suited for lowland areas, so direct comparisons are problematic. Sapsis and Bahro, *et al*. (1996) calculated the risk of large fires on public and private lands in the Sierra bioregion by weather zone, population density and vegetation type strata and consistently found a lower risk of large fire in more populated areas, regardless of elevation.

Figure 8. Probability of Burning

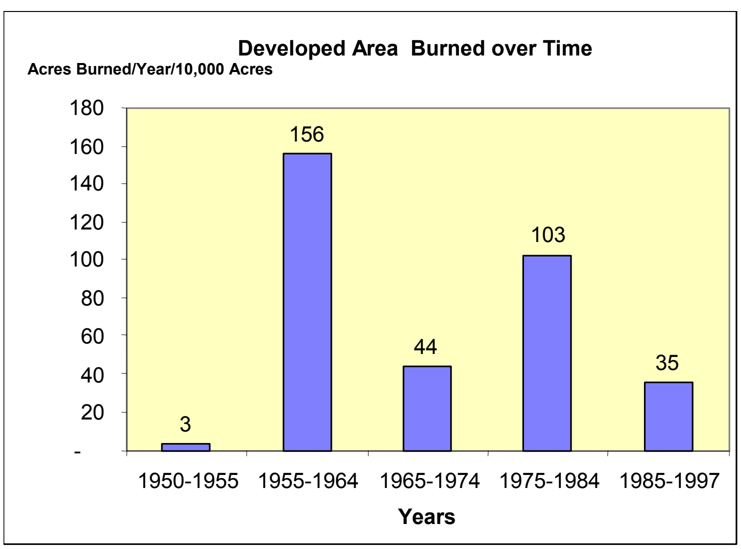


Discussion

How does FRAP know that the strata represents different fire regimes? Researchers look at the average annual acres burned per year over the 48-year fire history for each stratum and used various tests to determine how likely the differences are due to chance (See Methodology Appendix). The highly variable nature of yearly burned acreage may render these tests artificial, but the results are generally consistent with *a priori* expectations. To compare fire data taken from areas of different size, all annual averages are converted to mean acres burned per thousand acres. Researchers can reject the idea that there is no difference in means for the combined strata, for the vegetation only strata, and for the Developed/Wildland strata, and hold that there are real differences. Significant differences are also found when comparing Wildland versus Developed on Mixed, Hardwood and Grass. Researchers could not completely reject the hypothesis that there were no differences for the Conifer Developed/Conifer Wildland or for the Shrub Developed/Shrub Wildland comparison. These results are not surprising given the similar FR in the Conifer strata, but are perhaps contradictory to the results for the Shrub strata.

Will developed areas become more at risk in the future? Development of Wildland areas continues and there is no guarantee that fire suppression effectiveness and fire prevention efforts will keep pace with possibly more numerous ignitions and certainly more assets at risk. Since 1950, the infrastructure and landscape changes that development can bring seem to help to mitigate the fire risk, however, without those changes; fire risk might increase in developed areas. To compare burning rates in developed areas by decade, the number of developed acres burned was divided into the total area of development for each period and multiplied by 10,000, then that product was divided by the number of years in the period. Figure 9 shows the results of these calculations.

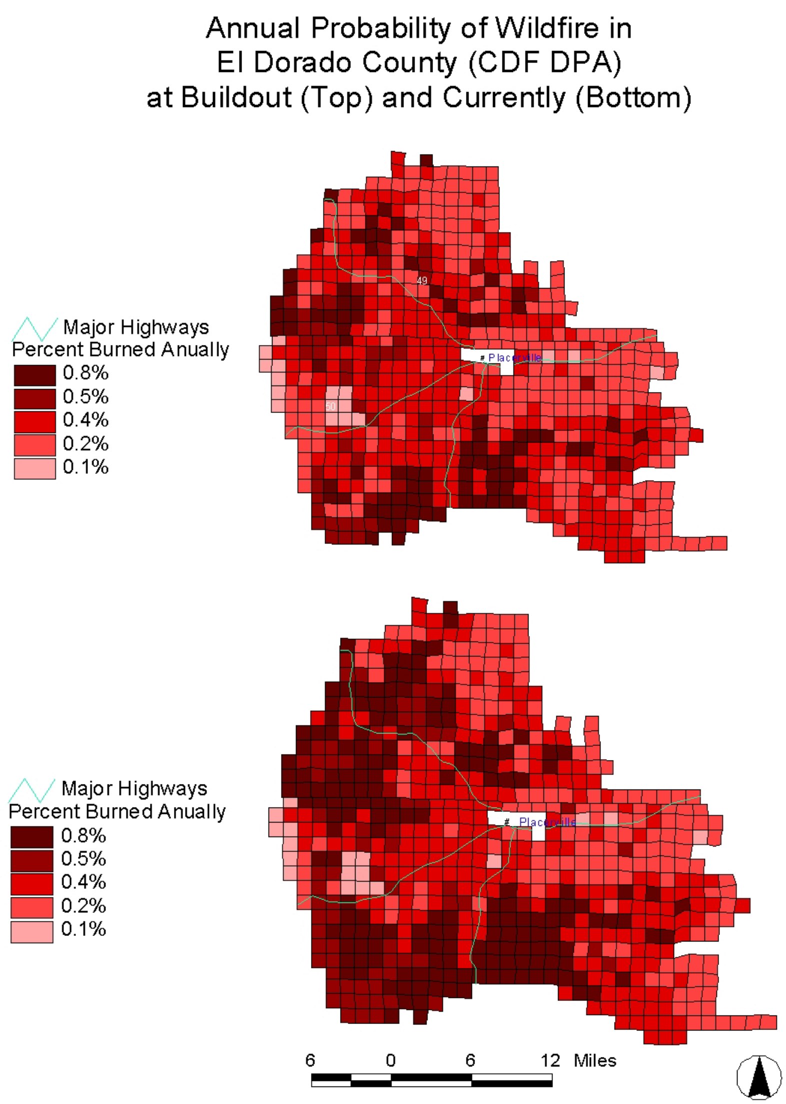
Figure 9. Developed area burned over time



Application of Results in the Buildout Model

The purpose of this study is to develop annual fire probabilities for the "Buildout" study area of Western El Dorado County (Greenwood and Saving, 1998). The probabilities from Table 4 are applied to Public Land Survey (PLS) Sections coded with predominant Vegetation Type and housing density. Figure 10 shows the percent of area burned annually assuming 1990 population (Bottom) and assuming predicted population at buildout (Top).

Figure 10. Probability of burning in western El Dorado County study area



Note: the decrease in area in the highest fire risk class (0.4 percent to 0.8 percent burned per year) with population increases concentrated in the I-50 (East/West) and Hwy 49 (North/South) corridor.

Conclusions

FRAP researchers found in Mixed Hardwood-Conifer, Hardwood, Shrub and Grass vegetation a consistent pattern of lower amounts of fire occurring in developed areas as compared to Wildland areas. The Conifer vegetation strata do not exhibit the pattern, however. The Shrub vegetation strata are apparently different in the FR analysis but not significantly different in the statistical test. High variability in annual acres burned totals may be confounding the statistical tests to some degree, but overall indications point to the statistical validity of the strata.

Researchers conclude that failure to account for development when estimating the amount of wildfire could result in overestimates of the average amount of burning in these areas, and thus, overstate total costs in the "buildout" model.

Applying the map of fire probability to the near future is contingent on maintaining the same level of fire protection as in the past. As development brings more houses and other assets into Wildland areas, the frequency of ignitions may well rise. Increases in fire suppression capability are by no means assured; therefore the probability of burning may increase in some locations along with development. In any event, the advancing footprint of development makes contact between wildfire and assets at risk a continuing and growing concern.

These results are specific to the study area and may not be representative of National Forest lands or other areas of California, but FRAP methodology may be very useful to evaluating the development of other rural areas in the fast-growing state of California. For example, in the southern part of the state where hot, dry winds (e.g., Santa Ana) blow regularly, the risk of fires in developed areas might be no different than Wildland areas. Moreover, actual fire frequency for a particular area might be different than for the strata as a whole, due to averaging from other areas of the stratum. FRAP researchers do not believe that the probability of burning immediately falls as an area develops, only that these areas will begin to experience a gradual decrease in burning over time.

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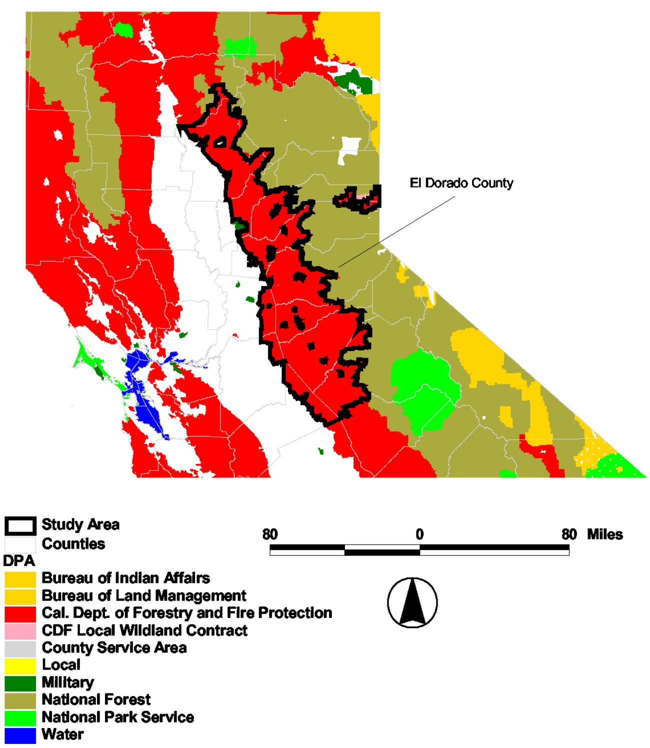
Methodology Appendix

Computation of fire probability involves querying landscape attributes, linking burned areas to both a vegetation type and historical (decadal) housing density class based on sample data from the 1990 Census of Population and Housing (long form) and the date of the fire.

FRAP researchers explored two methods of fire prediction: 1) point estimation using logistic regression, employing a 28-year fire history and 2) calculation of fire rotation (FR) periods (the number of years it would take to burn an area equivalent to the study area) for landscape strata, using a longer, 48-year data set. Both methods showed that inclusion of housing density as an explanatory factor results in measurements of lower fire probability in developed areas, and is thereby preferable because it avoids overstating risk in these areas (as would occur if basing estimates on vegetation information alone). Because the 28-year fire history was too short for use in Conifer vegetation, the FR method for the study area was adopted.

Study Area



Researchers first create landscape "strata" using FRAP's Arc/Info Geographic Information System (GIS) to create polygons from the intersected boundaries of vegetation types, census block group parts (housing density) and historical fire perimeters for the period 1950-1997. Only areas that actually burned within the study area are calculated.

Then a fire rotation period (FR) is calculated for each stratum, which is equivalent to an average fire probability. FR is the number of years required to burn the entire stratum area. Calculation of the FR is straightforward: Divide the average annual acres burned into the total number of acres in the stratum. The reciprocal of the FR is the average probability of an acre burning in any year.

Because the FR method averages fire activity over the area of a stratum it will inherently over or understate actual fire risk at any given point on the ground within that stratum. The purpose of stratification is to minimize this within-stratum variation in fire risk by measuring over areas that are reasonably homogeneous with respect to underlying factors that drive fire risk.

To reduce the potential for error in matching of fires to vegetation types due to changes in vegetation over time we use life form level vegetation labels (conifer, mixed hardwood/conifer, shrub, and grass).

How do we know that the measured FR's in various strata really represent different fire frequencies? We applied Analysis of Variance (ANOVA) techniques and t-tests to the average annual acres burned in various strata combinations (e.g., by vegetation only, by development status only, by vegetation and development status combined) to rule out differences that could be explained by mere chance.

Earlier attempts to use logistic regression techniques did not yield useful results because of constraints on the sample size. For that kind of analysis we must evaluate burn/no burn assuming that housing density and vegetation type is constant over time. That substantially limits the time period of the analysis and thus the number of fires in the data. The study area could have been expanded but this would have diluted the focus of the analysis on the area of interest and increased the innate variability of factors driving risk (weather, ignition types, vegetation, etc.).

Testing Strata Means

Stratifying the landscape should reduce error due to averaging fire activity across a larger, more heterogeneous landscape. As a check on our results we compare 48-year history of annual acres burned totals for various strata combinations to determine whether the means are significantly different. If they are, then the strata better account for differences in fire occurrence rates than a larger, un-stratified landscape.

To permit comparisons of fire data taken from areas of different size, all annual averages are first converted to acres burned per thousand acres.

Analysis of variance (ANOVA) tests whether the mean annual acres burned over a forty-eight year period in five vegetation strata is equal. The result: there is less than a one in 10,000 chance that the means are equal (p<0.0001). We reject that null hypothesis and accept the alternative hypothesis that the means are different. See Table 1.

Table 1. Vegetation Strata

Anova: Single Factor
SUMMARY (data are acres burned per thousand acres)

Groups	Count	Sum	Average	Variance		
ALL GRASS	48	3,831.27	79.82	9,383.00		
ALL BRUSH	48	580.86	12.10	694.56		
ALL WOOD	48	287.96	6.00	110.01		
ALL CON	48	117.06	2.44	31.18		
ALL MIX	48	210.91	4.39	45.92		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	210,434.25	4	52,608.56	25.63	<0.0001	2.410061484
Within Groups	482,439.69	235	2,052.93			
Total	692,873.94	239				

A two-sample test for all developed land versus all Wildland is also significant (p<0.0001, one-tailed). See Table 2. A one-tailed test assumes that burning is greater in Wildland than in Developed areas.

Table 2. Developed/Wildland Strata

t-Test: Two-Sample Assuming Unequal Variances (data are acres burned per thousand acres)

	All developed	All wildland
Mean	10.46	122.49
Variance	837.05	23,626.12
Observations	48	48
Hypothesized Mean Difference	0	
df	50	
t Stat	(4.9629)	
P(T<=t) one-tail	0.000004	
t Critical one-tail	1.6759	
P(T<=t) two-tail	0.000008	
t Critical two-tail	2.0086	

The combined strata (vegetation and development status) are highly significant (p<0.0001). See Table 3.

Table 3. Vegetation and Development/Wildland status combined

Anova: Single Factor
SUMMARY (data are acres burned per thousand acres)

Groups	Count	Sum	Average	Variance		
Grass/Dev	48	75.60	1.57	21.44		
Grass/Wild	48	3,755.67	78.24	8,818.64		
Shrub/Dev	48	206.76	4.31	259.16		
Shrub/Wild	48	374.10	7.79	154.38		
Hardwood/Dev	48	81.85	1.71	25.36		
Hardwood/Wild	48	206.10	4.29	44.57		
Conifer/Dev	48	62.18	1.30	25.22		
Conifer/Wild	48	54.88	1.14	4.25		
Mixed/Dev	48	67.22	1.40	15.77		
Mixed/Wild	48	143.69	2.99	15.35		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	246,803.43	9	27,422.60	29.22	<.0001	1.90
Within Groups	441,054.13	470	938.41			
Total	687,857.56	479				

Eliminating the Grass strata still yields significant differences. See Table 4.

Table 4. Vegetation and Development/Wildland status combined – except for Grass strata

t-Test: Two-Sample Assuming Unequal Variances (data are acres burned per thousand acres)		
	CON/DEV	CON/WLD
Mean	1.30	1.14
Variance	25.22	4.25
Observations	48	48
Hypothesized Mean Difference	0	
df	62	
t Stat	0.1941	
P(T<=t) one-tail	0.4234	
t Critical one-tail	1.6698	
P(T<=t) two-tail	0.8468	
t Critical two-tail	1.9990	

Pairwise comparisons for each vegetation type/developed status follow.

A t-test for the conifer vegetation type does not indicate a significant difference in developed areas versus Wildland areas (p=0.4234, one-tailed). See Table 5. The Shrub vegetation type is also not significant (p=0.1191, one-tailed). See Table 6.

Table 5. Conifer Vegetation Developed/Wildland

t-Test: Two-Sample Assuming Unequal Variances (data are acres burned per thousand acres)		
	CON/DEV	CON/WLD
Mean	1.30	1.14
Variance	25.22	4.25
Observations	48	48
Hypothesized Mean Difference	0	
df	62	
t Stat	0.1941	
P(T<=t) one-tail	0.4234	
t Critical one-tail	1.6698	
P(T<=t) two-tail	0.8468	
t Critical two-tail	1.9990	

Table 6. Shrub Vegetation Developed/Wildland

t-Test: Two-Sample Assuming Unequal Variances
(data are acres burned per thousand acres)

	SHRUB/DEV	SHRUB/WLD
Mean	4.31	7.79
Variance	259.16	154.38
Observations	48	48
Hypothesized Mean Difference	0	
df	88	
t Stat	(1.1877)	
P(T<=t) one-tail	0.1191	
t Critical one-tail	1.6624	
P(T<=t) two-tail	0.2381	
t Critical two-tail	1.9873	

The remaining pair wise comparisons are significant at the 0.05 significance level (one-tailed).

Table 7. Mixed Hardwood/Conifer Vegetation Developed/Wildland

t-Test: Two-Sample Assuming Unequal Variances
(data are acres burned per thousand acres)

	MIX/DEV	MIX/WLD
Mean	1.40	2.99
Variance	15.77	15.35
Observations	48	48
Hypothesized Mean Difference	0	
df	94	
t Stat	(1.9787)	
P(T<=t) one-tail	0.0254	
t Critical one-tail	1.6612	
P(T<=t) two-tail	0.0508	
t Critical two-tail	1.9855	

Table 8. Hardwood Vegetation Developed/Wildland

t-Test: Two-Sample Assuming Unequal Variances (data are acres burned per thousand acres)		
	HARDWOOD/DEV	**HARDWOOD/WLD**
Mean	1.71	4.29
Variance	25.36	44.57
Observations	48	48
Hypothesized Mean Difference	0	
df	87	
t Stat	(2.1446)	
P(T<=t) one-tail	0.0174	
t Critical one-tail	1.6626	
P(T<=t) two-tail	0.0348	
t Critical two-tail	1.9876	

Table 9. Grassland Vegetation Developed/Wildland

t-Test: Two-Sample Assuming Unequal Variances (data are acres burned per thousand acres)		
	GRASS/DEV	**GRASS/WLD**
Mean	1.58	3.71
Variance	21.44	16.53
Observations	48	48
Hypothesized Mean Difference	0	
df	92	
t Stat	(2.40)	
P(T<=t) one-tail	0.0091	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.0183	
t Critical two-tail	1.99	