FOREST HEALTH ASSESSMENT: AIR QUALITY TRADEOFFS[1]

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ABSTRACT: In this air quality assessment, aerial photo attributes and an emissions inventory approach were used to estimate smoke production over time for the Deschutes, Grand Ronde, Methow, Pend Oreille, Wenatchee, and Yakima river basins in eastern Oregon and eastern Washington. Emissions of particulate matter less than 10 micrometers in diameter (PM10) changed significantly over time ($P = 0.10$) for three of the river basins. For example, PM10 produced from wildfires burning today in the Grande Ronde River Basin have increased by 80 pounds per acre from the historic period. Increases occurred because of a vegetation type and density shift over time in the Grande Ronde. This assessment showed that wildfires would produce nearly twice the amount of smoke as prescribed fire for the current period for all river basins. Tradeoffs in air quality in terms of past and current smoke production, and differences in prescribed fire versus wildfire smoke production, will enable society to make informed decisions with regards to managed fire, wildfire, air quality, and forest health.

INTRODUCTION

This report is a portion of the Forest Health Assessment (Lehmkuhl et al. 1993). It compares smoke production over time from prescribed fires and wildfires for six selected river basins in eastern Oregon and eastern Washington. The objectives of this assessment are to (1) describe the variation of smoke production from prescribed fires and wildfires over time on National Forest lands in selected river basins of eastern Oregon and eastern Washington; (2) describe current variation in smoke produced by prescribed burning in the selected river basins, and assess deviation from proposed increases in prescribed burning for forest health restoration; and (3) examine tradeoffs in air quality with regards to managed fire, wildfire, and forest health.

The fire-adapted ecosystems of eastern Oregon and eastern Washington have a serious forest health problem. Fire exclusion is one of the major contributors to the forest health decline (Mutch et al. 1993). A 3- to 5-fold increase in prescribed burning has been suggested for this area to restore the ecosystems to a more healthy

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state. Unfortunately, prescribed fire produces smoke and has the potential to degrade visibility, violate current air quality standards, and impact human health. Some of these impacts run contrary to current Federal and state laws, and are extremely unpopular with the public. If fire is to be reintroduced into the ecosystem, fire managers, air quality regulatory agencies, and the public will need to understand the tradeoffs between prescribed fire, forest health, wildfire occurrence, and air quality. Understanding will enable society to make informed decisions when considering managed fire versus future catastrophic wildfire, forest health, and air quality.

LITERATURE REVIEW

Forests in the Blue Mountains of eastern Oregon have been the focus for examining the existing or potential problems of all the forest ecosystems in eastern Oregon and Washington. Recently, the seriousness of the forest health situation in the Blue Mountains was reviewed and a strategy was presented to restore and maintain the health of these fire-adapted ecosystems (Mutch et al. 1993). The tradeoffs between increased use of fire for forest health restoration and subsequent air quality impacts can be assessed with a smoke emissions inventory (Peterson 1988). Peterson describes four variables that affect the production of smoke during prescribed fires and wildfires: (1) fuel loading, (2) acres burned, (3) fuel consumption, and (4) emission factors. These variables are required to inventory emissions.

METHODS

Study Area

Six river basins (fig. 1), which represented conditions in major forested ecoregions, were sampled in eastern Oregon and eastern Washington (Lehmkuhl et al. 1993). The river basins selected were the Deschutes, Grand Ronde, Methow, Pend Oreille, Wenatchee, and Yakima. Each river basin was divided into sample watersheds with a mean area of 21,930 acres (range 12,600 to 33,400 acres).

Photo Interpretation

Mapping teams of National Forest personnel interpreted aerial photographs and created historical and current vegetation maps for selected watersheds within the six river basins. Photographs dated between 1932 through 1959 were considered historic. Photographs between 1981 through 1991 were considered current (Lehmkuhl et al. 1993). Quality control of map data was a high priority for two skilled photo-interpreters, who visited mapping teams weekly to exam results and consistency. There was not enough time or support to complete a field validation. Consequently, the information was to be used only for research associated with the forest health assessment.

Fuel Loading

Existing published information was used to calculate ground woody and duff fuel loadings for each polygon in the sample watersheds (fig. 2). Interpreted air photo characteristics were matched to the closest situation represented in one of several published fuel photo series (Maxwell and Ward 1980, Maxwell and Ward 1976, and Fischer 1981) by developing a key based on vegetation composition and structure. Of the fuel photo series available, 36 photos were selected or stylized to represent the range of fuel conditions within the six river basins. These photos were applied to fuel complexes representing nonforested conditions, forested in natural conditions, and post-logging, thinning, and other management activities.

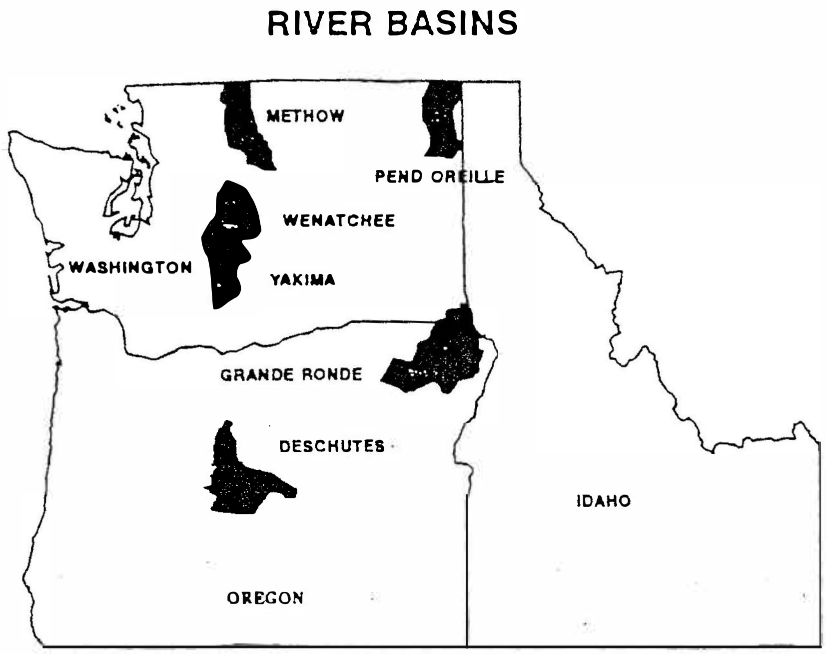

Figure 1. River basins selected for study.

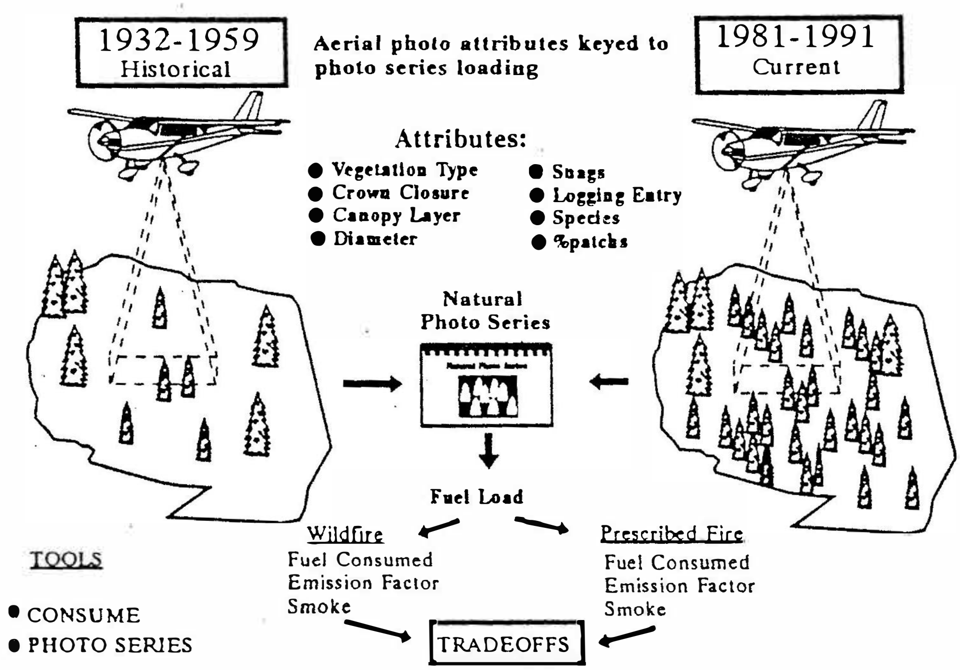

Figure 2. Aerial photo attributes, fuel consumption models, and emission factors used to calculate emissions production from historical and current landscapes.

Fuel Moisture and Fuel Consumption

An average fuel moisture content was applied for prescribed fires and wildfires. This is an important variable for calculating fuel consumption. Because most wildfires occur during the summer months, an average large-fuel moisture content of 20 percent was assumed. Most prescribed fires are conducted during spring-like conditions (Ottmar et al. 1990); therefore, an average large fuel moisture content of 40 percent was assumed. Fuel loading and fuel moisture content were entered into CONSUME (Ottmar et al. 1993) to estimate fuel consumption. CONSUME calculates fuel consumption by using the latest fuel consumption algorithms for the Pacific Northwest.

Emission Factors and Emission Production

Each polygon fuel condition was assigned a fire-average emission factor for particulate matter less than 10 micrometers in diameter (PM10). Emission factors for prescribed burning in natural forested Douglas-fir/hemlock, ponderosa pine/lodgepole pine, mixed conifers, or hardwoods and ranged from 25.0 pounds per ton to 20.5 pounds per ton (Ward et al. 1989). Polygons dominated by shrubs were assigned an emission factor of 21.2 pounds per ton for chaparral (Hardy and Teesdale 1992) or sagebrush (Hardy and Teesdale 1991). Polygons dominated by gras were assigned an emission factor of 20.0 pounds per tons for grass (U.S. Environmental Protection Agency 1991). All managed polygons were assigned an emission factor of 23.1 pounds/ton, which is the factor that comes closest to being the average of the four Pacific Northwest forest types (Ward et al. 1989).

Emission factors for wildfire were estimated by calculating a ratio between the prescribed fire emission factor and a fire-average emission factor of 29.8 pounds/ton (Hardy et al. 1992). The ratio was then applied to each prescribed-fire emission factor, except grass and shrub vegetation types, to determine a wildfire emission factor.

Analysis

The sampling technique designed for the entire eastside forest health assessment is a stratified, random sampling within each one of the river basins. The sampling unit within a river basin is the watershed. However, to collect the data, the watershed was divided in homogeneous polygons and the ecological attributes were assigned to them. Then, the fuel and smoke-related attributes were keyed to each one of the polygons.

Because the minimum analysis unit is the watershed, all the polygons within a watershed were combined to obtain a mean value for the fuel and smoke-related attributes. To compensate for the differences in polygon sizes, a weighted mean was used (Hoshmand 1988). Hence, the contribution of a polygon to the watershed mean value is proportional to its size. Maps were produced of selected watersheds to illustrate the watershed-level pattern of fuel loading and emission production during historic and current time periods.

Mean values for the watersheds were obtained for the following variables: forest fuels (tons/acre), fuel consumption (tons/acre) in prescribed and wildfire scenarios, smoke emission factors of PM10 (pounds/ton of fuel consumed) and smoke production of PM10 (pounds/acre) for prescribed fire and wildfire situations.

Once the watershed mean values were obtained, the procedure to calculate the historic and current means for the river basin follows the procedure described by Lehmkuhl et al. (1993).

RESULTS AND DISCUSSION

Fuel Loading

Fuel loading averages for each of the six river basins selected for the study ranged from 33.6 tons per acre on the Methow River Basin (current), to 45.8 tons per acre on the Yakima River Basin (historic) (table 1 and fig. 3). The fuel loading differences between the historic and current periods at the river basin levels were very small, ranging from an increase of 3.5 tons per acre on the Deschutes River Basin to a decrease of 5.2 tons per acre on the Yakima River Basin. No basin differences were statistically significant ($\underline{P} = 0.10$)

Although statistical tests indicated no significant differences between historic and current fuel loadings at the river basin level, many of the sample watersheds within a river basin indicated large differences. For example, the Grande Ronde River Basin showed a decrease of 0.6 ton per acre in fuel loading. The Grande Ronde sample watershed #35, however, had a decrease of 20.9 tons per acre in fuel loading (table 2, fig 4, and fig. 5). This watershed was located in the Eagle Cap Wilderness area, where no harvesting activities had occurred in the past.

Reviewing the vegetation type change as noted by the aerial photograph interpretations, a major shift occurred. Subalpine fir (Abies lasiocarpa (Hook) Nutt.) and Englemann spruce (Picea engelmanii Parry) forests decreased from 69 to 30 percent of the area, while whitebark pine (Pinus albicaulis Engelm.) and subalpine larch (Larix lyallii Parl.) forests increased from 0 to 38 percent. Further investigation indicated the area had been burned during several wildfire episodes in the past 20 years. This accounted for the shift in vegetation type and decrease in fuel loading.

The Grande Ronde sample watershed #55 indicated the opposite trend. It had an increase of 15.7 tons per acre in fuel loading from historic to current (table 2 and fig. 4). Watershed #55 is located 60 miles north of watershed #35, and is within the Wenaha-Tucannon Wilderness, where no harvesting or large wildfires had occurred. A major shift in vegetation type was noted in the photo interpretation. The watershed changed from an open ponderosa pine (Pinus ponderosa Laws.) and young Douglas-fir [Psuedotsuga menziesii (Mirb.) Franco] stand to an older stand, dominated by Douglas-fir and true fir (Abies spp.). The stands have few open areas, resulting in an increase in fuel loading over time.

The Yakima River Basin also showed no significant difference between historic and current fuel loading (fig. 3). However, a decrease of 24.1 tons per acre in fuel loading was noted in sample watershed #30 (table 2 and fig. 4). A combination of wildfire and harvest activity shifted a portion of the vegetation type to younger-aged stands and decreased fuel loading. The forest of uneven-aged, old-growth true fir, western hemlock [Tsuga heterophylla (Raf.) Sarg.] and western red cedar (Thuja plicata Donn) decreased from 41 percent of the area to 5 percent. The younger, even-aged true fir, western hemlock, and western red cedar increased from 7 to 28 percent; the stands of young, even-aged Douglas-fir and true fir increased from 1 to 21 percent.

We assessed the fuel loadings for duff and dead, woody fuels on the ground. We were not able to address the tree-crown fuels and live vegetation. Confining the study to dead ground fuels will underestimate fuel loading by 5 to 50 percent (Snell and Brown 1980, Snell and Anholt 1981, Anderson, 1982). This will result in an estimate of less fuel consumed and smoke produced than what may occur.

Table 1. Historic and current fuel loading, fuel consumption, emission factors, and smoke production for six river basins of eastern Oregon and Washington.

		River Basin					
Variable	Period	Deschutes	Grande Ronde	Methow	Pend Oreille	Wenatchee	Yakima
Forest fuels	Historic	37.92	37.67	33.58	37.44	43.73	45.76
Tons/acre	Current	41.44	37.12	33.56	38.04	41.41	40.55
	Change	3.52	-0.55	-0.02	0.60	-2.32	-5.21
Fuel consumption	Historic	16.60	14.01	13.77	16.11	15.12	16.03
Prescribed fires	Current	16.64	15.42	14.34	15.64	14.25	15.69
Tons/acre	Change	0.04	1.41	0.57	-0.47	-0.87	-0.34
Fuel consumption	Historic	25.10	21.57	21.42	23.97	24.59	25.56
Wildfires	Current	25.56	23.32	22.13	23.94	23.05	24.45
Tons/acre	Change	0.46	1.75	0.71	-0.03	-1.54*	-1.11
Smoke emission factors	Historic	21.92	20.56	21.61	22.63	20.92	20.84
PM10, Prescribed fires	Current	21.79	21.52	21.74	22.05	21.14	21.07
Pounds/ton consumed	Change	-0.13*	0.96*	0.13	-0.58*	0.22	0.23
Smoke emission factors	Historic	28.18	25.47	27.45	29.12	26.47	26.60
PM10, Wildfires	Current	27.87	27.13	27.71	28.33	26.71	26.94
Pounds/ton consumed	Change	-0.31*	1.66*	0.26*	-0.79*	0.24	0.34*
Smoke production PM10	Historic	364.92	288.72	296.70	364.33	316.29	334.72
Prescribed fires	Current	364.03	331.84	311.59	344.43	301.61	331.41
Pounds/acre	Change	-0.89	43.12*	14.89*	-19.90	-14.68	-3.31
Smoke production PM10	Historic	707.59	555.01	586.07	696.91	651.49	680.70
Wildfires	Current	713.05	635.00	612.39	677.47	616.47	660.08
Pounds/acre	Change	5.46	79.99	26.32	-19.44	-35.02	-20.62

Note: Stars indicate significant differences at α=0.1.

Table 2. Historic and current fuel loading, fuel consumption, emission factors, and smoke production for three watersheds of eastern Oregon and Washington.

		River Basin		
Variable	Period	Grande Ronde 35	Grande Ronde 55	Yakima 30
Forest fuels	Historic	45.57	36.44	54.41
Tons/acre	Current	24.70	52.09	30.35
	Change	-20.86	15.66	-24.05
Fuel consumption	Historic	13.63	13.51	13.85
Prescribed fires	Current	12.90	18.75	11.69
Tons/acre	Change	-0.73	5.23	-2.16
Fuel consumption	Historic	24.02	20.10	24.25
Wildfires	Current	19.93	27.98	17.90
Tons/acre	Change	-4.09	7.88	-6.35
Smoke emission factors PM10	Historic	20.56	20.70	18.30
Prescribed fires	Current	20.92	20.70	18.75
Pounds/ton consumed	Change	0.36	0.00	0.45
Smoke emission factors PM10	Historic	25.99	25.16	23.54
Wildfires	Current	26.94	26.29	23.98
Pounds/ton consumed	Change	0.95	1.13	0.44
Smoke production PM10	Historic	280.10	279.69	253.50
Prescribed fires	Current	269.79	388.06	219.16
Pounds/acre	Change	-10.31	108.37	-34.34
Smoke production PM10	Historic	624.19	505.85	570.96
Wildfires	Current	536.70	735.68	429.27
Pounds/acre	Change	-87.49	229.83	-141.69

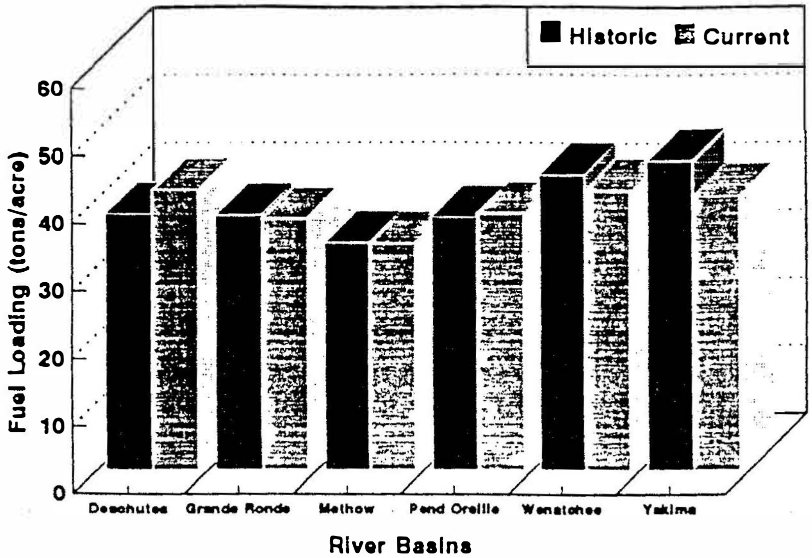

Figure 3. River basin fuel loading averages for historic and current period. Stars indicate significant differences at P = 0.10.

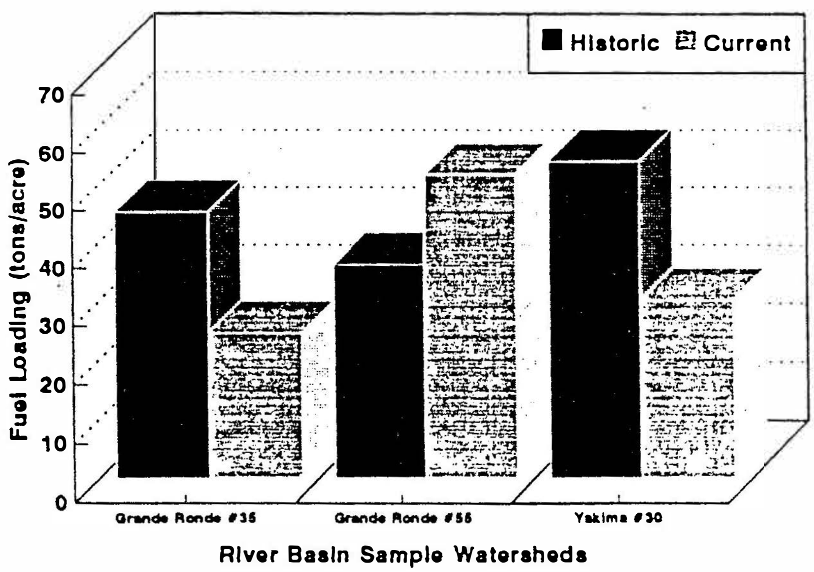

Figure 4. Selected sample watershed fuel loading averages for historic and current period.

Fuel Consumption

Averages for fuel consumption from prescribed fire for the six river basins ranged from 13.8 tons per acre on the Methow River Basin (historic) to 16.6 tons per acre on the Deschutes River Basin (current) (table 1). Wildfire fuel consumption averages were approximately double, ranging from 25.6 tons per acre on the Deschutes River Basin (current) and Yakima River Basin (historic), to 21.4 tons per acre on the Methow River Basin (historic). The Grande Ronde River Basin and Methow River Basin were the only areas with significant differences in fuel consumption between the historic and current periods. For wildfire fuel consumption, the Wenatchee River Basin was the only one tested that showed a significant difference in historic and current periods.

Smoke Production (PM10)

If fuel consumption is multiplied by the PM10 emission factor, smoke produced per acre burned can be calculated. Prescribed fire smoke production ranged from 288.7 pounds per acre on the Grande Ronde River Basin (historic) to 364.9 pounds per acre on the Deschutes River Basin (current and historic) (table 1 and fig. 6). The greatest difference between historic and current for prescribed fires was in the Grande Ronde River Basin, which showed an increase of 43.1 pounds per acre. The Methow was the only other river basin to show a significant difference in smoke production for prescribed fires.

Although two of the six river basins indicated a significant difference between historical and current wildfire emissions production, the differences were rather small (fig. 6). Many sample watersheds within a river basin indicated much larger differences (fig. 7). For example, the Grande Ronde River Basin showed an increase of 80.0 pounds per acre in smoke production. Sample watershed #55 within the basin, however, had an increase of 229.8 pounds per acre, while sample watershed #35 had a decrease of 87.5 pounds per acre). The Yakima River Basin showed a small wildfire smoke production decrease of 20.6 pounds per acre. Watershed #30 within the basin had a 141.7 pounds per acre decrease (fig. 6 and fig. 7).

Areas where fire had been excluded showed a trend toward higher fuel loadings and higher smoke production from wildfires. For example, if a wildfire occurred today at watershed #55 in the Grande Ronde River Basin, 230 pounds per acre more smoke would occur than if the same wildfire would have occurred in the past (fig. 7 and fig. 8) The watershed was located in a wilderness area where no management activity, except wildfire suppression, had occurred. The suppression of wildfires increased fuel loading and resulted in an increase in emission production.

Watershed #35 in the Grande Ronde and watershed #30 in the Yakima River Basin showed opposite trends. Both watersheds showed a decrease in wildfire smoke production of 87.5 pounds per acre and 141.7 pounds per acre from historic to current periods respectively. Further investigation indicated both watersheds had been burned during several wildfire episodes, although wildfire suppression management strategies were in place. This accounted for vegetation shifts, less fuel on the ground, and less smoke production.

We also noted a remarkable difference between wildfire and prescribed fire smoke production. A wildfire would produce nearly twice the amount of smoke as a prescribed fire for the current period at both the river basins and watershed levels (tables 1 and 2, and fig. 9).

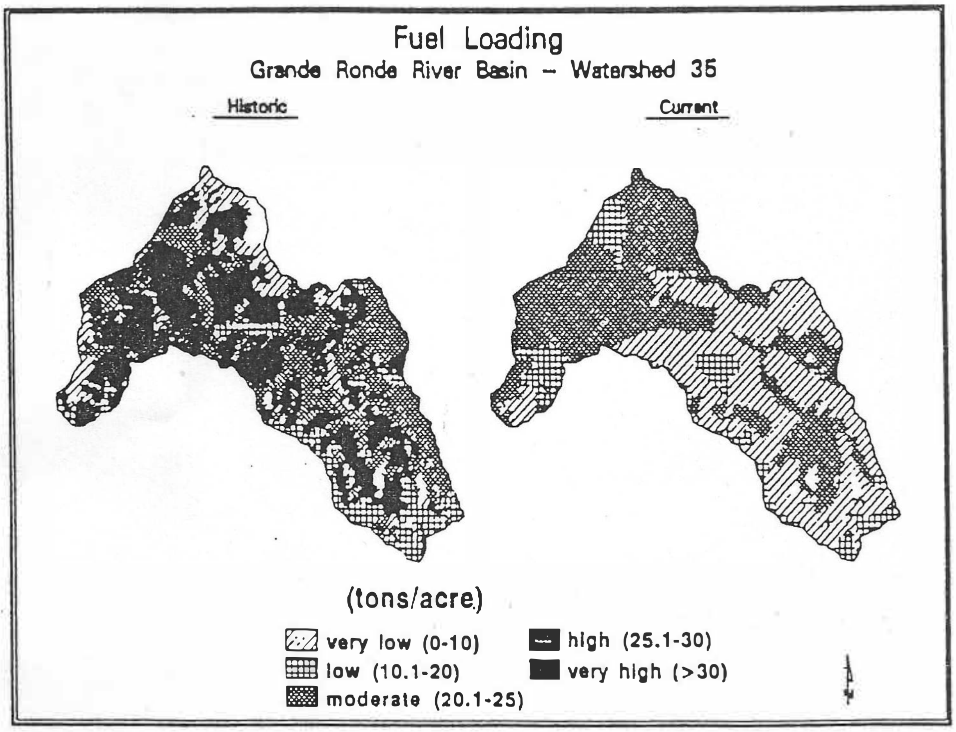

Figure 5. Fuel loading map for historic and current periods at watershed #35 in the Grande Ronde River Basin.

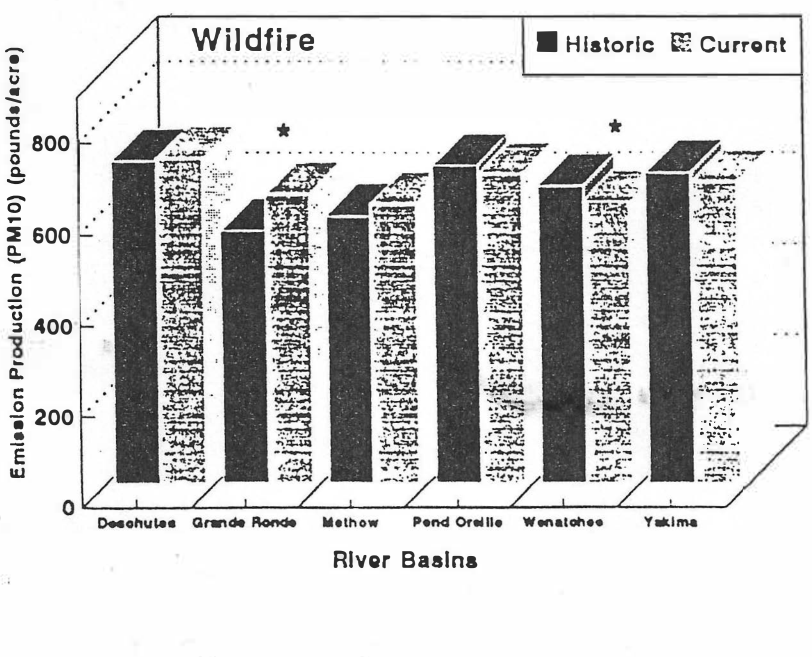

Figure 6. River basin averages of wildfire smoke production for historic and current period. Stars indicate significant differences at P = 0.10.

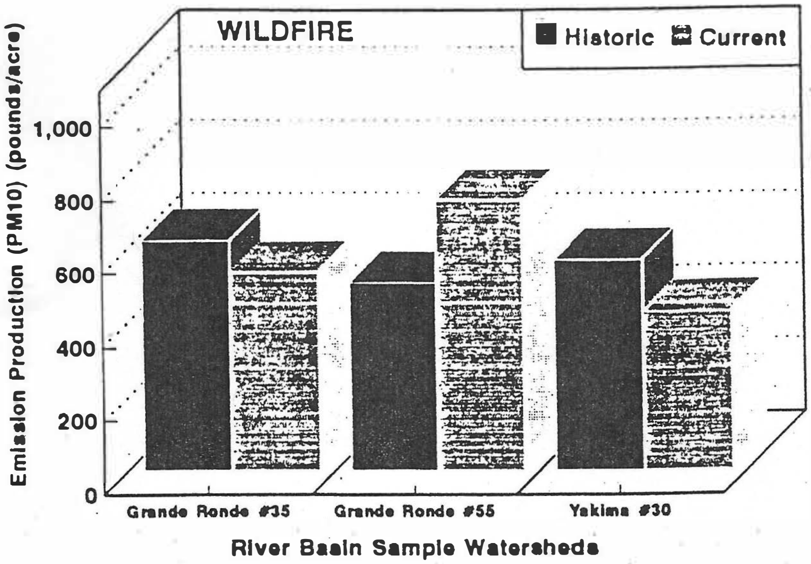

Figure 7. Wildfire smoke-production averages for selected sample watersheds--historic and current periods.

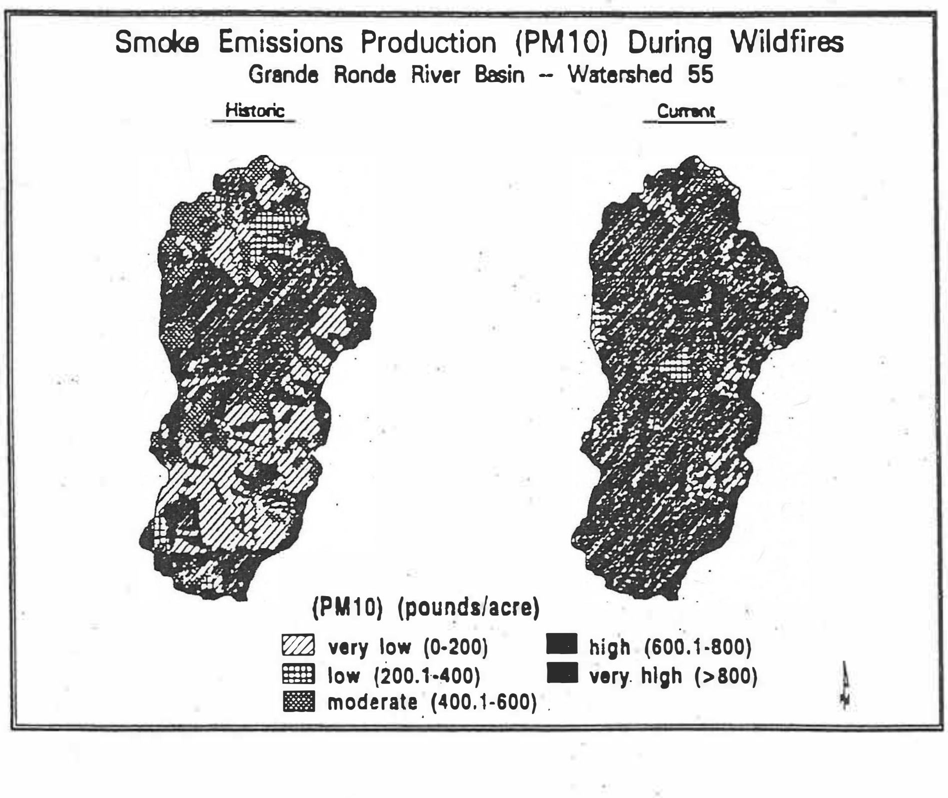

Figure 8. Wildfire smoke production map for historic and current periods at watershed #55 in the Grande Ronde River Basin.

There were two main reasons for the differences. First, wildfires generally occur during drought periods; consequently, a lower fuel moisture content was used to represent wildfires. This increased the fuel consumption when compared to prescribed fires. Second, the emission factor for wildfires is about one third higher than that of prescribed fires (Hardy et al. 1992).

To understand the magnitude of the differences between prescribed fires and wildfires, let's assume 50,000 acres burned during a wildfire in the Grande Ronde River Basin during the current time period. Multiplying the number of acres burned by the current emission production figure estimated for the basin--635 pounds of PM10 per acre for wildfires--approximately 32 million pounds (16,000 tons) of PM10 would be released into the atmosphere from the fire. If the same area is prescription burned, 332 pounds of smoke per acre would be produced, resulting in a total release into the atmosphere of nearly 17 million pounds (8,300 tons) of PM10. This is half the projected emissions for a wildfire in the same area.

We can also use the PM10 smoke production figures to project future smoke production if prescribed fire becomes a major tool for managing ecosystems. For example, the Grande Ronde sample watershed #4 is 15,311 acres in size and has the potential for reintroducing fire into this ecosystem. The average number of acres prescription burned within that watershed was 555 per year during 1990 and 1991. Let us assume the entire watershed will need to be treated with periodic fire at some time in the next 15 years, if the forested areas that have 80 years of fuel build-up and dead and dying trees are brought to a healthy state. This would result in a managed fire target of 1,020 acres per year.

If we multiply the current prescribed fire emissions at the Grande Ronde River Basin, 332 pounds per acre (table 1), by the projected number of acres to be burned per year in the future for watershed #4 (1,020 acres), then compare that result with the current burning program (555 acres), the difference is substantial: from 184,260 pounds (92 tons) to 338,640 pounds (169 tons). A portion of the PM10 could be reduced, and the impact lessened, by burning when less fuel is consumed, mechanically treating fuels so that burning is not needed, and conducting burns when dispersion conditions and wind direction are favorable. If a wildfire burned 1,020 acres per year at watershed #4 in the Grande Ronde, (647,700) pounds (323 tons) of PM10 would be produced. That is nearly double the amount that would result from prescribed burning (fig. 10).

CONCLUSIONS AND RECOMMENDATION

Do we accept that the earlier forest ecosystem structure, which was dependent upon fire, was healthier and more desirable? Many scientists, politicians, land managers, and members of society do. They also agree that prescribed fire, combined with mechanical treatment or other management alternatives, is necessary to restore or maintain fire-adapted ecosystems. Nevertheless, prescribed fire has the potential to degrade ambient air, impair visibility, and expose the public to concentrations of smoke. These negative effects of prescribed fire contradict current state and national air quality regulations. Scientists will need to describe--and the public will need to understand--the tradeoffs among increased prescribed fires, wildfires, ecosystem health, visibility degradation, and public exposure to smoke.

One of the most important tradeoffs to consider is the substantial increase in smoke production from wildfires versus prescribed fires. Wildfires occur when fuels are dry, fuel consumption is greater, and the fuels are consumed during the less efficient smoldering stage, which nets approximately twice as much PM10 when compared to a prescribed fire. If prescribed fire can be used to restore or maintain

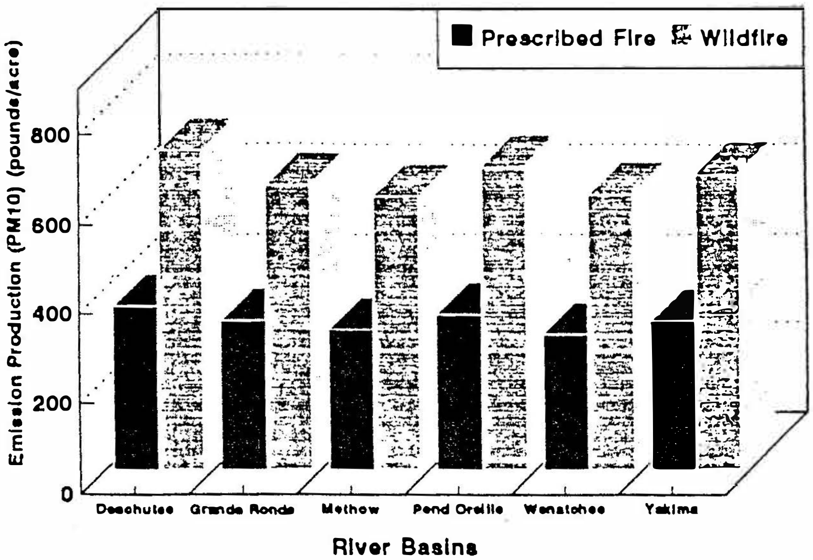

Figure 9. Smoke emissions production for wildfire and prescribed fire occurrence for current period.

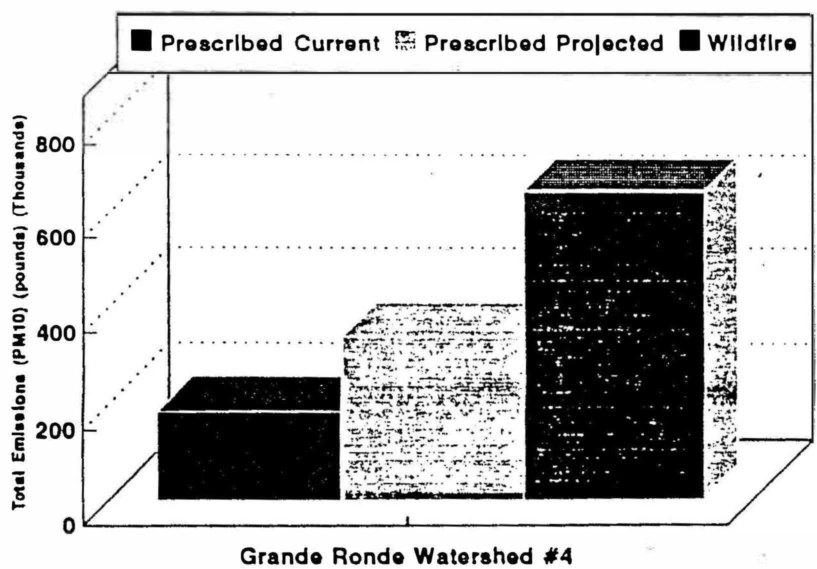

Figure 10. Comparison of total emissions produced at watershed #4 in the Grande Ronde if (1) current prescribed burning program continues, (2) watershed is treated with prescribed fire periodically over the next 15 years, and (3) if wildfire occurs periodically over 15 years.

fire-adapted ecosystems, yet reduce the potential of wildfire, PM10 production from landscape burning could be reduced considerably. In addition, prescribed fires are planned in advance, and four mitigation techniques are available to further reduce air quality impacts. Managed ignitions can be planned for a time when (1) smoke will disperse quickly, (2) smoke will avoid sensitive air sheds, (3) less fuel will consume or fuel will consume more efficiently and produce less smoke, and (4) fuels have been removed or reduced, eliminating the need to burn. In cases where specific objectives are to be met, some of these mitigation techniques may not be employed to the fullest extent possible.

Wildfires are not planned; therefore, there is little opportunity to employ mitigation techniques except to suppress the fire as quickly as possible. The smoke generated will be directed and concentrated according to the prevailing wind and atmospheric stability. This will often occur during the summer months when fuel moisture is low, fuel consumption and smoke production is high, and stable atmospheric conditions may persist. Wildfire does have one advantage over prescribed fire: it may never occur. Will the public be willing to accept smoke from prescribed fires spread over a period of years, or is it preferable to gamble that a catastrophic wildfire, which sends out large amounts and greater concentrations of smoke in a few months, will not occur?

It is commonly noted that if we do not prescribe burn now, wildfire may soon do the job in a way that is much less acceptable from an ecosystem and air quality standpoint. In spite of that, this premise will not be accepted by society and cannot be used as an excuse for not providing quality information about potential impacts of prescribed burning for forest health. The public has previously chosen to bear the costs associated with clean air. Will the public rate air quality values higher than forest health values by choosing to accept wildfire in place of managed fire? Probably yes, unless (1) a strategic plan is developed to address all regulatory requirements such as Prevention of Significant Deterioration guidelines, visibility, emissions reduction, and health risks associated with prescribed fire; (2) the public understands the tradeoffs; (3) the public regulatory agencies are involved with fire-management planning; and (4) a strong research program is provided.

The air quality assessment provided in this report is a cursory look at the change over time of smoke production from managed prescribed fires or wildfires that have occurred and will occur across the landscapes of eastern Oregon and eastern Washington. This assessment has only scratched the surface on what must be done to produce a comprehensive air quality and forest health tradeoff analysis which society deserves and will require. Still, the structure and methods for completing the comprehensive tradeoff analysis have been formulated through this study; further work could begin immediately and move ahead quickly.

Fire is an essential component in the dynamics and sustainability of many ecosystems in eastern Oregon and eastern Washington. Fire is not a tool that should be used on all sites or situations. It is, however, a tool that should be available and understood when designing a management strategy for certain ecosystems. Proper application of fire, in harmony with other management techniques, may often be the best option for meeting specific objectives while creating the fewest adverse effects.

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