Smoke Considerations for Using Fire in Maintaining Healthy Forest Ecosystems

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Fire is the single most important ecological disturbance process throughout the interior Pacific Northwest (Mutch and others 1993; Agee 1994). It is also a natural process that helps maintain a diverse ecological landscape. Fire suppression and timber harvesting have drastically altered this process during the past 50 to 90 years. Natural resource specialists generally agree that the forests of the interior Pacific Northwest are less healthy, less diverse, and more susceptible to larger and more destructive wildfires as a result of this human intervention (Everett 1994). Analysis of current and historical aerial photographs for the East Side Forest Health Assessment (Huff and others 1995) indicates there has been an increase in forest fuels, crown fire potential, and smoke production potential since the 1930's brought on by selective logging and fire suppression activities. In addition, acres burned by wildfires across Washington and Oregon on USDA Forest Service lands have been increasing (fig. 1).

Prescribed fire, often in combination with other management techniques, can be used to restore wildland forests to a more sustainable structure while simultaneously reducing the potential for catastrophic wildfires (fig. 2). Unfortunately, prescribed fire runs contrary to current Federal and state environmental laws because any fire event has the potential to degrade ambient air quality, impair visibility, and expose the public to unhealthy pollutants.

Air regulatory agencies and the public must come to understand the complex tradeoffs between increased prescribed fire, inevitable wildfire, forest health, visibility impairment, and public exposure to smoke before this issue can be resolved. To improve this understanding, land managers and researchers have cooperated in two development activities. The first activity we discuss in this paper is called the Wildfire/Prescribed Fire Tradeoff Model (FETM), a stochastic simulation model to evaluate the tradeoff between prescribed fire and wildfire emissions over time. The second activity we present is an assessment of prescribed fire and wildfire emissions over time for 337 watersheds within the Columbia River Basin.

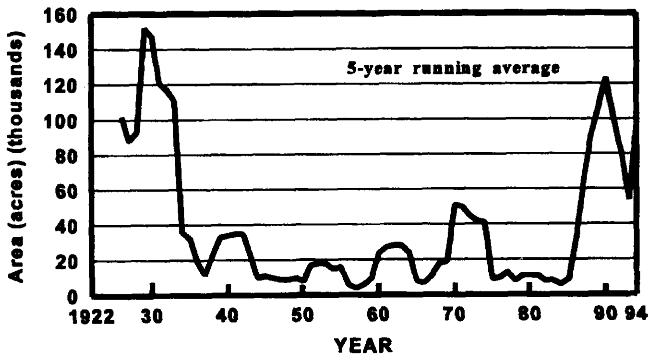

Figure 1—Five-year running average of wildfire acreage burned in Region 6 between 1922 and 1994 (unpublished wildfire data for USDA Forest Service, Pacific Northwest Region).

Wildfire/Prescribed Fire Tradeoff Model

For air regulatory agencies to consider a substantial increase in prescribed fire emissions, it will be necessary to demonstrate that the program would reduce the total emissions from both wildfire and prescribed fire. In 1994, the USDA Forest Service, Pacific Northwest Region brought together a team of managers, scientists, and a private consultant to embark on a model development project to test

Figure 2—Prescribed burn in northeastern Oregon.

In: Hardy, Colin C.; Arno, Stephen F., eds. 1996. The use of fire in forest restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

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the hypothesis that a reduction in total smoke emissions should occur in northeast Oregon following an expansion of the current prescribed burning program. The objective of the project was to determine the level of prescribed fire treatment that would minimize combined emissions from both prescribed and wild fires. To accomplish this objective, a stochastic simulation model—the Fire Emissions Tradeoff Model (FETM)—was developed to track acreage distribution by utilization, mechanical treatment, prescribed fire, wildfire, and natural succession in 192 fuel types over time (fig. 3). The model was evaluated on the 1.2 million acre Grande Ronde River Basin in northeastern Oregon.

The model was evaluated using the arithmetically averaged results from 30 independent model simulations, each consisting of six levels of prescribed fire treatment (zero through 5 percent of the evaluation area per year, in 1 percent increments) over 100 years of simulation. The preliminary results showed that under the conditions that currently exist in the Grande Ronde River Basin, the total emissions from wildfire and prescribed fire is expected to increase continuously over the next 40 years with increasing levels of prescribed fire treatment. Between 40 and 80 years hence, the total fire emissions are expected to remain constant with increasing levels of prescribed fire treatment. Beyond about 80 years, a slight dip in the total emissions curve is expected to occur, with the minimum point at about the 4 percent level of prescribed fire treatment (fig. 4).

The FETM model also produced a dramatic reduction in the number of wildfire acres burned, and associated wildfire smoke emissions, with increasing levels of prescribed fire treatment. However, the decrease in wildfire emissions was largely offset by the increase in prescribed fire emissions. In the future, a combination of prescribed fire and non-smoke-producing silvicultural methods (such as thinning and whole-tree utilization) will likely be needed to mitigate the current fire hazard and to minimize total smoke emissions in the Grande Ronde River Basin.

Future plans for FETM include (1) adapting the model for use in other river basins of the Western States, (2) improving the crown fire algorithms, and (3) modifying the user interface for land managers.

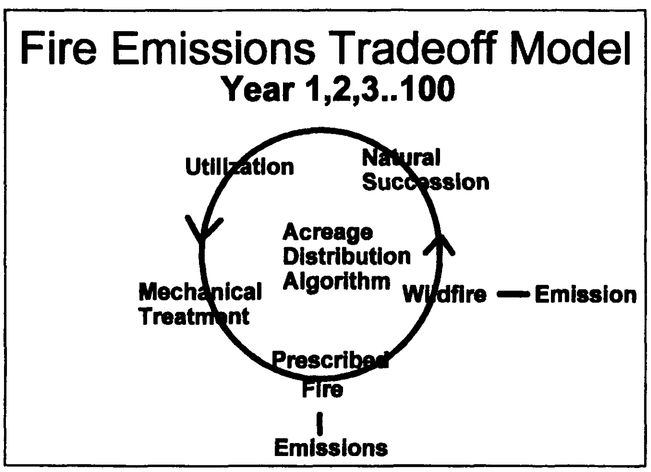

Figure 3—Fire emissions tradeoff model.

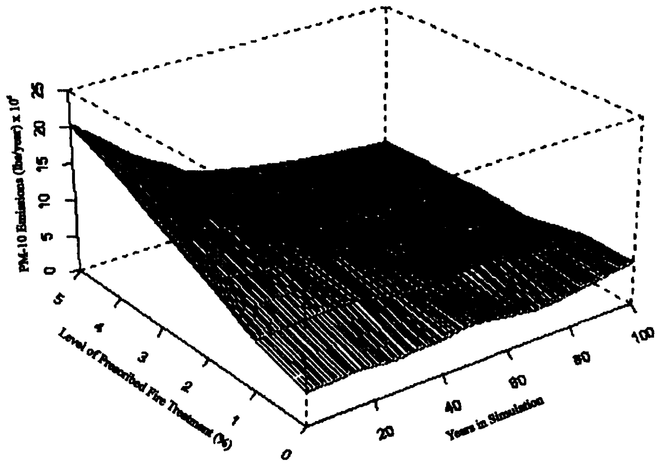

Figure 4—FETM-generated surface plot of combined wildfire and prescribed fire emission PM10 emissions.

Prescribed Fire and Wildfire Emissions Assessment of the Interior Columbia River Basin

The mid-scale assessment of prescribed fire and wildfire smoke emissions within the Interior Columbia River Basin is one portion of the landscape ecological assessment to characterize changes in natural resource conditions of all lands within the Interior Columbia River Basin. This assessment will provide information for USDA Forest Service and USDI Bureau of Land Management decisionmakers who administer lands in this area. The objectives of the smoke emissions portion of this assessment are to (1) describe the variation of smoke production from prescribed fires and wildfires over time; (2) describe current variation in smoke produced by prescribed burning in selected watersheds and Ecological Reporting Units (ERU), and assess the deviation from proposed increases in prescribed burning; and (3) examine tradeoffs in air quality with regards to managed fire, wildfire, and forest health.

Methodology

We modeled the loading (quantity by mass) of dead surface fuels and the smoke emissions from potential wildfires and prescribed fires for each GIS polygon coverage for a historical (1930's to 1960's) and current (1985 to 1993) period of time in 337 selected watersheds within the Interior Columbia River Basin Ecological Reporting Units (fig. 5). Vegetation, stand structural stage, and logging type classifications were delineated from historical and current aerial photograph interpretations by Hessburg and others (1995). We used published information and expert knowledge to assign ground fuel loadings for each GIS polygon coverage. We used the CONSUME (Ottmar and others 1993) and FOFEM (Keane and others 1990) model algorithms to estimate potential fuel consumption under wildfire conditions (large, woody fuel moisture content of 15 percent), fall prescribed fire conditions (large, woody fuel moisture content of 30 percent), and spring prescribed fire conditions

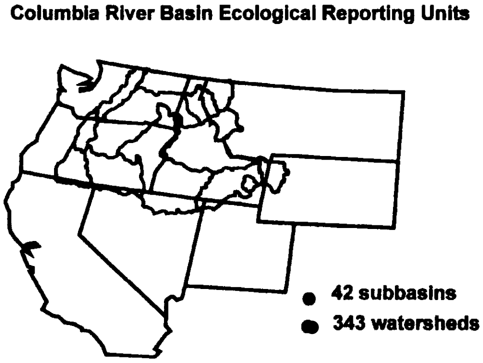

Figure 5—Ecological reporting units for the Interior Columbia River Basin Assessment.

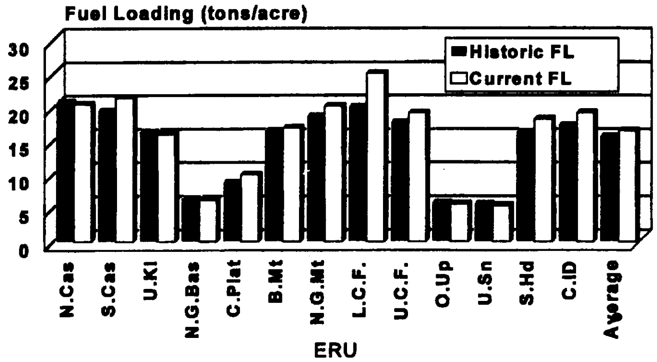

Figure 6—Historical and current fuel loading for Ecological Reporting Units of the Interior Columbia River Basin.

(large, woody fuel moisture content of 40 percent). We used emission factors developed by Ward and Hardy (1995) for the burning of biomass to calculate the potential emissions production. The emission factors correspond to a flaming and smoldering consumption ratio for each fuel condition class and fuel model. Each emission factor was expressed as grams of particulate matter less than 10 micrometers in diameter (PM10) produced per ton of fuel consumed. The PM10 emission factors are inferred values from real measurements collected for (1) all particulate matter and (2) particulate matter less than 2.5 micrometers in diameter (Ward and Hardy 1991). We used PM10 emission factors because most current regulations are based on PM10 standards. Potential PM10 smoke production was estimated, on a per acre basis, by multiplying fuel consumption by an assigned emission factor for PM10.

Fuel Loading Results

Average loading of dead surface fuels for each of the 13 ERUs ranged from 5.3 tons per acre on the shrubland-covered Upper Snake ERU (current) to 25 tons per acre on the forested Lower Clark Fork ERU (current) (table 1). Eight of the 13 ERUs have experienced an increasing trend toward higher fuel loadings over time (fig. 6). The remaining ERUs experienced a decreasing trend. The fuel loading differences between the historical and current periods at the ERU levels were very small except for the Lower Clark Fork ERU (with an increase of nearly 5 tons per acre).

Although the fuel loading differences at the ERU level were rather small, many of the sample watersheds within an ERU indicated large differences (fig. 7) (table 2). For example, the Blue Mountain ERU showed an increase of 0.3 tons per acre in fuel loading. The Wallowa watershed #35, however, had a decrease of 6.7 tons per acre in dead surface fuels. This watershed was located in the Eagle Cap Wilderness area, where no harvesting activities had occurred in the past.

Upon reviewing the vegetation types, as delineated through aerial photograph interpretations, a shift in tree species was apparent. Relative amounts of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) forests decreased while whitebark pine (*Pinus albicaulis*) and subalpine larch (*Larix lyallii*) stands increased. Further investigation indicated the area had been burned during several episodes in the past 20 years. This accounted for the shift in vegetation and the decrease in fuel.

The Lower Grande Ronde watershed #55 indicated the opposite trend. It had an increase of 6.2 tons per acre in dead fuels from historical to current. Watershed #55 is located 60

Table 1—Fuel loading and PM10 emissions for dry (wildfires) and wet (spring prescribed fires) for the Ecological Reporting Units of the Interior Columbia River Basin.

ERU		N.Cas	S.Cas	U.Kl	N.G.Bas4	C.Plat	B.Mt	N.G.Mt	L.C.F.	U.C.F.	O.Up	U.Sn	S.Hd	C.ID	Average[1]
Fuel Loading (tons/ac)	Historic	20.94	19.55	16.44	6.47	8.92	16.62	18.77	20.19	17.89	5.87	5.71	16.43	17.73	15.74
	Current	20.39	21.36	15.94	6.06	9.94	16.88	20.15	25.03	19.09	5.57	5.33	18.18	19.11	16.45
	Change	–0.55	+1.81	–0.50	–0.41	+1.02	+0.26	+1.38	+4.84	+1.20	–0.30	–0.38	+1.75	+1.38	+0.71
PM10 Dry (Wildfire) (lb/ac)	Historic	407.71	381.65	308.94	127.62	167.37	314.37	370.80	389.10	345.05	122.09	120.12	320.90	351.18	306.23
	Current	395.15	407.59	286.97	117.13	182.24	320.72	393.97	498.19	369.78	115.30	111.42	360.30	382.33	318.99
	Change	–12.56	+25.94	–21.97	–10.49	+14.87	+6.35	+23.17	+109.09	+24.73	–6.79	–8.70	+39.40	+31.15	+12.75
PM10 Wet (Prescribed fire, spring) (lb/ac)	Historic	120.56	120.74	109.09	60.73	67.31	105.40	106.98	162.49	108.53	60.51	56.07	92.75	100.75	98.59
	Current	138.52	160.26	133.79	54.93	80.29	118.87	139.32	177.69	131.00	56.55	50.45	100.44	107.62	114.17
	Change	+17.96	+39.52	+24.70	–5.80	+12.98	+13.47	+32.34	+15.20	+22.47	–3.96	–5.62	+7.69	+6.87	+15.58

[1]Average weighted by the number of watersheds in each ERU.

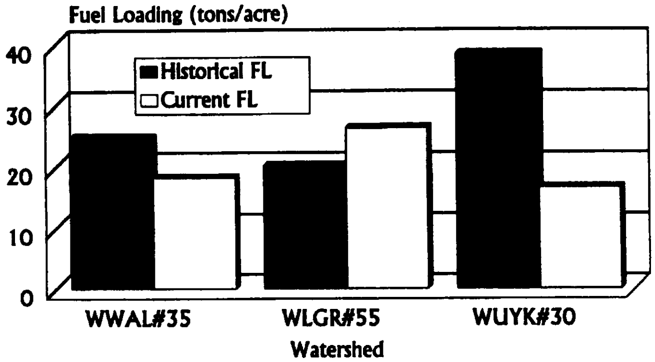

Figure 7—Historical and current dead surface fuel loadings (FL) for selected watersheds.

Table 2—Fuel loading and PM10 emissions for dry (wildfires) and wet (spring prescribed fires) for sample watersheds of the Interior Columbia River Basin.

ERU		WAL#35	LGR#55	UYK#30
Fuel Loading	Historic	24.89	20.18	38.41
(tons/ac)	Current	18.20	26.35	16.54
	Change	–6.69	6.17	–21.87
PM10 Dry	Historic	501.22	379.63	727.00
(Wildfire)	Current	357.84	566.59	310.64
(lb/ac)	Change	–143.38	186.96	–416.36
PM10 Wet	Historic	110.89	96.18	188.45
(Prescribed fire,	Current	89.68	118.41	100.12
spring) (lb/ac)	Change	–21.21	22.23	–88.33

miles north of watershed #35 and is within the Wenaha-Tucannon Wilderness, where no harvesting or large wildfires have occurred during the period. A shift in vegetation was also noted in the photograph interpretations. The watershed changed from a predominantly open ponderosa pine (*Pinus ponderosa*) and young Douglas-fir (*Pseudotsuga menziesii*) stand with dry meadows to older stands, dominated by Douglas-fir and true fir (*Abies* spp.). The current stands had fewer open areas, resulting in an increase in fuels over time.

The Upper Yakima watershed #30 showed a decrease of nearly 22 tons per acre between historic and current dead fuels (fig. 7). A combination of harvest activity and wildfires shifted a large portion of the vegetation type to younger-age stands and decreased fuel loading. Aerial photographic interpretation indicated nearly 50 percent of the 26,000 acre watershed had logging activity or was burned by wildfire since the historic period.

PM10 Emissions Results

Wildfire smoke production ranged from 111.4 pounds per acre on the Upper Snake ERU (current) where the dominant vegetation was shrubland, to 498.2 pounds per acre on the Lower Clark Fork ERU (current) where the dominant vegetation was coniferous forest (fig. 8) (table 1). Potential prescribed fire smoke production ranged from 50.5 pounds per acre on the Upper Snake (current) to 177.7 pounds per ton on the Lower Clark Fork ERU (current).

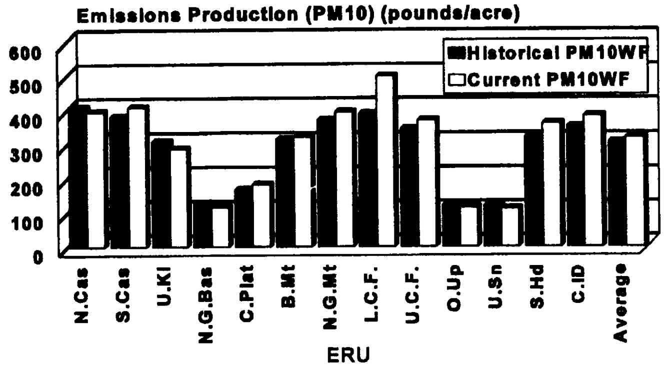

Figure 8—Potential wildfire emission production (PM10) for the Ecological Reporting Units of the Interior Columbia River Basin.

The small differences between the historic and current fuel quantities at the ERU level generated a small difference in potential PM10 smoke production for both wildfires and prescribed fires (fig. 8). The greatest difference between historic and current potential smoke emissions for wildfires was in the Lower Clark Fork ERU, which showed an increase from historic to current of 109.1 pounds per acre. The greatest difference for prescribed fire was in the Southern Cascades ERU, with an increase of 39.5 pounds per acre (table 1).

Areas such as Wallowa watershed #35 and Upper Yakima watershed #30, where harvest activity and/or disturbance occurred, showed a trend toward lower fuel loadings and lower potential emissions production (fig. 9). Areas such as Lower Grande Ronde watershed #55, where fire had been excluded, showed a trend toward higher fuel loadings and higher potential smoke production from wildfires. A wildfire burning in that watershed today would generate 187 more pounds of PM10 per acre burned than if the same fire had occurred during the historical period (fig. 9).

We also noted a large difference between wildfire and prescribed fire smoke production (fig. 10). Potential PM10 from a wildfire was twice the amount as from a prescribed fire of the same size for the current period (at both the ERU and watershed levels).

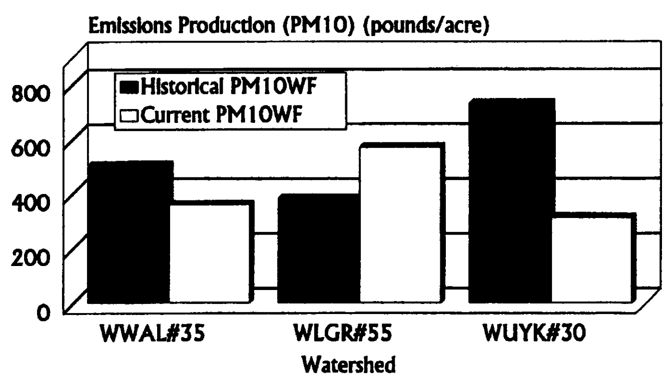

Figure 9—Historical and current potential wildfire emission production for selected watersheds.

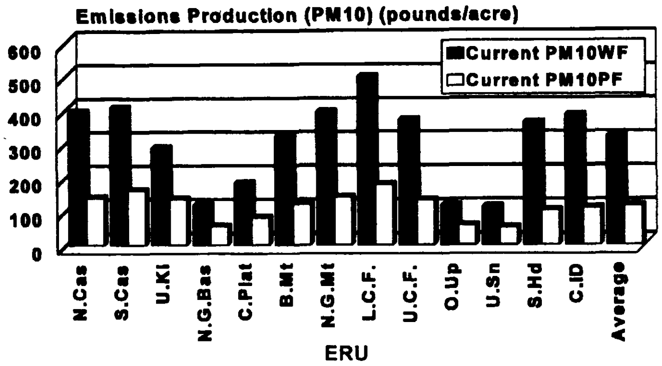

Figure 10—Potential wildfire (PM10WF) and prescribed fire (PM10PF) emissions production (PM10) for the Ecological Reporting Units of the Interior Columbia River Basin.

Conclusions

Air quality regulations have the potential to seriously limit land management actions that use fire for ecological restoration. Air regulatory agencies, land managers, and the public must understand the complex tradeoff issues that the reintroduction of fire poses in terms of forest health, wildfire occurrence, visibility degradation, and human health. The burden of proof is with the land manager to provide estimates of the potential impacts from fire use scenarios and monitor for those effects. The best opportunity to keep fire as a viable tool in ecological restoration involves (1) fostering an atmosphere of cooperation between regulatory agencies and the public and (2) providing a sound impact analysis of management activities.

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