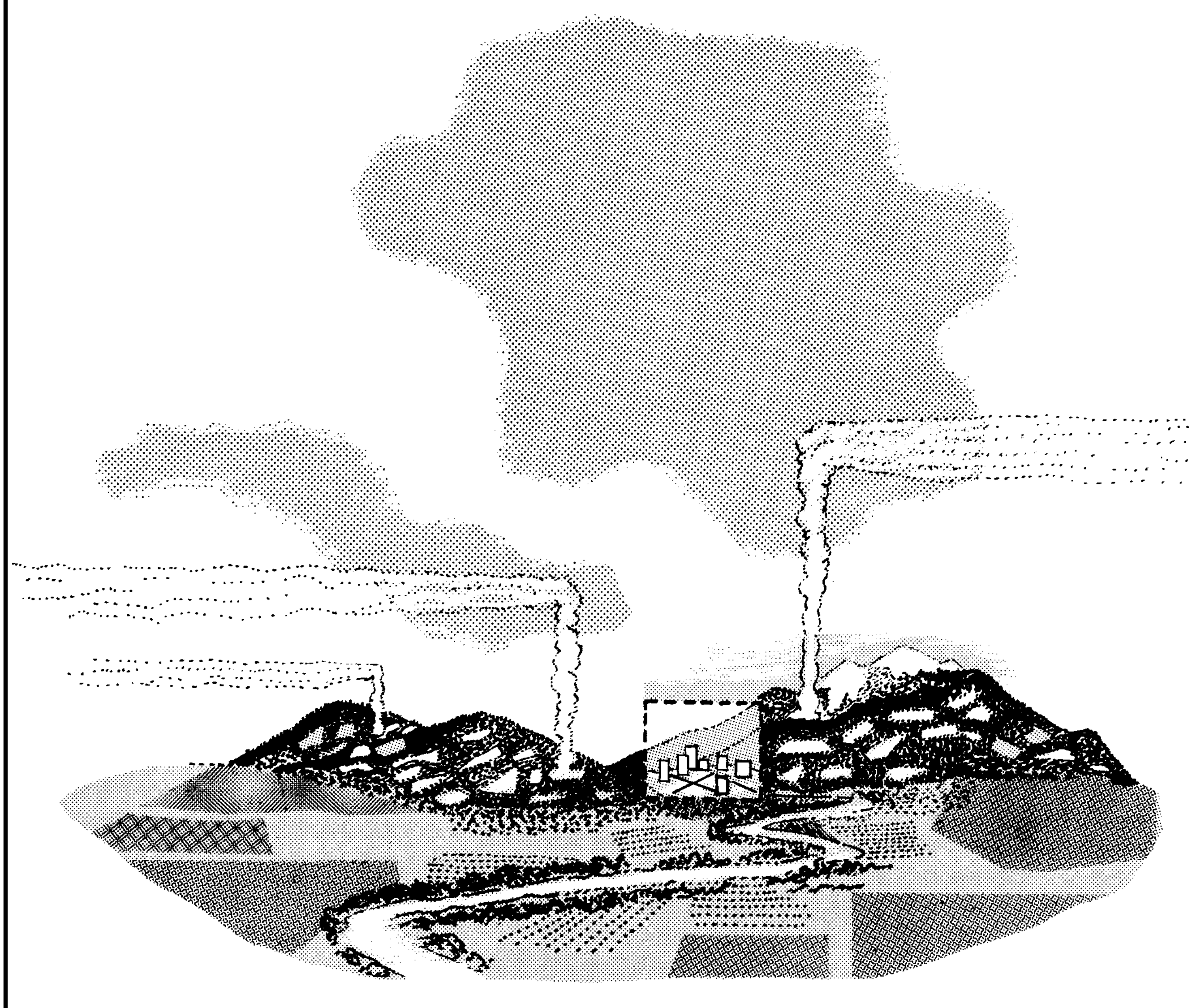
PACIFIC SOUTHWEST
Forest and Range
Experiment Station

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
P.O. BOX 245, BERKELEY, CALIFORNIA 94701

POTENTIAL IMPACT OF AIR QUALITY RESTRICTIONS ON LOGGING RESIDUE BURNING

Owen P. Cramer   James N. Westwood



USDA FOREST SERVICE RESEARCH PAPER PSW- 64 /1970

Cramer, Owen P., and James N. Westwood.

1970. **Potential impact of air quality restrictions on logging residue burning.** Berkeley, Calif., Pacific SW, Forest & Range Exp, Sta., 12 p., illus. (USDA Forest Serv. Res. Paper PSW-64)

The number of potential burning days and the potential burn acreage under smoke control restrictions were estimated for hypothetical forest areas on both sides of a pollution prone area, the Willamette Valley in western Oregon. On the basis of a sample of 2 dry years, the greatest impact on burning operations applied to low elevation forests west of the Valley. The study indicates that considerable burning can be accomplished under the assumed air quality restrictions. In some areas, however, it may be necessary to consider other alternatives for coping with logging residue.

OXFORD: 332.3–436:(795):U628.53 [+425.1] .
RETRIEVAL TERMS: slash disposal; broadcast burning; air pollution; smoke abatement: Willamette Valley; Oregon.

Cramer, Owen P., and James N. Westwood.

1970. **Potential impact of air quality restrictions on logging residue burning.** Berkeley, Calif., Pacific SW, Forest & Range Exp, Sta., 12 p., illus. (USDA Forest Serv. Res. Paper PSW-64)

The number of potential burning days and the potential burn acreage under smoke control restrictions were estimated for hypothetical forest areas on both sides of a pollution prone area, the Willamette Valley in western Oregon. On the basis of a sample of 2 dry years, the greatest impact on burning operations applied to low elevation forests west of the Valley. The study indicates that considerable burning can be accomplished under the assumed air quality restrictions. In some areas, however, it may be necessary to consider other alternatives for coping with logging residue.

OXFORD: 332.3–436:(795):U628.53 [+425.1] .
RETRIEVAL TERMS: slash disposal; broadcast burning; air pollution; smoke abatement: Willamette Valley; Oregon.

CONTENTS

	Page
Introduction	1
Burning and Air Pollution	1
Method	2
Specifications	3
Classification	4
Results	5
Discussion	8
Application of Study	8
Limitations of Study	9
Summary	10
Literature Cited	11
Appendix	12

The Authors

OWEN P. CRAMER, a meteorologist, is doing research on Pacific Northwest weather conditions important to protecting forests from fire. Assigned to the Station's fire meteorology studies, he is headquartered in Portland, Oregon. He earned a forestry degree at Oregon State University (1941) and received meteorological training at the University of California, Los Angeles (1943). A former fire-weather forecaster, he has been in fire meteorology research since 1949, and with the Pacific Southwest Station staff since 1965. **JAMES N. WESTWOOD,** formerly a meteorological technician with fire meteorology studies at Portland, is now on active duty in the United States Navy. He holds a bachelor's degree in history from Portland State University (1967), and joined the Pacific Southwest Station staff in 1965.

Among a forest manager's many responsibilities is the reduction of fire hazard. In the Pacific Northwest, the greatest fire hazard is logging slash–the burnable material remaining after a forest crop is harvested. Where the hazard is great enough to require abatement, the usual method and often the only feasible one is judicious application of fire. But this job of burning has exacting requirements:

- The fuels must be dry enough to burn, but they must not be so dry that the fire will bake the soil severely or become difficult to control. Deep drying should be limited to lessen the chance of holdover fire in roots.
- The fuel or forest on the surrounding area must be damp enough to resist ignition from flying embers.
- Winds must be light so that the fire can be easily controlled.
- Forecasts of weather after burning must not indicate a combination of wind and humidity that would cause spread from wind-blown embers.

These requirements oblige foresters to consider only certain times of year suitable for burning. Because of the normal variation between years, in some years there may not be enough days with the ideal burning conditions, at least by some standards. When additional weather requirements are added to keep slash smoke out of populated areas, then the difficulty is intensified. The question immediately arises–if smoke dispersion limitations are imposed, will there be enough days with the right weather conditions to permit the burning job to be done, particularly during a year when burning conditions are unfavorable?

This paper provides at least a partial answer to that question, based on analysis of two seasons in western Oregon when excessive dryness would have limited the number of burning days.

BURNING AND AIR POLLUTION

What is the magnitude of this smoke source and why is it important? In recent years, some 90,000 acres of slash have been burned annually in western Oregon. This amount has been decreasing and will continue to decrease as utilization improves and as the total cut includes progressively less old-growth with its extremely high proportion of unusable rotten wood. But some old-growth will be cut until about the year 2020. By then, all cutting will be in younger managed forests in which the considerably lighter slash may require removal by fire only in special situations. In the meantime, commercial forest land must be quickly returned to production of a new crop. The soil must be accessible for natural reseeding or planting. Severe competition from brush must be controlled for several years. The fire hazard must be reduced to the point where protection of a young forest from fire becomes practical. These jobs can be accomplished by burning–and often only by burning.

State and regional air pollution control groups have been increasingly vocal in objecting to the large quantities of smoke produced by slash burning. Most objectionable is smoke that reaches the lower layers of air in populated areas, adding to the already more than ample load routinely placed there by urban and industrial sources. As an occasional component of polluted air, slash smoke is, by association, also blamed for the usually mentioned undesirable characteristics of polluted air–soiling, corrosion, health effects, visibility reduction, and photochemical smog formation. The absence of concrete evidence of these effects from slash smoke, except for visibility reduction, detracts very little from the increasing demands that slash smoke be controlled.

This trend is further accelerated by the air quality control agencies. They regard any visible plume as contributing to pollution. And they are basically opposed to open burning. Slash burning is open burning and certainly produces substantial plumes of smoke. The fact that these plumes are predominantly away from populated areas and at high elevations brings the additional criticism that by reducing visibility of and in mountain areas under some weather conditions, slash smoke may be damaging to the tourist industry. There is no question that the practice of burning logging slash is under real pressure from the various proponents of clean air.

Additional pressures can be expected. In 1969, the Oregon State Legislature directed the State Forester and the Environmental Quality Commission to set up procedures for control of pollution from slash smoke. The National Air Pollution Administration (1969) has issued guidelines to State agencies for preparing air quality standards for particulate matter. Slash burning produces slightly less than 10 pounds of particulate (smoke size particles) per ton of slash burned (Fritschen, *et al.* 1970; Darley 1969). According to the NAPCA, particulate, in association with sulfur dioxide, is corrosive to iron and steel when the mean annual concentration exceeds 60 micrograms per cubic meter. This concentration is considered equivalent to a reduction of visibility to about 13 miles. Also in association with sulfur dioxide, particulate has adverse health effects at concentrations equivalent to a reduction in the visual range to about 10 miles. Sulfur dioxide is not produced in slash smoke, but slash smoke particulate would not be welcomed where sulfur dioxide is produced. Because of corrosive and health effects listed for particulate, we may expect increasing objection to slash smoke for other than esthetic reasons.

Slash smoke is likely to get additional attention as a source of hydrocarbons. Slash burning liberates about 12 pounds of hydrocarbons per ton of slash consumed. This amount compares with 130 pounds in auto exhaust per ton of gasoline burned. Though photochemical smog has not as yet been produced in the laboratory from wood smoke as it has from auto exhaust, some of the same reactive hydrocarbons have been shown to be present, as have slight amounts of photochemically active nitrogen oxides (Darley, *et al.* 1966).

With increasing indictment of slash smoke, justified or not, the popular and legal pressure to keep concentrations of slash smoke out of the urban areas at least may be expected to mount. Strict limiting of burning to periods when weather conditions will assure that smoke does not enter what we might call *smoke-sensitive areas* may be the answer. A smoke-sensitive area is one in which smoke from sources outside it is intolerable, owing to heavy population, existing air pollution, or intensive recreational or tourist use. This restriction would amount to limiting the emission rate to the dispersion potential. With slash burning this is possible because: (a) Most commercial timber areas in the Pacific Northwest are remote from and at a significantly higher elevation than smoke-sensitive areas; (b) slash fires produce hot, high-rising convective plumes; and (c) each burn lasts only a few hours and can be delayed until predicted burning and dispersion conditions are right for the particular area.

Considerable adjustment of current burning practice may be required. Where suitable days for burning have always been at a premium, additional restrictions would raise the questions: How much burning can be done under the additional restrictions necessary for maintaining air quality? Will it be enough to prevent the extreme pollution conditions and wildland damage caused by large forest fires, precisely what hazard-reducing slash fires are designed to prevent? And will it be enough to accomplish other forestry jobs such as necessary control of brush to secure forest regeneration?

METHOD

The study procedure consisted of estimating the number of days when broadcast burning could be done and the theoretical acreage that could be burned during two similar burning seasons on five hypothetical administrative units the size of a U.S. Forest Service Ranger District. The slash burning season was assumed to be May 1 through October 31. The years chosen, 1966 and 1967, were both unusually dry, and were intentionally selected to represent poor burning seasons.

The Willamette Valley is assumed to be a smoke-sensitive area to an elevation of 2,500 feet above mean sea level. The area consists of the portion of the Valley, including population centers, ending at the foothills of the Coast (west) and Cascade (east) Ranges, and extending vertically to 2,500 feet elevation. Lateral boundaries correspond to weather zone 20. The five hypothetical administrative areas for which suitability of burning conditions was judged are on either side of the Valley near Salem and at

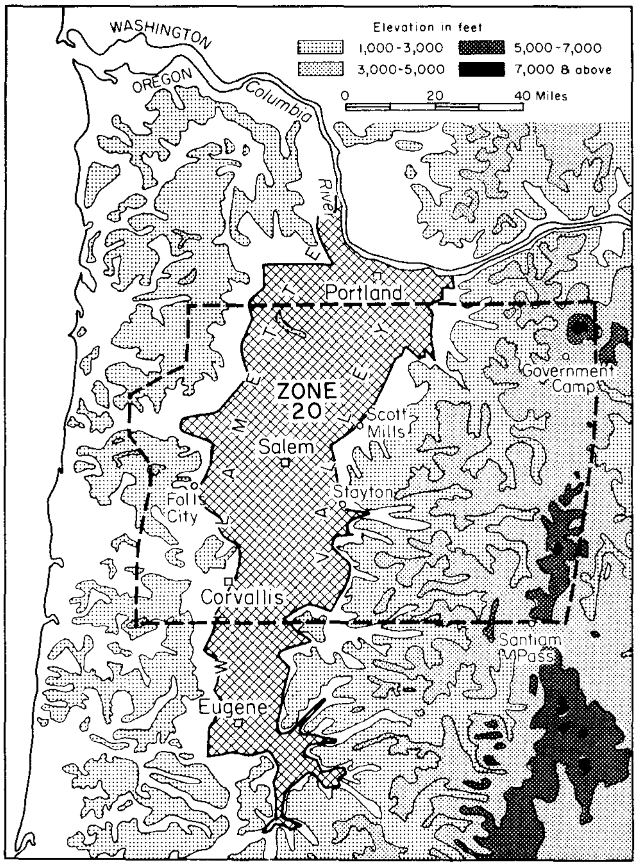


Figure 1–*The study area (defined by dashed line) and the smoke-sensitive area, weather zone 20, in Northwest Oregon.*

several elevations representing the forest areas on the east half of the Coast Ranges and west half of the Cascade Range *(figs. 1,2)*.

Although in actual practice the weather and fuel conditions sampled would vary appreciably from place to place, for this study, all conditions were determined from surface and upper air weather observations made at the Salem U.S. Weather Bureau Airport Station (see Appendix).

Specifications

The count of days available for broadcast burning of logging slash was based on specifications established for this study in the categories of (1) fuel condition, (2) burning weather, and (3) smoke dispersion conditions.

1. *Fuel condition*–Fuels must have dried sufficiently both to carry the fire over the area and to consume enough of the fuel to accomplish the hazard reduction or brush removal objective. Conversely, fuels must not be so dry as to make confinement of the fire difficult or to produce such a hot fire as to damage the soil.

Favorable conditions were as follows: Adjusted fuel moisture between 8 and 18.5 in the spring, and 8 and 25.5 in summer and fall at the Salem airport at 1600 P.s.t. (National Fire Danger Rating System). Fuel moisture limits are adopted from Morris (1966). Buildup, representing deeper drying in heavier fuels and duff, between 25 and 75 in spring and summer,

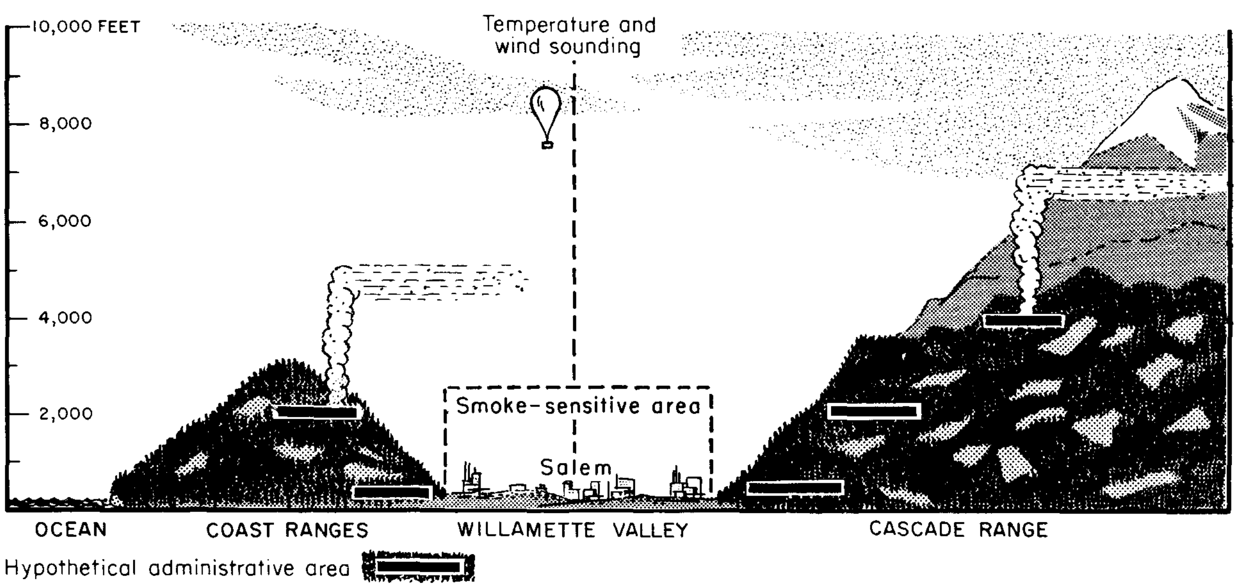


Figure 2–*Schematic cross section shows east-west and vertical arrangement of hypothetical administrative areas and smoke-sensitive area.*

and 0 to 75 in fall at Salem. After September 1, 1 inch of rain must have fallen within the preceding 10 days at Salem. This specification assumes considerably greater precipitation amounts in mountain areas and is intended to minimize soil damage by hard burning after a summer drought.

2. *Burning weather*–Conditions must be such that fire intensity would permit easy control with limited rate of spread and no trouble from spotting on the day of the burn. For study purposes, actual weather the following day was required to be such that there was no danger of spot fires from embers blown from remnant fires. Limits were: Maximum allowable wind, 10 m.p.h. (1000 to 1600 P.s.t.); burning index not over 21 on burn day or following day.

3. *Dispersion conditions*–Smoke in objectionable concentration must be kept out of the populated central portion of the Willamette Valley, which was designated a smoke-sensitive area. Several conditions were considered: (1) Direction of winds acting on the smoke from base to venting height–wind directions carrying smoke toward the Valley were differentiated from directions carrying smoke away from the Valley. And to allow for some variation in wind and smoke behavior, winds parallel to the Valley were considered blowing toward it. (2) Speed of wind acting on the smoke–this wind must be of sufficient force for classification of wind as blowing from a definite direction and not as variable or calm. (3) Stability conditions that limit the smoke rise over slash area; i.e., the dispersion level, which may vary with the terrain. The dispersion level is the height at which smoke loses buoyancy and moves with the prevailing motion of the surrounding air. In this study, dispersion level is considered to be at mixing level over the slash area. Mixing level is the top of the layer within which vertical mixing may be expected during midday as a result of heating at the ground (see Appendix). (4) Stability conditions over the Valley that would limit smoke descent into the Valley.

Classification

Each day on which fuel and burning weather conditions were determined to be favorable was classified for smoke dispersion characteristics on the basis of the wind and temperature profiles indicated by the 1600 P.s.t. rawinsonde observation at Salem. Mixing levels on both sides of the Valley were determined by assuming dry adiabatic ascent from the maximum temperatures at representative surface stations to intersection with the Salem temperature curve (Miller 1967; Holzworth 1967). Through use of data from such stations as Fall City, Stayton, Scotts Mills, and Government Camp, account was taken of any temperature gradients in the airmass from west (Coast Ranges) to east (Cascade Range) and of any

Table 1–*Restrictions of burning imposed by midafternoon dispersion conditions, Willamette Valley, Oregon*

Daily burning quota[1]	Midafternoon dispersion conditions		
	Direction of wind on smoke plume	Dispersion level (ft.) of smoke plume over Valley	Dispersion conditions
1. Unlimited burn (240 acres per day average)	Away from smoke-sensitive area at 9 m.p.h. or greater	Any level	No requirement
2. Slight limitation (160 acres per day)	Toward smoke-sensitive area[3] or less than 9 m.p.h. any direction	Above 5,000	Stable layer[2] over smoke-sensitive area and below dispersion level
3. Moderate limitation (120 acres per day)	Same as above	(a) Above 5,000 or (b) Above 2,500	(a) Deep mixing (b) Stable layer[2] over smoke-sensitive area and below dispersion level
4. Severe limitation (80 acres per day)	Same as above	2,500-5,000	Deep mixing
5. No burning	Same as above	Below 2,500	Any condition

[1]Applies to an administrative unit of ranger district size including 6 to 10 townships.
[2]See Appendix for method of determining existence of stable layer.
[3]Includes winds too light to depend on –in this study, less than 9 m.p.h.

greater heating over the mountains (see Appendix).

The burning restrictions imposed by smoke dispersion conditions in terms of the acreage of permissible burn assumed in this study for each condition is summarized in *table 1*. The 240 acres for an unrestricted day is not a quota but an estimate of an average amount. The assumed quotas would apply to an administrative area of Ranger District size, which may include 6 to 10 townships. The basic assumption is that emissions are controlled by limiting the acreage of burn according to dilution potential, vertical separation, and horizontal displacement of the smoke with respect to the smoke-sensitive area.

There is a distinct difference between these estimates of suitable burning days based on many assumptions and partial data, and the actual operational prediction and measurement of conditions influencing the suitability of burning. Only data readily available have been used and the method followed for the sample years is not intended as a model for predicting or determining by observation the suitability of burning conditions. We hope that the operational procedures will be based on considerably more complete weather and fuel data as well as on a more precise statement of burn requirements for each area.

RESULTS

In the first phase of the procedure, potential burning days were identified on the basis of suitable fuel moisture and favorable existing and following burning weather. In the two 6-month seasons examined, a total of 89 days *(table 2)* qualified as potential burning days on this basis. These days were about equally divided between the 2 years. Nearly all were in spring or fall, when 40 to 45 percent of the days

Table 2–*Potential burning days and summary of conditions precluding burning for areas east and west of the Willamette Valley, Oregon, May 1-Oct. 31, 1966 and 1967*

Month and year	Number of suitable days	Number of days unsuitable due to:					
		Condition of slash			Burning weather[1]		
		Too wet	Too dry	Buildup too high	Burning index too high	Burning index too high next day	Too windy
May 1966	15	2	0	0	5	4	5
May 1967	16	8	0	0	2	1	4
June 1966	2	0	14	12	0	1	1
June 1967	11	0	6	3	5	4	1
July 1966	5	1	13	7	2	2	1
July 1967	0	0	30	1	0	0	0
Aug. 1966	0	0	28	3	0	0	0
Aug. 1967	0	0	31	0	0	0	0
Sept. 1966	8	0	16	0	1	1	4
Sept. 1967	0	0	30	0	0	0	0
Oct. 1966	16	3	1	0	4	2	5
Oct. 1967	16	2	2	0	0	0	11
Total	89	16	171	26	19	15	32

[1]If more than one burning weather criterion applies, the day is listed under the first applicable heading, reading from left to right.

offered good burning conditions. Only 7 days in the 2 years qualified from the June 16 to September 15 period. Greatest deterrents in May were high fuel moistures and too much wind, with about the same frequency. From June through September, most days were unsuitable because of excessive dryness. In October, the greatest problem was too much wind. These fire-weather and fuel moisture conditions were assumed to be similar at all elevations. Effect of any residual snowpack at the higher elevations was ignored.

The 89 potential burning days were then classified according to weather conditions affecting dispersion of smoke. Predominance of winds from a westerly quadrant permitted the Coast Ranges only 14 unlimited burning days at the low elevation compared with 45 such days for the low level in the Cascades on the east side of the Willamette Valley *(table 3)*.

On only 15 of the 89 potential burning days was burning at the 200-foot elevation prohibited on one or both sides of the Valley (11 days each side) by a combination of low dispersion level and wind not

Table 3–*Smoke dispersion conditions affecting burning on the 89 suitable days, by portion of season, 1966-67 combined, for representative elevations east and west sides of the Willamette Valley, Oregon*

Area, elevation and date[1]	Number of days with indicated daily burning quota and midafternoon dispersion conditions[2]					
	(1) Unlimited bum (240 acres average)	(2) Slight limitation (160 acres)	(3a) Moderate limitation (120 acres)	(3b) Moderate limitation (120 acres)	(4) Severe limitation (80 acres)	(5) No burning
West, 200 ft.						
May 1-31	2	1	2	14	11	1
June 1-July 15	4	0	0	6	8	0
Sept, 16-Oct. 31	8	0	3	6	13	10
Total	14	1	5	26	32	11
West, 2,000 ft.						
May 1-31	3	2	1	21	4	0
June 1-July 15	3	0	0	9	6	0
Sept. 16-Oct, 31	5	7	12	6	9	1
Total	11	9	13	36	19	1
East, 200 ft.						
May 1-31	17	0	2	3	8	1
June 1-July 15	8	1	0	6	3	0
Sept. 16-Oct, 31	20	0	2	2	6	10
Total	45	1	4	11	17	11
East, 2,000 ft,						
May 1-31	21	1	2	3	4	0
June 1-July 15	9	0	0	5	5	0
Sept. 16-Oct. 31	25	0	8	3	4	0
Total	55	1	10	11	12	0
East, 4,000 ft.[3]						
May 1-31	27	1	2	1	0	0
June 1-July 15	8	1	1	3	5	0
Sept, 16-Oct. 31	28	2	7	0	3	0
Total	63	4	10	4	8	0

[1] Favorable burning days, by portion of season, for 2-year period: May (31 days); June-July 15 (18 days); September 16-October 31 (40 days), No favorable burning days in 1966 and 1967 from July 16 to September 15.
[2] See table 1 for descriptions of quotas and conditions in each numbered classification.
[3] Dispersion level elevation classes are 4,000-7,000 ft. (3b and 4) and over 7,000 ft. (2 and 3a).

Table 4–*Poor dispersion and low visibility during 89 potential burning days' at low elevation, Willamette Valley, Oregon*

Dispersion conditions	Potential burning days[1]		
	Low visibility days[2]	Other days	Total days
Dispersion level below 2,500 feet:[3]			
West winds (no burning west of Valley)	2	2	4
East winds (no burning east of Valley)	1	3	4
Indeterminate winds (no burning)	4	3	7
Total	7	8	[4]15
Dispersion level above 2,500 feet:[5]			
All wind conditions combined	2	72	74
Total	9	80	89

[1]Fuel and burning weather conditions satisfactory.
[2]Days with average visibility of less than 7 miles at Salem airport; all after September 15.
[3]Applies only to burning at 200-foot elevation. Midafternoon dispersion condition 5 (see table 1).
[4]Includes one day in May; all others after September 15.
[5]Midafternoon dispersion conditions 1-4 (see table 1).

blowing away from the Valley *(table 4).* All but one of these days occurred after September 15. Also included in the low dispersion level group were 7 potential burning days when visibility in the sensitive area averaged below 7 miles. Two other low-visibility days in October had dispersion levels near 3,000 feet. Burning at the 2,000-foot level was prohibited by a low dispersion level on only 1 day and then on one side of the Valley. Incidentally, the mean mixing level in October on potential burning days averaged 1,000 to 2,000 feet lower than May mixing levels over each burning elevation.

On all the remaining 78 potential burning days, some burning could be done in the low elevation areas. West of the Valley, however, dispersion conditions imposed severe restrictions on burning on 32 days and moderate limitations on another 31 days. Even at the 2,000-foot level in the Coast Ranges, moderate restrictions on burning were necessary on 49 days, and there were only 11 days of unrestricted burning compared with the 14 unrestricted burning days at the lower elevation.

The relative importance of each type of day becomes apparent from the total acreages of potential burning under each heading *(table 5).* In the Coast Ranges, because of the scarcity of offshore winds during the burning season, lesser acreages must be burned on the more frequent days with sufficiently high mixing levels in air moving toward the Valley. The 2,000-foot level in the Coast Ranges has a higher mixing level, particularly during the fall. This permitted hypothetical burning of 1,650 acres more in the 2-year test period than was burned at low elevation in the Coast Ranges.

In forest areas on the east side of the Willamette Valley at all elevations, there are more days than in Coast Ranges forests when slash may be burned without contributing smoke to the Willamette Valley. The effect of the predominating westerly winds throughout the 6-month season studied shows plainly in *table 3.* Even at the Valley levels, on 45 of the available 78 days, windflow was generally away from the Valley. The difference increases with elevation, so that 55 days were available for unlimited burning at 2,000 feet and 63 days at 4,000 feet. The advantage of the Cascade location and of elevation is reflected in potential acreage burned *(table 5).* At the 2,000-foot level, the Cascade advantage over the Coast Ranges amounts to 5,000 acres for the two test seasons. The altitude advantage on the Cascade side totals more than 4,000 acres between the 200- and 4,000-foot elevations, clearly showing the effect of more favorable dispersion conditions at higher elevations.

Table 5–*Potential acreage burn totals,*[1] *May l-October 31, 1966 and 1967 combined, at representative elevations, east and west sides of the Willamette Valley, Oregon for hypothetical administrative areas of ranger district size*

Site and elevation	(1)[2] Unlimited burn (240 acres/day average)	(2) Slight limitation (160 acres/day)	(3) Moderate limitation (120 acres/day)	(4) Severe limitation (80 acres/day)	Two-year total (acres)
West:					
200 ft,	3,360	160	3,720	2,560	9,800
2,000 ft.	2,640	1,440	5,880	1,520	11,480
East:					
200 ft.	10,800	160	1,800	1,360	14,120
2,000 ft,	13,200	160	2,520	960	16,840
4,000 ft.	15,120	2,240	1,440	0	18,800

[1]Maximum allowable burn each day is assumed.
[2]See table 1 for description of dispersion conditions in each numbered classification.

DISCUSSION

Application of Study

The significance of the potential burn acreages *(table 5)* lies in how they compare with the acreage of slash to be abated on any given district in the study area in any 2-year period. A forest manager faced with the prospect of limiting slash smoke production should be able to predict about how much slash he will be able to burn in a normal year, using all opportunities. If the potential acreage is too low when only fall burning is assumed, he should consider the potential burn acreage in spring. If the total is still short of the acreage of slash created, important changes in operations or policy may be necessary:

1. Abate slash by methods other than burning, including changes in logging practice.
2. Accept responsibility for protecting greater acreage of unabated slash.
3. Burn under more severe or otherwise limiting weather conditions, accepting the increased costs of preparation, burning, and mopup that would accompany an all-around more intensive burning operation.
4. Reduce the annual cut until an acceptable balance can be achieved between hazard created, hazard protected, and hazard abated.

All these alternatives require planning and implementation time. A study such as this helps the manager evaluate the need for revision of his slash disposal strategy.

Before applying the results of this study or starting a similar study for another area, the manager might consider some pertinent details. Though other limits of restrictions to burning might have produced slightly different results, some of the basic conditions are illustrated by this 2-year sample of a May-October season. A longer season may be desirable. Additional weather favorable for both burning and smoke dispersal is likely in many years both before and after this burning season. Note that suitable burning days occurred in both study years on May 1 and October 31. This might be of particular importance for Coast Ranges burning, which would be favored by the greater frequency of offshore flow in earlier spring and later fall periods (Cramer 1957).

The frequency of favorable burning weather in the 2 study years is probably less than normal as both years were very thy. In 1966, the Siuslaw National Forest, on the west slope of the Coast Ranges, reported its driest fire season since 1952. And at Eugene, the April-August rainfall was the lowest ever recorded. Similarly, the 1967 season was the warmest and driest of record in western Oregon. On the damper west slope of the Coast Ranges, not included in this study, these dry years may have been more favorable for slash burning than damper years when adequately dry days are at a premium.

It would seem that many burning days are available in spring and early summer, on a basis of burning conditions and smoke dispersal conditions alone. However, these are not the only considerations that determine the time of year suitable for burning. The extra risk of holdover fires in large and underground fuels from spring and summer burns has been the primary reason that spring burning is limited. Holdover fire potential would have to be taken into account for otherwise unrestricted burning days noted in the May 1-July 15 period, particularly east of the Willamette Valley. Some burns would not be considered and others would require thorough mopup and patrol. Immediately west of the Coast Ranges area considered in this study, the Siuslaw National Forest has practiced spring and summer burning successfully for many years. But specifically because of the risk of holdover fire, this has not been the practice in the Cascades where drier summer fuel and weather conditions normally prevail. This restriction would be less applicable in other regions where the summer is not normally a drought period as it is in the Pacific Northwest.

Limitations of Study

This study obviously cannot cover all possible variations in requirements for burning conditions and air quality restrictions. Only a single set of simplified conditions has been used. Results should be interpreted only with awareness of attendant limitations.

The study model encompassing fuel moisture, burning weather, and air quality requirements has the following limitations:

1. Since the sample is limited to exceptionally dry years, we have no estimate of comparative frequency of favorable burning conditions during unusually wet years. Wetness may prove even more limiting than dryness in some areas.

2. Assumed limits of fuel moisture and fire danger for suitable burning days are not likely to apply to every slash situation. Presumably, the limits imply that conditions are favorable in some slash somewhere within the study areas. Limits were set after consultation with field foresters experienced in prescribed burning; however, there was not complete agreement. In actual practice, because of basically different climatic and fuel conditions, favorable limits for east slope Coast Ranges burns may be different from limits for west slope Cascade Range burns. Even greater differences may be expected between individual slash areas.

3. Burning conditions have been assumed not to change with altitude. In the Willamette Valley and adjoining mountain ranges, this would not necessarily be justified, primarily because of the fluctuating height and intensity of the marine inversion and contrast of airmass properties above and below. An assumption of no change with elevation is probably not too much in error, on the average. Actually, variations due to difference in aspect at one elevation probably exceed average differences due to elevation.

4. In this study, burn quotas for a given condition were assumed for a hypothetical administrative unit of a single elevation. In actual practice, burns must be made at many elevations. An ideal basis for quotas would be the amount of smoke, hence, acreage of burn, contributing to a particular air layer. But the differentiation of significant layers changes with the weather. Quotas could be set up currently for the existing layer structure on the basis of whether the smoke-receiving layer was mixed and in contact with the smoke-sensitive area or whether it remained in a stratum entirely above the sensitive area.

5. No allowance was made for hot convective columns that might push smoke well above the mixing height. Fires with this capability might very well be burned when lesser fires might not be desirable, or such fires might be ignited earlier in the day.

6. Possible nocturnal drainage of smoke from smoldering slash fire remnants within reach of a smoke-sensitive area may be more important than the primary plume. Downslope flow of smoke into low places would be most noticeable on windless nights with stable air. Such nights would be expected to follow days with light winds and clear skies. The amount of fire still in the smoldering stage when nocturnal drainage winds commence can be minimized by scheduling ignition early in the morning.

7. Increasing diffusion with distance between smoke source and smoke-sensitive area has not been taken into account. For individual fires, this may be an important factor, but if many adjacent administrative areas are all under similar guidance, the cumulative effect of smoke sources at various distances may tend to offset dilution effects unless timing is also considered. Actual spacing of burns by time and location to avoid reinforcing smoke plumes from fires upwind may be necessary.

8. Wind aloft over the burn site determines the extent of burn restriction. In some situations, error may have been introduced by assuming winds aloft over burn areas in the Coast and Cascade Ranges were represented by Salem upper wind observations.

9. A few days would have been assigned higher burning quotas if the data had permitted use of a lower speed for indeterminate wind direction, which

included all winds less than 9 m.p.h. A 5 m.p.h. threshold might be adequate.

10. Instability is not considered an impediment to burning. Experimental burning of slash areas under all summer weather conditions in western Montana, where instability is often more pronounced than over western Oregon, indicates this assumption is justified. This applies to the usually considered thermodynamic atmospheric stability, not to aerodynamic stability of flow around obstacles.

11. Potential burn acreages have been assigned on the basis of weather at 1600 P.s.t. Diurnal changes have not been taken into account. A day with wind toward a smoke-sensitive area, classified on the basis of 1600 P.s.t. dispersion conditions as deep mixing (3(a) or 4 in *table 1*), could often become a night with smoke *above a stable layer* (2 or 3b in *table 1*), allowing greater burn acreage at least at higher elevations. The possibility of additional burning at night in the higher areas was not evaluated.

12. Assumption of full use of every favorable burning period may not be realistic. Conflicting activities and burning bans on weekends may eliminate some opportunities. Another important variable is the accuracy of weather forecasts upon which scheduling of the burning would actually depend. Although accuracy of general forecasts may be high, the detailed structure of winds and stability required for control of slash smoke may be quite difficult to predict for mountain areas. The forecaster is now handicapped by an absence of upper air reports from mountain areas and even surface reports during early and late portions of an expanded burning season.

14. Greater acreages might be burned under "unlimited" burning conditions, for which an average figure of only 240 acres per day was assumed.

The burning conditions assumed have been for broadcast burning. Burning of large yarded piles of slash–an increasingly common practice–would involve a broader spectrum of favorable weather conditions. The piles could be burned in late fall and winter under wetter conditions when broadcast burning would be impossible. In drier weather, night burning might be favored. For yarded-pile burning favorable smoke dispersion weather may include precipitating cloud systems in which removal of slash combustion products from the atmosphere might be accelerated.

The range of conditions under which hazard reduction or other prescribed burning can be safely done can be further broadened by varying: (a) fuel preparation, (b) fireproofing beyond the fire perimeter, and (c) ignition procedures. The potential burning days under air quality restrictions, as determined here for exceedingly restricted conditions, should be considered a near minimum that might be significantly increased in actual practice.

SUMMARY

Cramer, Owen P., and James N. Westwood.
1970. **Potential impact of air quality restrictions on logging residue burning.** Berkeley, Calif., Pacific SW, Forest & Range Exp. Sta., 12 p., illus. (USDA Forest Serv. Res. Paper PSW-64)

Oxford: 332.3–436: (795): U628.53 [+425.11.
Retrieval Terms: slash disposal; broadcast burning; air pollution; smoke abatement; Willamette Valley; Oregon.

The potential number of days for burning logging slash and the potential burn acreage under smoke control restrictions were estimated for hypothetical forest areas on both sides of a pollution prone area in the Willamette Valley, western Oregon. The hypothetical areas were five administrative units the size of U.S. Forest Service Ranger Districts. The slash burning season was assumed to be May 1 to October 31. The years chosen for study–1966 and 1967–were both unusually dry, and were intentionally selected to represent poor burning seasons. The count of days available for burning was based on specifications set up in the study for the categories of (a) fuel conditions, (b) burning weather, and (c) smoke dispersion conditions.

The requirement of favorable smoke dispersal weather, in addition to the usual rather exacting requirements of favorable burning weather, greatly restricts the number of days when unlimited broadcast burning of slash may be done west of the

Willamette Valley. Though still substantial, the restriction is much less for burning east of the Valley, and decreases progressively for slash at 2,000 feet and 4,000 feet elevation. The greater restriction of Coast Ranges burning is the direct result of more frequent windflow from a westerly quadrant toward the Willamette Valley smoke-sensitive area.

If the burning season is expanded into spring, the theoretical number of burning days is nearly double the number available only in fall. The total of days classed as favorable for burning was probably well below normal because, in the test years, weather during the summer period was too severe for burning under the limits set. On the other hand, unusually wet years might provide even fewer burning opportunities.

A few additional burning days can be picked up in some years in March and April and again in November. Offshore flow is more frequent in these months, making them important to Coast Ranges burning.

Low mixing level or valley inversion conditions are a serious impediment to burning at low elevations only in fall. These conditions account for most of the low-visibility days. Dispersion from high-elevation sources is not affected except that smoke from higher sources is possibly prevented from descending to lower elevations.

In actual practice successful management of the smoke from prescribed burning depends fully on optimum use of specially tailored weather information. Of primary importance would be accurate, timely forecasts of upper wind and stability conditions over the mountain areas. Such forecasts would depend on current surface and upper air reports from mountain areas.

This study assumed broadcast burning of rather heavy slash in place, with normal precautions. With favorable burning days at a premium, other possible alternatives need to be further developed to broaden the range of conditions under which slash burning and other prescribed burning may be successfully accomplished. Faced with the prospect of increasing accumulations of slash if he continues business as usual in the face of limitations on smoke release, the forest manager may be forced into one or a combination of several alternatives: These might include redefining the material that must be removed in logging and changing the treatment of residual material. Other possibilities are more intensive burning during periods of less ideal weather with the necessary fuel preparation, special ignition techniques, fireproofing of the surrounding area, and aggressive mopup. But, if costs of both intensive burning and protection of increasing acreages of slash make these unacceptable alternatives, and clean logging is not feasible, there is still another possibility–reduce the acreage cut each year to a level at which the slash can be handled.

The impact of smoke control regulations may be great on some districts and slight on others, depending, of course, on normal local weather conditions and on the specific smoke control limitations imposed. After specific regulations have been adopted, it may be helpful to assess their effect on probable annual burn acreage by some such study as this one.

LITERATURE CITED

Cramer, O. P.
1957. **Frequency of dry east winds over northwest Oregon and southwest Washington.** U.S. Forest Serv. Pacific NW. Forest & Range Exp. Sta. Res. Paper 24,19 p.

Darley, E. F.
1969. **Proceedings, Air Pollution Workshop.** Pacific NW. Forest & Range Exp. Sta.. Portland, Ore. 6 p.

Darley, E. L., F. R. Burleson, E. H. Mateer, and others.
1966. **Contribution of burning of agricultural wastes to photochemical air pollution.** J. Air Pollut. Control Ass. 16(12): 685-690.

Fritschen, Leo, Harley Bovee, Konrad Buettner, Robert Charlson, and others.
1970. **Slash fire atmospheric pollution.** USDA Forest Serv. Res. Paper PNW-97, 42 p., illus. Pacific NW. Forest & Range Exp. Sta., Portland, Ore.

Holzworth, G. C.
1967. **Mixing depth, windspeeds and air pollution potential for selected locations in the United States.** J. Appl. Meteorol. 6(6): 1039-1044.

Miller, E. M.
1967. **Forecasting afternoon mixing depths and transport windspeeds.** Mon. Weather Rev. 95(1): 35-44.

Morris, W. G.
1966. **Guidelines offered for slash burning.** Forest Ind. 93(10): 62-63.

National Air Pollution Control Administration.
1969. **Air quality criteria for particulate matter.** Publ. AP-49, Washington, D. C.

APPENDIX: *Detailed Procedures*

Determination of mixing levels. Plotted daily afternoon radiosonde observations (raobs) from Salem were used as a basis. Daily temperature maximums for the stations listed below were taken from the Weather Bureau's Monthly Climatological Summaries for Oregon and plotted on a pseudo-adiabatic chart at appropriate pressure heights as shown below. Mixing levels were defined as the intersection of the potential temperature of the maximum temperature and the Salem raob curve. The pressure height thus found was converted to the nearest hundred-foot elevation by using the standard-atmosphere-based scale on the pseudoadiabatic chart. This means that on warm days the actual mixing level may have been 100-200 feet greater than that recorded for the study.

Stations used, and the pressure heights at which their daily maximums were plotted:

Location	Station	Elevation	Pressure height
		Feet	
East Coast Ranges:			
200 ft.	Falls City No. 2	440	Salem pressure minus 10 mb.
2,000 ft.	None (estimated)	--	--
West Cascade Range:			
200 ft.	Salem	196	Given
	Stayton	465	Salem pressure minus 10 mb.
2,000 ft.	Scotts Mill 9 SE	2,315	930 mb.
4,000 ft.	Government Camp	3,980	880 mb.

For west Cascade Range, 200 ft., the Salem surface temperature was used unless Stayton's temperature differed by 3°F, or more. In that event, the midpoint between the two temperatures was used. On days when Government Camp's northerly location made it appear unrepresentative of the west Cascade Range 4,000 ft. temperature, the 4,000-ft. station used was Santiam Pass (4,748 ft., 850 mb.).

A subjective warming or cooling (up to ± 3°C.) was made in the Salem raob curve to better simulate conditions over the Coast and Cascade Ranges for those days on which there appeared from upper air maps to be a strong east-west temperature gradient. The east or west side mixing levels changed accordingly.

Stability conditions. The smoke column from an active slash fire was assumed to have sufficient heat to lift it to the mixing level for the particular locality. The smoke was presumed to be above a stable layer over the smoke-sensitive area when all the following conditions existed:

1. Winds at dispersion level, as measured over Salem, blew in a direction that would move smoke toward the smoke sensitive area.
2. Mixing level (dispersion level) over the slash area exceeded 2,500 ft. and also exceeded the mixing level over Salem.
3. The layer between the Salem and slash area mixing levels was stable on the Salem sounding.

Adjusted fuel moisture. This simulated value of 1/2-inch fuel moisture sticks was determined from Spread Phase Tables of the National Fire Danger Rating System using 1600 P.s.t. Salem temperature, relative humidity, and 24-hour precipitation.

Buildup index. This index of cumulative drying in larger fuels was determined from the same tables as above.

Burning index. This index is based on spread index computed from the above-mentioned tables utilizing fuel moisture, buildup, and 1600 P.s.t. Salem wind plus additional weighting for fine fuel moisture in accordance with tables used in USDA Forest Service, Region 6.

Limits for adjusted fuel moisture. Limits used for adjusted fuel moisture are taken from the study by Morris (1966) of late summer and fall slash fires on six National Forests west of the Cascade divide. The values used (8 to 18.5 in spring and 8 to 25.5 in summer and fall) include a range covering all terrain aspects. Highest values apply to south-facing slopes and lowest to north-facing. Experience with spring burning on the Siuslaw National Forest, west of the Coast Ranges area considered here, indicates that fuel moistures as low as 5 percent may be desirable to assure an adequate burn at that season, in some situations.

Although the limit values were actually derived for the time of burning regardless of time of day, they have been applied here to the Salem 1600 P.s.t. adjusted fuel moisture. This may have eliminated some days as too dry when burning may have been possible at other times such as in the evening.

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Cramer, Owen P., and James N. Westwood.

1970. **Potential impact of air quality restrictions on logging residue burning.** Berkeley, Calif., Pacific SW, Forest & Range Exp, Sta., 12 p., illus. (USDA Forest Serv. Res. Paper PSW-64)

The number of potential burning days and the potential burn acreage under smoke control restrictions were estimated for hypothetical forest areas on both sides of a pollution prone area, the Willamette Valley in western Oregon. On the basis of a sample of 2 dry years, the greatest impact on burning operations applied to low elevation forests west of the Valley. The study indicates that considerable burning can be accomplished under the assumed air quality restrictions. In some areas, however, it may be necessary to consider other alternatives for coping with logging residue.

OXFORD: 332.3–436:(795):U628.53 [+425.1] .
RETRIEVAL TERMS: slash disposal; broadcast burning; air pollution; smoke abatement: Willamette Valley; Oregon.

Cramer, Owen P., and James N. Westwood.

1970. **Potential impact of air quality restrictions on logging residue burning.** Berkeley, Calif., Pacific SW, Forest & Range Exp, Sta., 12 p., illus. (USDA Forest Serv. Res. Paper PSW-64)

The number of potential burning days and the potential burn acreage under smoke control restrictions were estimated for hypothetical forest areas on both sides of a pollution prone area, the Willamette Valley in western Oregon. On the basis of a sample of 2 dry years, the greatest impact on burning operations applied to low elevation forests west of the Valley. The study indicates that considerable burning can be accomplished under the assumed air quality restrictions. In some areas, however, it may be necessary to consider other alternatives for coping with logging residue.

OXFORD: 332.3–436:(795):U628.53 [+425.1] .
RETRIEVAL TERMS: slash disposal; broadcast burning; air pollution; smoke abatement: Willamette Valley; Oregon.