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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture
Forest Service
Ogden, Utah 84401

INFLUENCE OF HARVESTING AND RESIDUES ON FUELS AND FIRE MANAGEMENT

James K. Brown

Research Forester, USDA Forest Service
Intermountain Forest and Range Experiment Station

ABSTRACT

Fuel and fire behavior potential in clearcut lodgepole pine and in Douglas-fir/larch under clearcutting, group selection, and shelterwood silvicultural systems were compared after logging to near-complete and conventional utilization standards. Fuels and fire behavior potentials were unaffected by silvicultural systems but varied substantially by utilization standards and method of skidding. Predicted rates of spread on conventional units were 3-4 times greater than on near-complete units. Predicted fireline intensities were 6-10 times greater on the conventional units. Conventional utilization left fireline intensities exceeding capabilities for direct fire control for 3-5 years up to 20 years or more. Whole tree skidding without slashing reduced hazard to acceptable levels by trampling and transporting material from the site. Fuel less than 0.25 inches in diameter was reduced to 0.4 of that created by cutting while all fuel less than 3 inches in diameter was reduced to 0.7 of that created by cutting. Whole tree skidding coupled with slashing left unacceptable hazards for 3-5 years. Near-complete utilization left acceptable levels of hazard but also left insufficient fuel for prescribed burning. Methods with which land managers can appraise fuel and fire behavior potentials on specific cutting units are presented. Deciding "how much fuel is acceptable" is discussed.

KEYWORDS: Fuel appraisal, fuel management, slash hazard, residue, utilization standards

INFLUENCE OF HARVESTING AND RESIDUES ON FUELS AND FIRE MANAGEMENT

Timber harvesting produces forest fuels with fire behavior potentials of great concern to land managers. Fires involving slash fuels can be particularly difficult to control, generate high costs of suppression and threaten resource values. Fuel quantities from harvesting vary substantially and can be excessive, depending on volumes cut and methods of harvest (Howard 1973; Benson and Johnston 1976). Utilization standards and methods of skidding offer the manager opportunities to modify fuel hazards, because they influence fuel loading, size distribution, continuity, and compactness.

Little has been documented on the extent to which harvesting methods can alter fuel characteristics and fire potentials. However, techniques developed over the past few years for measuring and predicting fuels and fire behavior have made it possible to appraise slash fuels. This paper describes how different harvesting methods altered fuels and fire potential on two study areas and discusses how managers can appraise fuels on any cutting area before slash is created.

CASE STUDIES AT UNION PASS AND CORAM

Study Procedures

Effects of harvesting on fuel and fire behavior potential were evaluated at two locations: Union Pass on the Bridger-Teton National Forest in Wyoming, and Coram Experimental Forest on the Flathead National Forest in Montana. Forest conditions and study designs were different.

UNION PASS

Two mature, even-aged lodgepole pine stands were studied. In each stand, two 20-acre harvesting units were established. One unit was clearcut to "conventional" utilization standards, the other to utilization standards that were called "near-complete". On both the conventional and near-complete harvesting units all sound trees to a merchantable top diameter of 6 inches were removed. In addition, on the near-complete units chips were produced from: (a) tops of all merchantable trees; (b) all remaining live and dead sound standing trees with a d.b.h. of 3 inches or larger; and (c) all material remaining on the ground that was more than 6 inches in diameter at the larger end, more than 6 feet long, and sound enough to permit skidding. On the conventional units, trees were limbed and bucked where felled, then skidded by crawler tractor to the landing. On the near-complete units, trees were felled and then bunched and skidded to a central point where the sawlog material was removed. The remaining top material was then skidded to the chipper.

CORAM

Mature Douglas-fir/larch stands were divided into six cutting units. Clearcut, shelterwood, and group selection cutting methods were each applied to two units. In addition, each unit received four levels of utilization ranging from current standard utilization ("intensive tree" and "sawlog") to near-complete removal of tree material (fig. 1) as follows:

Utilization level	Treatment and utilization standards
Intensive tree	Trees down to 5 inch d.b.h. cut; all material (live and dead, standing and down) 3 inches in diameter and 8 feet long or larger removed; smaller trees slashed.
Sawlog	Trees down to 7 inches in d.b.h. cut; logs to a 6 inch top diameter (live and recently dead) removed; smaller trees slashed.
Intensive log	Trees down to 7 inches d.b.h. cut; logs (live and dead, standing and down) to a 3 inch top diameter and 8 feet long removed; smaller trees protected (no slashing).
Near-complete	All trees down to 1 inch d.b.h. cut; all material (live and dead, standing and down) to 1 inch removed.

Harvesting was accomplished using a running skyline system that provided lift and travel to the suspended load. Trees up to 8-10 inches in d.b.h. were skidded whole. Larger trees were bucked before skidding; their tops were left in the woods consistent with utilization standards.

Downed woody fuels were inventoried before and after logging using the planar intersect method (Brown 1974b). Additionally, at Coram, loadings of slash fuels were predicted from an inventory of trees and crown weight relationships (Brown 1978). This permitted a comparison of worst possible fire potential and actual fire potential created by the harvesting. Sampling design and procedures are described in detail for Union Pass by Brown (1974b), and for Coram by Benson and Schleiter.[1]

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[1]Benson, Robert E., and Joyce Schleiter. Volume and weight characteristics of a typical Douglas-fir/western larch stand, Coram Experimental Forest, Montana. USDA For. Serv. Gen. Tech. Rep. INT (in process).

Figure 1.--The sawlog treatment (above) and near-complete treatment (below) illustrate the range in fuel quantities and size encountered in the Coram Douglas-fir/larch study.

Fire behavior was predicted for inventoried and predicted fuels using mathematical models described by Rothermel (1972) and Albini (1976a and 1976b). In fire behavior modeling, moisture contents were held at 5-7 percent, and slopes were averaged for the study areas. Wind speeds shown in tables and figures are for wind at mid-flame heights. Slash at 5 years of age has been reduced in depth to 0.7 of the depth for 1-year-old slash; retained foliage has been reduced to 0.2 of that in 1-year-old slash (Albini and Brown 1978).

Union Pass Results - Lodgepole Pine

The main differences between the two harvesting treatments concerned the amount of material over 3 inches in d.b.h. and the depth of fuel left after logging. After cutting on the near-complete units, loading of material over 3 inches was reduced to 9 tons per acre, one-third of the prelogging amount. On the conventional units, loading increased three times--from 16 to 44 tons per acre. Although this size would contribute little to the spreading flame front of a fire, it would contribute measurably to total fire intensity and resistance to control. It also would contribute indirectly to fire spread by helping support smaller sized fuel at a more flammable level of compactness. Further discussion of fuel changes have been described by Brown (1974a).

Rate of spread and fireline intensity for the propagating flame front of a fire (this excludes spotting of fire brands) were estimated using the inventoried fuel data. The predictions showed that rate of spread would be about 3-4.5 times greater on the conventional units. Byram's fireline intensity (rate of heat release per linear foot of the propagating flame front) would be about 6 times greater on the conventional units for any wind speed and fuel moisture (fig. 2).

Fireline intensity is probably the most useful characteristic of fire behavior for evaluating slash fuel hazard. At fireline intensities of 500-700 Btu's/ft./s, direct attack becomes ineffective and spotting begins to be a problem.[2] At 1,000 Btu's/ft./s, crowning and serious spotting can be expected. Considering 500-1000 Btu's/ft./s to represent an unacceptable hazard, figure 2 shows that for at least one year after cutting, conventional logging creates unacceptable hazards. By 5 years, hazard in conventional units reduces to an acceptable level due to loss of needles and settling of slash. Figure 2 shows that hazard in the near-complete units is always acceptable.

Coram Results - Douglas-fir/larch

SILVICULTURAL SYSTEMS

After harvesting, fuel quantities and fire behavior potentials were similar for the shelterwood, group selection, and clearcut silvicultural systems. Quantities of fuel less than 3 inches in diameter within harvesting units varied greatly, thus masking possible statistical differences among silvicultural systems. For like treatments, the rates of spread in table 1 show the similarities among silvicultural systems.

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[2]Hal E. Anderson, Lesson Plan for Advanced Fire Behavior Officer Training S-590. USDA For. Serv. 1978.

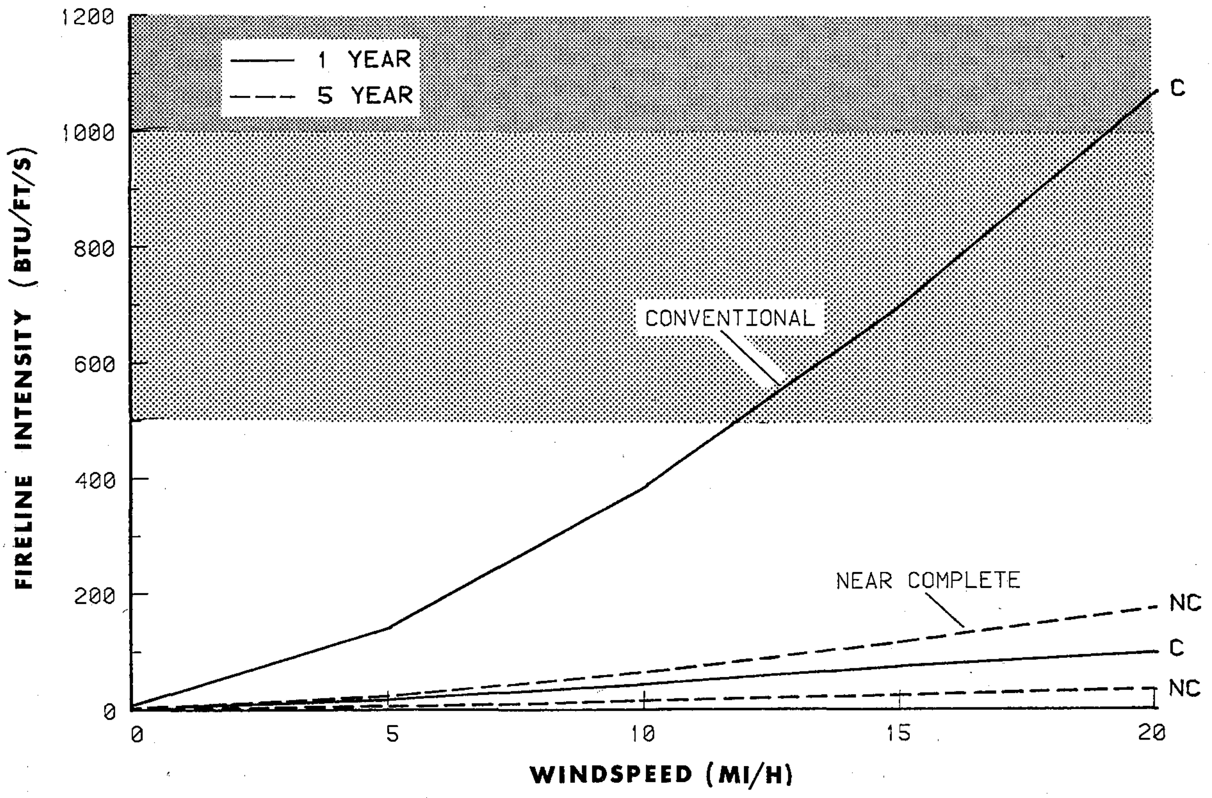

Figure 2.--Byram's fireline intensity for 1-and 5-year-old lodgepole pine fuels left after logging to conventional (C) and near-complete utilization standards (NC) at Union Pass. Shaded areas warn of unacceptable hazard.

Table 1.--Rate of spread for post-logging Douglas-fir/larch slash 1 year and 5 years after cutting at 0, 5, 10, and 15 mi/h windspeed, Coram.

Treatment	Silvicultural System	1 year				5 year			
		0	5	10	15	0	5	10	15
		-----------Feet per minute-----------							
Intensive	Shelterwood	26	32	42	56	10	13	16	19
	Group selection	39	49	65	87	14	18	22	26
	Clearcut	29	36	49	65	10	12	15	19
	Average	31	39	52	69	11	14	18	21
Sawlog	Shelterwood	40	51	68	90	17	21	26	31
	Group selection	27	34	46	60	13	16	20	23
	Clearcut	33	41	55	72	13	16	20	24
	Average	34	42	56	74	14	18	22	26
Intensive log	Shelterwood	17	21	28	35	9	12	14	16
	Group selection	12	15	20	26	5	6	7	8
	Clearcut	12	15	19	25	5	7	8	9
	Average	14	17	22	29	6	8	10	11
Near-complete	Shelterwood	7	9	12	15	4	4	5	6
	Group selection	9	12	15	20	4	5	6	7
	Clearcut	8	10	14	19	3	3	4	5
	Average	8	10	14	18	4	4	5	6

COMPARISON OF UTILIZATION LEVELS REFERRED TO AS TREATMENTS

Intensive tree and sawlog treatments, both having understories slashed (small trees cut and left on the ground), showed similar fire behavior predictions. Slashing created a major portion of the fine fuels. Although the utilization standards for the sawlog treatment allowed more residues, this additional fuel was not great enough to produce fire behavior predictions different than those of the intensive tree treatment. Consequently, for the remainder of this paper's discussion of treatment effects on fire behavior, intensive tree and sawlog utilization levels will both be referred to as "slashed" treatment.

As at Union Pass, near-complete utilization resulted in substantially less fire behavior potential than the other treatments. For example, predicted rate of spread for the near-complete treatment was approximately 0.25 of that for slashed and 0.6 of that for no slashing (intensive log) treatments (table 1). Fireline intensity for the near-complete treatment was approximately 0.1 of that for slashed and 0.25 of that for no slashing treatments (fig. 3).

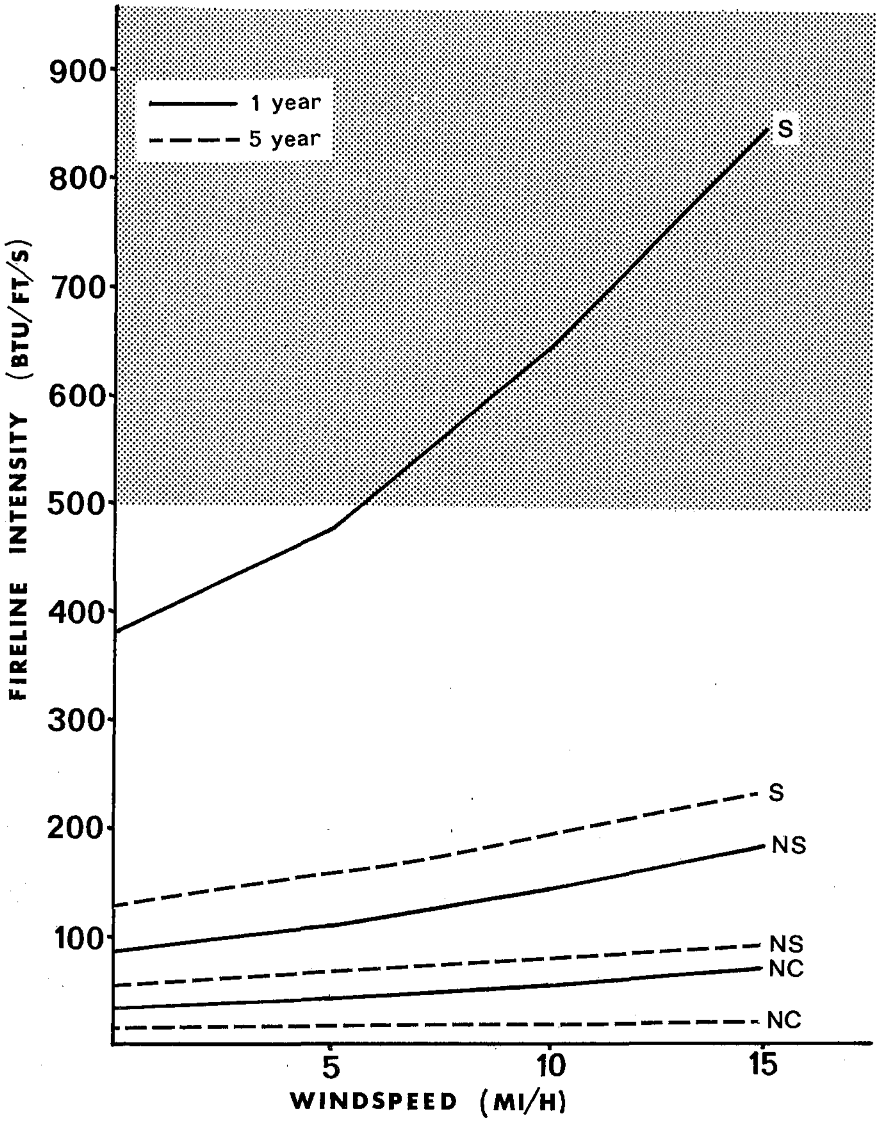

Figure 3.-- Byram's fireline intensity in 1-year and 5-year-old Douglas-fir/larch slash for slashed (S), no slashing (NS), and near complete (NC) treatments. The shaded areas signal unacceptable hazard.

Loading of fuel smaller than 3 inches in diameter was less for near-complete harvesting than for other treatments. This fuelbed was also more compact as illustrated by the relative compactness in Table 2. Both factors contributed to lower predicted burning rates. The fuelbed under the near-complete treatment became very compact--twice that of the sawlog treatment--due to extensive trampling and removal of residues. The slashing treatment's fuelbed also was very compact because of the absence of a fluffy, slashed understory. The least compact (most porous) fuelbed resulted from the sawlog treatment that had the largest merchantable diameter limits along with a slashed understory.

Unlike lodgepole pine at Union Pass, loadings of 3 inch and larger fuels were left at reasonable levels in all treatments (table 2). The reason for this is that the utilization standards specified removal of merchantable sound dead wood.

Table 2.--Loadings and relative compactness of downed woody material by treatment, averaged over silvicultural systems at Coram

Treatment	3 inches and greater			Less than 3 inches			
	Pre-logging	Post-logging	Change[1]	Pre-logging	Post-logging	Change[1]	Relative compactness[2]
	(T/a)	(T/a)	pct.	(T/a)	(T/a)	pct.	
Intensive tree	17.1	15.1	-12	3.90	10.77	176	1.2
Sawlog	16.5	17.0	3	4.18	10.74	157	1.0
Intensive log	16.4	13.0	-21	4.40	10.60	141	1.6
Near-complete	19.2	10.4	-46	3.87	7.66	98	2.1

[1]Percent change is $(100)\left(\frac{\text{Postlogging - Prelogging}}{\text{Prelogging}}\right)$

[2]Based on fuelbed bulk densities for 1-year-old slash. Sawlog treatment was a common divisor.

Whole tree skidding removed considerable slash from the surface fuelbed by transporting it off-site and grinding it into the forest floor and soil. Because whole tree skidding effectively reduced fuels, the no slashing treatment showed only slightly greater fire behavior potentials than near-complete harvesting (table 1 and figure 3).

For group selection and clearcutting systems, the only unacceptable hazards expected to last for about 5 years resulted from the slashing treatments (intensive tree and sawlog). After that, hazard fell to an acceptable level (fig. 3). Under shelterwood, where protection of the overstory is important, the no slashing treatment might have left unacceptable hazards depending on the fire resistance of the remaining trees. Near-complete harvesting under all silvicultural systems resulted in acceptable fuels and hazards.

OTHER TREATMENTS OF FIRE POTENTIALS

Considerably greater fire potentials could be expected from harvesting that leaves all tops and limbs on-site such as would result from ground lead skidding of only bucked and limbed merchantable pieces. For example, fuel and fire behavior were predicted for the two slashing treatments assuming all residues less than 3 inches in diameter remained on the site. A comparison of fire behavior for all fuels present with that for fuels from actual harvesting showed rates of spread that were 2-4 times greater for all fuels present. Fireline intensities with all fuels present were approximately 4 times that produced by the Coram harvesting (fig. 4).

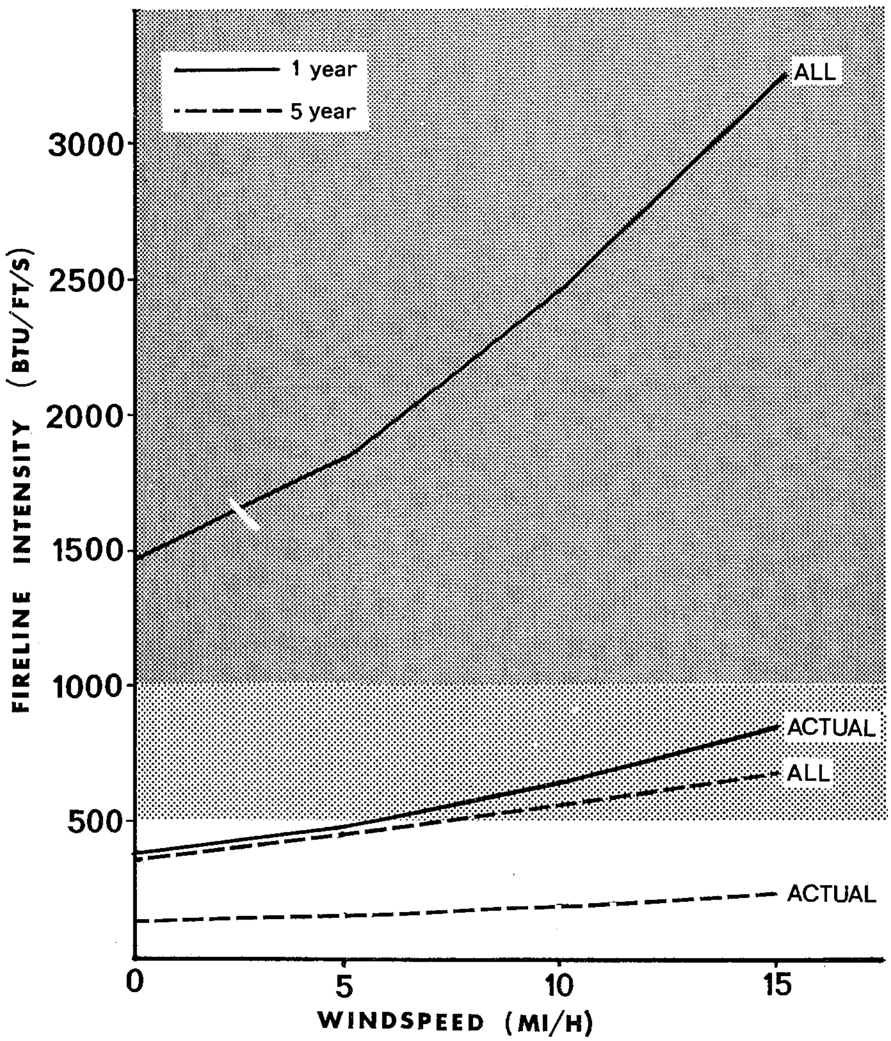

Figure 4.--Byram's fireline intensities in 2-year and 5-year-old Douglas-fir/larch slash for all potential fuels present and for actual fuel, after partially whole tree skidding. Shaded areas indicate unacceptable hazard.

Unacceptable hazard levels persisted beyond the 5-year prediction and could be expected to hold for 20 or more years.

PREDICTED VERSUS ACTUAL LOADINGS

Actual slash loadings (post logging minus prelogging inventories) of all material less than 3 inches in diameter averaged 0.7 of the predicted loadings. Interestingly, actual loadings of branchwood 0-0.25 inches in diameter averaged 0.4 of the predicted loadings. Thus, partially whole tree skidding removed considerably more fine fuel than larger branches from the slash fuel bed. Apparently, more finer, flammable branchwood than larger material is trampled into the forest floor during skidding.

Fire Management Implications

The following implications on fire management were apparent from the Union Pass and Coram studies:

1. Conventional Utilization Without Fuel Treatment. Conventional harvesting leaves unacceptable hazard levels with fireline intensity exceeding capabilities for direct fire control. Depending on species and volume cut, excessive hazards can exist for 3-5 years up to 20 years or more. There are ways to reduce hazards to an acceptable level. For example, utilization standards calling for removal of most bolewood and some dead material can mitigate hazards. If large-sized fuels are expected to be a problem, removal of some dead material is necessary to alleviate hazard. But it is important to remember that whole tree skidding coupled with slashing produces an unacceptable hazard for 3 to 5 years. Costs of skidding unmerchantable material may exceed the benefits of reduced hazard. This latter possiblility should be evaluated on a case by case basis.

2. Near Complete Utilization. Logging to near-complete utilization standards reduces fire behavior potential to a point requiring no further fuel modification for hazard reduction. In fact, insufficient fuel may exist for prescribed burning to meet silvicultural objectives. The same applies to whole tree skidding under conventional utilization standards without slashing, even though whole tree skidding results in somewhat greater fire potential than near-complete harvesting. To facilitate prescribed burning after whole tree skidding, understory slashing would be an asset and perhaps a necessity.

Although complete utilization can probably be relied upon to reduce fire hazard to an acceptable level, as it did in these studies, the desirability of complete utilization also depends on the need for residue material to carry prescribed fire, stabilize soils, shade seedlings, and recycle nutrients.

3. Conventional Utilization, with Fuel Treatment. Broadcast burning and piling and burning both reduce fire hazard to an acceptable level. Except for time limitations in scheduling, broadcast burning is a more desirable treatment because it causes less disruption of soil and leaves more large pieces of residue scattered throughout an area to provide site protection and a source for nutrients.

At Union Pass, lopping of slash solely for hazard reduction appeared unnecessary because natural deterioration alone should reduce hazard to acceptable levels. However, lopping may be desirable for bringing large pieces in contact with the soil to hasten decay and for aesthetic or other reasons.

4. Prediction of Fire Behavior. When predicting fuel and fire potential using procedures described in the next section of this paper, over-estimates are likely because material less than 0.25 inches in diameter is trampled out of the slash fuel bed. The significance of this problem varies with harvesting method and should be evaluated for individual situations.

METHODS FOR APPRAISING SLASH HAZARD

Procedures for estimating fuel quantities and fire behavior potential are available for appraising slash hazard on specific land units. Land managers who wish to appraise slash hazard should first decide on how accurately they need to know fuel quantity and fire behavior potentials. Then, one of the following methods can be used to help appraise slash hazard.

1. Nomographs of Rate of Spread, Fire Intensity, and Flame Length. Using nomographs developed by Albini (1976b), fire behavior at variable fuel moisture and wind speed can be predicted for low, medium, and heavy logging slash. These nomographs were developed for slash left after logging to an 8-inch top and skidded using a ground lead system. Resolution in the fire behavior estimates is relatively broad since the method recognizes only three levels of fuel quantity.

2. Photo Series. A series of photographs depicting a wide range of slash conditions identified by estimates of fuel loadings and fire behavior ratings were developed by Koski and Fischer (1979) for thinning slash in northern Idaho, and by Maxwell and Ward (1978a, 1978b) for forest residues in Washington and Oregon. U. S. Forest Service Region 1 and Region 6 also have developed a photo series. These photos in field manual edition can be compared with existing slash accumulations. By selecting the photo that most nearly compares with what is seen on the ground, one can estimate fuel loading and fire behavior potentials. This method affords more resolution than the preceding one, but its accuracy is unknown and probably somewhat limited. The method is appropriate where the most accurate other method available is not needed.

3. Computer Analysis Using Program HAZARD. Estimates of head fire spread rate, perimeter growth rate, flame length, crown scorch height, fireline intensity, and other fire characteristics can be obtained using a computer program, HAZARD, that can be accessed through the USDA Forest Service Computer Center at Fort Collins, Colo. Procedures for making the hazard assessment are described in a users' guide published by the U.S. Forest Service Northern Region (Puckett and others 1979).

Operation of the HAZARD program requires estimates of downed woody fuels existing before, and debris expected from a cutting. If necessary, existing fuels can be inventoried using the planar intersect method (Brown 1974b). Expected quantities of debris can be estimated using tables developed by Brown and others (1977) for some western U.S. Forest Service Regions, using a computer program called DEBMOD. This program furnishes predictions of debris from timber stand inventories.

Of all current methods, HAZARD provides maximum resolution and accuracy. It permits assessment of slash problems before they are created and is flexible enough to apply to a variety of harvesting systems through an adjustment of fuel inputs.

HOW MUCH FUEL IS ACCEPTABLE

Fire managers commonly want to know the tonnages of fuel that are acceptable. This question is difficult to answer because fire behavior depends not only on fire potential at one location but also on other factors, such as distribution of fuels and fire behavior potential over surrounding areas that may cover one or more drainages. Acceptable fuel loading depends on resource values, management objectives, pattern of land ownership, suppression capability, and multi-resource considerations. Professional judgment is certainly needed to determine acceptable fuel tonnages.

Decision Steps

Deciding how much fuel is acceptable requires one to integrate many factors (fig. 5). This can be done systematically as follows:

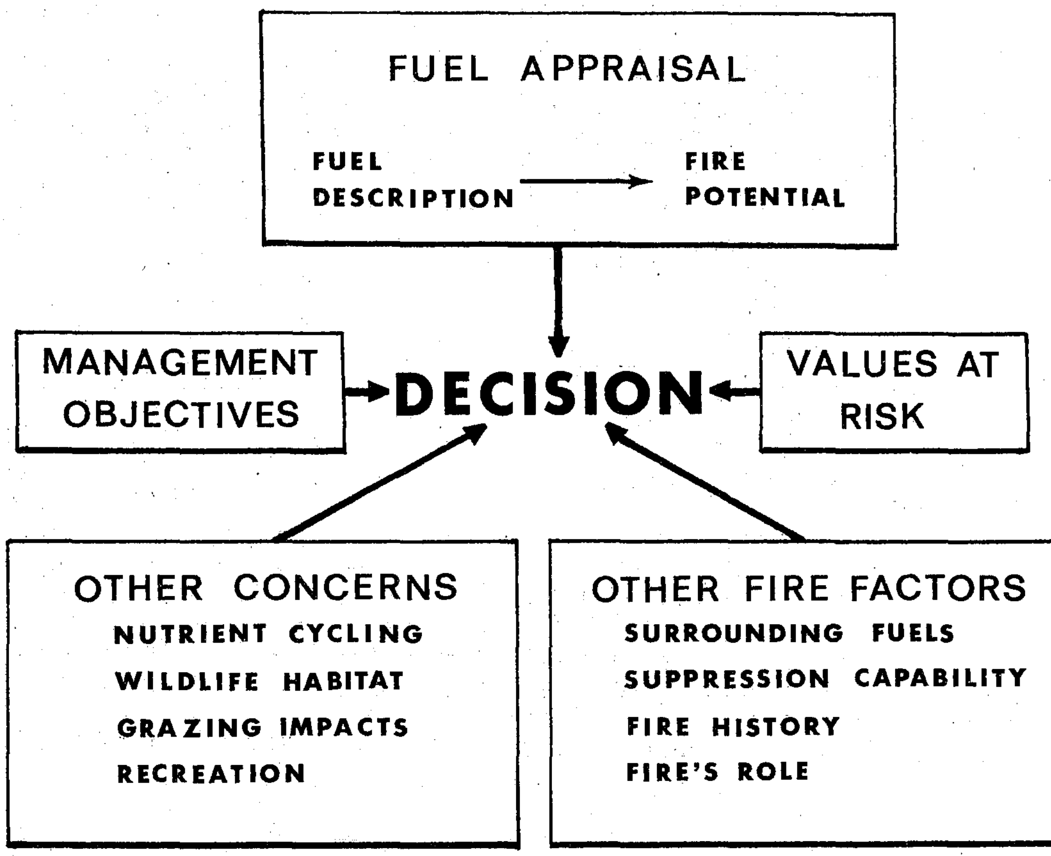

Figure 5. -- Factors to consider when deciding how much fuel is acceptable.

1. Consider management objectives and values at risk. For the latter, one considers both resource values and the risk of a fire causing damage during a high fire-danger period.

2. Appraise fuels by (a) describing fuels from inventory and prediction and (b) interpreting fire behavior potentials such as rate of spread, flame length, intensity, and scorch height.

3. Consider other fire-related factors such as fuel and fire behavior potential on adjoining areas, suppression capability, frequency and severity of historical fires, and fire's ecological role. Acceptable fuel loadings can depend to a high degree on these factors. For example, a heavier fuel loading would be acceptable on a unit surrounded by sparse fuels with little chance of ignition than on a unit surrounded by heavy fuels with a high chance of ignition.

4. Consider requirements of nonfire factors for attaining land management objectives. For example, some downed woody material is needed as a source of nutrients--particularly nitrogen. Debris fulfills habitat needs for some wildlife. Too much debris adversely affects grazing, wildlife, and recreational opportunities. An optimum quantity of downed woody material certainly exists and will vary by localities. Determining this optimum requires professional judgment integrated over several disciplines. Importantly, debris fuels represent an organic reserve that has a vital role in the functioning of ecosystems. They are more than just a fire problem.

Cost-Benefit Analysis

Cost-benefit analysis of fuel treatment alternatives can help a manager decide how much fuel is acceptable. However, the validity of cost-benefit analysis rests on several weakly quantifiable factors. Specifically, dollar values of some nonfire concerns are difficult to establish. Improvement in protection due to fuel treatment requires considerable speculation. Finally, risk of a fire occurrence is a very low probability event of considerable uncertainty.

Cost-benefit analysis of fuel treatment investments on the Lolo National Forest (Wood 1979) and Clearwater National Forest[3] have shown that:

1. Benefits due to factors other than fire protection can strongly influence the outcome.

2. Fuel treatment may be justified on high-value sites but is difficult to justify on low-value sites.

3. When benefits accrue only to treated areas, fuel modification is difficult to justify. Where possible, fuels must be treated so larger than the area benefited by reduced fire control costs and losses is larger than the area treated. For example, by treating fuels on a strategically located 100 acres, fire control costs and losses may be reduced on a surrounding 500 or more acres.

In conclusion, this study shows that fuel quantity and fire hazard can vary substantially with utilization standards. Often, conventional utilization standards result in unacceptable fuel and fire hazard. However, by implementing a high degree of utilization, acceptable fuels can result. Including an appraisal of fuels in preparation of harvesting prescriptions offers managers a way to deal with fuel problems before they are created.

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[3]Memo from the National Fuel Inventory and Appraisal Systems Project, Rocky Mountain For. and Range Exp. Sta., Fort Collins, Colo. to the Clearwater National Forest.

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