PROCEEDINGS
WEED CONTROL IN FOREST MANAGEMENT

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ENVIRONMENTAL IMPACTS OF WEED CONTROL ALTERNATIVES ON WATER

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The forester defines a weed as a plant out of place and attempts to cc "weeds" to achieve specific timber management objectives. When all is and done, weed control is simply killing one plant to favor another. Bu ing vegetation affects nontimber as well as timber values. Thus, it i propriate to devote some time to nontimber values.

I would begin with Hewlett's (1964) observation that "good res managment and good water management are often the same, right do particulars. . . Human activities on the land always have some influen the water resource. Any continuing activity which damages the resource cannot help in the long run but to damage the total product usefulness, and beauty of the land. Thus we have in water a sensitiv dicator of the long-term success or failure of land management prog and resource conservation." This philosophy suggests that weed control water management ought to be compatible—that weed control met should be selected to meet water quality as well as silviculture objectives. compatibility is not as difficult as you might suppose. The major requis minimizing conflict among objectives is to understand the resource res to treatment.

In this paper I indicate probable effects of weed control activities upo water resource in forests in the eastern United States. Of necessity, the di sion is general and exceptions to the generalities abound and must be gua against. Here I present some general ideas that you may find helpful i ting objectives and in writing your own prescriptions.

The Water Balance

Consider first the hydrologic cycle—the movement of water from th mosphere to the land and oceans and back to the atmosphere. Under na conditions, the amount, rate of movement and quality of water yielded specific catchment or watershed will vary but will tend to return to the general level each year. For a specific land area, this annual cycle can b pressed mathemtically as the water balance:

$$\text{Runoff} = \text{Precipitation} - \text{Evapotranspiration} \pm \text{Storage}$$

Storage is the change in soil and ground water over a particular pe Evapotranspiration is the vapor loss to the atmosphere. Although it is ficult to measure these quantities, it is easy to see that the equation balance.

When vegetation is killed, evapotranspiration is reduced. Because precipitation is not changed, runoff, water storage, or both must change to maintain the balance. The equation does not show exactly how much yield, runoff rate, and quality of the water are changed by killing vegetation. These computations are in the province of the hydrologist.

To assess the impact of weed control, water yielded from an undisturbed forest serves as a convenient reference. Emphasis here will be on water quality or pollution effects of weed control because most adverse effects are of this type. For our purposes, the definition of pollution and a weed are analogous—pollution is a resource out of place. Any change in the physical or chemical properties of water from the undisturbed is a form of pollution.

Pollution can be the indirect result of a chain of environmental reactions, but first let us consider the direct impacts of weed control and put them into perspective.

Direct Impacts

Any foreign material deposited in streams during weed control activities is in this category. Ash from prescribed burning is an example. This form of pollution is seldom serious, because the quantity usually is small and the chemicals are similar to those already present in the stream. The chemicals are nontoxic, and if the burn is small the concentration is quickly diluted as water moves downstream.

Herbicides also can enter streams directly during aerial or ground applications. Normally, herbicide concentrations peak rapidly, and chemicals move out of the treated area as a pulse. Because these chemicals are exotic, they may be toxic, and they have different environmental effects from ash during their tenure in the stream. The amount of chemical that enters the stream during aerial applications is proportional to the area of exposed water surface (rarely more than 3% of the watershed area) and the application rate, if no attempt is made to provide buffer zones for the stream. Actual pollution is usually less and is controllable through choice of chemicals, chemical formulation, method of application, type of equipment used for application, and use of buffer strips. Direct contamination from ground applications is usually insignificant from a practical standpoint and excessive direct contamination usually, but not always, represents a management failure.

A third avenue for direct contamination is deposition of dust, soil, wood, or other foreign matter into streams during hand or mechanical control methods. Contamination by dust is insignificant; contamination from other foreign matter is illegal in some states and is an indication of sloppy workmanship and supervision. Deposition of material in flowing streams can also cause indirect and long-term changes if it causes instability of stream channels.

To summarize, direct pollution of streams varies with the weed control treatment used. With fire, little can be done to minimize the deposition of ash in streams, but the effects are minimal. Even with little or no precaution against direct exposure of water surfaces, pollution from herbicides applied aerially will normally be less than 3% of the applied chemical. Perhaps most important, direct contamination of water by all methods of weed cor controllable by management.

Indirect Impacts

Indirect impacts on water occur when weed control sets off a chain vironmental events which affect the hydrologic cycle. When vegetation is (or reduced in density), microclimate and soil relationships change, a change influences water.

When vegetation is killed, transpiration, which is the largest compor evapotranspiration, decreases approximately in proportion to the red in density of the canopy. Likewise, interception of rain is reduced, anc 10% more water reaches the forest floor or soil. Because shading is re more energy reaches the forest floor (Figure 1), and wind moveme creases near the ground. These microclimate changes increase evapc from soil and litter but not enough to offset the reduction in transp (Figure 2). The effects are a reduction in evapotranspiration proporti the reduction in vegetation density, and an eventual increase in strea (Figure 3, Douglass and Swank 1975). The timing of microclimate varies from almost immediate, if vegetation is felled or sheared, to del death of vegetation is gradual, as when hericides and (or) girdling ar The streamflow response (rate and total flow) lags behind evapotransp

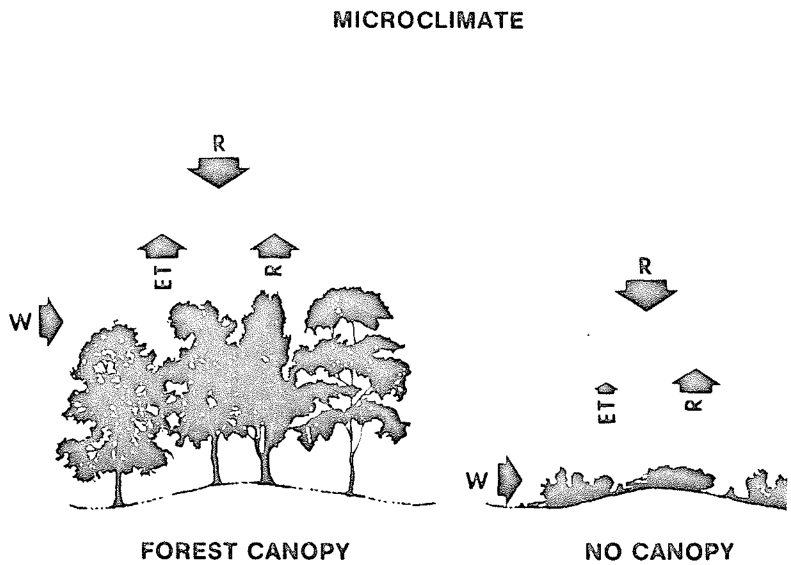

Figure 1. Killing vegetation changes the microclimate. Less incoming radiation is us more radiation is used for heating the ground; and back radiation and wind moven the ground both increase. Arrow size is relative.

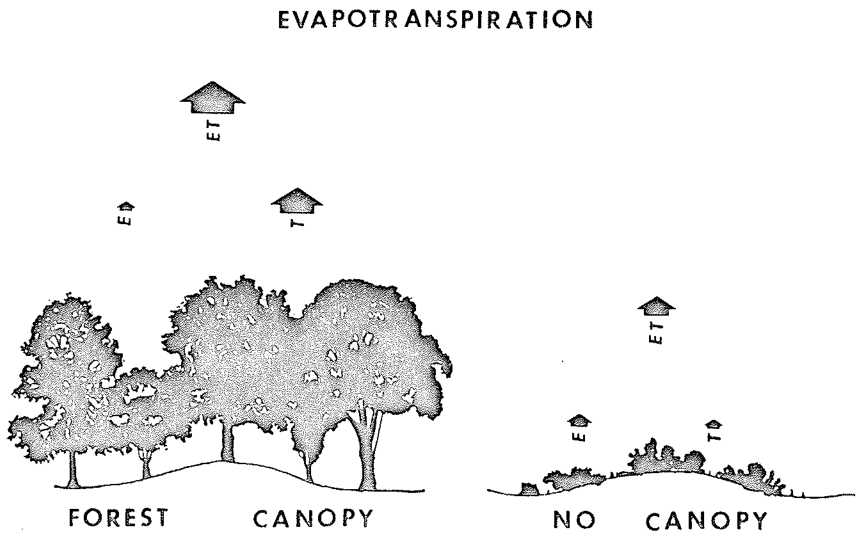

Figure 2. Killing vegetation reduces evapotranspiration and changes the proportions of vapor lost as evaporation and transpiration. Arrow size indicates relative importance.

changes. Changes in water quality can be either almost immediate or delayed, depending upon climatic patterns and other factors.

Soil conductivity, which is the rate of flow of water through soil, is proportional to moisture content. When evapotranspiration is reduced, soil moisture content rises, and moisture flow through the soil increases. The water balance equation indicates that streamflow, storage, or both must increase when evapotranspiration decreases. When the storage capacity of the surface soil is filled, water from storms flows over the surface as well as through the soil. And as water yield increases, the opportunity for transport of dissolved chemicals and suspended soil and other solids increases.

All areas in a watershed do not yield water equally (Hewlett and Nutter 1970). Water comes mostly from an expanding and shrinking source area (Figure 4), which is nearest the channel network. This variable source area comprises from 1% of the watershed area when soils are dry to as much as 50% when soils are very wet. Because this area transmits water through the soil and on occasion over the surface very quickly, it is the most responsive area on the watershed. It is also the most sensitive to management practices, and it is good policy to tread lightly in this area. Ridges and upper slopes, by comparison, are drier. Thus, water movement through soil is slower, and it must travel a greater distance. The likelihood of transport of pollutants to streams decreases as distance from stream increases. These concepts underlie the rationale of streamside management zones and buffer strips.

In their undisturbed state, forest soils ordinarily absorb water 10 to 20 times faster than rain falls, and water is delivered to streams through soils. However compaction, puddling, and sealing of the soil surface during

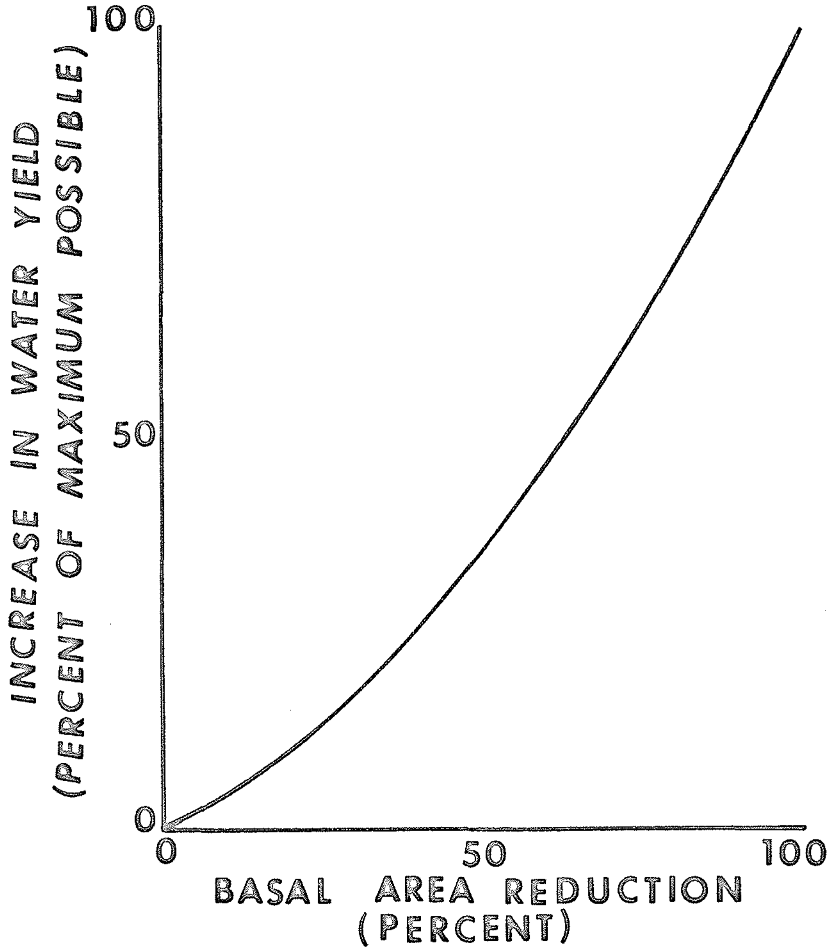

Figure 3. In the East, the amount of extra water yielded after vegetation is killed deper primarily upon how much of the total basal area is killed.

management can reduce infiltration and increase the proportion of wat delivered overland to streams. The pollutants available for transportatic vary greatly depending upon whether surplus water is transmitted over through soil; thus water quality is affected by the pathways water follow The rate of water flow is slow through soils and rapid over them.

Removal of litter exposes mineral soil to the enormous kinetic energy raindrops; often their energy is one thousand times that of the equivale volume of water flowing across the land. Raindrops usually detach the sc particles that overland flow transports to streams. But flowing water al possesses great energy. If water is carrying particles the size of a dime and i

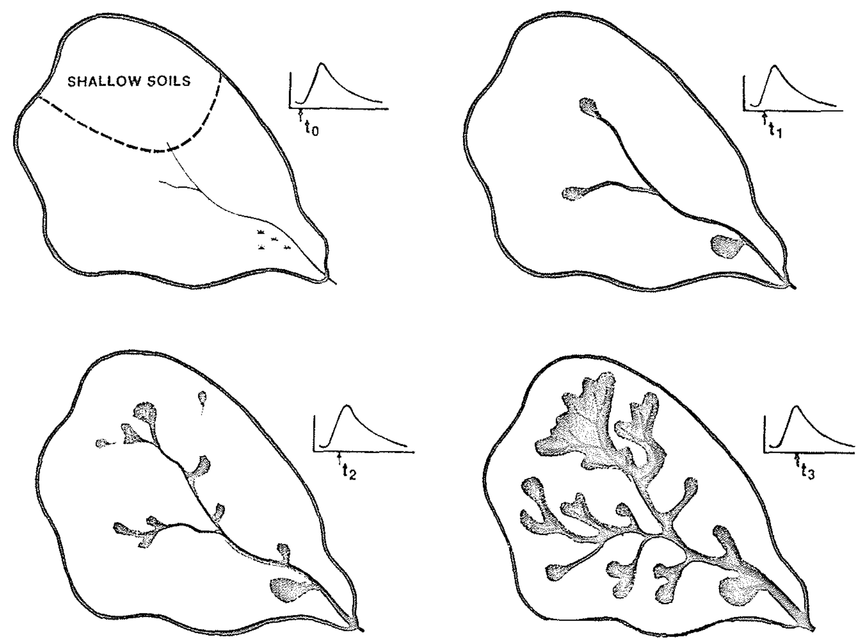

Figure 4. The area of a watershed which contributes water to the stream during storms varies with the wetness of the watershed. It may be as little as 1% or over 50%, depending upon moisture conditions and size of the storm (after Hewlett and Nutter 1970).

velocity doubles, it can carry 4-foot boulders, given adequate water depth and volume. Doubling its velocity increases the weight water can carry 32 times. As runoff concentrates in rills and gullies, both water depth and velocity of flow increase. Clearly, practices which bare soil, increase overland flow, or increase flow velocity cannot help but increase soil erosion and water pollution. Conversely, a resistance to flow, such as litter and other organic debris, or a reduction in land gradient reduces velocity, and deposition of excess sediment will occur.

Wischmeire and Smith (1965) expressed erosion from agricultural fields as a function of raindrop energy, soil erodibility, topographic variables, and vegetative cover and management. The same general relationship among factors exists for forest land, and the functional relationship is diagrammed in Figure 5. Bare ground is the most important variable in determining erosion. In the East, 2 inches of litter can mean the difference between no erosion and 200 or more tons/acre annually. After bare ground, slope is the next most important variable in determining erosion.

With weed control as well as with all other silvicultural practices, nothing is more important for preventing erosion and protecting water quality than maintaining soil characteristics which encourage rapid infiltration and maintaining an energy absorbing litter covering over the soil.

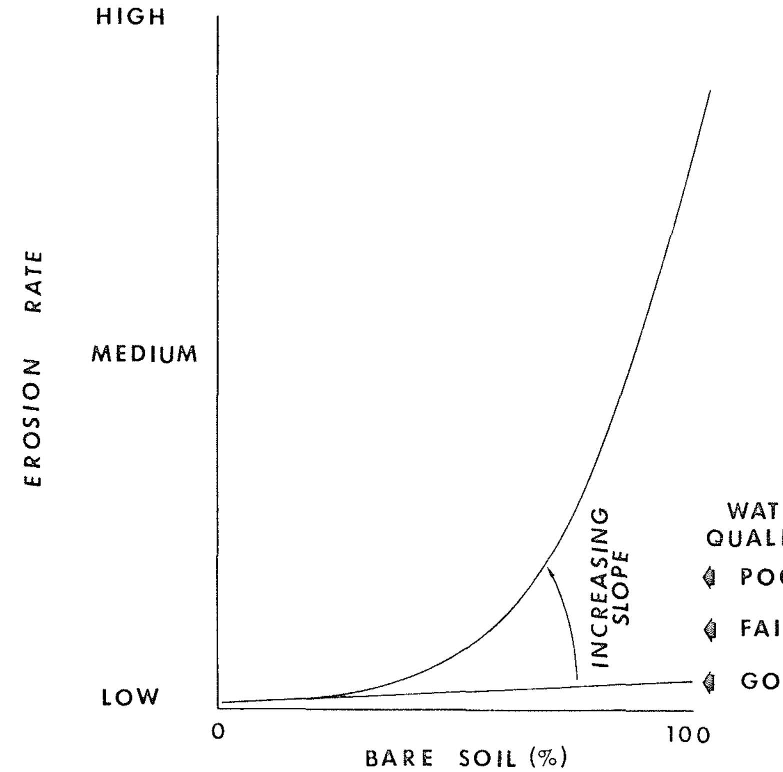

Figure 5. Bare soil is the main factor determining erosion. Land slope is only sligh important, and it only takes a small change in erosion to ruin water quality.

Although sediment is the predominant pollutant in managed systems, other pollutants exist. Treatments that modify the microcl (temperature, light, moisture, etc.) at the soil surface also alter biol and physical processes such as litter decomposition, nitrification, denit tion, soil acidity, and ion exchange. Not all of these processes ar understood, but their effects on stream chemistry have shown up as ch in the concentration and export of certain nutrients after vegetation is For the most part, these changes have been small and of minor conc pollutants. Conceivably, some changes may improve water quality ar aquatic environment.

Herbicide pollution is another matter. Because these chemicals are to the forest system, and can and often do reach water sources as a poll they are of greater concern than soil or "natural" chemicals. The imp point to be remembered is that concentration in water depends upor hydrologic considerations as well as properties of the herbicide. A moc ists which allows maximum "edge-of-field" concentrations to be predic the properties of the herbicide, formulation, and rate and place of ap tion (foliage, soil surfaces, or incorporated in soil) are known (Wauchope 1978). Although the model was developed for agricultural purposes, factors which are important for agriculture are also important in forestry. While more sophisticated models are available, this one is simple enough to be practical for the manager. Still, judgment is required to extrapolate results to the forest situation because availability of the chemical for transport and route by which the chemical moves to water can be considerably different from agricultural conditions. In practice, concentrations in forest streams should be less than those predicted for agricultural situations.

To summarize, because weed control reduces evapotranspiration, it causes more water to go into ground water storage or streams, thereby increasing total water yield. The changes in hydrologic conditions favor more rapid movement of water from rains. The water carries its normal complement of chemicals but in greater or lesser quantities because of changes in availability of nutrients from fire, the natural cycling of minerals or chemicals applied. Water will carry a far greater load of sediment if the soil and litter are disturbed sufficiently to cause overland flows.

Rating Practices for Impacts

The same practice applied on two different sites can produce grossly different responses. In many cases, it is not *what* is done but *how* and *where* it is done that matters. Despite these uncertainties, I have tried to rank weed control alternatives from least to most impact on water quality.

Manual methods of felling or girdling weed species have the least impact on the environment (Figure 6). Water yield increases in proportion to the

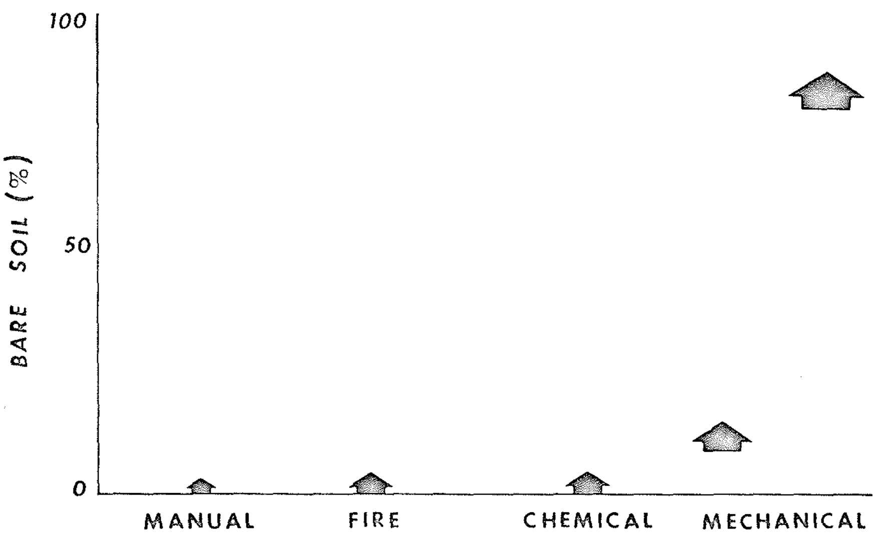

Figure 6. The relative impact of weed control on soil disturbance varies from slight, for manual, fire, and herbicides, to significant for mechanical methods.

amount of vegetation killed; water moves through the system some faster; and only minor changes in water quality, perhaps not even detect can be expected. Disturbance will be so slight that erosion will be negli although very small increases in sediment load should be expected creases in the rate and volume of flow occur. Manual methods are comp with even the most stringent water quality objectives.

Burning can be used alone or in combination with other weed contr tivities. In the South Carolina Piedmont (Douglass and Van Lear, In p two prescribed burnings on four pine-covered watersheds before harves natural regeneration did not significantly affect water yield, erosion, or quality during storm runoff. Litter was not completely consumed b burning and continued to provide protection against erosion. Likewise, ressive burning of 20% of a South Carolina Coastal Plains catchmen nually for 4 years (one-half chain buffer strip around stream) di measurably affect water quality from perennially flowing streams (Ra personal communication). In general, fire used alone in weed control is patible with water management objectives. Exceptions may exist wher causes unwettable soil conditions and leads to accelerated erosion.

Fire in conjunction with other methods such as shearing, windrowing chopping can affect water quality. In the North Carolina Piedmont, er was considerably higher where organic debris was sheared, piled in g and burned than where slash was piled and burned on the contour (Do and Goodwin, In press). Here, the effect was not due so much to *wha* done but to *where* it was done. But even burning slash in windrows o contour can cause problems by exposing mineral soil to raindrop erosi soils become nonwettable after hot fires, burning should be avoided. T fects on erosion and water quality of using fire in combination with treatments will be cumulative.

As with burning, herbicides can be used alone or in conjunction with treatments. Because herbicides do not destroy litter cover or change ph properties of soil appreciably, erosion and surface runoff problem minimal. Water supplies can be polluted by deposition of chemicals di in water during application of chemicals, and indirectly if chemicals ar ried to streams by ground water or overland flow. When flooding is problem and all rain infiltrates, chemical toxicity, solubility, presistanc sorption by soil, and the method and rate of application need to be sidered in estimating possible pollution of streams. As toxicity incr availability for transport either overland or through soil assumes great portance. When herbicides are used according to manufacturer's recom dations, use of chemicals will generally be consistent with water q management.

From the standpoint of water quality, the choice between prescribe and herbicides is very close. Neither method of weed control, proper plied, causes large changes in water quality. Prescribed fire generally very small, if any, change in chemical composition of water in the East the changes may not be adverse. Small quantities of some herbicides enter streams, even when the manufacturers recommedations are foll

This does not imply that the use of these herbicides is necessarily bad: it simply means that a small amount of chemical pollution occurs. Thus, selection of fire or chemicals can often be made based on considerations other than water quality.

Mechanical methods have greatest impact on water quality because they change the hydrologic properties of soil and litter. Relative effects of alternative methods can be estimated by simply observing the impact of the methods on soil and litter. As depicted in Figure 5, erosion loss and decline in water quality both increase as exposure of bare ground increases. Roller chopping appears to be the least disturbing of the mechanical practices, with reported exposure of mineral soil ranging from about 1% to 2% of the area in Georgia (Hewlett, personal communication) to 37% in Mississippi where chopping was followed by broadcast burning (Beasley 1979). The combination of chopping and burning exposed enough more soil to increase the probability of water pollution. Shearing, windrowing and burning, and disking exposed as much as 90% of Piedmont watersheds in North Carolina (Douglass and Goodwin, In press), and such practices are definitely of concern because of erosion and water pollution. Combinations of mechanical treatments plus burning tend to be cumulative. Piling brush in gullies and burning is particularly unwise because fire kills vegetation which would otherwise resist erosion. The inevitable result is accelerated erosion and flushing of the ashed nutrient reserve and loose soil to the stream. Conversely, piling slash in old gullies without burning protects and enriches these problem areas.

In closing, we should remember that weed control is only one practice during the harvest and regeneration period. One practice follows closely on the heels of another. Hewlett (personal communication) points out that although roller chopping disturbed only 1% to 2% mineral soil in the Georgia study, soil exposure shortly after machine planting was nearly 40%. But, total sediment yield from all silvicultural operations (clearcutting, roller chopping, and mechanical planting) was only 17% of total sediment export. Roads and channel damage accounted for 83% of sediment yield, and most of this came from a small portion of the road. This is clear evidence that what is done, where it is done, and how it is done are all important and that the entire operation should be considered in assessing the impact on water.

Summary

All weed control methods increase water yield and the speed with which water leaves the watershed, but their effects on water quality can be grossly different. Manual, fire, and chemical methods have the least effect on water quality when they are properly applied. Conversely, even the best of the mechanical methods increases erosion and thereby reduces water quality. The effect may be negligible where land is nearly flat or severe where slopes are steep. Thus careful planning and quality workmanship are particularly crucial when mechanical methods are used.

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