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GEORGE W. BROWN
Forest Hydrologist, School of Forestry, Oregon State University

Summary

Oregon's forests appear as a highly diverse set of complex ecosystems in which soil, climate, topography, and the trees themselves interact to create the forests we see. Man and his timber harvest activities add to this diversity and complexity. Generalizations about the impact of timber harvest are difficult to make without specifying the characteristics of the natural system and the forest practice. Clearcutting as a forest practice, for example, is neither uniformly good nor bad for soil and water resources, but must be evaluated site by site.

Soil is the most basic forest resource. It provides the medium for plant growth and is a reservoir for water. *Surface erosion* is the result of exposing mineral soil to rain or severely disturbing or compacting surface soil. Infiltration rates must be reduced substantially to induce surface runoff. Forest fires or severe slash burning, poorly drained or constructed roads, and ground skidding on wet soils may produce such conditions. The hi-lead method of yarding, most common to the Northwest, does not increase substantially the amount of surface erosion. *Mass soil movement* is a catastrophic form of natural erosion and can be produced by road construction in unstable, steep topography. Poor road location, design, and construction may trigger large landslides that damage streams and structures. This is the most important erosion process in western Oregon, yet we know very little about the processes, how to predict their occurrance, or how to control them.

Timber harvest operations can affect both streamflow and water quality. Trees use great quantities of water for transpiration. When a forest is harvested, water normally transpired is available for streamflow. Large increases in the annual flow and summer flows have been observed after clearcutting. Normal timber harvest operations may increase peak flows from small fall and spring storms, but not the large mid-winter events. This is because soils are saturated in both forested and non-forested areas by mid-winter. In either

case, any additional precipitation that falls is readily available for stream flow.

Sediment, temperature, and dissolved oxygen are water quality characteristics that may be affected by timber harvest, again depending upon the type of forest system and the way in which the harvest operation is conducted. Controlling sediment requires controlling the erosion from surface soils or mass soil movement. Controlling temperature changes may be accomplished by leaving shade along streams. Maintaining aceptable levels of dissolved oxygen in streams is keyed to minimizing temperature changes and debris accumulation in the channel.

Controlling impacts of timber harvest on soil and water resources is a difficult task, one that requires a high degree of skill. The forester must understand not only the natural system he manages, but how his activities interact with this system. Diversity usually precludes easy solutions. The solution to these complex problems rests with land managers and the skill, time, and money they are able to apply.

Introduction

Oregon's forests present us with a complex pattern of species and ages, sizes, and densities. The diversity we see is the result of a complicated interaction between climate, soil, geology, topography, and the trees themselves. All parts of this soil-plant-atmosphere system are linked together. Changing one part may thus cause the other portions to change or adjust.

Superimposed upon this natural system is the activity of man. We add yet another dimension to the complexity of nature. Our activity in the forest takes many forms: harvesting timber, building roads, disposing of slash. The impact of each activity varies since each is carried out with varying degrees of intensity and skill, depending upon the situation and people involved.

Because of this complexity, this diversity, and this interaction, generalizations about man's impact upon the forest and its soil and water resources are difficult and dangerous to make. Difficult, because it is usually possible to find as many instances where the generality does not apply as where it does. Dangerous, because such generalizations may delude us into accepting one solution or one prescription for all of the complicated problems of land management.

This report discusses some general kinds of soil and water problems associated with timber harvest. Remember that the problem and the solution are functions of both the natural system *and* man's activity in it.

Timber Harvesting and Soil

In our complex forest systems, soil is the most basic resource. It provides the medium for plant growth and a reservoir for water. Many of the forest soils in Oregon are highly productive, and are also an ideal medium for storing and transmitting water. Erosion of soil material may therefore influence both the productivity of the site and the way water moves through the forest system. We find two types of erosion processes active in our forest lands: surface erosion and mass soil movement. Both may be accelerated by man.

Surface erosion

Surface erosion is the result of water running across the soil surface. In the highly porous soils of Oregon's forest land, this form of erosion is not common unless the soil surface is severely disturbed or unless the soil "reservoir" is filled to capacity. Rills, small channels, or gullies are evidence of this type of erosion.

Man's influence on this process can come from several sources. Exposing large amounts of mineral soil to the impact of rain or compacting surface soil with machinery are the most common. Research has shown that very hot wildfires or slash fires may increase erosion and cause high sediment concentrations in streams (Brown and Krygier, 1971; Fredriksen, 1970). The magnitude of the erosion is influenced by the intensity of the fire and the properties of the surface soil. Light slash fires which do not consume all of the duff and litter may have little impact on erosion.

Compaction of soils on skid trails or yarding roads may start channel formation if water flow over these compacted areas is uncontrolled. The degree of compaction depends upon the type of equipment and the soil type and its wetness. The amount of area disturbed varies with the yarding plan, the type of equipment used, and steepness of slope.

Surface erosion can also occur from the surface of roads that are poorly drained, or from cut banks and fills that are poorly stabilized.

Earlier we noted the difficulty of generalizing about the impact of forest practices on soil and water without specifying the site conditions, the type of practice, and the way in which the practice is applied. We have found that many timber harvest operations cause little or no surface erosion. One of our study watersheds in the Oregon Coast Range was completely clearcut using a conventional hi-lead system. The watershed was not burned. We detected no increase in sediment in the stream draining the area (Brown and Krygier, 1971). In another study, Fredriksen (1970)

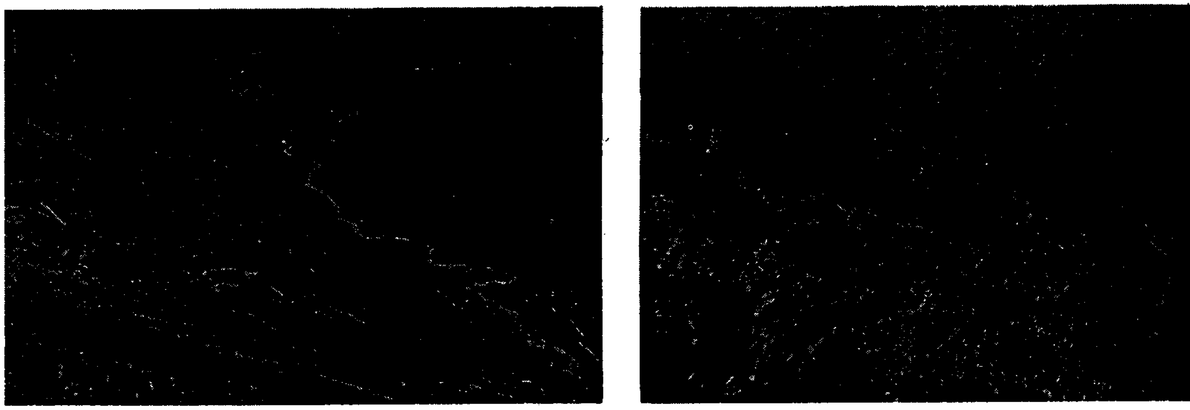


Figure 1. An experimental watershed a) immediately after logging and burning b) five years later. Rapid revegetation of logged or burned watersheds quickly reduces erosion of surface soil and limits nutrient losses.

noted no increase in sediment concentration in a stream after clear-cutting the watershed with a Wyssen sky-line system, even during the high-flow period of the 1964-65 floods.

Mass Soil Movement

The second form of erosion on our forest lands is mass soil movement. These events are often catastrophic in nature and may damage stream channels and structures alike. Much of the terrain on which forests grow in Oregon is steep and naturally unstable. In such terrain, mass soil movement often occurs in areas undisturbed by man.

Road construction in the steep, often unstable terrain of Oregon's mountains is both difficult and hazardous. It is also costly, both in terms of direct construction and damage to the aquatic environment. We know that in Oregon, forest roads are our greatest source of problems with mass soil movement (Brown and Krygier, 1971; Fredriksen, 1970; Dyrness, 1967). Yet we do not understand the processes well enough to be able to predict with reasonable certainty where road failures will occur or how alternative road designs will affect mass movements except in the most obvious places.

A few examples from studies conducted in Oregon provide some indication of the size of these mass movement events and their impact on sediment yields. Fredriksen (1965, 1970) noted that landslides from midslope roads constructed across a patch-cut watershed in the Cascades produced concentrations of sediment 34 times greater than expected from observations during the pre-treatment period. Mean annual sediment yield, including bed load, was 8,000 tons/mi^2-yr over a nine-year period, 109 times the loss from an adjacent undisturbed watershed.

In the Coast Range, we found that even on a well-constructed, mid-slope road, landslides could be a problem. Two small slides occurred during one storm and contributed an estimated 349 tons of material, or 40 percent of the annual sediment yield, to the stream (Brown and Krygier, 1971).

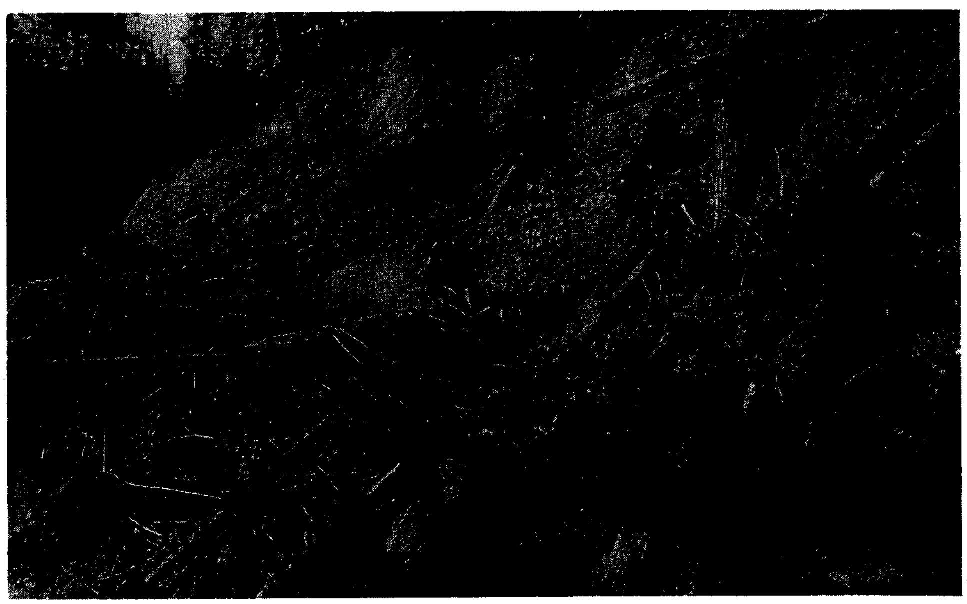
The impact of mass soil movement goes far beyond increasing sediment loads or turbidities. When large volumes of sediment enter a small stream, one of two profound changes may occur. If the landslide event is of sufficient mass in a channel sufficiently steep, serious channel degradation can occur. The stream bed may be scoured to the bed-rock base, temporarily eliminating productive aquatic communities. Channel banks may also be seriously scoured, setting the stage for future instability and erosion.

We often forget that the erosion process terminates in deposition of eroded material. Reservoirs, lakes, and estuaries receive much of the material eroded from headwaters areas. Studies of bed movement at Oregon State University (Klingeman, 1970) suggest that the porous gravels of our forest streams are also a "reservoir" for fine sediments. This material can interfere with spawning success for salmon and steelhead (Hall and Lantz, 1969).

Soil Nutrients

Timber harvest may also change the nutrient balance in forest soils. This is a subject of particular concern since it deals with the

Figure 2. Forest roads are our biggest source of sediment. Mass wasting triggered by this road added large volumes of sediment to the stream below. (*US Forest Service photo*)



productivity of forest lands and the streams draining these watersheds. Nutrients accumulate in forest soils from weathering or decomposition of rocks and minerals and from the atmosphere. Nutrients from the atmosphere are either delivered by precipitation or accumulate in the forest soil through the activity of soil microorganisms. Once nutrients enter the forest ecosystem they are either cycled between the soil and vegetation, or enter streams in water which drains from the soil, or are carried out attached to sediment. Here again, it is easy to see that the impact of timber harvest on nutrient loss from a forest is dependent upon a wide range of factors—geology, soil, climate, vegetation density after cutting, rate of revegetation, and erosion produced by the logging operation. This interaction and the variation in nutrient loss from different forest systems is well illustrated by two studies, one in New Hampshire and the other in Oregon.

The first study of the effects of large-scale forest cutting and complete vegetative destruction on nutrient release was completed at the Hubbard Brook Experimental Forest in New Hampshire (Likens, *et al.*, 1970). This forest is a mixed northern hardwood forest growing on very porous sandy soils called podzols. After a period of calibration, all standing vegetation on a small forested watershed was cut and left in place. Vegetation regrowth was prevented for two years by herbicide application. Changes in streamflow and water quality were monitored. The most interesting changes observed were those in the nutrient content of this water.

Nitrate concentrations in stream water from the treated watershed were 41 times higher than the undisturbed watershed the first year after cutting and 56 times higher the second year. Nitrate concentration was always above the 40 ppm limit recommended for drinking water by the Public Health Service and ranged as high as 85 ppm during the second year of complete vegetation destruction. The concentration of other elements in the stream water increased as follows: calcium by 41.7 percent, magnesium by 40.8 percent, and potassium by 1,558 percent. These changes represent a net loss of nutrients equal to about 150 lb/ac of nitrogen, 100 lb/ac of calcium, and 40 lb/ac of nitrogen, 100 lb/ac of calcium, and 40 lb/ac of potassium. These initial losses associated with complete vegetation destruction have led a few people to speculate that all forest harvest leads to rapid sterilization of forest soil. It is interesting to note that the losses quickly diminished when the area was allowed to revegetate. Nitrate concentrations dropped from the peak of 85 ppm to only 2.8 ppm by the second summer after herbicide application ceased (U. S. Dept. of Agric., Forest Service, 1971). Nutrient losses from these soils following normal logging (without herbicide applications) are also high and persist at least two years after cutting (Pierce, *et al.*, 1972).

What is our experience with more normal logging practices where trees were removed and revegetation allowed to proceed on soils typical of western Oregon? Fredriksen (1971) followed the nutrient release after clearcut logging of an old-growth Douglas-fir forest in Oregon's Cascade Range. Soils range from shallow and stony to moderately deep and well developed. The three most prominent soils average about 48 inches in depth and vary in texture from loam to clay loam (Rothacher, *et al.*, 1967). Thus, the nutrient release pattern on these soils provides a good contrast to that from the shallow, sandy soils in New Hampshire.

Following timber harvest and slash burning, nutrient loss increased 1.6-3.0 times that observed on an adjacent undisturbed watershed for a two-year period. Ammonia and manganese release increased markedly after burning, exceeding Federal water quality standards for a period of 12 days.

Nitrogen loss was observed after treatment in the Oregon study, similar to the pattern reported in New Hampshire (Likens, *et al.*, 1970), but at a considerably reduced level. Fredriksen (1971) reports that ". . . annual loss following burning averaged 4.6 lbs./acre; 53 percent of this was organic nitrogen contained in sediment. Inorganic nitrogen, dissolved in the stream, made up the remaining part. Annual loss of nitrogen from the undisturbed forest was very small —0.14 pounds per acre."

Nitrate concentrations were also much smaller. Concentrations increased the second year after logging and burning to about 0.4 ppm, far less than the 85 ppm observed in New Hampshire. The following year peak nitrate concentrations returned to about 0.05 ppm.

The study in the Oregon Cascades, and others like it, have shown that where erosion is minimal, soils are moderately heavy, and vegetation is allowed to begin again the process of nutrient uptake, very little nutrient loss is observed from managed watersheds.

Erosion, fire, reduced infiltration rates from compaction, and site revegetation are all processes over which foresters have some control and a great deal of concern. Recognizing that nutrient loss is keyed to minimizing soil loss and quickly revegetating the forest site will help foresters and forest engineers plan logging operations accordingly. In some areas, doing a careful job using normal logging techniques and reforestation methods may be sufficient to minimize soil disturbance while removing only a portion of the forest stand to insure uninterrupted cycling. On the other hand, skyline systems, or even helicopters, may be necessary in difficult situations if forests are to be logged and successfully regenerated with little or no nutrient loss. Better utilization of logging residue, improved fire detection and control systems, and refined techniques for planting in slash-covered areas will eliminate that portion of the nutrient flush associated with burning. Thus, by using a wide range of tools currently available, nutrient flow may be regulated in both the terrestrial and aquatic portions of the forest ecosystem.

Timber Harvesting and Water

Two questions are generally asked regarding the impact of timber harvesting on water. The first deals with the way logging influences the volume of stream flow and the timing of the yield. How much water can we gain by eliminating transpiration by trees and how is this increase reflected in stream flow during storms and seasonally?

The second question asked is "How does logging affect the quality of water in our streams?" In the well-watered western portion of our state this question holds greater public interest.

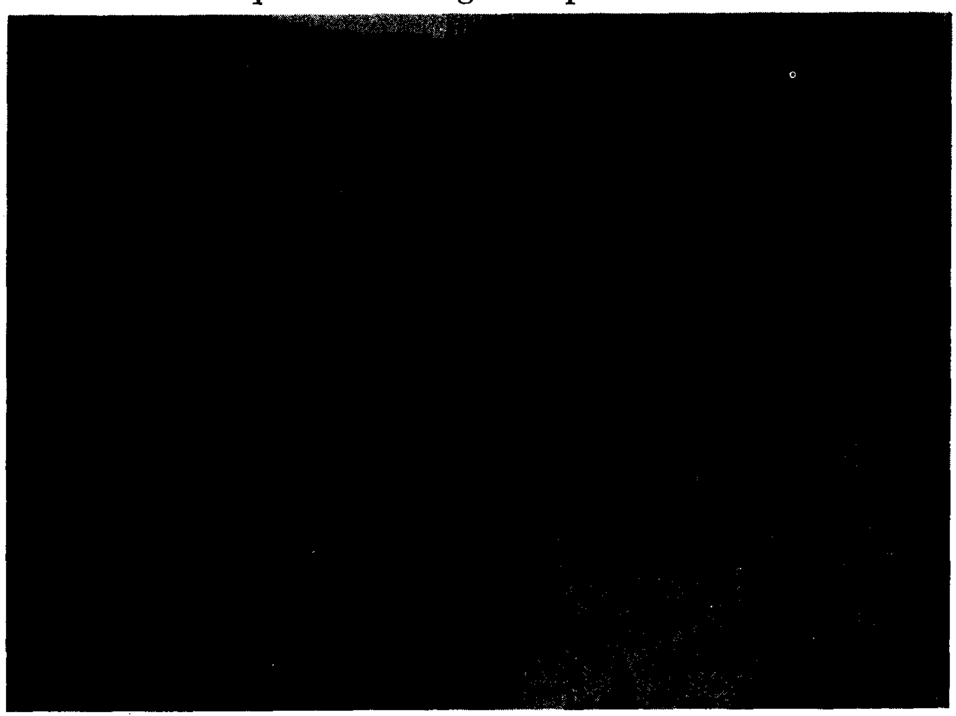


Figure 3. Clearcutting this watershed increased streamflow by 35-40 percent. The watershed was logged with a special system called a Wyssen sky-line, which minimizes soil disturbance. As a result, the increase in water yield was obtained with no loss in quality. (*US Forest Service photo*)

Water Yield and Peak Discharge

Forest soils serve as a reservoir for water. This soil moisture reservoir is the source of water that trees utilize for their life processes. Eventually, much of the water stored in the soil returns directly to the atmosphere as the trees transpire. Trees also intercept precipitation on branches and leaves. Much of this intercepted water never reaches the soil reservoir, but is evaporated. All of the water intercepted or transpired by trees is unavailable for streamflow. How, then, do streams respond if these avenues of water loss are eliminated by tree removal?

Several studies throughout the United States have shown that streamflow can be increased by logging (Hibbert, 1967). In Oregon, Rothacher (1970) has noted an annual increase in streamflow of over 35 percent after clearcutting an old-growth Douglas-fir forest. The seasonal change during the summer months when transpiration is greatest is even larger. Minimum streamflows were doubled after clearcutting. Large increases in summer flow after clearcutting were also observed by Harr and Krygier (1972). As less of a watershed is cut, as by partial or patch-cut logging, smaller increases in streamflow would be realized. Rothacher speculates that removal of 20 percent or less of the forest cover would result in no detectable change in streamflow. Any increase in soil moisture would be quickly utilized by the remaining trees.

Rothacher (1971) also studied the impact of clearcutting on flood flows or peak discharge. He noted that where "normal" clearcutting procedures were used (cable logging) and compaction of surface soils did not occur, logging did not increase major floods in the western Cascades. The small floods or peak flows that occur in the fall were increased, however.

These observations can be explained if we understand the amount of moisture stored in the soil prior to the storm. In the fall, a clearcut area has higher soil moisture levels, and a lower capacity to store incoming precipitation. There has been no transpiration drain caused by the trees. The forested area has been using water during the summer months and the soil moisture reservoir is depleted. Thus, more of the rain falling on the clearcut area reaches the stream. Much of the rain falling on the forested area goes to refilling the soil moisture reservoir and does not show up in the stream.

The major storms, such as the 1964-65 storms or the recent January 1972 storms, are so large that in both clearcut and uncut areas, soils are filled to capacity. Additional precipitation quickly finds its way into the stream. The floods resulting from these storms seem to be caused by excessive amounts of precipitation, and not the vegetative cover or lack of it. (Rothacher, 1971).

Water Quality

Water quality must be described with respect to the use intended for the stream or river. In Oregon, the reference for water quality in most small forest streams is usually its productivity for fish except where this water is used for domestic purposes. Three key characteristics of the water are usually used to judge the impact of logging activity on water quality and fish production: sediment, temperature, and dissolved oxygen.

Sediment

The source of most of the sediment in streams is erosion from the land surfaces of the watershed above and the banks and bed of the stream. We have discussed the erosion process and how logging affects erosion in the section on soil. Let's look now at the impact of this eroded material once it enters the stream.

The transport and deposition of sediment in streams and its impact upon aquatic organisms are complex processes. Natural variation in sediment levels are often so extreme that man's activity can be detected only if the changes are very large.

The impact of sediment on the aquatic system is dependant upon a wide range of biologic and physical factors. One significant impact, however, is related to the deposition of sediment in spawning gravel. It has been shown in laboratory studies that fine sediments clog the pores of the gravel bed in streams and reduce the survival of coho salmon and steelhead fry (Hall and Lantz, 1969). In nature, eggs of these species are deposited in the gravel during spawning. The gravel acts as a hatchery and temporary rearing site for the young fish. When the large pores in the gravel become clogged with fine sediment, the young fry cannot escape from the gravel into the stream above.

It is important to understand that fine sediment in stream gravel may continue to influence fish production long after surface waters become clear. It may take several years before these fine sediments are flushed from the gravel.

Water temperature

Water temperature is a water-quality characteristic that has received a great deal of attention in the Pacific Northwest. River temperatures changed by thermonuclear power plants, impoundments, or large irrigation projects have caused several problems for fisheries managers. Temperature is a significant regulator of water quality on small streams as well. The first year in the life cycle of many anadromous fish species is spent in the small headwaters stream. Pathogens, dissolved oxygen, competition from other species, and direct mortality are all influenced by temperature.

In a small, shaded stream, the temperature change induced by logging is directly proportional to the amount of exposure given the stream surface and indirectly proportional to the discharge. Many small streams drop below 1.0 cfs during the dry summer months. Logging that completely exposes such streams to sunlight causes large changes in water temperature, because direct sunlight provides the major source of energy for heating exposed streams.

Levno and Rothacher (1967) reported the effect of logging in two watersheds of the Oregon Cascade Mountains. The stream channel of one watershed was scoured by a flood, which removed most of the riparian vegetation. The stream was exposed to sunlight as it flowed through a small clearcutting. Mean monthly maximum temperatures increased by 7°-12° F during midsummer. A second watershed was completely clearcut. Logging debris accumulated in the stream channel, however, and provided some shade to the stream. In this stream, mean monthly maximum temperatures increased by only 4° F during the same period.

The impact of two patterns of clearcutting on stream temperature was measured in two Coast Range watersheds (Brown and Krygier, 1970). An 850-acre watershed contained three patch-clearcuttings, which included about 25 percent of the total watershed area. Clearcutting boundaries were separated from flowing streams by buffer strips of vegetation 50-100 feet in width. These buffer strips continued to provide shade for the small stream and no increase in water temperature was observed.

The second watershed, 175 acres in size, was completely clearcut and burned. No vegetation remained to shade the small stream, where discharge drops to 0.01 cfs during the low-flow period. Mean monthly maxima were increased by 14° F the first summer after logging. The annual maximum was increased by 28° F during the same year. Both annual and mean monthly maxima have declined as riparian vegetation, and thus shade, has returned.

One of the most effective means for preventing water temperature change is with a buffer strip between the clearcut boundary and the stream. The configuration of this strip (width, density, species composition) depends on the stream's orientation to the sun, the stream width, solar angle, and tree height. On very small streams, riparian brush is often sufficient to provide necessary shade. Wider streams require taller trees. In many instances, buffer strips for temperature control are inappropriate. For example, southerlyflowing streams which have little natural cover to protect the stream from midday sun would not benefit a great deal from buffer strips. It is also obvious that buffer strips on the north side of east-west-flowing streams contribute little to temperature control.

Figure 4. Shaded streams stay cool. These red alder were left during timber harvest in an experiment on a small stream in the Alsea basin. No temperature increase was observed in the stream after the slopes above the stream were clearcut.

In the final analysis, the degree to which stream temperatures are controlled during logging is dependent upon the skill and judgment of the forester, working in close cooperation with a fisheries biologist. The amount of shade left along a stream and the logging technique best suited to insure the permanence of this shade will vary with each stream. Standardization of technique or strip configuration is thus impossible; it is here that the professional skill and judgment of a forester become critical.

Dissolved oxygen

Dissolved oxygen, like temperature, is a primary regulator of biologic activity in an aquatic ecosystem. Dissolved oxygen present at any time in a stream is a function of the water temperature, which limits the saturation concentration, and channel characteristics, such as slope, roughness, and cross-section, which control the rate of oxygen exchange between water and air. Aquatic microorganisms also influence the amount of oxygen in stream water. These organisms utilize organic materials in the stream as an energy source and extract oxygen from the water in the process. Organic material can be characterized by the amount of oxygen required by microorganisms to decompose it. This amount is called the biochemical oxygen demand, or BOD.

Logging influences the amount of oxygen in streams in several ways. Clearcutting alongside a stream may increase its temperature as noted above, thus lowering the saturation concentration. In the extreme case cited above, where maximum temperatures increased from about 57° F to about 85° F, the saturation concentration drops from 10.26 ppm to 7.44 ppm.

Logging debris often accumulates in the channels of clearcut watersheds, particularly if logs are yarded across the stream channel. Once in the stream, debris can influence oxygen levels in two ways. Finely divided debris, such as needles, leaves, small branches, or bark, provides a source of energy for microorganisms. Needles and leaves, for example, contain large amounts of simple sugars, the product of photosynthesis. These sugars are leached rapidly from the needles and leaves submerged in the stream and consumed by the microorganisms. These materials thus have a very high BOD.

In many streams, small debris dams can restrict water flow and thus reaeration. Ponding also increases stream surface area and accentuates temperature increases.

The combination of these three logging effects was studied in a small stream in a clearcut watershed in the Oregon Coast Range. Hall and Lantz (1969) reported that in a short reach of stream where debris had accumulated, dissolved oxygen levels dropped to less than

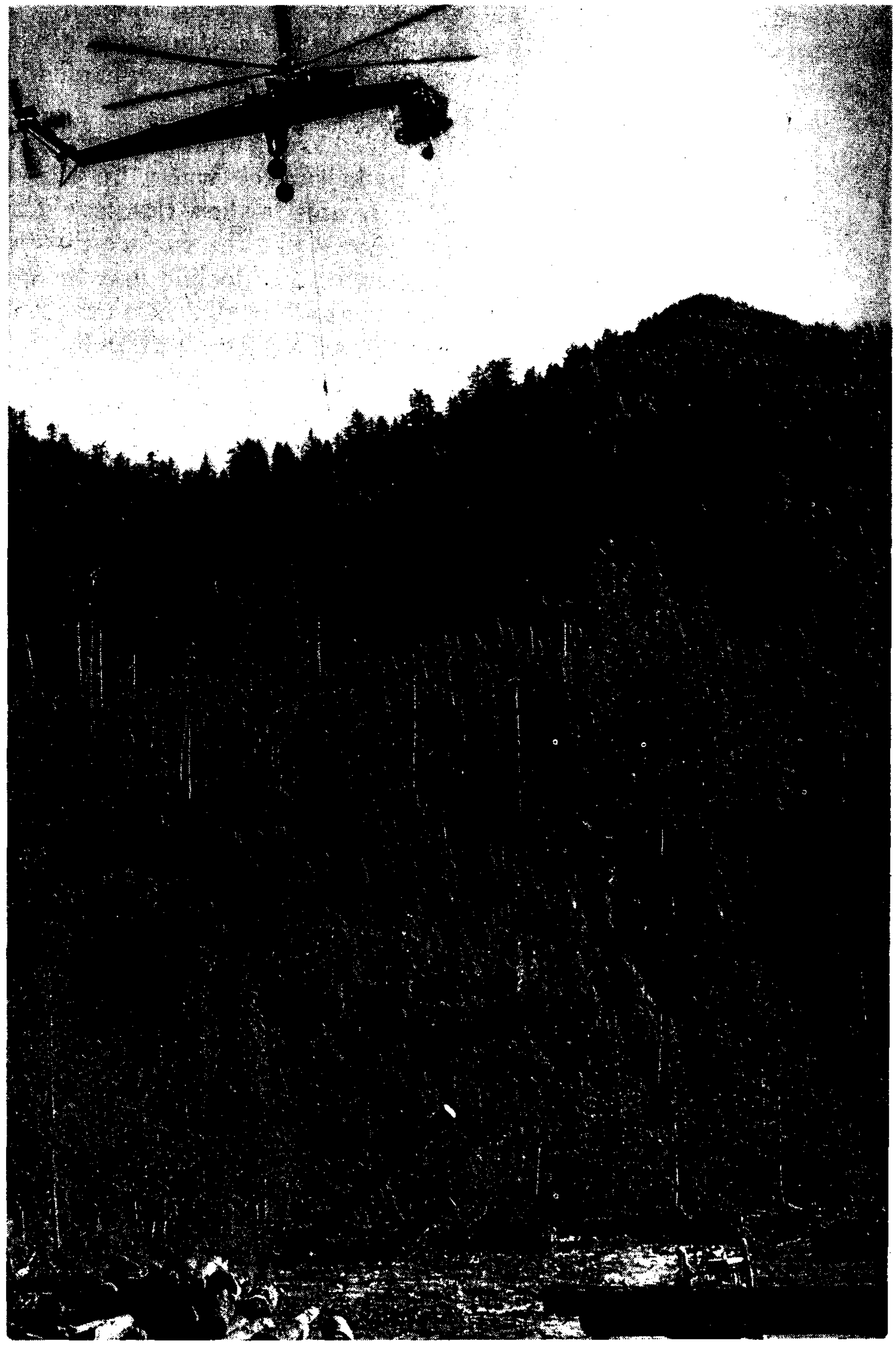


Figure 5. Helicopter logging in a national forest. New logging techniques such as the helicopter and balloon are being developed to harvest trees with minimum environmental impact in areas too hazardous for conventional systems. (*US Forest Service photo*)

1.0 ppm. On a neighboring watershed that was not logged, dissolved oxygen levels were at saturation, about 10 ppm. Surface waters returned to saturation after stream cleaning and fall rains removed the debris from the channel.

Dissolved oxygen in the intragravel water is equally as important as in surface water. In this same study, Hall and Lantz (1969) were able to show that levels of intragravel dissolved oxygen did not recover like the surface-dissolved oxygen, but continued to decline. Part of this decline may be attributed to long-term BOD of organic material intruded into the gravel. The major problem, however, seems associated with reduced circulation because of sedimentation of the gravel bed.

Several other studies provide indirect evidence about the impact of accumulation of plant material on water quality. Organic material of natural origin has caused problems in municipal water systems for many years. Allen (1960), for example, reported that alder leaves were responsible for taste and odor problems in the Seattle, Washington, water supply system. These problems had occurred since 1924 and were particularly noticeable where waters were removed from new reservoirs. Kinney (1961) noted that phenolic substances in pristine mountain streams often reached levels once classified as "polluted" by many water quality standards. Chase and Ferullo (1957) performed a series of tests to determine the effects of leaves and needles on the oxygen levels in reservoirs. The oxygen demand was 100 milligrams of oxygen per gram of pine needles after 20 days; it was 500 milligrams of oxygen per gram after 400 days. They concluded that large accumulations of organic materials could significantly reduce oxygen levels in small reservoirs.

Graham and Schaumburg (1969) studied the impact of submerged logs on water quality. They noted that freshly cut logs placed in simulated stream conditions colored the water and released about 5 grams of chemically oxidizable substance per square foot of log surface area over a 40-day period. Soluble, oxidizable organic release occurred through the cut ends, as expected. Color was attributed to bark materials. They concluded, however, that log storage in rivers and estuaries was not a serious water quality problem.

The impact of logging slash on dissolved oxygen and water quality has not been precisely determined. We are currently studying this subject at the School of Forestry.

In summary, maintaining high dissolved oxygen concentrations in the water of small, forest streams is keyed to minimizing temperature changes and debris accumulation in the channel.

Conclusion

I have tried to illustrate the diversity of impacts that timber harvest may produce in its effect upon soil and water resources. It is clear that the impact of timber harvest varies widely from site to site. In the face of such diversity of forest system, harvest practices, and impacts, how can we best cope with these difficult problems? It seems all too evident that if broad generalizations cannot describe the impact of timber harvest, then neither can these problems be solved with general prescriptions. This leads to some difficulty in preventing damages. For it means that each problem area, each logging operation, each road system, must be judged independently. It means that solutions to specific problems are not likely to be forthcoming from general regulations or rules. Thus, the solution lies with specific prescriptions, site by site, by professionals. This requires larger investments of time, effort, and money, and a great deal of skill.

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