DOCUMENT RESUME

ED 153 784 SE 023 484

TITLE Processes, Procedures, and Methods to Control Pollution Resulting from Silvicultural Activities.
INSTITUTION Environmental Protection Agency, Washington, D.C. Office of Water Programs.
REPORT NO EPA-430/9-73-010
PUB DATE Oct 73
NOTE 100p.; Photographs may not reproduce well
AVAILABLE FROM Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 ($1.25)

EDRS PRICE MF-$0.83 HC-$4.67 Plus Postage.
DESCRIPTORS Environment; *Forestry; *Land Use; Management Systems; Natural Resources; Pesticides; Pollution; *Post Secondary Education; *Soil Conservation; *State of the Art Reviews; *Water Pollution Control

ABSTRACT

This report presents brief documentation of silvicultural practices, both those now in use and those in stages of research and development. A majority of the text is concerned with the specific aspects of silvicultural activities which relate to nonpoint source pollution control methods. Analyzed are existing and near future pollution control methods in terms of technical and economic practicability and usefulness. It provides information of a general nature regarding processes, procedures, and methods for controlling pollution caused by sediment runoff from logging roads, skid trails, and other areas of undisturbed soils in forest areas; pesticides and fertilizers used in forest regeneration activities; chemicals and other materials applied for forest fire prevention; and temperature increases in small streams exposed to solar radiation by logging of bordering timber stands. (Author/CS)

EPA 430/9-73-010

PROCESSES, PROCEDURES, AND METHODS TO CONTROL POLLUTION RESULTING FROM SILVICULTURAL ACTIVITIES

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Washington, D.C. 20460

FOREWORD

This report is issued in response to Section 304(e)(2)(A) of Public Law 92-500. This Section provides:

> The Administrator (Environmental Protection Agency), after consultation with appropriate Federal and State agencies and other interested persons, shall issue to appropriate Federal agencies, the States, water pollution control agencies, and agencies designated under Section 208 of this Act, within one year after the effective date of this subsection (and from time to time thereafter) information including . . . (2) processes, procedures, and methods to control pollution resulting from --
> "(A) . . . silvicultural activities including runoff from . . . forest lands,"

This report prepared under contract by the firm Midwest Research Institute, Kansas City, Missouri for the Environmental Protection Agency, provides information of a general nature regarding processes, procedures, and methods for controlling pollution caused by sediment runoff from logging roads, skid trails, and other areas of disturbed soils in forest areas; pesticides and fertilizers used in forest regeneration activities; chemicals and other materials applied for forest fire prevention; and temperature increases in small streams exposed to solar radiation by logging of bordering timber stands. It is intended to act as a state-of-the-art document useful for the development of effective programs to control nonpoint sources of pollution.

Russell E. Train
Administrator

EPA 430/9-73-010
October 1973

PROCESSES, PROCEDURES, AND METHODS TO CONTROL POLLUTION RESULTING FROM SILVICULTURAL ACTIVITIES

U.S. Environmental Protection Agency
Office of Air and Water Programs
Washington, D.C. 20460

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price $1.25

SUMMARY

The present status of "Processes, Procedures, and Methods to Control Pollution Resulting from Silvicultural Activities" has been analyzed in response to the directive given to the Environmental Protection Agency by the Second Session of the 92nd Congress in Section 304(2)(e) of Report No. 92-1465 titled "Federal Water Pollution Control Act Amendments of 1972," dated September 28, 1973.

Nearly 203 million hectares (500 million acres) in the United States are in forests managed primarily for the production of timber. The principal water pollutants from this land area are eroded mineral soil sediments transported in runoff; organic matter which is chiefly transmitted to the water by runoff; pesticides; fertilizers; fire retardant chemicals; and thermal pollution resulting from solar radiation. Of these pollutants, sediment, including both its organic and inorganic (mineral soil) constituents, is the greatest single cause of water quality degradation. Sediment additionally acts as a carrier of such pollutants as pesticides and phosphorus. Control of erosion due to runoff is thus the most important aspect of control of pollution from forests.

Pollution from forests is nonpoint in origin, and defies control or treatment in the conventional sense. The treatment and control methodology is, therefore, principally the forest management system--the combination of practices involved in harvesting trees; log transport; reforestation; protection from fire, disease, insects and weed trees; and growth promotion. The practices in current use require adaption to meet environmental goals as well as to achieve other objectives which govern forest land use.

A well-managed forest with a good stand of trees is usually quite resistant to erosion and also absorbs incident rainfall with little runoff. Disturbed soil caused by tree harvesting, skidding logs to a landing area, and constructing roads to haul logs from the forest, is highly erodible and is a principal source of sediment pollution. Control of erosion, therefore, requires strict attention to the period between harvest and re-establishment of the forest. Required also is good management of an established forest during its years of growth, so that a healthy forest is present to assure minimum erosion.

Several alternate methods to harvest and transport trees are available. These vary in potential to cause short-term pollution, in cost, in applicability to regions or topography, and in long-term impact on the forest and its potential to produce high quality water as well as timber. Log transport options include helicopter log transport, which at present is

a highly specialized and costly method best suited to logging from very steep and unstable slopes; skyline and balloon logging; tractor logging; and rafting in special situations. Harvest methods range from the controversial "clearcut" method to selection and harvest of individual trees. Logging roads are required for nearly all the harvesting and log transport systems. The roads are a prime source of erosion; and careful planning, engineering design, and maintenance of roads are necessary to control sediment pollution. Skid trails disturb the soil cover in harvested areas, and methods which minimize the extent of this disturbance will reduce erosion.

Reforestation methods range from hand planting, through man assisted natural regeneration, to unassisted regeneration. The method of preference from the standpoint of pollution control is the one which most quickly results in reestablishment of a healthy forest. Unassisted regeneration is to be avoided, as are practices which result in large acreages of marginal forest land.

Control of pollution from pesticides is a complex issue, one requiring in-depth analyses of environmental questions. The specific control options available to the silviculturist include the exercise of extreme caution in the use and application of pesticides, including the avoidance of streams in the application pattern; minimal or no use of prophylactic control; avoidance of persistent or highly toxic pesticides; and use of biological and cultural pest control methods.

Control of pollution from fertilizer and fire retardant chemicals consists chiefly of adherence to a use plan which eliminates direct application to surface waters, and which avoids excessive or unnecessary use.

Thermal pollution occurs when vegetation along water bodies is removed and solar radiation penetrates to the water and increases its temperature. Control consists of leaving protective stands of trees along stream banks.

One concludes that, while certain questions such as pesticides use remain unresolved, the basic methods, processes, and procedures needed to control nonpoint pollution from silviculture are available. One concludes further that the key to pollution control from a forest dedicated to timber production is intensive, well planned management rather than the laissez faire, let nature take its course, approach.

Intensive management systems emphasizing timber production and integrating the efforts of many technical and economic disciplines, are now in limited use. The operating philosophies of such systems need to be broadened to include pollution control, and pollution control management systems thereby developed and implemented. Development of pollution control management systems for specific areas is the prerogative of local planners and administrators, both public and private, with assistance on technical issues and guidance on questions of policy from the regional and national levels. Application and administration of pollution control on some 203 million hectares (500 million acres) now in commercial timber production are the challenge.

CONTENTS

FIGURES

FIGURES (CONCLUDED)

TABLES

1.0 INTRODUCTION

The gross area of the 50 states is 930 million hectares (2.3 billion acres). About one-fifth of this area, nearly 203 million hectares (500 million acres), is commercial forest land--the principal thrust of this report.

The potential for generation of nonpoint source pollution from commercial forest lands is substantial--so large a land mass is, in principle, capable of discharging large quantities of pollutants into the nation's waterways. The actual quantities of pollutants discharged to streams and other bodies of water are determined in large part by the manner in which the forests are managed and by efforts made to control and minimize pollution. The silvicultural practices employed in forestry therefore include, or should include, a basic forestry management system geared to both productivity and pollution control, using special practices and strategies that have been developed to deal with specific pollutional problems.

This report presents brief documentations of silvicultural practices, both those now in use and those in stages of research and development well enough advanced that they can be assessed for future use. A majority of the report deals with the specific aspects of silvicultural activities which relate to nonpoint source pollution control methods. The objective of the study is to analyze existing and near future pollution control methods in terms of technical and economic practicability and usefulness.

Pollution control in forestry does not consist of rectification and treatment of polluted effluents immediately prior to discharge to an environmental receptor, e.g., a stream or lake. Pollution from forest lands is nonpoint in origin and thus defies treatment in the conventional sense. The treatment and control methodology, therefore, principally the forest management system--a combination of practices and methods employed in the harvest of trees; log transport; reforestation; forest protection (fire, disease, insects, weed trees), and growth promotion--adapted as necessary to achieve environmental goals in union with realization of other goals, which include as a minimum the production of lumber and other forest products achieved by harvest of trees.

The study team examined more than 900 literature references and reports and elicited information and data, through personal contact, from authorities in Washington, D.C., the South, the Northeast, the Northwest, and the Southwest regions of the United States. The data and information which serve as the information base for the study were derived chiefly from the references cited in this report.

1.1 Scope

The primary concern of the study is control of pollutants which originate in commercial forest lands and degrade the quality of surface waters (streams, rivers, lakes, and oceans) and groundwater. The major identified sources of pollutants are mineral sediments; humic matter present in soils and in the forest cover; tree debris (leaves, twigs, slash); pesticides, including insecticides, fungicides, rodenticides, and silvicides; fertilizers (nitrogen in various forms and phosphorus); and fire retardants, which presently consist principally of the ingredients of fertilizers. Thermal effects resulting from solar energy, specifically the effect of forestry practices on stream temperatures, are also considered.

The national and state park systems managed for use [illegible]tion, wildlife preservation, preservation of tree species) not i[illegible]ng timber production have not been included in the study. Similarly, the small private woodlands have not specifically been evaluated; the pollution control methodology used in commercial forests will, however, have general applicability to small private holdings.

The study area embraces all the operations of a production cycle, from regeneration through harvest and transport of logs and other timber raw products out of the forest proper to processing sites. For this report the term silviculture is generally interpreted to include log transport processes that occur from the stump to a hard-surfaced permanent type road.

1.2 Water Quality in Relation to Silviculture

The U.S. Forest Service in the Department of Agriculture and the Bureau of Land Management in the Department of the Interior were both directed by congressional acts of 1960 and 1964, respectively, to apply multiple use concepts to lands under their respective jurisdiction.[1] The term, "multiple use", in the acts is defined broadly to include timber production, livestock range management, watershed protection, outdoor recreation, and fish and wildlife management.

Both agencies have been planning, classifying, and zoning lands under their jurisdiction by "principal use" concepts under the following guidelines:

Environmental enhancement at the local level

Public demand for local use

Economic development on a local basis

Sustained yield of timber on an area basis

By contrast, the national parks have been established on a no-use (no silvicultural use) concept, "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

In regard to American land area covered with commercial forests, the timber supply is not equally distributed across the country. In general, the East has a higher percentage of land area covered with commercial forests than the West (Figure 1). Since rainfall is a major delineating factor in the ecological development of forests, areas that have abundant rainfall tend to have lush forest growth. These areas include New England, the Appalachian Mountains, the Gulf Coast states, and the Pacific Northwest.

Because of the increasing demands for more timber products, both public and private forests are anticipated to be managed more intensively to increase production.2/ The greatest present and potential production is concentrated in the Pacific Northwest and in the South. The net result is expected to be the use of more pesticides, fertilizers, and fire retardants, and the construction of more logging roads. An increase in the potential for water pollution from silvicultural activities is, therefore, a certainty.

Silvicultural activities may increase the probability of periodically lowering the quality of water from forested watersheds. On a per-acre basis, however, forest lands are our best source of high quality water.2/ On the basis of comparisons with the output from agriculture and grazing lands, water from forests is high in yield, of good quality, and low in sediment. However, water quality can still be adversely affected by forest sediments, especially those generated by the harvest of logs and in the ensuing period of time in which the forest is (may be) deprived of protection from erosive forces. While sediment, both inorganic and organic, is conceded to be the principal forest land pollutant (and indeed is on a mass basis), pesticides, fertilizers, and fire retardants employed on forest lands contribute polluting materials to the water supply. Studies of these latter pollutants have been largely qualitative. They have demonstrated, for example, that pesticides or fertilizers applied to forest lands may appear in adjoining surface waters; how much of the applied materials reach the waterways is ill-defined, though conceded to be a small percentage.

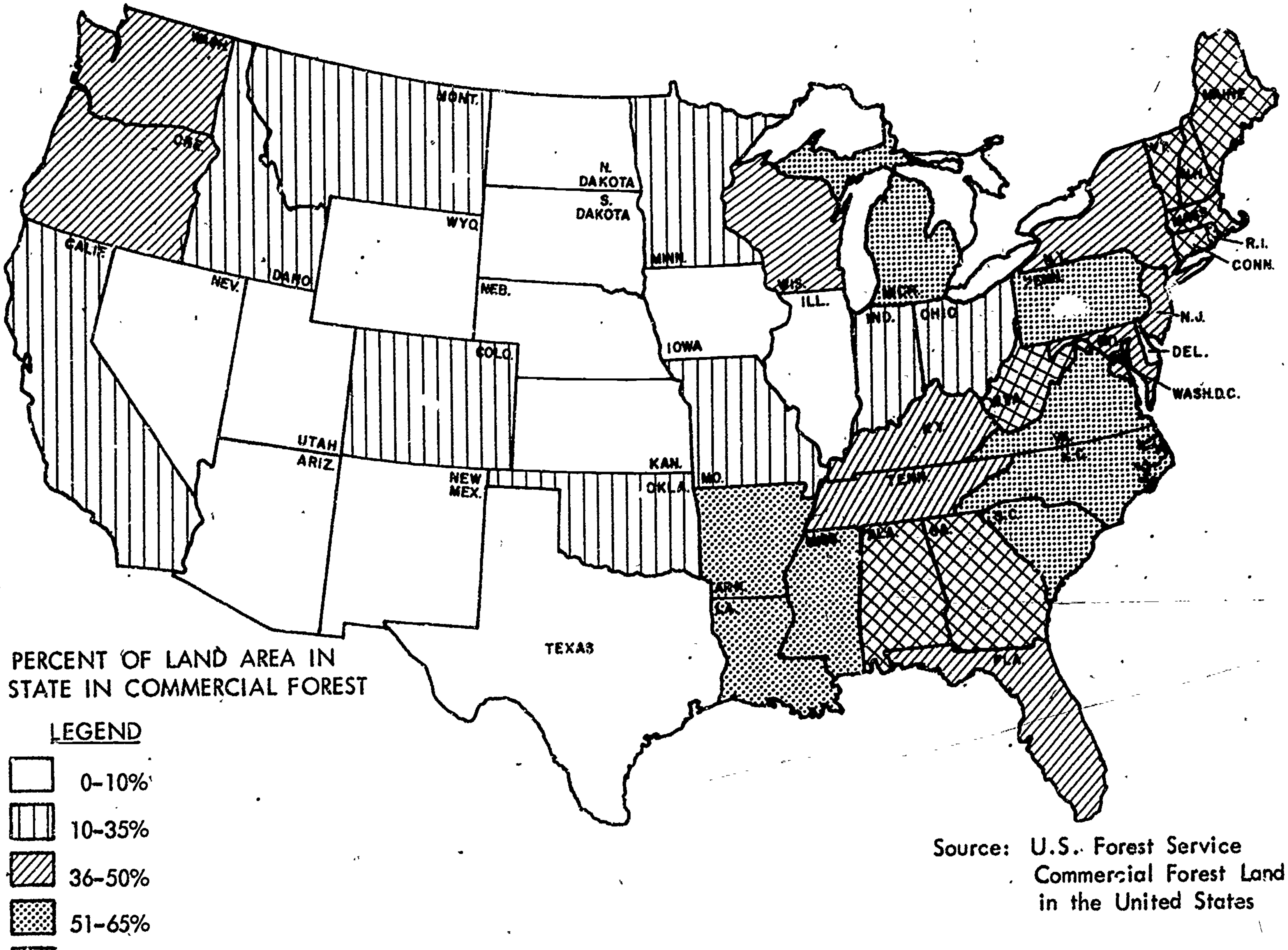

Figure 1 - Commercial Forest Land in the United States

2.0 BASIC SILVICULTURAL PRACTICES IN THE UNITED STATES

An evaluation of pollution control in silviculture must focus on the various operations involved in the life cycle of a forest. These operations are summarily discussed in this section.

2.1 Harvesting Methods

The tree harvesting operation is consummated in a period of time quite short in relation to forest lifetimes, and it has both a high short-term pollutional impact and a long-term impact spread out over the period of time required for the forest to regenerate--to regain the degree of stability one considers to be normal and nominally nonpollutional. Procedures employed at harvest time may irreversibly alter the character of the forest, perhaps to the detriment of both the environment and the quality of the forest in succeeding years. This is an important point because of the long-term importance of our nation's forests as a natural resource.

There are four principal harvesting methods[3/] recognized and practiced in the 37 major forest types in the United States. The harvesting methods are: selection (single tree and group tree), shelterwood, seed-tree, and clearcutting.

A particular harvesting method is chosen for a designated area based upon judgments of professional foresters. Factors influencing judgment decisions are aesthetics, forest-tree-regeneration potential of the species to be favored; erosion potential; fire hazards; topography; accessibility and economics of markets; insect and disease hazards; and requirements for wildlife, taxes, and costs.

On the average, 25% to 35% of the area annually harvested in the U.S. National Forests are harvested by the clearcutting method, but about 50% of all wood removed has its origin in clearcutting (Table 1).

On an acreage basis in 1970 of the total of 605,000 hectares (1.50 million acres) of national forests harvested, 218,000 hectares (540,000 acres) were clearcut, 146,000 hectares (360,000 acres) underwent intermediate cut, 142,000 hectares (350,000 acres) were harvested by the shelterwood and seed-tree methods, 69,000 hectares (170,000 acres) by shelterwood and seed-tree **preparatory** cutting, 47,000 hectares (70,000 acres) by the selection system, and 1,600 hectares (4,000 acres) from salvage operations.

TABLE 1

HARVESTING PROCEDURES ON NATIONAL FORESTS IN EASTERN AND WESTERN U.S., 1965 AND 1970[a/]

Silvicultural Harvesting Methods	All National Forests Thousands of Hectares (Acres)		Western Forests Thousands of Hectares (Acres)		Eastern Forests Thousands of Hectares (Acres)	
	1965	1970	1965	1970	1965	1970
Intermediate Cutting	348.7 (863.2)	147.6 (364.7)	127.2 (314.5)	61.1 (151.1)	222.0 (548.7)	86.4 (213.6)
Clearcutting	172.4 (426.2)	228.0 (563.6)	112.8 (278.7)	142.9 (353.3)	59.7 (147.5)	85.1 (210.3)
Shelterwood/Seed-Tree Cutting						
Preparatory Cutting	91.3 (225.6)	68.8 (170.1)	79.9 (197.4)	61.5 (152.1)	11.4 (28.2)	7.3 (18.0)
Removal Harvesting	84.8 (209.6)	141.5 (349.7)	72.0 (178.0)	125.8 (311.0)	12.8 (31.6)	15.7 (38.7)
Selection Cutting	11.9 (29.3)	28.2 (69.7)	11.7 (29.0)	28.2 (69.7)	0.1 (0.3)	0.0 (0.0)
Salvage Cutting	0.0 (0.0)	1.4 (3.5)	0.0 (0.0)	1.4 (3.5)	0.0 (0.0)	0.0 (0.0)
Total	709.1 (1,753.9)	615.5 (1,521.3)	403.6 (997.6)	421.0 (1,040.7)	306.0 (756.3)	194.5 (480.6)

a/ "An Analysis of Forestry Issues in the First Session of the 92nd Congress," April 1972, 64 pages, p. 31.

2.1.1 Selection: The selection system of silvicultural harvest is adapted to the tolerant species that will reproduce satisfactorily under severe competition for soil moisture, soil nutrients, and light. Such species include redwood on the Pacific Coast in California; white fir and incense cedar in California; ponderosa pine on the eastern slope of the Sierra Nevada and Cascade mountains; Engelmann spruce, alpine fir, and western larch in the Rocky Mountains; sugar maple and beech in the Northern hardwoods; and most of the white and red oaks in the central states.

The most tolerant forest tree species will reproduce satisfactorily following the single tree selection method but less tolerant trees reproduce better after the group selection method, where larger openings are made. The selection system results in an all-age stand.

2.1.2 Shelterwood: As the name implies, the shelterwood system of tree harvest removes all mature trees in a series of several harvests and thereby leaves adequate overstory to shelter the site. The protective shelter serves to improve aesthetics and to provide partial shade for reproduction of forest species with a requirement for shade. Heavy-seeded species such as the oaks usually reproduce well under this system.

The shelterwood system of harvest is well adapted to the Appalachian mixed hardwood forest type, including species such as northern red oak, yellow poplar, basswood, hickories, and white ash. Nearly all species reproduce by sprouting as well as by seed. Eastern white pine is well adapted to the shelterwood system, as is red pine in the Lake States.

A continuous shelterwood system of harvest results in forest stands that are essentially even-aged.

2.1.3 Seed-tree: The seed-tree method is a timber harvest method that clearcuts the area and leaves only sufficient trees to bear seed for natural regeneration. The system is applicable to light seed that can be borne by the wind. After a new forest is reseeded, the seed trees may be harvested. The new forest is therefore even-aged.

The four southern pines (loblolly, longleaf, shortleaf, and slash) are the principal species that are adapted to the seed-tree method of silvicultural harvest.

2.1.4 Clearcutting: Clearcutting is the silvicultural system that includes the cutting of all trees from the logged area, and not just the merchantable trees. The purpose is to clear the area in order to establish a new, even-aged stand, usually of very valuable and fast-growing species that will not reproduce satisfactorily under competition from other trees.

The area clearcut may consist of patches, strips, or an entire watershed. Regeneration may be obtained through established reproduction, natural seeding prior to cutting, artificial seeding after cutting, sprouts from stumps (coppice), or planting.

Examples of clearcutting to achieve satisfactory reproduction of valuable species include Douglas fir in the Pacific Northwest, western white pine in northern Idaho, jack pine in the Lake States, loblolly pine in the South, lodgepole pine in the Rocky Mountains, and black cherry in the Allegheny Mountains.

Clearcutting is a standard practice used with several different logging systems. With large volume, the practice is almost essential to permit efficient use of high lead, skyline, balloon or helicopter systems.

Because of the great hazard of potential erosion, the advantages and disadvantages of clearcutting are given, as stated by Archie and Baumgartner[4/] as follows:

Advantages	Disadvantages
1. Creates good growing conditions for shade-intolerant tree species (e.g., Douglas fir, noble fir).	1. Exposes seedlings to injury from temperature extremes.
2. Eliminates danger of wind damage or disease infection to residual trees in the cutover area.	2. Increases risk of windthrow or heat damage to trees bordering the cutover area.
3. Improves forage for many game animals (e.g., deer, elk) and provides habitats for many animals not present before logging.	3. May increase stream temperature, debris jams, and sedimentation (effect on fish population) and reduce habitat of some animals (e.g., woodpeckers, tree squirrels).
4. Increases water yield during low-flow periods.	4. Elevates water table in swampy areas.
5. Permits harvesting on slopes too steep for ground equipment.	5. May in some instances reduce protection against erosion and landslides.
6. Minimizes road construction and increases logging efficiency.	6. Is conspicuous and unattractive during the harvest stage.

Advantages	Disadvantages
7. Facilitates administration in that it limits tree marketing to definition of boundaries.	7. Magnifies need for proper harvest boundary layout.
8. Facilitates slash disposal and site preparation.	8. Increases quantity of debris (and fire hazard) to eliminate at one time.
9. Usually maximizes the immediate financial return.	9. Eliminates merchantable timber from the small landowners' cutover area for many years.
10. Permits the use of genetically improved tree planting stock.	10. Creates good growing conditions for many unwanted brush species, which compete with the young seedlings.

2.2 Log Transport Engineering

All log transport methods require roads, and most methods use skid trails to move logs to a yarding area from which they are usually moved by truck over public and private roads to market. In some locations, logs may be transported by water or by railroad. The principal log transport methods for each logging operation include one or more of the following engineering systems: rafting (plus possible storage in water), tractors, high lead, skyline cable, balloon, or helicopter.

2.2.1 Trails and roads: Soil sediments are a major pollutant from forests, and logging roads and road construction are prime sources of soil sediments. This statement is true for all commercial forests of the United States. Roads are constructed primarily during, or preceding, the logging period. They serve one or more of the three basic purposes during harvest: provision of access by men and equipment to the logging area; transport of logs out of the harvested acreage; and transport of logs from yarding areas to sawmills, pulpmills, streams, or other destinations. After harvest, the roads may be maintained as necessary for use in reforestation, fertilization, pest control, fire fighting, and public recreation.

Roads may be of low standard and highly susceptible to erosion, or they may be well-built and relatively resistant to erosion. Even under ideal conditions, roads are a source of eroded soil during construction and during the harvest period of heavy use.

The fraction of the forest acreage devoted to roads depends on several factors, notably the harvest system, planned long-term use, and preconstruction engineering design and planning. A well-planned and coordinated road building-harvesting system can require much less road mileage than results from an unplanned operation.

Road layout, especially in relation to topography, slope, and proximity to watercourses, is quite important in pollution/sediment control.

Factors important in road construction are discussed further in Section 4.1 under Control of Sediment Sources.

2.2.2 Rafting and storage in water: Logging operations in the northwestern U.S. can best be done during the dry summer months when damage to the watershed environment will be a minimum. Pulp mills, plywood mills, and saw mills must operate year-round to be efficient. This means that many logs must be stored before use. Storage on dry yards induces losses by excessive cracking because of rapid drying. Where water is available, storing logs in water has been an acceptable solution.5/

Log rafts and log storage in surface waters contribute directly to pollution of water. Bark dislodged from logs and chemicals leached from logs are major local potential sources of pollution.

Guidelines for minimizing pollution from these two practices (where they are judged to be both environmentally acceptable and economically expedient) are presented in Section 4.

2.2.3 Tractor: Tractor logging is the most popular system of moving logs from where they are cut to the log yard. Forests on slopes of less than about 30% are usually logged by tractors; on slopes of more than 30% and on very fragile soils, the skyline, balloon, or helicopter system of engineering transport is less injurious to the environment.

Tractor logging is substantially less expensive, in situations where tractors can operate, than other log transport systems.

2.2.4 High lead: The high lead system of logging consists of the use of a mobile spar and yarder with mounted engine and winches, guy lines to support the spar, and main line and haul back cables that carry log hooks. Logs are dragged over the ground toward a loading yard (Figure 2). Only the front end of the logs is lifted to clear obstacles or to reduce soil disturbance. For short distances, a skilled operator can "fly" the entire log over unstable areas such as a stream by increasing the speed.

2.2.5 Skyline cable: As early as 1915, skyline cable logging was tried as a method adaptable to remote areas, steep slopes and unstable soils where road building creates excessive erosion from landslides and exposed cuts and fills. When operated skillfully, skyline cable logging does not produce skid trails because the entire log is lifted in transport.

Herman[6/] reported that skyline cable logging required only one-tenth the road construction needed for conventional logging methods such as tractor and high-lead systems. The system of skyline cable logging is adapted for clearcutting as well as for the selection method of harvesting.

The skyline system may consist of a single span (Figure 3) or a multiple span, with intermediate supports attached to firmly anchored trees or stumps.

Yarding of logs may be done near the bottom of the slope (but away from streams) or near the top rim of the watershed divide. A very important consideration is to install the cable system at such a height that logs being transported will not disturb the protective surface of the soil. Disturbance will then be confined to yarding areas where logs are loaded on trucks.

2.2.6 Balloon logging: Gardner, Jacobsen, and Hartsog[7/] reviewed the practice of balloon logging in Idaho, especially as it has had a new thrust because of its low pollution potential.

The system of balloon logging (Figure 4) is well adapted to steep slopes (45 to 90%) and shallow and/or fragile soils, where only helicopter logging or skyline logging may compete. The study suggests that the system is also adapted to selective logging where the minimum harvest is about 70 cubic meters per hectare (12,000 board feet per acre).

Balloon logging causes soil disturbance only at the yarding areas, from which trucks haul the logs to the mill. Yarding areas can be as far as 914 meters (3,000 ft) apart but they must be downhill and therefore may be a hazard to streams.

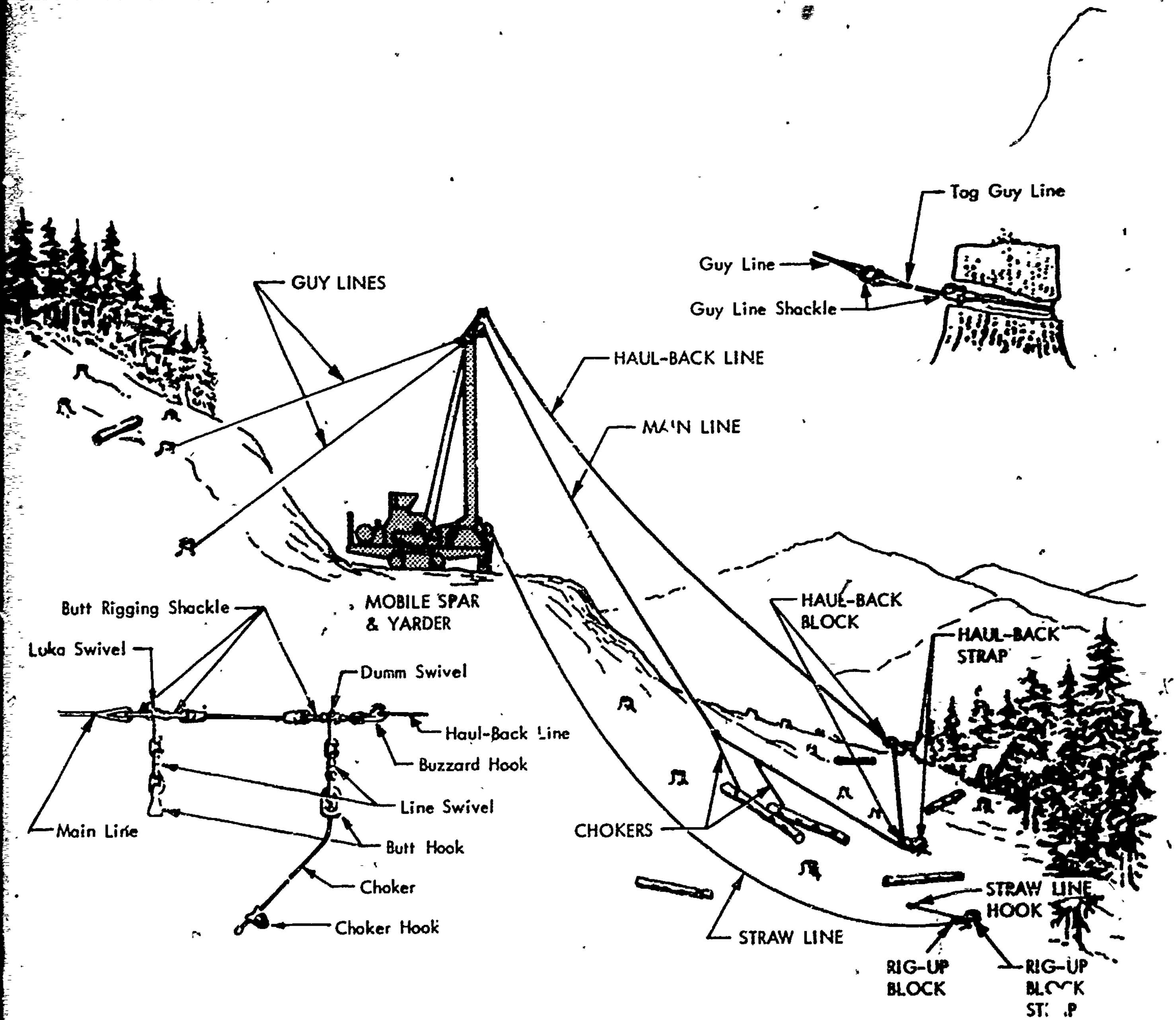

Figure 2 - High-Lead Logging

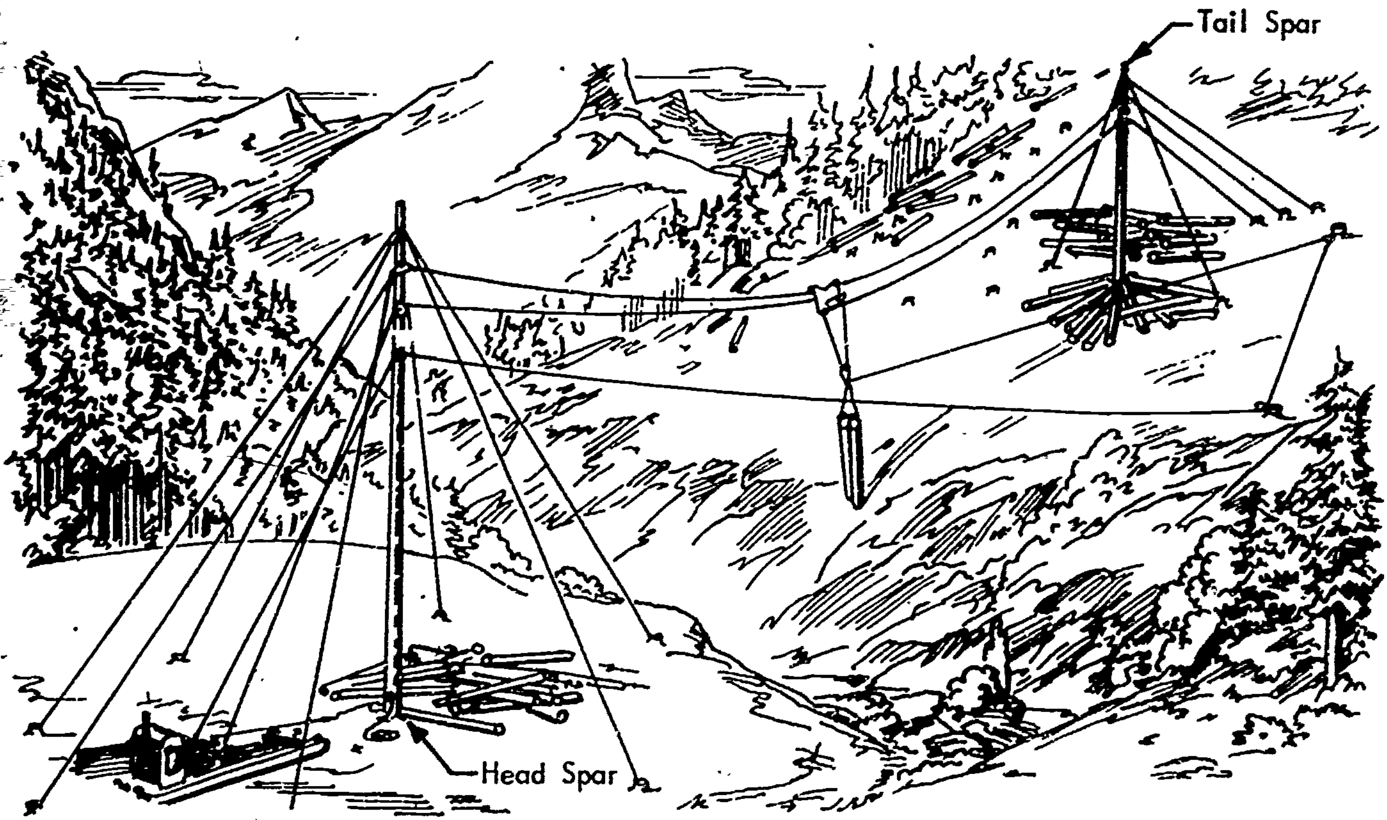

Figure 3 - Skyline Logging

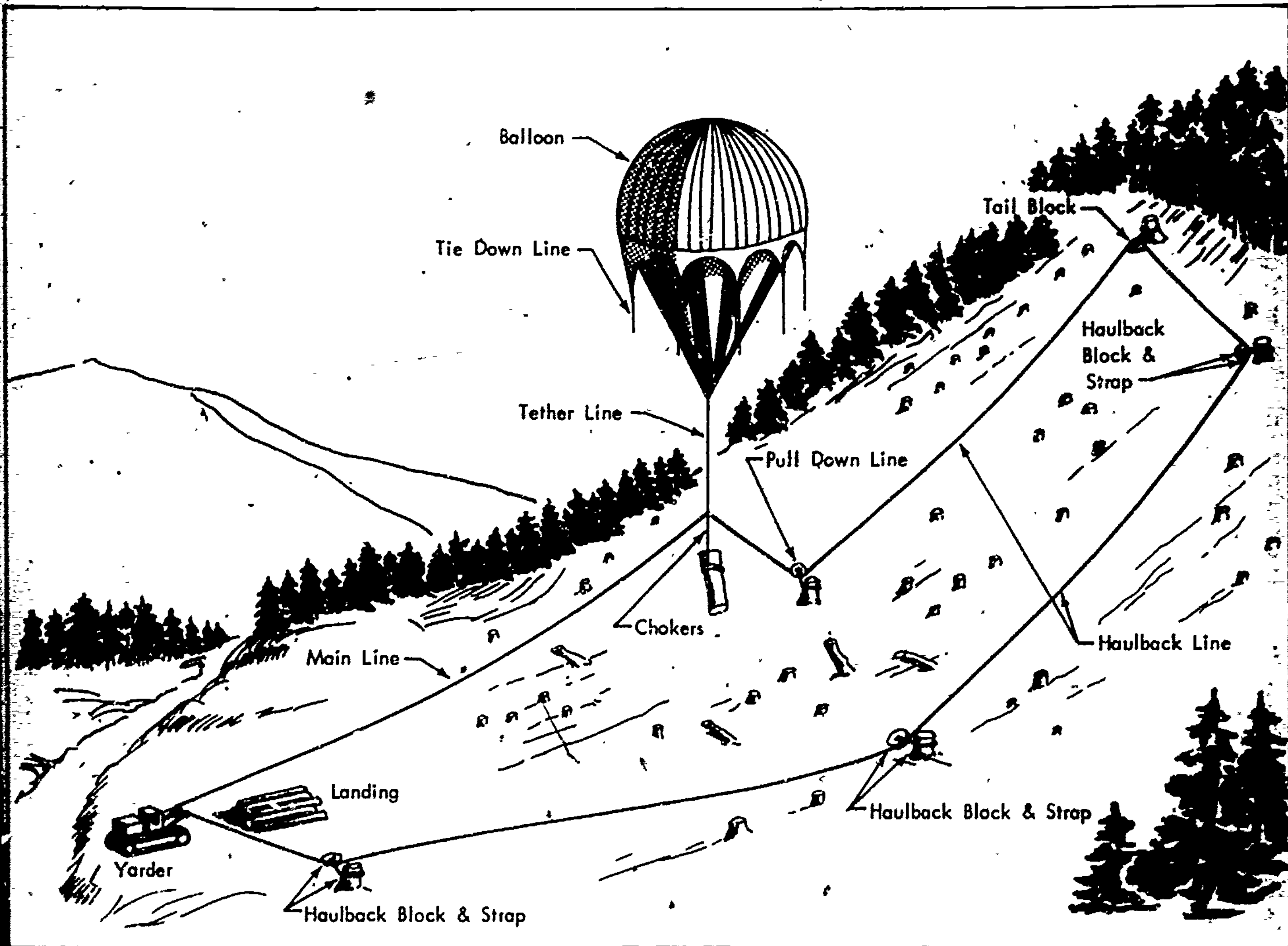

Figure 4 - Balloon Logging

At present, balloon logging is more expensive than most other logging systems.

2.2.7 Helicopter: Because of the potential for minimizing pollution, logging by large helicopter (Figure 5) is the apparent answer to the fondest dreams of concerned environmentalists. Reducing the dreams to engineering, aesthetic, and economic realities was the objective of Binkley.[8/]

Logging by helicopter was demonstrated to be feasible from the engineer's judgment for any topography and for any forest type. Aesthetically, only a heavy concentration of slash in the harvested areas detracts from their appearance. However, costs of delivering logs to landings were higher than for any transport system.

Logging by helicopter requires fewer access roads (and therefore probably results in minimized sediment pollution of streams), costs more per thousand board feet, and is the most versatile system of moving logs from where they are cut to a yarding area for truck loading and hauling. It was suggested by Binkley that helicopter logging probably should be used at present on the most inaccessible areas with the most rugged terrain and high timber value, and where aesthetics has high priority.

A weakness in the "no-road-take-it-out-by-helicopter-concept" is the need to enter the forest on the ground to replant, thin trees, take out the commercial thinning (poles), and for fire control. Normally the cost of constructing forest access roads has been borne by profits from harvesting the mature timber and justified on the necessity for haul roads to remove the logs. This silvicultural management problem has not yet been resolved in the light of new aerial logging technology.

2.3 Reforestation

A majority of this country's forests are regenerated by natural processes. The regenerative process differs substantially for different regions and types of forests, and the harvesting method is usually geared to favor propagation of desired tree species. Several types of reforestation methods are discussed briefly in the following subsections.

2.3.1 Tree planting: Tree planting on clearcut areas and on eroded soils in forested areas is an increasingly popular and effective practice. Since 1930, 14.7 million hectares (36.3 million acres) have been planted to trees. The U.S. Forest Service, the state forest services, and the private forest industries have led in this silvicultural activity. Further, the U.S. Soil Conservation Service has made a major contribution to the science and practice of tree planting.

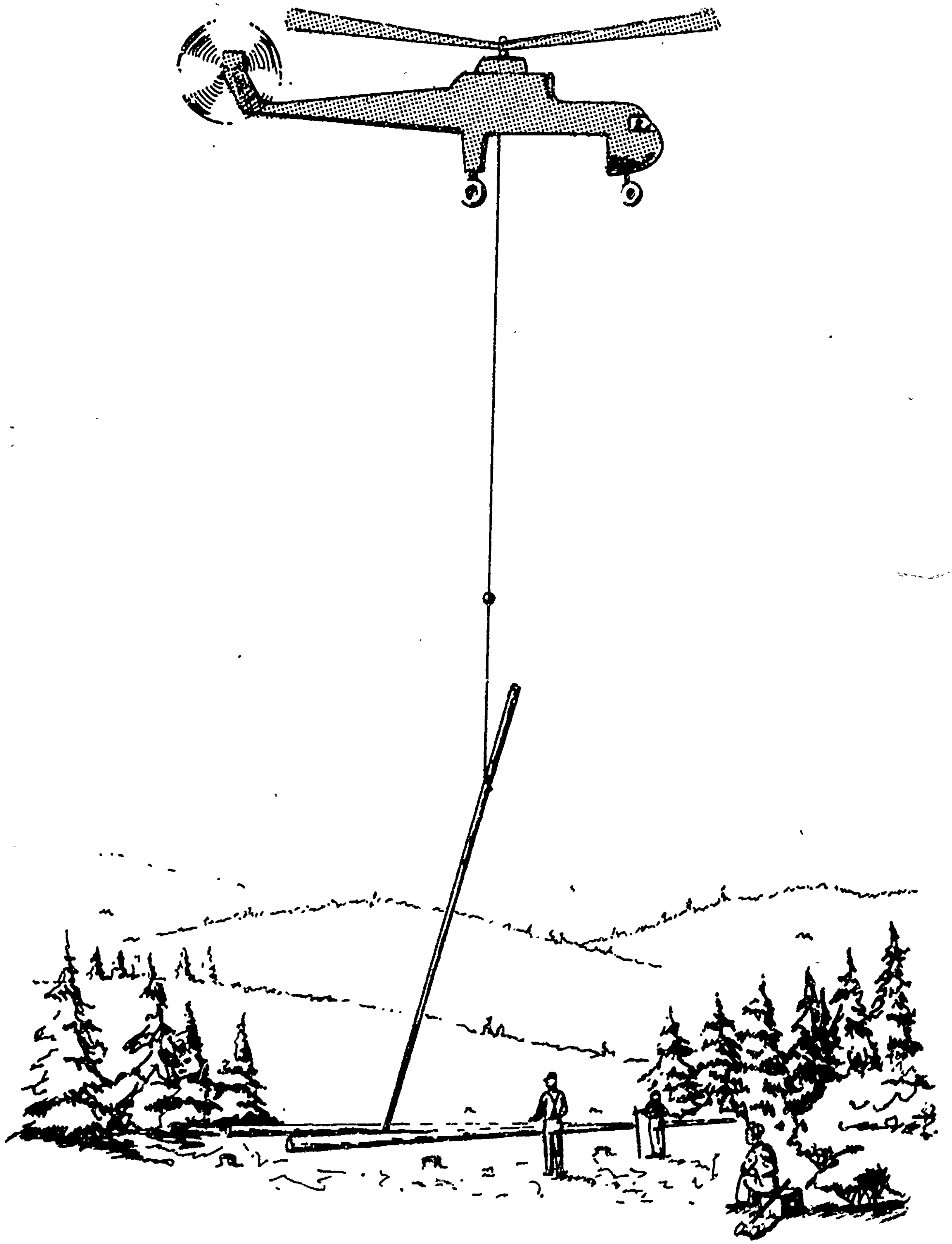

Figure 5 - Helicopter Logging

Scientific guidance from the above-named agencies is available to enable the establishment of productive forests in marginal areas as well as areas suitable for high yield timber production.

2.3.2 Natural regeneration. Natural regeneration to reestablish productive stands of preferred tree species is best obtained when the forest practice is set up to provide favorable conditions for natural seeding or sprouting and growth of the desired species. The method of harvest is an important factor in establishing the required conditions. The seed-tree method is suitable for propagation of selected southern pines species. The shelterwood system of harvest is well adapted to regeneration of Appalachian mixed hardwoods. The selection system is adapted to propagation of species such as the redwood in the Pacific Southwest and Engelmann spruce and alpine fir in the Rocky Mountains. The clearcut harvest method is suitable for establishment of uniform stands (even-aged) of intolerant species that do not reproduce readily under competition from other trees; Douglas fir in the Pacific Northwest, and western white pine in northern Idaho are among the classic species which achieve satisfactory reproduction from clearcut areas.

2.3.3 Influence of fire on reforestation: Historically, forest wildfires in nature have played an important role in natural regeneration and maintenance of some of our preferred tree species. Hendrickson[9/] has stated that from studies of tree rings, the frequency of fires in various types of forests are shown in Table 2. Silvicultural theory interprets these and other data as evidence that fires have an important and necessary silvicidal function in maintaining stands of specific forest species. Periodic fire to reduce competition from competing vegetation and to expose mineral soil is considered to be necessary for maintenance of the Douglas fir forests west of the Cascade Mountains and the pine forests of the south.

As the art of silviculture has advanced, the use of fire has been beneficially controlled, and in recent years use of prescribed fires in silvicultural activities is a scientifically accepted practice. Prescribed burning is extensively employed to reduce potential wildfires by systematically preventing the surface buildup of fuel resulting from slash and other forest debris. Traditionally it has been an accepted silvicultural practice to remove unwanted vegetation by a process of controlled burning to permit direct mineral soil contact of seed of intolerant and most valuable tree species.

With the new emphasis on control of pollution in our nation's forests, there is a search for ways to reduce or eliminate the use of fire as a necessary tool to silvicultural management. Up to the present time, our known technology has not been able to encourage a no-burn strategy. There is now evidence, however, that on specified forest locations, burning can be eliminated as a requirement for reforestation of some of the intolerant tree species.

TABLE 2

FREQUENCY OF FOREST FIRES NECESSARY TO MAINTAIN SPECIES

Tree Species Requiring Fire to Maintain Themselves in a Forest	Frequency of Fires (years)
Slash Pine, Longleaf Pine	3-18
Ponderosa Pine, Pitch Pine	12-25
Douglas Fir	25-50
Quaking Aspen	50-100
Lodgepole Pine, Jack Pine	100-300

Source: Hendrickson, William H., "Perspective on Fire and Ecosystems in the U.S.," in, Fire in the Environment--Symposium Proceedings, Denver, Colorado, 1-5 May 1972, 151 pages, pp. 29-33.

As an alternative to controlled burning, the U.S. Navy has successfully established good stands of Douglas fir in the Pacific Northwest without the use of fire in the period from 1966 to 1972.[10] The slash was contour windrowed with track-type tractors, followed by rootrakes. Tree seed was then sown directly on the bare mineral soil exposed between windrows. In time the piled vegetation rotted down. This highly successful new system for reforestation of an intolerant tree species should have wide application in the major forests of the Northwest and South. The system has the potential, where topography permits, to significantly minimize pollutant emissions from forests. Research and more field studies are required before it can be widely adopted, however.

2.4 Intermediate Practices

Certain practices are employed primarily for the benefit of the growing forest. Pest control, fertilization, fire retardation, thinning and silvicide chemicals belong in this category. Prescribed burning may also be an intermediate practice, specifically when controlled burning is used to dispose of forest debris to reduce the dangers of wildfires and for silvicidal purposes, e.g., to destroy small weed trees in a large established forest. Prescribed burning has been treated in Section 2.3.3.

2.4.1 Pest control: Chemical pesticides are used in forestry for control of insects, weeds and weed trees, plant diseases and rodents. The U.S. Department of Agriculture reports that insects and diseases are responsible for losses in the U.S. that far exceed losses from forest fires. Current annual losses from these causes distributed about equally between mortality and growth loss are estimated to be about 135.8 million cubic meters (4.8 billion cubic feet). If no pest control activities were carried out, an additional loss of 28.3 million cubic meters (1.0 billion cubic feet) is predicted. Insecticide and fungicide use is credited with about two-thirds, 19 million cubic meters (0.67 billion cubic feet), of this savings. In 1969, 1,251,367 trees were treated for insect control, and an additional 13,535 hectares (33,839 acres) of trees were sprayed to control insects.

The U.S. Forest Service has made a concerted effort to move away from the use of persistent insecticides toward cultural, biological and integrated control methods and to nonpersistent specific chemicals. From 1965 to 1970, the total use of pesticides in Forest Service programs decreased from 500,000 kg (1,353,000 lb) to about 115,000 kg (310,000 lb).

The Forest Service sprayed 107,500 hectares (268,666 acres) with herbicides in 1969. Only a small portion (< 0.1%) of forest lands is treated with herbicides each year to control undesirable tree species and reduce growth of combustible plant materials.

Current public concern related to the pollution hazards of pesticide use has brought about the consideration of new management alternatives in the control of forest insects. Rather than use spray in some areas, dying trees are salvaged; clearcutting has been practiced to harvest the trees and realize some economic benefit. Increasingly, a no-spray policy is being carried out with the hope that natural controls will keep insect damage to some acceptable level of damage. Research is in progress to find nonchemical means of biological control to assist in policy of let-nature-take-her-course. Hardly anyone will advocate a policy of continuous prophylactic spraying because the practice contributes to overhead cost and must continue indefinitely. The practice of spraying insect infestations in relatively small areas before they can spread to epidemic proportions appears to be a sound management practice.

Research investigations are being carried on to compound effective chemicals that will kill unwanted insects, then break down into chemicals that are harmless in a forest ecosystem. It will take time to develop the research finesse needed to adapt to requirements for environmental compatibility.

Owners of small timber holdings generally do not spray because of cost and intensive management requirements. Little information is available on pesticide use by the private forest industry with large acreages of timber. Unlike public agencies, the private industry is not required by law to report use of chemicals to spray insects.

2.4.2 Fertilization: Recent research has established that selected tree species respond well to the application of chemical plant nutrients, especially to nitrogen. A great deal of practical judgment has been involved in the decision to use fertilizer; however, very little actual research information is available at this time. Aside from the technical question of application rate and most effective distribution procedures, there are the two overriding questions: (1) cost effectiveness of fertilization in long time span for growing trees, and (2) the risk of contributing nutrients to surface waters in the area, and increasing the potential for eutrophication.

In the Pacific Northwest, on a commercial basis, forest fertilization with nitrogen started in 1965 and reached a level of 47,500 hectares (118,750 acres) in 1970. This practice is anticipated to be 100,000 hectares (250,000 acres) per year during 1975-1980.

Forest fertilization in the South started in 1963 on a commercial basis; and in 1971, it is estimated that 44,440 hectares (110,000 acres) had been fertilized.

More extensive reporting is needed to document the use of fertilizers in forestry.

2.4.3 Fire retardation: The use of chemicals to control or manage fire is an essential practice in silviculture.

The use of all types of fire retardants was reported by Hartong[11/] in 1966 to have been 40.5 million liters (10,708,160 gal). At that time the 1967 use estimate of consumption was 60 million liters (16 million gal.), and the estimate for the year 1971 was in the range of 37.8 to 56.8 million liters (10 to 15 million gal.).

Historically, fire retardant chemicals were primarily bentonites and borates, which are still used to a limited extent. However, the most effective and widely used chemicals to fight or control forest fire are made by industry in two proprietary formulations of ammonium sulfate and diammonium phosphate. These compounds contain the ingredients of plant fertilizers, N and P, and enhance the growth of trees. Their release into surface waters can yield toxic concentrations of ammonia and promote eutrophication.12/

3.0 THE NATURE OF POLLUTION AND ITS CONTROL IN SILVICULTURE

As stated in preceding sections of this document, forest lands, by their basic characteristics and their size, are potentially contributors of substantial quantities of pollutants to the aquatic environment. An assessment of the actual contribution of forest land to water quality, or the lack thereof, is beyond the scope of the present study. One can hardly evaluate control of pollution without first having established an understanding of the basic nature of pollutional problems in silviculture, however. In this section, the general nature of pollution from forests will be discussed, and certain basic issues will be defined.

3.1 The Basic Approach to Pollution Control

In Section 1.0 the forest management system was identified as the focus of controls for nonpoint pollution. Silvicultural pollution is, therefore, controlled by: (1) the exercise of informed judgment in introduction of potential pollutants (e.g., pesticides, fertilizers) into the forest; perhaps most importantly, (2) by systematic use of methods and management practices which minimize the generation of pollutants from the forest environment; and lastly (3) by containment of pollutants within the forest proper. In other words: (a) introduce potential environmental contaminants into the forest with impunity; (b) manage the forest so that it is a minimum creator of pollutants; and (c) see that pollutants picked up by pollutant transport vehicles are kept within the bounds of the forest ecosystem.

The above precepts must be tempered with the boundaries of technical and economic practicability. It is necessary, furthermore, to evaluate overall control strategies in terms of four related objectives, which are as follows:

1. Timber production in quantity and quality necessary to meet consumer demand.

2. Water production--forests are the most important natural system for providing high quality inland water.

3. Protection of the quality of water emanating from forests for the use of man.

4. Direct preservation of the habitat for woodland aquatic life, and indirect preservation of the habitat for downstream aquatic life.

This study has been addressed primarily to Objectives 3 and 4. Timber production and water production are broad objectives which encompass issues, such as land use and societal priorities, which are recognized as important but are outside the scope of the present study.

3.2 Major Pollutants From Silviculture

Water pollutants generated by forest lands are of essentially the same character and nature as pollutants generated by agriculture. Mineral soil matter (soil sediments) is transported to surface waters by the erosive action of runoff from rainfall and snowmelt. Organic matter of vegetative and animal origin is likewise transported to surface waters by runoff. The organic matter ranges from green vegetative refuse through well-decomposed humic matter. The organic matter sometimes has a high nuisance value (floating debris); sometimes physically interferes with normal aquatic ecology (bark deposited in spawning beds); and nearly always becomes involved in biochemical processes which are nature's way of degrading organic matter and which can markedly alter chemical/biological balances in an aqueous ecosystem--an oft-mentioned imbalance is the depletion of oxygen in water to a point of inadequacy for fish. Fertilizers and fire retardants contribute nutrient elements to the forest environment. These elements, primarily nitrogen and phosphorus, can be transported overland to surface waters in runoff and to both surface and groundwaters by infiltration through groundcover and subsurface soils and mineral formations. Nitrogen is a "water soluble" element in both the reduced (ammonia) and oxidized (nitrite and nitrate) forms and is much more susceptible to transport in runoff water and infiltrating water than is phosphorus. Ammonia is toxic to fish at a concentration less than 1 ppm. The nitrate and nitrite ions are toxic, especially the latter. Phosphorus is chiefly noted for its role in the eutrophication process. Both nitrogen and phosphorus are essential elements for plants, animals, and man--they are pollutants only when present in too high a concentration. Fertilizer and fire retardant uses are polluting practices only to the extent that they create a nutrient imbalance in aqueous ecosystems or generate concentrations in water directly toxic to aquatic and animal life.

Thermal pollution from solar energy is a possible result of silvicultural activities. Strictly speaking, both negative and positive deviations from "normal" temperatures in surface waters are pollutional. However, thermal pollution popularly consists of an elevation of temperature above an accepted norm. The source of thermal pollution from forests is the presence or absence of protection from solar energy. Trees along streams protect the water bodies from the direct rays of the sun, and water temperatures may be substantially higher when these trees are cut.

Finally, pesticides used in silviculture are potential water pollutants. Insecticides, fungicides, herbicides (silvicides) and rodenticides used to control silvicultural pests may be deposited directly in surface water courses by careless application or be transported thereto in surface or subsurface runoff.

Pesticides differ from pollutants enumerated above in that the great majority of pesticides used in silviculture are not materials native to the forest environment. Pesticides furthermore are toxic, by design, to some part of the environment in the accepted mode of use. Control of pesticide pollution is, therefore, a more complex issue than is control of other forest pollutants. Analyses of the question require knowledge of persistence of the pesticide at the point of use, of rates of degradation, of modes of degradation and of biological and chemical metabolites, of mechanisms of transport through the environment to nontarget species in the event that pesticides do not degrade easily and completely to nontoxic end products, and knowledge of toxicity to nontarget species.

Pesticide use in silviculture is inextricably related to ecosystem stability in the forest system. Control of pesticide pollution in the aquatic environment is thus intimately related to controls imposed for protection of the forest ecosystem.

In the present state of silviculture, soil sediment is easily the most important pollutant. Sediments are generated in quantities and concentrations far in excess of pollutant loadings from fertilizers, pesticides, and fire retardants. Sediments degrade water quality physically and biochemically and are an economic burden in urban water uses. It is also of prime importance that sediments are carriers of pesticide residues and nutrient elements. Effective control of sediment discharge will constitute a high level of effective control as well of pesticide and nutrient emissions from forest lands.

3.3 Principal Sources of Pollution

An established, well managed forest can be remarkably resistant to emission of pollutants to the aquatic environment. Incident rainfall is deprived of most of its erosive force by the tree cover, and rates of infiltration through ground cover and into subsurface soils are often high enough that intense rainfall can be accommodated without runoff and the accompanying carryoff of silt by erosion. Such a forest has the attributes popularly decreed by the public to be necessary and desirable as well as technically and economically sound. Many forests do indeed possess such attributes, and are at the same time, useful productive entities. Productivity can be maintained over the long term only with assistance (interference) from man, which necessarily includes harvest of trees. A silvicultural cycle thus includes a relatively long period of growth which can be essentially free of pollutional output, and a relatively short period of harvest and reforestation, which can be a time of high pollutional output. In some silvicultural systems the trees are all-age and are harvested as they mature. Man's encroachment on the forest is in this case every few decades, and the pollutional output is likely to be relatively constant but at a low level.

Insults to the forest come from nature as well as from man. Disease, insects, windstorms, drought, and fire can devastate a forest and degrade it to a polluting condition. Silviculture is concerned with both the prevention of such events and with restoration to a state of health and productivity.

The principal sources of pollution from silviculture thus are disturbances which are natural in origin or are caused by man in the activities of harvesting, reforestation, growth promotion, disease prevention, fire fighting and fire prevention, and rectification of the effects of natural occurrences.

Specific sources of pollutants are indicated in the following subsections.

3.3.1 Sources of sediments: Roads are the principal source of mineral sediments as a result of erosion by water. Roads ordinarily are constructed just prior to the logging operation. They provide access for equipment and serve as routes for transport of logs out of the forest.

Skid trails, the disturbances created by hauling logs from the freshly cut area to yarding areas or roads, are a significant source of sediments.

Yarding and staging areas contain exposed, compacted mineral soil with little capacity to absorb rainfall and which, therefore, are erodible sources of runoff which initiate erosion in less disturbed areas.

The entire harvested area is susceptible to erosion until the scars of harvesting and logging are healed by a combination of engineering design practices and reestablishment of vegetative (grass, shrub, tree) cover sufficient to protect the soil surface and prevent erosion.

Burned-over areas may be deprived of the protection needed to forestall erosion.

Landslides generate a mass of displaced soil and organic sediments, which may be deposited in streams, and leave exposed, unstable and highly erodible surfaces. Landslides are most probable in areas which have been disturbed, e.g., by road construction or fire.

Streambanks vary in erodibility. Similarly, major drainage paths are more exposed and prone to erosion than is the majority of the forest floor. Logging patterns can influence the water hydrology of an area and can increase the peak runoff causing streambank erosion.

Forest debris (leaves, bark, twigs, slash) is a significant source of organic sediment and waterborne wood litter. Waterways used for transport and storage of logs become contaminated to a degree by bark knocked off the logs.

3.3.2 Sources of nutrient elements: Nitrogen, phosphorus, and other mineral elements are present naturally in growing or decaying vegetation and in mineral soils. One or more may be added to the forest environment by fertilization (usually only nitrogen) and in fire retardants (nitrogen and phosphorus). Wastes from wild animals are also sources of these elements. Aerial application of fertilizers is increasingly practiced and drift or error can directly contaminate streams.

3.3.3 Sources of pesticides: Pesticides are applied by man, often by aerial spray, occasionally from the ground. Aerial application can contaminate streams directly, from drift or as a result of error.

3.3.4 Sources of thermal pollution resulting from solar energy: Thermal pollution results from removal of shade cover from stream banks and the solar heating of the water of streams.

4.0 NONPOINT SOURCE POLLUTION CONTROL METHODS

Methods to control pollution resulting from silvicultural activities must include ways to prevent polluting effects from sediments, pesticides, chemical fertilizers, fire retardant chemicals and thermal pollution caused by solar energy.

Control of sediment from soil erosion can be most effective when all factors in the silviculture and harvest system are systematically planned with soil and water management to prevent soil erosion as a principal objective. The selection of a harvest system is basic to sediment control and must be responsive to a range of conditions on any particular logging location. Selective logging methods are likely to generate low yields of sediment at frequent intervals. In contrast, the practice of clearcutting all the trees from an area at one time can result in sediment yields that are confined to one continuous period of perhaps 2 to 5 yr, followed by a long period of time when the forest floor is undisturbed, giving maximum control of erosion and minimal outputs of sediment pollution.

During the harvesting period sediment can also be controlled by the proper selection of a logging system. To harvest a given location there is usually a choice between two or more major systems, these being--tractor; high lead; skyline; balloon; and helicopter, or variations and combinations of these systems which vary substantially in physical impact on the forest and in potential for erosion and sediment production. These harvest systems also vary substantially in cost and in adaptability to forest types and different terrains.

In addition, research has clearly documented that logging roads and trails over which logs are dragged are major sources of erosion and sediment. However, pollution from these sources can be substantially prevented or controlled by careful planning of the layout, construction and use of roads, including the after-harvest use.

Seeded grasses, legumes or other vegetative cover can effectively stabilize soils on such locations as logging-road banks, unused and abandoned road surfaces, fire lanes, and open harvested areas. Grass cover is usually temporary, but may be a permanent part of the forest management system.

In some locations vegetative cover alone cannot effect sediment control, and engineering structures are requi. .d to manage water to prevent erosion or trap sediment in the overall forest management control system.

There is evidence that controlled and well managed grazing of domestic animals can benefit the forest and help minimize erosion. On the other hand, improper or excessive grazing will compact soil, remove cover, cause downhill trails and promote erosion.

A major factor in any coordinated system to control sediment is effective reforestation, which is considered to be the most important remedial control.

Stands of trees should be propagated in harvested areas, mismanaged areas, and areas devastated by disease, fire and other natural causes. Methods used to propagate new stands of trees range from essentially unmanaged natural regeneration to hand planting of genetically improved nursery stock.

Pesticide pollution control is a current and continuing management problem. Some of the approaches employed to effect better control follow.

. Rigorous management of aerial application to protect nontarget areas, including bodies of water, and to maximize effectiveness on target species.

. Application from the ground on specific targets, including direct injection into infected or weed trees.

. Scheduling of applications for maximized effectiveness and minimized dispersal to nontarget areas.

. Avoidance of highly persistent, bioaccumulated pesticides.

. Minimun use of prophylactic applications.

. Increased use of cultural and mechanical methods to control pests and weeds.

. No spray, with complete dependence on natural prey-predator relationships in combination with cultural and mechanical control.

The preferred use of pesticides for insect and disease control is one of the more undecided issues at this time in silvicultural management.

Fertilizers can be safely used in silvicultural management. Control measures to prevent water pollution from the application of fertilizers in a forest consist of using the amounts and kinds based upon a soil test, and in careful application procedures to avoid streams.

Control of water pollution from the use of fire retardants includes both the precision application of material and location of drops in relation to streams or lakes. Unless these chemicals are carefully used, they represent an almost certain source of water pollution.

In recent years the warming of streams from solar energy has been widely discussed. Control measures to prevent such thermal pollution will require policy planning followed by planned retention of riparian vegetation needed to achieve thermal pollution goals.

4.1 Control of Sediment Sources

Inorganic and organic sediment is a m contribution to deterioration of water quality from commercially tim ed watersheds. It is generated primarily during specific functions in the overall silvicultural management activities. Sediment may or may not be directly related to man's management procedures. Substantial research has been conducted on this subject by the collective forest industry. In addition, a great deal of sediment control technology used in highway construction and in agriculture is being effectively adapted to sediment control from forest roads, logging procedures and the watershed area at large.

Sediment control technology is sufficiently advanced and mature enough to provide a scientific and engineering procedural base for extensive implementation on a secondary watershed basis, and to permit the formalizing of plans to effectively protect the integrity of surface waters discharged from forested watersheds. Such plans and procedures should, however, be tested in the field to develop a realistic picture of man's ability to control sediment pollution.

Control of sediment involves control of three factors: (1) the quantity and intensity of runoff; (2) the susceptibility of ground cover and mineral soils to erosion; and (3) the quantity and placement of certain types of forest debris. Control methods are directed generally at the establishment and maintenance of vegetative cover to reduce the erosive impact of rainfall, to bind mineral soils in a root network and to furnish an organic soil cover permeable to moisture and with high moisture retention capacity. The vegetative cover, in addition, enhances the permeability of mineral soils to water. Rainfall, therefore, infiltrates readily, and runoff is minimized. When disturbance of forest cover and exposure of mineral soils is necessitated, to build logging roads for example, engineering and vegetative stabilization procedures are called for, as well as design of the disturbance (such as a road) to be minimum both in size and in susceptibility to erosion.

4.1.1 Sediment control by proper design of the harvest system: Erosion and sediment generation can be markedly affected by proper selection and design of harvesting and logging systems, and by construction and use of accessory roads and skid trails.

Surface soil erosion is described by Swanston and Dyrness[13/] as a two-stage process--detachment and transport. Detachment is accomplished when the raindrop with high kinetic energy strikes bare soil of medium to fine texture and turns it into flowing mud. As long as the 2.5 to 7.5 cm (1 to 3 in.) layer of surface organic matter remains intact, there is seldom any detachment and subsequent transport of sediments. In fact, there is seldom any surface runoff water.

In addition to bare soils, compaction of soils is also important in inducing surface soil erosion. Compacted soils have lower rates and lower capacities for infiltration of water. When rains and water from melting snows cannot move by infiltration into the soil as fast as they must be removed, surface runoff and a soil erosion hazard exists.

Logs skidded over the surface of the soil can cause soil compaction that may be evident for 5 yr or more. When skidding is up or down the slope, the results are bare soil that is easily detached by the falling raindrop, a compacted soil beneath with a low rate of infiltration, and a channel through which soil sediments are transported rapidly to the streams.

Logging methods that result in a large percentage of bare soil and of compacted soil are methods that must be avoided in this environmental age of the 1970's.

Dyrness[14/] studied the relative soil disturbance incident to logging transport by tractor, high lead, skyline, and balloon systems. The data in Figure 6 and Table 3 show that balloon logging results in a larger percentage of undisturbed area and a smaller percentage of the logged area with compacted soils. Sediment washed from a logged area and into a stream is directly proportional to soil disturbance and soil compaction.

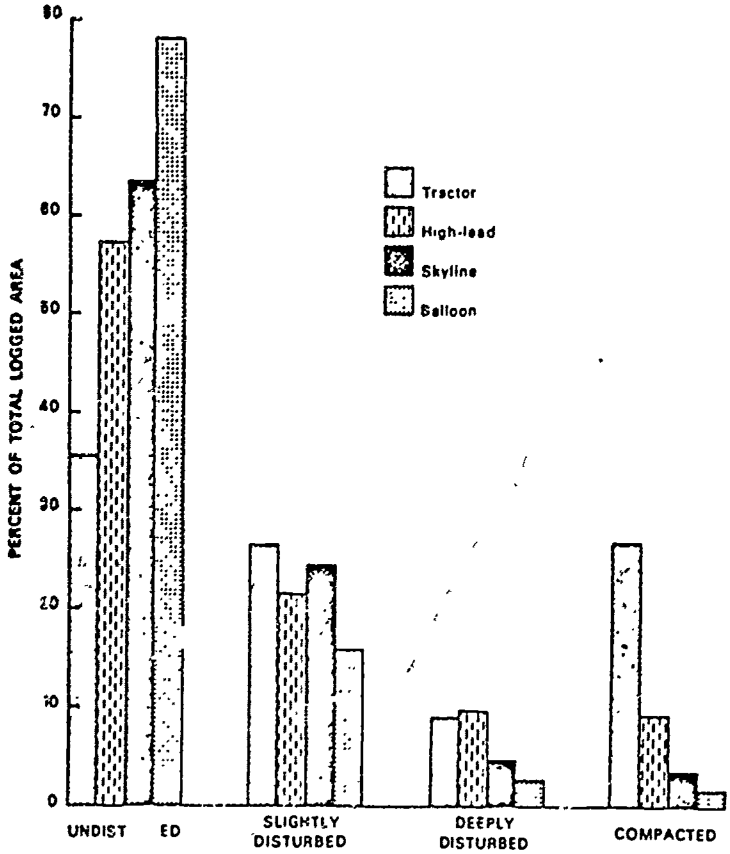

Figure 6 - Soil Surface Condition Following Tractor, High-Lead, Skyline and Balloon Logging in the Western Cascades of Oregon

TABLE 3

EFFECTS OF LOG TRANSPORT SYSTEM ON FOREST SOILS

Log Transpor System	Percentage of Logged Wat shed with Bare Soil	Percentage of Logged Watershed with Compacted Soil
Balloon	6.0	1.7
Skyline	12.1	3.4
High lead	14.8	9.1
Tractor	35.1	26.4

Of great significance to potential soil sediment loss from logged areas is the difference in the percentage of soil surface area compacted by two logging systems. Two hundred separate bulk density measurements were made to a depth of 5 cm (2 in.) on soils before and after logging. The logging systems compared were high lead and tractor.[15]

Slopes on the areas logged by the high-lead system during the wet season in the winter of 1963 varied from 20-80% and averaged about 55%. This was in contrast to the area with 10-40% slopes, which averaged about 25%, that was logged by tractor during the dry season during the fall of 1963.

From Figure 7 it can be observed that following tractor logging, soil compaction increased an average of 48.2% on 26.9% of the area logged. This is in comparison with an increase in soil compaction of 33.7% on only 9.1% of the area logged by the high-lead system.

The potential for sediment generation, from high erodible soils, was demonstrated in a study in central Idaho.[16] Monitored watersheds not logged, and where no logging roads were constructed, lost an average of 0.025 metric tons/sq km (140 lb/sq mi) of soil sediment per day over the 6-yr period under study. Both jammer logging and skyline logging of similar watersheds and the roads built to transport the logs resulted in an increase of soil sediment loss by a factor of 750.

Rice, Rothacher, and Megahan[17] have summarized from published and unpublished data the percentage of soil in logged areas made bare by various logging systems in Washington, Oregon, Idaho, and California. The assumption can be made that when other ecological factors are similar, the more bare soil exposed the greater the soil sediment that moves to pollute streams.

If this assumption is correct, the control of soil sediment can be achieved by the selection of the logging system that exposes the least mineral soil. The greatest percentage of soil bared resulted (in decreasing order) from: jammer (group selection), tractor (clearcutting), and cable (selection).

Klock[18] compared soil disturbance during logging and soil erosion after logging, using the logging systems: cable skidding, tractor skidding on bare soil, tractor skidding on snow, and helicopter.

The percentage of the logged area observed to be eroded following logging plus two summer rainstorms was:

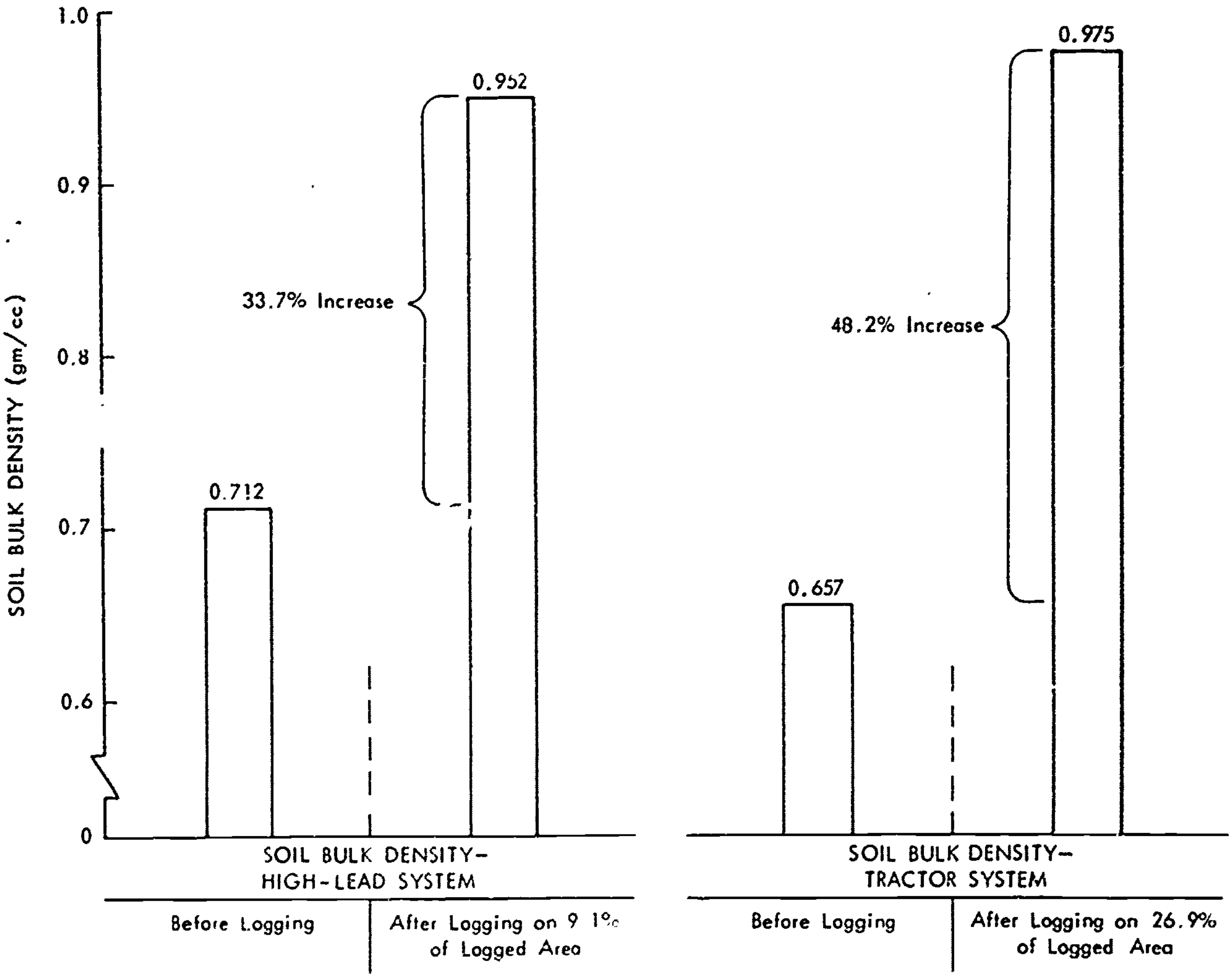

Figure 7 - Effect of Logging Practices on Soil Compaction

TABLE 4

EROSION AS A FUNCTION OF LOGGING SYSTEMS

Logging System	Percentage of the Logged Area Observed to be Eroded
Helicopter	3
Tractor skidding on snow	13
Tractor skidding on bare soil	31
Cable skidding	41

Assuming that these four systems are applicable to a watershed to be logged, and that the costs were comparable, the order of preference would be from first to last: helicopter, tractor skidding on snow, tractor skidding on bare soil, and cable skidding.

Dyrness[14/] compared the relative soil disturbance hazard of four logging transport systems: tractor, high lead, skyline, and balloon. Using only one of his categories, soil compaction, as an indirect measure of erosion potential, the systems responsible for the greatest soil compaction, in order from highest to lowest, were: tractor, high lead, skyline, and balloon.

In the selection of a log transport system with the least sediment pollution hazard under the conditions monitored, the priorities would be: balloon, skyline, high lead, and tractor.

Dyrness[19/] analyzed the cause of 47 mass soil movements in the winter of 1964-1965 on the H. J. Andrews Experimental Forest in western Oregon. About 72% (34) of the mass movements were associated with road construction and 17% (8) of these were in areas that had been logged. Only 11% (5) of the mass soil movements occurred in the areas undisturbed by man; the remaining 42 were related in some way to man and machines. Soils developed from pyroclastic rocks (volcanic rock fragments such as tuff or breccia) occupy only 37% of the total area studied, but were responsible for 94% (44) of the mass soil failures. Soils on a southern or southwestern aspect were more stable than those on any other aspect, probably because they tend to be shallower and drier. Slopes steeper than 45% were responsible for 83% (39) of all mass soil failures.

The Dyrness study confirms the generally expressed opinion that logging roads are the principal source of soil sediment.

On deep soils in western Oregon, with slopes up to 110%, sediment yields were measured by Fredriksen[20] for 9 yr following clearcut logging by the skyline system (no roads and no skid trails versus patch-cut logging on 25% of the total forested area by the high-lead system, 2.65 km (1.65 miles) of roads). An uncut forest nearby was used for comparison.

Although 100% of the clearcut area was logged as against only 25% of the total area that was patch-logged, the clearcut area yielded less than 4% as much soil sediment. The reason was because there were no roads in the clearcut area, but 2.65 km (1.65 miles) of roads in the patch-cut area (Table 5).

TABLE 5

SEDIMENT LOSSES RESULTING FROM SILVICULTURAL AND LOG TRANSPORT SYSTEMS[a]

Silvicultural Harvesting System	Logging Transport System	Logging Roads: Km (Miles)	Logging Roads: % of Area Harvested	Sediment Lost in 9 Yr Metric Ton/Sq Km/Yr (Tons/Sq Mi/Yr)
Control (no harvest)	0	0 (0)	0	32.5 (93)
Clearcutting	Skyline	0 (0)	100	107 (307)
Clearcutting in patches	High lead	2.65 (1.65)	25	2,794 (7,982)

a/ Fredriksen, R. L., "Erosion and Sedimentation Following Road Construction and Timber Harvest on Unstable Soils and Three Small Western Oregon Watersheds," USDA Forest Service Research Paper PNW-104, 15 pages (1970).

A comparison of the soil sediment yields was as follows: control, 32.5 metric tons/sq km/yr (93 tons/sq mi/yr) of soil sediment; clearcutting (no roads), 107 metric tons (307 tons); and clearcutting in patches, 2.65 km of road (1.65 miles of road), 2,794 metric tons/sq km/yr (7,982 tons/sq mi/yr).

The roads, from which the sediment came, met the U.S. Forest Service standards for all-weather roads with culverts, cross drains, base rock, and crushed rock surface. The construction of the 2.65 km (1.65 miles) of roads exposed 6.3 hectares (15.6 acres) of bare soil in order to harvest three patches of timber that totaled 25 hectares (61 acres).

On the U.S. Forest Service lands in the Pacific Northwestern Region (Region 6, Figure 8), private timber contractors construct more than 4.827 km (3,000 miles) of logging roads each year at a cost of $50 million. A special team was appointed to study road construction performance on 63 recently completed roads located on every forest in Region 6.[21]

<u>Principal conclusions and recommendations for sediment control included</u>:

(1) On slopes greater than 60% no roads should be built until all other alternatives have been exhausted. These include a change in the harvesting method, such as the use of skyline, helicopter, or balloon logging systems.

(2) In critical areas, assign the most experienced personnel to supervise tne timber sales contract.

(3) More time and expertise should be assigned to geotechnical investigations before road construction. This includes geologic and soil surveys to determine the most stable location for roads and for sources of gravel, rock, and other subgrade materials.

(4) More flexibility should be given to timber sales contractors and U.S. Forest Service personnel to adapt road construction techniques to local conditions.

(5) Road construction should be started as soon as the weather is suitable after the timber sales contract is awarded.

(6) Road construction equipment is often too large for efficient use in building logging roads. Furthermore, newly designed skyline logging equipment is too large for transport on the narrow logging roads. Building wider roads invites more landslides and more erosion sediments, and procedures have not been developed to fly the equipment to the site by helicopter skycranes.

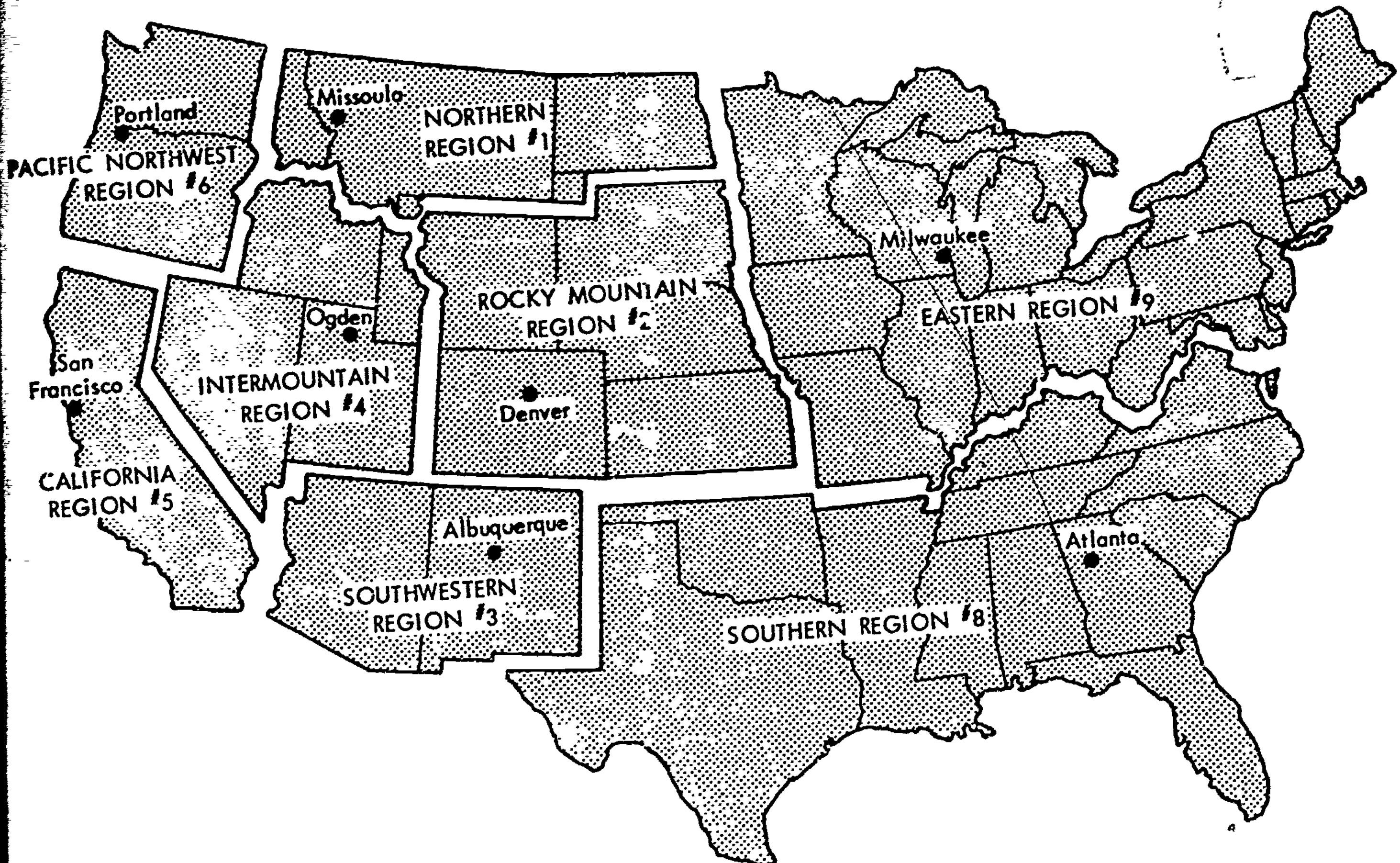

Figure 8 - Forest Service Regions

Although variations occur because of differences in forest ecosystems, soils, geology, climate, and logging systems, specifications given by Kochenderfer[22/] for the Appalachian Region are indicative of essential techniques for the control of soil sediment resulting from the construction and use of logging roads. In the Appalachian Mountains, logging roads should be laid out on grades between 3% (to permit surface water to drain) and 10% (to avoid erosive velocities of water). Erosion on newly-built roads can be reduced by seeding, with a mixture of fescue grass and ladino clover, all bare soil in cuts and fills as soon as possible and on all roadbeds after logging has been completed.

Filter strips are defined as undisturbed forest areas and should be left to collect soil sediment between streams and l gging roads. Kochenderfer recommends that in the Appalachian Region, roads should be built at least 30 m (100 ft) from a stream to permit the unbroken forest biomass to absorb the surface runoff water and to deposit soil sediment before it pollutes the stream. Seepage areas in the logging road can be drained by an open-top culvert set at an angle to permit drainage, or by the construction of broad-based drainage dips.

Using the data from the H. J. Andrews Experimental Forest in western Oregon, the Federal Water Pollution Control Administration[23/] compared the logging road density, the acres needed for roads, and the percentage of the roads with specific grades, for a road system that was laid out systematically versus a system laid out at random (Table 6). The random system had 12% more roads per unit area, 37% more area in roads, and 267% more roads with grades between 8% and 12%.

Sediment control should be engineered into road design and construction during the planning phase. Erosion prevention techniques include the building of logging roads with widths, grades, cut, and fills compatible with soil and geologic stability; the maximum efficient use of natural and artificial drainage; and limitation of use of the roads by heavy equipment when subgrades are saturated. For logging operations the equipment should be selected that causes the least soil disturbance.

The Coweeta Forest Watershed in North Carolina[24/] is proof that a great deal of sediment control can be designed into the management of a watershed during and after logging operations. Water quality was monitored from two sites in this watershed. The "logger's choice" site, which had traditional logging roads (Figure 9) and poor logging methods, produced stream water turbidities as great as 5,700 ppm during storms with average rainfall. A 144-hectare (356-acre) hardwood-covered watershed was engineered for sediment control with proper roads and proper

TABLE 6

A COMPARISON OF ROAD PARAMETERS ON THE
H. J. ANDREWS EXPERIMENTAL FOREST IN WESTERN OREGON[a/]

Parameter	Logging Road System: Systematic	Logging Road System: Random
Road density, km/sq km (miles/sq mi)	3.08 (4.97)	3.47 (5.59)
Area needed for road construction, hectares/sq km (acres/sq mi) of watershed	10.65 (68.00)	14.6 (93.00)
Percentage of logging road system having grades of (%)		
0 - 4	45.4	37.7
4 - 8	40.6	10.9
8 - 12	14.0	51.4
Total	100.0%	100.0%

a/ "Industrial Waste Guide on Logging Practices," Federal Water Pollution Control Administration, U.S. Department of the Interior, 40 pages (1970).

Figure 9 - A "Logger's Choice" Traditional Unimproved Logging Road Located in a Southeast Hardwood Forest. (Courtesy U.S. Forest Service)

logging methods. Figure 10 shows the grassed surface of a road constructed to an engineered grade on part of a 73-hectare (180-acre) clearcut and a 32-hectare (80-acre) thinning operation. The maximum recorded turbidity from this watershed was 400 ppm for a rainstorm which is expected to occur only once in 100 yr. The difference in water quality from these two practices is graphically seen at the confluence of streams discharging from each area. In Figure 11 the clearflowing stream is seen on the left and the right-hand stream is discharging sediment from the logger's choice area.

Some technology does not transfer successfully without radical adaptation. This statement applies to the standard and routine technique in the conterminous 48 states of constructing fire lanes to slow or halt the spread of a fire. When the same practice is tried in Alaska on fine-textured soils with permafrost, the surface of the permafrost melts, the mineral soils above the ice prevent percolation, the ice may collapse, and cavernous erosion as well as surface gullies result. The silts and clays add soil sediments to nearby streams and lakes.25/

The techniques used to successfully control erosion on bare soils with permafrost include the building of a terrace across the slope of the fire lanes at intervals of 27 to 46 m (30 to 50 yd) to divert surplus surface water into undisturbed vegetation along the sides of the fire lane, and seeding an adapted grass and legume mixture over the entire fire lane after liming and fertilizing the soil according to the recommendations resulting from a chemical soil test. The most successful grass seeded so far has been Manchar smooth bromegrass.

Another technique to control sediment that can be used in Alaska on fire lanes is recommended by Lotspeich, Mueller, and Frey.26/ This system consists of bulldozing the natural and protective organic layer back over the mineral soil of the fire lanes, after the fires have been suppressed and before the bulldozers leave the area.

4.1.2 Sediment control by reforestation: The preferred way to control sediment generation from previously forested but now eroding lands is to plant trees or to encourage establishment of good tree stands by natural regeneration. Tree planting on areas recently clearcut and on eroded soils in forested areas has been an increasingly popular and effective practice to enhance water quality. The U.S. Forest Service, the state forest services, and the private forest industry have led in this silvicultural activity. Furthermore, the U.S. Soil Conservation Service has made a major contribution to the science and practice of tree planting. Since 1930, 14.7 million hectares (36.3 million acres) have been planted to trees.

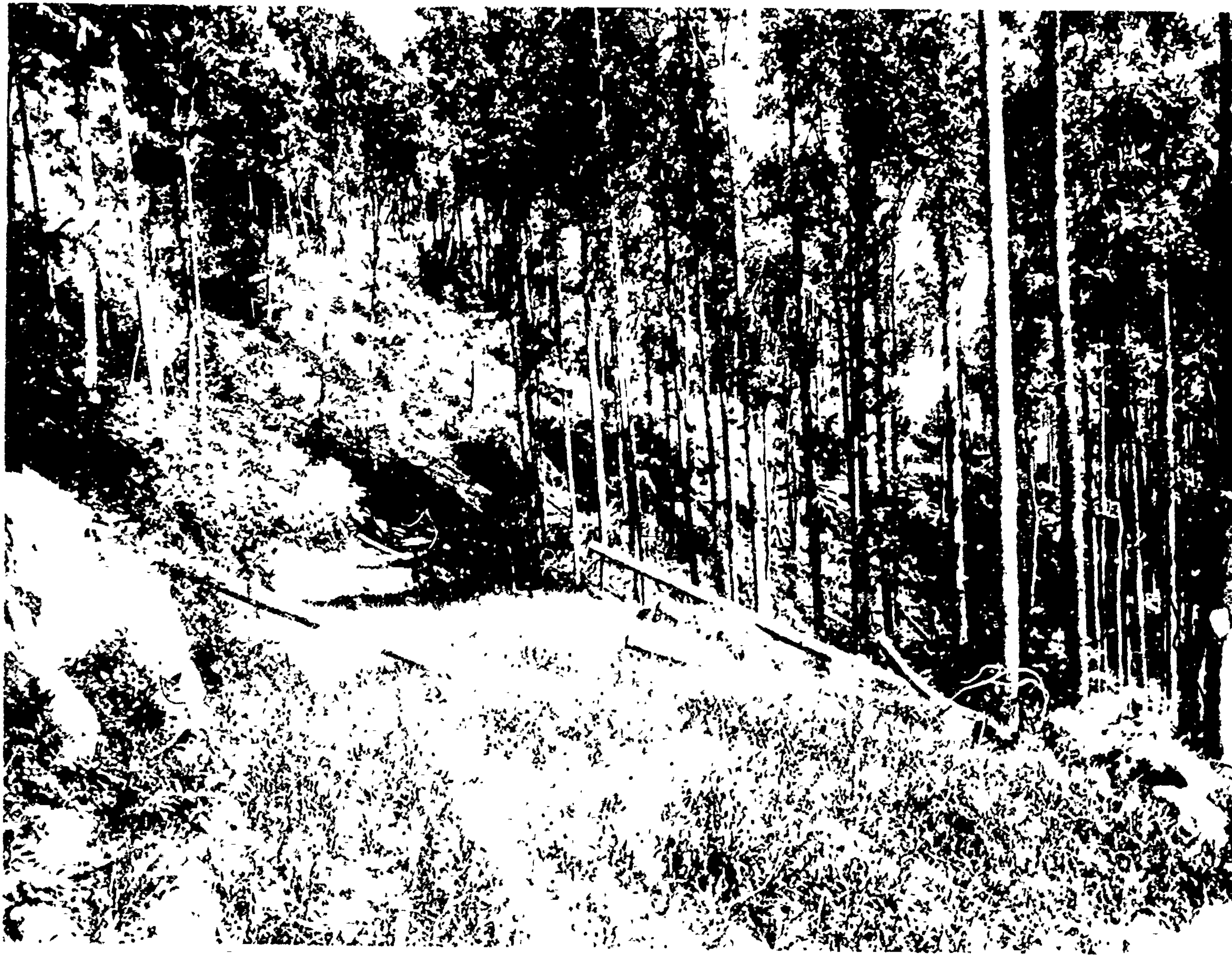

Figure 10 - Forest Road Engineered on Specified Grade Through a Stand of Hardwood in the Southeast Planted to Grass. (Courtesy U.S. Forest Service)

Scientific guidance is given by the Soil Conservation Service to private landowners in the selection of forest tree species that are suitable to the soils. Soil interpretations for woodland use are based upon 22,000 plots of trees planted or managed on model soils throughout the United States where climate and soils favor tree growth. On the test plots are measured the site index (height over age at 50 or 100 yr), soil sediment erosion hazard, equipment limitations, windthrow hazard, and annual growth rate in volume of wood.[27]

Information on woodland suitability groups of soils is incorporated in individual farm/ranch conservation plans and also is included for all soil mapping units in published county soil survey reports.

An example of how to use the woodland suitability groups of soils is presented in a recently publish ' soil survey report of Chilton County in central Alabama.[28] The so survey report indicates that 26 hectares (65,000 acres) of land in Chilton County are in need of tree planting for one or more reasons, including soil sediment control for the enhancement of water quality. To assist in selecting the most suitable tree species for planting, all soil mapping units in the County are placed into one of 15 woodland-soil suitability groups, based upon their ecological similarities. Each of the 15 groups of soils on the County soil map are assigned a corresponding group of adapted (suitable) trees of high commercial value with predicted site index and volume of annual growth per acre.

"Soil-Vegetation Surveys in California" describes three kinds of maps: generalized soil maps, soil-vegetation maps, and timber-stand/vegetation cover maps.

Soil maps are available for a part of California on a scale of 2.04 cm/km (1/2 in./mi.)[29] Information shown on the soil map is: soil series, soil depth classes, dominant trees/shrubs, dominant grasses, and timber production site index classes. Soil-vegetation maps are printed on a scale of (8.16 cm/km) 2 in./mi. On these maps are shown soil series; vegetation types such as forest types, grass associations, meadows, and marshes; site quality potential for timber production; and miscellaneous areas such as bare rock. Timber-stand/vegetation cover maps were published at one time, but their publication has been terminated. These maps can be used to assist in determining what species to plant for the maximum assurance of success.

Scientific guidance is thus readily available from many sources the U.S. Soil Conservation Service, the U.S. Forest Service, the state forestry and natural resource services, the state agricultural experiment stations, and the state departments of agriculture) to assist in selection of a plan to plant forest trees of high value on watersheds to enhance water quality.

4.1.2.1 Reforestation of watersheds in Tennessee: Lull and Reinhart[30] quote results of sediment reduction resulting from tree planting and check dam construction on the White Hollow and Pine Tree Branch watersheds in Tennessee. Planting about one-third of the severely eroded White Hollow watershed resulted in a reduction of an average storm sediment yield from 6.6 metric tons (7.3 tons) in 1935-1936 to 0.27 metric tons (0.3 tons) in 1954-1955--a reduction of 96% in 20 yr. Planting two-thirds of the Pine Tree Branch watershed in 1942 reduced sediment yield from 155.5 metric tons/hectare/yr (24.3 tons/acre/yr) to 2.46 metric tons/hectare/yr (1.1 tons/acre/yr) in 1960--again a reduction in sediment of 96% in 18 yr.

Lull and Reinhart, also in analyzing and summarizing the work of Wark and Keller, stated that in 15 subbasins of the Potomac River, the percentage of land area with forest cover was inversely related to the sediment yield, as follows (Table 7):

TABLE 7

INFLUENCE OF FOREST COVER ON CONTROL OF SEDIMENT YIELD BY EROSION

Land Area with Forest Cover (%)	Sediment Yield Metric Tons/Sq Km/Yr (Tons/Sq Mi/Yr)
20	140 (400)
40	70 (200)
60	31.5 (90)
80	15.75 (45)
100	7.7 (22)

4.1.2.2 Reforestation in Mississippi: In north central Mississippi (on abandoned, gullied, loessial, silt loam, acid soils) surface and gully erosion is as serious as in any area in the U.S. For many years it has been common practice to plant trees on such sites to control soil losses and sediment pollution of streams. One problem is to determine which forest tree species or mixtures of species are most effective in increasing infiltration and thereby reducing surface water runoff and sediment.

McClurkin[31] studied the change in soil infiltration that took place during 1951 and 1966 under several species and mixtures of species. The data are in Table 8.

TABLE 8

COMPARATIVE CHANGES IN WATER INFILTRATION RATES IN SURFACE SOILS FOLLOWING 15 YEARS OF TREE GROWTH

Species Planted	Year	Infiltration Rate mm/hr
Red cedar plus loblolly pine	1951	42
	1966	132
Shortleaf pine	1951	38
	1966	141
Loblolly pine	1951	85
	1966	187
Red cedar plus shortleaf pine	1951	43
	1966	43
Red cedar	1951	133
	1966	84

The data indicate that during the 15-yr period increases in infiltration were recorded for: red cedar plus loblolly pine, shortleaf pine, and loblolly pine. Red cedar plus shortleaf pine did not increase infiltration, and soil under red cedar planted alone decreased in infiltration rate during the period.

Ursic[32] monitored runoff and sediment from three watersheds in north Mississippi, each comprising 2 to 3 acres. The background data were collected during 1 0-1963, after which Watersheds I and III were burned and planted to loblolly pine. Watershed II remained untreated to serve as the control.

Sediment yields from Watersheds I and III increased by factors of 18 and 78 during the first year after burnings and the increases appeared to have persisted from 2 to 4 yr (Table 9). Although further comparisons may be somewhat masked by the natural improvement of the vegetation on the control, average sediment yield from each of the two treated units 5 to 7 yr after the pine was planted was less than one-half that during the years prior to planting.

TABLE 9

EFFECTS OF BURNING ON SEDIMENT PRODUCTION AND OF TREE PLANTING ON SEDIMENT CONTROL[a]

Year(s)	Kilograms of Sediment per Hectare per Year (Oven-Dry Basis) (Pounds of Sediment per Acre per Year) — Treatment: No Burning, No Planting of Trees (Watershed II)	Burning and Planting to Loblolly Pine Trees (Watershed I)	Burning and Planting to Loblolly Pine Trees (Watershed III)
1960-1963[b]	635 (690)	77 (84)	68 (74)
1964	588 (639)	1,418 ([illegible]542)	528 (5,759)
1965	259 (281)	81 (88)	477 (519)
1966	115 (125)	30 (33)	43 (47)
1967	137 (149)	22 (24)	99 (108)
1968	128 (139)	53 (58)	29 (32)
1969	91 (99)	29 (32)	31 (34)
1970	193 (210)	24 (26)	35 (38)

a/ Ursic, S. J., "Hydrologic Effects of Prescribed Burning on Abandoned Fields in Northern Mississippi," USDA Forest Service, Research Paper SO-46, 20 pages (1969). Note: Data from 1967 through 1970 were transmitted by letter, Ursic to Donahue, dated 5 June 1973, with this caution: ". . .please consider these data tentative. . ."

b/ Watersheds calibrated during 1960-1963 before treatment.

4.1.2.3 Sediment control by reforestation on clearcut areas without burning: It has been the traditional and recommended practice by professional foresters that tree limbs, tops, and other wood material be burned after a clearcutting operation to remove the fire hazard and to expose the mineral soil required for the reforestation of intolerant species of trees. For 8 yr now, U.S. Navy Foresters[10] have demonstrated that it is technically practical to establish new Douglas fir stands by artificial seeding and without burning, on level land and on slopes up to 25%. The following report has been prepared by the U.S. Navy and is here reported for the first time exclusively for this document.

THE U.S. NAVY REPORT

For the past 8 yr, Navy foresters in the Puget Sound area have been direct-seeding Douglas fir (*Pseudotsuga menziesii*) without burning the slash created by clearcutting operations. The slash remaining from logging operations is bunched or piled in windrows by using a crawler tractor equipped with a brush blade (Figure 12).

The windrow system of slash disposal was first used by the Navy in 1965 at Camp Wesley Harris, a Marine Corps rifle range located near Bremerton, Washington. The sale covered 4 hectares (10 acres) on which slash left from logging was windrowed in 1965. In March 1966 the area was seeded with endrin-treated Douglas fir seed, using 0.46 km of seed per hectare (1/2 lb of seed per acre) applied with a cyclone seeder. At the present time, the area contains a fully stocked stand of Douglas fir.

The windrow method proved so successful that its use was continued. The following additional areas have been windrowed and seeded to date:

Station	Hectares	(Acres)	Date Logged	Date Seeded
Indian Island	20	(50)	12/65	3/66
Bangor Annex	19	(48)	9/66	2/67
Camp Harris	16	(40)	12/66	2/67
Lake Hancock	6	(16)	12/66	2/67
Bangor Annex	13	(31)	5/68	2/69
Indian Island	18	(45)	2/69	3/69
Bangor Annex	16	(40)	7/69	2/70
Bangor Annex	8	(20)	7/69	2/70
Indian Island	24	(60)	8/71	2/72

All the areas listed above are fully stocked with Douglas fir (Figure 13). Another 20 hectares (50 acres) of Bangor Annex was logged during May 1973 and will be direct-seeded in February 1974. Windrowed slash has deteriorated at a more rapid rate than had been anticipated, and soil particles

Figure 13 - Five-Year Old Douglas Fir Trees That Were Seeded Directly onto a Slash Windrowed Area, without Control-Burning. (Courtesy Department of the Navy)

mixed with the slash support thrifty Douglas fir seedlings. Some natural regeneration of such species as western hemlock (Tsuga heterophylla), western white pine (Pinus monticola), western red cedar (Thuja plicata), lodgepole pine (Pinus contorta) and grand fir (Abies grandis) takes place, but not of sufficient numbers to seriously compete with seeded Douglas fir. Douglas fir is considered as subclimax in the area, and fully stocked stands are not likely to become established under natural conditions due to the higher degree of tolerance of some of the other species. The predominating deciduous type, usually on wetter sites, is red alder (Alnus rubra), associated with bigleaf maple (Acer macrophyllum). Early seeding of Douglas fir following harvest and windrowing is necessary to establish this valuable species to the desired degree of stocking, particularly on the more moist sites. Regeneration of Douglas fir by direct seeding has the advantage of getting the species established for an early start in competition with red alder. Where seeding is left to nature, red alder is capable of suppressing Douglas fir on many sites in the area. Direct seeding of Douglas fir at an early date following logging tends to offset the advantage given alder.

Most soils are of glacial origin (glacial drift and outwash) and tend to be gravelly or sandy on the surface at most locations. They vary from light to medium in texture and from shallow to moderately deep. Some soils are underlain by a cemented hardpan layer of varying thickness which retards vertical movement of water.

Terrain where the method has been used varies from almost flat to slopes of 25%. From the standpoint of environmental protection, windrowing accomplishes two purposes. Emission of pollutants into the air is precluded, and soil erosion is checked. The exclusion of fire as a means of slash disposal is desirable in fuel and ammunition storage areas because of the safety factor.

The following clause was used in the timber sales contracts, which required slash treatment by windrowing:

> "The slash shall be disposed of by bunching or piling in windrows. The windrows shall be continuous strips not more than 20 feet wide and not less than 75 feet apart, such measurements to be determined at ground level. The windrows shall be at least 75 feet from any existing road and standing timber. As a fire precautionary measure, windrows shall be broken into segments approximately 5 chains (330 feet) in length. The break between segments shall be no less than the width of a dozer blade. When the grade exceeds 15 percent for an area of more than one acre, windrows shall be constructed on the contour at right angles to the direction

of the slope. Windrows shall be constructed by a crawler tractor equipped with a brush blade having a minimum of seven teeth. These teeth shall project at least 12 inches below the bottom of the blade."

No problems have occurred to date using the windrow system. It is estimated that the cost of windrowing slash is between $2.12 and $4.25 per cubic meter ($5 and $10 per thousand board feet) of harvested wood.

It is reported the windrow system of slash disposal and direct seeding of Douglas fir following harvest has proven successful beyond any doubt, as indicated by field observations and the pictorial evidence in Figures 12 and 13. The Navy will continue the use of this method on areas where regeneration of Douglas fir is desired.

4.1.2.4 Reforestation for sediment control on surface mine areas: The State of Pennsylvania passed a Conservation Act in 1945, amended in 1963, requiring surface mine operators to post a bond equal to $247 per hectare ($100 per acre) of mine spoils, refundable when the spoils have been satisfactorily revegetated with grasses plus legumes or trees/shrubs. From 1945 to 1963, 3,400 hectares (84,060 acres) of strip mine spoils had been been planted to trees/shrubs. The Research Committee on Coal Mine Spoil Revegetation in Pennsylvania[33] has been the technical body to coordinate research on this subject.

Spoils from bituminous mines are extremely variable as to acidity (pH), stoniness, and slope, with acidity being the principal determinant of success or failure of vegetation. Acidity may vary from below pH 3.5 to above 7.5, stoniness may vary from few to 100%, and slope from zero to more than 25%.

Trees recommended for planting on median (Group C) spoils include Austrian pine, jack pine, pitch pine, red pine, scotch pine, white pine, Japanese larch, black locust, red oak, and European alder. Shrubs approved are autumn olive, lespedeza bicolor, and mugho pine.

Before planting black locust trees, an application of fertilizer consisting of 37 km of N and 74 km of P_2O_5 per hectare (40 lb of N and 80 lb of P_2O_5 per acre) is recommended.

4.1.3 Sediment control by planting grasses and legumes: Stabilization of disturbed soils and geologic materials in forest areas, especially on new road cuts and fills and on logging road roadbeds when current logging operations have ceased, is usually more rapid when grasses and legumes are seeded than when trees are planted.

On the H. J. Andrews Experimental Forest in western Oregon, sediment yields were compared from a bare and seeded-to-grass road cut (Table 10), as reported by Wollum.[34]

TABLE 10

COMPARATIVE SEDIMENT YIELD FROM BARE AND SEEDED ROAD CUT ON THE H. J. ANDREWS EXPERIMENTAL FOREST IN WESTERN OREGON[a]

Condition of Plot	Period of Measurement	Sediment Yield Kilograms/Hectare (Tons/Acre)
Bare	9/58 to 9/59	23,370 (12.7)
Seeded to grass	9/59 to 9/60	7,728 (4.2)
Seeded to grass	9/60 to 9/61	4,232 (2.3)

a/ Wollum, A. G., "Grass Seeding as a Control for Roadbank Erosion," USDA Forest Service Research Note 218, 5 pages (1962).

The plot was fertilized with 147 kg/hectare (160 lb/acre) of 16-20-0 fertilizer and seeded with an 86-8-4 mixture of ryegrass, meadow fescue, and highland bentgrass at a rate of 90 kg/hectare (98 lb/acre) in April. The sediment yield was reduced by 67% the first year and by 82% the second year.

Planting of grasses/legumes on strip mine spoils in Pennsylvania has been mandatory since 1945. From 1945 to 1963, 7,885 hectares (16,489 acres) of mine spoils had been revegetated with grasses/legumes.

Recommended for planting on the Group C and Group D (inferior) classes of spoils are tall oatgrass, tall fescuegrass, and redtop grass. The one legume recommended is lespedeza sericea.[33]

4.1.4 Streamcourse classification for erosion control: "Title 2400--Timber Management" and other "Titles" of the U.S. Forest Service Manuals state environmental objectives very clearly and expect compliance in the forest but at this time there is inadequate organization and manpower for relevant research and demonstrations.

Monitoring of pollution and compliance with environmental objectives during implementation of a timber sale contract is a developing technology that must yet regionalize appropriate techniques in methodology to control pollution at the time timber is harvested.

The "Title 2400--Timber Management" manual, dated May 1968, has made an initial step to classify area streams and define ways to protect the stream channel from erosion during the duration of a timber sale operation. Section 2456.5 of this document headed, "Protection of Streamcourses (B6.5 -C6.5)" provides that each sale or other use of national forest timber will be authorized only after the approving officer is satisfied that practical fire prevention measures and methods of cutting and logging are prescribed which will secure favorable conditions of water flows. The timber sale contract provides two basic provisions to accomplish this objective. They are B6.5 and R5-C6.5. The use of these two provisions requires classification of streamcourses on the sale area based on susceptibility to damage. This directive is intended to be a guide to streamcourse classification for application of these provisions of the timber sale contract.

"Streamcourse classification. All streamcourses within a proposed timber sale area shall be classified during the field examination stage of sale preparation on the basis of their susceptibility to damage by logging activities. At this time, those streamcourses that have well defined or scoured channels, that show evidence of developing sufficient head of water to move debris or erode the channel, or which may develop such characteristics if diverted or blocked by logging activities, will be classified as (1) 'sensitive,' or (2) 'resistant' based on the following criteria:

"SENSITIVE streamcourses (Figures 14 and 15) include all perennial streams except those with solid rock streambeds and streambanks. Intermittent streamcourses with riparian vegetation and those with unstable streambeds or streambanks are also classified as sensitive. Segments of streamcourse so classified are to receive the protection specified in B6.5.

"RESISTANT streamcourses (Figures 16 and 17) include perennial streams with solid rock streambeds and streambanks and intermittent streams with stable channel conditions and little or no riparian vegetation. Streamcourses classified as resistant receive the protection specified in C6.5.

"Other streamcourses on the sale area are protected by careful location of roads, skid trails and other developments and by erosion control work

Figure 14 - A Typical Perennial Streamcourse That Should Be Classified as Sensitive (Courtesy U.S. Forest Service)

Figure 15 - A Typical Sensitive Intermittent Streamcourse Before It Becomes Dry. (Courtesy U.S. Forest Service)

Figure 16 - Resistant Streamcourses Stabilized by Solid Rock or Heavy Boulders. (Courtesy U.S. Forest Service)

Figure 17 - A Resistant Streamcourse. (Courtesy U.S. Forest Service)

specified for the entire sale area. These are usually ephemeral in character. They should not be used as skid trails. Locations for necessary crossings must be chosen carefully. Careless 1 ,ing or road construction can transform these streamcourses into eroding channels. Authority to regulate road and skid trail location is given in B5.1 and C6.4. Other provisions of the contract which provide protection for these streamcourses include B6.21, B6.61, and C6.6.

"Strea urses often have segments falling into each of these categories. Ordinar..y the classifications should be applied to segments one-half mile or longer in length."

In addition to current efforts of the U.S. Forest Service, the states of Oregon and California, and the Department of Natural Resources in the State of Washington have made individual efforts to anticipate water pollution control problems. To illustrate, the State of Washington has developed a system for classifying streams for the purpose of refining regulations relating to forest road building and logging transport systems. The point system of classification, Table 11, is based upon six stream characteristics to be used in placing streams into one of five stream classes. The six stream characteristics are: (1) water flow continuity; (2) size during mean annual flow; (3) recreational use; (4) other water uses; (5) fish life present; and (6) type of streambed.

All public forest lands are harvested by many private contractors who operate under a highly competitive auction bid system. The contractor is normally a local businessman who is usually concerned about the long-term productivity of the forests. In periods of high demand and limited supply of timber offered for sale, some operators become careless about logging practices that pollute the streams.

More current adapted technology should be incorporated during the timber harvest operation under timber sale contract terms. In addition, more accurate monitoring techniques should be developed to achieve a more satisfactory basis for establishing better guideline standards relating to the impact of individual timber sale operations on surface water quality.

4.1.5 Grazing control: Cattle grazing in hardwood forests can result in a partial destruction of tree reproduction, and compaction of the soil to depths as much as 0.6 m (2 ft). Compacted soil has less infiltration capacity, and surface runoff and erosion usually result.

Lull and Reinhart[30] quote Hays et al., on the damage of domestic livestock to watersheds in Wisconsin.

TABLE 11

STATE OF WASHINGTON
DEPARTMENT OF NATURAL RESOURCES

Stream Classification Key (TSD-8-8-71)

Sale No.________________ Stream____________________

	Points	
A. Water Flow Continuity		
1. Present above ground year round	10	
2. Present above ground most of the year	5	
3. Present above ground only during periods of runoff	0	____
B. Size of Stream During Mean Annual Flow (Average Flow)		
1. Width in 1-ft increments (points per increment).	3	
2. Depth in 4-in. increments (points per increment).	1	
3. Add 1 point for each 8% of stream gradient (3 points maximum)	0	____
C. Recreational Use		
1. Existing developed camp site and trails along water	10	
2. Substantial recreational use, but no developed sites or trails	8	
3. Proposed development or substantial recreational use expected within next 10 years	4	
4. Periodic or infrequent recreational use, such as hikers, hunters, etc.	2	
5. Rarely used for any recreational purpose . .	0	____

TABLE 11 (Concluded)

Stream Classification Key (TSD-8-8-71)

Sale No.________________ Stream________________

	Points	
D. Use of Water		
1. Human consumption within 3.2 km (2 mi) downstream	10	
2. Human consumption 3.2-16.1 km (2-10 mi) downstream	5	
3. Human consumption more than 16.1 km (10 mi) downstream	3	
4. Livestock consumption within 1.6 km (1 mi) downstream	7	
5. Livestock consumption 1.6 to 8 km (1 to 5 mi) downstream	3	
6. Recreational use such as swimming within 1.6 km (1 mi) downstream	3	
7. None of these	0	____
E. Fish Life		
1. Supports both anadromous (migrating) and sport fish or used as direct source of fish hatchery water	10	
2. Supports only sport fish	8	
3. Potential area for sport or anadromous fish	4	
4. Does not support or have potential of supporting fish (too steep, broken or lack of water year round)	0	____
F. Type of Stream Bed		
1. Well-defined channel with rock and gravel bottom	5	
2. Well-defined channel with gravel and mud bottom	3	
3. Well-defined channel with mud and grass bottom	1	
4. No well-defined channel with mud and grass bottom	0	____
Total		____

Class	Points
I	45+
II	30-44
III	20-29
IV	10-19
V	0-9

A nongrazed woodlot lost no soil, whereas a comparable grazed woodlot lost 257 kg/hectare/yr (0.14 ton/acre/yr). By comparison, at the Coweeta watershed in southern North Carolina during the ninth year of grazing by livestock, the maximum turbidity in the stream was 108 ppm vs 30 ppm from an adjoining ungrazed woodland.

It is very important that grazing on forest land be carefully controlled and inspected at regular intervals. Overgrazing, where a livestock population is too dense for available grass, particularly during dry periods, can result in severe tree damage from eating the tops of small trees, excessive erosion on "cow paths" and serious water pollution caused by the cattle cooling themselves in the stream.

4.1.6 <u>Control of bark sediment in water</u>: Bark fragments scuffing off logs in water is a local problem in some areas. The Pacific Northwest Pollution Control Council[35] has released a report on control of the environmental effects of floating/rafting logs down public waters and storing them in waters before use by mills, summarized as follows:

1. Log transport and storage does sometimes pollute public waters and interferes with small craft navigation. Under these conditions the practices should be restricted or eliminated.

2. The free-fall of logs from trucks into waters must be stopped because this is the principal cause of bark debris.

3. Both floating and settled bark should be collected and placed on dry land.

The report does not address itself to the cost of implementing these recommendations, nor does it estimate the economic tradeoffs and impact on the region if the recommendations should be implemented through law. In addition the report does not document the extent of damage caused by the bark.

4.2 Control of Pollution from Pesticides

The EPA Pesticide Study Series Report No. 7, "The Movement and Impact of Pesticides Used in Forest Management on the Aquatic Environment and Ecosystem," presents a thorough and current review of this subject. It describes forest application techniques, route of pesticides into the water environment, and the impact of pesticides on the aquatic environment and the forest ecosystem, with emphasis on experiences in connection with the control of the gypsy moth in New York State.

This comprehensive study documents how little is known about the fate and effects of all pesticides, including forest pesticides, in the environment after application. Control methods must, therefore, be formulated on a generally unsatisfactory base of knowledge of the true environmental impact of pesticide usage. Most of the pesticide use in forests is, therefore, as in other use areas, practiced for economic benefit at a calculated risk to environmental quality. The risks are assumed to be small relative to benefits. The element of uncertainty in this rationale is one reason that the basic role of pesticides in silviculture is lately being reevaluated. A second reason is the growing conviction that a forest is too complex an ecosystem to be treated profusely with pesticides--that we know so little about the ecosystem that pesticide use is likely to lead to unwanted, basic changes in the system which may offset benefits. Pesticide usage is for these and other reasons declining, and other controls are being substituted.

Rules and guidelines for pesticide use have been well stated by Witt and Baumgartner,[36] Benton,[37] and Schlapfer.[38,39] The rules are generally qualitative and are helpful, but much local interpretation and judgment are required in development of pesticide programs.

Selection of a pesticide for effectiveness and minimum toxicity to the environment is a form of pollution control. Low order toxicity to nontarget species, including aquatic life, is preferred for obvious reasons. The guidelines for pesticide selection include the following: low persistence in the environment; low susceptibility to transport through the environment (nonvolatile, water insoluble); highly selective (minimum toxicity to nontarget species); biodegradable to harmless end-products and not subject to bioaccumulation in the food chain; and minimum toxicity to animal and aquatic life.

Adherence to rules developed for application will minimize pollution from pesticides. These rules include:

1. Application when rain, fog, wind, and air temperature are most favorable for assuring that a maximum percentage reaches target species.

2. Avoiding watercourses, and leaving if possible, a buffer strip between streambeds and treated areas. Buffer strip widths of 30, 15, 7.5, and 4.5 m (100, 50, 25, and 15 ft) have been recommended by Schlapfer[38,39] for the application of herbicides by aerial, ground vehicle, hand spraying, and hand injection methods, respectively.

3. Proper disposal of all containers and pesticide residues.

4. Application specifically to areas requiring treatment rather than blanket treatment of diseased and healthy areas. It has been proposed that aerial application of pesticides be done mostly by helicopter to enable more accurate placement on target species.

Finally, policy regarding the mode and extent of use vitally affects the methodology for controlling pesticide pollution, particularly with regard to alternates to chemical pest control, namely biological control, control through cultural systems based on knowledge of the ecology of forests, and mechanical control methods. This basic issue is the subject of current debate, and the present study can only recognize that evolving concepts of pesticide use will yield, in the future, a modified set of pollution control problems together with updated control measures founded more firmly on fact than at present. Evolving policy has in recent years resulted in cessation of the use of certain pesticides; a general reduction in the quantity of pesticides applied to forests and a reduction in treated acreage; decreases in the extent of prophylactic treatment; and increased reliance on natural and cultural methods of pest control. This general trend, together with conscientious adherence to guidelines for selection and application of pesticides, should sum up to worthwile reductions of the hazard to the aquatic environment as well as the environment in general.

For the present and near future (5-10 yr), methods available for control of pesticide pollution from silvicultural activities will,therefore, consist of adherence to accepted guidelines for use in a plan which calls for optimization of chemical pest control. Optimization as it is used here denotes use to the extent deemed necessary.

4.3 Control of Pollution from Fertilizers

There are strong pressures to establish "principal use" categories for all public lands, including forest lands. This mood-of-the-day extends even into the management of private timber lands. With an accelerating demand for paper and lumber, the logical response for the public and private timber manager is to allocate the more productive and less fragile lands to timber production and to apply all available production technologies to enhance tree growth--including the judicious use of fertilizers.

Groman[40] has reviewed the current status of forest fertilization. At present, fertilizer use on forest, mostly nitrogen, is centered in the Pacific Northwest Douglas fir region and in the Southern pine region.

In addition, the young stands of commercial redwood in northern California and the western-hemlock-sitka spruce along the coasts of Alaska, Washington, and Oregon are judged to have a potential for responding economically to application of fertilizer.

In the Pacific Northwest, forest fertilization with nitrogen started in 1965, reached a level of 48,165 hectares (118,750 acres) in 1970, and is anticipated to be 100,000 hectares (250,000 acres) per year from 1975-1980.

Response of Douglas fir to nitrogen fertilization has averaged about 30% during a 5-7 yr period; trees as old as 300 yr have shown a growth acceleration.

In the South, the pines on well-drained soils respond well to fertilization. Here nitrogen alone is expected to enhance growth by about 5% a year. A second area of present and predicted future response is the flatwoods coastal plains, where both nitrogen and phosphorus give increased growth of pines. Forest fertilization in the South started on a commercial basis in 1963, and in 1971 an estimated 44,500 hectares (110,000 acres) had been fertilized.

Helicopters are preferred for use in fertilizing the forest. Environmentally, they are safer than fixed-wing aircraft because they can fly slower, and, therefore, avoid all streams and lakes.

A summarized brief on the relationships between forest fertilization and water quality is as follows:

1. The potential exists for increasing ammonia and nitrates in streams and lakes to environmentally hazardous levels; so far no incidents have been reported.

2. Unlike cropland that is usually devoid of growing plants when most fertilizer is applied, forest soils always contain a mass of roots at variable depths that are continuously absorbing nitrogen in the ammonium and nitrate forms.

3. A forested soil is so efficient in recycling nutrients that it is used in many places as an ideal, environmentally safe place to spray municipal effluent (Sopper).[41]

Possible pollution hazards from fertilization that must be avoided have been stated by Reinhart:[42]

1. Increased nutrients in streams and lakes.

2. Increased organic matter in watercourses.

3. Decreased water yield.

4. Damage to nontarget species.

5. Air pollution.

Because of the lower cost of application, forest fertilization has been practiced with solid fertilizers distributed by aircraft. With many agricultural and horticultural crops, spraying leaves with liquid urea fertilizer has been proved more efficient than application to the soil. Duffy[43] compared foliar application to ground application with loblolly pine seedlings under greenhouse conditions, and obtained data reproduced in Table 12. His tests indicate that foliar application (therefore, aerial spray application) less effectively utilizes nutrient values than does soil application.

Methods for control of pollution from fertilization are based on many of the guidelines which apply to pesticide use (Table 12).

1. Fertilize only when a soil test indicates that benefits are expected to be economically worthwhile.

2. Fertilize at rates which do not exceed the adsorption capacity of the soil and the uptake capability of timber stands.

3. Frequent fertilization at low rates is environmentally safer than infrequent application at high rates.

4. Do not spray over watercourses, and leave buffer strips between streams and fertilized areas.

5. Apply fertilizers when wind drift is minimal.

6. To the extent that rainfall can be predicted, avoid fertilization in periods of heavy rainfall.

7. Coarse pellets of fertilizer are environmentally safer than fine pellets; and liquid fertilizers have the greatest water pollution hazard.

TABLE 12

COMPARISON OF NITROGEN FERTILIZER APPLIED ON FOLIAGE AND ON SOIL FOR LOBLOLLY PINE[a/]

Treatment	Post-Treatment Height Growth		Foliage Weight		Foliage N	
	Ammonium Nitrate (cm)	Urea (cm)	Ammonium Nitrate (g)	Urea (g)	Ammonium Nitrate (%)	Urea (%)
56 kg (150 lb) N on Foliage						
One Application	3.7	4.6	4.33	2.40	0.73	0.77
Five Applications	3.4	4.1	4.10	3.26	1.17	0.70
56 kg (150 lb) N on Soil	14.5	4.7	9.53	5.10	1.04	0.93
112 kg (300 lb) N on Foliage						
One Application	12.1	8.1	6.67	3.93	0.85	0.85
Five Applications	8.4	9.2	5.20	4.86	0.97	0.83

a/ Duffy, Paul D., "Loblolly Pine Seedlings Respond to Foliar Nitrogen Fertilization," USDA Forest Service Research Note SO-122, 4 pages, 1971.

Fertilizers are presently used sparingly on forests, in comparison to agricultural use, and the impact on water is, therefore, limited to specific watersheds and is relatively insignificant in the macro sense. If the assumption that forest management will become more intensive in the future proves to be correct, now is the time to initiate research studies and planning action aimed at management and control of the potentially increased pollutional loads from fertilization.

4.4 Control of Pollution from Fire Retardants

Most fire retardants are delivered to fires by fixed-wing aircraft at an estimated cost of material plus spreading of $0.26/liter ($1/gal.).

Historically, fire retardants have been plain water, water with a wetting agent added, borates, bentonite clays, and currently Fire-trol (ammonium sulfate) and Phoschek (diammonium phosphate). Borates are herbicides that are no longer used extensively because of their hazard to the environment. Bentonite clays lost popularity because the slurries were too slippery for fire fighters to retain their footing in steep terrain. Bentonite sediments are nontoxic but when applied in or near streams, remained suspended for long periods of time. Both of the proprietary formulations of ammonium sulfate and diammonium phosphate liberate ammonia which is toxic to fish if released directly into the water. In addition, both nitrogen and the phosphorus in excess can cause eutrophication of streams and lakes. The environmental hazards of fire retardant use are thus essentially the same as the hazards associated with fertilization.

Annually there are about 42 million liters (11 million gallons) of all types fire retardant materials used (Table 13), with the U.S. Forest Service using about one-half the total amount, followed by the California Division of Forestry using over 11.4 million liters (3 million gallons) of material annually.

Unless the ammonium sulfate and diammonium phosphate are accidentally applied to streams or lakes, the hazard to the water environment is rare. Normal use of these fire retardants consists of dropping them from a fixed-wing aircraft ahead of the fire, in an inverted V pattern, at or beyond the crest of a ridge. Dropped at this location, the rate of spread of the fire is slower, fire fighters are more effective, and the distance from streams is usually so far that pollution is minimal.

The considerations involved in development of guidelines for fertilization (Section 4.3) apply to fire retardant use. However, the fire

TABLE 13

ACTUAL CONSUMPTION OF FIRE RETARDANTS IN 1966[a]

Agency	Total Liters (Gallons) Used in 1966	
U.S. Forest Service	22,490,000	(5,942,090)
California Division of Forestry	12,161,000	(3,212,600)
Bureau of Land Management	3,781,00C	(999,150)
Southeastern States	1,802,000	(476,320)
State of Washington	190,000	(50,000)
State of Oregon	106,000	(28,000)
Total	38,730,000	(10,708,160)

a/ Hartong, Allan L., "An Analysis of Retardant Use," Intermountain Forest and Range Experiment Station, U.S. Forest Service, Research Paper INT-103, 40 pages, August 1971.

fighter has little control over the time or the place. The most important guideline for fire retardant use is avoidance of surface waters in the application pattern.

4.5 Control of Thermal Pollution Resulting from Solar Energy

Temperature increases of water in streams from silvicultural activities are due to the cutting of shade-producing riparian trees and shrubs; and increases in stream water temperature are thought to be harmful to aquatic life.

The former Technical Advisory and Investigation Branch of the Federal Water Pollution Control Adminstration[44] summarized the relationship of stream and lake temperature to aquatic life in this way:

1. All chemical reactions in water vary with temperature, generally increasing with increasing temperature. One principal exception is the solubility of oxygen in water, which decreases with temperature. Furthermore, an elevation of water temperature hastens bacterial decomposition and oxygen is further decreased in the process. The rate of decomposition increases to about 30°C (86°F).

2. Cold-water nonanadromous fish such as trout thrive best in water below 14.5°C (58°F).

3. The maximum temperature tolerated for a given species of fish varies with the rate of heating, the size of the fish, and its physiological condition.

4. Substances toxic to fish are more toxic at higher temperatures.

5. There is no one ideal temperature for a particular species of fish. Reproduction requires one range of temperatures and larval development another range. From a specific water area, a fish species may be absent in summer and present during winter months.

6. An increase in temperature of a segment of a stream may block normal migration of anadromous species.

7. Some waters may be too cold for certain species of fish.

8. As water temperature increases, the predominant species of algae will change from diatoms to green algae to blue-green algae. Certain blue-green algae are capable of fixing atmospheric nitrogen and thus hastening eutrophication of waters.

Angular canopy density is proposed by Brazier[45] as a better measure of shading ability of a stream than width or height of vegetation. The angular canopy density was measured at solar noon (zenith) by a densitometer designed for the purpose. It is hypothesized that a buffer strip reduces elevation of stream water temperature by providing shade.

Data obtained in Brazier's study indicated that maximum shading ability was obtained by a buffer strip 24 m (80 ft) wide, and 90% of maximum by a 17-m (55-ft) wide buffer. Conclusions included the statement that the forest ranger should decide the proper width of buffer strip for each stream based upon the stream width, depth, velocity, initial temperature and height of the vegetative buffer.

Technologies to control thermal pollution in northwestern U.S. were summarized by Brown, Swank, and Rothacher[46] as follows:

Daily temperature variation in undisturbed streams may be about 2.2°C (4°F) or more. This value will rise to about 5.6°C (10°F) or higher when all shade along streams is removed. Cooling of waters downstream is due primarily to inflow of cooler tributary streams rather than by cooling of warmer waters due to the presence of shade. The shade does not cool water in streams; it merely reduces the variations in stream temperature.

Buffer strips of vegetation along streams is the only practical way to keep streams cool. The width of the buffer strip must be determined by on-site inspection. Narrow streams may be kept cool by low-growing cottonwood, alder, and willows, without sacrificing any merchantable timber. Wider streams will require taller trees to shade them.

5.0 PREDICTIVE METHODOLOGY FOR NONPOINT SOURCE POLLUTION CONTROL

Management of a silvicultural system in a manner which minimizes pollution could best be effected if factors responsible for discharge of pollutants were quantitatively related, by what might be called pollution indices to both the individual parts of the silvicultural system and to the system as a whole. Many factors must be considered, and the relationships are quite complex. Much additional information and data are needed to more fully develop the relationships between pollution and silvicultural practices.

Predictive methodology (methods, based on mathematical techniques, used for purposes of calculating pollution as a function of conditions in the forest) is as a consequence only available in part, and needs to be refined. A particular need is the development of criteria for relating quantities and concentrations of emitted pollutants that may degrade environmental water quality.

Much effort has been devoted to analyses of soil erosion. Cropland has been the principal concern of the studies; erosion of forest lands has been studied to a lesser extent. Predictive methods resulting from research and field tests still fall short of the capability to relate water quality to conditions in a forested watershed. However, the methods are based on consideration of the several factors which are important in erosion and erosion prevention/control. For this reason, it is appropriate here to present a summary description of three methods which have much in common. The first and best known method is the Universal Soil Loss Equation, which has been tested on forest lands.

No predictive methodology has been developed for other pollutants--such as pesticides or fertilizers. Since soil erosion and surface water runoff are major modes of transport of nutrients (fertilizers), pesticides, and other pollutants to surface waters, the Universal Soil Loss Equation is potentially useful for estimating quantities of these pollutants discharged into streams and lakes; further study and development is needed, however. The method available for predicting erosion as a function of forestry management practices is discussed in the following paragraphs.

5.1 Prediction of Erosion by the Universal Soil Loss Equation

Three components are involved in estimating soil erosion:

1. Soil characteristics, and topography.

2. Land cover conditions.

3. Regional rainfall characteristics.

The soil characteristics considered are erodibility, the relative susceptibility of the soil to the erosion process. Generally, the finer textured soils--high in silts and clays, are more erodible than the coarser textured sandy soils. Generally, steeper and longer slopes (topography component) are more susceptible to erosion than lesser and shorter slopes. The land cover component refers to the ability of a cover, such as crops, grasses, and trees to absorb the impact energy of the rainfall. Another important factor to be considered in quantifying the soil erosion rate is rainfall characteristics. When factors other than rainfall are held constant, the erosion rate is directly proportional to the total kinetic energy of a storm.

The essential factors discussed above in the erosion process have been incorporated in a "Universal Soil Loss Equation," presented by Wischmeier and Smith, in USDA-ARS Agriculture Handbook 282.[47/] This equation was originally developed to predict erosion from croplands, but has later been adapted to forestry areas to predict soil sediment removal by erosion and to better understand erosion control procedures by vegetative cover on the land.

In silviculture, the control practice is exemplified by the use of buffer strips between the eroding site and the nearest stream.

The use of a narrow buffer strip carries more risk than does a wide buffer strip that sediment, carried by water, can penetrate this vegetative filter and enter the stream or standing water body. The Wischmeier Universal Soil Loss Equation is a mathematical tool that can be used to estimate the width of a buffer strip necessary to protect stream water quality from a disturbed soil area.

The results of a study by Packer[48/] indicate a method to evaluate the relative vegetative trap efficiency of different types of buffer strips. This study was conducted in the Northern Rocky Mountains under certain fixed conditions. Table 14 gives the protective strip widths necessary to contain 83.5% of sediment flows from outlet of the logging road drainages. The results, presented in varying obstruction spacings and kinds of obstructions, are for conditions of 9-m (30-ft) cross-drain spacing, zero initial obstruction distance, 100% fill slope cover density, and 5-yr old roads built on the most stable soil that are derived from

TABLE 14

PROTECTIVE-STRIP WIDTHS REQUIRED BELOW SHOULDERS[a] OF 5-YEAR OLD[b] LOGGING ROADS BUILT ON SOIL DERIVED FROM BASALT,[c] HAVING 30-FOOT CROSS-DRAIN SPACING,[d] ZERO INITIAL OBSTRUCTION DISTANCE,[e] AND 100% FILL SLOPE COVER DENSITY[f]

Obstruction Spacing Meters (Feet)	Protective-Strip Widths, Meters (Feet)					
	Depressions or Mounds	Logs	Rocks	Trees and Stumps	Slash and Brush	Herbaceous Vegetation
0.3 (1)	10.6 (35)	11.2 (37)	11.6 (38)	12.2 (40)	12.5 (41)	13.1 (43)
0.6 (2)	11.2 (37)	12.2 (40)	13.1 (43)	14.0 (46)	14.9 (49)	15.8 (52)
0.9 (3)	11.9 (39)	13.1 (43)	14.3 (47)	15.8 (52)	17.3 (57)	18.5 (61)
1.2 (4)	12.2 (40)	14.0 (46)	15.8 (52)	17.6 (58)	19.5 (64)	21.3 (70)
1.5 (5)	12.5 (41)	14.6 (48)	17.0 (56)	18.2 (63)	21.6 (71)	23.7 (78)
1.8 (6)		15.2 (50)	17.9 (59)	20.7 (68)	23.4 (77)	26.1 (86)
2.1 (7)		15.8 (52)	18.8 (62)	22.2 (73)	25.5 (84)	28.6 (94)
2.4 (8)		16.1 (53)	19.8 (65)	23.4 (77)	27.1 (89)	30.7 (101)
2.7 (9)		16.4 (54)	20.4 (67)	24.6 (81)	28.9 (95)	32.8 (108)
3.0 (10)				25.8 (85)	30.0 (100)	35.0 (115)
3.3 (11)				26.8 (88)	31.6 (104)	36.8 (121)
3.6 (12)						38.6 (127)

a/ For protective-strip widths from center lines of proposed roads, increase given widths by one-half the proposed road width.

b/ If storage capacity of obstruction is to be renewed when roads are 3 yr old, reduce protective-strip widths 7.3 m (24 ft).

c/ If soil is derived from andesite, increase protective-strip widths 0.3 m (1 ft); if from glacial silt, increase 0.9 m (3 ft); if from hard sediments, increase 2.4 m (8 ft); if from granite, increase 2.7 m (9 ft); if from loess, increase 7.3 m (24 ft).

d/ For each 3.0-m (10-ft) increase in cross-drain spacing beyond 9.1 m (30 ft), increase protective-strip widths 0.3 m (1 ft).

e/ For each 1.5-m (5-ft) increase in initial obstruction distance beyond zero (or road shoulder), increase protective-strip widths 1.2 m (4 ft).

f/ For each 10% decrease in fill slope cover below a density of 100%, increase protective-strip widths 0.3 m (1 ft).

basalt. It was estimated that by adding 9 m (30 ft) to the strip width indicated in Table 14, the trap efficiency can be increased to about 97.5%. The footnotes to Table 14 indicate the variation in protective-strip widths from those in the table which are necessary with changes in soil, cross-drainage spacing, initial obstruction distance, road-age, and fill slope cover density.

Another method for evaluating soil cover efficiency in the equation involves a rule-of-thumb technique which is suggested for estimating required buffer strip width, which will provide sufficient protection. For a general situation, Trimble and Sartz[49/] suggest a 7.6-m (25-ft) width on level lands and adding 0.6 m (2 ft) for each 1% increase in slope. For areas close to municipal water supply, they suggest beginning with a 15.2-m (50-ft) strip and increasing by 1.2 m (4 ft) for each 1% increase in slope. These suggestions were made based on field measurement of the sediment path of culverts in the White Mountains, with well-drained sandy loam and a hardwood leaf litter of 5-10 cm (2-5in.). They emphasize the method may or may not apply elsewhere.

5.2 Other Prediction Methods

The Universal Soil Loss Equation was developed based upon information collected from 37 states east of the Rocky Mountains, and is being successfully used in most areas of this region. For western states, this equation has been used very little because adequate soil type correlations have not been done for western soils. However, some think that procedures developed by Musgrave[50,51/] may be modified for use in the West. Researchers are advised to consult the listed references to become familiar with the procedures, and also with the limitations of prediction with the Musgrave method.

It is important to note that the quantitative procedures presented with the Universal Equation and the Musgrave Equation are limited to the evaluation of on-site erosion for various types of land use and disturbances. For a water quality planner, however, prediction of suspended sediment levels entering surface water is more important than prediction of the on-site erosion. For example, the planner will need answers to questions such as: What is the suspended sediment contributions of each land use or disturbance within the forest? What control measures are required to reduce the sediment contribution to the acceptable level?

To answer these questions, Dissmeyer [52,53/] has developed a method now called the First Approximation of Suspended Sediment (FASS) which can be used to evaluate the impact of disturbances or control practices on suspended sediments in surface water, to identify problems, and to evaluate alternative methods to reduce suspended sediment. In addition to the contribution from sheet erosion, FASS also takes into account gully erosion, as well as channel erosion, and should also be applicable to nonforested areas such as agricultural lands, highways, and urban areas. This method has been applied in river basin planning in the Southeast. A detailed discussion of FASS is inappropriate here. Concerned individuals are referred to two publications which present the method in detail.[52,53]

5.3 Background Data and Information Needed for Planning Pollution Control

Knowledge in detail of environmental conditions which impact pollution control is essential.

5.3.1 Meteorological factors: Rainfall, wind, and temperature play important roles in pollution control. Meteorological data for the past are available from the National Weather Service, for specific regions of the country, and patterns established for a region should be used as the basis for scheduling silvicultural activities. Long- and short-term forecasts of weather are also important. Mean climatic records are used to determine the driest and, therefore, the best months to harvest timber, but day-to-day weather forecasts must be used to guide harvesting operations if damage to the soil environment is to be kept to a minimum. Harvesting equipment operating on wet and fine textured soils causes soil compaction and excessive soil surface disturbance that are conducive to accelerated yields of sediments. Aerial applications of fertilizers and pesticides should be scheduled for times when wind velocity is low and wind direction is predictable.

5.3.2 Soil and geologic surveys: The U.S. Soil Conservation Service has the responsiblity for mapping soils on all private lands in the nation, and works with the U.S. Forest Service and other public and private land management agencies. The U.S. Forest Service employs soil scientists and geologists to make soil and geologic surveys of the national forests for use in such analyses and planning activities as location of unstable and stable soils; suitability of soils as sources of sand, gravel, clay, or rock; suitability for road location; subsoil and surface soil erosion potential; drainage characteristics; compaction characteristics; potential for forest species regeneration; windthrow hazard; and suggested cutting and logging systems for maximum environmental protection (Snyder and Wade).[54]

Furthermore, the soil and geologic surveys are interpreted with respect to suitability for recreational development, permeability, consistence (water stability), and compaction. Such hydrologic interpretations are also made on the subjects of amounts and durations of water yield, erosion hazard, and potential sediment.

The soil surveys made by Steinbrenner[55/] for the Weyerhaeuser Company are an example of a technique developed by the National Cooperative Soil Survey and adapted to forestry use. Similar systems are used by forest soil surveyors employed by the USDA Forest Service, the states, and private timberland owners.

The system of forest soil surveys used by Steinbrenner is interpreted for use in these ways:

1. Land capability.

2. Forest site productivity by species.

3. Windthrow hazard.

4. Logging method suitability.

5. Priority for thinning.

6. Soil engineering capability.

6.0 CRITERIA FOR POLLUTION CONTROL MANAGEMENT SYSTEMS

The overall approach to control of pollution from silviculture must consider the individual pollutants, their sources, and specific methods of control. Effective control requires, however, that a pollution control management system be developed which encompasses all significant pollutants. Furthermore, the pollution control management system must be matched with watershed and regional characteristics, and should be consistent with national goals. The pollution control methods presented in Section 4.0 must therefore, be developed and used in the framework of management systems fitted to particular silvicultural situations.

The process of development of pollution control management systems is outside the scope of the present study, and is the prerogative of the local planner in cooperation with policy-making bodies. It is appropriate, however, to enumerate the criteria which apply to development of pollution control management systems

A primary factor is protection of water quality. Water quality goals set by law and transferred into policy and standards by national and local policy bodies are a requisite for the development of pollution control management systems.

The second and third primary factors are forestland productivity and the economics of timber production, both evaluated under constraints imposed by the need to control pollution.

Water quality and forest productivity in combination are the two key criteria for development of a pollution control management system for a producing forest, and the economics of timber production under the constraints of pollution control determine whether a silviculture operation is economically competitive with like operations in other regions. In a broader context, economics, including costs of pollution control, will determine the competitiveness of forest products with substitute, nonwood products.

The following secondary factors are important:

The time factor: A pollution control management system must be geared to the life cycle of the forest. Today's pollution control should make tomorrow's pollution control easier rather than more difficult, and a low total yield of pollution over a many year period is equally as important as transient pollutant yields.

The land-use factor: In some forests, timber production is the primary objective. In others, timber yield is subsidiary to other uses. The good pollution control management system will vary to match the use pattern appropriate for the land.

Closely related to land-use criteria is the physical stability of the forest system, which includes resistance to wildfire (a major destabilizing force and a significant cause of water pollution); resistance to disease; and general resistance to land movement (creep, mud slides, and debris slides).

A final factor, forest ecosystem stability, is closely related to land-use and physical stability of the forest. The ecosystem is essentially specified by designation of land-use. Its stability is guaranteed by adherence to good silvicultural procedures, including pollution control management.

The good pollution control management system therefore centers on water quality as the primary governing factor. Timber production and timber production economics are also primary factors; these may be affected either negatively or positively by the need to protect water quality. These three primary factors, together with secondary factors: time, land-use, forest system physical stability, and forest ecosystem stability, are the basis for development of pollution control management systems which meet goals for productive and environmentally acceptable use of forest land.

Overall systems analysis of a silvicultural situation in terms of these factors should yield rational policy and decisions about the use of specific control measures, including decisions about such troublesome questions as clearcutting, prescribed burning, and pesticide use.

Some silviculturists have integrated many technical and economic disciplines in intensive forest management systems. These systems emphasize production. Commercial forests are now being classified according to potential productivity; and on the areas with greatest potential a full "package of practices" is being applied. For example, Staebler[56] reports that a high yield forestry program in the Pacific Northwest is anticipated to double the yields over those achieved in forests with minimum practices (protection from fire, natural regeneration, no additional management). The doubling in yield is expected to be due to: 20% from fertilization; 30% from improved regeneration; and 50% from commercial and precommercial thinning.

It is an established fact that a well-kept, healthy forest is highly resistant to erosion and mass land movement, and transfers a high proportion of incident rainfall to subsurface water rather than to runoff. It follows then that intensively managed forests can be expected to be substantially better protectors of water quality than poorly managed--or naturally managed--forests. The high yield forestry programs appear thus to be a sound basis for development of a pollution-control-oriented management system.

Trask[5/] has presented a multidisciplined approach to planning a transportation system in forests which exemplifies the basic planning method needed for development of pollution management. The transportation system is designed to serve all predicted uses of each forest unit. The uses may be as contrasting as timber transportation, scenic viewing, skiing, hiking, and camping. Trask suggests that the planning team may be comprised of a logging engineer, a fisheries expert, a landscape architect, a soil scientist, a transportation engineer, and a silviculturist. He further adds that the team should work together to develop a management system rather than separately as independent and uncoordinated professionals.

There is a direct correlation between effectiveness of pollution control and the capability of personnel at the field level. As in all effective management systems, it is essential that field personnel be competent, well informed, and granted the authority needed to make and implement decisions relevant to pollution control. Long-range planning of pollution control management systems should therefore include an indepth evaluation of organizational structures for management planning and also for the day-to-day administration of forest lands.

In summary, the criteria for pollution control management include a thorough analysis of several technical and economic factors and alternatives in silvicultural management; a multidisciplined planning approach to development of specific plans and implementation procedures; and finally, competent administration, especially at the local level. It is essential that silviculturists undertake the development of pollution control management systems, and implement their use. The alternative is diversion of productive forest to nontimber activities to ensure protection of water quality.

7.0 ACKNOWLEDGMENTS

This report contains an evaluation of methods to control nonpoint pollution from silviculture prepared for the Environmental Protection Agency under Contract No. 68-01-1829. The work was performed by Midwest Research Institute under the supervision of Dr. A. D. McElroy, Head, Waste Treatment and Processes Control Section. Mr. Francis W. Bennett, and Dr. Roy L. Donahue, Principal Investigators, authored the report with assistance from Raymond Mischon, Dr. S. Y. Chiu and Dr. A. D. McElroy.

Grateful acknowledgment is extended to Robert E. Thronson, Project Officer, U.S. Environmental Protection Agency, and the Working Group, composed of representatives from many EPA Agency Offices. Acknowledgment for critical review is also tendered to the U.S. Forest Service, state forestry and environmental organizations, the Bureau of Land Management, and the National Forest Products Association.

8.0 REFERENCES

1. "One-Third of the Nation's Land," A Report to the President and to Congress by the Public Land Law Review Commission, Washington, D.C., 342 pages, pp. 41-65, June 1970.

2. Forest-Range Task Force, "The Nation's Range Resources--A Forest-Range Environmental Study," USDA Forest Service, Forest Resource Report No. 19, 147 pages.

3. "Silvicultural Systems for the Major Forest Types of the United States," USDA Forest Service, Agriculture Handbook No. 445, 114 pages, March 1973.

4. Archie, Steve and David M. Baumgartner, Clearcutting in the Douglas Fir Region of the Pacific Northwest, Washington Woodland Council, 17 pages, undated.

5. Pacific Northwest Pollution Control Council, "Log Storage and Rafting in Public Waters," Seattle, Washington, 56 pages (1971).

6. Herman, Francis R., "A Test of Skyline Cable Logging on Steep Slopes--A Progress Report," USDA Forest Service Station Paper No. 53, 17 pages, October 1960.

7. Gardner, R. B., F. L. Jacobsen, and W. S. Hartsog, "Balloon Logging," Agricultural Engineering, pp. 14-17, February 1973.

8. Binkley, Virgil W., "Helicopter Logging with the S64E Skycrane. Report of Sale," U.S. Forest Service, 23 pages, undated (probably 1972).

9. Hendrickson, William H., "Perspective on Fire and Ecosystems in the U.S.," in, Fire in the Environment--Symposium Proceedings, Denver, Colorado, 151 pages, pp. 29-33, 1-5 May 1972.

10. U.S. Navy, "Slash Disposal and Direct Seeding of Douglas Fir Following Final Harvest on Navy Lands Puget Sound Area," Donald C. Roppel, Western Division Staff Forester; Naval Facilities Engineering Command and Arthur K. Schick, Jr., Navy Forester, Naval Torpedo Station, Washington State; unpublished report communicated 28 June 1973, by letter from Roy H. Ledford, Head Forester, Department of the Navy, Alexandria, Virginia.

11. Hartong, Allan L., "An Analysis of Retardant Use," Intermountain Forest and Range Experiment Station, U.S. Forest Service, Research Paper INT-103, 40 pages, August 1971.

12. Blahm, Theodore H., Walter C. Marshall, and George R. Snyder, "Effect of Chemical Fire Retardants on the Survival of Juvenile Salmonids." National Marine Fisheries Service, Environmental Field Station, Prescott, Oregon, 23 pages (1972).

13. Swanston, D. N., and C. T. Dyrness, "Managing Steep Land," Journal of Forestry, 264-269, May 1973.

14. Dyrness, C. T., "Soil Surface Conditions Following Balloon Logging," USDA Forest Service Research Note PNW-182, 7 pages, July 1972.

15. Dyrness, C. T., "Soil Surface Condition Following Tractor and High-Lead Logging in the Oregon Cascades," Journal of Forestry, 272-275, April 1965.

16. Megahan, W. F., and W. J. Kidd, "Effects of Logging and Logging Roads on Erosion and Sediment Deposition from Steep Terrain," Journal of Forestry, 136-141, March 1972.

17. Rice, R. M., J. S. Rothacher, and W. F. Megahan, "Erosional Consequences of Timber Harvest: An Appraisal," Proceedings of a symposium on "Watersheds in Transition," held at Ft. Collins, Colorado, 405 pages, pp. 321-329, 19-22 June 1972.

18. Klock, G. O., "Helicopter Logging Reduces Soil Surface Disturbance," Proceedings of the 46th Annual Meeting of the Northwest Scientific Association, Whitman College, Walla Walla, Washington, 29-31 March 1973.

19. Dyrness, C. T., "Mass Soil Movements in the H. J. Andrews Experimental Forest," USDA Forest Service Research Paper PNW-42, 12 pages (1967).

20. Fredriksen, R. L., "Erosion and Sedimentation Following Road Construction and Timber Harvest on Unstable Soils in Three Small Western Oregon Watersheds," USDA Forest Service Research Paper PNW-104, 15 pages (1970).

21. Forest Service. "Timber Purchaser Road Construction Audit. A Study of Roads Designed and Constructed for the Harvest of Timber," USDA Forest Service, Region 6, 31 pages, January 1973. Note: "Regions" in this section refer to the U.S. Forest Service administrative regions, shown in Figure 8.

22. Kochenderfer, James N., "Erosion Control on Logging Roads in the Appalachians," Northeastern Forest Experimental Station, Upper Darby, Pennsylvania, Research Paper NE-158, 15 pages (1970).

23. "Industrial Waste Guide on Logging Practices," Federal Water Pollution Control Administration, U.S. Department of the Interior, 40 pages (1970).

24. The three documented pictures and testimony communicated by letter 28 June 1973 from James E. Douglas, Project Leader, USDA Forest Service, Southeastern Forest Experimental Station, Coweeta Hydrologic Laboratory, Franklin, North Carolina.

25. Bolstad, Roger, "Catline Rehabilitation and Restoration," in "Fire in the Northern Environment--A Symposium," April 13-14, 1971, University of Alaska, College (Fairbanks), Alaska, pp. 107-116 (1971).

26. Lotspeich, Frederick B., Ernst W. Mueller, and Paul J. Frey, "Effects of Large Scale Forest Fires on Water Quality in Interior Alaska," U.S. Department of the Interior, 155 pages, February 1970.

27. Communication by letter dated 25 May 1973, from Carrow T. Prout, Jr., Chief Forester, Soil Conservation Service, Washington, D.C. 20250 to Roy Donahue, Staff Associate, Ecology and Environment, Midwest Research Institute, 425 Volker Boulevard, Kansas City, Missouri 64110.

28. McNutt, R. B., W. H. Kelley, C. F. Montgomery, and H. C. Buckeles, "Soil Survey of Chilton County, Alabama," U.S. Department of Agriculture (Soil Conservation Service and Forest Service), in cooperation with the Alabama Agricultural Experiment Station and Alabama Department of Agriculture and Industries, 82 pages and 47 soil maps on photo base, pp. 44, 47-49, October 1972.

29. "Soil-Vegetation Surveys in California," Division of Forestry, Department of Conservation, State of California, Revised, 31 pages (1969).

30. Lull, Howard W., and Kenneth G. Reinhart, "Forests and Floods in the Eastern United States," USDA Forest Service Research Paper NE-226, 94 pages, pp. 72-73 (1972).

31. McClurkin, D. C., "Site Rehabilitation Under Planted Red Cedar and Pine," in, Tree Growth and Forest Soils, Proceedings, Third North American Forest Soils Conference, North Carolina State University, pp. 339-345 (1970).

32. Ursic, S. J., "Hydrologic Effects of Prescribed Burning on Abandoned Fields in Northern Mississippi," USDA Forest Service, Research Paper SO-46, 20 pages (1969).

33. Research Committee on Coal Mine Spoil Revegetation in Pennsylvania, "A Guide for Revegetating Bituminous Strip-Mine Spoils in Pennsylvania" (no publisher indicated), 46 pages (1965, revised 1971).

34. Wollum, A. G., "Grass Seeding as a Control for Roadbank Erosion," USDA Forest Service Research Note 218, 5 pages (1962).

35. Pacific Northwest Pollution Control Council, "Log Storage and Rafting in Public Waters," Seattle, Washington, 56 pages (1971).

36. Witt, James M., and David M. Baumgartner, "A Handbook of Pesticide Chemicals for Forest Use," Forest Pesticides and Their Safe Use. A short course sponsored by the Extension Services of Oregon State University, Washington State University and Region 6 of the USDA Forest Service, 58 pages, 6-7 February 1973.

37. Benton, Howard, "The Forest Service and Herbicides," USDA Forest Service, unnumbered (1971).

38. Schlapfer, Theodore A., "USDA Forest Service Environmental Statement, Calendar Year 1973, Herbicide Use," Pacific Northwest Region, Olympic, Mt. Baker, Snoqualmie, and Gifford Pinchot National Forests, paged by sections, March 1973.

39. Schlapfer, Theodore A., "USDA Forest Service Environmental Statement, Calendar Year 1973, Vegetation Management with Herbicides," Pacific Northwest Region, Siskiyou, Siuslaw, and Umpqua National Forests, paged by sections (1973).

40. Groman, William A., "Forest Fertilization: A State-of-the-Art Review and Description of Environmental Effects," U.S. Environmental Protection Agency, EPA-R2-72-016, 57 pages (1972).

41. Sopper, W. E., "Effects of Trees and Forests in Neutralizing Wastes," in, Proceedings, Symposium on Trees and Forests in an Urbanizing Environment, 18-21 August 1970, Planning and Resource Development Series No. 17, University of Massachusetts, pp. 43-57 (1971).

42. Reinhart, Kenneth G., "Critique: Forest Fertilization Impacts on Water and the Environment," in, Regional Forest Fertilization Symposium, Warrensburg, New York, 22-25 August 1972, USDA Forest Service General Technical Report NE-3, p. 243 (1973).

43. Duffy, Paul D., "Loblolly Pine Seedlings Respond to Foliar Nitrogen Fertilization," USDA Forest Service Research Note SO-122, 4 pages (1971).

44. "Temperature and Aquatic Life," Technical Advisory and Investigations Branch, Federal Water Pollution Control Administration, U. S. Department of the Interior, 151 pages (1967).

45. Brazier, Jon Roger, "Controlling Water Temperatures with Buffer Strips," A thesis submitted to Oregon State University for the degree of Master of Science, 65 pages, mimeographed, June 1973.

46. Brown, George W., Gerald W. Swank, and Jack Rothacher, "Water Temperature in the Steamboat Drainage," USDA Forest Service, Research Paper PNW-119, 17 pages, August 1971.

47. Wischmeier, W. H., and D. D. Smith, "Predicting Rainfall - Erosion Losses from Cropland East of Rocky Mountains," USDA-ARS Agriculture Handbook No. 282, 47 pages (1965).

48. Packer, P. E., "Criteria for Designing and Locating Logging Roads to Control Sediment," Forest Science, Vol. 13, p. 107 (1967).

49. Trimble, G. R., Jr., and R. S. Sartz, "How Far from a Stream Should a Logging Road be Located," Journal of Forestry, Vol. 55, pp. 339-341 (1957).

50. Musgrave, A. W., "The Quantitative Evaluation of Factors in Water Erosion - A First Approximation," J. of Soil and Water Conservation, Vol. 2, pp. 133-138 (1947).

51. Anderson, D. A., "Guidelines for Computing Quantified Soil Erosion Hazard and On-Site Soil Erosion," USDA Forest Service, Southwestern Region (1969).

52. Dissmeyer, G. E., "Estimating the Impact of Forest Management of Water Quality," presented at Cooperative Watershed Management Workshop, U.S. Forest Service, Memphis, Tennessee, 4-8 October 1971.

53. Dissmeyer, G. E., "Evaluating the Impact of Individual Forest Management Practices on Suspended Sediment," Journal of Soil and Water Conservation, (in press 1973).

54. Snyder, Robert V., and J. M. Wade, "Soil Resource Atlas of Maps and Interpretive Tables," Snoqualmie National Forest, Westside Pacific Northwest Region, USDA Forest Service (1960 and 1967).

55. Steinbrenner, E. C., "Forest Soil Survey on Weyerhaeuser Lands in the Pacific Northwest," Weyerhaeuser Center, Centralia, Washington, 119 pages (in press, 1973).

56. Staebler, George R., "What is Optimum Forest Management?" Abstract of testimony before the Interim Committee on Natural Resources, Salem, Oregon, 8 pages, 1 March 1972.

57. Trask, David B., "Transportation System Planning for Forest Resource Management Some Aspects of Resource and Transportation Analysis," Technical Report ETR-770-4b, Forest Service, U.S. Department of Agriculture, 17 pages, August 1971.

9.0 GLOSSARY

Jammer Logging - A stationary, low-lead, mechanical winch and cable system to pull logs over the soil surface from points on a field to a central location during tree harvest.

Nonpoint Source Pollution - A pollutant which enters a water body from diffuse origins on the watershed and does not result from discernible, confined, or discrete conveyances.

Pesticides - All materials, mostly chemicals, that are used for the control of undesirable insects, diseases, vegetation, animals, or other forms of life.

Rafting of Logs - The act of floating tied logs for transport in water.

Sediment - Water-worked fragments which have been detached, transported, suspended, or settled in water. Fragments moved by air are excluded from this report.

Silvicide - Chemicals to kill unwanted trees.

Silviculture (Webster) - "A phase of forestry dealing with the development and care of forests." In this report the definition includes all activities related to trees, from seed to sawlog/pulpwood, and the harvest and transport of the products from the forest to the first permanent road.

Skid Trails - A disturbance of the forest floor resulting from logs being pulled over the surface.

Water Pollution - A degradation of quality of water for a specified use.

Yarding of Logs - The act of assembling logs in a specified location after cutting for the purpose of further transport.

U.S. GOVERNMENT PRINTING OFFICE 1974 582-412/34 1-3