FOREST HARVEST-REGENERATION ACTIVITIES
AND
PROTECTION OF WATER QUALITY

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U.S. ENVIRONMENTAL PROTECTION AGENCY

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EPA Review Notice

This document is a draft report, submitted for review and comment which will be the basis for revisions, as appropriate, to be incorporated in a final report.

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INTRODUCTION

Purpose

This report is a preliminary draft and intended for review purposes. Comments, editorial suggestions and additional information are hereby solicited. A final revised draft should be available for printing in mid-1975.

Section 304 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) directs the U.S. Environmental Protection Agency to address the nature and extent of nonpoint pollution sources, including pollutants generated by silvicultural activities, and the processes, procedures and methods for preventing such pollution. To accomplish this the nonpoint pollution sources have been allocated to the various regions of the EPA. Region X of the EPA, covering Alaska, Washington, Oregon and Idaho have been specifically assigned the Section 304 responsibilities related to silvicultural activities. This Region X program involves the compilation of technical and legal/institutional guideline information relating to reduction, elimination and prevention of water pollution from such sources, and the development of methods and procedures for effective utilization of the information. The EPA will eventually develop an implementation strategy, and for the present is proceeding to define the "best available technology" for preventing such silviculturally-related pollution.

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The "best available technology" for preventing pollution resulting from silvicultural activities is being compiled and summarized through three consultant efforts which are intended to have little or no overlap. The first project, almost completed, involves methods of controlling pollution through the planning, design, construction and maintenance of logging roads. The second contract involves control of water pollution resulting from the application of forest chemicals. The third contract, which is the subject of this report concerns logging, residue management and reforestation activities. The intent is to summarize "state-of-the-art" techniques for preventing water pollution, not to prescribe or recommend comprehensive standards.

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Scope

This study geographically covers Idaho, Oregon, Washington and Alaska which comprise Region X of the EPA. The region has been divided into the following subregions based on similar forest zones, hydrologic and meteorologic characteristics, land systems and institutional constraints (see Figure 1):

1. Interior Alaska
2. Coastal Alaska
3. Western Olympics
4. Coastal Washington and Oregon
5. Klamath Mountains
6. Puget - Willamette Trough
7. Western Cascades
8. Eastern Cascades - North
9. Eastern Cascades - South
10. Blue Mountains
11. Okanogan Highland
12. Northern Idaho
13. Intermountain

The following technical areas as they relate to water quality are dealt with:

Harvest Methods

- clearcut
- shelterwood
- seed tree
- selection

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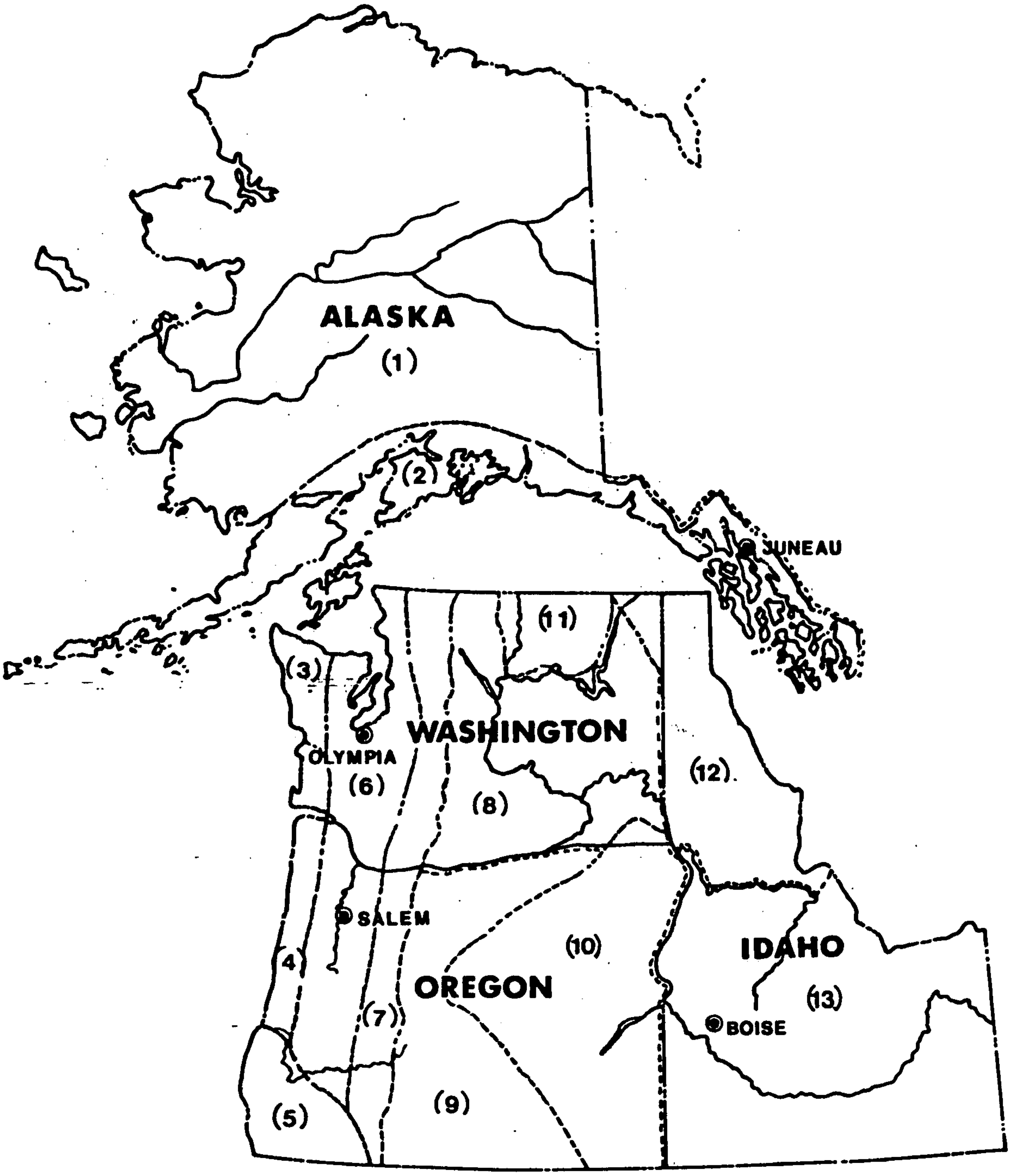

Figure 1

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- Forest Management Practices
  - thinning
  - reforestation
  - scarification
  - terracing
- Logging and Transportation Equipment Systems and Methods
  - aerial
  - cable
  - tractor
  - horselogging
  - skid trails
  - landing and staging areas
  - water rafting and storage
  - equipment (selection and operation)
  - haul roads (planning criteria related to the selection of harvest and logging methods)
- Residue Management Practices
  - salvage and use
  - burning
  - burial
  - retention on-site
  - reduction (selection and planning of harvest and logging method)

The report presents the following types of water quality protection information related to sedimentation and thermal and chemical pollution:

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Planning approaches and design criteria

Tables that summarize cause/effect information
related to logging and harvesting methods

Monitoring considerations

Models and optimization methods

Descriptions of equipment and methods

Summaries of handbooks, research studies and
recommendations

An annotated bibliography and a listing of
references

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Forest Statistics

Of the nearly 157 million acres of land in the Pacific Northwest (states of Washington, Oregon, and Idaho) nearly 59 million acres have been classified as commercial forest lands in either public or private ownership. An additional 16.5 million acres have been classified as non-commercial forest lands. Non-commercial lands include those that are unproductive or are productive forest land held in reserve. The coastal region of Alaska, which is almost entirely forested, consists of over 5.8 million acres of commercial forest land and more than 10 million acres of non-commercial forest lands. Consequently, approximately one-half of Region X is comprised of forest land of both a commercial and non-commercial nature.

From the standpoint of area covered the most important forest types are Douglas fir and ponderosa pine. Of the total area of commercial and non-commercial land well over one-third is occupied by Douglas fir, an additional third consisting of ponderosa pine forests and the balance occupied by several forest types including hemlock-sitka spruce, white pine, lodgepole pine, western larch, and true fir-spruce. The hemlock-spruce type, confined almost entirely to a narrow belt along the coast, covers over 3.5 million acres in Washington and Oregon. Consequently, including Alaska the hemlock-spruce type comprise over 7 million acres in Region X.

Of the substantial quantity of non-commercial forest land in the Pacific Northwest the bulk of that in the Douglas fir

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type is held in various reserves. In contrast to the Douglas fir type, non-commercial ponderosa pine lands are largely unproductive lands in the arid inland regions.

The ownership pattern of forest lands in the Pacific Northwest contrasts markedly with ownership in other parts of the continental United States. Approximately 65% of timber lands in the three northwest states are in some form of public ownership, 20% by industry and the balance classified as farm land.

The interior forests of Alaska occupy almost 120 million acres, or 35 percent of the total land area. The balance of interior Alaska consists of grassland, tundra, swamp, barren rock, and a very small part as agricultural lands. The forested areas are chiefly white spruce and white birch.

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Overview

Due to the economic significance in the Northwest of commercial and sport fishing and the wood products industries, both timber harvesting and water quality protection are very important. The Region's wide range of physical and biological characteristics make it impossible to solve all the forest-associated water quality problems through region-wide standards. The most efficient solutions involve site specific planning and new techniques. However, water quality protection is compatible with timber harvest in much of the region.

A basic land use decision concerning whether the primary allocation of the specific land unit is for wood fiber or other purposes must be made before addressing specific water quality protection objectives. This allocation relates only partially to the information presented in this report. Once this basic land use allocation is made and understood, water quality can generally be protected through planning and effective plan implementation. However, much of the current forest management controversy appears to be as much related to the question of land use allocation as to water quality protection. This report relates primarily to water quality protection needed as a result of timber harvesting on "commercial" forest lands (i.e., those lands allocated to wood fiber production). However, in some cases, it may have value in the question of land use allocation.

Because of the wide physical and biological variations within Region X, research conclusions are often taken out of context and applied inappropriately. For instance, certain water quality arguments against clearcutting may be relevant on the Idaho Batholith but not applicable to coastal areas in Washington and Oregon due to significant differences in soils, hydrology, climate, and forest type. On the other hand, a rationalization favoring clearcutting based on potential environmental benefits may be applicable to some sites in western Oregon but have little if any relevance on the Idaho Batholith.

Throughout Region X there are significant potentials for adverse water quality impact from many facets of timber harvest, residue management and regeneration. The most significant of these potential impacts appears to be related to erosion and sedimentation but in many areas thermal pollution is a major if not the most significant potential problem. Nutrients held by the soil media and vegetation can result in significant water quality problems but this is generally of less severity than sediment and elevated water temperature.

There are wide variations in the applicability of the techniques and methods presented in this report. This results from the varying significance from one sub-region to another of physical or biological factors such as:

temperature regime
soils/hydrologic characteristics
geology
fisheries

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precipitation pattern
aspect
forest types

For example, the main benefit of buffer strips on the Idaho Batholith may result from the sediment interception potential of such strips, but in the coastal zone the primary value is in preserving a water temperature regime conducive to resident and anadromous fish species. The effects of changing the temperature regime are also often different from subregion to subregion. In western Oregon the fisheries can be detrimentally affected by streamside vegetation removal due to increases in temperatures but in some other subregions a beneficial fishery effect may result from slight temperature increases. To add to the complexity many observers believe that in Alaska the most significant adverse temperature effect is the more thorough and longer freezing of the streams that can result from changing the micro-climate through vegetation removal adjacent to streams. Another example concerns the relative significance of the impact of residue management on water quality. Old growth stands can produce large amounts of slash when logged which may result in an organic chemical pollution problem. In other areas there appears to be very little water pollution potential from the entire range of residue management alternatives provided the slash is removed from the water-influence zone.

Because of the complexity and diversity of the problem the significant advances in water quality protection can be made through specific site planning involving interdisciplinary teams and predictive or impact models, expanded utilization of advanced logging equipment, and engineering guidelines which have been developed for the specific areas involved. Planning methodologies and predictive models now available to forest management planners are numerous and embrace a wide range of sophistication. It is the opinion of the project team that the Federal agencies, particularly the U.S. Forest Service have started to vigorously apply progressive land use planning techniques that incorporate water quality goals in most areas. There does appear to be an absence of formal water quality protection constraints other than those imposed by public agencies within some segments of industry.

Certain special problems were viewed by the project team. These included, for example, the accidental removal by county crews of the protective vegetation left along forest roads for erosion control purposes. Another such unusual problem is that of high runoff rates resulting in roadside rivulets along logging roads by an overapplication of dust control water.

Due to differences throughout the region in the availability of management expertise, field personnel, advanced logging equipment and automated analysis technology, a number of levels of water quality management is required. In addition, differences in field control from one operation to another will necessitate different types of management approaches. Where

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sophisticated planning and engineering is done and field control is adequate, specific water quality prescriptions, or plans, can be developed for each site.

On the other hand, where field control, planning or engineering is inadequate rules-of-thumb and legally enforceable guidelines are required. While this "codification" approach can result in solutions that vary from slightly inefficient to counter-productive, the most common implication is inefficiency. Unfortunately the predominant situation in Region X requires generally applicable guideline approaches to water quality management for the present.

In summary, there are areas within the region where the water quality problems are simple and lend themselves to straightforward solutions. Other areas exist where advanced logging methods and complex design and planning programs are needed to protect water quality. Still other areas exist where the cost of remedial or preventative measures is so great as to suggest that no exploitation of the timber may be the best approach to water quality protection.

Report Format and Use

This report is presented in two volumes. The first contains the basic text of the report and Volume II presents both an annotated bibliography and a reference section.

The report emphasizes summarization of research, currently applied prediction, prevention and control techniques, and guidelines/criteria for preventing water pollution.

Subregions have been defined due to the frequent need for specifying the applicability and relevance of the research information and "best available technology" presented. The sub-regional descriptions are presented in Section Two. As various aspects of the study are discussed, reference will be made when needed to situations in which the method is most applicable and if possible, to circumstances or locations where the method may not be relevant. An alternative report structure would have been to include separate subregional sections for each method, but this approach was not taken due to the enormous potential for redundancy.

Section Three summarizes the current forest practices utilized in Region X. Although these summaries are brief, they are sufficient to facilitate a general understanding of the report.

Section Four addresses the impact on water quality of the various forest practices presented in Section Three. Subsections are included concerning sedimentation, thermal pollution, and chemical pollution.

In Section Five of the report, various methods and approaches to planning and control are described. Emphasis is placed on providing the reader with summaries concerning: (1) the selection of silvicultural or logging systems based on water quality impact, (2) planning approaches and simulation models, (3) specific operational, design or planning constraints, and (4) the information requirements for monitoring, prediction or planning purposes.

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Glossary

ACCELERATED EROSION - the wearing away of the soil at a rate faster than it is being created.

ANADROMOUS - pertaining to fishes which ascend rivers to spawn.

CROSS DRAINS - a shallow ditch, water bar, or trench cut across a road at an angle, for diverting surface runoff from the road.

CUTTING METHODS

a) Clearcutting - removal of the entire stand, all trees large and small, in one cut.

Types of clearcutting

Patch cutting - Patch cutting is a series of clearcuttings made in patches. In the first cut portions of the stand are selected which for some reason should be cut before the rest of the stand. In succeeding operations patches are enlarged or new patches are created elsewhere in the stand. When cutting patches with time intervals between operations, each patch can be recognized as an individual stand.

Alternate strips - The stand is divided into a series of strips. Alternate strips are cut with the uncut strips serving as a seed source for reproduction. After reproduction is secured, the leave strips are cut.

Continuous clear-cutting - The stand is cut on a continually advancing front, i.e., no blocks, strips, or edges are left to serve as seed sources.

b) Group selection - A modification of the selection methods where mature timber is removed in small groups rather than by single trees.

c) Selection - Removal of mature timber, usually the oldest or largest trees, either as single scattered tree or in small groups at relatively short intervals, commonly 5 to 20 years, repeated indefinitely, by means of which the continuous establishment of natural reproduction is encouraged and an uneven-aged stand is maintained.

d) Shelterwood - Removal of the mature timber in a series of cuttings, which extend over a period of years, equal usually to not more than one-quarter and one-tenth of the time required to grow the crop by means of which the establishment of natural reproduction under the partial shelter of seed trees is encouraged.

DEBRIS - material of organic origin such as slash, slabs or sawdust.

EPHEMERAL STREAM - a waterway which flows during and shortly after storms but which is normally dry.

EROSION - the group of processes whereby soil or rock materials is loosened or dissolved and removed from any part of the earth's surface. Soil loss on natural slopes is usually small and referred to as geologic erosion. Where natural conditions have been disturbed, the rate of erosion increases rapidly and is referred to as accelerated erosion.

HAULING - transportation of trees or cut logs from the forest to sawmill or similar destination.

INFILTRATION - the flow or movement of water through the soil surface into the ground.

INTERMITTENT STREAM - a waterway which flows during moist periods of the year but which is seasonally dry.

INTOLERANCE - the incapacity of a tree to develop and grow in the shade of and in competition with other trees.

JACKSON TURBIDITY UNIT - a standard unit of measurement for determining turbidity.

LOGGING METHODS

a) Cable logging - system of logging where logs are transported from stump to landing by means of steel cable and winch.

b) Ground lead logging - cable logging with a low speed, stationary machine, the lead block being a few feet off the ground.

c) High lead logging - a modification of ground lead logging, wherein the main lead block is placed on a spar tree, generally 100 to 125 feet above the ground, giving a lifting effect to the incoming logs.

d) 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.

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e) Tractor logging - any system of logging in which a tractor operating as a mobile unit furnishes motive power in skidding logs.

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.

OUTSLOPED ROADS - where a road surface slopes downward from the toe of the cut to the road shoulder.

PEAK FLOW - maximum stream discharge occurring from snow melts or rainstorms.

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.

SEDIMENT TRANSPORT - the movement of soil particles in water suspension over the land surface.

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 logging road.

SKID TRAILS - a disturbance of the forest floor resulting from logs being pulled over the surface.

SLUMPING - movement of patches of the top foot of soil or more, when a surface layer resting upon a compacted lower layer of soil becomes saturated. The combined weight of soil and water causes a slip between the two layers.

SOIL AGGREGATE - soil particles held together by internal forces in a single mass such as clod, prism, block, or granule.

SOIL COMPACTION - decrease in soil macro-pore space owing to pressure or force exerted on the soil surface.

SURFACE RUNOFF - water that flows over the ground surface and into streams and rivers.

WATER BAR - a log of small diameter laid at a slight angle to direction of skid trail and staked in place. Purpose is to divert surface runoff into undisturbed areas.

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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.

Acknowledgments

Information was requested and received from federal and state state agencies, industries, associations, conservations groups, and research organizations. Such information was generally from agencies or states in the Northwest, but it was also provided by other regions and Canada. We are especially indebted to the U.S. Forest Service, the Weyerhaeuser Corporation, the Boise Cascade Corporation, the Ketchikan Pulp Company, and agencies of the states of Alaska, Oregon, Washington, and Idaho for assisting us with field trips to view various field operations. The University of Alaska, Oregon State University and the University of Idaho provided time and information.

The project director from Montgomery Engineers is Mr. H. Tom Davis with assistance provided by Mr. Fred Hagius. Dr. Benjamin A. Jayne, Director of the Center for Quantitative Science in Forestry, Fisheries, and Wildlife, University of Washington, is the project forester with assistance provided by Mr. Clifford W. Wylie, consulting forester, and Mr. Roger Guernsey, consulting forester. Dr. David D. Wooldridge, Associate Professor of Forest Hydrology, College of Forest Resources, University of Washington, served as a special consultant concerning forest soils and hydrology. Mr. John Somerville, Montgomery Engineers provided the basic management of the project.

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Hundreds of separate items of information including research papers, Forest Service manuals, handbooks of all descriptions, special association or organization papers, and verbal communications have been utilized in the study. Written communication has occurred with all groups having an identifiable interest in the results of the study. Numerous telephone conversations and personal visits have occurred with groups having particular interest in the study.

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COMMERCIAL FOREST LANDS OF REGION X

Region X has been subdivided into subregions on the basis of uniformity of forest type, uniformity of usual silvicultural practices and similarities in climate, physiography and hydrology. Justification for this subdivision is based on uniform silvicultural practices including residue management and forest stand regeneration within a subregion. Influence of a given forest land management practice on water quality varies from one subregion to another based on the season and free water input to a hydrologic regime.

At lower elevations in western Washington and Oregon, most precipitation occurs as rain which is immediately available to streams for a hydrologic response and transportation of dissolved and suspended materials. In contrast, precipitation occuring as snow at higher elevations accumulates during the winter and is released as a free water input to streams during the melt season. Thus, the solvent action of water in passing through the forest soil and erosive action in streams and rivers is concentrated in the late spring and early summer. Storms which cause flooding in western Washington and Oregon in November and December have little impact on streamflow in the snow accumulating zones. Conversely, a warm light rainstorm might produce what is termed a chinook condition east of the Cascades which causes flooding due to very rapidly melting snow (usually accompanied by vigorous winds). It is not uncommon to have temperatures rise from sub-freezing

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(0 to 15°F) to 50 to 55°F in less than an hour. Chinook conditions frequently produce localized flooding from small tributaries, but usually are not sustained long enough to produce flooding on major rivers.

The following discussion of subregions in Region X will identify major forest species of the commercial forests summarizing the occurrence of dominant types, climate, geology, and soil parent material where possible. These data present a framework for discussion of interacting water quality problems with forest management, soils erosion and basic hydrology. The magnitude of water quality problems to a large degree depends on associated water resources or uses of water that are affected. The importance of sports and commercial fisheries in Region X dictates consideration must be given to impacts on fisheries resources in the various subregions. Later discussions will expand on the relative importance of water temperature and suspended or dissolved materials.

Based on the above rationale, Region X has been divided into the following subregions:

Interior Alaska
Coastal Alaska
Western Olympics
Coastal Washington and Oregon
Klamath Mountains
Puget-Willamette Trough
Western Cascades
Eastern Cascades - North

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Eastern Cascades - South

Blue Mountains

Okanogan Highlands

Northern Idaho

Intermountain

The diversity of climate, forest vegetation, soils, geology and man's impact on the forest environment of the above subregions is obvious. While there is justification for separating the discussion of certain subregions there is also equal justification for consolidating many of these subregions as a particular discussion is pertinent to the larger region.

Climate of Region X is a function of the location and intensity of the semi-permanent high and low pressure cells over the North Pacific Ocean. In summer a strong high pressure cell develops over the Northeast Pacific which causes air to circulate in a clockwise direction around the cell. This circulation results in a prevailing westerly and northwesterly flows of air masses which are comparatively dry, cool and stable. In fall and winter an Aleutian low pressure cell develops, intensifies and moves southward resulting in a counterclockwise flow of air across the Pacific Northwest. Prevailing wind directions become south to southwesterly transporting very moist air masses in equilibrium with the ocean temperature across the Pacific Northwest. Condensation occurs as these warm moist air masses move over the cooler land surfaces. The climate generally resulting from the prevailing winds is typically cool, relatively dry in summer inland from the foggy coastal zone yet mild and wet during the winter.

Temperatures along the coastal zone are also significantly influenced by the prevailing ocean currents. The nearshore current reverses direction between summer and winter. In summer the California current flows south while in winter the Davidson inshore current moves north. Water temperatures along the Washington-Oregon coast range from 48°F in February and March to 58°F in August. The average air temperature in mid-summer ranges from 50 to 60°F, while coldest average winter temperatures range from 42 to 44°F. These dominating influences affect the climate of southern interior Alaska, Coastal Alaska and Coastal Washington and Oregon and provide the maritime climate common to Region X.

The mild humid temperate climate of Coastal Washington, Oregon and Alaska results in a common forest type, the western hemlock-Sitka spruce (Ruth and Harris, 1973) where western hemlock and Sitka spruce are the dominant forest species. Over this 2000-mile long strip of coast there are variations in the admixtures of associated species. Near Cook Inlet Sitka spruce becomes the dominant species while to the south western hemlock gives way to an increasing component of stand composition in Douglas fir and redwood. Douglas fir occurs along the coast of Washington and Oregon in decreasing amounts with increasing latitude. It does not occur in coastal Alaska. Characteristics of climate make fire a significant ecological factor in the western hemlock type of Washington and Oregon;

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however, Coastal Alaska is continuously far too wet to ever burn. Franklin and Dyrness (1973) consider western hemlock to be the climatic climax species throughout the subregions of: the Western Olympics, Coastal Washington and Oregon; the Western Cascades; and much of the Puget-Willamette Trough. Those areas of the Willamette Valley not included are lower elevations in dryer, warmer habitats. Eastern extensions of the western hemlock type are recognized in valleys along the east slope of the Cascades Mountains in Washington and Northern Oregon and west slopes of Northern Idaho.

The mixed conifer type east of the Cascade crest melds with the Coastal types before developing the typical characteristics of the northern Rocky Mountain forest types. Franklin and Dyrness (1973) cite the work of Daubenmire which indicates a continuum of climatic climax species from warm, dry to cold, wet habitats in the following order: ponderosa pine, Douglas fir, western larch, lodgepole pine, grand fir, western white pine, western red cedar, western hemlock, Engelmann spruce, subalpine fir, mountain hemlock and whitebark pine. Forest stands or species occur in a complex intermix as affected by: elevation, local habitat, soils and local climate east of the Cascade Mountains.

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Fisheries Resources

Commercial and sports fisheries resources of Region X are dependent on aquatic habitat or on streams and lakes within the commercial forest zone for reproduction and rearing. The more important species utilizing the fresh water environment are: pink (humpback) salmon, chum (dog) salmon, sockeye (red) salmon, Chinook (king) salmon, coho (silver) salmon, rainbow and steelhead trout, cutthroat trout, and Dolly Varden trout. The spawning habitats of reproducing species consists of suitable gravel with a continous supply of high quality water. Spawning beds must be protected from physical damage by floating debris or depositions of sediment while eggs are in the gravel. The quality of the aquatic environment is also important for the rearing and growth of juvenile fish.

While the life cycle habits of many of the species have many aspects in common, there are sufficient differences in their use of the fresh water environment that a distinction should be made between certain species. Pink and chum salmon utilize fresh water only for spawning and egg incubation. These species spawn low in streams very close to salt water in early fall, with fry emerging from stream bed gravels from late March to early May. Fry may migrate to salt water immediately or remain in the stream for a very short time. The life cycle in the ocean requires one and a half to three and a half years, then adults return to their streams of origin to spawn. Pink and chum salmon are important throughout southeast Alaska and in many of the rivers of Puget Sound.

Sockeye salmon generally require a lake in the river system used for reproduction. Adults move upstream to the lake where they spawn in upper tributaries. The emerging fry then migrate to the lake where they spend one or more years as residents. On reaching migratory size, they return to the ocean to complete their life cycle. The very red flesh of the sockeye salmon makes it one of the most prized commercial species. It is a particularly important species in the Columbia River system. Chinook and coho salmon and steelhead trout utilize rivers throughout coastal Alaska, Washington, Oregon and Northern California. Chinook salmon are the largest of the Pacific salmon, and generally favor larger river systems. There are runs in most of the large rivers from the Yukon south to San Francisco Bay. Three races of Chinook salmon are commonly recognized based on the time of entry into fresh water. Spring Chinooks enter these streams as early as March and April, while later runs peak in mid-July, and a fall run enters the streams in September and October. Coho salmon have a much wider range of suitable stream habitats as they will enter both large and small streams for spawning. Both coho and Chinook juveniles spend one or more years in fresh water before reaching migratory size to return to the ocean. They will then spend one or more years in the ocean completing their life cycle to return to spawn in fresh water. Rainbow trout (steelhead) and cutthroat trout also have similar life cycles, entering fresh water

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from the ocean to spawn, with juveniles spending differing times in the fresh water. The primary difference between trout and salmon in life cycle is that trout do not die after spawning and may return to spawn in fresh water several times.

Most major water bodies in Region X either have natural populations of fish that are important for sport or commercial use or have introduced species. Physical barriers have caused natural landlocking of both the salmon and trout in particular river systems. Landlocked sockeye salmon (silver trout and kokanee) are important in many of the larger lakes tributary to the Columbia River.

Interior Alaska

Interior Alaska is usually considered that portion north of the coastal zone and west of the Kenai Peninsula. The vast area of Interior Alaska has greatly varied topography, vegetative cover and climatic conditions. Permafrost is found on varying aspects to varying depths throughout much of Interior Alaska. The occurrence and depth to permafrost greatly influences the vegetative type, vegetative patterns and annual growth. In general Interior Alaska is a dry region; however, permafrost holds all moisture near the soil surface resulting in a relatively heavy ground cover of grasses, mosses and shrubs which retard any surface runoff.

Forest Types

Interior forests extend to arctic slopes on the north; however, the better forest stands are confined to lower slopes and valley bottoms of larger rivers and their major tributaries. The principal forest regions include the drainages of the Susitana, Copper, Tanana, Yukon and Kuskowim Rivers. Forest stands are classed commercial in the Interior if the site is capable of producing 20 cubic feet of wood per acre per year.

Interior forest types are seldom pure in species composition. They are usually a mixture of four major commercial species. The most important of which is white spruce followed by paper birch, quaking aspen, and balsam poplar. White spruce is generally classed as the climax forest species on most commercial forest lands of the Interior. The best stands of white spruce occur on well-drained soils in river bottoms.

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Mature stands generally require 100 to 150 years for development. Spruce stands destroyed by fire commonly reseed to aspen or birch with some mixing of white spruces. White spruce is shade tolerant so eventually will become dominant in the understory and replace the hardwoods.

Paper birch is the second most important species occurring on 5.1 million acres of forest land. Birch matures at 80 to 100 years of age and if not harvested becomes very defective and is replaced by the spruce understory.

Quaking aspen like birch frequently reseeds recent burns. It is fast growing usually maturing in 60 to 80 years to be replaced by spruce. Aspen is widespread in mixed stands throughout the Interior but grows especially well on south slopes and well-drained soils.

Balsam poplar is the major species on 2.0 million acres but also occurs widely in mixture with other species throughout the Interior. The best commercial stands of balsam poplar occur on well-drained river valley soils. Trees will range from 80 to 100 feet tall and up to 24 inches in diameter.

The commercial importance of timber stands in Interior Alaska has been compared with the Lake States region. It is estimated based on a 100-year rotation that Interior Alaska could provide enough pulpwood to sustain the operation of 10 pulp mills producing 500 tons of pulp per day. This is equivalent to an annual allowable cut of 900 million board feet of saw timber.

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Climate

The climate of Interior Alaska varies from a moderate continental in the southern portion near Cook Inlet to the subarctic climate of the remainder of Interior Alaska. In the transition between coastal and Interior Alaska (Kenai Peninsula area), mean annual temperatures vary from 32 to 35°F, with the months of June, July and August having average monthly temperatures in excess of 55°F. In the coldest months, temperatures average 10 to 12°F. Precipitation is also relatively uniform, showing moderate orographic influences. Over a broad area in the Kenai-Kodiak area, average annual precipitation varies from 30 to 40 inches.

The climate of Fairbanks might be considered as somewhat of an average for interior forested areas. Interior Alaska climate is influenced by several large mountain barriers which form effective blocks to the flow of warm moist air from the north Pacific Ocean. The lack of a moderating influence of maritime air results in greater extremes in temperature both highs and lows than coastal areas. The average annual temperature of Fairbanks is 26°F and can vary locally depending on elevation and aspect from 15 to 36°F. In Fairbanks, the official all-time low temperature was -66°F in January 1934, with the highest temperature recorded 99°F in July 1919. On the average the frost free growing season is approximately 90 days.

The Alaska Range south of Fairbanks forms a very effective barrier to moist air movement from the south. As a result

Fairbanks lies in the rain shadow with average annual precipitation of about 10 inches. Maximum monthly precipitation usually occurs in July and August (1.9 and 2.1 inches) with minimum amounts of precipitation between February and April (0.3 to 0.7 inches). Rainfall intensities are light to moderate, with up to 0.3 inches per hour, and maximum daily rainfall of 3.4 inches.

Geology and Soils

Underlying bedrock of Interior Alaska is predominantly Tertiary sediments with older Jurassic granitic intrusives. Uplifted sediments make up parts of the Alaska Range with Precambrian schists and a number of intrusive and extrusive igneous rocks occurring farther to the north. Many of the broad valleys contain very deep alluvial deposits of sand and gravel. During the Pleistocene glaciers covered most of Interior Alaska lowlands (regions occupied by commercial forests). Much of the existing topography is a result of reworked material and depositions by the glaciers.

As is common in association with glacial activity, many of the soils are windblown loess. These soils occur throughout the interior in depositions of a foot to 10 to 15 feet. In many places the highly erodible loess soils have been redeposited as alluvial soils in the valleys through normal erosional processes. Soils of the commercial forest stands are generally podzols (spodosols) developed on loess or alluvium in some cases mixed with ash. Muskeg develops on wet soils (Histosols) and in depressions. Areas of very young

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loess or ash and in some cases recent alluvial deposits are immature and are classed as Regosols.

Hydrology

The flow regimes of Interior Alaska streams closely parallel those expected from the cold snow zone. Since 40% of the annual precipitation usually occurs as snow, the snow accumulates and is released in a melt season from May through August. Streamflow from snowmelt is augmented by rainfall in July and August, the wettest months of the year. The spring breakup (May) results in a very rapid increase in streamflow, with peak flows usually occurring for two weeks immediately following breakup. There is a gradual decrease in flow through summer, with minimum flows occurring during the winter freeze-up. Over an extended area of the Interior, the average annual runoff is about ten inches per year; however, this can be highly variable depending on annual precipitation and summer temperatures. It is not uncommon to have a two- to three-fold variation in annual water yield in a very few years.

For example, the average annual flow of the Chena River at Fairbanks varied from 708 cubic feet per second (cfs) in 1958 to 1230 cfs in 1959, 2603 cfs in 1962, 1293 cfs in 1966, and 3160 cfs in 1967. Summer flooding is a usual occurrence and highly variable water yields can result from a combination of warm temperatures and/or excessive summer precipitation. Water yields per unit land area vary from very low during freeze up to 37 cubic feet per second per square mile (cfsm) on the Chena River (1980 square miles of watershed).

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Coastal Alaska

Coastal Alaska comprises an area of about 33 million acres of which 15.8 million acres are forested. A forested area is defined as one which has at least 10% stocking with trees. The forested zone consists of 5.8 million acres of commercial forest land. The commercial forest land is described as an area of 8000 board feet of saw timber per acre in minimum areas of 10 acres or more. Volumes are based on the International quarter-inch rule.

Coastal Alaska is made up of hundreds of islands with a narrow mainland broken by many fjords and inlets. The islands vary in size from those of less than an acre to islands such as Kodiak (2.3 million acres) and Prince of Wales (1.6 million acres). Coastal Alaska is about 150 miles wide at its widest point between the Gulf of Alaska and Canadian border and 800 air miles long from Ketchikan to the Anchorage-Cook Inlet area.

Forest Types

Alaska's coastal forests are an extension of the temperate coastal rain forests of Washington and Oregon. The major difference in forest type is the absence of Douglas-fir and an increase in Sitka spruce in the north. Commercial forests extend westward along the Alaskan coast to Cook Inlet and Kodiak Island. In the southeast near Ketchikan, forest stands are composed primarily of western hemlock and Sitka spruce. Randomly interspersed and in occasional small blocks are stands of western red cedar and Alaska cedar. Commercial hardwoods such as red alder and black cottonwood are confined to stream bottoms and exposed mineral soil in slide areas. Progressing northwest, western red cedar and Alaska cedar become much less important occurring primarily in swamps as far westward as Port Wells on Prince William Sound. Commercially important stands of cottonwood occur in the Haines area and on most alluvial soils to the west. Sitka spruce becomes an increasingly important component of the forest stand in the northwest coastal regions and in the only conifer occurring on Kodiak and Afognak Islands. Old growth saw timber comprises 84% of the commercial forests of coastal Alaska.

Geology and Soils

Land forms of southeast Alaska exhibit the complex effects of Pleistocene glaciation with great variety of bedrock types. There are extensive areas of granitic, metamorphic, volcanic and calcareous rocks. Granitic rock forms are generally more massive and resistant to the erosional powers of glaciers; consequently, they form the most extensive mountain systems with steeper topography to glaciated valley bottoms. Calcareous (marble and limestone) bedrocks are extensively fractured providing excellent subsurface drainage. Frequently these soil parent materials provide a relatively good site for growth of commercial forest.

Glacial ice covered most of southeast Alaska, including the islands, during the maximum advance of Pleistocene glaciers. The great pressure of glacial ice overriding previously deposited tills formed extensive areas of compacted till. These compacted tills occur to elevations of about 1500 feet in many of the U-shaped valleys.

Till deposits become thinner with increasing elevation and also tend to be thicker on south and west facing slopes than on north or east facing slopes. Most valley bottoms are U-shaped with low terraces of varying ages developed from relatively recent alluvium or deposits reworked by glacial melt rivers.

Post glacial, ash and pumice deposits occur over an extensive area on Revilla, Kruzof, Baranof and Chichagof Islands. These deposits evidently occurred as the Pleistocene ice age ended. Ash and pumice mantles the sides and upper valley walls and has been redeposited on terraces in major river valleys.

Climate

The climate of southeast Alaska can be described as wet and cool. Summers are relatively cool and extreme cold weather is uncommon except at higher elevations. Precipitation is abundant year-around with October often the wettest month of the year. Average annual precipitation near tide water is about 100 to 150 inches. With relatively small increases in elevation, precipitation ranges to 200 to 300 inches. Rainfall rates are moderate (0.3 to .5 inches per hour) and often of long duration. The frost-free growing season varies from about 100 days in northern areas removed from the water to about 200 days at tide water in the

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southeastern areas. Maximum summer day lengths range from 17½ hours at Ketchikan to 18½ hours near Juneau and 19½ near Anchorage. Overcast and cloudiness is the rule for most of southeast Alaska. From June to September the Juneau airport reports only 27% of the possible sunshine.

Hydrology

Coastal Alaska falls within the hydrologic regime of the warm snow zone. Large amounts of precipitation (20 inches) occur during October and November, with temperatures cooling in December as snow begins to accumulate. Frequent warm rainstorms occur even after snow accumulation begins, with the snow pack transmitting water to the soil and streams. The combination of steep slopes and abundant precipitation with shallow soils produces streams with highly variable flow characteristics, particularly for streams that do not have large lakes in their watersheds. Surface runoff varies from 60 to 100 inches for lower elevation watersheds to 100 to 150 inches and more for intermediate and higher elevations.

Perennial snow fields and glaciers are a major component of the water resources of Coastal Alaska. Most larger streams have elevations in their upper reaches which receive very heavy snowfall. Snowmelt initiates in early April, reaching a peak in late June or July; thus maximum streamflow occurs during the season of reduced precipitation.

The mean annual discharge per unit of land area varies from 8.5 to 19.1 cfsm, with an average of 13.8 cfsm. Maximum flood flows exceed 300 cfsm from many of the smaller watersheds during extended durations of heavy rainstorms.

Western Olympics

The coastal zone of the Olympic Peninsula combines forest types of the narrow shoreline Sitka spruce type with the western hemlock type. Soils and land forms of the Western Olympics, like Coastal Alaska, are dominated by Pleistocene glaciation. Lower elevation land forms are usually of gentle topography forming a coastal plain of varying width from Neah Bay south to Grays Harbor.

Forest Types

Near the ocean, Sitka spruce is the dominant species extending up river valleys on recent alluvial soils, frequently for many miles. The western hemlock zone is confied to elevations below 3000 feet. Coniferous stands of these zones are typically very dense with large diameter, very tall trees, probably the most productive commercial forest in the world. The species composition consists of western hemlock, Sitka spruce, western red cedar, and Douglas fir. Stand volumes range from non-commercial in cedar swamps on compacted till to 400,000 board feet per acre on well-drained soils of old growth Douglas fir. At higher elevations removed from the caost, Pacific silver fir becomes an important species. Red alder and cottonwood occur in commercial stands on recent alluvial soils along major rivers.

The zone also includes the Olympic Rain Forest. Plant communities representative of the Olympic Rain Forest occur on old river terraces in the U-shaped valley bottoms of the Bogochiel, Hoh, Quinault and Queets Rivers. Dominant species are western hemlock and Sitka spruce with occasional western red cedar and Douglas fir. Abundant rainfall and frequent summer fog also allows luxuriant development of epiphytic plants.

Climate

The climate of the Western Olympics is definitely maritime as air masses move inland from the Pacific Ocean. These air masses are nearly always saturated as evaporation from the Ocean is an equilibrium with their temperature. During colder periods of the year, condensation occurs as the air masses move across the colder land mass. Maximum rainfall occurs in December and January (15 to 20 inches) with minimum amounts in July and August (2 to 4 inches). Precipitation averages 70 to 90 inches at low elevations, increasing rapidly with elevation and distance inland to 150 to 170 inches at 1000 feet and in excess of 200 inches at higher elevations. Rainfall intensities are usually moderate (0.4 to .6 inches per hour) but may occur for long duration resulting in 5 to 10 inches of rain per day.

The average annual maximum temperature is 58°F. at Forks with an average annual minimum of 40°F and mean of 49°F. The coldest month is January with an average temperature of 39°F. while the warmest is August with an average temperature of 72°F. Extreme temperatures of -4°F and 101°F have been recorded. The average frost free growing season is about 200 days.

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Unusual weather conditions are a frequent occurrence along the Pacific Coast. Winds of 70 miles per hour occur almost annually, frequently causing extensive blowdown. Relative humidities are always high with significant amounts of summer fog during rainless periods. Fog intercepted in the forest canopy causes a substantial amount of fog drip augmenting the soil moisture supply during otherwise rainless periods. Departure in the ususal weather of the coastal area occurs with east winds which bring low humidities and low temperatures during the winter, or low humidity and high temperatures during the summer.

Geology and Soils

The central core of the Olympic Peninsula is made up of the very rugged Olympic Mountains which are surrounded by a glacially reworked, almost level lowlands or coastal plain. Ridges radiating from the Olympic Mountains slope from high elevations of 6000 feet, with major rivers occurring between these ridges. All major rivers are broad U-shaped valleys showing the dominating influences of glacial erosion. Bedrock of the Olympics consist of a volcanic horseshoe shaped formation extending from Neah Bay east along the north sides of the Olympics, south along Hood Canal and then east just south of Lake Quinault. The main Olympic Mountains are comprised of a sedimentary deposit of Tertiary origin. Rocks are largely graywackes with interbedded slates, siltstones, and conglomerates.

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Soils of the lower elevations formed on well-drained soils are largely reddish brown lateritics. At higher elevatons podzolization is the dominant soil forming process. A large variety of soils have formed on glacial materials, the type of soil is influenced by the degree of compaction, slope and internal drainage. Alluvial soils of a variety of textures occupy terraces and valley bottoms adjacent to major rivers. Other soils have been formed from marine terraces and glacial outwash fans.

Hydrology

The hydrologic regime of low elevation forest basins of the Western Olympics are classically that of the rainfall zone with summer lowflow in rainless periods and peaks in winter. Snow is relatively unimportant ranging from one to two inches per year close to the ocean, to five to twenty inches a few miles inland. Snowcover below 1500 feet is usually persistent for only a few days melting with rising temperature as the storms turn to rain. Average annual runoff varies from 60 inches at lower elevations to 140 for the mid-elevations. Major rivers flowing from high snowfall zones of the interior Olympic Mountains have runoff of 160 to over 200 inches per year. Low flow water yields range from 0.1 cfsm for rivers without snow zones to 1.1 cfsm (Hoh River) with perennial snow fields. Maximum yield ranges from 186 cfsm (Hoh River) to 280 cfsm (Soleduck River). The average yield is about 6.7 cfsm.

Coastal Washington and Oregon

The subregion of Coastal Washington and Oregon extends south from Grays Harbor to the vicinity of Coos Bay. The subregion essentially drains the western side of the Coast Range. Valleys are typically water eroded, with very limited glacial activity in the headwaters of a few streams with sources at higher elevations. Vegetation is somewhat similar to that of the Western Olympics, with increasing amounts of Douglas fir farther south.

Forest Types

The ocean side of the Coast Range is classed as the western hemlock zone (Franklin and Dyrness, 1973). In this zone, western hemlock is expected to be the climax species. Large areas of the zone, however, are dominated by second growth and some old growth Douglas fir forests. Much of the subregion has been logged or logged and burned during the past 150 years. Douglas fir regeneration is frequently favored over western hemlock on mineral soil, particularly in the hotter, drier areas of the zone. Major forest species are Douglas fir, western hemlock, western red cedar, grand fir, Sitka spruce (near the ocean) and western white pine in random locations. In Oregon, near the southern limits of the zone, incense cedar, sugar pine and occasional ponderosa pine occur. Near the upper elevational limit of the zone, Pacific silver fir occurs in mixed stands with western hemlock.

Important hardwoods include red alder and black cottonwood in northern portions of the zone, with increasing amounts of big-leafed maple, Oregon ash, madrone, white oak and tan oak in southern Oregon.

Climate

The maritime climate of the Pacific Coast prevails throughout this zone. Annual precipitation averages 60 to 70 inches near sea level in southern portions of the zone, to 80 to 90 inches in southwest Washington. Near the crest of the Coast Range, average annual precipitation varies from 100 to 200 inches, depending largely on elevation. Maximum rainfall rates are moderate (0.4 to .6 inches per hour), with 4 to 6 inches per day total. Snow on the ground seldom persists for more than just a few days, except at higher elevations.

Mean annual temperatures range from 53°F near sea level in Oregon to 50°F in the Grays Harbor area of Washington. Average annual maximum temperatures range from 61°F in the south to 59°F in the north. Average annual low temperatures show about the same spread, with 45°F in the south and 42°F in Grays Harbor. The average low temperatures during the coldest months show a 6° departure (40°F in the south, 34°F at Grays Harbor), thus greatly lengthening the frost free growing season from about 200 days in Grays Harbor to over 300 days in the south. The long term average sunshine varies from about 25% in the winter to near 50% in the summer. Fog occurs often in both summer and winter.

Geology and Soils

The Coast Range from the Willipa Hills in the north to

Coos Bay in the south is a complex of Eocene volcanics and Miocene sedimentary depositions (with certain interrelated volcanics). Oligocene sedimentary formations, which include siltstones, shales and sandstones, are found in northwest Oregon and the Willipa Hills of southwest Washington. These again are intermixed with extensive basalt flows which have occurred mostly along northern sections of the Oregon Coast Range and the Willipa Hills.

Land forms show the dominating effect of high rainfall from prevailing western winds. Valleys are typically V-shaped with steep side slopes and active erosional processes.

Soils developing on well-drained forest soils are typically classified as reddish-brown lateritics. These soils are relatively heavy-textured, with very high surface organic matter content. On steep mountainside slopes, soils tend to be shallower, with a stony loam texture often classed as western brown forest soils.

Hydrology

The hydrologic regime of Coastal Washington and Oregon is very similar to that of the Western Olympics. Rainfall predominates as a free water input, with maximum runoff occurring in December and January, the months of highest amounts of precipitation. Runoff can be highly variable from year to year, as indicated by the Siletz River in Oregon. Runoff during the period of record has varied from less than 60 inches to over 145 inches per year. Average annual runoff varies from 40 inches to 80 inches in southern portions of the Coast Range to 120 inches in northwest Oregon and the Willipa Hills of southwest Washington. Coastal areas of Washington and of Oregon have very high water yields, with very dynamic river channels. Flood flows of 150 to 250 cfsm are often sustained during periods of long duration of moderately heavy rainfall. Maximum flooding often occurs with the melting of several inches of snow over an extended elevational range by very heavy warm rains. Average flows are 4 to 6 cfsm, with a summer low of 0.1 cfsm.

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Klamath Mountains

The Klamath Mountains of southwest Oregon have been separated as a subregion based on their complex geologic formation, with related problems of mass movement, surface soil erosion and forest regeneration following timber harvest. The Klamath subregion includes the drainage of the Coos River and south, and interior valleys of the south forks of the Umpqua and Rogue Rivers.

Complexity of the subregion is somewhat indicated by the annual precipitation patterns, which vary from 100 to 200 inches along the coast to 20 inches in the interior valleys. This distribution of precipitation develops an equally diverse pattern of vegetation, with impact on soil formation processes.

Forest Types

The Klamath region is probably one of the most diverse in terms of variability in climate, soils in combination with the influences of aspect, and elevation. The forest types have been termed generally mixed conifer. The mixed forest includes Douglas fir, sugar pine, ponderosa pine and incense cedar, with a significant component of white fir and grand fir. These species occur in varying abundance throughout the western Cascade Range, the Siskiyou Mountains and portions of the east slope of the Coast Range.

On the ocean side of the Coast Range, significant amounts of redwood, Sitka spruce and western hemlock occur. These species are intermixed in the river bottoms as well as on

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the steeper hillsides. Their occurrence is confined to the mild, humid climate fronting the ocean, and their distribution becomes very limited in the interior valleys. Coastal forests under humid temperate conditions obtain maximum size in diameter and height, along with greatest longevity of northwest conifers. Redwood and western red cedar frequently exceed a thousand years in age, with diameters up to 10 and 12 feet and heights in excess of 250 feet. These stands contain very high quality trees, with some of the maximum recorded amounts of biomass per acre.

Climate

The Klamath region contains two contrasting climates. That of the coastal area is relatively wet, with very little year-round temperature change. There is considerable rain during the late fall, winter and early spring, and usually a large amount of fog and low clouds during the summer. Average annual precipitation varies from 100 to 200 inches at higher elevations immediately adjacent to the coast. Rainfall of 75 to 85 inches is common at sea level. The frost-free growing season at low elevations is in excess of 300 days. The interior valleys of the Umpqua and Rogue Rivers have a greatly modifed climate, as they lie in the rain shadow of the Coast Range. At lower elevations on the valley floor, average annual precipitation ranges from 20 to 35 inches. There is a gradual increase going both east and west to the Coast Range and the Cascades. Maximum rainfall from the Coast Range exceed 100 inches; however, the Cascades have few locations that exceed 60 to 80 inches.

Average monthly temperatures range from 35 to 40°F during the coldest months to around 70°F in the warmest months. Lowest temperatures observed are about -12°F, with a maximum of 115°F.

Geology and Soils

The Klamath Mountains are a complex range in southwestern Oregon and northern California. The northernmost portion of the range in Oregon is commonly called the Siskiyou Mountains. Geologically, these mountains are the oldest formation in Oregon. Terrain of the region is very rugged and deeply dissected. Geologic formations are quite complex, with areas of deposition of volcanic tuffs and sedimentary rocks which have been subsequently metamorphosed, largely into schists, gneisses, marbles and metavolcanics. Other formations have intruded to include a variety of granitics, diorites and pyorites.

Soils of the subregion reflecting the general influence of climates and plants fall into two main groupings. Those of the western portion are considerably wetter and more humid than those of the dry eastern condition. Soils of the western part generally fall in the reddish brown lateritic group. Parent materials for these soils include both sedimentary and igneous rocks. In the western portion there are major drainages which also contain a variety of well developed alluvial soils on terraces. Well drained soils of silt and clay textures develop western brown forest soils. Poorly drained streamside soils develop humic gleys.

Soils of the eastern portion of the region are classified most closely as reddish brown lateritics; however, they are continuously dry for long periods during the summer. These soils are relative shallow and show less profile development. They usually form on sedimentary parent materials. Granitic parent materials usually give rise to a Regosol soil of very low fertility. Soils formed from granitic parent materials are very coarse and well drained.

Hydrology

Major drainages in the Klamath region include the Umpqua and Rogue Rivers. These rivers bisect the Coast Range, and thus have characteristics of both the coastal rainfall zone and the snowpack zone at higher elevations. Discharge from smaller streams with their basins totally within the coastal rainfall zone have peak discharges (240 cfsm) in December and January, at times of maximum rainfall. Flows decline rapidly through March and April to minimum flows in August and September (0.06 cfsm). The Rogue River, gauged at an interior location, shows flow characteristics similar to those of the warm snow zone. Peak flows are sustained from February through May. Minimum flows occur in September and October. When the Rogue is gauged near the mouth at Gold Beach, it responds to the pattern of coastal rainfall, with peak flows occurring in January and minimum flows in September. Threefold variations in average annual yield are common for rivers in the Klamath region.

Puget-Willamette Trough

The Puget-Willamette Trough subregion includes the lower elevations on the western slopes of the Cascades and the eastern slopes of the Olympics and the Coast Range. The general characteristics of the maritime climate and distribution of plant species are quite similar to the Coast Range. However, the Coast Range provides a barrier for movement of air masses, resulting in a marked rain shadow effect along the eastern slopes of the Coast Range and in many places in the valley bottom. The Puget-Willamette Trough is bounded on the west by the crest of the Coast Range and on the east by the elevational transition to the warm snowpack which approximately coincides with increased dominance of Pacific silver fir in the forest stand.

Forest Types

Old growth Douglas fir forests of the Puget-Willamette Trough are unparalleled for quality and volume for use as saw timber. Soils of the lowland valleys were some of the most fertile in the northwest and have been extensively converted to agricultural uses. Throughout much of the Puget-Willamette Trough, western hemlock is considered to be the potential climax species. Currently, much of the zone has been logged and burned. Extensive areas were once converted to agricultural uses, but have reverted to forest growth. Douglas fir continues to be the dominant species in many of the second growth stands. Northern portions of the zone contain mixtures of Douglas fir, western hemlock and western

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white pine, with western red cedar and Sitka spruce occurring sporadically in favored habitats. Higher elevations on both the east and west sides of the zone grade into Pacific silver fir.

The warmer, drier valleys of the Willamette often preclude the occurrence of mesic species found farther north. Drier areas of the valley contain a mosaic of white oak, grasslands and chaparral shrub communities. The species composition of much of the Willamette Valley is much more complex as mesic species occur in favored habitats, but also the low rainfall and higher temperatures introduce a variety of plant communities adapted to the drier sites. Extensive areas of prairie or grassland were apparently native to the Willamette Valley, although they may have been maintained by the Indians through burning.

Climate

The Puget-Willamette Trough contains some of the most diverse precipitation patterns of any of the subregions. Northern portions of the Puget Sound area are strongly influenced by the rain shadow of the Olympic Mountains. The Dungeness Spit has less than 15 inches of average annual precipitation. Most of the Puget Sound lowlands average 30 to 40 inches, with rapid increases with increasing elevation on the west slope of the Cascades. Similar precipitation patterns occur in the Willamette Valley. High rainfall (up to 200 inches) on the summit of the Coast Range decreases very rapidly to lows of 40 to 45 inches in the valley bottoms.

Again, rapid increases in precipitation occur with higher elevations on the western slopes of the Oregon Cascades (50 to 70 inches). Maximum rainfall rates are moderate, seldom exceeding 0.5 inches per hour and 2 to 4 inches per day.

There is an expected progression in mean temperature from north to south. Mean annual temperature at Bellingham is 49°F, with the warmest months, July and August, averaging 74°F maximum temperature. Coldest months are January and February, with mean average low temperatures about 30°F. Lowest temperatures of record are 0°F or slightly below, with maximum temperatures near 100°F.

Geology and Soils

The Puget-Willamette Trough is dominated in current land form and in many aspects of soils by the Pleistocene glaciation. Landforms and soils are dominated by effects of flooding, redeposition of materials and formation of alluvial terraces throughout the subregions.

The Willamette Valley is bordered on the west by a variety of sedimentary and volcanic rocks of Eocene age. These include pillow basalts, conglomerates, sandstones and siltstones. Less resistant materials have eroded, forming a series of east-west valleys with resistant formations forming ridges as extensions of the Coast Range. The western margin of the Cascade Range is made up of marine sediments of Oligocene and Miocene age outcrops. Columbia River basalts also occur on eastern portions of this subregion.

In the Puget Sound region, the soils and landform are dominated by erosional and depositional activites of the Vashon glaciation. Again, glacial deposits have been reworked by rivers, and in some cases till deposits have been reworked and severely compacted.

The extreme variability of soil parent materials of the Puget-Willamette Trough, combined with the effects of extensive glaciation and reworking by meltwater, produce a very complex pattern of soils. These range from very shallow residual soils to deep silty alluvials and lacustrine deposits in the valley floors. Soils range from Regosols through brown podzolics to western brown forest soils, and under conditions of higher rainfall and moderate temperatures, reddish brown lateritics. These soils generally have a well developed forest floor layer with varying incorporations of organic matter, depending on soil formation processes and varying depth of weathering dependent on precipitation and vegetation.

Hydrology

Smaller streams with their watersheds completely within the subregion of the Puget-Willamette Trough have flow regimes which respond immediately to the free water input as rain. Peak flows occur in December and January immediately after rainfall maximums. Runoff varies from 5 to 15 inches per year, depending on precipitation. River systems draining the east slope of the Coast Range have average annual runoff from 40 to over 100 inches, again depending on precipitation of the basin. Most major rivers flowing west from the Cascade Mountains integrate the effects of the rainfall, warm snow, and frequently the cold snow zone. The combined effects of rainfall and the warm snow zone usually dominate, with peak discharges occurring during December and January, and with lowest flows in August and September. Other streams of the region are typically affected by annual precipitation, with the mean runoff possibly varying severalfold between successive years. Mean annual water yield averages 3 to 5 cfsm, with maximums of 60 to 180 cfsm and lows of 0.2 to 0.9 cfsm.

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Western Cascades

The Western Cascades subregion is bordered on the west by the Puget-Willamette Trough, on the southwest by the Klamath Mountains and on the east by the boundary between the commercial and non-commercial forest zone. This boundary approximates the boundary between the warm snow zone and the cold snow zone (about 3500 feet). The western boundary along the Puget-Willamette Trough approximates the boundary between the rainfall zone of the lowlands and the warm snow zone. The West Cascades subregion has many features in common with the Coastal Washington-Oregon subregions.

Forest Types

The Western Cascades has been classified (Franklin and Dyrness, 1973) as the Pacific silver fir zone. It is a zone intermediate between the temperate mesaphytic vegetation of the western hemlock lowlands and the mountain hemlock subalpine zone. It occurs at elevations approximately 2000 to 4000 feet between the Canadian border and central Oregon. Forest composition of this zone varies widely depending on age, stand history and local habitat, usually consisting of western hemlock, Douglas fir, western red cedar and varying amounts of western white pine and Englemann spruce and subalpine species, depending on location.

Climate

Climate of the Western Cascades subregion is wetter and cooler than the adjacent lowlands with considerably more of the precipitation in the form of snow. The winter pack usually accumulates in depths of up to 8 to 10 feet at upper boundaries of the zone. Snow is usually persistent from late October until May. Throughout the winter however, maximum temperatures consistently rise above freezing, thus the snowpack delivers free water to the soil sustaining higher levels of streamflow. Average annual precipitation ranges from 70 to 90 inches or more with maximums occurring in December and January (10 to 13 inches) and minimum amounts in July and August (1 to 2 inches). Amounts of precipitation can vary widely in short distances due to orographic effects of dominant land features or rainshadows. Maximum rainfall rates seldom exceed 0.5 inches per hour with daily accumulations of 3 to 5 inches.

Average annual temperatures of the zone are about 42°F, with average maximum temperatures in July of 72°F and average minimum temperatures in January of 22°F. The frost free growing season varies from 120 to 150 days per year.

Geology and Soils

The West Cascade Subregion could be divided into several lesser units based on origin of geologic material. From Mt. Rainer south, volcanic rocks predomiate of the Oligocene-Miocene era. These are mainly andesite flows with intermixed breccias in Washington with similar young volcanics and pyroclastics in the Western Cascades of Oregon. Major peaks of this area include Mt. Rainier, Mt. St. Helens, Mt. Adams, Mt. Hood, Mt. Jefferson and the Three Sisters. Oregon peaks may have originated during the late Pleiocene while other portions are of the older volcanics. Areas adjacent to these volcanic peaks are frequently mantled with pumice deposits of varying age, thickness ~~and~~ origin. The topography generally exhibits the effects of Pleistocene glaciation, but land forms are generally much less rugged than those farther north as the glaciation was much less extensive. North along the west slope of the Cascades from Mt. Rainier, bedrock is frequently much older sedimentary materials which have been extensively folded and metamorphosed. Sedimentary deposits occurred in the late Cretaceous with gradual uplifting during the Pliocene. Gradual uplifting exposed intruded granitics of Tertiary age as well as older rocks in some areas. Major volcanic peaks were built concurrently with volcanism of the southern portions of the subregion. Extensive Pleistocene glaciation has carved deep U-shaped glacial valleys with associated depositions of till and reworked alluvial materials.

Soils are formed from glacial deposits, reworked by rivers and residual soils. The dominant soil forming process is podzilation particularly at higher elevations with accumulations of forest floor material. Very shallow soils grade into Regosols and wetter locations into humic gleys. To the south soils are dominated by the occurrence of ejected volcanic materials and glacially reworked soil parent material. The central portion of the Western Cascades in Oregon is predominantly pyroclastics. These include tuffs, breccias and agglomerates. Glaciation and erosion has resulted in steeper slopes and rugged topography. Southeast portions of the subregion tend to have large amounts of pumice and ash as a soil parent material.

Hydrology

The hydrology of the Western Cascade subregion matches the regime of the warm snow pack zone. An early peak discharge frequently occurs in December and January coincident with maximum rain in lower elevation tributaries. Another peak occurs in late March or early April as snow melts at higher elevations. Annual runoff varies from 30 to 60 inches. This represents a mean annual water yield of about 4 cfsm with an instantaneous peak discharge of 70 cfsm and minimum flows of 0.2 cfsm. Floods on major drainages of this subregion usually occur as a result of rapid melting of early snowfall by heavy, warm rains.

Eastern Cascades - North

The Eastern Cascades are that portion of the commercial forest zone bounded by the subalpine on the west, the Okanogan Highlands on the northeast, the arid grasslands on the east and Mount Rainier on the south.

Forest Types

Douglas fir is the dominant, and probably climax species in the more mesic habitats of this zone, giving way to ponderosa pine at lowest elevations and less annual precipitation. The forest composition varies widely with microhabitat and past history, but generally consists of Douglas fir mixed with western hemlock, Engelmann spruce and western red cedar in higher elevation valleys, with extensive areas of lodgepole pine. With departure from high snow pack zones and warmer summer temperatures, western larch and ponderosa pine become significant components of the stand. Moist stream bottoms frequently contain significant amounts of grand fir. Ponderosa pine occurs in pure and mixed stands to elevations of 4,000 to 5,000 feet on south exposures. North aspects are dominantly Douglas fir and western larch. Lodgepole pine is a fire type, occurring in relatively pure stands on old burns. The lower elevation limit of forests generally follows the zone of 15 inches of mean annual precipitation. As south aspects tend to be hotter and drier, forest stands are very open, with interspersed sagebrush, bitterbrush and grasses. Reasonably dense stands occur on gently sloping or nearly level land. Ponderosa pine dominates in zones of lesser annual precipitation.

Climate

The climate of the commercial forest zone of the Eastern Cascades varies from the moist subalpine snow zone at higher elevations to the arid, ponderosa pine/grass type at low elevations. The Cascade Range forms a barrier to the easterly movement of moist air from over the Pacific, resulting in greatly reduced annual precipitation. The combination of the Cascades and Rocky Mountains forms a trough for north-south movement of air masses, resulting in seasonally very warm or cold conditions. Prevailing air mass movements are from west to east, resulting in a maritime climate.

The orographic lifting and then descent of air masses results in a marked warming by compression, with rapidly decreasing precipitation eastward from the Cascades summit. Stevens Pass averages about 80 inches of annual precipitation (elevation 4,000 feet), with a decrease to 24 inches in 20 miles to Leavenworth (elevation 1,100 feet), and a further decrease in 15 miles to less than 9 inches at Wenatchee. Seventy-five percent of the annual precipitation occurs between late October and early March. During this period, the bulk of the precipitation occurs as snowfall. Through much of the zone, annual precipitation averages 25 to 40 inches.

Extremes in temperature are common throughout the zone. Maximum summer temperatures are frequently in excess of 100°F, with minimum temperatures ranging from 10 to 30°F or more below 0°F. Average annual temperature for much of the zone varies from 45 to 50°F. Maximum average monthly temperatures occur during July and August, ranging from 85 to 90°F. Minimum average temperatures occur during January and range from 18 to 20°F. The growing season ranges from 130 days in the north to 150 days in the south.

Movement of moist air masses over the Cascades during the summer frequently results in instability of lapse rates, with intense thunderstorms. Rain and hail associated with these thunderstorms yield maximum rainfall rates of 6 inches per hour for short duration (5 to 10 minutes). Such storms produce flash floods and mud flows from localized forest drainages, but do not cover a sufficiently large area to produce flooding on major basins.

Geology and Soils

The geology of the Eastern Cascades is similar to that of the west side. Uplifting occurred during the Pliocene, with exposure of large areas of intruded granitics, including granodiorite, with metamorphosism of these formations into gneisses and schists. A large area of Cretaceous sedimentary rocks (Swank sandstones) occurs between the acid igneous granodiorite types (Chelan Batholith) to the north and the basic igneous Columbia River basalt flows to the south. This formation has been steeply tilted in places, giving rise to highly erodable soils. Topography of the Columbia River basalts is considerably more gentle than granitic formations farther north. Valley glaciers did extend eastward down

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major rivers; however, their impact is somewhat lessened. Northern portions of the zone were completely overridden by the continental icecap while valley glaciation dominates valley land forms. Granite and granodiorite parent materials form inherently unstable soils. Soils formed from Swank sandstones are also quite unstable, while soils formed on basalt tend to be more stable.

Soils of the higher elevations exhibit a dominating influence of organic matter accumulations, with acid leaching to form podzols. Western brown forest soils form in more humid situations, with poorly developed Regosols in areas of surface soil erosion or limited moisture supply.

Hydrology

The Eastern Cascades are predominantly in the hydrologic regime of the cold snow zone. Temperatures are consistently below freezing during seasons of maximum precipitation. Snow accumulates throughout the winter, to melt during late spring and early summer. Low flows occur during the coldest portions of the winter (January and February). Elevation zones with less than 15 to 18 inches of annual precipitation will not produce streamflow except under conditions of high-intensity storm or rain on snow. High snow pack zones of the alpine and subalpine produce 60 to 100 inches of runoff per year. Lower elevations and watersheds with south exposure tend to produce peak discharge earlier in the melt season (March and April) as compared with higher elevations and north-facing slopes. Major floods of this subregion occur as a result of delayed melt, with synchronization of melt from a wide range of elevational zones and heavy, late-spring rainfall (4 to 6 inches in 36 to 48 hours). The mean annual water yield is 1 to 3 cfsm, with instantaneous flood flows of 25 to 31 cfsm and minimum flows of 0.1 to .2 cfsm.

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Eastern Cascades - South

The eastern slopes of the Cascades have been differentiated with the geologic formations associated with Mount Rainier and the extensive Columbia River basalt flows. The area between Mount Rainier and the Columbia River is sufficiently similar to the Eastern Cascades of Oregon to be considered as one subregion. Most of the terrain is relatively gentle, interrupted at intervals by glaciated river channels. The area is dotted with volcanic peaks and cones of varying age, size and elevation. Geologically, portions of the area are very young, with recent lava flows. Most of the geologic formations, however, were extruded during volcanism in the late Pliocene and Pleistocene. Materials include a host of andesites and basalts, often obscured by mantles of pumice or ash. Locally, glacial deposits are abundant as major mountain peaks are typically mantled with snow, giving rise to accumulation areas for massive glaciation. Valley walls are frequently quite steep, with depositions of till and alluvial material in the valleys.

Soils of the subregion are generally quite young, but usually showing initial stages of podzolization. Brown podzolic soils also develop on certain parent materials, but yield a poorly developed A_2 horizon. Soils of recent ash or pumice deposits show little profile development and are usually classified as Regosols.

Forest Types

The mixed conifer zone of the northern portion of the eastern slopes of the Cascades grades from one of predominantly Douglas fir-ponderosa pine to a grand fir-Douglas fir type. Other species include ponderosa pine, lodgepole pine and western larch. White fir and sugar pine occur in southern portions of the zone in Oregon, with significant amounts of western hemlock and western red cedar in localized habitats.

Climate

The climate of the Eastern Cascades farther south is essentially a continuation of that in the northern area. As the Cascade Mountains do not represent an imposing climatic barrier in a continuous manner, some of the rain shadow effects are of less importance. The drift of polar air from Canada between the Cascades and the Rockies occurs with complexing effects on temperature and precipitation. Precipitation averages 60 to 80 inches annually at upper boundaries of the subregion, with 25 to 30 inches in lower elevations. About two-thirds of this precipitation occurs in a five-month period between November and March, mainly as snow.

The mean annual temperatures tend to vary from 45 to 50°F; however, they represent an expanding range in lows and highs. Recorded temperatures range from -10 to -30°F, with average maximum temperatures of 85 to 90°F in July and average minimums of 14 to 20°F in January. The frost free growing season ranges from 90 to 120 days.

Hydrology

The flows of major rivers draining eastern slopes of the Cascades parallels that of the cold snow regime, with peak discharges in late May and minimum flows during the coldest months, January and February. Water yields vary from 40 to 60 inches at higher elevations to 10 inches or less near the forest-grass boundary. Extensive areas of ash and pumice do not show the usual distribution or intensity of stream channels because of rapid percolation in ash and pumice beds. In places, numerous large springs deliver substantial flow of water to surface runoff. Over extended areas surface waters are extremely sparse. The Deschutes River, which combines the drainage of an extensive area of the zone in Oregon, sustains average annual water production of 0.5 cfsm, with instantaneous peak flows of 7.2 cfsm and minimum flows of 0.2 cfsm.

Blue Mountains

The Blue Mountains are comprised of several mountain ranges in northeast Oregon, with a small area in southeast Washington. The subregion is discontinuous with the balance of the forest zones of eastern Oregon and Washington in that it is separated by the interior Columbia Basin of Washington and the high deserts of Oregon. With increasing elevation, forests again reappear as precipitation increases due to orographic lifting.

Forest Types

The Blue Mountains include both the ponderosa pine type and the grand fir-Douglas fir type, as defined by Franklin and Dyrness. Limited areas of mixed conifers occur at higher elevations. Climax ponderosa pine is widely distributed in northeast Oregon and southeast Washington at the boundary between the sagebrush-grass zone and the forest zone.
The upper limits of the ponderosa pine forest grade into Douglas fir, grand fir and white fir depending on locale. Lodgepole pine also occurs in association with ponderosa pine-lodgepole pine on the more mesic sites, while drier sites are occupied by ponderosa pine. Other mesic sites are frequently occupied by quaking aspen. In transition zones to sagebrush and bitterbrush, groundcover is frequently pine grass-elk sedge.

Climate

The climate of the Blue Mountains is dominated by Pacific maritime air masses moving eastward. Orographic lifting causes rapid increase in annual precipitation with increasing elevation. Annual precipitation varies from 30 inches at lower elevations to about 80 inches at the crest of the Wallowa Mountains. The major portion of precipitation occurs as snow, with amounts exceeding 150 inches at higher elevations. The diverse topography results in an equally diverse distribution of both precipitation and seasonal temperatures. The frost free growing season ranges from 100 to 140 days per year, with temperature extremes similar to those of the eastern slopes of the Cascades.

Geology and Soils

The eastern portions of the Blue Mountains span a variety of rock types over several geologic eras. Permian formations consist of schists, limestones, slates, tuff and chert. Triassic sedimentary formations also occur intermixed, but are discontinuous due to erosion. Certain portions of the Wallowa Mountains appear to be extensions of the granitic formations of the Idaho Batholith. Other portions have recent depositions of Miocene lavas. Widespread glaciation occurred during the Pleistocene, with typical moraines, deposits and outwashes. Western portions of the Blue Mountains (John Day and west) are some of the oldest rock formations in Oregon. Limestone, mudstone and sandstone of Paleozoic formations occur in this western region. Certain of these formations in the vicinity of John Day are widely known for their abundant vertebrate fossils.

The Blue Mountains have been covered frequently with ash and fine pumice as aerial deposits. Subsequent erosion has removed much of the ash from south-facing slopes. Reworking by wind has also been common, with loess deposits. Forested soils developed on ash and fine pumice characteristically develop brown, podzolic soils. These soils have also developed on loess deposits. South aspects show lesser amounts of soil development due to frequent burning and intermittent vegetative cover. Soils of these situations are frequently classed as Regosols.

Hydrology

The hydrologic regimes of streams of the Blue Mountains closely parallel those of the cold snow zone. Snows accumulate during winter months to be released as snowmelt. Lower elevations and south aspects release snow as a free water input to streams in March and April. Northern aspects and higher elevations retain snow cover for release in mid- to late May. Annual water production is relatively low, with much of the Blue Mountains yielding 1 to 10 inches per year of runoff. Higher elevation snow packs in the Wallowa Mountains average 30 to 40 inches of runoff. The Grande Ronde River has a mean annual discharge of 1 cfsm, with peak flows of 10 cfsm and minimum flows of 0.1 cfsm. The John Day River, a major drainage in the western portion of the Blue Mountains, has a mean annual flow of 0.3 cfsm, with peak discharges of 5.6 cfsm and instantaneous low flows of near zero. Localized flooding often occurs as a result of warm rains on the snow pack.

Okanogan Highlands

The Okanogan Highlands are bounded by the Eastern Cascades on the west, Northern Idaho subregion on the east, Canadian border to the north and Columbia River to the south. The Okanogan Highlands contain the most extensive area of ponderosa pine timber type in the state of Washington. A small area of interior western hemlock and western red cedar occurs in the northeast corner.

Forest Types

Forest types of the Okanogan Highlands subregion vary from pure ponderosa pine at lower elevations in mixture with sagebrush and bitterbrush, to ponderosa pine, grand fir and Douglas fir mixtures on gentle north slopes. Aspen occurs extensively in riparian and poorly drained habitats. More mesic sites include significant amounts of western hemlock and grand fir. Lodgepole pine frequently occurs in extensive pure stands following fire. Groundcover of pine grass and elk sedge are common. Protection of the ponderosa pine forests from fire has resulted in an increase in tolerant grand fir with a dense understory of ceanothus.

Climate

The climate of the Okanogan Highlands is somewhat of an anomaly for the Pacific Northwest. Precipitation is much more consistent throughout each month of the year, with the driest months of July and August receiving about half the rain (1 inch) of the amount received in the wettest months of December and January (2.1 inches). The wettest month is June, with 2.3

inches. Grand Coulee Dam, with an average precipitation of 10.7 inches, receives approximately one-third of its total precipitation in the growing season months of April, May and June. Laurier, with a July-August rainfall of 1 inch and total annual of 20 inches, has more growing season rainfall than areas in the Eastern Cascades subregion with 70 to 90 inches of annual precipitation. This growing season rainfall is able to sustain good forest growth in 10 to 20 inches of average annual precipitation. Winter precipitation is primarily snow, with 2 to 4 feet at lower elevations and 6 to 10 feet in higher locations.

Temperatures of the Okanogan Highlands are very similar to those of the Eastern Cascades - North. Mean annual temperatures vary from 50°F at Grand Coulee Dam to 47°F at Laurier. Coldest months are January and February, with mean average low temperatures of 21°F and 14°F respectively. The frost free growing season varies from 100 to 128 days per year, with the last frost in mid-May and the early frost in mid- to late September.

late September.

Geology and Soils

Land form of the Okanogan Highlands is in considerable contrast to many others of the subregions of the northwest. The exposed bedrock formations and the topography have resulted entirely from a major lobe of the Cordilleran icecap which covered this area during Pleistocene glaciation. The usual complex of glacial drift and reworked deposits are found

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throughout the area.

Bedrock geology is equally complex. Rocks of the Paleozoic occur in the eastern portion of the subregion. Rocks of this formation include quartzite, graywacke, slate, greenstone and some limestone. Granitic rocks of the Mesozoic are most abundant of the area. These include some granitics and granodiorite. Limited areas of Tertiary deposition occur adjacent to major river valleys, with the most recent Tertiary eruptions consisting of andesite and basalt.

Soils of the subregion are equally complex in that recent deposits of ash have been reworked through erosion, providng a host of soil parent materials of widely varying textures. The soil formation process is dominantly podzolization, resulting frequently in well developed A_2 horizons underlain by high iron content B horizons. Extensive areas are classed as Regosols due to erosional processes or weak soil profile development. Soil erosion potential is relatively low as topography is usually gentle. Soils are noncohesive, however, and quite erosive, so disturbance of vegetation on the steeper slopes will result in significant soil movement both from high intensity growing season rainstorms and from snowmelt.

Hydrology

The Okanogan Highlands subregion is one of the most arid commercial forest zones in the Pacific Northwest. The bulk of the area receives less than 20 inches of annual precipitation. Combining low precipitation with very pervious soils

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results in a very low density network of surface runoff. Annual runoff ranges from zero to about 10 inches, with the bulk of the area averaging 5 inches. Mean annual water yields range from 0.4 to .8 cfsm, with maximum flooding 6 to 9 cfsm and minimum flows near zero (0.02 cfsm).

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Northern Idaho

The Northern Idaho subregion is bounded on the north and east by the state boundary, on the south by the Salmon River and on the west as an extension of the Okanogan Highlands subregion. A distinction is made as Northern Idaho is considerably more humid than the Okanogan Highlands. Significant increases in annual precipitation occur as air masses approach the Selkirk and Bitterroot Mountain Ranges.

Forest Types

There is a progression of forest types from lower elevations on the west to higher elevations in the mountain ranges bordering the subregion in the east. Ponderosa pine intermixes with Douglas fir and lodgepole pine at lower elevations. With increasing elevation and annual precipitation, western larch, western white pine, grand fir, Engelmann spruce and subalpine fir become important. Interior western hemlock and western red cedar often form climax forests.

Climate

The climate of the Northern Idaho subregion is typical of that of the cold snow hydrologic regime. Annual precipitation varies from 15 inches at lower elevations at the boundary of the commercial forest to 50 inches near the summit of the Selkirk and Bitterroot Mountain Ranges. The annual distribution is typically maritime, with driest months in July and August, and wettest months in December and January. About 70% of the annual precipitation occurs during the snow accumulation season of October through March.

Temperature regimes are very similar to those of the Okanogan Highlands. Warmest areas are at the lower boundary of the commercial forest (Spokane), with mean annual temperatures of 48°F. The average maximum monthly temperature is 84°F in July, and the average minimum monthly temperature is 18°F in January. Increase in elevation (such as Mullen Pass, 6,000 feet) results in significant decrease in temperature. At Mullen Pass mean annual temperature is 37°F, ranging from a monthly maximum temperature of 69°F in July to a minimum of 14°F in January. The frost free growing season varies from less than 90 days at higher elevations to 150 days at lower elevations in the ponderosa pine zone.

Geology and Soils

Northern portions of the subregion show the dominating influence of Pleistocene glaciation, with rolling topography and deep glacial deposits. Bedrock geology is quite complex in that glacial erosion intermixed with Tertiary lava flows leave a complex of deep lake deposits with exposed basalt. Erosion of the Kaniksu Batholith forms the Selkirk Mountains. Continental glaciation carved the Purcell Trench as far south as Lake Coeur d'Alene, where a glacial moraine now impounds the lake. An extensive area of Columbia River basalts occurs in the vicinity of Lake Coeur d'Alene. These flows overlay the Precambrian sedimentary rocks which also form the Bitterroot Range. Considerable metamorphism occurred where the basalts contact the northern boundary of the Idaho Batholith.

Forest soils of the subregion reflect the increasing moisture, with stronger processes of podzolization resulting in increased profile development. Regosols occur on eroded granitic materials of the Kaniksu Batholith. The young Columbia River basalts also have an eroded phase which classes as Regosols or undeveloped soils. The effects of continental glaciation have generally removed the weathered granitic surface materials. Formations of Northern Idaho are not as erosive as those farther south in the Idaho Batholith.

Hydrology

Several major rivers bisect the Northern Idaho subregion both east and west and from the north and south. The major drainage is the Clark Fork of the Flathead River, which has its headwaters near the Continental Divide in west central Montana. The Kootenai River also flows into the northeast corner of Idaho from Montana. Average annual runoff varies from less than 10 inches at lower elevations in the ponderosa pine zone to about 40 inches at highest elevations in the Selkirk-Bitterroot Mountains. Water yields average 2 cfsm with instantaneous flood flows ranging from 5 to 7 cfsm (St. Joe and Coeur d'Alene Rivers), with minimum flows of less than 0.1 cfsm.

Intermountain

The Intermountain subregion is that area of commercial forest of Idaho bounded on the north by the Northern Idaho subregion (approximately the Salmon River), and on the southwest by sagebrush grass. It is separated from Northern Idaho based primarily on the effects of continental glaciation on land form. Glaciation effects in the Intermountain subregion are limited to higher elevations where alpine glaciers locally affected the soils and topography. Parent materials of much of the area are Precambrian, metamorphics and other intrusives. Precambrain sedimentary rocks also occur in a complex intermixture.

Forest Types

Forest types are typical of the ponderosa pine-Rocky Mountain Douglas fir forests which cover about 20 million acres of northeast Washington, Idaho and Montana. Ponderosa pine is dominant and climaxes at lower elevations in mixtures with Douglas fir. With increasing elevation and more humid conditions, western larch, Engelmann spruce and lodgepole pine make up significant components of the forest stand. Localized in humid river bottoms, grand fir is also an important species.

Climate

The commercial forest zone occupies a precipitation range from 15 inches at lower elevations to 50 inches of annual precipitation at higher elevations in the Salmon River Mountains. Precipitation is typically maritime, with maximum amounts occurring in November through February. However, there is an extension of growing season rainfall, with significant amounts of rain occurring through June. For example, McCall, Idaho, receives 28 inches of average annual precipitation, of which 5.5 inches occur between May and August. Snowfall accumulates to maximums of 100 to 200 inches at higher elevations in the mountains.

Temperatures show the expected relationship with elevation for mean annual, highs and lows. Boise has a mean annual temperature of 51°F, an average July maximum of 90°F, and an average January minimum of 27°F. At higher elevations in the more mountainous areas, Lemhi has an average January temperature of 17°F, with an average July temperature of 64°F. The frost free growing season ranges from 140 days at lower elevations to less than 90 days at upper limits of the commercial forest zone.

Geology and Soils

The Intermountain subregion is probably famous as the location of the Idaho Batholith. This Cretaceous granitic intrusive has weathered in place for the last 70 to 90 million years. It is an extremely large outcrop covering over 14 thousand square miles. While uniform in its origin, it contains a host of grain and crystal sizes in various areas. Most grain sizes are relatively large, weathering to a very coarse-textured soil. The soil texture in combination with relatively steep topography has resulted in one of the most erosive geologic formations of the commercial forest area of the western United States.

The eastern boundary of the Intermountain subregion in Idaho is formed by the Beaverhead, Lemhi and Lost River Ranges. These ranges are Precambrian and Paleozoic sedimentary rocks. Older rocks of the Precambrian include slates and mudstones, while rocks of the Paleozoic are predominantly limestones and dolomites.

Soils of the Intermountain zone are predominantly podzols or Regosols. Areas of gentle topography frequently build up a sufficient forest floor layer to initiate processes of soil formation. Acids leaching result in development of A_2 horizons on finer-textured materials. Erosion and limited accumulations of forest floor material results in extensive areas of immature soils.

Hydrology

The hydrologic regime of the Intermountain subregion closely parallels those of the cold snow zone. Snow packs accumulate throughout the winter, to be released as snowmelt with peak flows occurring in late May. As typical within the zone, south exposures and lower elevations melt in late March and April. Average annual runoff varies from insignificant amounts at lower elevations in the ponderosa pine zone to maximums of 40 inches in the higher mountain ranges of the Bitterroot-Beaverhead. Water production of a typical river such as the Salmon averages 0.8 cfsm, with a maximum of 8 during flood flow and a low of 0.1 cfsm.

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FOREST PRACTICES IN THE PACIFIC NORTHWEST

Logging Systems

Systems for the movement of logs from the forest site to a landing can be categorized as one of two types in the Pacific Northwest. Tractive skidding is used over the entire region but is restricted to terrain of moderate slope. Cable logging of which there are several forms has been largely restricted to the west slope of the Cascades. However, cable logging systems were recently introduced into the interior but primarily on an experimental basis. Jammer logging, used almost exclusively in the northern Rocky Mountains, can be categorized as a particular type of cable logging. Its use is restricted almost entirely to the intermountain region, in particular northern Idaho. Tractor and jammer logging are associated predominately with some form of selection or partial cutting. Whereas cable logging is used primarily for clear cut logging.

At one time tractive skidding was accomplished entirely with animals primarily mules, horses, and oxen. Many mules and horses are still used for skidding and hauling logs, particularly in the northeastern and southeastern parts of the United States. However, animal skidding has all but disappeared in the Pacific Northwest. Recent years have witnessed a resurgence of interest in animal skidding primarily due to concerns over environmental damage inflicted by the use of mechanized logging equipment.

Various accessory items of equipment are available for use with tractors that reduce the degree of contact between log and ground. Efficiency of skidding is improved and the amount of site disturbance, in particular soil compaction, that results from log skidding is reduced. Arches, sulkies, skidding pans, scoots, and sleds are commonly used for this purpose.

The sulky is a wheel mounted device for raising clear of the ground the end of the log nearest the tractor. The arch is tractor mounted and serves essentially the same function. Both arches and sulkies have undergone intensive development and when used integrally with a winch are extremely beneficial both from the standpoint of logging efficiency and minimization of site disturbance. The wire rope choker is used almost exclusively for attachment of log to tractor.

Recent years have witnessed the introduction of rubber-tired wheel skidders (see Fig. 3-1). They have the advantage of greater speed and mobility, but suffer from limitations of traction and flotation. This type of tractor is normally fitted with a winch for partial lifting of logs during skidding, and with a front blade for movement of debris and road building. They range from 30 to 375 horsepower and weigh between 5 and 30 tons. The units consist of a compact, articulated frame and come equipped with other four- or two-wheeled drive systems.

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RUBBER TIRED TRACTOR LOGGING

Figure 3-1

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Ground skidding with animals is limited by slope; surface conditions, log size, skidding distance, and skid road spacing. Moderate slopes with favorable grade in the direction of skid are ideal. Adverse grades of 3 percent or more place an undue strain on most animals. Similarly, rocky ground, heavy brush, and swampy areas can easily overtax animals. Animal skidding is still practiced in New England and the southeast where log sizes are normally small in contrast to the Pacific Northwest. The maximum skidding distance of which most animals are capable under favorable conditions rarely exceeds 500 feet. Consequently, the roading system must be fairly dense for animal skidding.

Clearly, there exist many limitations to the use of animals for movement of logs. It is noted, however, that in the few instances for which data is available that site disturbance during animal logging is substantially less than that brought about by skidding with crawler tractors.

Diesel-powered crawler tractors were first used for logging in the early 1930's. Drawbar horsepower of these units range from 50 to 250 for the largest and weights range from 5 to 30 tons. With but few exceptions tractors are limited to down slope skidding. Logging tractors are normally equipped with a winch on the rear which serves a number of purposes among which is the capability of skidding logs short distances from the felling site to the tractor. When used properly this feature can substantially reduce the area used for tractor skid trails.

Articulated hydraulically operated grapples have recently been added to the larger rubber-tired skidders. With such devices considerable flexibility for winching logs to the tractor, for skidding, and for positioning logs at the landing is introduced.

Cable yarding, introduced in the late 1800's and used primarily on the west slope of the Cascade mountains, is designed to move logs from stump to landing by a machine equipped with multiple winches, commonly called a *yarder*. Yarders are mounted on rubber tires or crawler tracks for mobility between log landings. Logs are moved by reeling in a wire rope called the *mainline*. Chokers, looped around the log, are attached to the *butt rigging*, which in turn is attached to the mainline. The haulback line is used to return the butt rigging to the stump site. The direction of movement is controlled by the use of several blocks hung on stumps, trees, or portable steel towers.

The *high lead* system requires that the main line lead block be hung high above the ground on a *spar tree* or *steel tower*. The portable steel tower, ranging from 90 to 120 feet in height, is now used almost exclusively in high lead logging. The tower is instrumental in providing lift for the forward end of the log in order to reduce friction between log and ground and to minimize soil disturbance.

The *skyline* systems drag or carry the logs suspended from a carriage which rides on a cable stretched between

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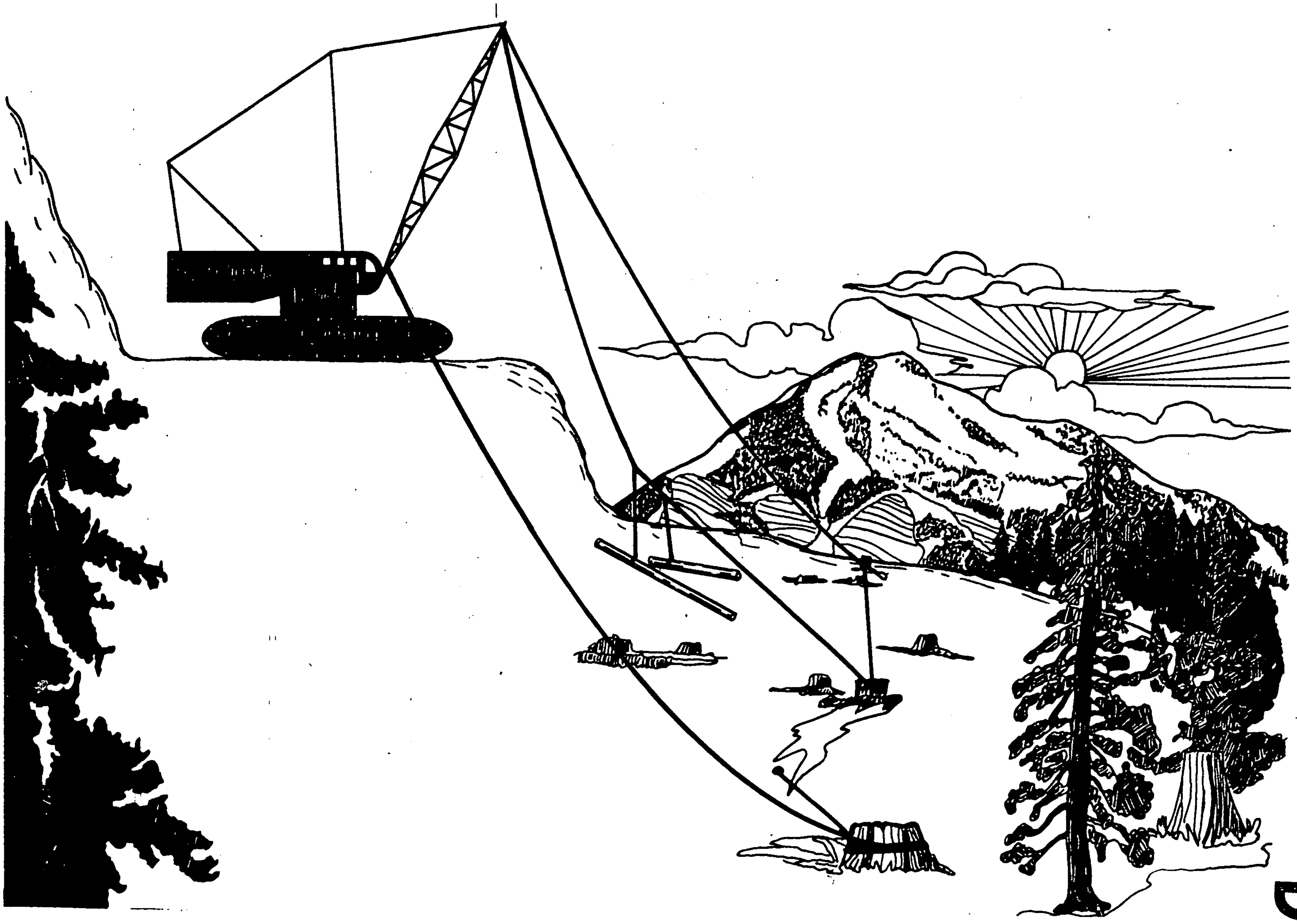
a head spar at the log landing and a tail hold at the far end of the yarding road. On many logging sites proper positioning of the two spars on both sides of slopes which are concave make it possible to lift the logs free of the ground. Consequently, the skyline system serves to reduce to a near minimum the amount of ground disturbance which occurs during logging.

Cable logging systems are highly efficient for logging steep rough ground on which tractors cannot operate. They can operate in any direction--upslope, downslope, and along the contour and during any kind of weather. Most importantly cable logging systems result in far less ground disturbance than tractive logging systems. Cable logging also offers the advantage of a large concentration of power operating from a stationary position.

The high lead is the most commonly used cable system (Fig. 3-2). The elevation of the mainline lead block on a steel tower serves to exert a vertical component of force which lifts the forward end of the log over stumps or other obstacles. The system is most effective when yarding upslope at distances not in excess of 1000 feet. Although downslope and sideslope yarding can be accomplished with high lead systems, control of log movement is minimal and more site damage results. The system is best suited for clearcut settings.



HIGH-LEAD LOGGING

Figure 3-2

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Mobile yarder-loaders, or mobile loggers introduced on the west side of the Cascades in recent years, are a modification of the high lead system which offers greater control of log movement (Fig. 3-3). Usually track mounted, these units make it possible to vary the lead by swinging the boom on which the mainline lead block is mounted. Consequently, better control of log movement is possible. Because the booms on these units are much shorter than the towers used for conventional high lead logging log, lift is reduced. Consequently, efficient yarding distance is reduced and more soil disturbance can result at the extremities of the setting.

The jammer, shown in Fig. 3-4, which came into widespread use in the northern Rocky Mountain region following World War II, is considered to be the forerunner of the mobile logger. The jammer is either track or wheel mounted. A vertical mast supports a pivoting pole boom which is set in a socket at the base of the mast. The units are equipped with either a one- or a two-drum winch. One drum is used to power the skidding line and the other the haulback line if used. Normally the skidding line is equipped with tongs for attachment to the log. Oftentimes haulback of the tongs is accomplished by hand or by an operator skilled in the motion of the boom. Jammer logging is limited to distances of 300 to 400 feet. Consequently, an intense network of roads, oriented predominately parallel to the contour is required for use of this particular system.

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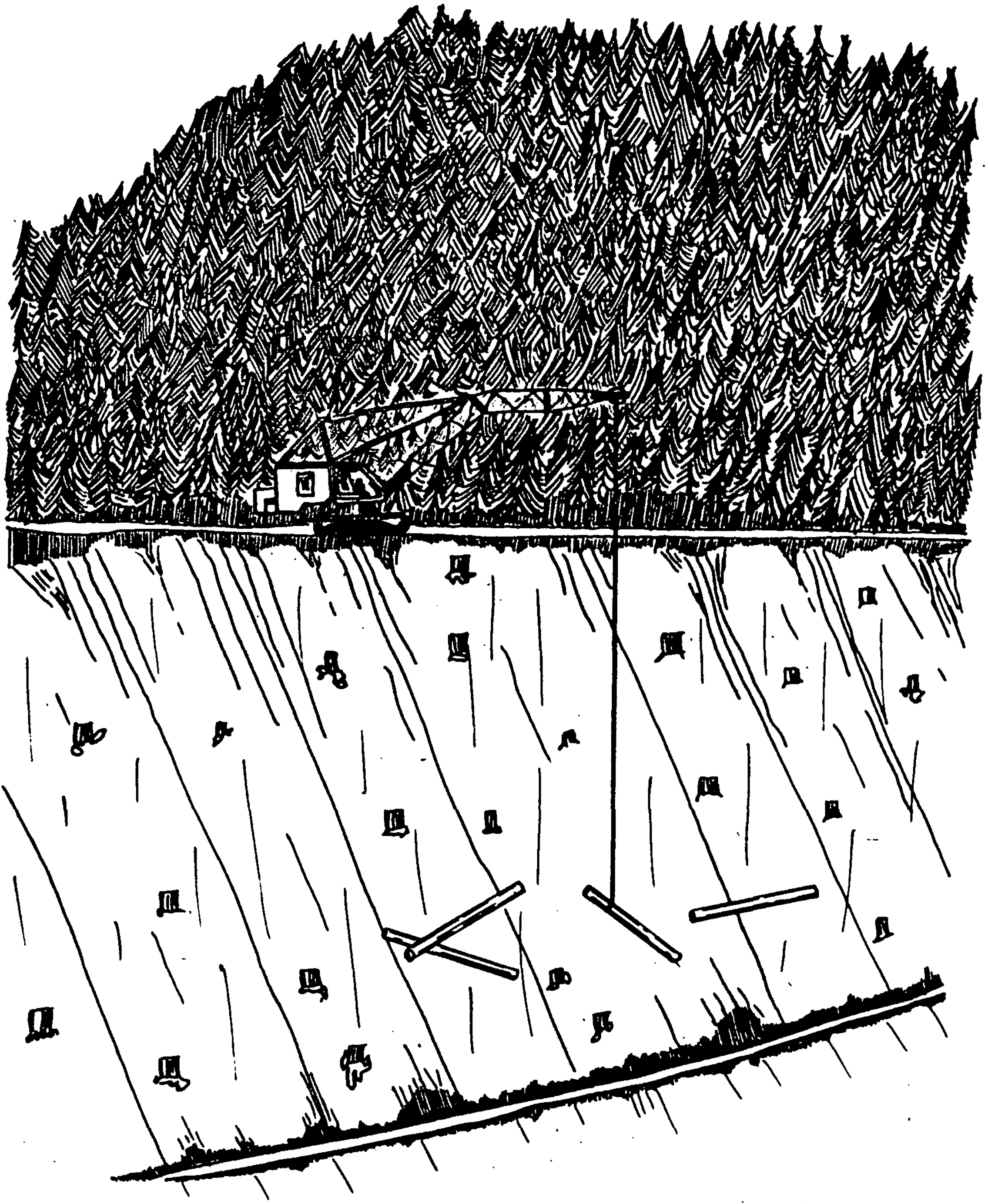

MOBILE YARDER—LOADER
Figure 3-3

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(To Be Furnished in Final Report)

Figure 3-4

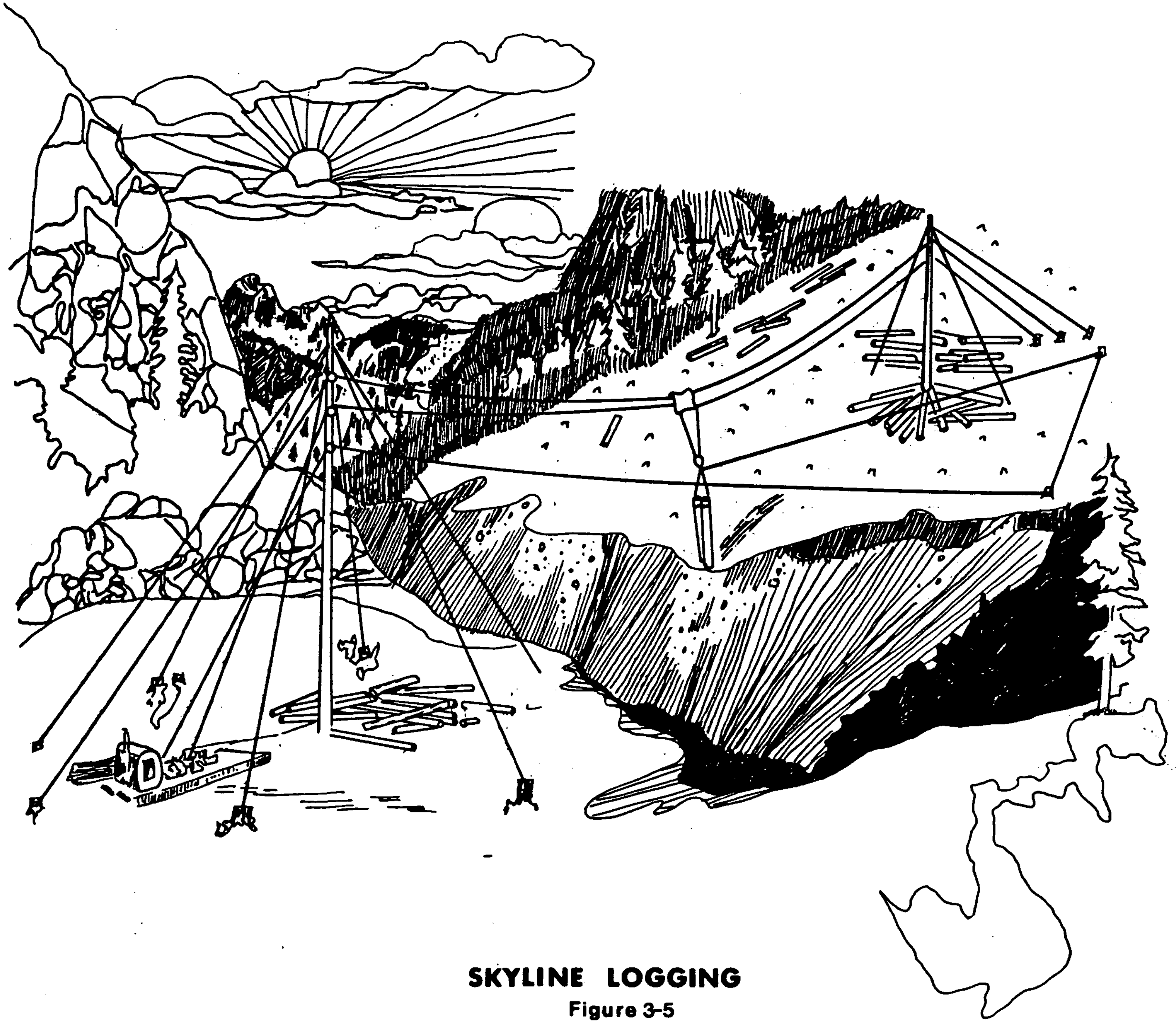
Jammer

Skyline systems (see Fig. 3-5) are the most versatile of all of the cable logging methods. Introduced to the Pacific Northwest from Michigan at the turn of the century, the use of skylines began to decline with the conversion from railroad to truck transport systems. The introduction of multi-span skyline systems in the late 1940's and the awakening of environmental interests in the late 1960's have served to rekindle interest in the use of skyline logging systems.

The standing skyline, also termed tightline system, uses a cable stretched between a head spar and a tail spar, and attached to stumps at both ends. Single span tightline systems include the north bend, the modified north bend (also called south bend), and the interlocking skidder variations.

The north bend, which is the simplest of the three, requires a carriage for travel on the skyline, a bull block and fall block for movement of the mainline and tail block, and tail block and corner block for control of the haulback line. Control of mainline and haulback line tension can be used to provide lift of the logs and thereby avoid obstacles and minimize site damage. The modified north bend system is characterized by improved control of movement between the fall block and the carriage. Consequently, improved lift over the older north bend system is offered.

Both systems can be used with any high lead yarder with sufficient line capacity. Consequently, both are popular skyline systems. Both operate best when yarding upslope or



SKYLINE LOGGING

Figure 3-5

on moderate downslopes. Yarding distances of up to 2000 feet are not uncommon. This system is also used frequently for swinging between cold decks.

The interlocking skidder (Fig. 3-6) is a tightline system which requires a special yarding machine and carriage. The yarder is equipped with three drums which can be interlocked so that they will operate together. Using this type of yarder and a more complex carriage provides a system which offers close control of log skidding. The interlocking skidder is particularly suitable for operating over rough topography for either upslope or downslope yarding. If adequate deflection is available, logs can be yarded completely free of contact with the ground. Because greater control of log movement is possible systems of this type are particularly efficient for selective logging.

Slackline systems require a special yarder with a large skyline drum. The skyline extends through the main block at the head spar, then through the carriage and to the tail spar. The mainline, haul line and chokers are all attached to the underside of the carriage. Lift of the turn of logs is provided by tensioning the skyline. Skidding is accomplished with the mainline, and return of the carriage is afforded by the haulback line.

Logs can be lifted clear of the ground during yarding or the forward end can be lifted leaving a part of the log to drag on the ground. Yarding distances of 1500 feet are

(To Be Furnished in Final Report)

Figure 3-6

Interlocking Skidder

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not uncommon but the system is capable of much greater distances. The system is adaptable to up- or down-slope yarding, on steep slopes, or across canyons.

For many years loggers have on occasion rigged *running skyline* systems using ordinary high lead equipment (Fig. 3-5). Such a system is particularly useful for yarding down steep slopes or across narrow canyons. The butt rigging is hung from a traveling block which rides on the haulback line. The haulback line extends from the headspar out through the tail block located well above the ground and back to the rear of the carriage. The mainline is attached to the front of the carriage. Lift of the turn of logs is provided by adjusting tension in the haulback line. Yarding is accomplished with the mainline. An interlocking yarder makes it possible to operate both haulback and mainline drum at the same rate. Consequently, the logs can be kept entirely free of the ground.

Recently mobile yarders have been equipped with interlocking drums and special running skyline carriages. These systems frequently referred to as skyline cranes are equipped with either wire rope chokers or grapples. Use of the grapple makes it possible to yard with only a two-man crew; yarder operator and spotter. Swing of the booms offers some control of log movement. Booms, restricted to heights of 50 feet or less, limit the amount of lift of the logs that is possible. Not uncommonly a crawler tractor is used for

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the tail hold in order that the yarder road can be changed rapidly. However, many operators have found the system much more efficient if a block anchored well up in a tree is used as the tail hold. Use of the tractor does introduce additional site disturbance since the tractor must be moved to various locations on the setting.

A crane equipped with a running skyline and either chokers or a grapple is a highly efficient and adaptable yarding machine. Logs can be yarded for distances up to 1200-1500 feet. The system can be moved with minimal losses of time. Logs can frequently be lifted clear of the ground thus minimizing soil disturbance. Both uphill or downhill logging can be accomplished. By moving the crane along a truck road with changes of the tail hold as needed, a near parallel network of yarding roads results. Logs are thereby distributed along the edge of the road rather than being concentrated at a landing. Clearly, this type of logging system has considerable potential for reducing site damage.

Skyline cranes developed in the alpine forests of northern Europe are designed to transport logs suspended above the ground from a carriage traveling on a cable. The Wyssen skyline crane was introduced in North America in the late 1940's. These systems can be categorized as standing skylines, which combine both lateral and longitudinal yarding capability. Single span and multi-span systems are possible. The systems are capable of lateral skidding distances of up to 250 feet. Logs can be yarded either partially or completely suspended above the ground. The multispan system is designed for complete suspension of the logs except during initial lateral skidding.

The multispan systems permit long skyline roads by the use of intermediate supports. Consequently, large areas can be yarded with but minimal site disturbance. Soil disturbance which does occur is limited largely to short distances along the contour. Consequently, erosion problems are reduced to a minimum. Yarding distances up to 6,000 feet have been reported. Indeed, one of the major advantages of the skyline crane is the unusually large yarding distance that is possible. These systems are adapted for both upslope and downslope yarding.

Balloon yarding was tested in northern Europe during the 1950's, and in Canada and the United States in the 1960's. Helium-filled balloons of a variety of types and sizes are used to provide lift of the logs. As shown in Fig. 3-7, a conventional yarding machine with mainline and haulback line drums is required for movement of the balloon and attached logs. A tail block and a series of corner blocks are required in order to bring the balloon close to the surface for attaching the logs. The blocks are moved as is needed to bring the balloon down to the ground at various locations. Each turn of logs can be lifted entirely free of the ground

BALLOON LOGGING
Figure 3-7

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surface. Hence, the system is particularly adaptable to logging steep slopes with fragile soil which are highly susceptible to erosion.

One of the more recent innovations in yarding involves the use of helicopters (Fig. 3-8). Although the first successful helicopter flew only 35 years ago, experimental attempts at using helicopters for logging were initiated in Scotland as early as 1956. Since that time helicopters have been used on an experimental basis in Canada, Russia and the western United States. The helicopter has been described as an infinitely mobile yarder which could eliminate many of the constraints that hamper conventional logging systems in areas of environmental concern. However, helicopter logging has engineering and environmental protection problems in addition to the problems posed by a complex and expensive yarding system.

Helicopters suitable for logging in the Pacific Northwest cost between $200,000 and $2,000,000. Lift capacity for the larger models ranges from 12,000 to 20,000 pounds; for the medium models 5,000 to 9,000 pounds and less than 5,000 pounds for the smaller models.

A typical yarding cycle consists of 1) flying from the landing to the pickup point, 2) hovering during attachment of the chokers to the tag line, 3) flying from pickup point to landing with the turn of logs, and finally 4) hovering at the landing to release the load. Typical cycle time

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(Photo Furnished)

Helicopter Logging

Figure 3-8

Helicopter bringing a log to a landing in the Boise National Forest ranges from 1.5 to 3.0 minutes. In contrast to cable logging methods, a large crew is needed to service the entire operation. A typical crew might consist of four pilots, three helicopter maintenance mechanics, a chaser, two hookers, four choke setters, and a loader operator.

At this particular stage in its development, it would appear that helicopter logging is suitable primarily for high quality, high value stands. Small log size, low stand density, or high defect can cause helicopter operations to be totally uneconomical. Clearly, helicopter logging can reduce site disturbance to a bare minimum. The system is thought to have promise on sites which are highly susceptible to erosion and other forms of soil damage.

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Silvicultural Systems

In general four silvicultural systems are used in the management of western coniferous forests--selection, shelterwood, seed tree, and clearcutting. In the Pacific Northwest, selection cutting is restricted almost entirely to the drier inland areas. In contrast shelterwood, seed tree, and clearcutting are practiced in the Cascades on the slopes west of the summit. All three lead to an even-aged forest. In this region clearcutting predominates except in the drier regions of southern Oregon. Clearcutting is also practiced in the inland region where artificial regeneration is used and even-aged stands are a management objective.

Both mature and immature trees, either singly or in groups, are removed in the *selection system*. Regeneration is established almost continuously, leading to an uneven-aged stand. Individual (single) tree selection leads to an increase in the proportion of shade-tolerant species in the forest, whereas group selection will tend to maintain a higher proportion of the less shade-tolerant species. Group selection can result in the removal of all trees from a zone from a fraction of an acre up to one or two acres in size. With the removal of larger groups, the forest has the appearance of small clearcut patches.

The *shelterwood system* requires the removal of the stand in a series of cuts. The new stand regenerates under the cover of a partial forest. The new even-aged stand develops in the open after the final cut. This system is especially

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well adapted to species or sites where protective cover is needed for the new reproduction, or where the shelterwood gives the regeneration an advantage over undesired competing vegetation.

The *seed tree system* requires the removal of nearly all the timber of an area, usually in one cut. Especially selected, vigorous, wind-firm trees of the desired species are left scattered over the area to provide a natural source of seed. With the advent of highly developed techniques for artificial regeneration of coniferous forests, the use of this particular system is destined to receive less use in the future.

Clearcutting involves the complete removal of the timber stand over a given area in a single cut. This particular system permits the use of intensive management practices in site preparation and regeneration of the new forest. Even-aged forest result from clearcutting. Clearcuts range in size from a few to several hundred acres. The areas range in shape from nearly square patches to long narrow strips oriented parallel but more often normal to the contour. Recently attempts have been made to clearcut in units that resemble the triangular-shaped avalanche zones of the higher elevations. Regeneration can be achieved through natural seeding. However, the larger clearcuts frequently must be regenerated artificially. Hand planting of nursery stock is considered to be the most reliable method for regeneration.

In the hemlock-spruce forests, which occupy a coastal strip extending from Alaska to northern California, clearcutting is practiced almost exclusively. With but few exceptions these clearcuts are regenerated naturally from seed disseminated by the surrounding stand. Artificial regeneration is used only on rare occasions, usually for the purpose of increasing the proportion of a particular species such as spruce or to add a component of Douglas fir.

The shelterwood silvicultural system can also be used in this forest type to produce even-aged stands. Since hemlock is the most shade tolerant, the leaving of an overstory favors hemlock reproduction and nearly pure even-aged stands of hemlock result. Such cutting can provide some control of competing shrubs that are promoted by full sunlight.

Coastal Douglas fir occupies a region of several million acres on the west side of the Cascades in Washington and Oregon. It is a subclimax species which is intermediate in shade tolerance. Silvical and regeneration requirements of coastal Douglas fir suggest the use of even-aged management by means of the clearcutting, seed tree, or shelterwood system. Clearcutting is by far the most commonly used system for harvesting Douglas fir. Patches 40 to 60 acres in size in a variety of shapes occur with considerable frequency.

If the clearcuts are of moderate size natural regeneration will usually occur within a relatively short period.

However, regeneration is somewhat more difficult on the hotter south facing slopes, on areas where frost damage occurs, and where a natural source of seed is inadequate. Consequently, the trend is toward artificial regeneration on all clearcuts. Clearcutting is particularly desirable in regions where heavy concentrations of slash occur.

On the drier slopes characterized by high levels of radiation, the shelterwood system has proven to be more satisfactory than clearcutting. Regeneration is established either artificially by planting or naturally if adequate seed sources are available. Planting is usually necessary on the more difficult steep, shallow soil, dry sites.

The mixed conifer zone of southwestern Oregon, a transition between the Douglas fir forests of coastal Oregon and Washington and the pine forests of northern California and eastern Oregon, includes Douglas fir, Sitka spruce, Port Orford cedar, ponderosa pine, sugar pine, incense cedar, grand fir and white fir. This unusually diverse collection of species offers a wide range of shade tolerance, drought resistance, and resistance to disease and insect attack.

Except under conditions of high soil moisture, clearcuts do not regenerate naturally. Furthermore, the seed tree system does not provide sufficient protection for stand regeneration. Shelterwood cutting is indicated for most of the region. The degree of overstory required is dictated

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by the species and site conditions. Selection cutting is appropriate where continuous forest cover is needed. As suggested earlier, clearcutting can be practiced in areas with adequate soil moisture. Areas along the coast can be clearcut. However, planting in these areas is required because of the relatively dense understory and high rodent population.

The upper slopes of the Cascades on the west side and coast range supports true fir-mountain hemlock forests which consist principally of Douglas fir, Pacific silver fir, Shasta red fur, noble fir, western hemlock, mountain hemlock, and western white pine. Both the shelterwood and clearcutting systems are used for management of these forests. The shelter wood system can be designed to provide sufficient light and seed for regeneration of these species. It is particularly applicable at the higher elevations near the upper limits of the coniferous forest. Clearcutting is practiced throughout much of this forest type in particular where site conditions are not subject to severe changes in temperature and exposure. Artificial regeneration is frequently required where clearcut management is practiced.

The mixed pine-fir type of the east slope of the Cascades consists principally of ponderosa pine, Douglas fir, lodgepole pine, grand fir, and western larch. Mixed stands of ponderosa pine and Douglas fir at the lower elevation give way to western larch and lodgepole pine at moderate elevations and finally to mountain hemlock and subalpine fir at the higher elevations.

Ecological conditions and difficulties with disease in this forest type point toward even-aged management. Consequently, the shelterwood, seed tree, and clearcutting methods are indicated. The shelterwood system is preferred on the more harsh sites in which regeneration is difficult. Clearcutting followed by artificial regeneration, particularly planting, is indicated for sites not subject to extremes of temperature and moisture. Clearcutting may be required in stands which are heavily infested with mistletoe.

The northwestern ponderosa pine forests occupy an extensive region of eastern Oregon and Washington and the southern part of Idaho. Since its range encompasses great diversity in climate, topography, and site conditions, a wide variety of regeneration practices can be applied. Consequently, depending on local conditions shelterwood, seed tree, clearcutting and the selection cutting methods are practiced. On the more moist sites natural regeneration occurs readily. However, planting is nearly always necessary in areas of low rainfall.

Western white pine and associated species as a forest type is found in the subregions of Northern Idaho and Eastern Washington. It consists of a mixture of the very light-demanding species of western larch and lodgepole pine with the increasingly shade tolerant species of western white pine, Rocky Mountain Douglas fir, grand fir, western red cedar, western hemlock, Engelmann spruce, and subalpine fir. Any of the even-aged silvicultural systems can be applied if the objective is to favor light-demanding species. Natural regeneration can be obtained from all systems, although in stands with heavy concentrations of residue, clearcutting with burning followed by artificial regeneration often proves to be the most satisfactory. If the objective is to manage for more shade tolerant species, such as hemlock, red cedar and grand fir, the selection system by individual tree or groups should be used. It is also used where continuous forest cover is needed.

The western larch type found mainly in the Northern Idaho, Okanogan, and Eastern Washington subregions is a very light-demanding, pioneer species which has been maintained over the years by wildfire. Because of its silvical traits, the even-aged silvicultural systems of shelterwood, seed-tree or clearcutting in patches can best maintain this type. Other systems will favor its more shade tolerant competitors. Susceptibility to severe dwarf mistletoe damage may demand clearcutting to prevent reinfection of the larch regeneration. Larch casebearer, a foliage eating insect, has caused reduced growth and light seed crops in recent years especially in northern Idaho and northeastern Washington. The chances for natural regeneration are substantially reduced.

Lodgepole pine covers a wide range of sites in all subregions east of the Cascade Range. Large acreages of pure lodgepole pine sometimes occur. In other situations it is mixed with other conifers. Like larch, it is very light-demanding and will be replaced by its more shade tolerant neighbors in forest succession. Due to problems of disease, lack of wind firmness, and slash residue, clearcutting is most often the only practical method of harvesting this species especially where it grows in nearly pure stands. Partial cuts can be used where mixtures of shade tolerant trees are associated with the lodgepole pine and where carefully controlled shelterwood systems are used.

The ponderosa pine and Rocky Mountain Douglas fir forests in the subregions of Northern Idaho, Intermountain, and Blue Mountains have similar characteristics and can be managed in much the same way as the mixed pine-fir of eastern Oregon and Washington as previously described.

The Engelmann Spruce-subalpine fir type occupy the cool moist sites at higher elevations of the Intermountain, Blue Mountains and Northern Idaho subregions. These species are shade-tolerant and grow in climax or near climax associations but often are not all-aged in structure. They are difficult to regenerate on many sites. If risks of disease, windfall, and beetle attack are high, small clearcuts are about the only system useable. If watershed or aesthetic considerations rank high it may be necessary to leave the stand uncut. There are opportunities for selection and shelterwood systems depending on the structure of the stand.

Log Storage

Because of the need to sort and to provide inventories for wood processing plants such as saw mills and pulp mills, a wide range of log storage facilities are maintained throughout the Pacific Northwest. Typical among these storage facilities are: cold decks of logs at landings in the woods, log sorting facilities located in close proximity to the forest site, and log sorting yards at or near wood conversion plants. The relatively small concentration of logs on cold decks or landings at remote locations in the woods are usually of a highly temporary nature. This type of storage facility is ground based but in some instances may be adjacent to an intermittent or permanent stream or a freshwater lake. In contrast, the remote log sorting facility designed to process logs for one or more drainages and the log sorting facilities maintained near conversion plants are either ground or water based.

Prior to World War II and the wide availability and usage of heavy equipment for handling logs, the bulk of sorting yards were located on water. Mill ponds were common in all parts of the Pacific Northwest. In the inland region water storage facilities were located on either free flowing rivers equipped with small dams to provide areas of quiet water or on freshwater lakes. The forest products industries located on the coast of Washington, Oregon, and southeast Alaska have used saltwater bays and estuaries for log storage.

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In general water-dependent log handling and storage facilities in southeast Alaska are of four types:

1) sale area dumping sites
2) sale area raft collecting and storage sites
3) winter raft and storage sites
4) mill storage and sorting sites

Because of the water-oriented geography and lack of roads, most commercially harvested timber in southeast Alaska is stored and transported on marine waters. By way of contrast, the size of saltwater storage facilities on the coasts of Washington and Oregon are much reduced, due primarily to a more highly developed land transportation system. In Alaska small bays and estuaries have proven to be the most desired location for log handling facilities. Teredo damage is at a minimum in these locales, particularly if a stream is continually supplying freshwater to the bay. Furthermore, small bays provide excellent protection from winter storms off the Gulf of Alaska.

Recent years have witnessed a return to more intense use of land-based log sorting and storage facilities. As suggested earlier, the development of highly mobile heavy equipment for log handling has been instrumental in bringing about this change, in addition to the greater flexibility in forest industry operations brought about by land-based sorting yards.

Many of these yards process large volumes of logs. Consequently, sorting yards that range upwards of 80 acres in area are not uncommon. Much of the area will be occupied by logs in storage. A considerable quantity of debris in the form of bark and wood fragments collects in the yards and must be disposed of periodically. Because of the fire hazard associated with such large volumes of logs and because of difficulties in manufacturing partially dried wood, large storage yards are nearly always equipped with sprinkling systems. For the most part these systems operate continuously, particularly in the drier summer months. Although, evaporative losses are high from these sites, it is not uncommon to have spent sprinkler water draining into nearby streams and lakes.

Many of the problems of water pollution brought about by log storage are closely related to the methods by which logs are placed in or removed from storage, particularly water storage. Free fall of logs singly or in bundles tends to dislodge bark in substantially larger quantities than easy let-down methods. Large quantities of bark dislodged during unloading in the water are responsible of course for buildup of debris, as well as for increased concentrations of leachates.

A wide range of methods are employed at water storage facilities for placing logs in the water. In the inland region the smaller operations may resort simply to dumping logs directly from trucks into the water storage facility. Dumping a load of logs, such as might be contained on a log truck, results in considerable impact between logs, impact with each other, with the surface of the water and perhaps with the bottom if the storage facility is shallow. However, it is much more common practice to bundle logs with steel bands while still in place on the truck. Subsequently, the entire bundle is lifted from the truck and eased into the water. In some instances, particularly in Southeast Alaska, logs are bundled on the land and later skidded or slid into the water. Also in Alaska logs are occasionally dumped on the beaches, banded into bundles and later towed to deeper water at high tide. Of all of these methods it is clear that bundling of logs on land followed by lifting and easing the bundle into the water tends to minimize the amount of bark and wood debris introduced into the water.

After the logs have been introduced into the water, a variety of handling sequences follow, depending on the particular operation. If the logs have been introduced singly and water transport is to follow, it is a common but by no means exclusive practice to bundle the logs prior to rafting and movement. On the other hand, logs introduced singly at a mill site are more likely to be sorted and held in reserve for processing. There are indications of unusually long water storage periods in some parts of the Pacific Northwest as evidenced by the growth of small plants and shrubs on logs in water storage.

If transport by water is to follow log dumping, it is common practice to tie the bundles together in the form of large rectangular rafts which might contain of the order of 500 M board feet. A bundle will contain 5-15 M board feet. Completed rafts are usually stored for a short period prior to being towed to a raft storage area or to a mill storage and sorting area.

Once the logs have arrived at the mill site, the bundles are frequently lifted from the water, broken down and sorted prior to processing. Alternatively, the bundles may be broken down in the water followed by single log water storage and sorting.

As suggested earlier in this section the location of storage areas and the method of log handling has a highly significant bearing on the extent of water pollution associated with log storage. Clearly, water storage has a far greater potential for introducing pollutants than land based storage. Furthermore, log handling in bundles rather than singly, taking care to minimize impact loading during introduction to and removal from the water is all-important for minimizing the quantity of wood debris and bark that enters the water.

Regeneration Practices

In the Pacific Northwest regeneration practices fall into two broad categories: 1) seeding and 2) planting of nursery stock. Seeding is accomplished by artificial means, usually machine application of seed over extensive areas. Alternatively, seeding may be accomplished by the natural distribution of seed from trees which are left following harvest of the timber. In the latter circumstance regeneration is, of course, a basic component of the silvicultural system.

Natural regeneration following clearcutting requires a source of viable seed of one or more species of interest in the surrounding stand. As one might expect, the size of the clearcut, topography, prevailing wind direction and many other factors have a significant bearing on the success of natural regeneration of clearcut areas. The shelterwood, seed tree, and selection systems offer marked contrast to clearcutting in that provision is made for a seed source in the immediate vicinity of the harvest area. Nonetheless, numerous other problems arise in obtaining regeneration in the area from which timber has been removed.

Some species will regenerate rapidly on cut over areas if the site conditions are at all conducive to their reestablishment. For example, adequate stocking and frequently overstocking of hemlock occurs in the spruce-hemlock zone following clearcutting. Providing that all the critical environmental factors are favorable, Douglas fir will regenerate naturally on many sites in most parts of the Pacific Northwest. Notwithstanding, natural reestablishment of Douglas fir is much more difficult than for hemlock in the coastal zone. Similarly, given the proper circumstances, ponderosa pine will regenerate naturally in many parts of its natural range. Nonetheless, there are many situations, particularly on the drier, less fertile sites, that are subject to extremes of temperature and radiation on which natural regeneration is difficult if not impossible to obtain.

Because of difficult regeneration problems on many cut over lands, modern forest practices have become more highly oriented toward the use of artificial means for reestablishing forests. Artificial seeding, usually by aerial means, and hand planting are being practiced with increasing frequency by both private and public agencies.

Both planting and artificial seeding frequently require some form of land preparation beforehand. Almost without exception site preparation involves a measure of soil disturbance. Not infrequently partial or complete removal of the layer of duff and litter and exposure of mineral soil is involved. Observations over a long period of time in the western United States indicates clearly that some exposure of mineral soil is nearly always essential for regeneration whether by planting or artificial seeding.

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Typically, one or more of three distinctive methods are used in the Pacific Northwest to prepare sites for artificial regeneration:

1) burning for removal of large as well as fine residue;
2) scarification, usually by the use of crawler tractors equipped with brush blades, or tractors equipped with large rake systems. Also, an especially prepared tool is sometimes dragged over the ground surface with high lead yarding equipment;
3) deep plowing or terracing with crawler tractors to create small benches on steep hillsides which impede runoff and promote the retention of moisture in the soil.

In addition to these treatments, it should be pointed out that the reestablishment of forest cover on brush lands is frequently accomplished by means of herbicidal treatment to kill the brush. Later, burning and/or scarification is employed prior to seeding or planting. The conversion of brush lands as well as lands occupied by inferior species has and will continue for some time to be a major management activity in the Pacific Northwest.

Of these techniques, controlled burning is by far the most prevalent. Scarification by tractor is practiced where costs are not prohibitive, slopes are relatively

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gentle, and site conditions are such that some mechanical disturbance is required in order to expose mineral soil. Frequently burning and tractor scarification are practiced together.

Scarification using a tool fastened to the butt rigging of a high lead yarding system has received limited use on the west side of the Cascade Range. Because this particular technique does not require the movement of heavy equipment over the surface of the growing site with concomitant compaction of the soil, it holds considerable potential as a rapid and relatively efficient scheme for obtaining the degree of site disturbance needed for regeneration of certain species.

Terracing is a relatively new method of site preparation which up to the present time has been practiced only in the inland region. Normally accomplished with a crawler tractor equipped with a deep plow, its objective as suggested earlier is to provide a means for retaining moisture on steep slopes in areas of low annual precipitation.

Controlled burning is practiced in virtually all forest types of the Pacific Northwest. As pointed out earlier, broadcast burning, and piling and burning predominate. In order to prepare the site adequately for regeneration close control of fire is essential. Burns of high intensity are damaging to soil structure, decrease wettability, and result in the loss of valuable nutrients. On the other hand, low intensity burns, particularly in areas of high slash density, may not reduce residue volumes adequately for for efficient regeneration.

Tractor scarification is accomplished with a crawler tractor equipped with a toothed brush blade. Several passes over the area to be prepared may be necessary in order to remove brush, old stumps, and other obstacles that occupy growing space. The objective of scarification is to obtain an intermixing of litter and duff with mineral soil such that soil adequate for regeneration is exposed and that the litter and duff act as a mulch for retention of water and slow release of nutrients. If the volumes are excessive, windrowing of brush and residue may be essential in order to provide sufficient space for planting. As indicated earlier burning of the windrowed material before planting is sometimes practiced.

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Logging Residue Management

Residue, principally in the form of defective logs, branches and tops which remain on the growing site following logging, has been a source of concern to foresters for many years. The loss of usable fiber has been cited by those concerned principally with utilization. Not infrequently the recreationist, who has objected strongly to the practice of clearcutting, is repulsed more by the unusually large quantity of debris left behind than by the actual removal of timber. The professional forester is concerned about a number of aspects of logging slash, among which the control of wildfire oftentimes receives top priority. However, the influence of slash and control procedures on insect infestation, on regeneration of the new forest, and on the quality of water from forested watersheds is also of extreme importance.

Considerably more attention has been drawn to the problem of logging residues in the past few years. As the costs of timber management have increased, there is naturally more concern with extracting as much of the resource as possible and also with reducing the cost of all aspects of forestry operations. More intense use of forested lands for recreational purposes has brought additional people in contact with the problem. Consequently, professional foresters are now acutely aware of the need for much more intensive planning for the management of residues.

Harvesting operations produce large quantities of residue, but so do many other forest operations. Small trees, tree limbs, and tops are left as residue following precommercial thinning. Clearing of roads oftentimes generates large volumes of residue. Similarly, the clearing of right of way for utilities, land clearing for urban development as well as agriculture, and for other types of improvements are responsible for the production of sizable volumes of residue. One source of residue frequently overlooked in the past is that generated during the conversion of forest lands from undesirable to more desirable vegetation. The conversion of brush lands to sawtimber and the conversion of one timber type such as alder to a softwood, a frequent occurrence on the west slope of the Cascade Range, will frequently produce large volumes of residue.

The quantity of slash remaining after timber harvest in the forests of the Pacific Northwest is governed primarily by species, stand volume, and percent defect. Without question, the old growth western red cedar stands along the Washington and Oregon coasts are the highest producers of logging slash. As an example, the volume of slash produced by logging of western red cedar on the Quinault Indian lands may exceed 200 tons per acre. Numerous decadent old-growth Douglas fir stands on the west side of the Cascade Range produce volumes of slash that exceed 100 tons per acre. In

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contrast, slash production of the forests in the inland parts of the Pacific Northwest is normally substantially smaller. This is primarily a reflection of the lower volumes of timber per acre on the more arid lands of eastern Oregon and Washington as well as northern Idaho.

Typically residue management techniques fall into four broad categories:

1) no treatment;
2) dispersal over the growing site;
3) complete or partial destroying by methods such as burning or burying;
4) mechanical processing into a form for redistribution on the site or into a form usable for the production of fiber or whole wood.

For the most part forest residues are simply burned. Burning techniques have undergone considerable development over the years and certain practices are area specific in the Pacific Northwest. Burying as a means of eliminating residues is hardly out of the experimental stage. Minimum experience is available on this method of control.

Utilization experts much prefer the production of usable materials from residue. Although highly desirable, product utilization is fraught with many problems of efficient mechanical processing and with high costs. Recently, increased attention has been given to the possibility of preprocessing residues at or near the forest site and dispersing the residue over the growing area. This is a form of utilization, albeit not one normally considered as a possible alternative. Equipment for crushing or chopping residues in place has been developed and tested in the western United States. Generally speaking the equipment is suitable only for areas in which residue sizes and total volumes are relatively low.

Portable chippers, available for many years, have recently undergone more intensive development. Larger models more adaptable to a variety of sites both with and without debarking facilities are now available. A few trials of the newer chippers have demonstrated that chips can be produced at remote locations. Subsequently, the chips can be returned to the growing site or they can be blown into a van for transport to a processing plant. Potentially a wide variety of end products are possible since both unbarked and barked chips can be produced.

Even though several options are available for the management of residues, prescribed burning is and will continue to be the most prevalent management method practiced in the region. Burning is a well established forest management tool. The technology of fire control, now highly developed, is such that the probability of fire escape has been greatly reduced over that of past years.

Several forms of prescribed burning are practiced in the Pacific Northwest. Area slash burning, piling and

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burning, and light underburning are by far the most commonly used control methods. These burning techniques have been used extensively for a number of years. More recently the use of incinerators, sometimes referred to as bin burning, has been introduced for disposal of residue in heavy use areas such as campgrounds, ski areas, along roads and near developments. Incinerators can be of simple design such as especially prepared open pits. Alternatively, portable prefabricated steel bins are sometimes used. Bin burners have to date received only limited use for residue management.

Area burning, more frequently called broadcast burning, is the most widely used of all burning techniques. Although used primarily on the west side of the Cascade Range in clearcuts, broadcast burning is used occasionally in the pine areas east of the Cascades where residue volumes are lower. Slash burning, a carefully planned operation, is usually done in the fall although summer burning is sometimes practiced along the coast. Fire lines are built either by hand or with bulldozers around the area to be burned. Site disturbance of this type can be responsible for adding sediments to runoff waters if not carefully planned and controlled. Snags are felled to lessen danger of fire escape and prelocated pumps, hose systems, tankers, and standby fire crews may be used.

Piling and burning is practiced primarily in the forests of the inland Pacific Northwest. This method is usually associated with selection cutting or with the shelterwood silvicultural system. Piling before burning affords a measure of protection to the remaining stand. Depending on the quantity, size, and dispersal of residue, piling is accomplished either by hand or with the use of machines. Machine piling is more common and the slash is bunched in piles or is windrowed. Bulldozers are equipped with special brush blades with teeth in order to minimize the quantity of soil that is deposited in the slash piles. Other types of piling equipment have been used but the bulldozer receives widest use. It should be noted that windrowing of slash is also practiced on the west slope of the Cascade Range as a part of the scarification of lands prior to artificial regeneration. This particular topic is addressed in more detail later.

Light underburning of uncut forest is a practice confined largely to the southern states. This particular control method has been suggested for ponderosa pine but to date has been used very little.

Since 1970 a practice termed YUMing (Yarding Unmerchantable Material) has been practiced for the management of residues on the west side forests. Either during or following the yarding of merchantable material the larger size classes of residue are yarded to the landing. In some instances, especially designed high lead yarding systems are moved in following regular logging for yarding of the residue. The material is piled at the landing for eventual burning. If the volume of such material is substantial and relatively sound, and market conditions are favorable, it may be sold on the pulp market.

As suggested earlier, the mechanical treatment of residue and dispersal over the site has received only limited use to date. Two treatment methods prevail: chipping followed by dispersal over the site, and crushing or masticating of the residue in place. Chipping is costly. In areas of high volume of slash, chips can reach a depth of several inches and thereby add to the fire danger and impede regeneration. On the other hand, chips protect the soil surface from high impact rainfall and can serve as an impediment to surface erosion.

Machines for crushing, chopping, or masticating residues in place normally must pass over the logged site at least twice before the residue is tolerable from a fire hazard standpoint. The practice is limited to gentle slopes. When practiced on heavy soils under wet conditions, soil compaction can result. As is the case for chips, crushed residue can result in some measure of soil erosion control.

The management of residues is associated closely with many aspects of forest management, including fire prevention and control, and protection from insects and disease as well as mammals and birds. Reproduction problems are associated with residues. Soils are modified by burning through loss of nitrogen, boron, sulfur, and phosphorous. Burning decreases wettability, usually in proportion to the burn. Burns that remove duff cover from steep clearcut slopes may suffer dry ravel erosion until revegetated. The incorporation of residues into the soil will improve aeration, infiltration and moisture retention properties of the soil. The destruction of residue will increase groundwater temporarily by the amount of transpiration eliminated. Residue treatments that channel runoff or reduce infiltration rates affect the timing of peak flow of streams. Burned residues release ions which can be transported to streams and lakes to lower water quality. Severe burns are known to increase the susceptibility of the growing site to surface erosion until the area is revegetated. When present in streams, residues increase the biochemical oxygen demand. Any residue treatment which disturbs litter and surface soil can lead to stream sedimentation. Residue in stream channels modifies stream behavior so that sedimentation may be increased. Flush outs of debris dams caused by residue in streams has been responsible for channel scouring.

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IMPACT OF FOREST PRACTICES ON WATER QUALITY

Suspended Materials

This pollution source can be divided into inorganic and organic suspended sediments. By far, inorganic sediments (i.e., sands, silts, and clays) are the major polluting agents from wildland watersheds. Organic suspended sediments cause less of a problem and receive less attention. Leachates from these materials can degrade water quality as well as the suspended particles themselves.

Suspended Inorganic Material

Erosion of soil produces sediment in the streams draining from forest lands. Three major erosion processes are of concern in forest lands: surface erosion, mass soil movement, and channel erosion. Forestry practices can influence and accelerate all three of these processes through disturbing and exposing mineral soil, damaging soil structure, and eliminating the mechanical reinforcement.

Roads are considered to be the most significant contributing factor of erosion. In the Northern Region of the U. S. Forest Service, studies and observations have shown that as much as 90% of the sediment produced from timber sale areas comes from roads (Packer and Christensen, n.d.). In other areas the percentages will be different. In any case, the non-road contribution would be significant even if the sediment from roads were eliminated. The accelerated erosion from road construction is not within the scope of this report.

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Therefore, only the accelerated erosion caused by silvicultural practices, logging practices, residue management, and reforestation will be discussed.

Surface erosion. Surface erosion is the direct result of rain striking unprotected soil surfaces, detaching soil particles, and transporting them by overland flow across the soil surface. Harvest methods and logging systems disturb and expose mineral soil in varying degrees (see Table 4-1). Clearcutting with tractor logging is the most destructive of all the techniques (wheel skidding is also often severe) when considering compaction of soil. Skyline yarding, in all cases, is less severe than high-lead yarding. Grapple yarding systems are intermediate between skyline and high-lead or jammers, as they combine features of each. Balloon yarding is substantially less severe than skyline yarding. Helicopter yarding probably results in the least compaction because it transports logs free in the air over most of the logged areas.

There have been numerous studies relating to forestry practice impacts on accelerated surface erosion and sedimentation (see Table 4-2). The great variety of techniques and machines used in the operations provide alternatives for minimizing watershed damage on many sites. A major rule here is the less the compactive and disturbing contact with the forest floor, the less watershed damage resulting from skidding and logging.

Suspended sediment discharge has been related to streamflow, topography, soil and land uses (Anderson, 1954, 1957;

Table 4-1. Soil Disturbance by Various Logging Methods (excluding road areas)

Treatment	Soil Disturbance % Compacted	 % Bare Soil	Source	Remarks
1. Clearcut				Douglas-fir forest type in the Oregon Cascades
Crawler (tractor)	64	--	Dyrness, 1965	
Highlead	43	14.1	Dyrness, 1967	
Skyline	--	12.1	Dyrness, 1972	
Balloon	4.3	6.0		
2. Partial cut				Ponderosa pine forest rangelands in eastern Oregon and Washington
Crawler	21	15.5	Garrison and Rummel, 1951	
Jammer cable	15	20.9		
Horse	12	--		
3. Partial cut				Mixed conifer forest type in eastern Washington
Crawler	22	29.4	Wooldridge, 1960	
Skyline	5	11.1		
4. Partial cut				Mixed conifer forest type
Crawler	22	--	McDonald, 1969	
Wheeled skidder	12	--		
5. Clearcut				Oregon coastal forests
Highlead	--	12.1	Ruth, 1967	
Skyline	--	6.4		
6. Clearcut				Western Washington
Tractor	--	26.1	Steinbrenner & Gessel, 1955	

	% of Area Observed to be Eroded		
7. Cable skidding	41	Klock, 1973	The percentage of the logged area observed to be eroded was measured following logging and two summer rainstorms
Tractor skidding on bare soil	31		
Tractor skidding on snow	13		
Helicopter	3		

Table 4-1. Continued

Treatment	Soil Disturbance	Source	Remarks
8. Balloon logging	Soil disturbance was noted only at the yarding areas. This method is well adapted to steep slopes (45 to 90%) and shallow and/or fragile soils.	Gardner et al., 1973	Idaho

Table 4-2. Impact of Various Logging Techniques on Suspended Sediment

Treatment	Variation in Suspended Sediment	Source	Remarks
1. Clearcut	Not significant.	Meehan et al., 1969	Southeast Alaska
2. Clearcut logging	Not significant.	Hornbeck, 1968	Two Fernow watersheds
3. Logging	Not significant.	James, 1957	Maybeso Creek, Alaska
4. Timber cutting	Not significant.	Packer, 1967	
Skidding of logs	Can increase sediment significantly.		
5. Clearcut with high lead system	Not significant (<15 ppm)	Brown & Krygier, 1971	Oregon Coast Range
Clearcut and burning	Sediment yields increased about five-fold. Maximum concentrations went from 970 ppm to 7,600 ppm after the fire.		
6. Clearcut with skyline system	Not significant.	Fredriksen, 1970	West Oregon Cascades
Skyline followed by slash burning	Sediment concentrations (100 to 150 ppm) for two years were 67 and 28 times greater than those recorded on an undisturbed watershed during the same periods.		Notes that sediment had been trapped by logging debris and was released only after burning.
Clearcut with high lead	The increasing sediment in streams draining these logged areas averaged more than 100 times the undisturbed condition over a period of years.	Fredriksen, 1970	Western Oregon, H. J. Andrews Experimental Forest

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
7. Clearcut and trees left in place	No increase in sediment occurred during the first year, but streamflow increased 65%	Liberman and Hoover, 1948	
8. Clearcut and trees left in place	Negligible increase in streamwater turbidity; however, the particulate matter was increased about fourfold.	Liken et al., 1970	Study done on the Hubbard Brook Experimental Forest, New Hampshire
9. Clearcut and carefully logged with little disturbance to the soil surface	A minor effect on water turbidity during the first year; the mean concentration was 6 times greater (16.5 ppm compared to 2.7 ppm) and the maximum 14 times greater (72 ppm to 5.3 ppm) on the clearcut than on the uncut forest. These differences in concentration became negligible during the next 4 years.	Lynch et al., 1972	Study done in central Pennsylvania in the erosion-resistant, sandstone ridge mountainous watersheds of the Ridge and Valley Province of the North Appalachian Mountains.
10. Clearcut and trees left in place	The result was no increase in overland flow and no increase in stream sedimentation.	Dils, 1957	Study done at the Coweeta Hydrologic watershed
Logged by horse and oxen skidding (no truck haul roads were built)	Stream turbidities during a 3-month summer period averaged 94 ppm; and maximum turbidity, consisting largely of mineral soil, was 3500 ppm. The control watershed averaged 10 ppm and the maximum was 80 ppm (primarily organic material).		

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
11. Strip and block clearcutting	When harvest method was precisely described and carefully supervised with reforestation initiated soon after the operations, the logged watersheds had no noticeable reduction in water quality (i.e., no increased sedimentation).	Horn, 1960	
	Maximum Turbidities (JTU)		
12. Clearcut (no plan)	56,000	Reinhart et al., 1963	Fernow Experimental Forest in West Virginia. The differences in turbidities attributed primarily to different skid road layouts and construction. These maximum turbidities occurred during and immediately after logging.
Diameter limit	5,200		
Extensive selection (well planned)	210		
Intensive selection	25		
Control	15		
13. Clearcut (deforested)	Erosion increased about 8-fold in the clearcut area, although always remained slight	Hoyt and Troxell, 1932	Wagon Wheel Gap area of Colorado
14. Clearcut entire watershed	Significant increase in suspended sediment	Lantz, 1971	Coastal watershed in Oregon
Partial patch cut (30%) and left streamside vegetation	No significant change or increase in sediment		
15. Commercial clearcut	Found that infiltration rates after logging remained well above maximum rainfall intensi-	Reinhart, 1964	Fernow Experimental Forest in West Virginia

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
15. (continued)	ties except on skid-roads. As a result, overland flow and surface erosion were largely confined to these skid-road areas.		
Selective cutting under careful conditions	Did not greatly affect the rate of sedimentation in adjacent streams.	Rich et al., 1961	Workman Creek experimental watershed in central Arizona
16. Silviculture	Forest Cover (percent) — Sediment Yield (tons/sq mi/yr) 20 — 400 40 — 200 60 — 90 80 — 45 100 — 22 (The above data computed from a regression equation of the data collected.)	Work and Keller, 1963	Potomac River Basin
17. Clearcutting with erosion hazard	The maximum measurement under careful cutting and logging was 83 ppm--far below the 56,000 ppm maximum measurement for the haphazardly logged commercial clearcutting.	Hornbeck, 1967	
18. Clearcutting Selection cutting Logging	The maximum measurement under intensive selection cut and careful logging was 25 ppm, while the maximum turbidities of streams was 56,000 ppm on the commercial clearcut.	Hornbeck and Reinhart, 1964	Fernow Experimental Forest, West Virginia

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
19. Silviculture stem selection group selection Logging	1. Soil was exposed by haul road and skid trail on 8.1% of total silviculturally treated area. 2. Cutting by stem selection exposed about 1.4 times more mineral soil than cutting by group selection. 3. 10-ft minimum width of buffer strip was a fair margin of safety but a wider minimum strip, perhaps 30 ft across, would have been more desirable.	Haupt and Kidd, 1965	Boise Basin Experimental Forest in central Idaho
20. Effect of logging and aspect	Logging increased sediment movement by fourfold on plots on southwest slopes with 42% bare soil. On northwest slopes with 3% bare soil, sediment increased fivefold, but the total amount was only 5% of that on the southwest slope.	Bethlamy, 1967	Study done in central Idaho. Differing amounts of sediment were probably due to differences in organic content of the soil.
21. Direct ground skidding of logs by teams	The rate of loss is 4,370 ft^3/acre of skid road for a three-month period.	Hoover, 1954	Southern Appalachian Mountains with steep topography
22. Tractor skid trails			
a.High-order gradient <10% drained by water bars	55 lb/acre of eroded soil after first year of logging	Trimble and Weitzman, 1953	Fernow Experimental Forest, West Virginia
b.Poor skid trails no limit on gradient no water bars	433 lb/acre		

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
23. Jammer and skyline logging	1. No difference in erosion resulted from the two skidding systems as applied in the study. 2. Logging operations alone (excluding roads) increased sediment action by about 60%.	Megahan and Kidd, 1972 Megahan, 1972	Study done in the Idaho batholith of central Idaho on steep, sandy soils.
24. Logged	A good correlation was found between peak overflow and accumulated sediment volume. The relationships indicate that a major part of the sediment load is derived from channel erosion.	Leaf, 1966	High mountain watersheds in central Colorado (Fraser Experimental Forest)
25. Burning Douglas-fir slash	Slash burning alters the physical properties of the soil in a manner such as to reduce its ability to absorb moisture during periods of plentiful rainfall.	Neal et al., 1965	Western Oregon
26. Slash burning	Severe burning reduced the percolation rate in the soil, which gives an increase in surface runoff causing soil erosion. Since severe burns usually cover a very small portion of the total surface of a slash-burned area, it is concluded that the overall influence on moisture properties of the soils studied is minor.	Tarrant, 1956	

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
27. Prescribed burning	In five locations studied, soil erosion was greater in the areas treated by prescribed burning, by factors ranging from 7 to 1,500 as compared to the unburned forests.	Ralston and Hatchell, 1971	Study areas were in the southern United States
28. Slash burning	The extent of severe burn rarely exceeds 5% of the area and in most cases is less.	Tarrant, 1956	Douglas-fir region
29. Clearcut and burned	Temporarily impaired watershed protection and increased overland flow and erosion. Maximum soil erosion (168 lbs/acre) from snowmelt overland flow was during the second year and treatment. Maximum soil erosion from summer storms was 151 lbs/acre and 1,506 lbs/acre on a different experimental watershed. Vegetal recovery returned conditions to near prelogging status within four years.	Debyle and Parker, 1972	Larch and Douglas-fir forests type of western Montana. Broadcast burned.
30. Logging Slash disposal	Water yield from snow zone runoff can be influenced both in amount and time of delivery by the manner in which the areas are logged and by brush removal.	Anderson et al., 1960	Cascade-Sierra Nevada Mountains, California

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
31. Logging Slash burning	A Douglas-fir logging operation disturbs surface soil conditions and leaves on the ground a great accumulation of slash. The total quantity of slash per acre averaged 24,000 ft^3, including 15,000 ft^3 of small branch wood, twigs, chips, bark, and slabs.	Isaac et al., 1937	Wind River Experimental Forest, Carson, Washington
32. High lead logging Slash burning	1. Only 8% of the soil surface was severely burned. 2. Logging by the high lead method and slash burning in the fall after rainfall has occurred have had no appreciable detrimental effects upon soil structure.	Dyrness and Youngberg, 1957	Reddish brown latosol soils of the Coast Range of western Oregon
33. Logging Prescribed burning	1. Burning drastically reduced the proportion of the ground surface protected by plants, litter, and logging residue to less than 50%. 2. Overland flow from the logged-burned areas was from two to several times greater than that from the unlogged-unburned ones. 3. Soil erosion from the logged-burned plots averaged 56 lbs/acre the first year after burning, but then increased to 168 lb/acre in the second year, while none of the unlogged-unburned plots produced any soil erosion from snowmelt flow during the 7 years following burning.	Packer and Williams, 1966	Larch, Douglas-fir forests, northern Rocky Mountains

Table 4-2. Continued

Treatment	Variation in Suspended Sediment	Sources	Remarks
34. Wildfire	During the first summer approximately 1 acre-foot of sediment was eroded from the burn. Sediment was deposited in unburned forest vegetation immediately below the burn, in the stream channel, and in the weir pond.	Rich, 1962	Ponderosa pine forest of central Arizona
35. Fire	Heat from forest fires creates a water repellent barrier in the soil. The severity of this condition is positively correlated with burning temperatures.	Debano, 1968	Study done in southern California
36. Fire	High fire temperatures at the soil surface actually reduce infiltration rates by the production of a non-wettable layer, inducing increased erosion by overland flow.	Swanston, 1971	
37. Logging Grazing	In a logged area, it was estimated that 50% of the sedimentation production is caused by logging, 20% is natural, 15% caused by deer use and 15% by cattle and sheep grazing.	Klubber, 1967	North coastal California

Anderson and Wallis, 1963). By combining the effects of all the various potential sources of sediment, they found that the sediment potential for nonagricultural lands varies by a factor of 100 and from agricultural lands by a factor of 7.

Timber management planning to minimize erosion should consider the following physiographical causes of erosion.

Climate. The basic climatic factors affecting erosion are precipitation intensity, duration, and drop impact; freeze-thaw relationships in the surface soils; and the historical climatological constraints on soil formation (annual moisture and temperature).

Precipitation intensity, duration, and drop impact affect the detachment of soil particles and the concentration and patterns of runoff. Borst and Woodburn (1942) isolated the influences and importance of raindrop impact and found a 95% reduction in soil loss when the soil was protected from drop impact (equal quantities of overland flow). The velocity and turbulence of overland flow controls the transport of detached soil particles and affects detachment.

Cycles of *freezing* and thawing of the surface soil can separate the soil masses and increase the susceptibility to erosion by weakening the soil structure and increasing the turbulence of flow by roughening the soil surface.

Wischmeier (1959) developed a rainfall erosion *index* that correlated kinetic energy times the 30-minute maximum intensity with soil loss. On an individual storm basis, the rainfall erosion index explained 72 to 97% of the variation

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in erosion for bare soils. Generally, soil erosion losses are believed to be caused by relatively few storms, with two-year or longer return periods, but a recent study by Piest found that 50% of the annual soil loss in 72 watersheds was contributed by storms that could expect to occur several times a year.

Soil characteristics. Soil properties pertinent to the erosion process include physical, chemical, organic, saturation, parent material, and resistance to detachment.

Wooldridge (1970) concludes that "mean water stable aggregate size" was of most value for assessing soil erosion hazard of forest and rain soils. Middleton (1930) developed two indices for indicating inherent soil erodibility, the "dispersion ratio," and the "erosion ratio." Both are based on laboratory determinations of aggregate stability, particle size distribution, and moisture content. Henderson (1951) developed a "surface aggregation" ratio with the "surface" component referring to the amount of surface in square centimeters per gram on particles larger than silt. The aggregation portion refers to the amount of aggregated silt and clay.

Wooldridge showed a considerable decrease in mean aggregate size with increasing erodibility.

In general, the *physical* properties important are the size and shape of the particles or aggregates and the soil compaction. Compaction generally retards particle detachment, but also has an inverse relationship by reducing infiltration and increasing overland flow.

Wallace and Stevan (1961) evaluated through regression analysis the effects of *chemicals* (calcium, magnesium, potassium, and sodium) on erosion, and found that calcium and magnesium had a positive and significant correlation with soil erodibility due to ionic dispersion and flocculation.

Organic content was found by Wooldridge to have a significant effect on erosion primarily through affecting the variation in mean aggregate size. Willen (1965) also found that those soils which were the most stable had the highest organic matter content. This organic content is affected by vegetation, precipitation, and other climatic factors, consequently varying with aspect and elevation.

Saturation or water content of soils affect the buoyancy of the particles and the capillary forces, thereby affecting the resistance to detachment.

Parent material affects erodibility, and Andre and Anderson (1961) demonstrated that the soils derived from acid igneous rocks tend to be considerably more erodible than soils derived from other parent materials. Wallace and Willen ranked 12 parent materials in the following manner:

> Erodible parent materials--granite, quartz diorite, granodiorite, Cenozoic nonmarine sediments, schist
>
> Intermediate--diorite, a variety of metamorphic rocks
>
> Nonerodible--Cenozoic marine, basalt and gabbro, pre-Cenozoic marine sediments, peridotite and serpentinite, and andesite

Resistance to detachment also depends on *cohesion* (or electrical bonding), *adhesion* (or chemical and physical cementation), compaction, and the effective diameter-surface area relationships. Cohesion, adhesion, and compaction affect the internal forces holding the soil together. The effective diameter-surface area relationships affect the detachment force.

Hydrologic characteristics. Hydrologic characteristics affecting the erosion process include the infiltration-runoff relationships, cover, runoff characteristics, soil-water interfacial characteristics, and snowmelt.

Infiltration-runoff relationships include percolation, or the surface water intake potential; permeability, or the potential groundwater flow rate; and the surface detention and storage capability of the land surface.

One of the most important factors involved in the erosion process is the amount of *cover*, which not only protects the soil surface from raindrop detachment but aids significantly in the interception, retention, and infiltration process. Such cover can consist of either plants, litter and organic humus, or artificial cover such as jute blankets. Lowdermilk (1930) concluded that the beneficial effects of litter cover were not due to its water absorbing capacity, but rather to its action in protecting soil from the destructive action of raindrops. Packer (1957) in the Boise Basin in Idaho, found that total ground cover and the maximum size of bare soil openings exerted the most influence on the erosion process, and concluded that in order to minimize runoff and erosion ground cover

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density should be at least 70%, with maximum size of bare openings no greater than four inches.

Figure 4-1, taken from Wooldridge (1970), shows the relation between ground cover and erosion for range land in central Utah.

Flow *concentrations, velocities* of flow, and the amount of *suspended material,* including both size and quantity, are important factors in runoff which greatly affect erosion. Most forested areas have little, if any, surface runoff, and consequently very little natural erosion.

Soil-water interfacial characteristics depend on water velocity and surface roughness. Surface roughness can move the flow boundary layer up, creating a zero velocity layer at the surface which reduces entrainment capacity. Such roughness creates settling areas that reduce sediment transport (rip-rapping).

Snowmelt affects erosion in much the same way as precipitation. Maximum and average melt rates and total volume of the snow pack are important. Although concentrations may be considerably less than during the summer, most soil movement occurs during the snowmelt (high runoff) periods.

Topography. The primary elements related to the topographic effects on erosion include elevation, slope, and aspect.

Elevation affects erosion primarily through its relationship with soil formation and climate.

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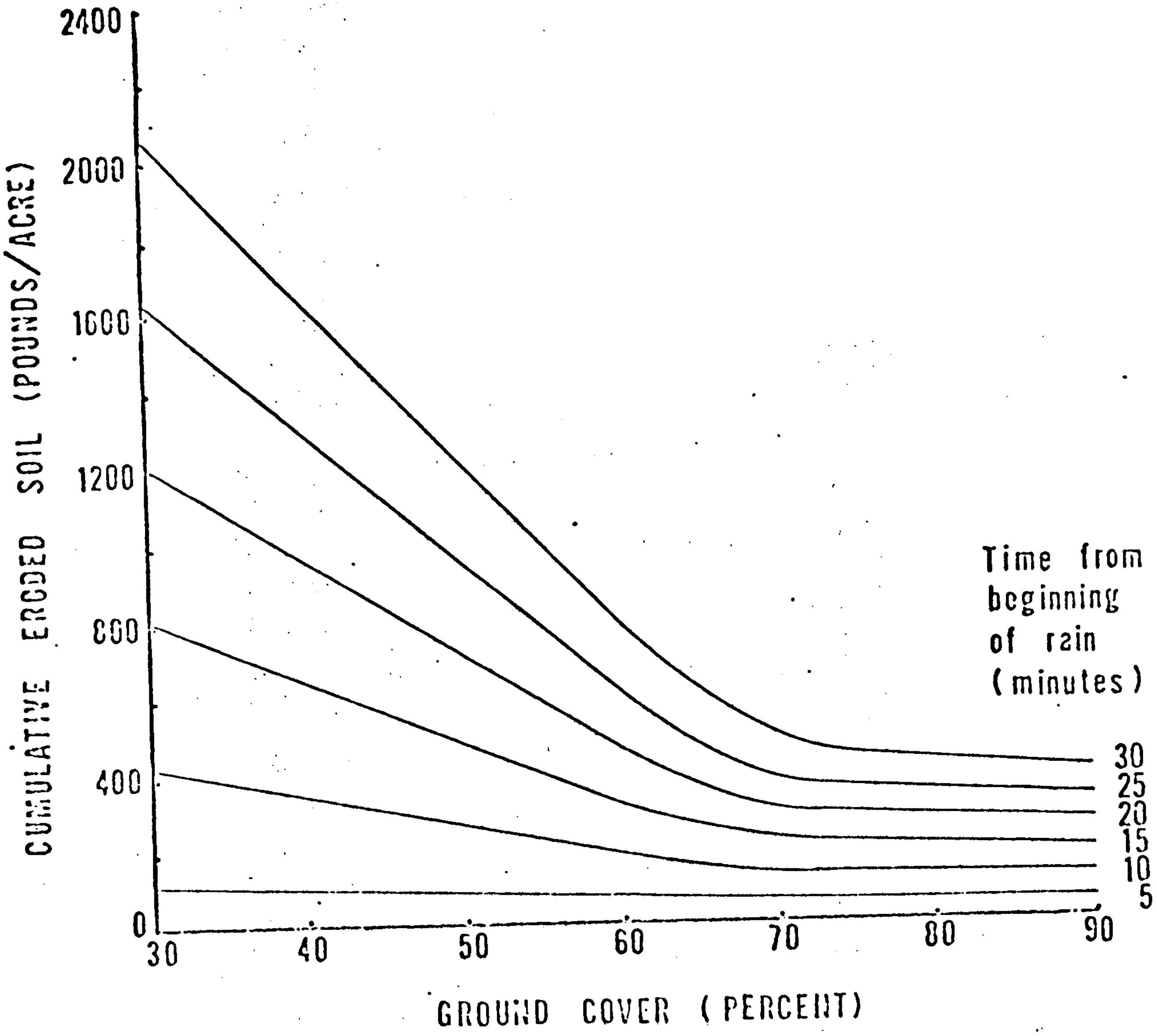

FIGURE 4-1. RELATIONS OF CUMULATIVE SOIL ERODED WITH GROUND COVER

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The percentage of slope and the length of slope affect runoff velocities and erosion.

Aspect or exposure has been investigated by Bethlahmy (1967) in central Idaho, who found that erosion was much more severe on southwest facing slopes. He concluded that this is primarily due to differences in the organic content of the soil which relates to soil formation and climatic variables.

Mass soil movement. Soil mass movements in timbered areas were broken down by Swanston (1970, 1974) into two major groups, differentiated roughly on the basis of type of material, depth of movement, and character of failure surface. The first and widespread group includes debris slides, debris avalanches, and debris flows. These often involve initial failure of a relatively shallow, cohesionless soil mass on steep slopes as a consequence of surface loading, increased soil water levels, or removal of mechanical support. The second group includes deep seated soil creep, slumps, and earthflows. These three entities are closely related in terms of their occurrence and genetic process.

The contributing factor of timber harvesting in accelerating soil mass movements was a lessening of the mechanical support of the slope, chiefly by timber cutting and burning.

Bishop and Stevens (1964) have also shown a direct correlation between timber harvesting and accelerated soil mass movements following heavy rains in the fall of 1961. More detailed work in this area by Swanston (1967, 1969, 1970) has shown that sections of almost every logged slope exceed that natural angle of stability of the soils (±34°). Dyrness (1967) investigated accelerated soil mass movements on the west flank of the Cascade Range following heavy rains in the winter of 1964-1965. He reported that out of 47 recorded debris avalanches, debris flows, earthflows, and slumps, 72% were directly associated with roads and 17% with logging.

A study by Rothacher and Glazebrook (1968) found that in the national forests of Region VI on highly erosive granodiorite soils, slopes over 40% cannot be clearcut without considerable soil loss from numerous slides.

A second major contributor to accelerated mass movements is fire, both wildland fire and slash burning. This is due largely to the destruction of the natural mechanical supports of soils.

Both controlled slash burning and wildland fire in forested areas are often followed by increased rate of surface erosion (Dyrness, 1967). Krammes (1960, 1965) reported that in October 1959, a wildfire swept through the Los Angeles River Watershed and debris movement began almost immediately after the fire passed. Great quantities of debris moved downslope and into stream channels. The increase in the production of sediment by mass soil movements is from 10 to 16 times greater. Packer and Williams (1966) investigated the effects of logging and prescribed burning on the hydrologic and soil stability behavior of larch-Douglas fir forests in the northern Rocky Mountains. They showed that both logging and prescribed burning treatments significantly influenced soil and vegetative characteristics and altered runoff and soil erosion behavior.

Logging residue frequently hinders forest regeneration. It can prevent seed from reaching the forest floor. It can affect seed germination and seedling survival adversely by denying them sufficient moisture and/or light. On the other hand, logging residue can be beneficial in the regeneration of some forest species by providing protection and shade. Finally, logging residue can constitute a serious physical barrier to planting, especially by machines (Packer, 1971).

A prescribed broadcast burning of logging residue on clearcuts in the Pacific Northwest, on the average, left 47.2% of the area unburned, 45.8% lightly burned, and only 5.4% severely burned (Tarrant, 1956; Dyrness and Youngberg, 1957). These results suggest that the prescribed use of fire in forest lands does not have to be highly destructive to the soil structure.

The forest cover affects the deep-seated stability of soil slopes in two ways: (1) through affecting the hydrologic regime in the soil mantle and (2) by mechanical reinforcement from its root system.

Actually, little information exists concerning the effect of clearcutting. However, Bishop and Stevens (1964) noted a significant increase in the frequency of slides in their study area after logging. Croft and Adams (1950) concluded that before modern day land use, landslides were rare, and possibly absent from their study area. Kittredge (1948) observed that in the coast ranges near San Francisco many slides occur in wet years on the heavily grazed, grassland-covered, clay soils, but that similar slides do not occur on the same soils in the eucalyptus plantations of more than 25 years old. Kawaguchi (1956, 1959) emphasizes the value of a well-rooted forest cover for minimizing landslides. Gray (1969) concluded that there was a definite relationship between clearcutting and mass soil failures and pointed out that "There has been no rational attempt to predict what will be the factor of safety of a natural slope against sliding before and after clearcutting." Gray is presently continuing his research in developing such a predictive tool.

Varnes (1958) grouped the variables affecting slope stability into (1) those tending to reduce shear strength and (2) those increasing shear stress. The following table (Table 4-3) shows the factors contributing to instability of earth slopes, according to Varnes.

Gray listed the possible ways vegetation might affect the balance of forces as follows:

1. <u>Mechanical reinforcement from the roots</u>: Indirect evidence reported in the literature suggests that this may be the most important effect of trees on slope stability. Presumably deep-rooted species of trees or woody shrubs whose roots penetrate through the soil mantle to bedrock would enhance stability the most. Conversely, removal of such a vegetal cover with subsequent rotting and deterioration of the roots would have the most serious consequences Root density studies as a function of depth have been reported in the literature (Gaiser, 1952; Patric <u>et al.</u>, 1965), but no studies have been reported which isolate the contribution to slope stability of various root systems.

TABLE 4-3

FACTORS CONTRIBUTING TO INSTABILITY OF EARTH SLOPES

(After Varnes, 1958)

Factors that Contribute to <u>High Shear Stress</u>

A. Removal of Lateral Support
   1. Erosion - bank cutting by streams and rivers
   2. Human agencies - cuts, canals, pits, etc.

B. Surcharge
   1. Natural agencies - wt of snow, ice and rainwater
   2. Human agencies - fills, buildings, etc.

C. Transitory Earth Stresses - earthquakes

D. Regional Tilting

E. Removal of Underlying Support
   1. Subaerial weathering - solutioning by ground water
   2. Subterranean erosion - piping
   3. Human agencies - mining

F. Lateral Pressures
   1. Water in vertical cracks
   2. Freezing water in cracks
   3. Swelling
   4. Root wedging

Factors that Contribute to <u>Low Shear Strength</u>

A. Initial State
   1. Composition - inherently weak materials
   2. Texture - loose soils, metastable grain structures
   3. Gross structure - faults, jointing, bedding planes, varving, etc.

B. Changes Due to Weathering and Other Physico-Chemical Reactions
   1. Frost action and thermal expansion
   2. Hydration of clay minerals
   3. Drying and cracking
   4. Leaching

C. Changes in Intergrannular Forces Due to Pore Water
   1. Buoyancy in saturated state
   2. Loss in capillary tension upon saturation
   3. Seepage pressure of percolating ground water

D. Changes in Structure
   1. Fissuring of preconsolidated clays due to release of lateral restraint
   2. Grain structure collapse upon disturbance

2. <u>Surcharge</u>: At first glance this would appear to increase shear stress, but the effect is largely negated by a concomitant increase in shear strength due to the confining effect of the surcharge. Furthermore, Bishop and Stevens (1964) estimate that the surcharge due to the weight of the forest (spruce and hemlock) amounts to only 50 psf. This is equivalent to a layer of soil only 6 inches thick. Although the surcharge will have little effect on the calculated factor of safety, it will affect creep rates to some extent as shown later.

3. <u>'Wind throwing' and 'root wedging'</u>: Strong winds blowing parallel to the slope will exert an overturning moment on the trees. This can lead to so-called wind throwing of trees which creates localized disturbances in the soil mantle. Wind throwing is a fairly common occurrence in some forests, but it normally affects only aged and diseased trees. The total down slope force created by a wind blowing through a forest and hence its overall effect on slope stability has never been evaluated. The effect of root wedging, an alleged tendency of roots to penetrate a soil, thereby loosening it up or opening cracks and fissures, likewise is presently unknown. Judging by evidence reported in the literature, particularly the observations by Bishop and Stevens (1964), the beneficial effects of root systems on slope stability far outweigh any possible adverse effects.

4. <u>Modification of soil moisture distribution and pore water pressure</u>: Trees transpire water through their leaves and this in turn depletes soil moisture. Hoover (1953) has measured the ability of a pine forest to deplete soil moisture to considerable depth and to reduce or eliminate the runoff from winter rains. Soil moisture depletion produces negative pore water pressure (or suction), which as seen previously is conducive to slope stability. A forest can also intercept moisture either in the crowns of trees or in the ground litter.

Gray developed three principal equations that can be used to determine the influence of a key variable, such as piezometric level on slope stability. These three equations concern (1) factor of safety of the slope, (2) allowable height of piezometric level, and (3) the maximum rate of planar depth creep.

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Gray concluded that as the piezometric level approaches the surface of the soil layer, the creep rate accelerates markedly.

Through calculating a factor of safety, Gray maintains it is possible to classify forested areas in terms of susceptibility to slope failure based on slope data and measurement. Gray concluded that by using "Ter-stepanian" equations we can (1) classify forested areas in terms of susceptibility to slope failure based on slope data and measurements of soil strength properties and average piezometric levels and (2) evaluate the probable effect of clearcutting on slope stability.

Swanston (1967) had good results in calculating the critical piezometric level in a drainage basin in Southeast Alaska.

Dyrness (1967) showed the relationship between the occurrence of mass movement events and certain site factors in the H. J. Andrews Experimental Forest.

The best means of preventing landslides, earth flows, slips, and other mass soil movements is through consideration of this aspect in the planning process and the avoidance of critical areas.

Channel erosion. The logging debris in the streams can divert stormflow from the channel to the road and/or the streambank, resulting in excessive erosion (Lull and Reinhart, 1963). Rice and Wallis (1962) reported that 13% of the 3,000 feet of stream channel measured showed severe logging disturbance. In most cases, bulldozers had scoured or filled the former channel.

Suspended Organic Material

Logging and related activities can introduce living and dead particles of plants into streams. The investigation in this area has been sparse. As mentioned earlier, organic sediments can degrade water quality by decreasing dissolved oxygen in the water and by releasing organic solutes by leaching.

Lammel (1973) described the natural debris accumulation in five small streams in western Oregon. He found that total residue increased after clearcut falling in all streams except the one with a wide (50 m) buffer strip. Residue volume increased from 1.2 to 3.3 times greater than before falling. But a prescribed method of felling can prevent debris accumulation in the streams (Burwell, 1971; McGreer, 1973).

Froehlich (1973) reported that logging, especially at the tree-falling stage, can produce large changes in debris loads. Directional falling with the tree-pulling system can reduce quantity of material reaching the channel to a very small amount. Buffer strips were found to be effective debris barriers even when they were not continuous or of large widths.

Meehan, et al. (1969) noted that the number of large pieces capable of jamming two Alaskan streams increased during four years of patchcutting. One watershed was about 20% logged and debris in the stream channel increased by 23%. About 25% of the area was logged in the second watershed and debris in the stream channel increased by 62%. Debris in an unlogged watershed nearby increased about 7% during the same period.

A major problem with debris in streams is that it forms debris jams. Failure of debris jam release vast quantities of water together with logs, rocks, and impounded sediment. This results in abrasion of the channel banks, exposing fresh surface to erosion, as well as scouring the stream channels. Sediment released by the failure is often distributed great distances downstream, filling pools and the gravel bed of streams.

Reforestation Effects on Suspended Sediments

The severely disturbed soils by logging recover very slowly. The average time required for soil structure to return to the undisturbed state was estimated to be from 9 to 18 years (Anderson, 1972; Hatchell, et al., 1970).

Tree planting on the areas recently clearcut and on eroded soils in forested areas has been an increasingly popular and effective practice to enhance water quality. The Tennessee Valley Authority (1962) reported that tree planting on the White Hollow and Pine Tree Branch Watersheds reduced 96% of sediment yield over a period of 20 years. Wark and Keller (1963) showed that a five-fold increase in forest cover produced an 18-fold reduction in sediment yield.

Ursic (1969) found that on two watersheds that were burned and planted to pine in northern Mississippi, the average sediment yield after 5 to 7 years was less than one-half of that during the years prior to planting when sediment was very high due to logging and burning. Ursic (1965) also found that establishing pine on actively eroding abandoned fields had in two decades reduced sedimentation to amounts probably not in excess of the geologic norm for undisturbed climax forests of northern Mississippi.

Effect of Sediment on Fish Resources

There are essentially two mechanisms by which sediment can affect reproduction via the "redd" environment--it affects the intragravel water flow or acts as a physical barrier to emergence. A small percentage increase of sediment less than 3.327 mm or 0.833 mm in a given stream could reduce the emergent fry survival and the reproductive capabilities of that stream considerably (Koski, 1972).

Chapman (1962) investigated the effects of logging upon fish resources in the West Coast. He found that when slash was not removed from a stream after logging, there was a 75% decrease in spawning salmon because of the migration barrier.

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Thermal Pollution

Stream temperature, as a water quality parameter modified by silvicultural practices, is of prime importance in modification of the aquatic ecosystems. Thermal pollution, especially in coastal Oregon has gained much attention, as the streams and rivers of this area provide a habitat to valuable anadromous and resident fish species. Temperature increases can have a profound influence on dissolved oxygen, disease, increased competition from undesirable species, and vitality. Even direct mortality can result from increased stream temperatures. Stream eutrophication is also associated with increased temperatures.

Daily temperature variation in undisturbed streams is approximately 2.2°C(4°F) or more. This value will increase to about 5.6°C(10°F) or higher when all shade along the stream has been removed. In instances where the natural stream temperatures are in the upper range of the fish requirements, the complete removal of streamside vegetation and exposure of the stream to direct solar radiation can raise temperatures above the tolerance limits of most salmonoids.

Logging Activities and Their Effects

Temperature change brought about by logging is directly proportional to the amount of exposure to solar radiation the stream surface experiences and the heat load applied to this surface area. However, the change of temperature is inversely proportional to the rate of flow (Brown, 1970). This can be expressed in the form:

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$$\Delta T = 0.000267 \frac{(A x H)}{D} \qquad (4.1)$$

where ΔT = predicted change in temperature

A = surface area in square feet of the stream exposed by clearcutting, excluding isolated pools

H = rate of heat absorbed by the stream in British Thermal Units

D = minimum discharge rate in cubic feet per second

0.000267 = the constant that converts discharge in cubic feet per second to pounds of water per minute

For a detailed description of the application of the method see Brown (1969).

Recent studies suggest that stream temperatures are most drastically altered during periods of low flow after removal of a high percentage of streamside vegetation. Therefore, any logging method or silvicultural activity that exposes a large area of the stream surface to sunlight can cause substantial changes in water temperature, especially during low flow periods.

As shown in Table 4-4, numerous studies have provided data to substantiate the inference that stream temperatures increase when streamside vegetation is removed. The amount of temperature increase is proportional to the factors cited above. It is clear that increased exposure to solar radiation caused by the removal of riparian vegetation is the major factor. However, it is noted that certain stream characteristics can mute the impact of incident radiation on temperature increases.

Table 4-4. Variation in Stream Temperatures Due to Removal of Streamside Vegetation

Treatment	Temperature Variations	Source	Remarks
1. Watershed of 850 acres with 25% clearcut in three patches, buffer strips used (50-100 ft. wide)	No significant change in stream temperatures	Brown & Krygier, 1970	Oregon Coastal Streams
2. 175-acre watershed, clearcut burned and no buffers	+14° F mean monthly maximum +28° F annual maximum	Brown & Krygier, 1970	0.01 cfs during low flow
3. Clearcut, no buffer	(57° to 85° F) significantly higher maximum stream temperatures in growing season, lower minimum in dormant	Eschnaer, 1963	Location West Virginia
4. Most riparian vegetation removed (due to flood scour)	+7° - 12° F mean monthly maximum	Levno & Rothacher, 1967	Oregon Cascades
Debris accumulated in stream and provided shade	+4° F mean monthly maximum	Levno & Rothacher, 1967	Oregon Cascades
Slash burning	+14° F mean monthly maximum	Levno & Rothacher, 1969	Oregon Cascades
5. Clearcut, no buffer	+9° F mean monthly maximum	Meehan et al., 1969	Southeast Alaska
6. Compared unshaded stream to shaded undisturbed forest stream	+9° to 20° F maximum on unshaded stream	Green, 1950	Coweeta Experimental Forest, North Carolina
7. Lower half of watershed clearcut	+7° F maximum increase	Patric, 1969	West Virginia

Table 4-4. Continued

Treatment	Temperature Variations	Source	Remarks
8. Complete removal of streamside vegetation on 70- and 23-acre watersheds	+12° F maximum increase (66° to 78° F)	Swift & Messer, 1971	Southern Appalachians
9. Various logging methods that left no riparian vegetation	Water temperature increased about 1.5° to 2.0° F per mile in unshaded areas compared to 0.5° F per mile in shaded areas	Fisk, 1966	California Redwood Forests
10. Removal of riparian and surrounding trees	Produced a marked rise in summer temperatures	Gray & Edington, 1969	
11. Clearcut, no buffer (175 acres)	+16° F (59° to 75° F) maximum increase	Hall, 1967	Oregon Coastal Streams
	Maximum diurnal fluctuations were 29° F before cutting	Hall, 1969	
12. Removal of riparian vegetation by fire	+10° F maximum increase	Helvey, 1972	North-Central Washington
13. Various logging methods	Increase in maximum temperature (stream temperature seldom exceeded 70° F because of cool climate of coastal fog belt)	Kopperdahl et al., 1971	Northern California Coastal Streams
Use of buffer and alternate cut and uncut blocks on stream	Temperatures remained normal		

Table 4-4. Continued

Treatment	Temperature Variations	Source	Remarks
14. Clearcut	+10.3° F maximum mean weekly difference; maximum stream temperature was 70.5° F. +9° F mean daily difference between control and cut areas	Likens et al., 1970	New Hampshire, White Mountains
15. Clearcut and burned, no buffer	+11° F (59° - 70° F) was difference between upstream timbered sections and downstream logged areas. Temperatures greater than 68° F lasted only a few hours each day.	Narver, 1972	Coastal Streams of Vancouver Island
16. Clearcut, no buffer	Notes that stream temperatures increase much more rapidly than in unlogged areas and maximum stream temperature was reached 2.5 hours after peak solar radiation.	Salo et al., 1973	Salmon Streams of Southeast Alaska

According to equation (4.1), the temperature change brought about by a specified quantity of heat is inversely proportional to the volume of water heated, i.e., the discharge of the stream. Therefore, streams with low discharge rates should heat faster and undergo a higher maximum change in temperature. Variation in the magnitude of temperature changes observed in several different studies is partially due to this factor.

The stream surfaoe area exposed to the sun by clear-cutting is another important factor which causes variation in the magnitude of temperature change. As mentioned earlier, temperature change and stream surface area exposed are directly proportional. Therefore, the temperature of a narrow, deep stream will not increase as rapidly nor to the same level as a wide, shallow stream of equal discharge rate. The latter is an important factor to consider when comparing and analyzing absolute temperature changes from various studies following logging.

One final consideration that can be a source of variation in results from study to study is the amount of heat absorption by the streambed. On small, clear streams a high percentage of the solar radiation incident on the stream will be transmitted to the bottom. Depending on the nature of the stream bottom, heat flow can be as high as 15 to 20% of the incident heat (Brown, 1969). Consequently, maximum temperatures will be lower and a lower duirnal fluctuation will be observed.

Also, the streambed will emit heat during the night, thereby reducing minimum nocturnal temperatures.

Water Temperature Manipulation

The preceding discussion suggests that thermal pollution of forest streams is basically the result of the absence of protection from direct solar energy. Therefore, any silvicultural activity that removes riparian vegetation will subject water temperatures to substantially higher radiation loads, depending on amount of increased exposure of the stream to solar energy. Other factors such as increased suspended sediment and debris accumulations can also produce changes in water temperature by altering the spectral properties and discharge of the stream. Accumulations of logging residuals in the stream will decrease the current and broaden the surface area. These conditions are likely to produce greater temperature increases also, since more surface area is present to absorb direct solar radiation for a longer period of time. However, conditions such as these usually don't create thermal pollution problems to the degree that the removal of riparian vegetation does.

Consequently, the primary concern of the land manager during any silvicultural operation is that of preventing thermal pollution of small streams by controlling streamside vegetation. The practices to be adopted depend on existing water quality standards and the nature of the aquatic ecosystem.

The use of buffer strips between the logged area and the stream has proven to be effective in preventing increases in

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water temperatures (Brown and Krygier, 1970; Brown, et al., 1971; Swift and Messer, 1971). Table 4-4 shows clearly that a buffer strip substantially reduces net radiation incident on the stream when compared to no protection at all. The effectiveness of buffer strips has been repeatedly shown by a number of studies (Brown and Krygier, 1970; Brown, et al., 1971; Swift and Messer, 1971). The global radiation is the amount received from above the vegetational cover. Global radiation minus reflection is the expected net radiation, i.e., the amount of energy the stream surface would receive if shade from trees was not available. The net radiation for Cedar Creek was recorded within an uncut block of timber. The net radiation for Little Rock Creek was recorded within a 50 to 80 foot wide buffer strip. Note that the strip was nearly as effective as the uncut block in attenuating the solar energy.

To be effective the buffer strip must prevent a significant change in the area of the stream which is exposed. The orientation of the stream is highly important. For example, if the stream flows in an east-west direction, a buffer strip on the north side would be ineffective in shading and controlling stream water temperatures.

The efficiency of a buffer strip is best estimated by measuring the angular canopy density rather than width or height of the streamside vegetation (Brazier and Brown, 1972). That portion of the canopy actually providing shade to the stream during the critical midday hours can be determined using a canopy mirror placed in the stream, pointed south and tilted to the complement of the zenith angle of the sun during the period of high thermal loading. Using this method, vegetation providing the actual shade can be left and the rest removed if desired.

Equation 1 can be used to obtain estimates on the limits of exposure of streams without imposing detrimental effects to valuable fish populations. Table 4-5 lists desirable temperature limits. Given a maximum temperature that can be tolerated, equation 1 can be rearranged to determine the maximum amount of stream area (A) that can be exposed.

Since small streams drain into larger tributaries, one must consider downstream impacts as well. The thermal effect of a tributary entering into a main stream can be estimated by the following equation:

$$\text{Adjusted temperature} = \frac{D_m\ T_m + D_t\ T_t}{D_m + D_t} \qquad (4.2)$$

where D is the discharge, T is temperature, and the subscripts m and t denote the temperature and discharges of the main stream and tributary. This equation weights the resultant temperature by discharge. A small tributary entering into a large mainstream will have a negligible effect on mainstream temperatures. However, if a large area is clearcut and the tributaries draining these areas all have high temperatures, their impact on the mainstream can be significant.

A heated stream is cooled as it continues downstream due both to the inflow of cooler tributary streams and the

Table 4-5. Optimum Temperatures for Fish Life

	Optimum Temperatures
Resident situations (trout)	
winter	42 - 58° F
summer	45 - 68° F
Migration routes (anadromous salmonoids)	45 - 60° F
Spawning areas (resident and anadromous salmonoids)	45 - 55° F
Rearing areas (resident and anadromous salmonoids)	50 - 60° F

presence of shade as it passes through protected areas. The shade does not cool water in streams, rather, it reduces variations in stream temperatures (EPA #430, 1973).

It should be pointed out that in cases where riparian vegetation has been removed completely and stream temperatures increased significantly, maximum temperatures will drop as the area revegetates and shade is again provided. In some cases stream temperatures have nearly returned to those of pre-logging levels within three or four years.

Thermal pollution of streams by silvicultural activities can be controlled, if the forester carefully plans various operations with emphasis on maintaining streamside vegetation to control temperature fluctuations within a predetermined range. The amount of shade and the logging technique, of course, will vary with each stream. By using the above relationships water quality can be preserved during and after removal of the timber.

Solar loading has been identified as the most important factor in increasing the temperature of streams. Maintenance of buffer strips in a relatively undisturbed fashion has been suggested and demonstrated as a solution on research watersheds. Coastal Alaska has identified potential decreases in water temperature by increased radiation loss as an important aspect of buffer strip removal. Cold conditions allow the development of increased amounts of anchor-ice which physically damage eggs while they are in the gravel through freezing. If forest canopy removal increases the insulation

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value of a snowpack over a stream, then removal of the buffer strip maintains higher water temperatures. Portions of the western Olympics and southeast Alaska would benefit from increased low temperatures as many of the smaller headwater streams are below optimum temperature. Increasing average low temperatures without detrimental effect on maximum temperatures is a complex problem.

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Chemical Pollution

This discussion of organic and chemical "pollutants" from logging activities is divided into two sections: (1) dissolved inorganic materials including both minerals and oxygen and (2) dissolved organic materials from forest debris, i.e., leaves, bark, logs, etc. that accumulated due to logging, and the storage and rafting of logs in lakes and rivers as well as saltwater lays and estuaries. These constituents, of course, occur naturally in streams. However, they are regarded as "pollutants" when concentrated to abnormally high levels due to the activities of man on forested watersheds.

Alteration of the aquatic ecosystem by the production of algae blooms is oftentimes considered to be the major undesirable effect of chemical pollutants. Changes in color, odor, and taste are also frequently cited as undesirable effects. Dissolved oxygen deficits often occur due to the death and decay of the algae which removes oxygen from the water by aerobic decomposition. All of these can be toxic to fish and other aquatic organisms. Under some circumstances, particularly where the stream is municipal water source, effects on potability must be considered.

Research on this subject has been relatively sparse. The literature indicates that the impact of logging activities through chemical pollutants varies greatly from one area to another, depending on various factors such as soil type, vegetation recovery rate, mode of precipitation, to name only a few.

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During the past few years the quality of water, especially in small streams from forested watersheds, has been under more intense investigation. The influence of water quality on native and anadromous fish population is of particular concern. The streams of the coastal regions of Oregon and Washington, which are important rearing areas for these fish, are supplied by water from forests subjected to several impacts of forest management practices. The result of these activities can and often does produce changes in the chemistry of dissolved water. The harvesting of timber generally accelerates the addition of both dissolved inorganic and organic substances into the stream. The effect of these materials which result from logging activities is at present not entirely clear.

Effects of Logging Activities

Disturbance of the forest, whether by man or by natural disasters, tends to produce similar results--a disruption in the nutrient cycle. Since water is the primary transporter of these dissolved constituents, variations in concentrations in streams will result from all forms of disturbance. The trees, once removed, no longer take up nutrients. Logging residue increases the quantity of forest litter. Also, removal of the forest canopy produces drastic changes in the microclimate. The temperature and moisture content of the soil increases, thereby promoting increase in the activity of microorganisms that decompose forest litter. The level of anions necessary for the leaching of cations from the disturbed watershed is raised as a result of this sequence of events. Increases in dissolved organic material in streams can also result from an accumulation of logging debris in the stream itself.

Dissolved inorganic constituents.

Minerals (nutrients). The level of concentration of nutrients in streams draining watersheds which have been cut and/or burned is dependent on several factors including soil type, forest type, climate, and method of treatment (see Table 4-6).

Brown (1972) explains that:

> Soil characteristics, such as porosity and texture determine the pathway and rate of water movement in or over soil, soil erodibility, and how strongly nutrients will be held within the soil matrix. Vegetation characteristics, such as species composition, influence the rate of nutrient uptake. The revegetation rate influences the rapidity with which recycling begins after system disruption. The form, chemistry, amount, and intensity of precipitation influence the leaching rate.

Table 4-6 describes how concentrations of nutrients vary with different treatments and site conditions. Studies at the Hubbard Brook Experimental Forest, of which there were two (Pierce, et al., 1972; Likens, et al., 1970), showed relatively large increases in most cations following treatment. In the first study a herbicide was applied after the vegetation had been cut and left. In a second study commercially valuable timber was removed after clearcutting. Both studies showed increased concentrations of the nitrate anion and of several cations. The latter study, in which the logs were

Table 4-6. Forestry Practice Impacts on Dissolved Inorganic Materials

Treatment	Variations in Concentration Maximums (mg/l)				Source	Remarks
1. Clearcut (12 ha) (29.7 acres)		Before Clearcut	After Clearcut (1 year)		Pierce et al., 1972	Conducted in the White Mountains of New Hampshire. Shallow, infertile, podzolized soils, 20% slope, south facing cut in 1970.
	NO_3^-	2.0	23.0			
	Ca^{++}	1.5	3.0			
	Mg^{++}	0.4	0.8			
	K^+	0.3	1.2			
	Na^+	1.3	1.3			
	$SO_4^=$	7.0	6.0			
	NH_4^+	0.3	0.7			
	Cl	0.7	0.9			
2. Clearcut	Average Maximum Concentrations (mg/l) April-November, 1971, for 7 Clearcut Watersheds				Pierce et al., 1972	Same conditions as above except slope and aspect. These watersheds were cut in 1968, 1969, and 1970.
		After Clearcut	Control			
	NO_3^-	2.9	16.7			
	Ca^{++}	2.7	5.3			
3. Clearcut and left (nothing removed)	Maximum Concentrations (mg/l)				Liken et al., 1970	Same locations as above. Cut in 1965 (Oct-Nov). No logging or roads. Herbicide applied.
		Before Clearcut	After Clearcut	Control (uncut)		
	NO_3^-	1.0	90.0	4.0		
	Ca^{++}	2.5	12.0	1.8		
	Mg^{++}	0.4	2.0	0.4		
	K^+	0.5	4.2	0.3		
	Na^+	1.6	2.7	1.1		
	$SO_4^=$	7.8	5.2	8.0		
	Cl^-	0.8	1.4	1.0		
	SiO_2	5.5	7.6	7.5		
	Al	0.2	3.2	0.3		

Table 4-6. Continued

<table>
<tr><th>Treatment</th><th>Variations in Concentration (mg/l)</th><th>Source</th><th>Remarks</th></tr>
<tr><td>4. Clearcut and slash burning</td><td>
<table>
<tr><th></th><th>Maximum (after cutting and burning)</th><th colspan="2">12-Day Average</th></tr>
<tr><th></th><th></th><th>Clearcut</th><th>Control</th></tr>
<tr><td>NO_3^-</td><td>0.60</td><td>0.43</td><td>0.01</td></tr>
<tr><td>Ca^{++}</td><td>31.0</td><td>17.0</td><td>4.1</td></tr>
<tr><td>Mg^{++}</td><td>10.8</td><td>6.4</td><td>1.3</td></tr>
<tr><td>K^+</td><td>4.4</td><td>1.89</td><td>0.49</td></tr>
<tr><td>Na^+</td><td>6.7</td><td>4.90</td><td>3.0</td></tr>
<tr><td>PO_4</td><td>0.13</td><td>0.05</td><td>0.05</td></tr>
<tr><td>HCO_3</td><td>21.6</td><td>15.8</td><td>4.11</td></tr>
<tr><td>NH_3</td><td>7.6</td><td>1.19</td><td>*</td></tr>
<tr><td>Fe</td><td>0.04</td><td>*</td><td>*</td></tr>
<tr><td>Mn</td><td>0.44</td><td>0.11</td><td>*</td></tr>
</table>
*Below level of detection</td><td>Fredriksen, 1971</td><td>Old growth Douglas-fir stands in Oregon's Cascade Range. Soils range from shallow and stony to moderately deep, well-developed profiles. The three most prominent soils average about 380 cm in depth and vary in texture from loam to clay loam.</td></tr>
<tr><td>Clearcut with rainstorms</td><td>
<table>
<tr><th colspan="2">Annual Net Losses</th></tr>
<tr><td>Ca^{++}</td><td>47 kg/ha</td></tr>
<tr><td>Na^+</td><td>28 kg/ha</td></tr>
<tr><td>Mg^{++}</td><td>11 kg/ha</td></tr>
<tr><td>K^+</td><td>1.5 kg/ha</td></tr>
</table></td><td>Fredriksen, 1972</td><td>Annual loss of nutrient is dominated by winter rainstorms arising from the Pacific Ocean through Douglas-fir ecosystem.</td></tr>
<tr><td>5. Clearcut of 25% in 3 small patches (buffer strips of alder left)

Clearcut and burned</td><td>
<table>
<tr><th></th><th colspan="3">Maximum</th></tr>
<tr><th></th><th>Before Cutting</th><th>After Cutting</th><th>Control</th></tr>
<tr><td>NO_3^-</td><td>3.20</td><td>2.96</td><td>2.82</td></tr>
<tr><td>NO_3^-</td><td>0.75</td><td>2.10</td><td>-</td></tr>
</table>
Other elements showed no increase or increased only slightly after treatment.</td><td>Alsea Watershed Study (Brown, 1972)</td><td>The control and the 25% clearcut watersheds were covered with Douglas-fir and alder in equal proportions with alder on the streamside sites. The tota clearcut and burned watershed was predominantly Douglas-fir. The study area was in the Oregon Coast Range.</td></tr>
</table>

able 4-6. Continued

<table>
<tr><th>reatment</th><th>Maximum Concentrations (PPM) in Overland Flow</th><th>Source</th><th>Remarks</th></tr>
<tr><td>. Clearcut and burned</td><td><table>
<tr><th></th><th>1 yr after treatment</th><th>Control</th><th>2 yr after treatment</th><th>Control</th></tr>
<tr><td>P</td><td>58</td><td>10</td><td>4</td><td>6</td></tr>
<tr><td>Mg</td><td>9</td><td>0.6</td><td>1</td><td>0.3</td></tr>
<tr><td>Ca</td><td>13.5</td><td>7.5</td><td>6</td><td>6</td></tr>
</table></td><td>DeByle and Packer, 1972</td><td>This study was done in the larch and Douglas-fir forest types. The concentrations recorded were of overland flow and not taken directly from streams.</td></tr>
<tr><td>'. Clearcut</td><td><table>
<tr><th></th><th colspan="2">PPM</th></tr>
<tr><th></th><th>Maximum</th><th>Average Range</th></tr>
<tr><td>NO_3</td><td>6.4</td><td>1.3 to 4.5</td></tr>
</table>
The effect on other nutrients was negligible.</td><td>Reinhart, 1973</td><td>Study area in White Mountains of New Hampshire. Podzol soils with large accumulation of organic matter on surface and mineral horizons generally low in available nutrients and low ability to retain nutrients.</td></tr>
<tr><td>3. Clearcut</td><td>Measured elemental movement in soil water and concluded that "total elemental movement, as measured by N, K, Ca, increased slightly from both the forest floor and 36 in. depth. In all cases, the amount is less than 1% of the total element in the soil system moved below 36 in. The increase in release of elements was greatest immediately after clearcutting, after which the release of elements in the drainage water was equal to or less than the original level. In all cases, elemental movement was greatest at the beginning of the wet season in September and October. Because of the increased amounts of water passing through the soil after clearcutting, the actual elemental composition of the drainage water was lower."</td><td>Gessel and Cole, 1965</td><td>Study area is the Cedar River watershed which is a source of the Seattle City water supply.</td></tr>
</table>

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Table 4-6. Continued

Treatment	Variations in Water Quality	Source	Remarks
9. Wildfire	No specific effect of fire on the ionic composition of the stream. It was postulated that ash constiuents were dissolved by light rainfall and leached into the permeable forest soil before the first snow. Because of the acidic nature of the soil, the dissolved cations were absorbed on the exchange complex rather than washed directly into the stream.	Johnson and Needham, 1966	The study was made in California on a mountainous area of an altitude of 5,000 feet on well drained soils of andesite and andesite breccia parent material.
.0. Logging and road construction	No abnormal concentrations of dissolved oxygen, alkalinity hardness, dissolved solids, phosphate, chloride, sulfate, nitrate, tannin and lignin, or pH were detected. Carbon dioxide was low in most streams, except in one where it reached 8 ppm during decomposition of logging debris in the summer of 1968.	Kopperdahl et al., 1971	Water quality was monitored in six coastal streams in northern California. Four were subjected to logging (method not described) and two were controls.
.1. Clearcutting	The net losses of Ca^{++}, Mg^{++}, Na^{+}, and K^{+} were 9, 8, 3 and 20 times greater, respectively than similar losses from undisturbed.	Bormann et al., 1968	Determine the effects of removal of vegetation on nutrient yields.

removed and the site was allowed to revegetate, showed less drastic increases in ion concentrations. This change was attributed to the revegetation of the site which tends to minimize nutrient losses and thus promote "a return to steady-state cycling characteristic of a mature forest" (Marks and Bororan, 1972). The shading of the forest floor by the new vegetation reduces surface temperatures and the rate of decomposition of organic matter.

From Table 4-6 it can be seen that in almost all cases most nutrients exhibited increased concentrations following harvesting on the watershed. In the majority of cases, the increase was small and declined rapidly as the watershed was revegetated.

In summary, nutrient concentrations following logging are a result of several characteristics that describe a watershed, i.e., soil, vegetation, and climate. Vegetation characteristics, such as species composition, influence the rate of nutrient uptake. The rate of revegetation influences the rapidity with which recycling begins after watershed disturbance. Several characteristics of the soil such as porosity and texture, determine the pathway and the rate of water movement in or over soil. These same characteristics also influence soil erodibility and the tenacity with which the nutrients are held within the soil matrix. The form, chemistry, amount, and intensity of precipitation influences the rate of leaching.

Dissolved oxygen. The character and productivity of aquatic ecosystems in small, forested streams is significantly influenced by the concentration of dissolved oxygen (D.O.). Fish and other aquatic organisms depend on oxygen for survival, growth, and development. Various forestry practices change the D.O. concentration in small streams, either directly or indirectly. Changes in stream temperature brought about by the removal of streamside vegetation, increases in nutrient concentrations as a result of harvesting, and the accumulation of logging debris in the stream are some of the more important practices which effect D.O. concentration.

Dissolved oxygen in a stream is a function of the water temperature. Churchill et al, (1962) have reported an empirical equation for calculating the temperature effect on dissolved oxygen:

$$S = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3$$

Where: S = the solubility of oxygen, mg/l

And: T = temperature, °C

Channel characteristics, such as slope, roughness, and cross-section, which controls the rate of oxygen exchange between water and air, also have a significant effect on D.O. concentrations.

Aquatic microorganisms utilize organic materials in the stream as a source of energy and thereby modify oxygen content. The organic material is often described as the biochemical oxygen demand (BOD). BOD represents the amount of oxygen required by microorganisms for decomposing organic materials in the stream.

Forestry practices can influence the amount of oxygen in streams in several ways. Removing vegetation that shades the stream will increase the water temperature and lower the D.O. The accumulation of logging debris in streams influences oxygen levels in two ways: (1) Needles, small branches, bark, etc. which contain organic substances are rapidly leached into the stream and consumed by the microorganisms. These materials have a very high BOD. (2) The restriction of water by debris dams reduces aeration. This ponding effect increases stream surface area and accentuates temperature increases.

The increased concentrations of nutrients leached from the forest floor can also cause oxygen deficits indirectly. Stream eutrophication can result from an increased concentration of nutrients. Subsequently, when the stream flora dies, large amounts of oxygen can be consumed in the decay process.

Unfortunately, a minimum of research results are available in this domain. A study by Hall and Lantz (1969) showed that in one short reach of a stream containing an accumulation of debris, D.O. levels dropped to less than 1.0 ppm. On a nearby watershed that was not logged, D.O. levels were at the saturation level of about 10 ppm. After stream cleaning and the removal of debris from the channel by fall rains, surface waters returned to saturation levels of oxygen.

Slack and Feltz (1968) have reported the effect of leaf fall on water quality changes in a small Virginia stream. Oxygen concentration dropped from 8 to less than 1 mg/l when leaf fall rate increased from 2 to 2g/m^2 day $^{-1}$. After natural flushing by a storm the D.O. climbed to a level greater than 11 mg/l.

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A recent study by Ponce (1974) includes data describing the potential for oxygen extraction by decomposition of finely divided logging debris and slash typical of that found in the Pacific Northwest. This data on oxygen depletion might prove to be useful in developing a *predictive model* for water quality management on forested lands.

The storage of logs in water produces leachates with a significant quantity of BOD substances. Atkinson (1971) found that the highest BOD, 1.36/ft.^{2} of submerged surface area, was exerted by leachates from ponderosa pine stored with the bark removed. The study also included Douglas fir and western hemlock.

Narver (1970) found that the introduction of logging debris particularly leaves, small branches and bark into a stream can result in a change in the D.O. content of the water. He also noted that soluable organic substances such as woodsugars, leached from logs, exerts a considerable C.O.D. (chemical oxygen demand). Further, rate of leaching did not decline over a period of 80 days.

Dissolved organic constituents. It is now recognized that the presence of logging slash in streams, as well as the storage of logs in water, can result in the introduction of leachates in the water. Some of these leachates are toxic to fish and other aquatic organisms. The taste, color, and odor of the water can also be degraded due to high concentrations of organic solutes. Nevertheless, relatively few studies are available which report measurements of organic solutes in water resulting from forestry practices.

Atkinson (1971) points out that test results show that leachates removed from Douglas fir logs stored in fresh water possess a slight acute toxicity to fish. A TLm_{96} of 20% leachate by volume, for a 50-year-old Douglas fir log, was the most toxic leachate observed. Leachates from ponderosa pine, hemlock, and older Douglas fir logs stored under identical conditions produced no measurable acute toxicity.

Buchanan (1971) tested the toxicity of spruce bark, hemlock bark, and barite ore to Dungeness crab and shrimp larvae. He found that spruce bark had the highest toxicity of the three materials tested. When cessation of swimming was used as a criterion of toxic effect, the 24-hour Ec_{50} levels were 53 and 210 mg/l for shrimp and crab larvae, respectively, and the 48-hour Ec_{50}'s were 45 and 190 mg/l, respectively. Hemlock bark proved to be the least toxic.

Buchanan and Tate (1973) also tested the acute toxicity of sitka spruce and western hemlock bark to pink salmon fry, adults and larvae of pink shrimp, and the larvae of Dungeness crab. Using death as the criterion, the 96-hour Ec_{50} for spruce bark leachates to salmon fry was 100 to 120 mg/l. The 96-hour Ec_{50}'s for hemlock using death was 56 mg/l. Although hemlock had little effect on the invertebrates tested, spruce bark leachates were consistently toxic to both vertebrates and invertebrates. Using death again, the 96-hour Ec_{50}'s for spruce bark leachates to larval shrimp, adult shrimp, and larval crabs were 415, 205 and 530 mg/l, respectively. The 96-hour Ec_{50}'s using loss of swimming for larval shrimp and larval crabs were 155 and 255 mg/1, respectively. For shrimp larvae, spruce bark particles were found to be 2 to 6 times more toxic than leachates.

A study by Graham (1970) on the quantity and properties of substances leached from logs floating in water, and the rate of leaching of these substances reports that ponderosa pine logs contributed measurably greater quantities of soluble organic materials and color-producing substances than Douglas-fir logs. Leaching rate appeared to be affected by the concentration of soluble organic materials in the stagnant holding water. However, experiments showed that in flowing water the leaching rate was nearly constant. Extrapolation of laboratory test data to field conditions resulted in a prediction that 800 pounds of COD per day would be contributed by approximately 8 million board feet of floating logs to a typical log storage facility.

Narver (1970) believes that soluble organic materials such as woodsugars, tannins, and lignin-like substances leached from logs can produce a considerable COD along with yellow and brown colors in water.

A recent study by Ponce (1974) to determine the BOD of finely divided logging debris in stream water resulted in an indirect measure of soluble organic leachates. He also determined the toxicity of the leachates on guppies and steelhead trout fry. The concentration of material needed to produce toxic effects was so high that oxygen depletion probably would be responsible for death long before the leachate had effect.

Schaumburg (1970) proposes that large accumulations of logging debris in a small sluggish stream could result in toxic concentrations of log leachates.

PLANNING AND CONTROL

Previous sections of this report have outlined subregions of Region X, described the forest practices utilized in the Region and presented research summaries concerning the impacts of such forest practices on water quality. This section presents a summary of planning and control methods which represent the state-of-the-art for preventing water pollution from logging, residue management and reforestation. The purpose of this study was not to develop new methods but to summarize existing technology.

Most of the information in this section has been excerpted from the literature concerning water quality and forest management. Only the information relating logging, residue management and reforestation to water quality protection, and to some degree fisheries, is presented. In some cases, the total context of the original paper may be obscure; however, the meaning and significance of the water quality portions of such information have been preserved. A small percentage of this section, by necessity, results from the objective synthesization of available information for the specific purposes of this report.

Timber harvest has certain features that relate to water quality protection, as follows:

- o the activity is areally dispersed and distributed over time
- o physical, biological and chemical factors vary

considerably from site to site and from sub-region to sub-region, resulting in widely varying water pollution potentials

- levels and types of management quality control cover a wide range within the region
- the knowledge and field testing of methods for reducing water quality impacts vary significantly within the four-state study area
- the values and uses of similar water bodies differ from one sub-region to another

For these reasons, water quality improvement technology for timber management activities is distinguished from point source control technology. Industrial, municipal and other point source effluents can generally be adequately improved through a more specific, narrower range of alternative methods than pollutant discharges from nonpoint sources. These basic differences result in a much greater potential for improving the quality of runoff from timber harvest areas through site-specific, interdisciplinary planning than for point source discharges. Certain standard requirements for timber harvesting can be beneficial for water quality purposes, but the greatest potential benefit appears to involve site-specific planning. This section of the report includes sub-sections on planning and control.

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Planning

Planning is the process of analyzing and evaluating potential future actions and their implications, followed by the selection of a plan that can best realize multiple goals. These goals should be determined early in the process, but after some of the base data and site conditions are understood. Planning is best summarized as the process of forethought and strategy selection. It must be followed by implementation, meaning the transformation of the plan into action programs, projects and performance criteria. Figure 5-1 illustrates a basic planning methodology.

Basic Methodology

Water quality planning on forest lands should be integrated into a comprehensive forest land use planning effort and not treated as a separate process. The team of planners responsible for such planning on forest lands should be interdisciplinary and include the following types of backgrounds:

- aquatic biology and water quality
- forestry
- soils/geology
- hydrology and geohydrology
- fisheries and wildlife
- engineering
- economics

In addition, the planning team should include representation by the pertinent federal, state and local agencies

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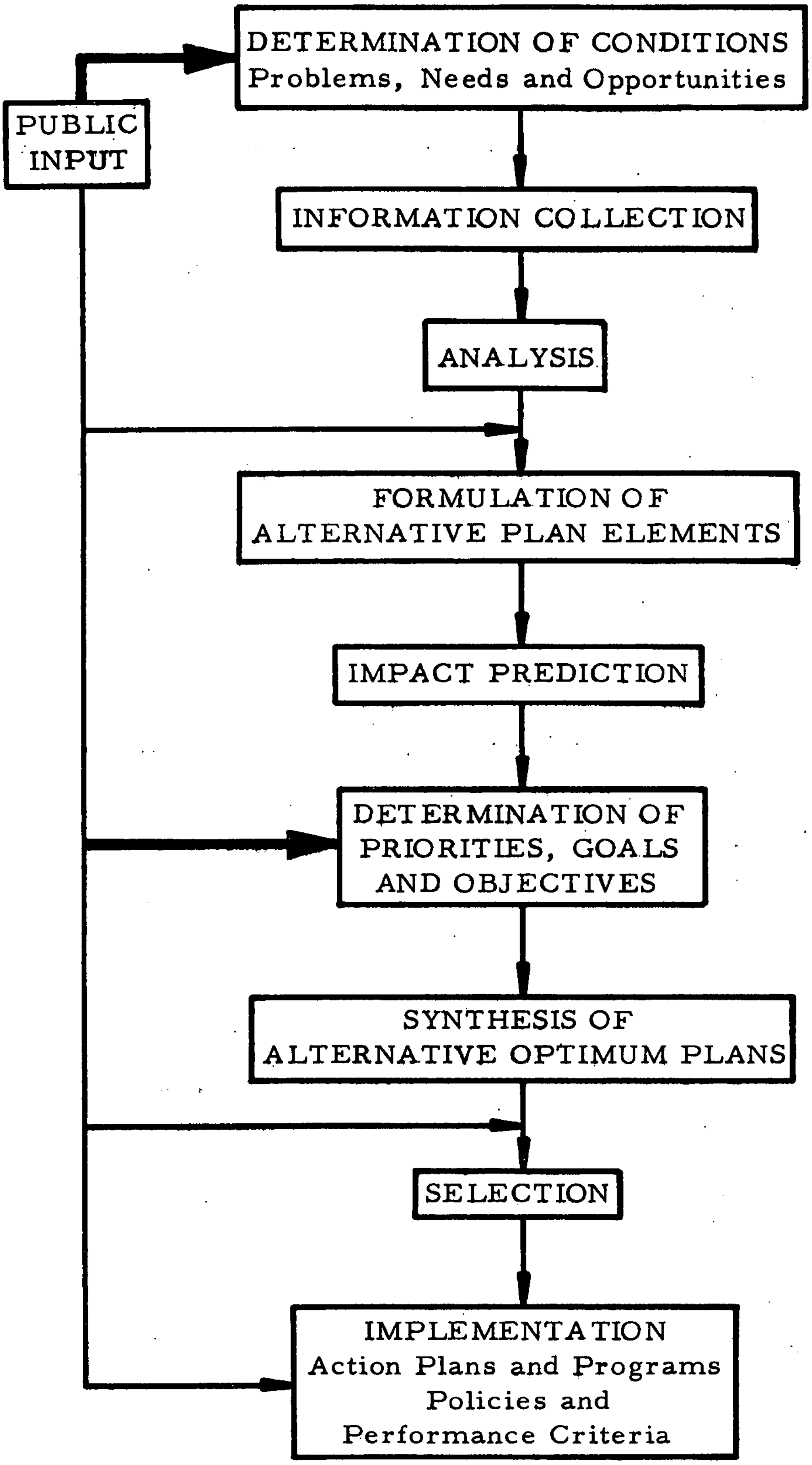

FIGURE 5-1. BASIC PLANNING METHODOLOGY

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such as fish and wildlife, planning and environmental agencies. For nonpublic lands, formal interagency planning teams may not be feasible. However, the interdisciplinary nature of the effort is still important, and early involvement of state, federal and local regulatory agencies can save time in the long run.

The planning methodology depicted in Figure 5-1 should not be interpreted to imply that all elements of forest land planning must proceed simultaneously through this procedural logic. The basic data required for decision-making in certain planning areas may be adequate much earlier than in other areas, and the needs more critical. Most importantly, some types of early decisions do not preclude other important planning options. Once the information base is adequate for these limited-committal decisions, it may be acceptable, and often desirable, to initiate limited action early in the process, provided that proper plan selection procedures are followed. For example, it may be desirable to revegetate the critical slope areas within a previously logged watershed before finalization of a comprehensive land use plan due to a) critical water quality needs for early revegetation, b) program scheduling needs and early availability of manpower and/or funds, and c) the non-preclusion of other management options. The following criteria should be satisfied in order for such early decisions to be advisable:

- other important management/planning options are not precluded,

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- o the information base is adequate for the type of decision contemplated, and
- o delayed action would result in adverse effects on the basic physical resources involved.

An important additional consideration affecting the desirability of such early decision-making would be the availability of financial or manpower resources now that might not be available at the time of plan finalization.

The planning process must be a continuing program, not only to direct land mangement in new geographic areas, but to refine, revise or expand previously made planning decisions in response to new or feedback information. The success of planning and implementation programs should be monitored and evaluated continually. As such information is fed back into the ongoing planning process, existing land use plans may require revision to provide for greater efficiency and effectiveness.

The following discussion follows the methodology presented in Figure 5-1:

Basic information. The first phases of a forest land use planning process should involve a) a determination of the conditions which will constrain the planning, and b) collection and analysis of the information and data pertinent to the study. Certain types of information required for the planning will be available, but additional data may be necessary. In general, the type of forest land information required for water quality planning includes:

1. soils
2. geologic
3. hydrologic and geohydrologic
4. tree species, forest types and stand densities
5. water quality (background and existing levels)
6. topographic
7. meteorologic
8. erosion rates and sediment yields
9. aquatic and/or marine biology

There are numerous potential sources of such information which are outlined later in this section. For most studies, however, many of the information needs will require collecting or assembly specifically for the planning study.

A preliminary overview of the study area's intrinsic physical/environmental, social and economic qualities is needed to determine the problems, needs and opportunities requiring emphasis. Public involvement is advisable during this phase, which in effect is the first attempt to set study goals. General information requirements are defined and the method and scope to be used are determined.

Alternative plan elements. During this phase, the planning study is divided into logically separable elements (e.g., logging method selection), analyzed, and the impact and implications predicted. Such impact prediction should include environmental, social, economic and financial analyses. All such elements and their impacts are interrelated, necesitating a reiterative type of analysis where the effects of one alternative and its mitigation measures are taken into consideration in the analysis of other elements. The number of interrelationships requiring separate analysis, however, can usually be minimized to allow a reasonably simplified analysis procedure. Where this is impossible, computer models, particularly for impact prediction, are available and are discussed later in this section.

Priorities, goals and objectives. One of the most important planning phases involves the determination of all the implicit and explicit goals, objectives and priorities of the study. These study "directives" must be understood by the planning team and interested parties external to the planning effort, particularly the public if the land involved is public, if public agency approval is required, or if public resources are affected.

For water quality planning, recent national goals and objectives have been established by Congress through the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500). In addition, all states have enacted legislation that defines water quality goals which should be included in forest land use planning. Additional goals have been set through laws and regulations specific to federal or state forest resource agencies. Many local land use agencies have also formally expressed water quality goals, and more local water quality requirements are likely through the implementation of the local/areawide planning section of P.L. 92-500 (Section 208). These local water quality requirements

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are generally embodied in local ordinances which are legally binding on private, state and federal lands (P.L. 92-500, Section 313).

Goals, and the more specific objectives, should be outlined for each land unit according to its characteristics and values in addition to the goals mandated by federal, state and local laws. Throughout the planning process, choices and tradeoffs will be made according to value judgements by the planning team. The "priorities" for choosing one alternative over another should be explicit and formulated early in the process.

Synthesis. Once the potential elements of the final plan and the implications are understood, alternative plans can be synthesized. Such alternatives should represent a range of optimum methods to achieve various, possibly conflicting goals. Examples of such goals include resource conservation, regional development, national economic stability, private economics and environmental quality.

Selection. Once the alternative plans are examined, a selection can be made. The final plan may be one of the alternatives examined, or a combination of parts of various plans. The examination of alternatives can serve to stimulate thinking on entirely new approaches. At this point in the process, external parties, particularly the public on public land, should be aware of the process and choices being made.

Implementation. Planning is no more than the means to an end -- the initiation of efficient, effective programs and policies. Plan implementation can involve, for example, broad or specific policies for guiding forest management decisions, action plans such as a watershed rehabilitation plan, financial or funding programs, and performance criteria by which to judge the logging methods used within the project area.

Public involvement. Informing the interested public throughout the planning effort and encouraging their comments and involvement is beneficial, and for public lands, necessary. In this way, individuals are given the opportunity to express their values and concerns and the planning process is strenthened through early exposure to criticism and a broad spectrum of information.

Information Requirements

Planning information requirements vary according to the specific use anticipated, and these types of data can be categorized as for:

1. forest-land water quality planning per se,
2. predicting effects, and
3. monitoring impacts.

Forest-land water quality planning. Federal agencies such as the U. S. Forest Service have compiled a considerable amount of information relating to forest lands within their jurisdictions. Such agencies also have expertise available to generate additional information for planning purposes if necessary. On state or private lands this is not always the case. For such lands, the following outline of possible information sources is presented:

1. Soils
   a. U. S. Soil Conservation Service
   b. County agricultural extension agents
   c. Adjoining land owners (i.e., private, USFS, BLM)
   d. Local land use agencies
   e. Independent surveys for the plan being studied
2. Geologic
   a. U. S. Geologic Survey
   b. State mining or geologic agencies
   c. Universities
   d. Adjoining land owners (i.e., private, USFS, BLM)
   e. Independent surveys for the plan being studied
3. Hydrologic and geohydrologic
   a. U. S. Geologic Survey
   b. State water agencies
   c. Universities
   d. Water user organizations
   e. Independent monitoring for the plan being studied
4. Tree species, forest types and stand densities
   a. State forest resource agencies
   b. Universities
   c. County extension agents
   d. Adjoining land owners (i.e., private, USFS, BLM)
   e. Independent surveys for the plan being studied
5. Water quality

   a. U. S. Geologic Survey
   b. U. S. Environmental Protection Agency
   c. State environmental agencies
   d. State water agencies
   e. Universities
   f. Independent monitoring for the plan being studied

6. Topographic
   a. U. S. Geologic Survey
   b. Adjoining land owners (i.e., private, USFS, BLM)
   c. Local land use agencies
   d. Private mapping and aerial photography companies
   e. Agricultural Stabilization and Conservation Offices (USDA)
   f. Independent mapping for the plan being studied

7. Meteorologic
   a. National Weather Service (U. S. Department of Commerce)
   b. Universities
   c. County agricultural extension agents
   d. Independent monitoring for the plan being studied

8. Erosion rates and sediment yields
   a. U. S. Soil Conservation Service
   b. U. S. Geologic Survey
   c. Local land use agencies
   d. County agricultural extension agents
   e. Universities
   f. Adjoining land owners (i.e., private, USFS, BLM)

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g. Independent study for the plan being studied

One important requirement for forest land planning is an inventory of the land systems involved. Wertz and Arnold (1972) have outlined the requirements for such a land system inventory, which is presented as Figure 5-2.

In addition, the "System Outline" for the land base portion of an integrated environmental inventory as proposed by Wertz and Arnold is presented as Figure 5-3.

Certain basic hydrological and meteorological information is needed for forest land planning as follows:

1. Annual hydrographs for key locations for at least three to five years
2. Peak flow hydrographs for major flood flows for at least five years
3. Stream order definitions
4. Precipitation, including snow, preferably as isohyetal maps (annual average yield, maximum precipitation)
5. Critical event precipitation patterns
6. Erosion rates and sediment yields

In areas where streams or lakes present important forest values or may be affected by forest activities, limnological and stream habitat information is required. Base aquatic habitat information involves a minimum of one-year data collection prior to the planned watershed disturbance.

The U. S. Forest Service Northern Region has prepared a publication concerning lakes entitled "Lake Habitat Survey"

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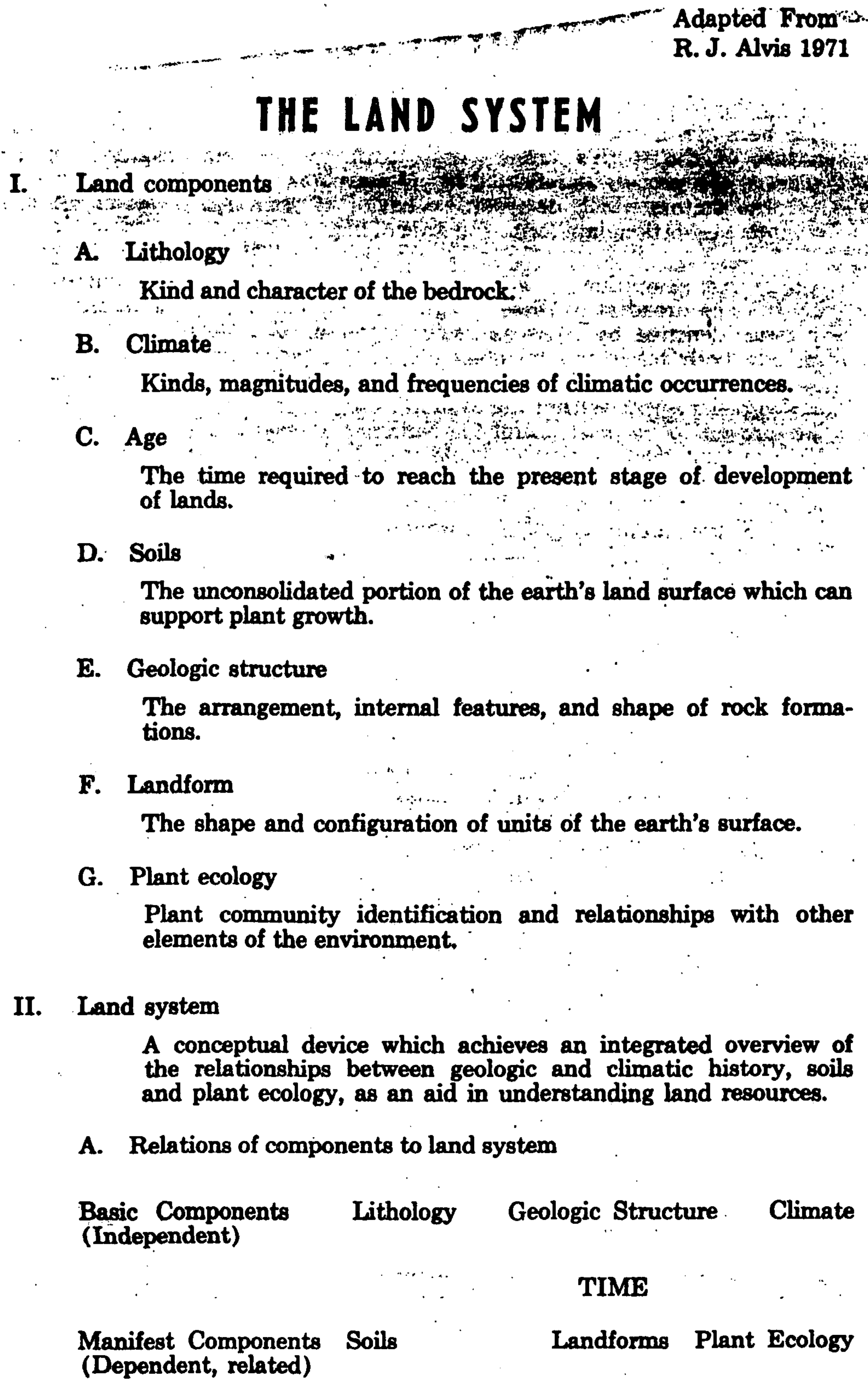

Adapted From
R. J. Alvis 1971

THE LAND SYSTEM

I. Land components

A. Lithology

Kind and character of the bedrock.

B. Climate

Kinds, magnitudes, and frequencies of climatic occurrences.

C. Age

The time required to reach the present stage of development of lands.

D. Soils

The unconsolidated portion of the earth's land surface which can support plant growth.

E. Geologic structure

The arrangement, internal features, and shape of rock formations.

F. Landform

The shape and configuration of units of the earth's surface.

G. Plant ecology

Plant community identification and relationships with other elements of the environment.

II. Land system

A conceptual device which achieves an integrated overview of the relationships between geologic and climatic history, soils and plant ecology, as an aid in understanding land resources.

A. Relations of components to land system

Basic Components (Independent)	Lithology	Geologic Structure	Climate
		TIME	
Manifest Components (Dependent, related)	Soils	Landforms	Plant Ecology

Figure 5-2

from Wertz and Arnold (1972)

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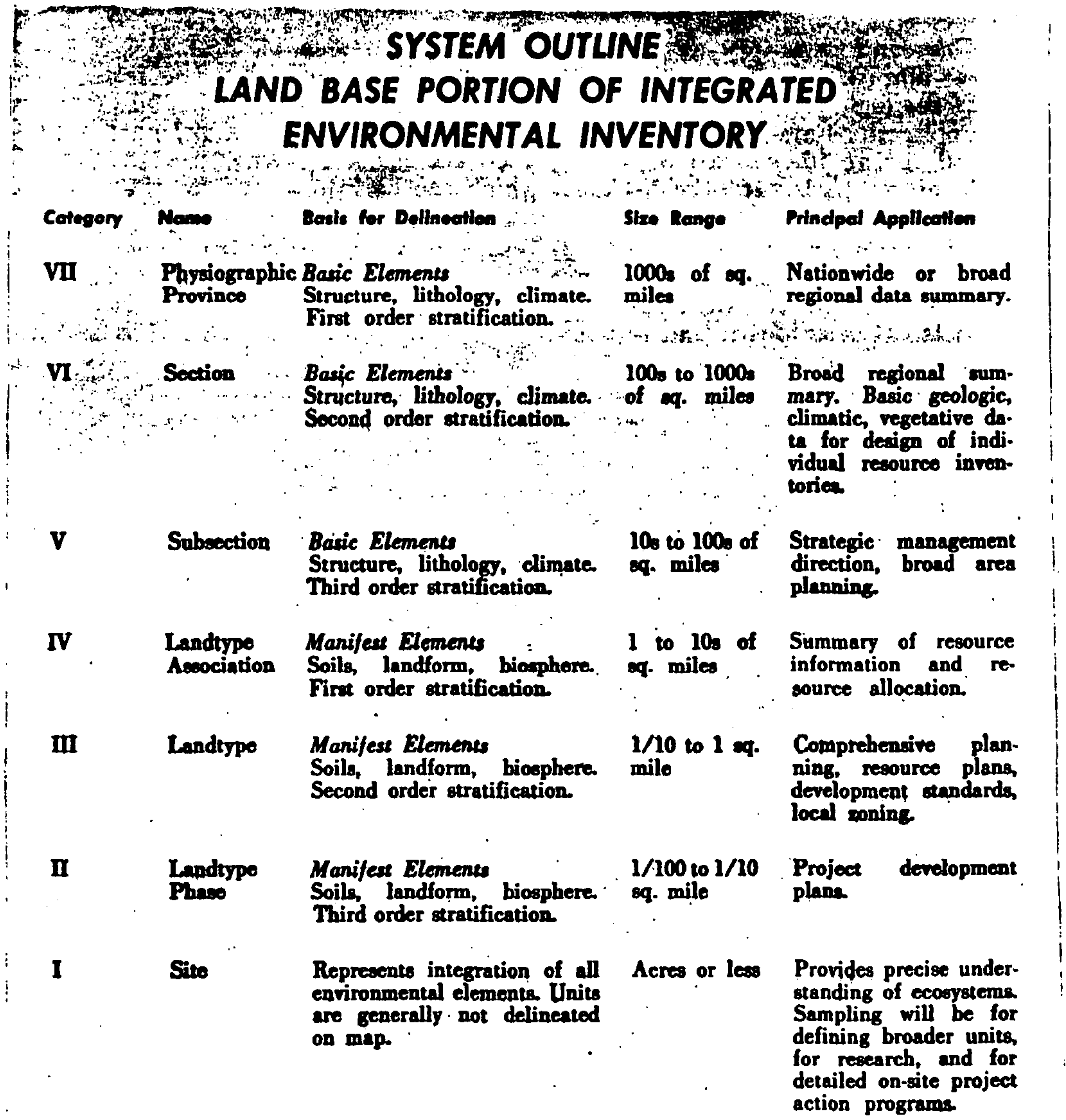

SYSTEM OUTLINE
LAND BASE PORTION OF INTEGRATED
ENVIRONMENTAL INVENTORY

Category	Name	Basis for Delineation	Size Range	Principal Application
VII	Physiographic Province	*Basic Elements* Structure, lithology, climate. First order stratification.	1000s of sq. miles	Nationwide or broad regional data summary.
VI	Section	*Basic Elements* Structure, lithology, climate. Second order stratification.	100s to 1000s of sq. miles	Broad regional summary. Basic geologic, climatic, vegetative data for design of individual resource inventories.
V	Subsection	*Basic Elements* Structure, lithology, climate. Third order stratification.	10s to 100s of sq. miles	Strategic management direction, broad area planning.
IV	Landtype Association	*Manifest Elements* Soils, landform, biosphere. First order stratification.	1 to 10s of sq. miles	Summary of resource information and resource allocation.
III	Landtype	*Manifest Elements* Soils, landform, biosphere. Second order stratification.	1/10 to 1 sq. mile	Comprehensive planning, resource plans, development standards, local zoning.
II	Landtype Phase	*Manifest Elements* Soils, landform, biosphere. Third order stratification.	1/100 to 1/10 sq. mile	Project development plans.
I	Site	Represents integration of all environmental elements. Units are generally not delineated on map.	Acres or less	Provides precise understanding of ecosystems. Sampling will be for defining broader units, for research, and for detailed on-site project action programs.

Figure 5-3

from Wertz and Arnold (1972)

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(1974). This publication, involving guidelines for such surveys, is recommended as a basic reference for lake habitat information collection.

Platts (1974) discusses an inventory method for aquatic systems in a publication entitled "Geomorphic and Aquatic Conditions Influencing Salmonids and Stream Classification," which should be generally applicable in the Northwest. Platts collected the following information:

1. Stream, pool and riffle widths to the nearest foot
2. Four stream depths at equal intervals across the stream to the nearest inch
3. Ratings, locations and features of pools
4. Stream channel surface material classifications
5. Cover, conditions and types of streambanks
6. Channel elevations and gradients
7. Geologic process groups and geomorphic types
8. Stream order
9. Whether the watershed was disturbed or undisturbed
10. Fish species, their numbers, and the length of fish occurring in selected streams between transect one and transect two

The data requirements for planning are considerably different than for impact monitoring, particularly in cases where impact data may be used in court as part of a legal proceeding. Planning information should be comprehensive in order to establish the basic character of the area in question. Trends and unique or special intrinsic qualities require emphasis as opposed to specificity. Planning involves general constraints and the avoidance of problem areas, so specific data are not nearly so important as comprehensive data. Trend projection and broad scope statistical analysis are particularly useful in planning.

The reader is referred to "Three Approaches to Environmental Resource Analysis," a report prepared by the Landscape Architecture Research Office of the Graduate School of Design, Harvard University (1967). The three planning approaches presented have general applicability to land use planning, and include planning method articles by G. Angus Hills, Phillip H. Lewis and Ian L. McHarg.

Prediction. The type of data required for prediction models generally varies somewhat from that required for planning and impact monitoring. The consistency of analysis procedures is of secondary importance for planning information, provided the trends are reflected. Prediction methods, however, usually require very specific types of data and analysis, since computer programs or analytical procedures are developed assuming a specific data input. Occasionally, a non-specified but similar type of available data can be utilized through program revision, provided the necessary data relationships can be defined.

The data most often required for models related to water quality and silviculture generally fall into one of the following categories:

1. hydrology

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2. water quality
3. erosion rates and sediment yields
4. precipitation
5. aquatic or marine biology
6. cover type and density

Certain considerations are important for each of the above types of data, including:

- a. length of data collection period required for adequate significance
- b. collection pattern or sampling network
- c. critical periods requiring sampling (e.g., spawning)

Hydrologic. Hydrologic models involving frequency of occurrence, e.g., peak flood flows, require a minimum of three to five years of data, preferably ten to fifty years. The location of data collection stations should show the normal and altered situations.

Simulation models generally require more types of data but involve shorter time periods for usefulness. Most hydrologic data is collected continuously.

Water quality. Water quality data collection is often coordinated with hydrologic data collection networks, but usually continuous data is not taken for water quality prediction modeling purposes. "Grab" sampling for select parameters at critical periods is the most common approach.

The water quality parameters generally significant to silvicultural activities include:

1. dissolved oxygen and biological oxygen demand
2. nutrients
3. temperature
4. turbidity and/or suspended solids

Erosion rates and sediment yields. Models to describe erosion processes are based either on a phenomenological base or are constructed from first principles using Newton's laws of motion, the laws of viscous forces, and some of the basic concepts of fluid mechanics. Because of the complexity of developing models from first principles, most of those that have been developed, including the equation developed by Megahan (1974), are of a phenomenological basis.

This type of approach is relatively straightforward and frequently leads to an ordinary differential equation of low order which requires auxiliary conditions for integration. Typically, one or two constants appear in these equations that are characteristic of a particular soil type. Before the equations can be applied, it is necessary to conduct simple erosion experiments and evaluate the constants for each soil type under consideration. Once experimental data are available from a range of soil types, it may be possible to approximate the constants for untested soils based on comparative structure as a basis.

Models of aquatic ecosystems. The most commonly used models of aquatic ecosystems are based on man and energy flow from the lower to higher trophic levels of the system. A typical aquatic model might include the aquatic plants as the first trophic level involved in fixing radiant energy. Other trophic levels present would include benthic organisms, herbivores, and at least one or possibly more levels of carnivores.

Typically, these flow models require information on the rate of transfer of energy from one level to the next. Rates may depend on several factors, including the biomass available at other trophic levels and constants characteristic of feeding rates, reproduction, mortality, etc. These types of models are most frequently designed as compartment type simulation models. Some investigators prefer to use first order linear or possibly nonlinear differential equations to couple trophic levels. If simulation is used, the computer can be programmed to step through a series of time increments and provide information on the biomass at each level as a function of time. If the system has been modeled as a set of simultaneous differential equations, it is sometimes possible to obtain an analytical solution. Irrespective of the type of model used, a large investment of time and effort is essential to obtain the data necessary to characterize a particular aquatic ecosystem.

Plant competition models. Models that can be used to predict the rate of revegetation of forested areas subjected to logging would be of enormous value for predicting erosion rates, stream sedimentation, and the concentration of organic pollutants in surface waters. Unfortunately, a limited amount of research has been conducted in this domain. Nonetheless, a voluminous literature exists in the field of plant ecology that could be used for purposes of model construction.

Ideally, models of this type would be designed to predict the time rate of change of plant density on areas subjected to some form of disturbance. In all likelihood, the model would be phenomenological in nature and would take the form of ordinary or partial differential equations. A few attempts at developing models of this type for intertidal communities have been reported. The governing equations usually appear in the form of a partial differential equation which is first order in time and second order in two spatial dimensions.

It is much too early to predict the success of these models. Clearly, much remains to be accomplished in their development, and more time will be required to collect the constants typical of highly competitive plant communities.

Meteorological models. Not unlike erosion processes, models designed to predict meteorological conditions can be founded on first principles or can be simply descriptive of the gross processes observed. Using first principles from thermodynamics and fluid mechanics is in principle possible but highly unlikely to yield useful models, particularly in the micrometeorological situation of primary interest in this report.

Alternatively, observed phenomena can be used to devise simulation models which will yield useful results under specific circumstances. Few such models have been developed in micrometeorology, and the macro models available are in

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general much too coarse for predictive purposes of the type needed in ecology.

Most of the emphasis in micrometeorology in ecology has been directed toward energy balance models which can be used only to predict or to describe the energy budget of relatively simple ecosystems. Information on surface absorptivities and emissivities of the many surfaces present is required. However, these models are limited in scope and at present hold little promise of application to water pollution problems.

Impact monitoring. Monitoring the water quality or aquatic life impact of silvicultural practices presents a complex array of problems which are usually best assigned to specialists. The highly diverse hydrological regimes of Region X, with great seasonal variablity as well as year-to-year variability in average conditions, create problems in impact monitoring that usually require careful instrumentation and sound statistical analysis. Those parameters that lend themselves most to routine monitoring include measurements of temperature, dissolved oxygen, specific conductance, turbidity and suspended solids. In most cases, commercially available instrumentation is adequate for accurate measurement of the above parameters when instruments are properly calibrated. Analysis of biological properties such as coliform or dissolved organic and inorganic chemicals usually requires sophisticated instrumentation and specific sample handling methods.

Detection of the impact of silvicultural practices may be evaluated by selected sampling upstream and downstream from the activity to be monitored. If no inflow occurs and it has been previously established that the parameters measured should be unaffected through that reach of the stream, then samples so compared should be useful. The shortest possible time period should exist between the two sample intervals. If complete mixing cannot be achieved, or a substantial inflow occurs from underground or surface flow, then results will be of less value.

Water temperature. Water temperature can be measured to establish the effects of canopy removal which would reduce shading or increase the solar loading on the small streams. Flows of greater than 5 cfs will probably be unaffected by shade removal. (Brown, personal communication (1974): Sampling location should be shaded so solar radiation does not affect reading of the sensor. Maximum and minimum temperatures are important along with the duration of the exposure, particularly to maximum temperatures.)

Suspended sediment. The measurement of suspended sediment establishes the impact of silvicultural practices on the physical condition of the stream. Suspended materials are transported as a function of the energy of the stream; thus there is a stratification within the stream with heavier, denser materials near the bottom and lighter, less dense materials near the surface. Depth-integrated samples are usually taken for most accurate results. The rate of vertical movement of the depth-integrated sampler should approximate

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the rate of horizontal movement of the flow of the stream.

Dissolved oxygen. Organic debris that ends up in the stream channel as a result of timber-felling or yarding can consume dissolved oxygen in the decomposition process. Dissolved oxygen is also a function of water temperature; thus increases in water temperature will reduce the dissolved oxygen concentration.

Several portable meters are available for field measurement of dissolved oxygen. Oxygen-permeable membranes are placed across a sensor, which is then immersed for determination of dissolved oxygen. As the meter reads in percent saturation, it is calibrated against the atmosphere.

Low temperature water usually maintains a higher oxygen concentration than warmer water. The most critical period for dissolved oxygen is during warm summer months when biological activity is high and water temperatures are also high.

Accurate determination of the effects of silvicultural practices on dissolved oxygen can be made by taking measurements upstream and downstream from the affected area.

Specific conductance. Specific conductance is a measure of the electric current carrying capacity of water. Increasing values of specific conductance indicate an increasing load of dissolved ions; low values of specific conductance generally indicate very clean, pure water.

Specific conductance meters must be calibrated using standard solutions for the approximate range of values of the stream water in question. It is corrected to a standard

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temperature of 25° C, usually internally within the meter.

Predicting Effects

General methodology. Methods for predicting the effect of forest practices on various environmental factors have been of interest to those concerned with forestry for many years. Such methods are applicable to water quality, aquatic ecosystem analysis, growth rates expected given certain stand and environmental variables, and the influence of various levels of fire intensity on site productivity. All prediction methods being used or developed have the same essential character -- given a set of conditions, a prediction may be made, with some degree of certainty, about the effect of specific practices.

One of the first prediction methods used was that of statistical analysis which provided the basis for some of the earliest models used in forestry. Many of the models, particularly those based on regression, were of a predictive character and thereby replaced or reinforced some of the earlier rules of thumb. Most importantly, statistical methods, based on probabilistic concepts, made it possible to devise predictive models which were stochastic in nature. One of the most important uses of models is the more definitive description of a problem.

Multiple regression has been used extensively in forestry to predict the influence of several independent variables on a single dependent variable; for example, the effect of soil nutrients, soil moisture and temperature on tree growth.

Similarly, analysis of variance has been used to test differences between treatments.

Over the years, many deterministic models have also been used in forestry. Prediction of the board or cubic foot volume of a tree is based on a geometric model of log size and shape. Similarly, the models used by forest engineers for predicting road cut and fill volumes are based on simple geometric models which provide the basis for deterministic predictive equations. Other examples can be cited. Those outlined above are but a few examples of two broad classes of models which have been, and will continue to be, used for predictive purposes in forestry.

The rapid increase in the use of models has led to some confusion in concepts and terminology. Not infrequently, the term "model" is thought to mean "computer model". Computer modeling is becoming more widely applied in forestry, particularly as it becomes desirable to attack multi-variable problems with complex interrelationships. To others, "model" implies an iconic or geometric representation of a particular object or system. Still others speak of "flow models", which trace the movement of information through an organization, or material through a set of processes.

"Simulation models", frequently but not necessarily used in conjunction with a computer, are designed to simulate or mimic a particular phenomenon. Many phenomena are of such complexity as to defy the straightforward application of mathematics. In such instances, computer simulation is

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adopted. It is noted that to many the term "model" implies a mathematical equation.

All models are simplifications of a real phenomenon. In development of many models, the geometric or iconic model is the first stage of the process. This type of model is an attempt at simplification in the form of a drawing which captures the salient features of the phenomenon. The results can range from a simple geometric representation to a flow diagram.

Primarily, variables as well as the essential parameters are identified and specified as part of the model. Interrelationships between variables are noted diagrammatically, sometimes by the use of simple directional arrows.

Quantification follows if the problem is such that mathematics can be applied. The mathematics may be of a deterministic or probabilistic nature. Because of the stochastic character of many problems in forestry, the latter predominates. Complex problems which cannot be written in mathematical form are frequently coded for computer manipulation.

For a variety of reasons, computers are being widely used with models. Mathematical models may be highly nonlinear and numerical methods required, or it may be necessary to solve a number of algebraic or differential equations simultaneously. The computer is nearly always required in this type of circumstance. Not infrequently, a number of stochastic variables constitute the model. The computer is essential for storing and processing information in such instances.

The final step in the application of modeling is comparing the model prediction with the behavior of the real system, sometimes called verification. Modeling has been justified on occasion for the clarity and definity it can bring to a problem. Notwithstanding, the test of any model is its predictive capability. Clearly, model precision is governed by many aspects of the total process, including available data, the precision of relationships between variables, and the degree to which the problem can be defined. Several models of both a stochastic and deterministic nature are described in subsequent sections. For the most part, these models are expressed in deterministic form. However, it is recognized that many of the parameters included in equations are determined by the conditions of specific forest sites.

Soil erosion methods. The prediction of soil erosion involves a complex interaction of variables; consequently the development of models for analysis is difficult. To quote Wooldridge concerning such models (1970),

> ...frequently their greatest value is in the manipulation of the various factors to see if they give realistic estimation for soil loss and relationships between factors.

Wischmeier equation. Smith and Wischmeier (1962) have developed an equation to predict the average soil loss in tons per acre. Although this equation is primarily intended for agricultural land, it provides insight into the soil erosion process and may, upon modification, be useful for predicting erosion for bare soils resulting from logging road construction or vegetation removal. The Wischmeier equation is presented as follows (Equation 5.1):

$$A = RKLSCP \qquad 5.1$$

where A = the average annual soil loss in tons per acre
R = the rainfall-erosion index
K = the soil erodibility factor (range from 0.02-0.50)
L & S = the topographic factors

$$L = \sqrt{\frac{\text{length of slope in feet}}{72.6}}$$

$$S = \frac{0.52 + 0.36s + 0.52s^2}{6.613}$$

C & P = crop management and erosion control practices

Another expression of soil erosion similar to the Wischmeier equation was developed earlier by Musgrave (1947). At this time, the Musgrave equation has not been adapted for use in the west. Dissmeyer (1971) developed an equation to evaluate the effect of disturbance on suspended sediments and surface water, and alternative methods for reducing erosion and sedimentation. This method, the "First Approximation of Suspended Sediment" (FASS) has been used primarily in the southeast and considers gully and channel erosion.

Megahan erosion model. A model, or equation, has been developed by Megahan (1974b) that may be used to predict surface erosion (not mass erosion) from watersheds which have experienced roading and logging. A negative exponential equation containing three parameters was derived to describe time trends in surface erosion on severely disturbed soils (primarily roads). This "model" is most appropriate on Idaho Batholith soils, and is presented as follows:

$$E_t = E_n{}^t - S_0 (e^{-kt} -1) \qquad 5.2$$

E_t = the total erosion since disturbance (tons/mi^2)
E_n = the erosion rate to be expected after a long period, assuming no major disturbance; this value is an estimate of the long-term norm for the site (tons mi^{-2} day^{-1})
S_0 = the amount of material available to be eroded at time zero after disturbance (tons/mi^2)
k = an index of the rate of decline of erosion following disturbance; this can be thought of as an index of the recovery potential for the site in question (day^{-1})
t = days of elapsed time since disturbance

Data from four different studies of surface erosion on roads constructed from the granitic materials found in the Idaho Batholith were used by Megahan to develop the equation parameters. Two of these studies, Deep Creek and Silver Creek, involve erosion from the entire road prism (cut slopes + road bed + fill slopes). The other two studies, in the Bogus Basin and Deadwood River areas, were located on double-lane forest roads and designed to measure erosion on road fill slopes only. Plotted data from these studies were used to determine E_n, S_0 and k. The long term erosion rate (E_n) determined in the Deep Creek data was validated by comparison with average sediment yields for Ditch Creek in the Silver Creek study area.

It was found that the erosion rate for undisturbed lands on the Idaho Batholith average about 0.07 ton/mile^2/day. For the first year after disturbance, erosion rates per unit of area involved in road construction were three orders of magnitude greater than those on similar undisturbed land, and after almost forty years they are still one order of magnitude greater. According to Megahan, "The potential for damage by such accelerated erosion should be apparent." The study found that, "By far the largest percentage of soil loss occurs within one to two years after disturbance.", and that, "Erosion control measures must be applied immediately after disturbance to be effective."

Rainfall intensity data were used to illustrate that variations in erosion forces, as indexed by a rainfall kinetic energy times the maximum 30-minute rainfall intensity, "the erodibility index", were not the cause of the time trends in surface erosion. Although vegetation growth can be an important factor in reducing accelerated erosion, it did not cause the rapid erosion decreases found in the cases studied. The evidence suggests that surface armoring was a dominant factor causing the time trends in surface erosion. The significance of time trends in surface erosion is discussed in the paper.

Other studies, including those by Anderson (1972) and Frederickson (1970b), have found decreasing time trends in sediment from poorly logged areas in California and in Oregon, respectively.

The Megahan equation is a valuable tool for estimating potential soil losses from roading and logging systems on the Idaho Batholith. It does require some field data from logged areas of a similar character in order to determine the basic parameters of the soil/hydrologic zone in question.

Water temperature. Increases in stream water temperature are caused primarily by increased exposure of the stream to direct solar radiation as a result of removing streamside vegetation (Brown 1966, Brown and Krygler 1967, and Brown 1970a). Shade removal may increase radiation loads by six to seven times (Brown 1970). Air temperature and the cooling effects of evaporation are much less important than solar radiation in controlling temperature on small, unshaded streams. Brown (1970) found that solar radiation accounted for over 95 percent of the heat input during the midday period in midsummer.

Several silvicultural practices can change or influence the nonclimatic factors which affect the amount of heat received at the stream surface. These factors include:

1. vegetation
2. topography
3. stream channel characteristics
4. inflow of surface and ground water
5. area, depth and velocity of the stream

Streamside shade is the most important factor influencing changes in water temperature over which the land manager has some control. By maintaining vegetative cover of such height and density as to adequately shade the stream during periods of maximum solar radiation, water temperature increases can be prevented and/or minimized as necessary to meet management goals. The replacement of vegetation after clearcutting along streams may be an acceptable means of rapidly reestablishing vegetation that could adequately provide shade protection and thereby reduce increased stream temperatures. Another approach to reducing the impact of clearcutting along streamsides and the resultant changes in temperature could be accomplished through predicting what temperature changes might occur by regulating the silviculture system and the size of cutting units.

Brown (1966, 1969) has developed a technique by using an energy budget for predicting temperature changes of small streams once the streamside vegetation has been removed.

The general equation for the energy budget takes the form, Brown (1969):

$$\Delta S = Q_{NR} \pm Q_E \pm Q_C \pm Q_H \pm Q_A \qquad 5.3$$

where ΔS = net change in energy stored
Q_{NR} = net thermal radiation flux
Q_E = evaporative flux
Q_C = conductive flux
Q_H = convective flux
Q_A = advective flux

The sign is positive for energy added to the stream and negative for energy losses. The budget techniques used for temperature prediction seek to evaluate the net change in the energy level of the stream (ΔS). Net thermal radiation is the difference between total incoming and total outgoing all-wave thermal radiation. This flux can be measured directly with a net radiometer.

Heat is added or removed by condensation or evaporation at the surface of a stream. The amount of heat exchanged is a function of the latent heat of evaporation and the vapor pressure gradient at the stream-air interface (Brown 1969):

$$Q_E = 0.6140\ U\ (e_w - e_a) \qquad 5.4$$

where Q_E = evaporative flux (Btu/ft^2 - min)
U = wind speed (miles/hour)
e_w = saturated vapor pressure at the temperature of the stream (inches of mercury)
e_a = ambient atmospheric vapor pressure (inches of mercury)
0.6140 = exchange coefficient (k x latent heat of vaporization, L)

Conduction describes a molecule-to-molecule heat transfer process. Conduction occurs at the bottom of small, clear streams because thermal energy reaching the stream surface is not strongly attenuated by water only a few inches deep. Conduction is computed as the product of the thermal conductivity and the measured temperature gradient of the bottom material (Brown 1969):

$$Q_C = K\ (dT/dz) \qquad 5.5$$

where Q_C = conduction (Btu/ft^2 min^{-1})
dT/dz = temperature gradient in the bottom material (^oF/inch)
K = thermal conductivity of the bottom material (Btu/ft^2 $inch^{-1}$ min^{-1} $^oF^{-1}$)

Convection occurs at the stream surface. It results from boundary layer conduction and subsequent transfer of heat through displacement of the mass fluid. Wind speed and the temperature gradient between the air and water are the driving forces for convective heat transfer at the air-water interface (Brown 1969):

$$Q_H = 0.0002\ U\ P\ (T_W - T_a) \qquad 5.6$$

where Q_H = convection (Btu/ft^2 min^{-1})
0.0002 = exchange coefficient
U = wind speed (mph)
P = atmospheric pressure (inches of mercury)
T_W = water temperature (^{o}F)
T_a = ambient air temperature (^{o}F)

Energy is added to a stream by introducing water at a different temperature. This transfer of energy from some source outside the area being considered is termed advection. Advective energy comes from precipitation, tributary streams, or ground water inflow. If the volume and temperature of this inflow are known, the stream temperature may be adjusted by a simple mixing or temperature-dilution ratio.

The predicted water temperature change is then a function of the heat applied and the volume of water heated.

$$T_W = \frac{A\ x \Delta S}{F}\ x\ 0.000267 \qquad 5.7$$

where T_W = predicted temperature change (^{o}F)
ΔS = change in energy storage (Btu/ft^2 min^{-1})
A = surface area of study section (ft^2)
F = discharge (cfs)
0.000267 = constant converting discharge from cfs to pounds of water per minute

On unshaded stretches, net all-wave radiation is the predominant energy source during the day; evaporation and convection account for less than 10 percent of the total energy change. Conduction of heat into the stream bottom is an important energy balance component only on shallow streams having a bedrock bottom. Up to 25 percent of the energy absorbed by such a stream is transferred into the bed.

Therefore, the maximum daily stream water increase is estimated by:

$$\Delta S = Q_{NR} \qquad 5.8$$
$$\Delta T = \frac{A \times \Delta S}{F} \times 0.000267$$

The above equation can be used to predict what temperature increase might occur on the site. The impact that such increases can have downstream is predicted by the following mixing ratio formula (Brown 1970a):

$$T = \frac{D_m T_m + D_t T_t}{D_m + D_t} \qquad 5.9$$

where T = temperature of the main stem after the tributary enters
D_m = discharge of main stem before tributary enters
D_t = discharge of tributary
T_m = temperature of main stem before tributary enters
T_t = temperature of tributary

Peak flow accentuation and channel erosion. The U. S. Forest Service, Region I, has developed a procedure (water yield increase analysis procedure) for predicting increases in water yield and peak flows due to timber management (or vegetation manipulation). The procedure includes methods for locating, sizing and phasing timber management activities to assure that the percentage of flow increase remains within acceptable limits as determined by channel stability and soil erosion hazards.

This procedure is explained in "Forest Hydrology: Part II, Hydrologic Effects of Vegetation Manipulation," U.S.D.A. Forest Service, and is summarized as follows:

1. Determination of the normal annual runoff for the

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subject watershed from SCS and USGS information.

2. Determination of the allowable increase limits for annual yield and periods of maximum channel impact peak flows as affected by (a) soil erosion hazard ratings, (b) stream channel stability, (c) on-site analyses (streambed inspection), and (d) average annual peak flow patterns and departures.

3. Synthesization of the water yield, peak flows and channel impact periods due to actual or potential vegetation manipulation operations. Such water yield and hydrograph changes are affected by: (a) equivalent clearcut areas and locations, (b) evapotranspiration changes, (c) redistribution of snow accumulation patterns due to timber management activities, and (d) changes in interception patterns.

4. Synchronization of proposed harvest patterns, locations and phasing in order to stay within the accepted yield and peak flow limitations.

These procedures were developed primarily as a part of planning programs for the Nez Perce and Panhandle National Forests. The "Forest Hydrology, Part II" handbook details four variations of the procedure. While the methodology is still in the development stage, the basic approach is sound and presents a significant first step toward including channel erosion analysis in forest management planning.

The guidelines, curves and functions (which must be developed for each individual watershed) are based on the following:

1. geology

2. soil erosion hazards
3. mean annual runoff
4. stream order
5. hydrologic recovery rate
6. stream channel stability
7. hydrologic response
8. type of vegetation manipulation
9. past use or abuse by man
10. wildfire and flood history

In proposing a matrix evaluation format, the publication lists the following information needs: watershed size, soil types, soil mass failure hazard, soil surface erosion hazard, geologic type, drainage pattern, mean slope, habitat type, commercial timber type, channel stability, stream order, basin orientation, stream gradient, on-site water use, off-site water use, past watershed natural activities, past watershed man activities, mean basin elevation, mean basin precipitation, mean basin runoff, hydrologic condition, proposed method of logging and proposed silvicultural treatment. An overall consideration is the conformance to State water quality standards.

The report lists five alternatives for meeting established water yield increase guidelines, as follows:

1. Increase or decrease the area or size of vegetation to be removed
2. Modify the method of removal, i.e., clearcut vs. shelterwood harvest

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3. Collect additional soil, geology and hydrology data, i.e., refined input data
4. Modify the harvest by energy slopes to desynchronize the increased water yield
5. Exceed guidelines after inclusion of mitigation such as these measures: (a) sediment basins, (b) road stabilization, (c) debris clearing, (d) bank stabilization, (e) progressive revegetation, (f) high lead logging, etc., (g) buffer strips, (h) channel stabilization, (i) eliminate spring logging, (j) modify method of harvest

The report presents a useful "Stream Reach Inventory and Channel Stability Evaluation" procedure and form which is presented in Figure 5-3a and 5-3b. The report also goes into detail concerning the calculation of acceptable limits for increases in yields and peak flows, primarily based on channel characteristics and soil/slope information.

Aquatic or marine eco-system modeling. Numerous models are available for predicting the effects of pollutant discharges on a water body. Most of these models synthesize the concentration of pollutants at critical locations. For a lake, reservoir or marine environment, these locations may vary by depth and distance from the discharge, or be primarily determined by critical aquatic or marine life areas. For stream environments, the evaluation points are downstream from the pollutant discharge, generally at critical locations such as just above a community water supply or major

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R-1 STREAM REACH INVENTORY and CHANNEL STABILITY EVALUATION

LOCATION

Forest Name________________ & No.____ Ranger Dist.________________ Survey Date__________

Observer(s)________________ Stream Name________________

Reach Description & Other Identification________________

Aerial Photo No.__________ & Coordinates Identification__________ P.W.I. W/S No.___ ___ ___ ___ ___ ___ ___

INVENTORY MEASUREMENTS & ESTIMATES☆

Stream Size & Discharge Survey Date Width_____Ft. Ave.Depth_____Ft. Velocity_____f/s Discharge_______cfs

At Maximum _____Ft.☆ _____Ft.☆ _____f/s☆ _______cfs☆

Gradient_____% Sinuosity ratio_____ Stream Order_____ Turbidity Level__________ Stream Stage__________

Channel Flow Pattern________________

Soils Description________________

Landform and/or Geologic Type________________

Vegetative Type________________

Number of debris jams &/or fish blocks/mile_____. Upstream watershed impacts (Types)__________

Size Composition of Bottom Materials (Total to 100%)

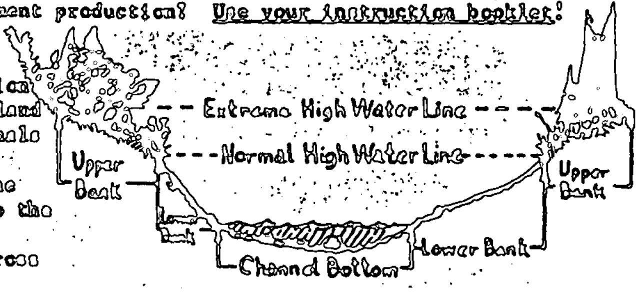
1. Exposed bedrock............____%
2. Large boulders, 3' + Dia..____%
3. Small boulders, 1-3'.......____%
4. Large rubble, 6"-12"......____%
5. Small rubble, 3"-6"......____%
6. Coarse gravel, 1"-3"......____%
7. Fine gravel, 0.1"-1"......____%
8. Sand, silt, clay, muck...____%

Weather and Other Remarks________________

INSTRUCTIONS

Use a separate rating form for each length of stream that appears similar. Complete the inventory items above using maps, aerial photos, and field observations and measurements. On the opposite side of this page, the channel and adjacent flood plain banks are subjectively rated, item by item, following an on-the-ground inspection. Circle only one of the numbers in parentheses for each item rated. If actual conditions fall somewhere between the conditions as described, cross out the number given and below it write in an intermediate value which better expresses the situation. Don't key in on a single indicator or a small group of indicators but use them all for the most diagnostic value. The indicators are interrelated so don't dwell on any one item for long. Do the best you can and the pluses and minuses should balance out. Keep in mind that each item directly or indirectly seeks to answer three basic questions: (1) What are the magnitude of the hydraulic forces at work to detach and transport the various organic and inorganic bank and channel components? (2) How resistant are these components to the recent streamflow forces exerted on them? (3) What is the capacity of the stream to adjust and recover from potential changes in flow volume and/or increases in sediment production? Use your instruction booklet!

DEFINITION OF TERMS AND ILLUSTRATIONS

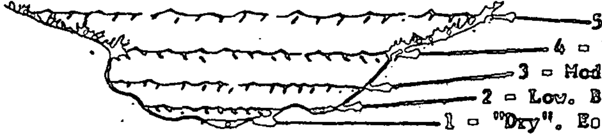


Upper Bank - That portion of the topographic cross section from the break in the general slope of the surrounding land to the normal high water line. Terrestrial plants & animals normally inhabit this area.

Lower Banks - The intermittently submerged portion of the channel cross section from the normal high water line to the water's edge during the summer low flow period.

Channel Bottom - The submerged portion of the channel cross section which is totally an aquatic environment.

Stream Stage - The height of water in the channel at the time of rating is recorded on the top half of this page using numbers 1 through 5. These numbers, as shown below, relate to the surface water elevation relative to the normal high water line. A decimal division should be used to more precisely define conditions, ie. 3.5 means 3/4ths of the channel banks are under water at the time of rating.



5 = Flooding. The flood plain is completely covered.
4 = High. Channel full to the normal high water line.
3 = Moderate. Bottom and ½ of lower banks wetted.
2 = Low. Bottom covered but very little of the lower banks wet.
1 = "Dry". Essentially no flow. Water may stand in bottom depressions.

☆ Use an asterisk behind all estimates that could be measured but weren't.

Figure 5-3a

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USDA-FOREST SERVICE

R-1 STREAM CHANNEL STABILITY FIELD EVALUATION FORM

Item Rated	Stability Indicators by Classes							
I. UPPER BANKS	EXCELLENT		GOOD		FAIR		POOR	
Landform Slope	Bank slope gradient <30%	(2)	Bank slope gradient 30-40%	(4)	Bank slope gradient 40-60%	(6)	Bank slope gradient 60% +	(8)
Mass Wasting (Existing or Potential)	No evidence of past or potential for future mass wasting into channels.	(3)	Infrequent and/or very small. Mostly healed over. Low future potential.	(6)	Moderate frequency & size, with some raw spots eroded by water during high flows.	(9)	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	(12)
Debris Jam Potential (Floatable Objects)	Essentially absent from immediate channel area.	(2)	Present but mostly small twigs and limbs.	(4)	Present, volume and size are both increasing.	(6)	Moderate to heavy amounts, predominantly larger sizes.	(8)
Bank Protection from Vegetation	90% + plant density. Vigor and variety suggests a deep, dense root mass.	(3)	70-90% density. Fewer plant species or lower vigor suggests a less dense or deep root mass.	(6)	50-70% density. Lower vigor and still fewer species form a somewhat shallow and discontinuous root mass.	(9)	<50% density plus fewer species & less vigor indicate poor, discontinuous, and shallow root mass.	(12)
I. LOWER BANKS								
Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	(1)	Adequate. Overbank flows rare. Width to Depth (W/D) ratio 8-15.	(2)	Barely contains present peaks. Occasional overbank floods. W/D ratio 15-25.	(3)	Inadequate. Overbank flows common. W/D ratio >25.	(4)
Bank Rock Content	65% + with large, angular boulders 12" + numerous.	(2)	40 to 65%, mostly small boulders to cobble 6-12".	(4)	20 to 40% , with most in the 3-6" diameter class.	(6)	<20% rock fragments of gravel sizes, 1-3" or less.	(6)
Obstructions Flow Deflectors Sediment Traps	Rocks, old logs firmly embedded. Flow pattern of pool & riffles stable without cutting or deposition.	(2)	Some present, causing erosive cross currents and minor pool filling. Obstructions and deflectors newer and less firm.	(4)	Moderately frequent, moderately unstable obstructions & deflectors move with high water causing bank cutting and filling of pools.	(6)	Frequent obstructions and deflectors cause bank erosion yearlong. Sed. traps full, channel migration occuring.	(8)
Cutting	Little or none evident. Infrequent raw banks less than 6" high generally.	(4)	Some, intermittently at outcurves & constrictions. Raw banks may be up to 12".	(8)	Significant. Cuts 12"-24" high. Root mat overhangs and sloughing evident.	(12)	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	(16)
Deposition	Little or no enlargement of channel or point bars.	(4)	Some new increase in bar formation, most from coarse gravels.	(8)	Moderate deposition of new gravel & coarse sand on old and some new bars.	(12)	Extensive deposits of predominately fine particles. Accelerated bar development.	(16)
I. BOTTOM								
Rock Angularity	Sharp edges and corners, plane surfaces roughened.	(1)	Rounded corners & edges, surfaces smooth & flat.	(2)	Corners & edges well rounded in two dimensions.	(3)	Well rounded in all dimensions, surfaces smooth.	(4)
Brightness	Surfaces dull, darkened, or stained. Gen. not "bright".	(1)	Mostly dull but may have up to 35% bright surfaces.	(2)	Mixture, 50-50% dull and bright, ± 15%, ie 35-65%.	(3)	Predominately bright, 65% +, exposed or scoured surfaces.	(4)
Consolidation or Particle Packing	Assorted sizes tightly packed and/or overlapping.	(2)	Moderately packed with some overlapping.	(4)	Mostly a loose assortment with no apparent overlap.	(6)	No packing evident. Loose assortment, easily moved.	(8)
Bottom Size Distribution & Percent Stable Materials	No change in sizes evident. Stable materials 80-100%.	(4)	Distribution shift slight. Stable materials 50-80%.	(8)	Moderate change in sizes. Stable materials 20-50%.	(12)	Marked distribution change. Stable materials 0-20%.	(16)
Scouring and Deposition	Less than 5% of the bottom affected by scouring and deposition.	(6)	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	(12)	30-50% affected. Deposits & scour at obstructions, constrictions, and bends. Some filling of pools.	(18)	More than 50% of the bottom in a state of flux or change nearly yearlong.	(24)
Clinging Aquatic Vegetation (Moss & Algae)	Abundant. Growth largely moss like, dark green, perennial. In swift water too.	(1)	Common. Algal forms in low velocity & pool areas. Moss here too and swifter waters.	(2)	Present but spotty, mostly in backwater areas. Seasonal blooms make rocks slick.	(3)	Perennial types scarce or absent. Yellow-green, short term bloom may be present.	(4)
COLUMN TOTALS →			→		→		→	

Add the values in each column for a total reach score here. (E.____+ G.____+ F.____+ P.____= ____).

Reach score of: <38=Excellent, 39-76 =Good, 77-114= Fair, 115+=Poor.

Figure 5-3b

R1-2500-5 (6/73)

tributary confluence.

Water quality or aquatic and marine eco-system models can be very beneficial for predicting the effects of silvicultural practices on water bodies. Through reiterative analysis, alternative land use and management schemes can be evaluated for water quality impact.

One of the most useful models for stream eco-systems was developed by Chen and Orlob (1972). The data requirements for this model are very specific and the program must be adapted to the particular stream involved. This type of model differs from the water quality types in that the biological or aquatic life effects are examined as contrasted to water quality per se. Essentially, the same model is available for lake, reservoir and marine environments.

Sensitive Areas and Facilities Location

Planning is the most important key to preventing water pollution from timber harvesting, logging, residue management and reforestation. The most important consideration in such planning is avoiding or minimizing the soil and vegetation disturbances on or affecting sensitive areas. Such areas include:

- stream channels
- stream banks and water influence environs
- marine, lake or reservoir environments
- steep slopes or unstable soils

A complementary and equally important planning objective is the location of facilities and layout of logging systems

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in a manner that not only avoids and protects sensitive areas but capitalizes on land that is 1) the most stable, and 2) has a minimum potential for producing water pollution impacts.

Cosens (1951) concluded that preventing logging damage would be made easier by:

1. Preparing and carrying out a detailed logging plan aimed at reduction of damage.
2. Properly training and supervising logging crews.
3. Focusing engineering and logging ingenuity on designing equipment that will lessen damage to the advance growth as well as increase efficiency of yarding logs.

Stream channels. Based on the available information, the following criteria for stream channels would protect the quality of waters on, or affected by, timber harvest areas:

- Utilize experienced fisheries management specialists and State Fish and Game Department personnel to determine 1) the importance of the stream for fisheries and water quality, and 2) special management requirements for stream channel protection.
- Remove all debris and residue attributable to timber harvesting from below the high water level, except where such debris will definitely improve stream channel structure.
- Avoid using construction equipment or skidding logs in or across streambeds; yard across streams only if logs are fully suspended above the stream channel.
- Fell and limb trees away from all streams and watercourses.

- Avoid channel alterations.
- Avoid locating landings, slash piles and other facilities or residuals within any watercourse.
- For stream channels or watercourses in which flow is intermittent and fish spawning or rearing is negligible:
  - a) remove slash and other timber harvest debris below the high water level
  - b) hold surface disturbance to a minimum
  - c) minimize the operation of logging and construction equipment below the high water level and allow such operation only during no-flow periods and if downstream fisheries will not be affected
- Obtain written concurrence for a specific plan from State water rights, fisheries and environmental agencies before diverting water from any stream.
- Provide for the protection and maintenance of streamside vegetation as discussed later in this section.

The Alaska Departments of Fish and Game and Natural Resources and the U. S. Forest Service (1974) have recommended the following to protect stream channels in Alaska:

- Clear debris from streams.
- Avoid skidding logs in, or across, streambeds.
- Avoid using equipment in the streams.

The following two stream protection guidelines also have merit:

- o Fell the trees away from drainage channels to keep the slash out of waterways (Hopkins 1959).
- o Conduct all operations so as to preclude interference with the resident or migratory fisheries of the area. Do not divert the water out of any stream without the written approval of the State fishery biologist who has jurisdiction over the area involved and the State engineer who is concerned with the administration of water rights (FWPCA 1970).

In addressing the question of guidelines for planning forest practice rules in Class II streams in Oregon (streams of little or no value for fish spawning or rearing, but which affect downstream water quality), the Oregon Department of Forestry concluded the following:

1. Positive preventive measures must be taken to keep the material out of streams.
2. The greatest concern is the potential for 'sluice-outs' which could carry material to Class I streams.
3. Stream clearance requirements can be relaxed where:
   a. the is no 'sluice-out' potential,
   b. 'sluice-outs' cannot reach Class I streams.
4. Due to steeper gradients, low flows and narrow canyons characterizing Class II streams, water quality problems, particularly with regard to dissolved oxygen temperature, appear to be minimal.
5. Where cleanup is required, it should be done in a manner least likely to create undesirable disturbance.
6. Presence of slash in streams can have a beneficial effect on some streams, through the sediment trapping and shading capabilities.

THE FOLLOWING GUIDELINE IS INTENDED TO AMPLIFY THE ABOVE POINTS:

Positive Preventive Measures

1) Trees should be felled away from Class II streams

whenever possible. Improper felling practice is probably the greatest single contributor to debris in Class II streams. Because of the usual time lag between felling and yarding, limbs and tops which fall into streams may cause damage to water quality which persists even after removal after yarding.

2) When it can be done, trees which do fall into streams should be yarded out a least to a point above the high water level before removing limbs and tops. Fine material such as needles has a greater effect on dissolved oxygen than does larger material.

3) Avoid yarding across Class II streams where possible, to minimize disturbance of the bed and banks.

One of the most comprehensive assemblies of guidelines for stream channel protection is being applied by the U. S. Forest Service Intermountain and Northern Regions. Portions of these criteria are related to logging roads, but much of it is related to timber harvesting, logging, residue management or reforestation activities. These criteria summarize a number of important stream channel protection concepts. Only the portions related to harvesting, logging, residue or reforestation are presented, as follows:

> *Procedural criteria* All activities that may significantly affect stream hydrology or aquatic environment will be reviewed prior to commencing work, using a multidisciplinary approach including appropriate inputs from a fishery biologist and/or aquatic ecologist, hydrologist, soil scientist, engineer, landscape architect, and other disciplines as needed.
>
> A fishery biologist and/or aquatic ecologist will evaluate the stream area considered for alteration as an anadromous or resident fishery and the effects of the proposed alteration to onsite and offsite aquatic environments.
>
> All significant stream alteration projects will be evaluated by a multidisciplinary team of appropriate specialists to determine alternative methods to meet

stream channel protection objectives.

The land manager, utilizing the multidisciplinary inputs, will assure that any necessary stream alteration is carried out in accordance with prescribed specifications to at least meet the following performance criteria.

Performance criteria Avoid channel changes wherever this is possible.

In any needed channel work, every reasonable effort shall be made to preserve or minimize adverse effects on the natural aquatic environment.

Where channel changes are deemed necessary, natural channel velocities shall not be increased in the affected stream reach. This will be assured by installing drop structures, by constructing acceptable meanders, or by other approved methods. Where drop structures are installed they shall be designed to permit fish passage, if this is an established occurrence.

Construction and other activities affecting stream channels shall be limited to those periods when such activities will have the least detrimental effect on the aquatic environment, unless emergency situations deem otherwise.

Adequate mitigation measures shall be taken if construction or other activities will adversely affect water temperatures.

Construction and other activities affecting channels above spawning areas shall be deferred if they will adversely affect eggs or alevins in the gravel.

During construction and other activities affecting channels, areas containing anadromous fish redds shall be protected.

When channel changes or alterations are the best alternative, mitigating measures shall be provided to foster replacement of the aquatic habitat to as near natural condition as is possible.

Streamside vegetation shall be maintained if feasible or, if destroyed, shall be replaced to provide for the necessary needs of the aquatic environment.

When channel changes are unavoidable, new channels shall be completed, including scour and erosion protection, before turning water into them.

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Logs shall not be yarded across a stream unless fully suspended above the stream channel.

Skidding of logs across a perennial stream is prohibited.

No activity shall be undertaken which will needlessly or permanently degrade present water quality.

Construction equipment service areas shall be located and treated to prevent gas, oil, or other contaminants from washing or leaching into streams.

Streamside vegetation shall be protected or replaced when its removal can result in:

1) Increased stream temperature detrimental to aquatic habitat.

2) Increased turbidity, bedload, and suspended solids which would be detrimental to fish spawning beds or other aquatic habitat.

Transport of sediment from disturbed areas shall be minimized by ponding, vegetative barrier strips, or other means.

Log landings shall not be located adjacent to stream channels or on areas where surface runoff will discharge directly into the channel.

Construction shall be avoided during wet season or other undesirable runoff periods to minimize sedimentation directly into streams. If construction is essential during such periods, sedimentation damage will be minimized by installing debris basins or using other methods to trap sediment.

Wheeled, track-laying or other heavy equipment shall not be operated in stream courses except when approved by the land manager at crossings designated by him; or if essential to construction activities as specifically authorized by the land manager.

Slash piles shall be located away from streams or drainage channels so that residues will not reach perennial streams.

In timber harvest areas and on road rights-of-way, buffer strips shall be left near streams to maintain existing water temperatures.

Flushing of desilting basins, ponds, and reservoirs into streams is prohibited.

Borrowing materials from stream channels shall be practiced only when this is not detrimental to water quality, fisheries, or channel hydraulics.

Stream banks and water influence environs. One of the most important forest land areas to protect for water quality purposes is the land adjacent to streams and watercourses. Retaining vegetation and minimizing soil disturbance in such zones can significantly reduce water quality impacts by:

- retention of stream shading and temperature regimes favorable to salmonid fisheries
- minimization of drop impact, soil particle entrainment and subsequent sedimentation during periods of high flow or intense rainfall
- interception and deposition of sediment, particularly the larger particles, in the small rivulets resulting from major storms

The question of "buffer zones" or "leave strips" has received much emphasis, particularly during the past five years. It must be stressed that this report deals with such zones only insofar as they contribute to the protection of water quality. Other important forest land management goals, e.g., wildlife protection, may also require the retention of the vegetation adjacent to streams. Such requirements will not always coincide with the water quality requirements for buffer zones. The primary point is that there are multiple needs for maintaining vegetation along streams that should be analyzed separately and then synthesized.

It appears that some form of minimum requirements for buffer zones along spawning or rearing streams is advisable in most of the sub-regions covered by this report. However, such requirements will vary considerably from one sub-region to another because of differences in topography, hydrology, meteorology, silvicultural practices, soils, fisheries and geology. The ideal approach involves minimum requirements, based on a range of stream classifications, that are subject to enlargement or revision through comprehensive interdisciplinary planning. The objectives of such planning and revision should be to achieve a level of water quality protection that 1) adequately protects the fishery, 2) meets state and federal water quality requirements, and 3) provides an equal or greater protection than the minimum specified. With this procedure, the differences in stream use and classification can be recognized.

General. In a brief to the Select Standing Committee on Forestry and Fisheries of the British Columbia Legislature, Narber, Mason and Mundy (1973) made the following observations concerning stream bank management:

> Blanket, ironclad provisions for green strips along all streams should not be adopted; both the operator and the resource managers should remain flexible and each stream or stream section should be evaluated individually on an integrated resource basis. However, we suspect that in most cases leaving untouched a strip of non-merchantable deciduous or coniferous vegetation two or three times the width of the stream channel on both sides of the stream will satisfy most requirements for stream protection.
>
> We urge that top priority be given to improving the inventory of fisheries, wildlife and recreational values

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in our watersheds. Frequently in the past solutions to logging-fish conflicts have been delayed or resulted in unsatisfactory decisions because the fisheries or wildlife resource was not known as precisely as required. However, this requirement for better inventory data should not delay the implementation of strong, workable guidelines.

Because of our concern for the health of streams, we view with alarm the continued practice of alder suppression. A number of studies to further evaluate the importance of streamside alder are underway on Vancouver Island, but some general comments are in order. Alders are by far the most common deciduous tree species along our coastal streams and appear to be valuable in bank stabilization, shade, leaf fall, insect production, nitrogen fixation and site improvement. Alder probably should not be removed from stream banks in the logging of old growth stands and where logging has already occurred, the regeneration of streambanks with alder should be encouraged rather than discouraged. In Oregon and Washington, alders are not generally cut or treated with herbicides along streams; if plantations are infested with juvenile alder, aerial spraying is undertaken - usually by helicopter and well away from water courses.

Streeby (1970) offered the following in connection with buffer strips:

> Buffer strips have been receiving a great deal of attention as a method of protecting streams and the stream environment. But they are not equally useful in all places. The desirability of applying buffer strips is dependent on three classes of factors--physical-biotic factors, outside cultural factors, and management objectives. Some potential costs and benefits associated with buffer strips are identified, but all these costs and benefits should not be expressed in dollar terms. Rather, all costs and benefits associated with each management objective should be explicitly recognized in their own natural measure of contribution to goals, and decisions should be made on the basis of this information. (Author's abstract.)

The Federal Water Pollution Control Administration (1970) suggested the following guidelines:

> Leave all hardwood trees, shrubs, grasses, rocks, and natural "down" timber wherever they afford shade over a perennial stream or maintain the integrity of the soil

> near such a stream.
>
> Carefully and selectively log the mature timber from the buffer strip in such a way that shading and filtering effects are not destroyed. Protect the buffer strips by leaving stumps high enough to prevent any subsequently-felled, up-slope trees from sliding or rolling through the strips and into the streams.
>
> Neither an optimum nor a minimum width can be set arbitrarily for buffer strips. It is recommended, however, that a minimum width of 75 feet on each side of the stream be used as a guide for establishing buffer strips. At the same time it must be realized that the necessary width will vary with steepness of the terrain, the nature of the undercover, the kind of soil, and the amount of timber that is to be removed.
>
> One modification of the buffer strip plan calls for the removal of only dead, dying, mature, and high risk trees from strips at least 75 feet wide on medium sized or larger streams. It provides also for removal of all merchantable trees from within a 15-foot strip along each bank of the stream. Such removal relieves pressure on stream banks and prevents weakening the support for larger trees and thus prevents stream bank destruction.
>
> Where old growth timber must all be removed because it is subject to windthrow (for example, pure western hemlock) and where it is difficult to leave full-width buffer strips of timber to shade the stream, plan to re-establish cover along the stream after cutting is completed. Fast-growing deciduous species will be required to restore shade as quickly as possible. In the meantime, leaving the understory vegetation as undisturbed as possible will result in the filtering of the runoff and the stabilizing of the soil.

Anderson (1973), summarizing other authors, reports, "Since an optimum width cannot be arbitrarily established for buffer strips, a minimum of 75 feet on each side of the stream is recommended."

The following recommendations were made by a consultant (Jones and Stokes Associates, Inc., and J. B. Gilbert Associates, 1972) to the California Water Resource Board concerning operations on the California north coast:

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In order to protect water course character and water quality, each logging plan shall contain detailed descriptions of water course protection strips (WPS). For that part of the logging area bordering perennial and intermittent streams the WPS shall have a width of 100 feet; variations from this width may be justified if the stream protective qualities of the strip are maintained or improved. Any logging operations in the strip must be done without the use of heavy machinery and adequate to meet the purpose and goals as described in this section. Rules regulating the detailed characteristics of the WPS based at least on stream class, topography, climate and soil types shall be adopted by the Board.

Concurrent with logging and any associated activity, all slash, debris and hazardous conditions shall be removed from the water course protection strip in a manner that maintains or improves the quality of the strip. Slash, debris and sidecast earth that presents a hazard to the WPS or water course as a result of surface water flows, shall be removed or stabilized prior to the start of the rainy season.

Thermal. One of the impacts of forest land management is an increase in water temperature when shade-producing vegetation is removed. Some nonclimatic factors and influences that should be considered are described below:

Latitude Since the angle of the sun varies with latitude, vegetation that shades the stream effectively at high latitude is less effective at lower latitudes. At lower latitudes, vegetative cover should be taller to provide adequate shade.

Stream width Brush or hardwoods can effectively shade small, narrow streams, while conifers or taller vegetation are needed to fully shade wide streams. Therefore, the wider the stream, the taller the vegetation needed to provide shade.

Topographic shading and orientation At certain times of the day, topographic influences on the south side of an east-west oriented stream are effective in shading the stream without any vegetative cover; but on north-south oriented streams, the effect of vegetative cover is needed on both sides of the stream. At midday, the vegetation which overhangs or is immediately adjacent to the stream is the most effective. Later in the day, when the declination of the sun has changed, vegetation further from the stream can also provide shade.

Spacing of vegetation If vegetation is not spaced closely enough, the stream may not be effectively shaded even though the vegetation is of sufficient height. Tables 5-1 and 5-2 show how tree density or stocking affect the light intensity (Resler n.d.).

Table 5-1

Stand Density Effects on Light Intensity

	% of fully stocked stand removed	light intensity (% of open)
stem density	0	8
	25	14
	50	26
	75	55
canopy closure	0	4
	25	6
	50	16
	75	43
basal area	0	10
	25	15
	50	27
	75	52

Table 5-2

Spacing Effect on Light Intensities

spacing (ft)	trees (number/acre)	light Intensity (% open)
4 x 4	2721	15
6 x 6	1210	16
7 x 7	889	36
9 x 9	538	60

<u>Type of vegetation</u> A mature stand of conifers, with much of the lower bole free of limbs, may offer only partial shade, whereas a younger, bushy stand of trees may provide more shade. Understory species, such as hardwoods or brush, generally provide very adequate shade for small streams.

<u>Area and volume of stream</u> Temperature change is directly proportional to the area of stream exposed and the duration of exposure, and indirectly to the volume of water. The temperature change will be higher for wider streams with shallow water than for narrow streams with deep water.

<u>Stream gradient</u> The stream directly influences the flow speed. The higher the flow speed, the shorter the exposure time. Therefore, fast-flowing streams heat up less than slow, low gradient streams.

<u>Channel type</u> The type of stream bottom or channel can strongly influence stream temperature. Soil rock bottoms act as a heat sink storing the sun's energy. As a consequence, stream temperature does not rise nor cool as rapidly. In contrast, gravel, sand, or boulder

bottoms will both heat and cool more rapidly.

Water temperature criteria Brett (1952) notes that the upper and lower limits of temperature which a fish can withstand define the extreme of his tolerable environment. The lethal temperature and thermal tolerances vary from species to species. Salmonids have the lowest thermal tolerance, with the maximum upper lethal temperature barely exceeding 77°F. Anderson (1973) reviewed the literatures about the ideal and maximum water temperatures for various fish species. He summarizes as follows:

Table 5-3

Ideal and Maximum Temperature Ranges by Species

fish species	ideal temperature °F	maximum temperature °F
salmon		
spawning	45 - 55	57.5 - 60
rearing	50 - 60	77
migrating	45 - 60	77
trout		
rainbow	70 - 80	83
eastern brook	66 - 70	75
brown	70 - 80	
largemouth bass and bluegill	55	90
resident trout	45 - 68	

Brown and Brazier (1973) report several conclusions in a study of the effect of buffer strips on stream temperature:

> The results of this study lead to some interesting conclusions about designing buffer strips for temperature control.
>
> Commercial timber volume alone is not an important criterion for temperature control. The effectiveness of buffer strips in controlling temperature changes is

independent of timber volume.

Width of the buffer strip alone is not an important criterion for control of stream temperature. For the streams in this study, the maximum shading ability of the average strip was reached within a width of 80 feet; 90 percent of that maximum was reached within 55 feet. Specifying standard 100- to 200-foot buffer strips for all streams, which usually assures protection, generally will include more timber in the strip than is necessary.

Angular canopy density is correlated well with stream temperature control. It is the only single criterion the forester can use that will assure him adequate temperature control for the stream without overdesigning the buffer strip.

The U. S. Forest Service water quality guides include the following information:

The heights of vegetative cover needed to provide effective shade for various stream widths and latitudes are listed in the table below. The data shown are those which occur in mid-July when water temperatures are more likely to be critical.

Height of Vegetative Cover Needed to Offer Shade

Stream Width (ft.)	Latitude 42°	Latitude 45°	Latitude 49°
	- - - - - Height of Cover (ft.) - - - - -		
2	6	5	4
4	20	9	7
8	21	18	15
12	31	27	23
18	47	40	34
20	52	45	38
30	78	67	56
40	104	90	75
50	130	112	94
75	195	169	141
100	260	225	188

The height of vegetative cover needed for any width of stream and any latitude can be calculated used the formula:

$$\text{tangent } A = \frac{a}{b} \text{ or}$$

height (ft.) = natural trigonometric function of the tangent of the sun angle times stream width (ft.)

The sun angle for any latitude for any date in question can be calculated by referring to a solar ephemeris to obtain apparent declination and using the following formula:

solar angle = 90 - (latitude - apparent declination)

Sediment. In a central Idaho ponderosa pine cutting which covered sixteen small watersheds, Haupt and Kidd (1965) found with careful planning and good logging supervision that sediment did not reach the stream with undisturbed buffer strips averaging more than 30 feet wide. When strips were reduced to an 8-foot width, however, sediment entered the stream. As was to be expected, proximity of a road to the stream affected the frequency with which sediment flows reached the stream when 8-foot buffer strips were being used.

Trimble and Sartz (1957) recommend the guidelines listed as Table 5-4.

Table 5-4

Recommended Widths for Filter Strips (after Trimble and Sartz, 1957)

slope of land %	width of filtration strips in feet
0	25
10	45
20	65
30	85
40	105
50	125
60	145
70	165

It has been suggested by Trimball and Sartz (1957) that a logging road should be a minimum of "25 feet plus 2 feet for each one percent of slope between stream and road." A curve was prepared showing the relationship between degree of slope and the distance sediment is carried by storm runoff which is shown as Figure 5-4.

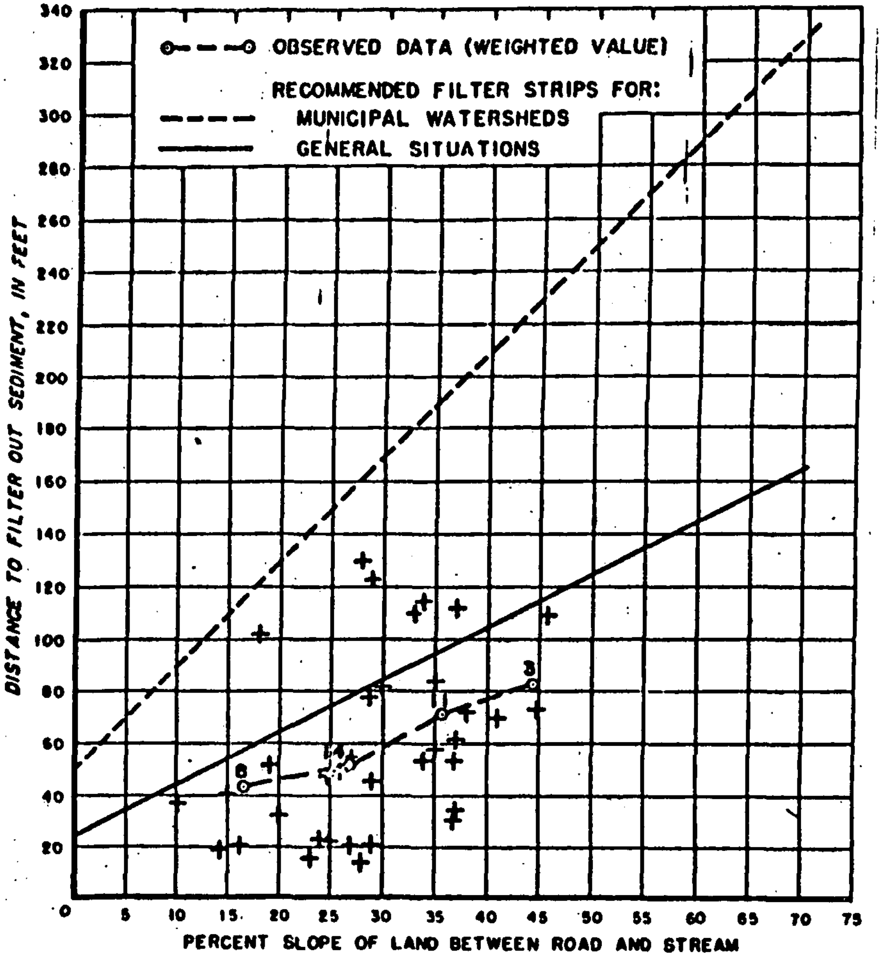

Figure 5-4: Relationship between degree of slope and the distance sediment is carried by storm runoff.

Marine, lake or reservoir environments. The management for water quality purposes of estuaries, lakes or reservoirs and the adjacent land and vegetation has not been the subject of extensive research. Such shoreline management has most often been practiced for esthetic, wildlife er recreational purposes rather than water quality per se.

While the importance of shoreline protection to water quality is apparently greater for small to medium sized streams than for estuaries, lakes or reservoirs, this general rule can be expected to have exceptions. Small fresh- or salt-water bodies, particularly shallow spawning or rearing areas, can present a high potential for water quality degradation. This depends on:

- exposure
- normal temperature regime
- hydraulic characteristics (flushing)
- soil/slope characteristics
- relative amount of the sensitive area affected

For example, a shallow, narrow estuarine area normally provided with shade by tall trees along a steep, erodible shoreline to the south could be subjected to dramatic thermal and sedimentation impacts if the vegetation is removed and the soil extensively disturbed. If such an area is an important rearing area for fish, the biological impacts could be severe. Since such areas are generally less active hydraulically than streams, under certain conditions the potential for adverse effects could be greater.

The U. S. Forest Service proposed the following three guidelines for the Southern Chilkat Study Area, Tongass National Forest, which exert a significant influence on a productive marine environment:

- Consult a biologist prior to any developmental action along the shoreline and estuarine areas.
- Give preference to dryland storage and barging in any logging activity.
- Exclude any timber harvest within approximately

a one-fourth mile fringe of the shoreline except for salvage of blowdown, insect, disease, or fire damaged timber.

The National Marine Fisheries Service (NOAA), Juneau, Alaska, has recommended the following to reduce the adverse impact of fisheries from log dumps and raft storage areas:

1. Maximize the distance between the mouths and intertidal channels of anadromous fish streams and the sites.
2. Maximize the distance between tide flats and subtidal beds of aquatic vegetation and the sites.
3. Use the steepest shores having the least intertidal and subtidal zone.
4. Minimize disturbance of the shoreline as a result of clearing, road building and other activities that might produce silt or otherwise disrupt the estuarine environment.
5. Minimize storage time for rafted logs before transport to the mill.
6. Minimize the number of active dump sites and log storage areas in any given bay or bay complex.
7. Minimize the filling of intertidal and subtidal areas for the construction of log dumps, fuel transfer facilities, equipment loading ramps, etc.
8. Minimize the use of intertidal areas as a source of borrow.
9. Minimize interference with other established uses such as commercial and sport fishing, hunting and anchorages for commercial and recreational boats.
10. Whenever possible locate sites outside bays, along straits and channels.
11. Locate dump sites in deep bays rather than in shallow bays. Select bays without sills or other natural restrictions to tidal exchange.
12. Locate dump site near mouths of bays rather than at heads of bays unless the environment at the mouth of the particular bay in question has some special significance.

13. Use the deepest water possible for booming grounds and log raft storage areas.
14. Select sites that accomodate future timber development without requiring continual relocation.

Steep slopes and unstable soils. Areas of steep slopes or unstable soils present potential water quality problems that are best avoided whenever possible. The most advantageous approach involves the critical/sensitive soil and slope areas being identified and allocated to low disturbance uses, such as no roads and minimum to no timber harvest. Information pertinent to the study of steep slopes and critical soils as affecting water quality can be found in Section 4 (pages 14-26).

The following guidelines summarize the water quality protection criteria for timber harvest, logging, residue management and reforestation:

- A land systems management plan, including programs for minimizing soil loss, erosion and mass soil failure, should be developed for all forest land units by experienced soil scientists and geologists.
- Avoid locating skid trails in ravines or V-notches.
- Limb logs before yarding if they are to be ground-skidded.
- Apply zone-sensitive saturation (max/min) and slope limits to each type of logging used, particularly tractor logging.
- Minimize soil disturbance through the use of aerial logging methods such as skyline, running skyline,

helicopter or balloon systems in steep-sloped or unstable soil zones (e.g., the Idaho Batholith).

- Consider the use of slash for soil protection purposes.
- Consider limiting logging to periods when snow cover can provide protection to the soil and understory.

The following portions of this section are excerpted from various sources.

In a report concerning the California Forest Protective Law, Jones and Stokes Associates, Inc., has proposed certain standards to the Watershed Conservation Board that pertain to critical areas and the location of facilities as follows:

> The Board shall set permissible soil loss levels for the district areas.
>
> The Board shall monitor logging operations and shall report individual and cumulative soil losses attributable to logging.
>
> Permittee shall include an erosion control program in each logging plan describing in detail the facilities and techniques used to keep soil losses at permissible levels.
>
> Permittee shall pay the cost of erosion monitoring.

The Alaska Departments of Fish and Game and Natural Resources and the U. S. Forest Service have outlined the following for minimizing erosion and sedimentation from steep slope or unstable soil areas:

> Avoid logging in critical V-notch areas.
> Avoid yarding across or out of V-notches.
> Revegetate disturbed soil.

The Oregon Soil Conservation Service prepared a paper entitled "Agronomy Practices Standards and Specifications for Critical Area Planting." These standards can be applied to any area of surface disturbance with some modification for each site. The two following are pertinent to steep slopes or unstable soils:

> On soils with a severe erosion hazard, the slope length must be limited to a distance that will help prevent erosion and rilling. Diversion above the slope may be required; also adequate drainage, a stable channel for the water course to prevent cutting action, and a stable flat area for draining discharge or drop structure are usually necessary. Urban areas will need a well designed water disposal system.
>
> Use a mulch where seeding problems are severe or seeding establishment is difficult.

W. J. Kidd, U. S. Forest Service, in studies on the Idaho Batholith, summarized his research on 569 intervals of 105 logging skidtrails as follows:

1. Erosion is greater and rate of healing is slower on soil derived from granite than on soil from basalt.
2. More soil is eroded from skidtrails unavoidably located in ravine bottoms than from trails on sidehills.
3. Control structures that divert water off the skidtrail onto undisturbed forest floors are superior to those that only retard water movement and filter out sediment along the skidtrail.
4. Any increase in spacing between control structures is accompanied by increase in soil movement.
5. Optimum spacing between erosion control structures depends on the percent of slope, whether location of the skidtrail is on a sidehill or in a ravine, and the soil parent material.

Kidd concluded that proper treatment of bared skidtrails after logging reduces the hazard of potential erosion. He also concluded that all types of erosion control structures on skidtrails were generally ineffective in ravine bottoms. Water diverting structures (log water bars and cross ditches) are more effective than the sediment filtering methods (slash dams and lopping and scattering of slash).

Gonsior and Gardner (1971) proposed design criteria for the improvement of logging roads in areas subject to slope failure. Since road design has been dealt with in a previous report, those recommendations will not be listed, but the reader is referred to that publication when areas subject to slope failure are involved in road design, landing location, or the location of other logging facilities.

The Tongass National Forest (1974) proposed the following as a means of reducing soil disturbance:

> Utilize winter snow conditions and frozen ground to minimize soil disturbance during timber harvest.

Hopkins (1957) made the following observations concerning the minimization of soil disturbance:

> Limb the logs before yarding. Be sure the loggers know the location of the skid trails. Then, they can place the trees so that yarding crews can roll and skid the logs with a minimum amount of soil disturbance.
>
> Slash disposal is often considered solely as a method of reducing fire hazard. Don't overlook the opportunity, however, for using slash from tops and other debris to minimize or prevent erosion damage. Slash and litter properly placed in skid trails will lessen soil movement and divert excess water out of trails; improperly placed, it is ineffective, wasteful of effort, and may even increase erosion. Place the material in good contact with the soil and the larger pieces at such angles that they will lead water out of the skidway at frequent intervals. Portable chippers, now in use on two of the southern California national forests, will chip slash and blow a mulch into old skid

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trails and other bare and unstable areas. In general, the combination of good road location, well-placed waterbreaks, and slash placement in critical spots, will provide effective erosion protection.

The Federal Water Pollution Control Administration (1970) recommended the following soil protection criteria:

> Limb all logs before yarding in order to minimize disturbance of soil and damage to reproduction and water quality.
>
> Avoid tractor yarding on all saturated areas and on all slopes steeper than 30 percent. On critical soils, limit crawler-tractor yarding to slopes of less than 15 percent.
>
> Minimize logging road construction on very steep slopes or fragile areas by using skyline or balloon yarding systems.
>
> Consider the use of helicopters, balloons, or modified cable systems for logging of areas that would have high conventional yarding costs or for fragile, sensitive areas.
>
> Take all possible care to avoid damage to the soils of forested slopes, and to the soil and water of natural meadows as well. Minimize this damage by operating the logging equipment only when soil moisture conditions are such that excessive damage will not result.
>
> Limit tractor-built firelines to areas where they will not involve problems in soil instability.

Table 5-5 is taken from the FWPCA (1970) report.

Facilities location and logging system layout. The emphasis of this section up to now has been on avoiding or minimizing disturbances on critical or sensitive areas. While such avoidance is necessary, proper timber management planning should also include the identification and utilization of stable areas for locating logging facilities (e.g., landings) and systems (e.g., skid trails).

In most northwest forest sub-regions, the greatest

Table 5-5

RELATIVE EROSION HAZARD OF LOGGING AREAS IN RELATION TO SITE FACTORS

Site Factors	High Erosion Hazard	Moderate Erosion Hazard	Low Erosion Hazard
Parent rock	Acid Igneous	Sedimentary and Metamorphic	Basic Igneous
	Granite, diorite, volcanic ash, pumice, some schists	Sandstone, schist, shale, slate, conglomerates, chert	(Lava rocks) Basalt, andesite, serpentine
Soil	Light textured,[a] with little or no clay	Medium textured, with considerable clay	Heavy textured, largely clay and adobe
Mantle stability	Unstable mantles (cutbank stability Class V)	Mantles of questionable stability (cutbank stability Class IV)	Stable mantles (Classes I, II and III
Slope	Steep (over 50%)	Moderate (20-50%)	Gentle (0-20%)
Precipitation	Heavy winter rains or intense summer storms	Mainly snow with some rain	Heavy snow or light rain
Vegetation and other organic matter on and in the soil	None to very little	Moderate amounts	Large amounts

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[a] Soil texture refers to the size and distribution of the mineral particles in the soil, the range extending from sand (light texture) to clay (heavy texture).

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potential for reducing stream sedimentation related to silvicultural activities appears to lie in the minimization of logging road and skid trail densities. Much of the literature concerning the Idaho Batholith, for instance, indicates that erosion and sedimentation is heavily influenced by the extent of the area disturbed by roads (Megahan and Kidd, 1972a and b).

Because of this relationship between logging roads, density and sedimentation, one method offers significant advantages for water quality protection. This is simply the reiterative layout on a topographic map of alternative road systems with the concommitant harvest and logging systems. This analysis allows the selection of a combination that minimizes soil exposure due to cut/fill and road surfaces. Such road/logging system selection should consider the following:

- minimizing total road density and soil disturbance
- avoiding critical or sensitive areas
- long term harvesting plans for areas allocated to intensive commercial timber use
- minimizing cut/fill surface area and ensuring that cut/fill slopes are less than maximum limits set for each soil type

Certain models or procedures have been developed for locating timber management facilities. Most of these "models" are based on economic feasibility, but could have programs for minimizing water quality degradation incorporated with a minimum of effort. It is not within the scope of this report to present detailed descriptions for each one. However, the following list is presented to acquaint the reader with the types of models presently available that may have considerable potential through modification for use in water quality management planning:

1. LOCATION-ALLOCATION MODELS FOR ESTABLISHING FACILITIES (Gibson and Rodenburg, 1974)
2. OPTIMUM REFUELING FOR HELICOPTER LOGGING: A MODEL (Gibson, 1974)
3. HELICOPTER LOGGING: A MODEL FOR LOCATING LANDINGS (Egging and Gibson, 1974)
4. RUNNING SKYLINE DESIGN WITH A DESK TOP COMPUTER/PLOTTER (Parson, Studier and Lysons, 1971)
5. RESOURCE-ALLOCATION PROCEDURE FOR PLANNING AND SCHEDULING ACTIVITIES DEPENDENT ON A LIMITED RESOURCE POOL (Carson and Burke, 1972)
6. ROAD AND LANDING CRITERIA FOR MOVABLE-CRANE YARDING SYSTEMS (Burke, 1972)
7. AUTOMATED ANALYSIS OF TIMBER ACCESS ROAD ALTERNATIVES (Burke, 1974)

Hopkins (1957) stated the following as a guideline for locating landings:

> Locate landings in natural, level openings and on firm dry ground whenever possible. In moderate terrain this is easily attained; in steep country, careful designation of landing sites is necessary to minimize watershed damage. Often you can make landings by widening the haul roads at some distance from water courses. Cribbing built with cull or unmerchantable logs and chunks on the downhill side will support a landing fill and thus minimize excavation.

The following criteria were formulated by the Federal Water Pollution Control Administration (1970):

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Correlate all skid trail locations with cutting areas, topography, soil types, and climatic factors. Locate such trails carefully and drain them adequately so that muddy and turbid waters will be kept out of stream channels and off stream banks. Use temporary log or metal culverts wherever such trails must cross stream channels, and keep the number of such crossings as few as possible. Use each skid trail only a small number of times in order to avoid soil gouging and compacting and the channelization of runoff.

Locate log landing areas on firm dry ground away from live stream channels wherever possible. Widening of the logging road will permit this in some places. Borrow the material for the extra fill from a long stretch of road rather than from a single spot, thus keeping the cut slopes reduced in extent. Use cull or unmerchantable logs and chunks to form a cribbing on the downhill side to support the fill for the landing and thus minimize the borrow excavation and help control slumping and erosion.

Avoid servicing tractors, trucks, and similar equipment on forest lands adjacent to roads, lakes, streams, or recreational facilities. Permit no contaminants to remain in the logging area following completion of operations.

Maintain in a clean and sanitary condition all improvements such as camps, mills, quarries, and the grounds adjacent thereto that are used in connection with the timber harvesting process. Locate all buildings, toilets, garbage pits, and other structures in those places that will prevent pollution of the water in streams, ponds, or lakes.

Locate log loading or log storage areas (landings) along ridge tops, on other areas having gentle slopes, or along widened road areas.

Place landings in the channels of intermittent streams only in those emergency situations where no safe alternative locations can be found. Adequately drain any landing that must be placed in such channels. Immediately after completing all log loading from these landings, clear the channel to its full capacity, spread the fill material in areas where it will remain stable, and reseed those areas to herbaceous vegetation.

Silvicultural System Selection

The harvest or cutting method used has historically been based on the silvics of the tree species present, the

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profitability of the system used to extract the wood products, and the type of logging equipment available in the region. However, the selection of the silvicultural system directly affects the water pollution potential of the harvest and logging operation. By recognizing this relationship, the water pollution potential of an area to be logged can be reduced through the selection of the silvicultural system.

To reduce the effects of any silvicultural system on water quality, a number of general recommendations may be followed:

1. Know the classes of stream within the cutting areas and the degree of protection needed (Washington-Oregon Forest Practices Acts 1974).
2. Design cutting areas to reduce logging impact on streams so as to avoid yarding across the streams and minimize disturbance to stream bed and banks.
3. Choose the type and size of logging equipment that will minimize soil disturbance.
4. Use buffer strips of vegetation along streams to intercept sediments and organic material and maintain normal water temperatures (Anderson 1973).
5. Avoid logging of steep unstable slopes which have landslide potential. Guidelines for identifying such areas are available for coastal Alaska (Swanston 1969).
6. Develop general drainage plans jointly with all owners in the vicinity of the operations.

7. Design the clearcut with a minimum of roads (Frederickson 1971).
8. Locate landings away from stream courses in easily drained areas to avoid mud accumulations and so that skid trails will not contribute excessive drainage into them.
9. Avoid falling trees into or across streams whenever possible. Remove logging debris from stream channels (SAF 1959).
10. Restrict cable logging to uphill yarding. Depending on soil conditions, tractor or wheel skidding should be restricted on steep slopes and immediately after heavy rains or snow melt periods (SAF 1959).
11. Revegetate the area as soon as possible after logging. Stabilize roads, skid trails and landings.
12. Periodically inspect drainage previously established through proper construction of skid trails, landings, spur roads and fire lines and maintain to avoid future site degradation (SAF 1959).
13. Locate skid trails in tractor logging where they can be drained and construct with discontinuous grades (SAF 1959).
14. Maintain good supervision of the personnel responsible for the operations.

The recommendations listed above apply to all silvicultural systems.

Studies in the Wagon Wheel Gap watersheds in Colorado, the Coweeta Experimental Forest in North Carolina, and the Hubbard-Brook watersheds in New Hampshire have demonstrated that the felling of trees alone contributes very little to overland flow or soil erosion. However, because each harvest technique necessitates different types and amounts of road building and other soil disturbances, soil erosion is a function of harvest technique. Table 5-6 presents some typical data that illustrate sediment production as related to different logging and harvesting practices.

Table 5-6

Maximum Turbidities Under Four Cutting Practices on the Fernow Experimental Forest in West Virginia (taken from Hornbeck and Reinhart, 1964)

Quality of Logging Operation		Cutting Practice	Maximum Turbidity (ppm)
very poor	1.*	commercial clearcut	56,000
poor	2.	diameter-limit	5,200
good	3.	extensive selection	210
very good	4.	intensive selection	25
undisturbed		(control watershed)	15

* Numbers refer to the cutting practice descriptions which follow.

The following restrictions were placed on the logging operation in each cutting practice:

1. In the commercial clearcut, no restrictions were placed on the logger; he was permitted to harvest the timber in what he considered the quickest, most economical method.
2. The only restriction in the diameter-limit cut was the installation of water bars (diversions) in the skidroads at specific intervals. The water bars

divert water off the road and onto the undisturbed soil, where it may be absorbed safely.

3. Requirements on the extensive selection cut were the installation of water bars, 20 percent maximum grade of skidroad, and no skidding in stream channels.
4. The logging operation was most carefully controlled in the intensive selection cut; requirements in this treatment were installation of water bars, a 10 percent maximum grade of skidroad, no skidding in or near streams, and seeding disturbed areas following logging.

Studies on the water supply watersheds of Seattle, Washington, and Oregon City, Oregon (Horn 1960 and Thompson 1960), illustrate that sedimentation can be independent of harvesting method. Harvesting methods included strip or block clearcutting, but in each case the logging operation was precisely prescribed and carefully supervised, with the roads designed to minimize erosion and reforestation initiated soon after the operation. Both watersheds were logged without a noticeable reduction in water quality.

Rothwell (1971) presented Table 5-7 to illustrate the degree of disturbance associated with each cutting method.

Table 5-7

Cutting Method Versus Degree of Site Disturbance

cutting method	degree of disturbance
clearcut	high
seed tree	
shelterwood	
group selection	
selection	low

The following describes the various silvicultural systems relative to water quality impact.

Clearcutting is a silvicultural system in which the old crop is cleared over a considerable area at one time. This system is not suitable on fragile soils or on sites characterized by severe climatic conditions. Some advantages of the clearcutting system include:

1. Logging damage to growing stock is prevented because immature trees are concentrated in stands other than those being harvested (Hawley and Smith 1954).
2. Losses from windthrow are kept to a minimum (Hawley and Smith 1954).
3. It is profitable and efficient with the lowest production cost per unit of any harvesting system (Archie and Baumgartner n.d., Harris 1974).
4. One of the best methods for regeneration of shade intolerant species in even-aged stands is found in clearcutting (Hawley and Smith 1954).
5. This system is desirable for handling diseased or insect-infested stands (Harris 1974).
6. The method is simple and easy to practice (Twight 1973).

Several disadvantages of clearcutting are well known:

1. The clearcutting system temporarily destroys forest cover, changing the microclimate of the area (Hawley and Smith 1954).
2. The potential for disease and insect epidemics may increase in large, even-aged stands (Harris 1974).
3. Fire hazard is increased, and suitability of the area for some types of wildlife may be reduced (Hawley and Smith 1954).
4. There is a risk of deterioration of the physical properties of the soil (Hawley and Smith 1954).

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5. Clearcutting tends to reduce protection against erosion, landslides, snowslides and rapid runoff of water, depending on the care taken in planning the clearcut (Hawley and Smith 1954).

6. Aesthetically it is the least desirable of the harvesting systems used in the region (Hawley and Smith 1954).

7. In some areas and sites, regeneration may be difficult due to invasion of brush species or microclimatic changes (Archie and Baumgartner n.d.).

A number of lectural papers have addressed the question of the advantages and disadvantages of clearcutting. Other publications for reference include EPA Report #430/9-73-010: "Ecological Forestry for Douglas Fir Region," by Twight 1973; and "The Effects of Clearcutting and Burning on Water Quality," by Snyder 1973.

Clearcutting exposes the entire forest floor from stump level down to the direct impact of precipitation. The soil is protected by stumps, slash and duff to some degree even after yarding, but measures must be taken to protect the watershed to lessen this impact.

Streams within and below a clearcut may show water temperatures that vary considerably after timber harvest.

From Rothwell (1971):

> If clearcutting is employed, careful consideration should be given in the logging plan to size and distribution, both areal and temporal, of the cutting blocks. Generally speaking, increasing the size of clearcut blocks and shortening the cutting cycle will increase the potential for watershed damage.
>
> Considering a watershed as a whole, large clearcuts and a short cutting cycle concentrate the disturbance in area and time and increase the impact on watershed values. Furthermore, large cut blocks may create habitats that are difficult to revegetate, thereby extending the recovery period.

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Small cut blocks and longer cutting cycles may result in the same total amount of disturbance, but distribution in time and area reduces impact. In addition, residual vegetation maintains a forest environment and reduces and slows runoff, erosion, and the amount of sediment entering streams.

Selection is an uneven-aged silvicultural system in which trees are removed individually, on a dispersed basis, from a large area each year; ideally over a whole forest or working circle, but from practical considerations almost always over the annual groups of cutting series. Regeneration is mainly natural and the crop is ideally all-aged (SAF Term. 1971). A modification of this system in which trees are removed in small groups at a time is called the group-selection system.

Within the Pacific Northwest, the selection system is used mainly east of the Cascade Range and in southwest Oregon east of the coastal zone. Single tree selection tends to favor shade tolerant species, whereas group selection tends to maintain a higher proportion of the less shade tolerant species. The selection system frequently is used where continuous forest cover is needed in addition to maintaining an all-aged forest. The system is used in all regions subject to intense public use, such as campgrounds and recreation areas.

Some advantages and disadvantages of the selection system are listed below (Hawley and Smith 1954):

Advantages:

1. A high degree of protection is afforded the site as well as to the reproduction.

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2. Danger of windthrow of the trees is quite low.
3. The mixture of age classes tends to reduce the danger of outbreak of injurious insects and disease, as the environmental conditions are maintained in nearly constant state.
4. From the aesthetic standpoint it is the best system, owing to its picturesque uneven-aged form and the absence of anything approaching clearcutting.
5. For some types of wildlife, the group-selection modification is beneficial because of the balance between cover and food supply.
6. The selection method is the only practicable means of securing a sustained annual or periodic income on very small forest ownerships.

Disadvantages:

1. The system requires relatively light cuttings carried out at frequent intervals, which increases logging costs.
2. Because of the mixture of age classes, it is necessary to take extreme care to prevent logging injury to remaining stems.
3. The selection method has a tendency to favor reproduction of shade tolerant species over that of shade intolerant species unless modifications of the system are used.
4. Intensive application of the method requires great skill on the part of the forester and close supervision of logging. There may be a tendency to degenerate the system into a form of high-grading, which lowers the productivity of the forest.

The inherent characteristics of the selection system place it at the top of the four silvicultural systems with regard to maintaining high water quality when skilfully applied. The biggest drawback is the frequent return to the forest for the periodic or even annual cutting, resulting in small disturbances occurring with greater frequency than with other silvicultural systems.

To reduce the impact on water quality, all the recommendations in this section should be reviewed. In addition, care should be used to stabilize skid trails, landings and roads after each harvest (FWPCA 1970).

Shelterwood is an even-aged silvicultural system in which, in order to provide a source of seed and/or protection for regeneration, the stand is removed in two or more cuttings, the first of which is ordinarily the seed cutting and the last is the final cutting, any intervening cuttings being termed removal cuttings (SAF Term. 1971). The system is adaptable to a large number of species (Hawley and Smith 1974).

In the Pacific Northwest, the shelterwood system is used in the coastal stands of Oregon and Washington where it favors hemlock (Williamson 1966). In Alaska, shelterwood cutting experience is lacking (Ruth and Harris 1973). Recent trials using the shelterwood method have been successful in providing natural regeneration in portions of the high Cascades in Oregon as noted by Williamson (1973). Throughout the remaining regions, shelterwood is practiced to varying degrees, and it appears that it will be increasingly used as a silvicultural system. The regions east of the Cascade Range are characterized by a wide variety of climatic and biological factors. In some regions such as northern Idaho, a large number of tree species may be adaptable to the shelterwood system.

Some advantages of the shelterwood system include (Hawley and Smith 1954, USDA 1973):

1. Natural reproduction is more complete and certain than under other methods which create even-aged forests.

2. The average length of rotation can be shortened because one even-aged crop starts before the preceding one is harvested.

3. It is especially adapted to species or sites where shelter is needed for the new reproduction, or where the shelterwood gives the desired regeneration an advantage over undesired competing vegetation.

4. It is superior to all other systems except the selection method with respect to protection of the site and aesthetic considerations.

5. Slash disposal is less of a problem than with clearcutting or seed-tree methods because each cutting leaves less debris and shaded conditions reduce the danger of fire.

6. If handled correctly, the principle of retaining the best trees of the most desirable species as a seed source improves the characteristics of the future stand.

Some disadvantages include:

1. Intensive application of the shelterwood system requires markets for products of small size and low grade for full utilization.

2. The system cannot be applied in cases where isolated trees are unusually susceptible to damage by wind.

3. Greater technical skill is needed than for clearcutting or seed-tree methods, but probably less than equally intensive application of the selection method.

4. More frequent return to the area with its attendant disturbance of the forest cover is necessary than with clearcutting or seed-tree, but less so than with the selection system.

Because the shelterwood system disturbs the site less than all other silvicultural systems, with the possible exception of the selection method, its effect on the watershed is relatively low. Depending on the number of successive cuttings and the intervals of time between them, the major factor is the degree of cover disturbance at each return.

To reduce the impact of the shelterwood system on water quality, it is necessary to review previous recommendations noted under clearcutting and, as was the case for the selection method, to stabilize sources of water pollution after each successive harvest.

Seed-tree cutting method, not a true silvicultural system, is the removal in one cut of the mature timber from an area, save for a small number of seed-bearers left singly or in small groups (SAF Term. 1971). Only a small percentage of the original volume, ordinarily less than 10 percent, is left standing in the seed-trees. After a new crop is established the seed-trees may be removed in a second cutting or left. The retention of some trees on the cutover area is the distinction from clearcutting. In general, the method is applicable only to wind disseminated species that frequently bear large crops of seeds and can become established in exposed locations (Hawley and Smith 1954).

In the Pacific Northwest, the seed-tree cutting method was used much more extensively in the past, especially east of the Cascades, than at present. The method has been declining in use in favor of shelterwood or selection methods which are more advantageous and adaptable to various site conditions.

The advantages and disadvantages of using the seed-tree method are very similar in many instances to the clearcut method, but there are important differences as listed below:

Advantages:

1. As contrasted to clearcutting, with natural reproduction, it provide better control of the species in the new crop, since only desirable species are left for seed-trees. The supply of seed is also more uniformly distributed and may be even more abundant than when clearcutting is used (Hawley and Smith 1954).

Disadvantages:

1. There is serious danger of windthrow of the isolated seed-trees before they have restocked the cutover area. Therefore, windfirm species must be selected (Hawley and Smith 1954).
2. Seed-trees may be lost before they can be salvaged, and values represented may be substantial (Hawley and Smith 1954).
3. Unlike clearcutting, the seed-tree method is rarely applicable in stands of overmature timber because the individual trees may be too decadent to serve the purpose or too valuable to leave (Hawley and Smith 1954).
4. Scattered seed-trees may tend to self-pollinate, resulting in inferior seedlings or infertile seed.

Under this system, because it exposes the forest floor only slightly less than clearcutting, the effect on the watershed is quite similar to clearcutting. When it becomes necessary to return to the area to remove the seed-trees after their purpose has been accomplished, the ground is subjected to another round of logging with concommitant disturbance. For this reason, the period of water quality impact will often be longer than for clearcutting and of similar peak magnitudes.

Logging Method Selection

The selection of the logging method and its attendant equipment has depended in the past on the silvicultural system to be used, the type of equipment available, logging costs, the constraints of climate and soil conditions, and state or federal regulations. Just as the silvicultural system selection affects water quality, so does the selection of the logging method. Thus one element of timber management planning for water quality purposes should involve the evaluation and selection of logging methods that minimize adverse water quality impacts.

Lyson and Twito (1973) have enumerated some environmental and silvicultural criteria for determining the type of logging method to be chosen:

Environmental and silvicultural criteria

- Minimum landing area
- Minimum access road density
    - capability to yard extended distances
    - capability for uphill and downhill yarding
- Minimum soil and water disturbance, including soil compaction
- Minimum impact of fish, wildlife and range habitat
- Suitability for partial cuts and clearcuts
    - minimum damage to residual stand
- Suitability for harvesting irregular-shaped settings
- Suitability for clean yarding
- Minimum energy consumption and air pollution

Economic criteria

- Minimum yarding cost
    - maximum production per man-day
    - maximum production per invested capital
    - minimum maintenance
- Minimum sensitivity to yield per acre
    - minimum move-in cost
    - minimum set-up cost
- Maximum return on stumpage
- Minimum invested capital
- Maximum reliability

Physical criteria

- Minimum sensitivity to ground profile

Compatibility with the timber size
Minimum sensitivity to atmospheric conditions
Compatibility with health and safety codes
Compatibility with road restrictions

To illustrate the range of soil disturbance associated with the various logging methods, Figure 5-5 and Table 5-8, presented below, are taken from Dyrness (1972).

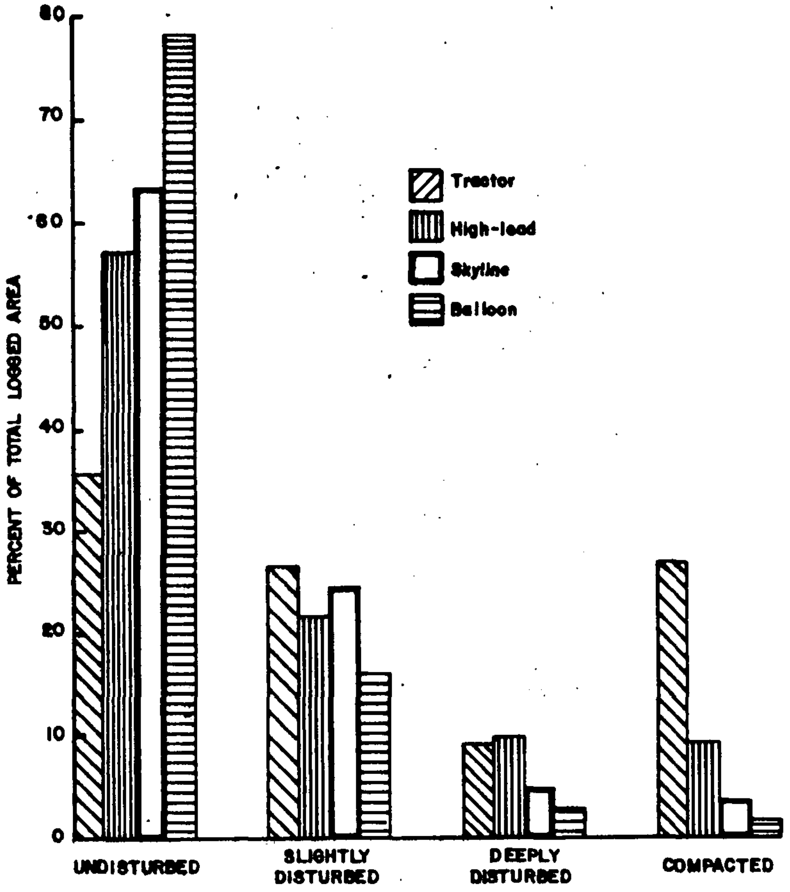

Figure 5-5. Soil Surface Condition Following Tractor, High-Lead, Skyline and Balloon Logging in the Western Cascades of Oregon (taken from Dyrness 1972)

Table 5-8

Effects of Log Transport System on Forest Soils

log transport system	percentage of logged watershed 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

Felling and bucking. The initial phase of a logging operation is the felling of the tree and then the bucking or cutting of the stem into suitable log lengths, either where the tree fell or at a log landing. Although this phase of the operation contributes a comparatively low impact to water quality, there are a few points that should be considered.

A number of felling patterns are in use, but one of the classic types is the herringbone pattern. Trees are felled at an angle of from 30° to 45° to the skid road. This practice tends to reduce damages to the residual stems, as well as to the forest floor, as it provides a better lead for the skidding machinery. Soil erosion, especially in the shelterwood and selection silvicultural systems, is reduced by correct felling patterns in connection with skyline logging in thinnings of Douglas fir on steep slopes.

Most trees are felled using power saws or a feller-buncher machine. Where individuals cut the trees, an assist by cables or hydraulic jacks is often given. For instance, Burwell (1970) noted:

> Felling trees uphill using a truck-mounted donkey

> and climber to attach the line, prevents breakage and distributes limbs and tops on slopes instead of in stream bottoms. Costs are two to three times those of comparable conventional cutting. Savings include the intangibles of increased safety, lessened breakage, reduction of slash to eliminate burning and enable quicker regeneration, and reduction of expensive creek cleaning. These may more than offset additional costs. (Author's abstract).

Hydraulic jacks accomplish the same task and are probably less time-consuming and more flexible to use, depending on conditions involved.

McGreer (1974) reported that in a study in western Oregon, "conventional felling added an average of 47 tons of debris per 100 feet of stream whereas cable-assist felling added only 14 tons per station, thus demonstrating its applicability as a stream protection technique." He also noted that stream debris removal costs were fairly low for the observed buffer strips. With conventional felling treatment, cleanup costs average about two and one-half times that of cable-assist felling.

Construction of beds to minimize breakage of large heavy trees (Sommer 1973) has been used in the past, and renewed interest in this technique is being shown. Besides a value loss if the trees break up into unusable pieces, this debris may slide downhill into stream bottoms, eventually causing dams and possible flushing downstream to cause further damage.

The cutting of high stumps (high-stumping) is sometimes done to keep upslope felled timber from rolling into streams. Lane (verbal communication, 1974) noted, however, that this practice used occasionally in western Oregon has not always proven to be a good technique because of other associated problems.

Limbing includes the removal of branches and unusable portions of the top of the tree. If accomplished before skidding or yarding, soil disturbance and subsequent soil erosion is minimized. The disturbance may be of somewhat less consequence on snow-covered or frozen ground.

A combination of the feller-buncher machine and grapple skidders may preclude limbing until the logs reach the landing. A "harvester"-type machine, which fells the tree, feeds tree lengths through a delimbing device and bunches them for skidding, is fairly new and is at present limited by terrain and timber size.

Tractor. Tractors, including track-laying types and rubber-tired wheel skidders, are used in all parts of the Pacific Northwest. Wheel types are more common in eastern Washington and Oregon, the Intermountain region, Blue Mountains, Okanogan and northern Idaho than in Alaska and western Washington and Oregon, due to maximum efficiency in the less dense timberland of these regions. However, the track-laying type is a more versatile machine and can be used for jobs other than skidding.

If care is not used, both machines result in soil disturbance and consequent erosion. In moist soils, the wheel skidder is generally the worst of the two in compacting soil, as the tracked type has more flotation. Winch lines reduce skidding distance and reduce ground disturbance in marshy areas. A sound rule of thumb is to limit these machines to less than 30 percent slopes. Special conditions must be used on steeper slopes. If pre-built skid trails are not necessary, the use of wheel skidders is advantageous since less of the soil mantle is disturbed.

The feller-buncher, which shears the tree from the stump and bunches the stems for skidding or loading, is becoming popular for use on the gentle slopes. Tracked or wheeled types are available. Very little if any research has been done in the Pacific Northwest concerning soil mantle disturbance with this machine. However, the soil disturbance apparently increases over conventional saw felling. The feller-buncher must maneuver up to each tree to be felled and thereby covers more of the cutting area than skidding machines. Most of the comparative ratings of the various types of logging equipment list the tractor as causing the greatest soil mantle disturbance.

High-lead. High-lead, one of several cable logging methods, is used mainly in clearcutting and is found almost entirely on the west side of the Cascade Range and in Alaska. Of the cable logging methods, it is responsible for the greatest degree of soil disturbance. Nevertheless, the disturbance is much reduced as compared to tractors. This is especially true on a comparative basis if high-lead yarding is conducted uphill. The resultant pattern of yarding paths radiates down and out from the landing, tending to disperse runoff evenly over the slope. The erosion potential is considerably reduced (Rothwell 1971). Tractors skid downhill and the resultant skid trails converge at the bottom landing, concentrating runoff. The high-lead method can operate on steep slopes, but is not as flexible as other skidding equipment. Care must be taken in planning settings to avoid yarding across streams and of filling intermittent stream beds with debris which if not removed may sluice out later into downstream waters.

Skyline. Basically there are three types of skylines: tight line, slack line and the running skyline. Several modifications of each of these types as outlined in an earlier section are in use, but all are cable systems.

Their greatest use has occurred west of the Cascade Range and in Alaska, primarily on clearcuts. More recently they have been used in other parts of the Northwest on all types of silvicultural systems. Some forms are adapted for thinning stands of small trees and low volumes. Efficient interlock mechanisms have helped to increase their popularity. Suspension of at least one end of the log reduces soil mantle disturbance.

Skyline logging is normally rated ahead of high-lead and tractor logging in terms of watershed impact. Skyline logging, especially the running skyline, is improving steadily with the development of more mobile and versatile equipment. The fact that the skyline method can be used in partial cuts would indicate that the shelterwood and selection silvicultural systems may be used more intensively. These are the systems with the least effect on water quality. Lyson and Twito (1973) have suggested that the running skyline may become the primary logging system where there is need to operate economically and to reduce the environmental impact of timber harvesting.

Idaho jammer and shovel skidder. These machines use the cable system and are mounted on tracks or wheels. They are not widely used west of the Cascade Range. Shovels with an average yarding distance of 75 feet are used to skid right-of-way timber. The Idaho jammer is gradually fading from use in northern Idaho and the Intermountain region. Used both in partial cuts and in clearcuts, it has an average skidding distance of about 450 feet and is used mostly on the steeper slopes in place of tractors. Skidding with jammers necessitates a fairly extensive road system, but the skidding of the logs causes less disturbance to the soil mantle than tractors.

Megahan and Kidd (1972) compared the effects of jammer and skyline logging systems and reported:

> Erosion plots and sediment dams were used to evaluate the effects of jammer and skyline logging systems on erosion and sedimentation in steep, ephemeral drainages in the Idaho Batholith of central Idaho. Five-year plot data indicated that no difference in erosion resulted from the two skidding systems as applied in the study. Sediment dam data obtained concurrently showed that the logging operations alone (excluding roads) increased sediment production by a factor of about 0.6 over the natural sedimentation rate. Roads associated with the jammer logging system increased sediment production an average of about 750 times over the natural rate for the six-year period following construction.

Balloon. The balloon method of logging is of fairly recent origin and has been tried in various parts of the

Pacific Northwest.

An EPA publication concerning pollution from silvicultural activities reports (EPA 1973):

> Balloon logging: Gardner, Jacobsen and Hartsog (1973) 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 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 feet) apart but they must be downhill and therefore may be a hazard to streams.

The primary concern of many operators is the failure of the balloon fabric, loss of helium, snow and wind hazard and the high initial cost of approximately $500,000 (Peters 1973). More experience and study of this system is needed before its place in logging methods is established.

Helicopter. Another recently developed logging method is the helicopter, which is in effect an extremely mobile and flexible yarding machine. Helicopters have been used in almost all parts of the Pacific Northwest. Much more experience with them is needed to determine their contribution to preventing water pollution.

Their extremely high hourly operating costs, often $500 to $2,000 (Burke 1973), weather restrictions, altitudinal limits, and lack of suitable landing locations are the main disadvantages of the use of helicopters. Nevertheless, their obvious potential for minimizing pollution is substantial.

Helicopters can be used in any type of silvicultural system, but may be best suited for certain types of applications, including removal of insect- or disease-damaged trees, high timber values, inaccessible areas, widely scattered pockets of high-value trees, areas of fragile soils, or where aesthetics cannot be protected by other means.

The helicopter rates at the top in causing the least amount of soil disturbance of any logging system. However, log landings and helicopter service pads are potential water pollution sources.

Where helicopters are used to eliminate unjustifiable road building costs or in inaccessible areas, these log landings and servicing pads are generally difficult to locate and are often near vulnerable streams. Indirectly, the independence of this logging method from the road system may subject the area to later problems in residue management, reforestation, fire control and other silvicultural and administrative work.

Horses. Horse logging is the oldest method used in the region. Early-day logging made use of the ox and the horse, both of which faded from use for obvious reasons.

Lately there has been a minor revival of the horse in all parts of the study region. The horse is limited to skidding on slopes of less than 20 percent and to the weight of the log being skidded. The animal is often more economical than other logging methods in selection-type cuttings where aesthetic values must be maintained, and in thinning young stands of timber. The horse's impact on water quality is very low, as noted in a study by Garrison and Rummell (1951) which compared the various effects of horse, cable and tractor logging on soil disturbances and impacts on grasses, shrubs and weeds in ponderosa pine rangelands of Oregon and Washington.

Control

This section deals with the measures that can be taken to limit the water quality impacts after the particular forest practice has taken place. Although planning and knowledge of the various factors which lead to water pollution will reduce the need for control and remedial measures after the forest practice has been carried out, post operation control is also important.

Reducing the amount of residue or slash, which can impact water quality, from a previously logged area can be beneficial. However, it is often economically infeasible unless some of the material can be utilized.

Yarding unmerchantable material (YUM) is sometimes profitable when market conditions are favorable. The unmerchantable material can be converted to pulp chips at the site, or in special situations hauled to the mill for log fuel and energy conversion. It also may be chipped for on-site use, and by spreading or incorporating it into the soil, erosion potential can be reduced. These systems are generally employed on clearcut areas. In the Pacific Northwest, this method is practiced mainly west of the Cascade Range where the volume of debris is high, such as in old growth coastal Douglas fir or western hemlock-Sitka spruce types. If the material is not chipped, it can be burned at the landing.

Another ~~method adapted to clearcut or seed-tree~~ systems is chopping, crushing or masticating the slash with a variety of machines designed for the purpose. Decay of the material is hastened and the residue is mixed with the top few inches of the forest floor. Soil erosion is reduced and overland flow of soils is limited. Burying of residues has been used but will probably be limited to right-of-ways and for aesthetic reasons. Unless burying sites are picked with care, this method can increase the area of soil surface disturbed. All of these aforementioned systems reduce potential blockage of streams by debris, but they also disturb the soil mantle for the second time.

Dozer piling or windrowing of slash is used to a large degree for disposal (see Fig. 5-6). The piles are generally burned, but windrows are sometimes left to enhance protection of reproduction (U. S. Navy 1973). During dozer piling, care should be taken to avoid burning residual trees and to insure that subsequent burned material will not drain into streams. Under certain conditions where piles were burned under a light snow cover, wood tars entered a municipal watershed. It is sometimes necessary to modify or change bulldozer slash disposal operations on steep slopes to reduce soil disturbance that results from continuous downhill piling of slash (Bitterroot Report, USFS 1970). Both of these residue management methods disturb the soil mantle. The tradeoff involves the possibility of further erosion as against reduced wildfire hazards and better preparation for revegetating the site.

Dispersal of slash over the area by machine or limbing and scattering by hand is practiced for the most part on

(Photo will print in finished report)

Figure 5-6. Bulldozer Piling of Slash

Bulldozer piling of logging residues, while sometimes necessary for site preparation, further disturbs the soil mantle and often requires additional measures for erosion control.

partial cuts where the main objective is fire hazard reduction. In clearcuts of lodgepole pine, dispersal may be used as a reforestation technique with subsequent burning which opens the serotinous cones for seed dispersal. Dispersal of slash may be required by state regulations in some sub-regions under certain conditions in order to reduce fire hazard (States of Idaho, Washington and Oregon), but it is also helpful in reducing soil erosion by creating small sediment dams more uniformly over the logged area. The depth of the slash is also reduced, which can facilitate regeneration. With some tree species, the logging residue may aid regeneration by providing shade and protection.

Broadcast burning has been one of the most widely used methods for reduction of woody residues on clearcuts. It is usually necessary to construct firelines around the area before burning. The FWPCA (1970) advised these precautions to limit water pollution from firelines constructed as part of the slash residue management activities:

> Limit tractor-built firelines to areas where they will not involve problems in soil instability.
>
> Adequately 'cross-ditch' all firelines at time of construction and revegetate them with adapted grasses and legumes.

Rosgen (1973) added:

> Construct hand lines instead of dozer lines for fuel breaks on steep, erodible slopes and adjacent to stream buffer strips.

Packer and Williams (1974), in a study of larch-Douglas fir forests in the Northern Rocky Mountains, concluded:

Results of this study show that the jammer type logging employed on these timber harvest units produces changes in surface soil properties and vegetative characteristics that enhance the hydrologic and soil stability performance of larch-Douglas fir watersheds on Belt series soils. They also show that prescribed burning exerts effects on these same soil properties and vegetative characteristics that are detrimental to watershed performance for runoff and soil erosion control. This impairment of watershed protection conditions and the attendant increases in runoff and erosion appear to be of a rather temporary nature, recovery occurring within only a few years. A possible exception of this conclusion may be the south-facing aspects, which, being the driest aspect, suffered the most intensive burns, exhibited the most adverse effects to soil and vegetative characteristics as a result of burning, and responded most poorly in the improvement of these characteristics during the 7 years following burning. It is believed that the south aspects still remain in a more delicate runoff and erosional balance than any of the other aspects.

Finally, the soil erosion behavior of the logged-burned units appears to be related more to the amount of total protective cover on the ground and to the magnitude of climatic events than to any other measured site factors. The effects of logging and burning on protective cover conditions and their subsequent change with time can be predicted. The magnitude and recurrence interval of climatic events capable of generating overland flow and soil erosion on logged and burned watersheds are not so readily predictable. There is no question that logging and prescribed burning on gentle to moderately steep slopes of larch-Douglas fir watersheds on Belt series soils creates a runoff and soil erosion hazard. The moderate degree of this hazard and the relative rapidity with which it declines indicate that, with the possible exception of south-facing aspects, this type of treatment is probably not permanently damaging to the watershed protection characteristics of these forests. The extent to which this conclusion applies on steeply-sloping watersheds is being investigated on Newman Ridge in the Lolo National Forest in western Montana.

The Western Forestry and Conservation Association (1972) included the following, concerning prescribed burning, as to information needed on this subject:

1. Predictive models to enable the manager to select a burning schedule for a given set of conditions,

topography, and other relevant factors, that will result in the minimum environmental impact.

2. A knowledge of the conditions under which natural accumulations of fuel occur, the rate of accumulation, and how the organic material can be reduced without burning.

3. Decision models that will assist the manager in evaluating the consequences of his selection from alternatives open to him, including the calculation of the probabilities of fire escape as part of the models.

4. More intensive studies to determine the effects of fire on forest ecosystems over time, and the effects of non-burning as well.

Prompt revegetation of forest land for control of soil erosion and reduction in water pollution has been expounded for many years by the U. S. Forest Service, Soil Conservation Service, State agencies, private industry, and research institutions. It is one of the most important methods of post-operation control available. Residue management is an integral part of revegetation and most often the covering of the exposed soil with trees and herbaceous plants is the end result of residue management.

Reforestation efforts often require some type of site preparation to receive the seedling trees or seed. The main types of site preparation involve the use of fire, chemicals, and mechanical means.

Chemicals are used in site preparation in some parts of the region to reduce or eliminate competing herbs, grasses and shrubs. This study is not directed to the control of water pollution resulting from the application of forest chemicals, so mention is made here only to alert the reader to the fact

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that reforestation includes this method of site preparation.

Mechanical methods of site preparation during the last ten years have included: scarification, stripping, and terracing (Packer 1971a).

Machine scarification can be accomplished and still leave duff and small portions of woody material to provide adequate cover over most of the area. Alternatively, debris can be spread in irregular patterns over the site. Packer (1971) shows that by creating depressions, this kind of treatment usually increases the storage capacity of the land, but seldom increases the overland flow and soil erosion hazard. Avoiding excessive scarification will reduce the impact on the watershed (Rosgen 1973).

Stripping involves removal of long strips of competing vegetation along the contour of the land by tractors. The strip is generally narrow for hand planting. Interruption of ground water flow and control of soil mantle disturbance is inherent in the narrow width. Furrows constructed along the strips may impart greater control. Packer (1971) cautions that, "in preparing sites that slope directly to stream channels, untreated ground should be left (as a buffer to water and soil movement) between strip sites and the stream."

The type of terracing used today was initiated in southern Idaho (USFS Intermountain Region) and is commonly used on dry, moisture-deficient, often erosive soils. The sites may have a heavy cover of brush or contain unusually steep slopes. Some terraces result in a contour bench while others

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are built to slope slightly inward. Packer (1971) states little erosion has resulted since its first use in southern Idaho. A U. S. Forest Service task force appraisal (1969-1970) on the Bitterroot National Forest found few signs of serious erosion on most of the terraced slopes but cautioned that long-run erosion could not be determined as yet. Data regarding slope, geologic origin of material and hydrologic processes--including subsurface flow characteristics and soil mechanics--should be obtained before selecting areas to be terraced.

After site preparation, planting is initiated as the control desired. Hand planting or seeding, aerial seeding, or auger planting generally entail truck transportation. Machine planting requires tractors with some potential for further erosion if the planting is done a year or more after post-harvesting stabilization, a subject treated in the next sub-section.

Immediate reforestation of the harvested area is usually desirable. Washington and Oregon state forest practice regulations now require regeneration within one to six years, depending on the region and type of regeneration. The Washington Act also prohibits the use of heavy equipment for site preparation under certain conditions of soil type or soil moisture and water areas. A number of regulations address the practice of terracing or contouring, particularly with respect to water drainage. As of March 1975, the Washington State Forest Practices Act has not been finalized regarding

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terracing and contouring.

The Weyerhaeuser Company has initiated a program of "High Yield Forestry" and accelerated reforestation with a goal of regenerating the harvested areas within a 12-month period. Although the program involves much more than is noted herein, attention is brought to the idea of quickly revegetating the harvested area, which in turn reduces the impact of logging on the watershed. The program includes:

1. containerized seedlings
2. hand planting within one year after harvesting
3. soil surveys for site determination
4. planting during the winter
5. seed selection from similar sites
6. planning coordination between harvesting, nursery planting and reforestation

Of critical importance in preventing or limiting water pollution from forest operations is the stabilization of the surface of the land after it has been subjected to a high degree of disturbance. Measures taken at this stage of management must necessarily compensate for mistakes made in planning the original operation. By the same token, good planning and close supervision of the forest management activities will minimize the need for extensive post-harvesting measures. Although post-harvesting implies a final note to logging operations, one must recognize that it may be necessary to institute many of the guidelines which follow on a progressive basis as the forest activities proceed or when temporary shutdown of activities continues for a period of a few weeks or months. It also includes any activity which disturbs the watershed and not just that due to logging.

Ground skidding of logs by tractive type machines entails the building of skid trails or skid roads. The furrows which result during skidding are a main source of runoff and erosion. Some types of cable systems using downhill yarding or skyline systems with one end of the log dragging create a similar type of disturbance. Cross drains, also called cross ditches or water bars, are frequently used as a method of control after logging. A number of guidelines for the spacing of cross drains are available and depend on such things as climate, soil structure, topography, parent rock and percent grade. Each user must obtain additional information as to suitability of his particular area, as well as the conditions, before using any one guide. The drain can be constructed with a bulldozer, or at times, hand-shoveled. Log water bars can also be used in place of a ditch as described by Kidd (1963).

Sopper and Hull (1967) maintain that:

> ...logging or skidding of logs from forests can sometimes increase sedimentation considerably, depending upon the location and drainage of skidways, the erodibility and stoniness of soils, and the rapidity of revegetation of skidways; roads that are inadequately drained or are located too close to streams are the main cause of deterioration in forests.

A series of water bars that divert runoff onto undisturbed vegetation will help reduce accumulation of the runoff on skid roads and landings (Rothwell 1971). Rothwell also suggests a useful rule for spacing cross drains: the distance between each structure in feet should be equal to 1000 divided by the percent of road grade. Care should be taken when applying this rule of thumb by considering the factors mentioned previously.

Snow or frozen conditions can pose special problems in constructing water bars on skid roads or spur roads. In Alaska, northern Idaho, the Intermountain, Blue Mountains, eastern Oregon, and Washington and the Okanogan sub-regions, logging on the snow or on frozen ground is common. If the snow is deep or ground frozen, skid track may not be apparent, but often times warmer conditions prevail for periods of time and the soil mantle becomes incised. At the termination of logging, snow may have recovered the area or machines cannot adequately cross ditch. During the spring melt, it may be impossible to return to the harvested ground and runoff damage can be severe.

Occasionally, skid roads may have temporary fills. Various types of culverts will be placed in them, and for all practical purposes, they become a temporary road. Rosgen (1973) suggests removing this type of structure at the termination of logging or prior to expected seasonal runoff.

Skid roads can be revegetated and more will be discussed about this at the end of the section. Slash dams or lopping and scattering of slash in skid trails may be helpful (Kidd 1963).

Log landings are an important source of sediment and require post-operation stabilization. The following procedures may be used:

> Landing fill, like road fill, is an accumulation of unstable, loose soil highly susceptible to erosion. Cribbing, using cull logs or seeding and mulching can impart a degree of stability to the fill (California Water Resources Board).
>
> Upon abandonment, 'erosion-proof' all landings by adequately ditching or mulching with forest litter, as needed. Establish a herbaceous cover on those areas that will be used again in repeated cutting cycles and restock to coniferous species those landings, located in clearcut areas, that will not be reused for a long time, if ever (FWPCA 1970).

Oregon State Forest Practices Rules state: "Leave or place debris and reestablish drainage on landings after use to guard against future soil movement."

The following measures can be used on spur roads and skid roads which may approximate spur roads (Rothwell 1971):

> Secondary roads that are closed or seldom used should be 'put to bed', i.e., provisions should be made for erosion control. Open-topped culverts should be replaced with cross drains to control and direct runoff from road surfaces. In the spacing of cross drains, guides outlined should be followed. Steps to follow in the construction of cross drains are:
>
> 1. Excavate roadbed to a minimum depth of 6 inches next to the cut bank and 8 inches at the road edge, with a definite adverse grade on the downgrade side of the cross drain.
> 2. Spread excavated material on the roadbed below the cross drain to a depth of not more than 3 inches.
> 3. Extend the cross drain to the full width of the road so that water drains downhill from the toe of the cut bank to the shoulder.
> 4. Tie the cross drain into the cut bank at the upper end of the cross drain.
> 5. The long axis of the cross drain should form an angle of not less than 30° with a line perpendicular to the center line of the road.

> After logging operations, logging roads should be completely closed to travel. Where this is not feasible, traffic should be regulated, especially during wet weather when roads are easily damaged. Periodic inspections for damage and necessary repairs should be made.

Streams, especially the intermittent type, may become plugged with logging debris. When dry streambeds become plugged, they may eventually sluice out, causing problems further downstream. State forest practice rules generally are written to avoid this occurrence. It may be necessary to remove material by machine methods which will not further disturb the channel and banks. Hand methods will also be required in some instances.

Suggestions concerning how much debris should be removed have been proposed by Rothacher (1960):

> The author points out problems associated with the question of where logging debris should be removed from streams. He suggests that if a stream is fed by a watershed larger than 40 acres, logs and chunks should be withheld from the stream or removed before the winter flows.

The Washington State interim forest rules refer to not removing deadfalls which are firmly embedded in the bed of certain classes of streams without the permission of the Department of Fisheries and Game.

Wastes from machinery used in logging include oils, fuels, filters, containers, pieces of metal and wire rope. All may contribute to pollution of the watershed. Removal of these items is required by some states in the Pacific Northwest. According to most public health agencies, human sanitation facilities should be removed and wastes neutralized.

The use of catchment and sediment ponds in post-harvesting rehabilitation are generally used in connection with the road system.

Revegetation is one of the best control measures that can be used for stabilization of the land. Its most negative feature is the time period for it to become effective. Returning the cover to the exposed soil is essential whether it be in the form of trees, shrubs, herbs or grasses. The type of plants to be used and instructions in seeding or planting can be obtained from a number of federal and state agencies concerned with the management of natural resources. Exposed soil can also be stabilized through soil binders, mulching and light terracing (FWPCA 1970).

In all control work, supervision is very important. The success of any forest management program will be limited by the quality of the field application and the ability of field personnel to handle special problems that emerge during the operation.

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