CUMULATIVE EFFECTS OF FOREST PRACTICES ON THE ENVIRONMENT

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Brian Boyle · Commissioner of Public Lands
Art Stearns · Supervisor

CUMULATIVE EFFECTS OF

FOREST PRACTICES ON THE ENVIRONMENT

A STATE OF THE KNOWLEDGE

Compiled and Edited

By

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FOREWORD

Terrestrial and aquatic ecosystems are dynamic systems providing a moving target for the learning curve on which we attempt to single out specific problems and solutions. This is an on going reiterative process tempered by social and economic perceptions. There are few absolute answers to the questions of past and future forest management. What we know best is what happens today.

This report on cumulative effects is today's experience on the subject. It is not intended to be all inclusive. It represents the first in what could be many steps to understanding how forest practices interact with air, earth, water, flora, and fauna to produce anticipated changes in the environment.

At a minimum, this report will increase the reader's awareness of cumulative effects. At a maximum it will bring about progressive change in the way forest managers perceive their problems, cause researchers to work more closely with forest managers and administrators to fill data and knowledge gaps, and provide administrators with new perspectives on environmental effects of forest practices.

ACKNOWLEDGMENTS

This study has been made possible through the generosity, patience, and personal committment of many people.

First and foremost, we would like to thank the Washington Forest Practices Board for their progressive thinking in identifying the subject of cumulative effects as a concern fundamental to the future management of Washington's natural resources.

Forest Practices Board Members

Brian Boyle - Chairman; Commissioner of Public Lands
Claudia Michalke - Representative of the Public
John McMahon - Representative of the Public
H. A. "Buzz" Chevera - Representative of the Public
Ben Hayes - Representative of the Public
Harold Brunstad - Independent Logging Contractor
Ben George - Forest Land Owner
Roy Lumaco - Kittitas County Commissioner
M. Keith Ellis - Director, Department of Agriculture
Donald Moos - Director, Department of Ecology
Merlin Smith - Representative, Department of Commerce & Economic Development

Second, we want to thank the organizations that funded the project:

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Northwest Fund for the Environment
Washington Environmental Foundation
Steelhead Trout Club of Washington
Federation of Fly Fishers
Northwest Steelhead and Salmon Council of Trout Unlimited, the chapters of:

South King County	Bremerton
Yakima	North Shore
Upper Columbia	Des Moines Salmon
Lake Stevens	Bellevue-Issaquah
Grays Harbor Men	White River

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Gene Nielsen, Central Area Manager, DNR, and former Executive Secretary of the Board.

M. Robert Dick, Director of Forest Management, Washington Forest Protection Association.

READER'S GUIDE

This guide is offered as a means of orienting the reader to the location of specific information. In conjunction with the Table of Contents, this guide should allow the reader to find subjects of special interest. The Executive Summary contains the salient points of the study.

Chapter 1 introduces the project, outlines its purpose, and develops the historical background that lead to its need.

Chapter 2 describes the goals and objectives of the project as contained in our proposal to the Forest Practices Board dated January 14, 1982.

Chapter 3 describes the methods used to collect published and unpublished literature, interview key people, discuss preliminary findings at a one-day workshop, and review of draft material by a technical panel.

Chapter 4 explains our definition of cumulative effects, forest practices, and elements of the environment.

Chapter 5 explains how forest practices interact with the environment to cause direct and indirect cumulative effects.

Chapter 6 discusses our findings and conclusions.

Chapter 7 contains our recommendations.

A glossary of terms used in the report follows Chapter 7. Additionally, a bibliography of literature cited in the text follows the glossary. Several Appendices are attached containing detail too voluminous to be conveniently included in the text.

ECOSYSTEMS TEAM

This report was prepared by Ecosystems, Incorporated (EI) using an interdisciplinary team of 11 people with expertise in forest practices, air, earth, water, flora, fauna, and systems ecology.

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Special acknowledgement is given to Bruce R. Grogan for preparation of the historical development of cumulative effects, primarily in California (Appendix B); to Dr. Peter T. Haug, Systems Ecologist for assistance in making a logical "whole" out of the sum of the "individual parts"; to Rainer Muenter and Dr. Wolfhard Ruetz for assistance in locating and reviewing pertinent European literature; and finally to Joanna Barnes, our office manager, without whom there would be nothing to read.

TABLE OF CONTENTS

Table of Contents cont...

LIST OF FIGURES

Figures cont....

EXECUTIVE SUMMARY

Washington State has a surface area of 42 million acres of which 18 million or 43 percent is commercial forest land. From about 1820 to present many of these forests have been commercially harvested once and sometimes twice with even a few now in third growth. As a result of these forest practices, the character of the environment has changed. Whether these environmental changes accumulate in time and space is a concern to the Forest Practices Board (FPB).

In 1982 the FPB commissioned a study to:

1) derive a broad yet useful definition of "cumulative effects",

2) develop a first approximation of the nature, source, and extent of cumulative effects, and

3) provide direction for future study of cumulative effects.

These three goals were satisfied through an extensive review of the natural resources literature and interviews with forest managers, researchers, and administrators.

The study was conducted by an interdisciplinary team of 11 specialists with expertise in air quality, hydrology, fisheries, wildlife, systems ecology, forestry, geology, and plant ecology.

The literature search discovered ten documents that focused on cumulative effects of forest practices on the environment. None of these documents were the product of scientific research but rather were discussions of perceptions and proposed methods for analyzing effects on soil and water. The most prominent source of literature was California where the US Forest Service has selected cumulative watershed impacts (soil and water) as issues of concern. In Washington, only the Department of Natural Resources draft forest land management plan and accompanying environmental impact statement contained any recognition of anticipated cumulative effects from proposed forest practices.

After examining these documents, it was concluded that a more detailed analysis of the subject was necessary in order to provide the FPB with a useful product. To this end, the forest practices and elements of the environment were compartmentalized into discrete units and the factual and theoretical potential for cumulative effects examined based on a broader review of the natural resources literature. During the literature review period 107 researchers, forest managers, and administrators from seven states and three countries were also interviewed for their experience, training, and perceptions on cumulative effects.

Information collected from the literature review and from the personal interviews was used to develop hypotheses on cumulative effects. These hypotheses were discussed at an all day workshop attended by 31 researchers, forest managers, and administrators. Many of the workshop attendees were people interviewed earlier in the project. The workshop assisted in narrowing the focus of cumulative effects to specific issues. At this stage in the project the literature was again reviewed but this time for specific information that would confirm or reject information collected in all of the previous steps. From this second literature search factual and speculative conclusions regarding the nature and source of cumulative effects were developed. However, no estimates of the extent of cumulative effects were developed.

Cumulative effects are defined as:

Changes to the environment caused by the interaction of natural ecosystem processes with the effects of two or more forest practices.

The key to this definition of cumulative effects is the requirement of interaction between effects of multiple forest practices. A cumulative effect occurs whenever an environmental change caused by a forest practice interacts with environmental change(s) from other forest practices. If environmental effects of individual forest practices do not interact, there are no cumulative effects. Interaction may be additive (accumulate), subtractive, or synergistic.

Multiple forest practices include all possible combinations of the many diverse types of forest practices that may be ongoing within a forest (timber harvest, road construction, site preparation, etc.) as well as combinations and repetitions of the same type of forest practice. These forest practices may occur on the same site over time, or be widely dispersed within the forest, occurring simultaneously or in a sequential manner. In brief, there are no combinations of practices that are not multiple forest practices.

Since all effects are not cumulative, there must be another category of environmental change. Environmental change caused by a forest practice which does not interact with other changes from additional forest practices is defined as an "individual effect". All environmental changes caused by man are either individual or cumulative effects. Environmental change that occurs naturally is part of the natural baseline.

Cumulative effects are either temporary or persistent. Temporary cumulative effects will recover at some time within the forest management time frame with the affected element of the environment returning to its baseline condition. On the other hand, the change to the baseline caused by a persistent cumulative effect will continue as long as the forest practices that cause this change continue without modification. Restoration of persistent cumulative effects via natural ecosystem processes is slow and continually aggravated by additional forest practices. Persistent cumulative effects are probably more important than temporary ones and they are emphasized in this report.

The definition of cumulative effects relates changes in the elements of the environment to forest practices as the cause. Forest practices means any activity conducted on or directly pertaining to forest land and relating to growing, harvesting, or processing timber. These practices were categorized under the headings 1) Timber Harvest, 2) Road Construction, Maintenance, and Use, 3) Site Preparation, 4) Reforestation, and 5) Stand Maintenance and Protection. These practices cause changes to the five elements of the physical environment; air, earth, water, flora, and fauna.

Information gathered from the interviews and the literature review were combined to determine the effects on the environment caused by the most common forest practices. Discussion of cumulative effects describes which forest practices would most likely result in cumulative effects. Although extensive, this review was not all inclusive and forest practices that were considered minor, or for which no information was found, are not discussed.

In the discussion, conclusions are presented about the potential of specific forest practices causing cumulative effects and are meant to focus attention on these issues. They are our best estimate of potential cumulative effects and there is a need to further examine and test each of these conclusions and to add others where appropriate. Whereas potential cumulative effects are described, the consequences of either controlling them, or allowing them to continue was not determined. Both options have social implications that only the FPB can balance.

The major conclusion of this study was, "yes", there is a potential for cumulative effects from current forest practices. Also, if it is socially desirable, control of most, if not all, of these cumulative effects is possible by manipulating future application of forest practices in time and space. However, zero environmental effect can never result from forest practices. The steps necessary to control cumulative effects are:

1) identify cause-effect relationships,

2) identify which practices cause which effects,

3) rank cause-effect relationships for importance as environmental hazards,

4) assess importance of forest practices having adverse impacts and evaluate costs of alternatives,

5) balance trade-offs between environment, alternative forest practices, and social benefits derived, and

6) decide on acceptable environmental changes and regulate accordingly.

Steps one, two, and three have been addressed in this study.

Determination of persistent cumulative effects requires a knowledge of how practices are applied, where practices are located, and when they are carried out. Whether an individual change to any element of the environment becomes cumulative depends upon the balance of three variables:

1) the magnitude of change,

2) the rate of recovery from the change, and

3) the frequency of subsequent forest practices and their resultant changes.

Cumulative effects are not a universal phenonmenon, but are site specific and depend upon the interaction of time, space, and practices. Determination of whether or not a change becomes a cumulative effect requires addressing the following questions:

1) What properties or processes are changed by the forest practice?

2) What is the relative magnitude of change and its direction?

3) What is the duration of the effect?

4) What interaction with other changes is likely to occur?

5) Over what time and space frame are forest practices occurring?

Because future forest practices must occur before many cumulative effects will develop, forest practices were often extrapolated forward in time in order to speculate on environmental change several rotations into the future. Where this was done, the timing and location of future forest practices was based on an interpretation of current trends.

Three groups of practices have the highest potential for causing cumulative effects:

1) Forest practices that physically disturb or alter the soil, principally related to forest roads and timber harvest.

2) Forest practices that remove excessive quantities of biomass, principally high utilization harvesting often combined with short rotations, and site preparation.

3) Forest practices that change the composition and structure of flora, principally timber harvest and short rotations.

Within the first category, forest roads and timber harvest are forest practices that cause greatest disturbance to the soil. They accelerate erosion, increase the frequency of debris avalanches, and result in water quality degradation and a change to aquatic habitat. These practices also alter the timing and volume of runoff. Of these two practices, the environmental effects of road construction, use, and maintenance are the most persistent and constitute the greater potential for causing cumulative effects.

The second category consists of practices such as whole-tree harvest, prescribed fire, and short rotations that remove nutrients, accelerate nutrient leaching, and reduce the size and quantity of dead and down woody material. These changes can effect the future productivity of both flora and fauna. Of these practices, whole-tree harvest combined with short rotations has the greatest potential for causing cumulative effects. Cumulative effects likely to result include a gradual decline in available nutrients and other alterations in forest soil properties, a reduction in productivity of forest trees causing changes to both forest structure and composition, and a decline in quantitites of woody material in the soil causing changes to soil biology.

The last category consists primarily of forest practices involved in converting unmanaged forests to managed forests and include even-aged management using short rotations, selection harvest, artificial regeneration, and animal and disease control. These practices cause a shift from old growth forests cycled by wildfire, windthrow, and disease, to young forests cycled by timber harvest, site preparation, and planting. Cumulative effects that result are mostly related to reductions in large, old trees, changes in dominant species, and maintenance of a large land base in younger (smaller) trees. Changes to physical, chemical, and biological soil properties which are controlled by some aspect of mature vegetation (litter, large logs, nutrient cycle, microflora) are one effect. Also, the loss of old growth forest structure, both within the canopy (crown types, snags) and near the ground (large organic debris, subordinate vegetation) is another cumulative effect. These will cause additional changes to flora and fauna that depend on habitat provided by a mature forest. In most cases extinction of any species is not likely, but decreases in some species, and increases in others will occur. Forest practices in this last category, in particular those related to the old growth issues, are not easily modified. The long time necessary for a forest to develop old growth characteristics precludes the use of most intensive forest management activities.

This study provides the FPB with a foundation for understanding the subject of cumulative effects as it relates to the regulation of forest practices in Washington. We recommend the FPB use this information to:

1) develop an overview of the magnitude, duration, and frequency of forest practices having a potential for cumulative effects,

2) conduct an examination of methods used to analyze cumulative effects, and

3) conduct an examination of representative basins throughout Washington to develop models for quantifying and analyzing cumulative effects.

Following these steps, the FPB would be in a position to determine appropriate modifications of forest practices regulations necessary for controlling cumulative effects.

1. INTRODUCTION

What is meant by the term "cumulative effects" in relation to forest land management? Do cumulative effects occur on forest lands in Washington? How do forest practices interact with the environment to produce cumulative effects? These are just some of the questions posed by the Forest Practices Board (FBP), the sponsor of this project.

Why is the FPB interested in cumulative effects? How did this project get started? How will the results of the study be used? For the benefit of those readers not familiar with the Washington Forest Practices Act, FPB, and events leading up to this review, we have summarized the salient points of interest to help answer some of these questions.

1.1 FOREST PRACTICES ACT

The State Legislature enacted the Forest Practices Act in 1974 and amended it in 1975 as Chapter 76.09 of the Revised Code of Washington (RCW). The act created an eleven member Forest Practices Board charged with developing forest practices regulations (rules). Rules protecting water quality were developed in conjunction with the Department of Ecology and rules protecting other public resources were developed by the FPB and its advisory committees (Geppert 1978). These regulations satisfy the planning and program requirements of sections 208, 209, and 305 of the Federal Water Pollution Control Act (Geppert 1979). They were formally adopted by the FPB on June 16, 1976 and made effective July 16 as the Washington Administrative Code (WAC 222). The first revision of the regulations occurred in October 1982.

The Department of Natural Resources (DNR) administers the regulations in cooperation with the Department of Ecology (DOE), the Washington Department of Fisheries (WDF), and the Department of Game (WDG). Compliance with forest practice regulations requires that all non-federal land owners receive approval before implementing a Class II, III, or IV forest practice. Over 10,000 forest practice applications are reviewed, inspected, and approved annually by the DNR.

Presently, each application is reviewed independent of other forest practices applications on adjacent lands, with no consideration for past or future operations. No importance is attached to possible interactions between adjacent or future applications. However, the FPB recognizes that some individual forest practices have a potential for causing a substantial impact on the environment. These Class IV-Special forest practices are subject to the State Environmental Policy Act (SEPA).

In January, 1979, as a result of a lawsuit to restrict harvest on the "Classic U Tract" filed with the Island County Superior Court, the FPB recommended a review and reclassification of Class IV-Special forest practices

(Appendix A). In July of the same year, DNR commenced a factual review of the Class IV-Special designation by sending 57 letters of inquiry to special interest groups. Additionally, DNR conducted four public meetings, statewide, in August and September. As a result of these meetings, 14 issues were identified. Cumulative effects was one of them. The term cumulative effects was first voiced as concern about multiple slash burning practices and the resultant changes in air quality in testimony presented at the Everett meeting on August 30, 1979.

Following this review, the Commissioner of Public Lands appointed a technical advisory committee to investigate these fourteen issues. The committee worked from October 1979 to April 1980 and issued their final report in May (Class IV-Special Technical Committee 1980). The report recommended three of the fourteen issues for further study; they were 1) scenic transportation corridors, 2) sub-alpine and harsh climates, and 3) cumulative effects.

1.2 CUMULATIVE EFFECTS

The FPB decided that further study and documentation of cumulative effects was a high priority, and in May, 1981 issued a request for proposals. Respondents were asked to address five tasks:

1) Examine the state-of-knowledge about cumulative effects through a literature search and personal interviews, and develop hypotheses on the potential for cumulative impacts. Test these hypotheses in the remaining tasks.

2) Examine representative basins in Washington State to detect and, where possible, quantify periodic landscape changes.

3) Describe provisional confirmation and cause/effect relationships for existing or potential cumulative effects that are identified.

4) Provide a framework that the FPB can use to identify future baseline data and research needs on cumulative effects.

5) Display the rationale for the findings and conclusions in an audio-visual presentation.

After selecting three firms as preferred consultants, the FPB decided in December, 1981 to reduce the scope of work due to a lack of funds. The three preferred firms were asked to re-submit technical and cost proposals on tasks 1 and 4. Ecosystems, Inc. (EI) was awarded the contract in January, 1982. However, initiation of the study was delayed for five months while the FPB and DNR solicited funds from various private, state, and federal organizations in Washington State and elsewhere. In June, 1982, with about half of the needed funds in hand, the FPB decided to begin the project. The contract with EI was signed in August.

Information in this report was gathered and compiled for use by the Washington State Forest Practices Board. It provides a basic description of cumulative effects allowing the FPB to decide whether current regulations will accomodate anticipated cumulative effects, or whether additional regulations are needed. If the latter is the case, further studies of greater detail will be needed before formal regulations are written.

1.3 HISTORY OF FOREST PRACTICES

Forests, along with mountains and rivers, are a major landscape feature of Washington, the Evergreen State. They are a major renewable resource providing goods, services, and jobs to people around the world. These forests are not, however, the same forests that existed prior to settlement. Development has reduced the commercial forest land base to about two-thirds of its original area.

While the future of Washington's forests are tied to current forest practices, many of their present characteristics are a result of past activities. In many ways, this will constrain management options for a considerable time into the future. The present age class distribution in western Washington is an example. It is a result of logging first along Puget Sound and then progressively moving inland. This restricts when and where future harvest activities can occur. Understanding the historical development of forest management is necessary to appreciate the potential for cumulative effects of future activities.

Trees have been commercially harvested in Washington since about the 1820's. The state's first sawmill was constructed at Fort Vancouver in 1827 by Dr. John McLaughlin. Early water-powered sawmills were constructed on the Willamette River in 1838 and on Puget Sound at the mouth of the DesChutes River in 1846. The timber came from settlers clearing the land to make way for homes, farms, cities, and factories. Finished lumber was shipped to Alaska, Oregon, California, and Hawaii.

By 1850, 37 sawmills were in operation in the Pacific Northwest. Most of them were centered around the confluence of the Columbia and Willamette Rivers. Increased settlement had increased the demand for lumber to build homes, factories, and ships. Federal legislation, such as the Donation Law of 1850, played a major role in developing the west by granting settlers title to 320 acres after living on and cultivating the land for four years.

An expression of land settlement and Euro-American conquest of the west can be found in the establishment of reservations and signing of treaties with all major Indian Tribes in Washington by 1855. Land settlement was augmented with passage of the federal Timber and Stone Act of 1878 authorizing "any citizen or person who has made a declaration of his intention of becoming a citizen" to buy 160 acres of timberland at $2.50 per acre.

By 1858, log supply shifted from settlers clearing land of "nuisance trees" to organized teams of loggers dispatched to cut "timber" along the water's edge. Forests were initially selectively cut, taking the trees of highest value and leaving the remainder. When demand exceeded supply, forests were clearcut. Oxen pulled logs on skidroads constructed of logs 12-18 inches in diameter placed 10 feet apart, notched in the center, and lubricated with grease boiled from dogfish livers. The bull teams worked within reach of the streams, either fresh water or tidal, for they were capable only of short hauls (less than two miles) and could not pull the grades into distant hills. The road was by far the most important construction in the woods and was a determining factor in the success or failure of a logging show. Oxen were soon replaced with horses which were about four times as efficient.

Rivers, streams, and salt water served as the medium for transporting logs long distances from the woods to the mills. Coincident with skidroads was the use of log dams to form ponds for holding logs and to create a supply of water to move logs downstream to tidewater. Splash, roll, and pond dams were used extensively on coastal streams and well inland on larger rivers from about 1880 to 1920. As a result stream bottoms, banks, and riparian zones were changed dramatically from their pre-logging condition. Many of these changes persist today (Sedell and Luchessa 1981).

Once in tide water, steam powered tug boats moved the logs in rafts to the mills. This mode of transporting logs by towing was gradually replaced by railroads as logging progressed inland. Commercial rail lines were constructed from Portland to Tacoma in 1883, over the Cascades in 1887, and coast to coast by 1883. Railroad logging started in the 1890's and was used extensively from 1900 through the 1930's. Gasoline powered trucks with solid rubber tires came into use around 1925. Pneumatic tires and dual wheels appeared in the 1930's and diesel began replacing gasoline about 1940. Also in the 1940's, power saws began replacing hand saws.

Forests were recognized as a resource worthy of protection around 1905 when the US Forest Service was formed. Also in that year, the State Board of Forest Commissioners was formed to supervise the protection of state lands in Washington. Later, in 1908, the Washington Forest Protection Association was founded. The mission for these and similar organizations was one of protecting the forests from wild fires.

In 1909, the sulphate process for making newsprint was discovered and by 1920 hemlock gained recognition as a merchantable tree species for pulp. Prior to this it was viewed as a weed species. This transition in hemlock value took on a new dimension when a timber cruise of the Olympic Reserve showed that 42 percent of the trees were hemlock (Morgan 1980). In 1929, Washington produced 7.38 billion board feet of timber, the second highest annual production in history (7.81 billion board feet was cut in 1973). Prior to this, however, people were starting to show an increased awareness of how long the boom era would last. The "cut out and get out" attitude was in question and the future of logging was speculative at best.

In 1929, the Western Forestry and Conservation Association conducted the nation's first comprehensive timber study. This study was conducted in the Grays Harbor area to assure the future of Hoquiam, Aberdeen, Montesano and surrounding towns. The report showed that by cooperatively managing private and governmental forest resources, and by controlling fire losses that were ruining Grays Harbor county's regrowth, a high yield of production could be maintained permanently. Out of this study came new understandings and a firm foundation for the communities of Grays Harbor. Another study known as the Elma Survey, reinforced the need to manage forests for the future supply of

Sustained Yield Unit of 1946 between the US Forest Service, Olympic National Forest, and the Simpson Timber Company (Van Syckle 1981). These two studies may now be viewed as precedent setting insights for charting Washington State's future in forestry.

Reforestation of cut over lands gained importance in the 1930's, especially through such federal work relief programs as the Civilian Conservation Corps. In many areas, wildfire, both before and after logging, created vast acreages with little or no natural seed source. The Yacolt burn in southwest Washington is one example, 238,000 acres burned in 1902. Throughout the next 50 years, nine major fires reburned in the Yacolt (Felt 1977). Forest nurseries also came into existence in the 1930's, producing seedlings to replant the Yacolt and similar areas. The Division of Forestry's Capitol Forest nursery produced its first crop of 1,250,000 Douglas-fir seedlings in 1937. Bareroot Douglas-fir has continued to be the mainstay of forest planting in the Northwest. Early attempts at growing other species were not successful because of problems with nursery production and planting mortality.

In 1931, the legislature took the first step toward improving the economic climate for forest land owners in Washington by enacting the Reforestation Act (RCW 84.28). Unfortunately, this act had little effect in stopping the trend toward tax delinquency on private forest lands. The amount of tax delinquent acreage reverting to public ownership nearly tripled between 1932 and 1941. Tax delinquency was not restricted to cut over land. Over 40 percent of the delinquent acreage contained some mature timber. The high rate of tax delinquency on private forest lands during the 1930's created an administrative problem for many counties. In a study of 18 counties in western Oregon and Washington, the US Forest Service found that over 23 percent of the private commercial forest land in nine Washington counties was tax delinquent as of 1932 (Wilson and Malone 1948). In an attempt to solve this problem, the legislature enacted two laws in 1935 and 1937 which provided alternative means for the counties to dispose of the land. The 1935 law authorized counties to sell tax delinquent land to the federal government for addition to the national forests and wildlife preserves. The 1937 law authorized counties to transfer tax delinquent land to the State Forest Board for management as reforestation lands (Conklin 1980).

Land abandonment in the 1930's and 1940's was related to more than just the property tax laws. It was caused by a combination of poor economic incentives to retain property, poor wood prices and markets, inaccessible stands of timber, high risk of fire and insect epidemics, and annual property taxes. As a result, many land owners harvested the most valuable timber and let the land revert to public ownership. This is also the period when the Keep Washington Green program was established (1940), timber harvest was subject to the Capital Gains Law (1942), and the start of the Tree Farm Program (1941).

Until World War II produced a surge in demand for wood, many forest land owners viewed reforestation and retention of the land for production of a second timber crop as a form of financial suicide (Conklin 1980). Reforestation became a requirement in 1946 with the passage of the State's first forest practices act (RCW 76.09). In the post World War II years the practice of forest management took shape. Trees were no longer viewed as a nuisance but rather as a renewable resource capable of being manufactured into numerous commodities and sold around the world.

The next major change in forestry occured in the 1960's when intensive forest management gained popularity. Tree breeding, fertilization, pesticides, thinning regimes, and scarification were practices designed to increase tree survival and growth. Additionally, long reach cable systems (skylines) were re-introduced to increase production and lower road construction costs.

Early historical figures for timber harvest in Washington are based on lumber production rather than the current system of log volume production. Over time the methods of measuring volumes has varied as well, confusing the task of comparing historical records with any degree of accuracy. Figure 1-1 displays the trends of timber harvest over time, placing some perspective on where we are, where we have been, and possibly allowing some direction for the future.

The boom years before the Great Depression, 1928 and 1929 produced two of the state's largest harvests, 7.14 billion board feet (BBF) and 7.38 BBF respectively, exceeded only by the 1973 harvest of 7.81 BBF (Wall 1972, DNR 1981). In Western Washington the largest single yearly harvest reported is for 1929, at 6.83 BBF followed by 1928 at 6.68 BBF and 6.59 BBF in 1973 (Figure 1-1). Eastern Washington harvest early in the century was much less than the current rate, with the largest volumes occurring in 1978 and 1973.

Looking at acres reported through the Department of Natural Resources Timber Harvest reports one can get a picture of the number of acres receiving some type of treatment, though the type and extent of treatment is not clearly delineated. The data in Figure 1-2 demonstrate only a slight general trend upward in acres harvested. More important is the difference between federal, and non-federal acres. Clearly the non-federal have been, and continue to be the largest segment of the acres reported.

This brief review of forestry in the Pacific Northwest indicates a dramatic change in natural resource values and management in the 130 years between 1850 and 1980. From beaver pelts to beaver fever (Giardia), from old growth nuisance trees to high value veneer, from cut and get out to high yield forestry, from splash dams to riparian habitat and large organic debris management, from wildfires to smoke management; the comparison of change becomes endless.

Forestry as we know it today is, at best, only 20 years old. No land owner has ever been through a rotation of planning and intensive management. Add to this the concern for environmental protection, which is only about 15 years old, and the challenge of predicting or controlling changes in air, earth, water, flora, and fauna and the issue of cumulative effects becomes very complicated.

Both the management of forests and the methods of assessing resultant changes in the environment are based on a very narrow window of knowledge accumulated over a relatively short period of time. What does the future hold for the forest industry in the next 130 years? The fact that none of us will

Figure 1-1. Log production in Washington, 1869-1982 (1869-1925 data based on lumber production).

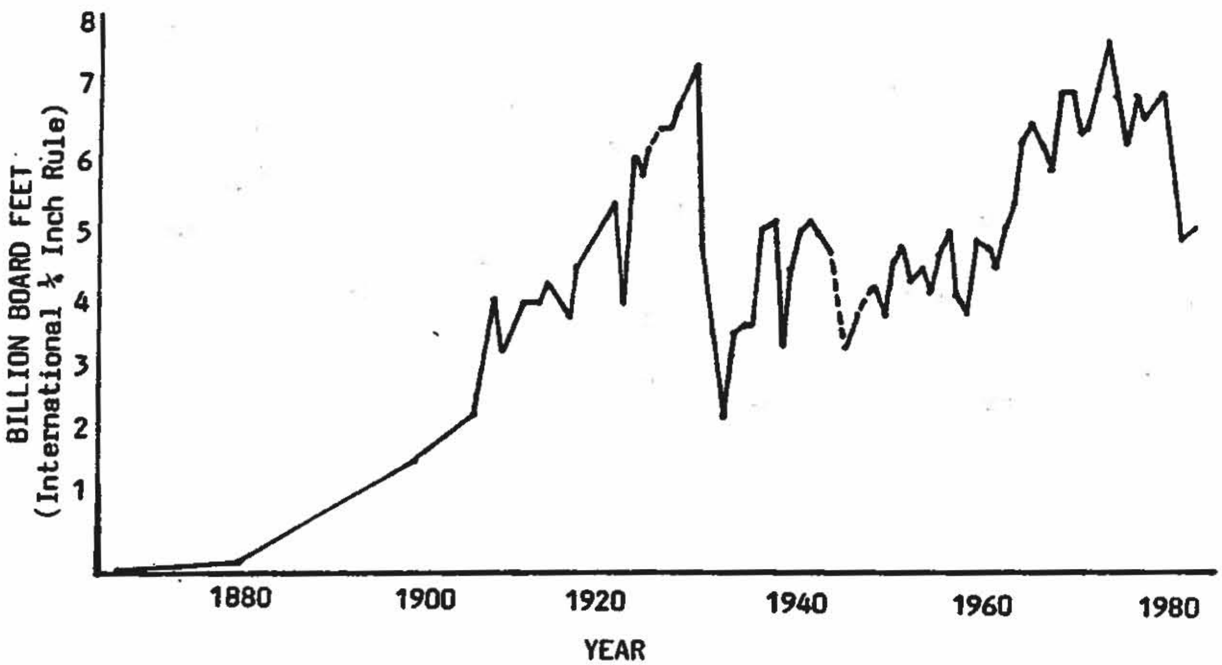
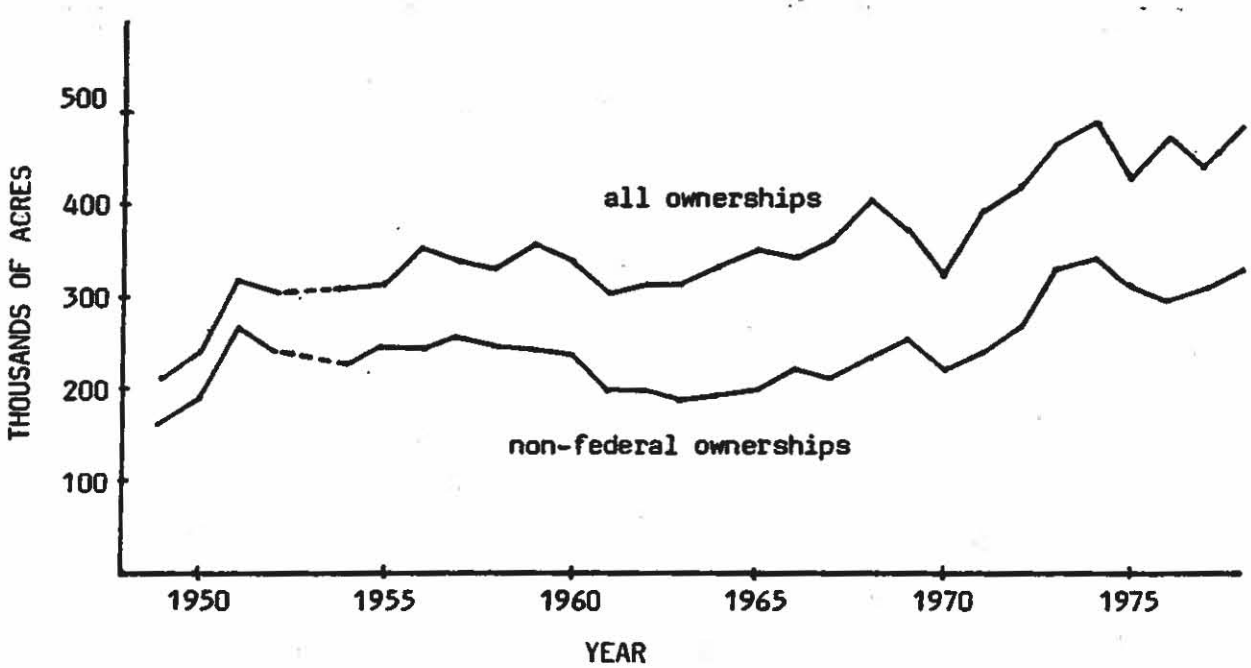


Figure 1-2. Trends in acres harvested by ownership 1949-1978.



be here to experience the change makes the question even more important because the progess of true civilization is judged by the consideration we give to the future, not only the present. This consideration for the future is exemplified by the Washington Forest Practices Board's desire to learn more about the interaction between forest practices and the environment and the potential for cumulative effects.

2. GOALS AND OBJECTIVES

The goals of this study were to:

1) Define what is meant by the term "cumulative effects" so that both spatial (i.e. throughout the forest or downstream, downwind) and temporal (i.e. throughout the forest or next year or 100 years from now) effects are included.

2) Develop a first approximation of the nature, source, and extent of cumulative effects on the environment arising from forest land management activities based on a review of the appropriate literature and consultation with knowledgeable professionals.

3) Provide a basis for directing future scientific studies on the significance of cumulative effects.

The objectives of this study were to:

1) Conduct an extensive literature review and conduct interviews with current researchers to identify cumulative effects of forest practices on the environment; prepare a library of pertinent literature. This review will establish a definition of cumulative effects and develop a first approximation of the nature, source, and extent of cumulative effects.

2) Conduct a one-day workshop with invited forest managers, researchers, and regulatory administrators to review draft hypotheses on nature, source, and extent of cumulative effects.

3) Develop a framework for future studies to fill information gaps on the presence or absence of cumulative effects, as well as the nature, source and extent. This will include a listing of baseline research needs and a process for evaluating proposed studies and study results.

To fulfill these goals and objectives within the time and cost constraints, we found it necessary to make some assumptions that would control the study's magnitude. Without these constraints such a study could easily consume our team in a decade of full time work. Since the intent was to develop a first approximation of the subject, we used the following assumptions as a guide:

1) The forest industry will continue to be a major industry in Washington.

2) Young growth management using short rotations will continue to be the policy for the majority of forest land managed in Washington.

3) The standard of performance of forest practices will continue as presently practiced and regulated by WAC 222, dated October 1, 1982. In other words, we are not predicting technological changes that would

influence the way forest practices are conducted.

4) The search for literature on cumulative effects will be world-wide, however, the interpretation of the information should be applicable to the biogeoclimatic conditions in Washington.

5) The study will consider all commercial forest land in Washington independent of the differences in ownership and management.

6) The study will be limited to establishing the potential for forest practices to cause cumulative effects. It was not a task to identify mitigating or control measures that could eliminate or reduce cumulative effects.

7) The Forest Practices Board will be responsible for determining the importance of each cumulative effect issue identified.

8) The Forest Practices Board will be responsible for determining whether current forest practices regulations adequately address cumulative effects.

3. METHODS

This literature review consisted of both standard and innovative methods for collecting and analyzing timely information on potential cumulative effects of forest land management activities on the environment. In addition to the published literature we concentrated on people: what they research, what they practice, and what they believe regarding the nature, source, and extent of cumulative effects. The challenge of this project was literally to examine the world of literature on the interactions between forest practices and the physical elements of the environment. Our approach to accomplish this consisted of 1) using an interdisciplinary team of 11 specialists and 2) separating the project into discrete tasks. The 11 tasks, each divided into distinct steps of manageable size were designed to complement and build upon preceding tasks and to determine the content of succeeding tasks, thus providing a logical progression of outputs and supporting data.

The project commenced on August 16, 1982 with a general scoping of the cumulative effects issue and the development of background information for use by team members. Douglas Canning summarized the regulatory processes contained in various federal and state laws for their applicability in controlling forest practices and changes to the environment. He outlined the relationship between cumulative effects, Class IV - Special, and SEPA (Appendix A). Bruce Grogan summarized the status of methods, studies, and programs used in California to address cumulative effects of forest practices on federal, state, and private forest lands. California has been the most active state in addressing cumulative effects, however, their programs emphasize the effect of forest practices only on water resources (Appendix B).

The second task was a literature search on cumulative effects using local and regional computer abstract services. Next, the team developed a draft definition of cumulative effects used, in conjunction with the above information, to conduct manual literature searches. Abstracts were prepared on pertinent documents reviewed using a standard format.

The manual and computer searches discovered ten documents on cumulative effects of forest practices. This finding confirmed our suspicions that the bulk of the information was contained in bits and pieces among site specific research projects and in the minds of people. Our next step was to pursue both sources for information. During the review of pertinent articles each team member noted key authors and other people as candidates for personal interviews.

In March, questionnaires were sent to many of these people to determine their experience with this subject and their interest and expertise that would merit a personal interview. Interviews were conducted primarily in April and May of 1983. Findings from the literature and interviews were summarized into short statements and presented for review at a one-day workshop on June 24. Review comments were analyzed and used to confirm or reject our hypotheses on cumulative effects. The draft report was prepared from July to September and presented to the Contracting Officer on October 5, 1983. Additional copies were given to a six-member technical review panel, selected by EI.

3.1 INTERDISCIPLINARY TEAM

The interdisciplinary team, consisting of eleven specialists, was selected for expertise and familiarity with literature and key people appropriate to the cumulative effects subject. The names and responsibilities of each team member are:

* Rollin Geppert - served as program director in charge of overseeing all aspects of the project. Additionally, he assisted other team members in the area of forest practices and flora, and supervised the compiling and editing of the final report.

* Charles Lorenz - provided information on forest practices and flora and was in charge of the questionnaire. He also assisted in compiling and editing the final report.

* Arthur Larson - provided information on water, soils, forest practices, and flora. Additionally, he was in charge of the computer literature search, all data processing, and much of the data analysis. He also assisted in compiling and editing the final report.

Matthew Brunengo - provided information on geology and soils.

Douglas Martin - provided information on aquatic fauna, especially fish.

Douglas Canning - provided information on environmental assessment methods, SEPA, NEPA, and terrestrial fauna; as well as insight to many aspects of the project.

Peter Haug - provided information on NEPA, living systems theory, environmental analysis, and conceptual frameworks for ecosystems modeling.

Bruce Grogan - provided the background information on the status of the cumulative effects issue in California plus valuable insight during the formative stages of the project. He authored the very first document in Washington state on cumulative effects in early 1980 as part of the Forest Practices Board's review of Class IV - Special practices.

Wolfhard Ruetz - a forest physiologist and geneticist living in West Germany provided sources of literature from Europe.

Rainer Muenter - a German forester currently living in the USA was also the source of European literature and performed translations to English.

Larry Sims - provided information on slash burning and air quality.

* Core Team Members

All phases of the project were directed, managed, and conducted out of EI's office located in Lacey, Washington. Eight of the team members met on a monthly basis for the first six months of the project. Thereafter the team met bi-monthly. Team meetings provided a forum for interaction between various disciplines. Other forms of interaction and communication were achieved via telephone, mail, and in meetings of two to four team members.

3.2 LITERATURE SEARCH

The search for appropriate literature was divided into two phases. The first was a search for publications that dealt directly with cumulative effects, either in forestry or a related discipline. The second was a broader search of the literature for publications describing the effects of forest practices on the environment, but with no restriction to being cumulative or even long-term. Both manual and computer-aided searches were made in each phase.

The manual literature search was initiated with a search of the Forest Service's West-For-Net library headquartered at the University of Washington's, College of Forest Resources Library (CFRL). In addition, CFRL's files of prior computer-aided abstract searchs were reviewed for relevant publications. Each EI team member also searched his personal library (several of which are quite extensive in their specialty field). Many additional publications were suggested by various scientists and administrators during the personal interview stage of this project.

A search of applicable abstract data bases kept on computer files was conducted in conjunction with the manual search. Facilities of the Natural Sciences Library of the University of Washington were used in this endeavor, and the search was restricted to those data bases available through DIALOG (a commercial data bank of the Lockheed Corporation). Data bases found to have the greatest volume of useful information were CAB (Commonwealth Agriculture Bureau - includes Forestry Abstracts), Agricola, Water Resources Abstracts, Pollution Abstracts, and BIOSIS (Biological Abstracts).

Computer searches matched forest practices with the separate elements of the environment. Major key words used are listed in Appendix C. The strategy used an initial search of broad topics followed by a narrowing to more specific issues until the number of abstracts found was of affordable size. It was not uncommon for the initial search to uncover several thousand related publications, the majority of which were extraneous to our needs. For instance, if a search of forest management versus water produced extraneous publications, then the search was narrowed to forest management and water quality, or even narrower, to forest roads and suspended sediment. Searches were conducted in this manner until the number of extraneous publications was minimized. At the end of a search the relevant abstracts were ordered from DIALOG.

If a search strategy proved successful on the initial data base, similar searches were made of other data bases. Additional data bases were searched until either the majority of useful publications found were duplicates of previous searches (there is a very large overlap in the journals abstracted by individual data bases), or until the total number of potentially useful publications exceeded our capacity to review them (within the given study time frame). Generally, our search strategy was halted by excessive duplication rather than an overload of material.

With the exception of those publications dealing directly with cumulative effects, we made no attempt to search out each and every publication on the effects of forest practices on the environment. The literature on this subject is immense. It was our goal, however, to review some publication on each forest practice issue of interest, and where the number of publications was large, to review a cross-section of the material. We continually attempted to narrow the available literature to those publiations having some relationship to our developing concept of cumulative effects.

Once the bibliographic information on potentially useful publications was gathered and catalogued, the documents themselves were located at one of the various libraries in western Washington, primarily the State Library in Olympia or the University of Washington Library in Seattle. Publications were also obtained from state agency libraries or ordered from various state and federal agencies. These publications were subsequently reviewed and abstracted for use in preparing this report. Many larger publications, such as textbooks and symposia proceedings, having several chapters or articles of interest, were not abstracted but either borrowed for the study duration or purchased.

3.3 QUESTIONNAIRE

Coincident with the developing cumulative effects philosophy and definition, a questionnaire was developed to provide input from a cross-section of forest managers, researchers, and administrators. The questionnaire had three purposes:

1) Identify and locate knowledgeable people with an interest in the subject.

2) Identify those people willing to participate in personal or telephone interviews and/or to review draft material.

3) Identify additional contacts with information or interest in the subject.

Initially, more than 200 questionnaires were mailed throughout the United States, Canada, western Europe, and Africa (for a complete listing see Appendix D). The sources for these initial names were varied, and included several of the funding organizations, as well as names already known to the EI team, and others identified through the literature searches. Additional names were suggested by early responders and even from personal inquiry upon reading or hearing about the study. Many of those suggested were part of the original mailing; however, 60 additional names were generated from this process. The final number of questionnaires exceeded 300. Geographically, the bulk of the sources were in the west, with 70 percent being in the west coast states and British Columbia.

Responses were greatly in excess of our expectations, with 60 percent of the questionnaires returned. Geographically, responses were similar to the original distribution, with 75 percent from the west coast. As could be expected, the variety of response was as great as the distribution, ranging from the bizarre to the common. Fully 80 percent of the respondents were willing to participate in either or both of the interview and review processes.

The information gleaned from the responses was useful in developing the interview strategy, and was extremely valuable in arranging for and conducting interview sessions at various locations throughout the country.

3.4 PERSONAL INTERVIEWS

The purposes of the interviews were threefold. First, we wanted to obtain unpublished research caught in the two- to five- year time lag in publishing by professional journals. Second, conversations with key people provided us with ever-broadening viewpoints on the entire cumulative effects issue. Third, the personal interviews were instrumental in locating obscure research projects that escaped discovery in the regular literature search process. Respondents to the questionnaire served as the source of key people willing to be interviewed. Appendix E contains additional information on the interview process.

Four methods were used to interview researchers, forest managers, and administrators:

1) Travel: During the course of working on other company projects and general travels we were able to start interviewing on an informal basis as early as August 1982 in Utah, northern California in September, and Minnesota in October. Experience from these early interviews was used to develop our formal interview strategy.

2) Conferences: We attended a variety of local and regional conferences where we interviewed key participants. These conferences discussed topics pertinent to some aspect of the cumulative effects issue. The interviews were most productive when we made appointments with people at least a week prior to the conference. The location of the interviews was a function of convenience ranging from in the hall during coffee breaks, in adjacent class or motel rooms, to discussions over dinner.

3) Interviews: Formal interviews with key researchers, forest managers, and administrators were conducted from April 5 to May 27, 1983. Interviews conducted in the Olympia area were generally organized into separate meetings of researchers, or forest managers, or administrators. Interviews conducted outside the Olympia area were arranged by geographical location as a function of efficiency and mutual convenience.

These group interviews were a mixture of researchers, forest managers, and administrators. Reference materials were sent at least two weeks prior to the interviews. Appointments were made with groups of people based on their geographic location or professional background. All meetings were tape recorded. When people were unable to attend the interviews, we held a second meeting in the Olympia area. The interviews ranged from one to four hours in length.

4) Telephone: Many people were contacted by telephone to obtain information on specific questions. General discussions on cumulative effects were usually not productive in discovering new information.

3.5 WORKSHOP

A workshop was conducted by EI on June 24, 1983 at The Evergreen State College in Olympia, Washington to display, review, and discuss cumulative effects statements contained in a working paper developed from the literature search and personal interviews. Workshop participants were selected based on their interest and expertise demonstrated during the interviews. Letters of invitation, including reference material, agenda, and vicinty map, were mailed to participants on May 31, 1983 (Appendix F).

The workshop was attended by 15 researchers, four forest managers, and 12 administrators from Washington, Oregon, California, Idaho, and British Columbia. Additionally, the workshop was attended by eight FPB members and five representatives of organizations contributing funds to the study.

Rollin Geppert, EI president, served as workshop chairman. Brian Boyle, Commissioner of Public Lands and FPB chairman, explained the purpose of the study and the importance of developing a first approximation of cumulative effects for forestry. Dr. Arthur Larson, EI hydrologist, explained the proposed definition of cumulative effects used to develop the working paper on forest practices and the affected physical elements of the environment. Included in this explanation were such key terms as baseline, multiple forest practices, and recovery rates. These are essential for differentiating between individual effects and cumulative effects.

Participants then formed groups to discuss the working paper and specific statements on cumulative effects of forest practices on air, earth, water, flora, and fauna. Eight EI team members served as facilitators in these groups to explain the working paper and record the response to each statement.

EI systems ecologist, Dr. Peter Haug, served as moderator for a discussion of the participants' general comments on the study and to identify future research needs.

The workshop was a success in many ways. Excellent comments were received at the workshop and later in writing from many of the participants. These comments were reviewed by the EI team and used to prepare the final report.

For the FPB, the workshop was the first time in their 8-year history that they were presented with an opportunity to interact with researchers, forest managers, and administrators in the Pacific Northwest.

3.6 ANALYSIS

Three stages of analysis were used to synthesize the data and information collected in this study. Each stage consisted of one or more tasks, as described in our proposal dated January 14, 1982. Each stage received two levels of review.

```
STAGE

  1        Background Information --┐
           Literature Search        ¦
                                    ¦  Level One        Level Two
  2        Interviews --------------├→ Core Team -----→ Full Team
                                    ¦    Review           Review
  3        Workshop ----------------┘
```

The core team was responsible for conducting the first level of review in each stage of the study. Their role was to test each piece of information using the following questions:

1) How is the information applicable to this study?

2) What biological, chemical, and physical processes are involved?

3) What forest practices are involved?

The full team was responsible for conducting the second level of review. Their role was to refine each piece of information developed by the core team using the following questions:

1) What are the primary and secondary effects of each forest practice?

2) Are these effects perceivable and measurable?

3) What is the documentation for the above answers?

The information was then fed back from the full team to the core team, who further refined the information by:

1) Determining the interaction between various effects.

2) Determining which effects are temporary or persistent.

3.7 TECHNICAL REVIEW PANEL

The draft report was reviewed by a six-member technical panel. Although many people were candidates for the panel, we limited the panel to a manageable group willing to make a quick and efficient review. Final selection of the panel was based on the expertise and interest expressed by people interviewed throughout the project. Members of the panel were:

<u>Members</u>

Jerry Franklin
Forestry Sciences Lab
3200 Jefferson Way
Corvallis, OR 97331

Ralph Coons
USFS, Olympic Nat'l Forest
P.O. Box 2288
Olympia, WA 98507

Chris Maser
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Corvallis, OR 97331

Jeff Cederholm
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Robert Beschta
School of Forestry
Oregon State University
Corvallis, OR 97331

David Handley
MacMillan Bloedel Ltd
65 Front St.
Nanaimo, B.C. V9R 5H9

The purpose of this review was to achieve two levels of critique prior to finalizing the draft for the Forest Practices Board. One level of review addressed the overall approach essential to understanding cumulative effects. The second level of review focused on our interpretation of the literature.

4. DEFINITION OF TERMS AND PROCESSES

This chapter defines the term "cumulative effects", and explains the forest practices, and elements of the environment to which it applies. We have included the salient points of each subject necessary for understanding fundamental concepts. These terms and processes are essential for understanding the direct and indirect cumulative effects contained in Chapter five. The description of forest practices is specific to the practice of forestry in Washington, and the description of elements of the environment is specific to the commercial forest lands of Washington.

The term "cumulative effects" as used here is not all-encompassing. Since no one can stop time, all things in nature will be cumulative. Evolution, succession, and even erosion are cumulative processes. Each modifies the environment resulting in a continual change in the world around us. Although change cannot be stopped, the rate at which change occurs can be influenced.

To speak of cumulative effects in a workable way, we restrict its meaning to changes which are caused, and therefore controllable, by man, and whose effects will manifest themselves in the foreseeable future. The forseeable future is probably less than 1000 years, certainly less than the average recurrence interval for ice ages or other natural processes that reshape the earth. We also restrict our discussion of man's actions to those activities known as forest practices.

4.1 CUMULATIVE EFFECTS

In the context of forest management a cumulative effect is:

A CHANGE IN THE ENVIRONMENT CAUSED BY THE INTERACTION OF NATURAL ECOSYSTEM PROCESSES WITH THE EFFECTS OF TWO OR MORE FOREST PRACTICES.

This definition combines all the elements necessary to identify a cumulative effect. A cumulative effect occurs whenever an environmental change caused by one forest practice interacts with environmental changes from other forest practices. The result of this interaction (or accumulation) of effects from more than one forest practice is always a cumulative effect. Conversely, if environmental effects of individual forest practices do not interact, there can be no cumulative effect.

The key to this definition of cumulative effects is the requirement of interaction between effects of multiple forest practices. Multiple forest practices include:

1) Combined practices: all possible combinations in time and space of the many types of forest practices (timber harvest, road construction, site preparation, etc.).

2) Repeated practices: repetition of a single type of forest practice in time and/or space.

Combined practices include road construction, timber harvest, and prescribed burning; thinning and fertilization; or any other possible combinations. They can occur on the same site, one following another; or they can occur on different sites within the forest or watershed. This might include fertilizing one acre, spraying herbicide on another acre, logging a third acre, and roading on the fourth acre. These latter combinations may be occurring simultaneously, consecutively, or continually.

Examples of repeated forest practices include repeated harvesting, and/or burning, spraying, etc. on the same acre of ground rotation after rotation; and the annual cropping of a larger forest. Combinations of practices can also be repeated rotation after rotation. Other continual practices in this category include road construction, maintenance, and especially road use. While we do not necessarily consider the passage of each vehicle to be a separate forest practice, we do consider such activities as log-hauling from a single harvest unit and rock-hauling for a new road to be separate practices. In effect, the annual construction, maintenance, or use of forest roads are all repeated forest practices.

This definition, as it relates to forest land management practices, is broader than earlier definitions by Standiford and Ramacher (1981). It is not restricted to water resources, but includes the environmental elements of air, earth, water, flora, and fauna. Other elements of the human environment, such as the social, economic, aesthetic, and recreational aspects, are not covered. This is not to say that this definition does not apply to these and others, only that its application has not been tested.

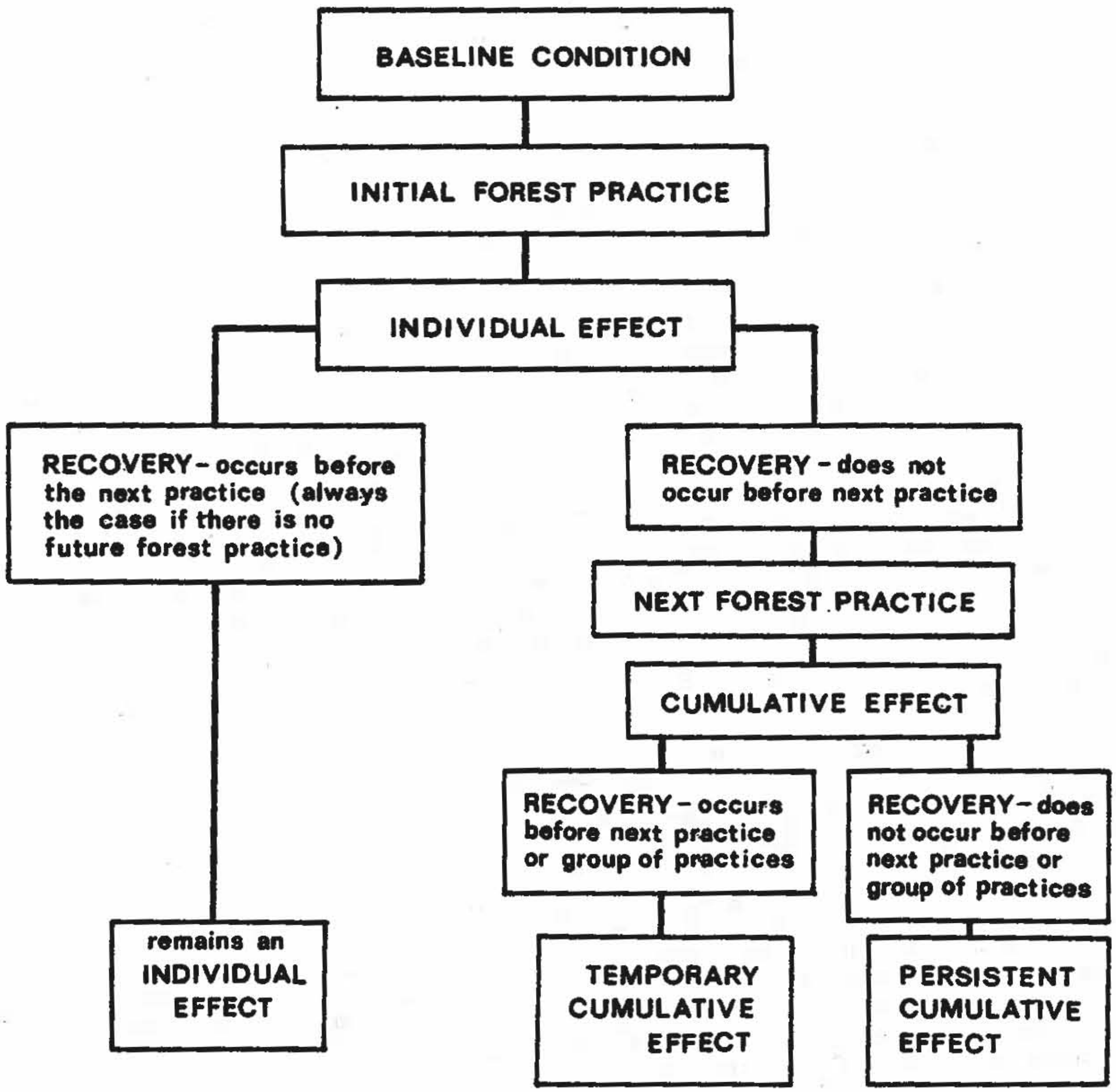
For cumulative effects to become a workable term, we must be able to separate them from other categories of effects. To this end, we define two types of environmental change, individual effects and cumulative effects (Figure 4-1).

Changes resulting from a single forest practice, without further intervention by man, are individual effects. Thus, long-term and in some cases chain-reaction effects that occur from a single practice are considered as direct or indirect individual effects. Although these effects may be long-term, with a potential for aggravation by natural ecosystem processes, there is no accumulation of effects.

Also, effects that persist for such a short time that there is no opportunity for interaction with other effects from future forest practices are individual effects. Specifically, if the effect is reduced to a baseline level before recurrence of the same practice, or application of a different practice, then it is an individual and not a cumulative effect. That is, there is no remaining effect to be additive with the new effect from the subsequent practice. Likewise, if the effect is reduced to a baseline level before leaving the treated area, there is no effect to be additive with similar effects from surrounding space, and it is again an individual effect.

For an environmental change to be considered a cumulative effect, it must be additive either in time or space with changes from other practices. This

Figure 4-1. A conceptual model illustrating individual and cumulative effects.



does not mean that the change increases indefinitely as forest practices continue over time, as there is probably a physical limit to any induced environmental change. Rather, as a change brought about by a forest practice declines over time, additions are made by similar impacts from subsequent forest practices.

Whether or not the environmental change returns to the baseline condition (i.e., recovery) before application of additional forest practices determines whether the effect is cumulative or individual. If recovery occurs it is an individual effect. If recovery does not occur and the environmental component is again affected by a forest practice, it is a cumulative effect.

The term "baseline" refers to the desired state or condition of the environment. It is the condition of the forest or watershed that we wish to maintain now and into the future and from which we measure the changes caused by forest practices. Setting appropriate baselines is required before determining if cumulative effects exist. It should be noted that to control a cumulative effect, neither the definition nor Figure 4-1 requires a return to an undisturbed condition, but rather only a recovery to the desired baseline. The desired baseline for various environmental components is generally set by society for public resources and by the land owner for private resources.

Because we did not consider the socio-economic interests of society in this study, we chose the old growth forest as the principal baseline. The old growth baseline includes the natural processes of fire, wind, flood, insects, etc. and the natural variations in the forest that result from these processes. The old growth forest includes all age classes of vegetation as they would appear if the natural successional processes were to continue unhindered.

The elements of time and space are not explicitly included in this definition of cumulative effects, but are implicit in our understanding of forest practices. Forest practices do not occur randomly in either time or space. For example, timber harvest occurs after a prescribed rotation period, and involves a specific unit size and positioning. A forest manager does not harvest a site the year following its reforestation, nor reforest a unit not yet harvested.

A consequence of excluding time and space from this definition is the necessity for two classes of cumulative effects. Because forest practices may be closely grouped or widely separated in space and/or time, the resulting cumulative effects may be temporary or persistent.

Temporary cumulative effects are those for which we can forsee at some point in the future the reestablishment of a baseline condition before recurrence of forest practices. These effects are not necessarily short-term, but they are temporary. Temporary cumulative effects are generally caused by forest practices that occur in sequence, for example timber harvest and site preparation, and after which there may be no additional forest practices for considerable time (often until the next harvest).

Persistent cumulative effects are obviously long-term, but of greater importance, their duration is indefinite. Restoration of the change via natural ecosystem processes is slow and continually retarded by additional forest practices. The result is a change in the equilibrium or average baseline of the affected component. The baseline now resides at either a higher or lower level than before forest practices, and as long as forest practices continue without modification the change will persist.

Temporary cumulative effects have the potential for becoming persistent, and persistent cumulative effects becoming temporary, depending upon the balance between the return period of the forest practice(s), and the recovery period from the effect. For example, shortening the rotation may cause a temporary change to become persistent. Or, a change in logging system such as from highlead to skyline, resulting in a reduction in the impact recovery period, may cause a persistent change to become a temporary one. It is our opinion that, magnitudes being equal, persistent cumulative effects are more important than temporary ones. This review emphasizes persistent cumulative effects.

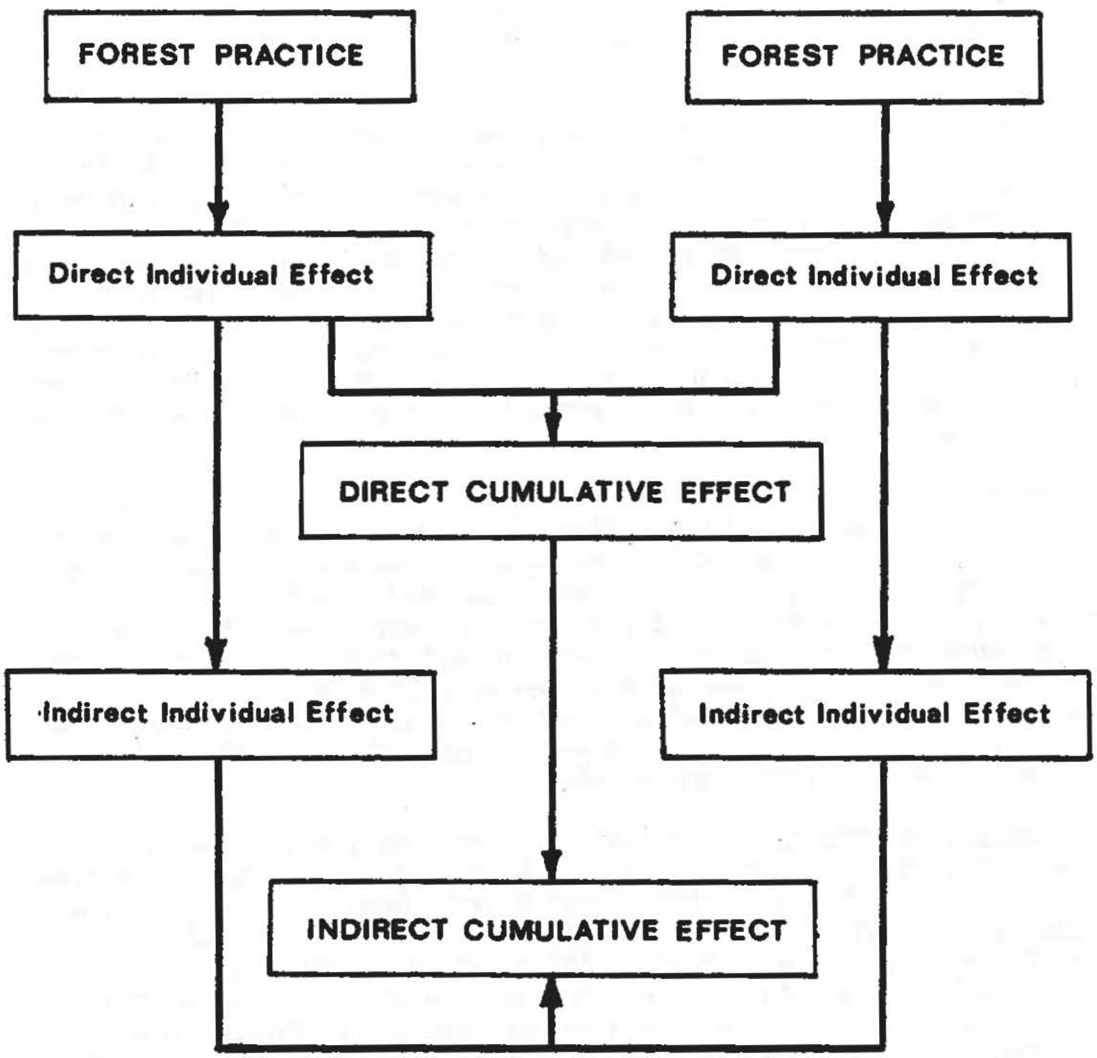
Effects can also vary as to their direct and indirect nature. All forest practices have a direct effect on the environment. In turn, these direct (primary) effects can become secondary change agents producing secondary effects, and so on. For example, construction of a forest road causes erosion. Erosion contributes to stream sedimentation. Stream sedimentation reduces spawning habitat for fish. Road construction is the primary change agent, erosion is the primary (direct) effect and a secondary change agent, sedimentation is a secondary (indirect) effect and a tertiary change agent, and finally, reduction in spawning habitat is a tertiary effect (also indirect). Changes are separated into direct and indirect effects based on the cause or change agent.

The above description is usually applied to individual effects, but we found it useful to divide cumulative effects into these same categories of direct and indirect. (Figure 4-2). The analogy between individual and cumulative effects is not, however, perfect. Cumulative effects are not as "direct" as individual effects. By definition, a cumulative effect requires interaction between effects from two or more forest practices, that is, two individual effects must accumulate in some manner before we have a cumulative effect. Therefore a cumulative effect can never be tied directly to the single application of a practice. Nevertheless, we have separated cumulative effects into direct and indirect categories.

<u>Direct cumulative effects</u> are caused by direct individual effects of two or more forest practices. Practices can be the same type spread out in time and space, or different types also distributed through time and space. <u>Indirect cumulative effects</u> are traceable to a prior cumulative effect or to two or more indirect individual effects. It is not necessary that an indirect cumulative effect be caused by a direct cumulative effect although this is generally the case. However, an effect that is indirectly related to a prior cumulative effect is always another cumulative effect. That is, cumulative effects can not interact to become individual effects.

By this definition, a single occurrence of a forest practice cannot cause a cumulative effect. We are interested in changes resulting from continual forest management and do not expect a single forest practice to occur in a management scheme. Management practices are necessarily recurring. This definition is also in keeping with the historical development of the term.

Figure 4-2. A conceptual model illustrating direct and indirect cumulative effects.



CUMULATIVE EFFECTS–PAST

The term cumulative effects has evolved to mean changes caused by man's actions, either to himself or to his environment, that add up or accumulate as new actions follow preceding ones. That multiple or repeated actions are inferred is evident in the evolution of this term. Although it is applied to describe changes to both the physical and human elements of the environment, the latter has probably been most responsible for elevating people's awareness of the cumulative effects concept.

Researchers in the fields of medicine, toxicology, and sociology have studied the effect of incremental stress (physical, chemical, and mental) on the human mind and body. In the field of medicine, researchers have studied the effect of repeated use of aspirin, birth control pills, tobacco, alcohol, sugar substitutes, etc. Toxicologists have studied the body's accumulation of DDT, dioxin, and other chemicals from repeated exposure to the environment both at work and home. Sociologists have studied the physical and mental stress resulting from multiple life changes including marriage, divorce, retirement, pregnancy, and career changes. This concept has even been perceived from an aesthetics standpoint. A recent example is the Shoreline Hearings Board ruling regarding construction of a 70-foot high office building in Olympia, Washington (DOE 1982):

> "The cumulative effect of allowing this and similar proposals on the isthmus would irreversibly damage the aesthetic views remaining."

In relation to the physical elements of the environment, man caused stress is expressed as changes in air, earth, water, flora, and fauna. Initial recognition of these cumulative changes can probably be traced back hundreds of years to the first visible changes to European landscapes caused by grazing and fires. Perception and concern for forest practice effects on the environment are more recent, starting in the 1930's and 40's. This era paralled development of the term "ecosystem" by the British ecologist A.G. Tansley in 1935.

The recognition that cumulative effects are caused by forest practices is even more recent, but not exactly new. David Smith, in his 1962 edition of The Practice of Silviculture, states:

> "It is important to understand the long-term, cumulative effect of cutting operations in building, or degrading, a forest."

This recognition of potentially beneficial cumulative effects is rare, but the recognition of detrimental cumulative effects is evidenced today in many of our laws, policies, and natural resource development practices.

The Council on Environmental Quality in formulating regulations for implementing the National Environmental Policy Act (NEPA) of 1969 made specific requirements for considering cumulative effects in the preparation of an environmental impact statement (Appendix A). The intent was to ensure that environmental effects of past, present, and forseeable future actions were integrated into the planning process.

Also, the Federal Water Pollution Control Act (PL 92-500) as amended by the 1977 Clean Water Act (PL 95-217), under the provision of Section 208 (b)(2)(F) carries the charge to examine a process to "(i) identify, if appropriate, agriculturally, silviculturally related non-point sources of pollution, including return flows from irrigated agriculture, and their cumulative effects". The U.S. Environmental Protection Agency has interpreted this requirement as applying to all non-point sources, including silviculture in Section 208 (Burd 1982). Based on this requirement, the California Water Resources Control Board found the State Board of Forestry's 208 report (1980) inadequate in not considering the cumulative effects of timber harvesting. Again the emphasis was on multiple practices as they expand over the landscape and/or time. A discussion of California's experience with cumulative effects is included as Appendix B.

CUMULATIVE EFFECTS-PRESENT

Cumulative effects of forest practices have recently received considerable attention. The California Department of Forestry and Resource Management, and the Cooperative Extension at University of California Berkely sponsored a two day conference, June 2-3, 1980, to discuss the cumulative effects of forest managment on California watersheds (Standiford and Ramacher 1981).

In Washington the subject of cumulative effects became a legal issue in the case of Steelhead Trout Club of Washington vs. Bert L. Cole, Commissioner of Public Lands. On October 29, 1980 the club filed a complaint for declaratory and injunctive relief stating in part:

> "The actions of defendants Cole and DNR in approving or acquiescing to forest practices on private forest lands have been taken without adequate study, knowledge or review of their environmental impact, of any unavoidable adverse environmental effects, of any alternatives to the proposed forest practices, of the relationship between local short term use and long-term productivity, and of any irreversible and irretrievable resource commitments involved in the permitting of such practices. No consideration has been given to the cumulative impacts of such forest practice approvals."

In April 1980, the Skokomish Indian Tribe filed a complaint for declaratory and equitable relief against the U.S. Forest Service (case known as Skokomish Indian Tribe vs. Richard D. Beaubien). The Tribe claimed, among other things, that the Forest Service failed to adequately assess the environmental effects of the 1977-1987 Timber Resource Management Plan on anadromous fisheries and game resources on the Shelton Cooperative Sustained Yield Unit.

In April 1981, the tribe's memorandum in support of a motion for preliminary injunction stated:

> "The FES (Final Environmental Statement) does not discuss the cumulative effects of this accelerated cutting of old growth acreage, especially the effects of harvesting areas adjacent to older clearcuts, and in steep drainages at higher elevations where the soils are less stable."

The tribe went on to say:

> "The potential cumulative impacts of additional roads and additional clearcuts are not adequately displayed in the FES. Without this information the decision maker is unable to accurately determine the immediate and long-term risks to the environment."

At their annual meeting in Sun Valley, Idaho on December 3, 1981, the Trustees of the Western Forestry and Conservation Association expressed their concern for cumulative effects. They requested the Northwest Forest Soils Council, the Western Reforestation Committee, and the Western Stand Management Committee to address the growing concern of possible long-term cumulative effects of forest practices on forest site productivity. Their resolution stated:

> "Existing information should be compiled and made available to foresters. Additionally, needed research should be identified and supported."

On May 21, 1981, C. Jeff Cederholm, DNR fisheries biologist, gave a presentation to the Washington Forest Practices Board titled, "Cumulative Effects of Logging and the Fishery on Coho Salmon". This same speech was given to the House Natural Resources and Environmental Affairs Committee on June 13, 1981. The purpose of these presentations was to familiarize decision makers with the subject of cumulative effects during the period in which the Board was receiving proposals from consultants to conduct a detailed literature search on the subject (Cederholm 1981, tape recording, and FPB May 21, 1981 minutes).

Coincident with recent interest in forestry related cumulative effects, concern has developed with respect to other natural resource uses, primarily energy development. Here again emphasis is on multiple developments spread out in space, but not necessarily in time.

In 1981, the U.S. Fish and Wildlife Service contracted with Dynamac Corporation in Fort Collins, Colorado, to conduct a literature search titled, "Methods for Determining Cumulative Effects of Coal Development Activities on Fish and Wildlife Resources".

Concern over the cumulative effects of another form of energy development, hydroelectric projects, has been expressed. The Northwest Power Planning council adopted cumulative effects provisions in the Columbia River Basin Fish and Wildlife Program on November 15, 1982. Section 1204(b) states:

> 1) "The federal project operators and regulators shall review all applications or proposals for hydroelectric development in a single river drainage simultaneously through consolidated hearings, environmental impact statements or assessments, or other appropriate methods. This review shall assess cumulative environmental effects of existing and proposed hydroelectric development on fish and wildlife."
>
> 2) "Upon approval by the Council, Bonneville (Power Administration) shall fund a study to develop criteria and methods for assessing

potential cumulative effects of hydroelectric development on fish and wildlife. The study shall also develop a method for incorporating these assessments into federal processes for review, authorization, or other support of hydroelectric development."

Volume one, page E-267 of the February 1983 draft environmental impact statement for the South Fork Skokomish River Hydroelectric Project states (CH2M Hill 1983):

"The potential hydroelectric projects on the Olympic Peninsula are especially important regarding cumulative impacts on fishery resources, because many streams on the peninsula contribute to the commercial and sport fisheries."

Additional interest was expressed on March 4, 1983 at a conference sponsored by the Institute of Environmental Studies at the University of Washington titled, "Small Scale Hydropower?" Attorney Lorraine Bodi spoke on the cumulative effects of hydroelectric projects. The Institute sponsored another conference on August 12, 1983 titled, "Perspectives on Cumulative Effects; e.g. Small Scale Hydropower".

The Los Padres National Forest in California is currently developing methods forassessing the cumulative effects of oil and gas leasing on watersheds. By mid-1982, the Forest had received 243 applications for oil and gas leasing. The need for a procedure to analyze the granting of multiple leases was demonstrated in early 1982 by the Draft Environmental Impact Statement for the Lomex Corporation's proposed mineral exploration in the Navajo vicinity of San Luis Obispo County.

In summary, the term cumulative effect is not new. It has been in active use for at least 20 years and probably longer to describe long-term effects of changes in the environment caused by interactions of multiple projects. In the last three years, the term has gained recognition as an expression of society's concern over semi-permanent environmental changes that result from expanded hydropower development, coal mining, oil and gas leasing, and forest practices.

For each of these resource uses, the term cumulative effects probably has a special meaning or usage. Each of these resource developments will cause different and sometimes unique changes to the environment with the environmental components receiving greatest change also differing. Nevertheless, one need only exchange the words "forest practices" with other appropriate terms to broaden (or narrow) the scope of this definition to include (or exclude) any of these or other of man's actions.

CUMULATIVE EFFECTS-OUR CONCEPT

Cumulative effects are an extension of the concept of individual effects. To clarify the definition of cumulative effects it is helpful to understand the meaning of environmental impact. As a guide to understanding the term "environmental impact" we use the basic terminology of Haug et al. (1983) and the following three statements:

1) The impact is a temporal or spatial change in some indicator in the ecosystem. This implies some baseline condition from which to perceive or measure the change, and it implies a magnitude and direction for that change.

2) The impact is initiated by human activities through a cause, a change agent. This distinguishes an environmental impact from a change in the ecosystem caused solely by natural forces.

3) The impact has a meaning or value separate from the change itself. Depending on the context within which a change takes place, an impact can be beneficial, adverse, or both simultaneously.

Throughout this report, we are interested in environmental change and although the term "change" is preferred we use the additional terms "effect" and "impact" interchangeably. This concept of change invites quantitative questions such as "how much" and "increase or decrease". These concepts of magnitude and direction are the scientific issues we address. Whether these changes are adverse or beneficial to another component of the ecosystem is also important, but only as long as this additional component is not man. An environmental change is perceived by man in terms of "significance" or "non-significance" and implies consideration of "value" and "threshold". These judgements are beyond our present responsibility and we have tried to eliminate the term significant from this discussion.

We evaluated the cumulative effects issues discovered but did not investigate all of them. Our criteria for selecting cumulative effects issues to review were related to the effects' importance to ecosystem processes. Those cumulative effects we perceive as affecting a large segment of the ecosystem for a long time are probably more important than those affecting only a small segment of the ecosystem. This is highly subjective, and ignores the basic ecosystem premise that all components, no matter how small, are interdependent parts of the total system. It further assumes we understand all processes that constitute a forest ecosystem and can identify the important ones, a tenuous assumption. Nevertheless it was necessary to continually narrow the scope of this study to keep it within workable bounds.

Our definition of cumulative effects relates changes in the elements of the environment to forest practices as the cause. Before discussing application of this definition, we must define what is meant by forest practices and elements of the environment.

4.2 FOREST PRACTICES

The statutory basis for the FPB's Rules and Regulations define forest practices as:

"...any activity conducted on or directly pertaining to forest land and relating to growing, harvesting, or processing timber, including but not limited to:

a. Road and trail construction

b. Harvesting, final and intermediate
c. Pre-commercial thinning
d. Reforestation
e. Fertilization
f. Prevention and suppression of diseases and insects
g. Salvage of trees
h. Brush control

"Forest practice" shall not include: preparatory work such as tree marking, surveying, and road flagging; or removal or harvest of incidental vegetation from forest lands such as berries, ferns, greenery, mistletoe, herbs, mushrooms, and other products which cannot normally be expected to result in damage to forest soils, timber, or public resources."
(RCW 76.09.020 (8)).

This framework was adhered to by the FPB in promulgating the original and subsequent Rules and Regulations (WAC 222). The necessary commentary is primarily contained within four sections:

222-24 Road Construction and Maintenance
222-30 Timber Harvesting
222-34 Reforestation
222-38 Forest Chemicals

Other sections of the Rules and Regulations, notably Definitions and Applications, are required to understand the intent and scope of the application procedures and requirements. We found it efficient to restructure these categories of forest practices into a format consistent with the sequence of most forest operations:

Categories of Forest Practices

Timber Harvest
- a. Intermediate Harvest
  - (1) immature timber
    - (a) pre-commercial thinning
    - (b) commercial thinning
  - (2) mature/overmature timber
    - (a) partial cutting
    - (b) shelterwood cut
    - (c) seed tree cut
    - (d) salvage cut
- b. Final Harvest
  - (1) immature timber
    - (a) conversion
    - (b) rehabilitation
  - (2) mature/overmature timber
    - (a) overstory removal
    - (b) clearcut

Road Construction, Maintenance, and Use
- a. Construction

(1) truck roads
(2) landings
(3) trails
(a) skid
(b) fire

b. Maintenance
(1) truck roads
(2) landings
(3) trails
(a) skid
(b) fire

Site Preparation
a. Prescribed burning
b. Mechanical
c. Chemical

Reforestation
a. Natural
b. Artificial

Stand Maintenance and Protection
a. Vegetation control
b. Fertilization
c. Animals, diseases, and insects
d. Wildfire

TIMBER HARVEST

Timber harvests can be either intermediate or final. Intermediate cuts are used in immature and mature/overmature stands and leave a productive forest. Thinning an immature stand is designed to stimulate growth on the remaining stems. While not a removal of merchantable timber, we included pre-commercial thinning here also. Within the mature/overmature stands, intermediate cutting takes several forms. One of those is salvage, which is the recovery of existing or imminent mortality.

The remaining categories of intermediate cuttings are principally regeneration cuts. Partial cutting is the principal form of harvesting under uneven-aged silviculture and management. Shelterwood and seed tree are variations on the same theme, merely leaving different levels of residuals. Their purpose is to provide a natural seed source for regeneration, as well as providing some site amelioration, particularly in shelterwoods.

Final harvests are applied to both immature and mature/overmature timber. Two categories of immature cutting are conversion and rehabilitation. Conversion is the removal of an undesirable timber type, frequently hardwoods, and replacement by a preferred crop. Rehabilitation is the replacement of a desirable timber type that is severely understocked or otherwise incapable of utilizing the site throughout the planned rotations. Within the mature/overmature forest, final harvests are either an overstory removal following successful regeneration under a shelterwood or seed tree cut, or a clearcut.

Clearcutting is the primary method of harvest in western Washington while some form of partial cutting is prevalent in eastern Washington. Based upon interviews with foresters throughout the state there appears to be a shift toward even-aged management in eastern Washington with the use of shelterwood cutting and increased clearcutting.

ROAD CONSTRUCTION, MAINTENANCE, AND USE

Forest roads are a necessary part of forest management. The road network provides access to the forest for harvests, for protection and administration, and for non-timber uses such as recreation, fishing, hunting, and camping. New construction is required to enter previously untapped areas, and frequently for re-entry to thin, salvage, or harvest again. Reconstruction of previous roads occurs as well, thereby maintaining and/or expanding the road system.

There are currently 18 million acres of commercial forest land in Washington (Larsen and Wadsworth 1982 - Figure 4-3). Using an average of five miles of road per square mile of land harvested, the total length of roads built to harvest all the commercial forest land may approach 150,000 miles. Since approximately 10 acres of land are cleared for each mile of road (Anderson et al. 1976), potentially about 1.5 million acres will be disturbed. This amounts to about 8 percent of the forest land base (Froehlich 1977).

CONSTRUCTION

Forest roads have evolved from crude but effective skid roads to, in some cases, mini-highways. A forest road is usually gravel surfaced and single laned with turnouts. While the running surface may be 10-15 feet in width, the right of way is often cleared to a width of 40-80 feet. Roads are normally drained by inside ditches and cross drains spaced at intervals less than 1000 ft. Outsloped roads are sometimes used and are more common in eastern than western Washington. Where heavy traffic and limited surface rock supply make it economical, forest roads are occasionally paved.

Through time, construction methods have taken advantage of changes in available machinery but processes have remained remarkably the same. One must still clear the roadway of trees and stumps, excavate and fill to provide an acceptable road grade, and install a drainage system to keep the road passable. Landings are frequently constructed concurrent with the road construction and are primarily a part of the road network. Therefore, we treat them as such.

Skid trails and fire trails are more specialized systems, one an extension of the transportation network, the other a principal protection tool. Though the horse might occasionally be seen on a skid even today, more commonly the rubber-tired skidder and the crawler tractor are the principal modes of skidding logs. Fire trails, in conjunction with forest practices, are principally used to contain prescribed burns, and are constructed either with crawler tractors or by hand. Like most skid trails they are temporary, frequently being replanted following use.

Figure 4-3. Area of commercial forest land by owner class and region for the state of Washington, 1980.

Owner Class	Western Washington		Eastern Washington		TOTAL	
	1000 Acres	Percent →	1000 Acres	Percent →	1000 Acres	↓Percent
National Forest	2,256	44.6	2,801	55.4	5,057	28.4
Bureau of Indian Affairs	187	11.9	1,390	88.1	1,577	8.9
State	1,252	68.3	581	31.7	1,833	9.7
Other Public	236	44.4	295	55.6	531	3.0
Forest Industry	3,544	82.8	735	17.2	4,279	24.0
Other Private	2,328	51.4	2,200	48.6	4,528	25.4
TOTAL	9,803	55.1	8,002	44.9	17,805	100.0

MAINTENANCE AND USE

Maintenance, the activity of keeping a road, landing, or trail in condition for use, includes grading, ditch and culvert cleaning, and brush control, as well as preparing the road to be abandoned. To the extent the processes are quite similar, they are treated collectively rather than as separate components in further discussion. Road use includes all traffic over the road.

SITE PREPARATION

Site preparation is the first forest management step in the rotation of a timber crop. It is the process of preparing a site for either natural or artificial reforestation. The objective is creation of a suitable environment for establishing desirable tree species. Generally, achievement of one or more of the following is desired (Stewart 1978):

1) reduction of logging slash or other debris
2) reduction of competing vegetation
3) preparation of a mineral seedbed
4) reduction in compaction
5) creation of more favorable microsites on harsh sites
6) and disease control

The most common goals are the reduction in the residue remaining after logging and reduction in competing vegetation. Residue includes both the slash created by logging and the natural debris that accumulates through mortality. Residue management techniques include prescribed burning, herbicide application, and mechanical clearing or scarification.

Herbicide application is often used in combination with prescribed burning to dispose of brush and undesirable tree species. It is applied aerially, or with ground equipment, or by hand. Washington's diverse topography and vegetation exclude any single method of site preparation as best for all conditions.

Mechanical site preparation includes scarifying and piling of debris, crushing, plowing, and masticating. These practices reduce debris and competing vegetation, and prepare a mineral-soil seedbed. Minor practices include furrowing and trenching to improve microsite conditions, removing infected stumps to control root disease, and ripping of landings and skid trails to reduce compaction.

The most common residue disposal tool is fire. Fire has always been one of nature's principal methods of preparing sites for regeneration. When used as a management tool, it is referred to as prescribed burning. Prescribed burning is "the controlled application of fire to wildland fuels in either their natural or modified state, under such conditions of weather, fuel, moisture, etc., as to allow the fire to be confined to a pre-determined area and at the same time to produce the intensity of heat and rate of spread required to further certain planned objectives of silviculture, wildlife management, grazing, fire-hazard reduction, etc." (Pierovich et al. 1975). Prescribed burning is widely used following clearcutting and also used in partially cut stands of fire tolerant species such as ponderosa pine.

Broadcast burning is the major method of residue disposal in western Washington accounting for greater than 90 percent of all slash burned on state and private forest lands (Carnine 1981). Although pile burning occurs year around, the vast majority of all burning occurs between June and October. In eastern Washington, nearly all burning is of machine piles with only limited broadcast burning. Because of its drier summers, burning is generally restricted to spring and early fall. Although large areas of federally managed lands (USFS, BIA) are burned in eastern Washington, acres burned by State and private land owners are relatively small.

Combinations of mechanical, prescribed fire, and chemical site preparation techniques have been most successful. Mechanical and chemical combinations reduce resprouting while mechanical and burning treatments combine to reduce the accumulation of debris and alter potential habitat for tree-damaging animals. Prescribed burning, particularly in western Washington, can be more effective when combined with herbicides, either in "brown and burn" or in "spray and burn". The primary difference is the type of herbicide used and the necessary timing of the two functions.

Because of its wide use, prescribed burning affects more acres of forest land than any other site preparation activity. In addition to slash disposal, prescribed under-burning is done in eastern Washington ponderosa pine forests to reduce fire hazard. This is primarily an attempt to mimic the results of natural fire frequency. Although the potential acres under-burned each year may be large we limit our discussion of site preparation to burning of logging residue.

A discussion of burning is not complete unless it accounts for man's prevention and control of wildfire. Historically, wildfire played an important role in determining the condition, distribution, and content of forests in the Northwest. The natural frequency of fire varied greatly from site to site depending on climate, vegetation, fuels, and topogrpahy. In western Washington fire was infrequent, occurring at intervals of 150-700 years. In eastern Washington the fire interval was much shorter with natural fires occurring every 5-15 years in pine types or up to 50 years in wetter cedar-hemlock types. The relative impact of fire in shaping the ecosystem varied by the size and intensity of the fire, with some setting succession back severely while others promoted succession toward the climax condition (Fahnestock and Agee 1983, Martin and Dell 1978). Prior to settlement, fire was the primary natural force modifying forest ecosystems.

Recently, man has been very effective in controlling wildfire. Concerted efforts at fire control began early in the 1900's, primarily as protection for man's life and investments, and secondarily for forest and watershed values. The area burned by wildfire in western Washington has been reduced from about 50,000 acres to 3500 acres per year (Fahnestock and Agee 1983). A result of this near elimination of fire from some areas has been a subtle change in plant communities (Wright and Bailey 1982). Although not a forest practice regulated by the FPB, prevention of fire and its effects on the environment must be considered with the re-introduction of fire as a management tool.

REFORESTATION

Individual efforts at reforesting cut-over lands have probably occurred since late in the nineteenth century. However, there was no generalized effort to secure and maintain adequate reforestation of harvested land until the 1940's. With passage of the Forest Practices Act in 1945 the State Division of Forestry was given the administrative responsibility for securing reforestation on all non-federal forest ownerships following harvest. The 1945 report of the Douglas-fir Second Growth Management Committee fixed the Western Washington acreage of poorly stocked, non-stocked, and recent cut-over stands at approximately 29 percent of the region's non-federal commercial forest lands at that time (Peet 1948). Today, this figure has been reduced to 21 percent. Data from the Washington Forest Productivity study (Larsen and Wadsworth 1982) list non-stocked land at 3 percent and recent cutover land as 18 percent of the current non-federal commercial forest base.

Reforestation is achieved by natural or artificial regeneration. Because desired regeneration, whether natural or artificial, usually involves conifers, especially Douglas-fir, we concentrate on conifers rather than hardwoods.

NATURAL REGENERATION

Natural regeneration occurs where adjacent stands provide the seed source for the next crop. Use of natural regeneration in western Washington is usually confined to high elevation harsh sites. On these sites the residual vegetation, stored seed, and surrounding seed source are usually the preferred species, and survival of planted stock is poor. In eastern Washington natural regeneration is the principal regeneration method under uneven-aged silviculture.

Historically, fire, inadequate or non-existent site preparation, and cutting of seed-sources often led to poor stocking when natural regeneration was relied on. Much of the hardwood timber harvested in recent years is a result of this inadequate conifer regeneration. Even following the 1945 Act, seed blocks left were often poorly situated or of inferior quality, or inadequately protected, resulting in the creation of brush and hardwood dominated sites. The present reluctance to rely on natural regeneration is often related to these past failures rather than to inadequacies of natural regeneration.

ARTIFICIAL REGENERATION

Artificial regeneration is obtained by planting young trees or by applying seed. Where direct seeding is used, it is usually by aerial methods. Either regeneration technique offers greater opportunity than natural seeding to control the genetic and species makeup of the resulting stand. In addition to species control, planting bypasses the critical stages of germination and early development, periods of greatest tree mortality in naturally regenerated stands. Planting seedlings, as opposed to seeding, usually increases the probability of successful and earlier reforestation to desired stocking levels.

Planting stock, primarily Douglas-fir, is grown in forest nurseries, usually in open fields as bare-root seedlings. Recently there has been an increase in use of seedlings grown in containers under greenhouse conditions. This has shortened the time to reach plantable size as well as provided better opportunity for growing and handling previously difficult species such as Sitka spruce and western hemlock.

Artificial regeneration requires collection of seed both for direct seeding and for nursery sowing. Seed is usually obtained by collecting cones from natural stands. Because trees are adapted to specific latitude and elevational zones, cones are collected from geographical areas representative of sites where resultant seedlings will be planted. The Oregon-Washington Interagency Forest Tree Seed Certification Program was developed to assure identification of the source of seeds and to maintain that identity from seed to seedling. The goal is the return of seedlings to the appropriate zones from which seeds were collected.

Collection of natural seed is, however, difficult and little control is generally available over the selection of genetic material (good parent or phenotype). To improve source control, cones are increasingly collected from pre-selected individual trees. To further improve the success of artificial regeneration and later tree growth, seed is also obtained from seed orchards. These orchards, established specifically for seed production, are composed of trees with desirable genetic characteristics.

Similarly, the desire for greater control over genetic traits has resulted in tree improvement programs aimed at increasing growth and vigor. These programs are anticipated to provide a significant portion of future planting stock.

Genetic selection for a few characteristics runs the risk that trees may later prove highly undesirable because of hidden characteristics not appreciated at the time of selection. This potential is generally recognized, although the magnitude of risk is largely unknown.

STAND MAINTENANCE AND PROTECTION

Adequate site preparation and successful reforestation are only the beginnings of a long cycle of practices commonly used to provide a continuing forest crop. Additional investments are frequently made through the silvicultural practices of controlling competing vegetation, controlling stand stocking, and enhancing growth. These practices are common in western Washington, and have gained recent acceptance in eastern Washington. Other practices influencing forest development are the control of animals, disease and insects, and wildfires.

Vegetation control is designed to favor preferred timber species. Control is principally achieved through the aerial application of herbicides but hand methods are also used. Precommercial thinning (see Timber Harvest) is the principal method for controlling stand stocking. Should a stand be determined to be understocked at an early age, interplanting to increase the stocking level may be required.

Growth of many forest stands can be improved by the application of nitrogen fertilizer. Nitrogen is aerially applied as Urea prill, containing 46 percent organic nitrogen, at a rate of about 200 pounds of N per acre.

Animal, disease, and insect control are carried on throughout the life of a stand. Control is accomplished by both chemical and mechanical means. Chemical control includes planting anti-palative treated seedlings and the application of anti-palatives on established plantations. Anti-palatives reduce browsing by animals. Aerial applications of insecticides to control insect epidemics and the use of pheromone baited traps to reduce population buildups are other examples of chemical controls. Mechanical protection includes the use of plastic mesh tubes, paper bud caps and leader protectors. These reduce browsing by big game and clipping by small mammals and rodents. Direct population reduction by trapping of small animals such as mountain beavers or hunting of bear are also used. Fencing may be installed to replace natural vegetative barriers removed through timber harvest or road construction where domestic grazing is a problem. Mechanical disease control includes removal of root-rot infected stumps and cutting of mistletoe infested regeneration.

Silvicultural methods are also used to control insects and diseases. Stands are thinned to encourage better growth, particular species are favored to avoid infestations, and potential disease carriers are removed through prescribed burning.

Wildfire control has been practiced since early in the twentieth century, principally to protect human life and property. Fire control includes the use of hand and mechanical means to construct firelines, the use of aerial retardants (generally ammonia fertilizers), and prescribed fire to reduce fuel buildups. Fire prevention during the past eighty years has contributed to the buildup of fuel levels, particularly in habitat types naturally subject to frequent fire. Fire pevention techniques have recently included prescribed fire as understory burning to reduce fuel accumulations.

4.3 ELEMENTS OF THE ENVIRONMENT

The focus of this section is on natural processes exclusive of human disturbance. We describe the important physical, chemical, and biological processes associated with the physical elements of the environment: air, earth, water, flora, and fauna. Determining the effects of forest practices on the human elements of the environment was not an objective of our study. As an initial guide to categorizing the environmenatl elements we used an abbreviated list of elements of the environment as found in SEPA (WAC 197-10-444):

Elements of the Physical Environment

Air

a. Air quality
b. Climate

Earth
- a. Geology
- b. Soils
- c. Topography
- d. Erosion

Water
- a. Surface water movement
- b. Runoff/absorption
- c. Floods
- d. Surface water quantity
- e. Surface water quality
- f. Ground water

Flora
- a. Numbers or diversity of species
- b. Unique species

Fauna
- a. Numbers or diversity of species
- b. Unique species
- c. Barriers and/or corridors
- d. Fish or wildlife habitat

Discussion of the five elements of the physicial environment, as they relate to natural processes, forest practices, and the inter-relationships of both, dictates a systems approach for understanding, predicting, and controlling environmental change. The ecosystem is the basic unit for ecological study (Evans 1956) and the level of biological organization most suitable for analyzing the effects of forest practices on the environment. An ecosystem is an ecological system composed of living organisms (flora, fauna) interacting with their non-living environment (air, earth, water). The term ecosystem stresses interaction, flow of energy, and the continuous cycling of matter (Figure 4-4).

An ecosystem has six structural components:

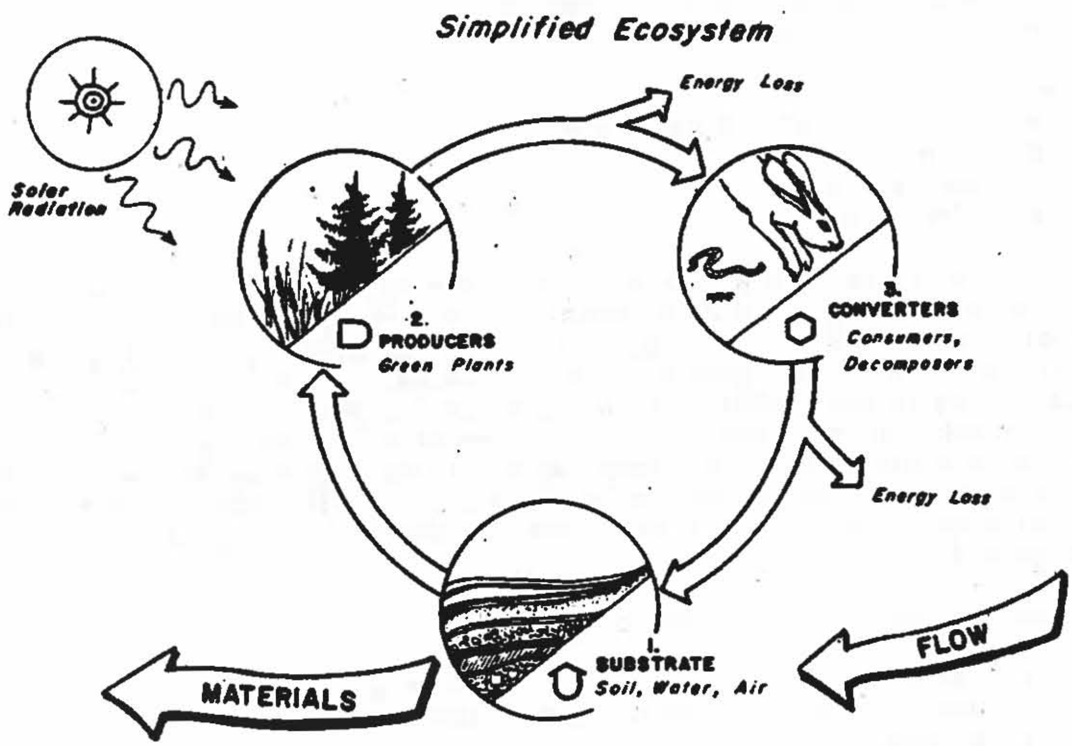
1) inorganic substances involved in material cycles
2) organic compounds that link the biotic and abiotic
3) climate
4) producers, mostly green plants that manufacture food from simple inorganic substances
5) macroconsumers, mostly animals which ingest other organisms or particulate organic matter
6) microconsumers, mostly bacteria and fungi which serve as decomposers and nutrient absorbers

Components 1-3 comprise the ecosystem substrate, component 4 the energy producers, and components 5 and 6 the energy converters.

An ecosystem has six functional processes:

1) energy circuits
2) food chains

Figure 4-4. A simplified ecosystem showing the basic components of an ecosystem and their interrelationship and flow of energy and matter. (after Proctor et al. 1980)



3) diversity patterns in time and space
4) nutrient cycles
5) development and evolution, and
6) control or cybernetics

The ultimate goal of study at any level of biological organization is understanding the relationships between structure and function (Odum 1971). Before integrating forest practices into our ecosystem concept it is necessary to briefly describe what we mean by the ecosystem components of air, earth, water, flora, and fauna. Our use of these terms is restricted from their traditional definitions to include only categories believed affected by forest practices. When discussing an element of the environment we include the processes that control the quantity or quality of that element within the ecosystem. For example, we are not only concerned with the chemical we call water but also the processes that control its distribution within a forested watershed, i.e., the hydrologic cycle.

AIR

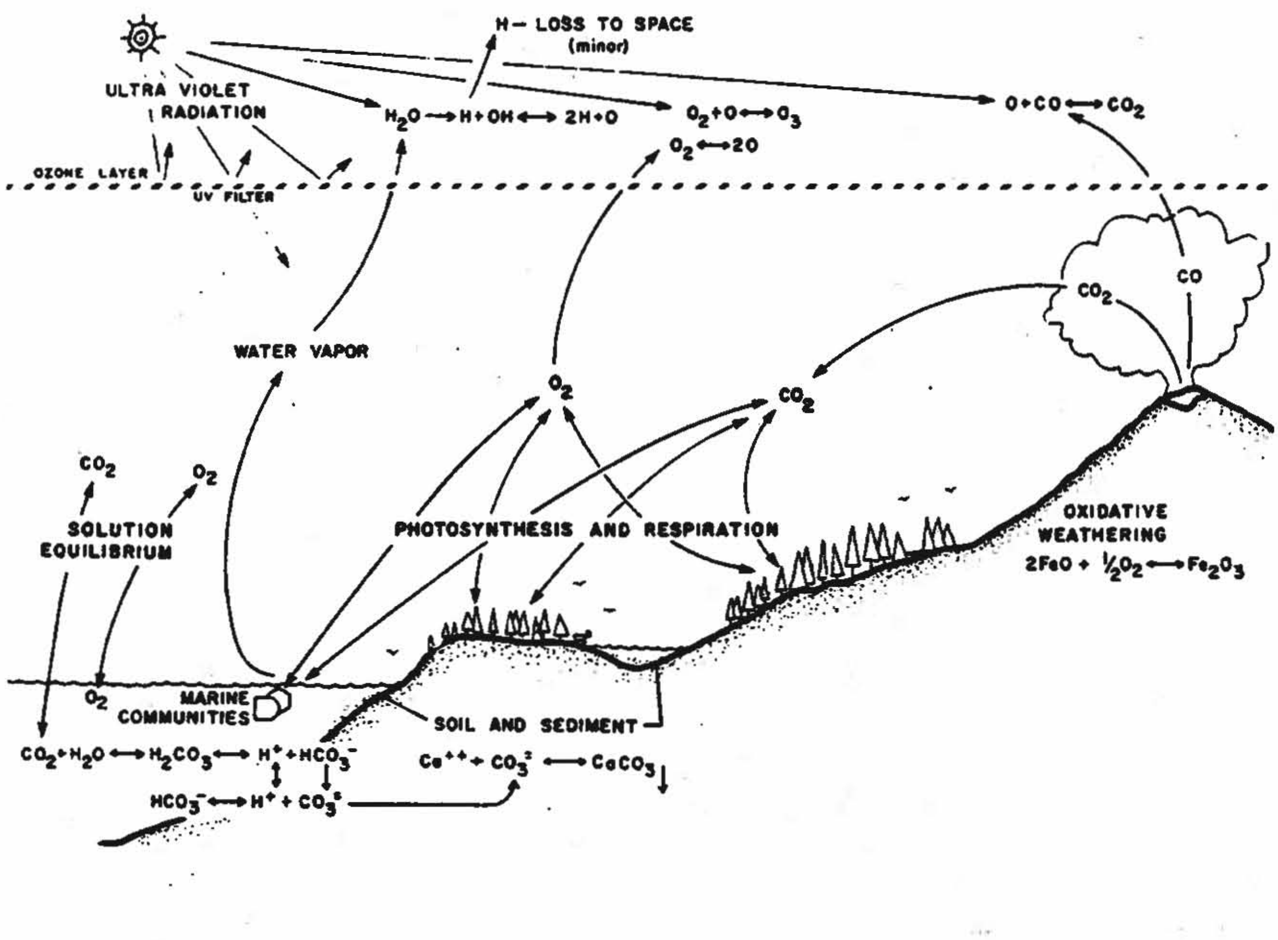
Air is the invisible mixture of odorless, tasteless gases that surround the earth, and as we use the term, it is synononous with atmosphere. The air we breath is primarily nitrogen (78 percent) and oxygen (21 percent) with all other components accounting for less than 1 percent. Carbon dioxide, the next greatest gas in volume makes up only 0.03 percent of the atmosphere. Like all other aspects of our environment, we are interested in both the air's quantity and its quality.

Our greatest concern with air quantity is maintaining a balance of the various gases, especially oxygen and carbon dioxide (Figure 4-5). The free oxygen in the atmosphere that supports life also arises from life. The oxygen now in the atmosphere is mainly, if not wholly, of biologic origin. The present supply of oxygen is continually replenished by photosynthesis, and if it were not, it would slowly be consumed in the oxidation of ferrous to ferric iron and sulfides to sulfates. The green photosynthetic plants are also the primary producers of the biosphere, converting solar energy into the organic compounds that maintain the plants and all other living things. Forests, which cover only about one-tenth of the earth's surface, fix almost one-half of the biosphere's total energy and in the process constitute a major and potentially unique control over the composition of our atmosphere.

Thus, the importance of forest practices on air cannot be overstated. However, unlike the other elements of the environment (with the possible exception of water), air is truly a global resource. Changes to the atmosphere caused by land-use practices can have global repercussions. Research is underway to define the global effects of the declining world forest land base as it relates to atmospheric composition (Reynolds and Wood 1977, Darling 1974). Questions being addressed include: Are de-foresting and burning decreasing the oxygen level and increasing the carbon dioxide level; are they contributing to the "greenhouse effect", or to cooling effects from particulate matter in the air?

Undoubtedly, forest practices in Washington have some bearing upon these global concerns. However, determining any such association is well beyond the

Figure 4-5. The oxygen cycle and its linkage with carbon and hydrologic cycles in a simplified form.



scope of this review. Potential contributions of forestry as practiced in Washington to the balance of gases in the atmosphere, or to a change in global climate due to particulates, are recognized but hereafter ignored.

The primary interest in Washington's air supply is one of quality. Our concern is with air pollution and the processes that contribute undesirable gaseous chemicals and particulates. The Clean Air Act of 1963 (PL 88-206) and amendments of 1970 and 1977 require control of air pollutants that have adverse effects on public health and welfare. It includes as a pollutant the impairment of visibility. Therefore, the discussion of cumulative effects on air is limited to forest practices that may result in air pollution.

EARTH

As it relates to forest practices, the term "Earth" is restricted to those geologic properties and controlling processes that occur at or near the Earth's surface. Specifically, we are interested in the regolith, the unconsolidated materials that overlie bedrock. In a general sense, we are interested in both the quantity and quality of the regolith. Its quantity is controlled by the balance between erosion and weathering processes. As to its quality, we are interested in the hydrologic, physical, and chemical properties of the soil. We are concerned with forest soil fertility, that is, the soil's ability to supply essential nutrients and water to plants in a proper balance for plant requirements. Therefore, we have divided our discussion of EARTH into erosion and soil properties.

EROSION

The set of processes known collectively as "erosion" simply involve the detachment and transport of materials from place to place on the land surface. In regions such as the timberlands of the Pacific Northwest, sheetwash erosion, soil creep, mass-wasting, and debris flows have always occurred in response to long-term weathering of rock to soil, the availability of water, the presence of topographic relief, and biological activity. The processes are active in different areas and at different rates, depending on such factors as the mechanical strength of materials, climatic conditions (especially storms), local geology, and vegetation.

Erosion includes both the movement of erosion products by a transport agent and their temporary or permanent deposition. Water, particularly streams, is the most important transport agent. The products of erosion are transported in streams as dissolved load, suspended sediment, and bedload. The dissolved load and suspended sediment are discussed further under WATER as water quality parameters.

These natural processes have many beneficial effects. For example, continual erosion replenishes the stream gravels necessary for a viable fishery. However, certain forest practices tend to exacerbate erosion processes on Washington forest lands, especially in mountainous areas. Accelerated erosion can cause excessive loss of soil from hillslopes, with resultant decrease in the ability to grow trees; and deposition of the eroded material in places where it is unwanted and/or in excessive volumes, especially in streams where it can adversely affect downstream resources and uses. Because of these negative effects, it is desirable to avoid or control any forest practices that accelerate erosion processes, or at least to ameliorate their effects. In this discussion, we have divided erosion into two types, surface erosion and mass movement.

Surface Erosion

Surface erosion refers to the movement of individual soil particles in response to gravity and/or fluid flow. It includes:

1) Dry ravel: movement of dry soil particles.

2) Needle-ice movement: slow movement as a result of growth and melting of ice needles.

3) Rainsplash erosion: displacement of particles due to the impact of raindrops.

4) Sheetwash erosion: movement due to the shear stress exerted by a thin layer of water flowing over the ground.

5) Gullying: erosion of rills in previously unchannelled slopes.

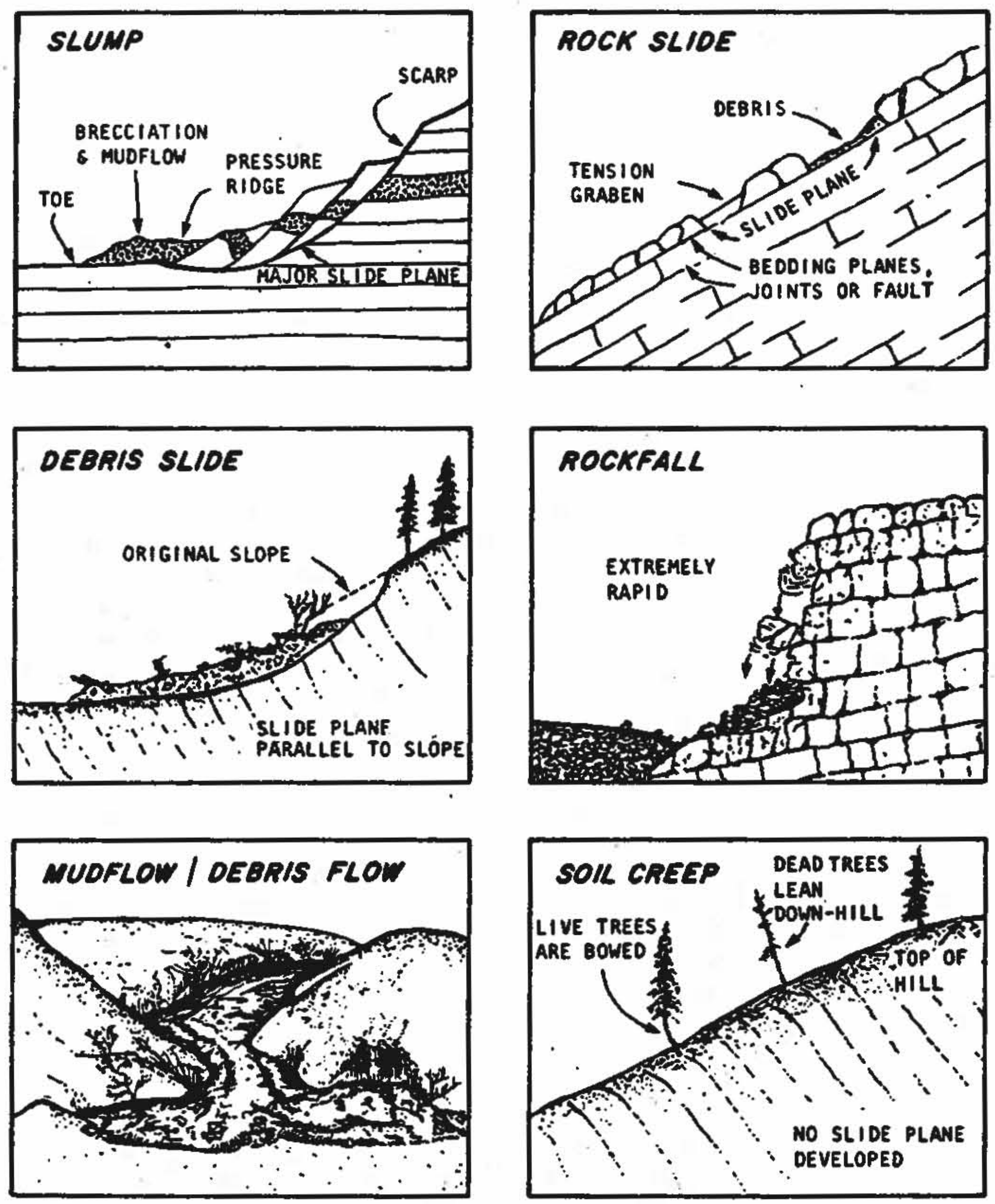
These processes are usually minor in undisturbed forest lands. Vegetation protects the soil from surface erosion by intercepting raindrops, providing cohesion (roots and organic material), and insulating the soil from ice formation. Overland flow is uncommon in these areas since soil infiltration capacity usually exceeds rainfall intensity. Therefore, sheetwash erosion and gullying are also uncommon. The drier forests of the east side of the Cascades, the Okanogan Mountains, etc., may experience overland flow during intense convective storms or snowmelt runoff. Under such conditions granular soils, such as those formed on granitic rocks and sandstones, are more susceptible to surface erosion than are more clay-rich, cohesive soils (Megahan et al. 1978). However, ground vegetation usually binds the soil together, and surface erosion processes become important only when forest land is disturbed, either by nature (landslides, wildfires) or by forest practices.

Mass Movement

Mass-wasting and mass movement are general terms for a group of processes by which fairly large volumes of earth are moved, at various rates of speed, under the influence of gravity (Figure 4-6). A fluid (especially but not exclusively water) may or may not be involved, but rates of occurrence and velocities are usually increased by the presence of a fluid. Mass movement is generally caused by long-term weathering and reduction of strength, but individual landslides are usually triggered by discrete environmental events, especially heavy rainstorms (and associated melting snow) and earthquakes.

The potential for mass movement is analyzed in terms of the balance between the forces tending to cause movement (gravitational shear stress) and

Figure 4-6. Modes of mass movement in soils and rocks.



the forces tending to resist movement (strength, especially shear strength). The major component of shear stress is the downslope component of the weight of the mass (rock, soil, soil moisture and trees). Strength also involves the weight and the slope angle, but this time as the component of weight acting to hold the mass against the slope, called the normal force. This normal force is reduced by the buoyancy of any water-saturated zone existing above the failure surface. Any increase in local gradient will increase stress and decrease the normal force; any increase in soil saturation will decrease strength, as will any reduction in cohesion. The effects of forest practices are related to their effects on these forces.

There are several kinds of mass-wasting processes operative on forest lands of this region (Schuster and Krizek 1978, Swanston and Swanson 1976):

1) Rockfall and rockslide: the rapid movement of bedrock.

2) Creep: the slow movement of the soil mantle in response to gravitational stress.

3) Slump-earthflow: the rotational movement of a block of material along a discrete slip surface.

4) Debris avalanche: a shallow mass failure that moves rapidly down steep hillslopes, by falling, sliding, flowing, or some combination thereof. The material in a debris avalanche is almost always wet, since large storms and high soil-water levels are usually the triggering events.

5) Debris torrent: a highly erosive mixture of slurry, rock, and organic debris, that moves down a defined channel, generally originating at a debris avalanche. Such torrents can scour steep channels to bedrock, undercut valley sides, and deposit large piles of logs, rock, and mud in larger downstream channels and alluvial fans. The deposits, up to 10-100 times greater in volume than the initial failure (Swanston and Swanson 1976), can have severe effects on channel morphology, stream behavior, and sediment transport.

Under both natural and disturbed conditions, mass-wasting processes are by far the most significant means of erosion in Northwest timberlands. This has been documented in many field studies throughout the Northwest. In Oregon, Fredriksen (1970) discovered that about 99 percent of the sediment derived from experimental watersheds moved out in years of landslide activity. One landslide in Idaho accounted for 70 percent of the total sediment production in a 6-year study (Megahan and Kidd 1972a). And Reid (1981) found that almost 60 percent of the sediment getting into streams from roads was moved by mass-wasting processes.

Although rockfall and creep are types of mass movement, they are not as important in Northwest forests as slump-earthflows or debris avalanches, and they will not be discussed. Rather, we concentrate on possible acceleration in the occurrence of earthflows and debris avalanches. Since most debris torrents begin as debris avalanches, any increase in activity of avalanches due to forest practices will be translated into increased frequency of torrents. Considering their frequency, their long reach (up to several miles), their ability to damage downstream structures and resources, and the long time periods required for channel recovery, debris torrents are arguably the most important erosional agents in steep timberlands of Washington, and along with debris avalanches, are a primary concern in this report.

FOREST SOIL PROPERTIES

Forest soil characteristically consists of a layer of organic material, the forest floor, underlain by several layers or horizons of mineral soil. The properties of each horizon vary as a result of soil-forming processes acting on the parent material over time. These soil-forming processes are broadly influenced by climate, vegetation, topography, and time. A fully developed forest soil may take several thousand years to form (Mitchel 1979).

Weathering of rock-forming minerals at the earth's surface is the first step in soil formation. Chemical weathering along with physical weathering (mechanical breakdown) form the more stable clay minerals, concentrate iron and aluminum oxides, release the major plant nutrients potassium, phosphorus, sulfur, and iron, as well as several minor nutrients, and increase acidity. This contributes to the solute composition of the soil water and ultimately of groundwater and streamwater. The weathering of rock to soil is caused by large quantities of water, dissolved gases in the water, and the presence of organic compounds, notably organic acids and chelating agents (Clayton et al. 1979). Understanding these chemical weathering processes, including their rates, is necessary to understand soil formation and related soil fertility in natural ecosystems.

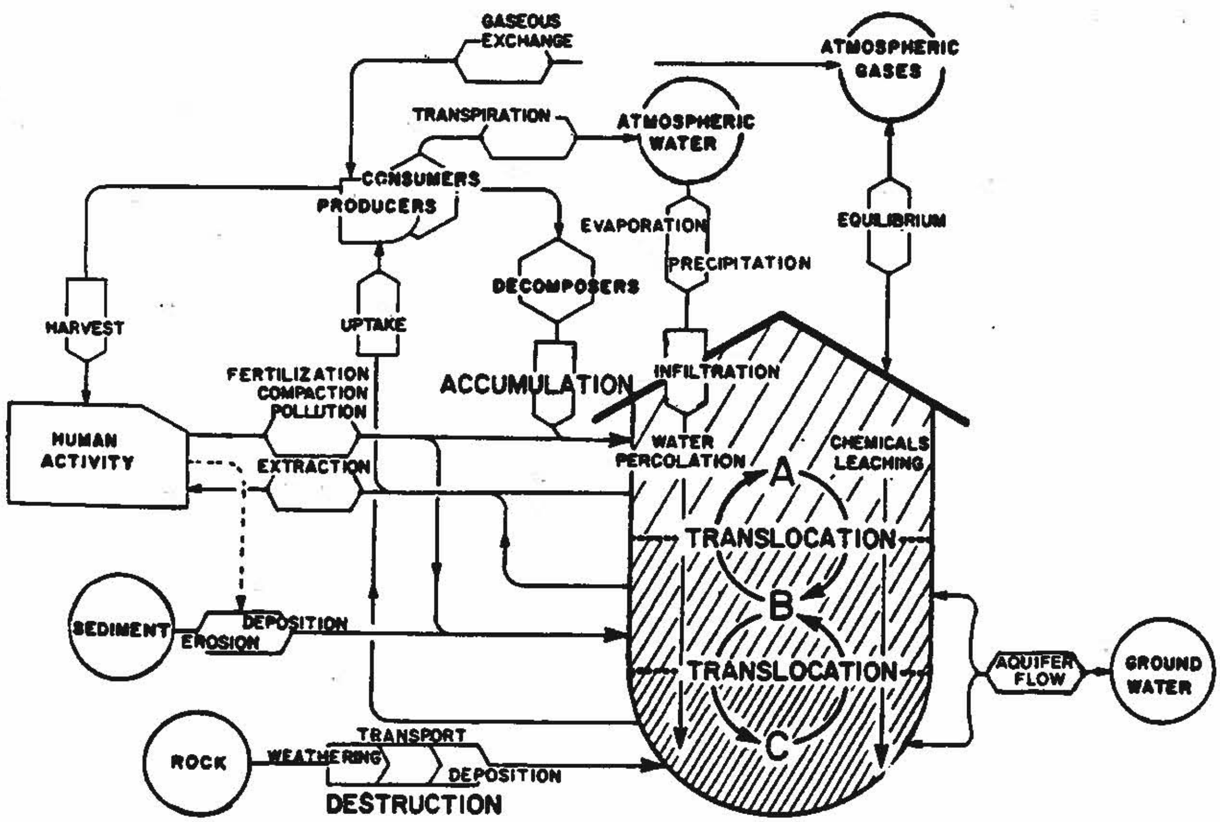
Soil fertility and its contribution to forest productivity depend upon the soils' physical, chemical, and biological properties (Figure 4-7). These properties and their associated processes influence the nutrients available for plant uptake, soil moisture, root aeration, and root growth.

Physical Properties

Soil physical properties control the drainage and availability of soil water and aeration of the root zone, affecting both root growth and nutrient transformations. Physical soil properties include texture, structure, consistence, and density. Texture refers to the relative abundance of sand, silt, and clay in the soil and is often used as an indicator of forest productivity with somewhat finer textures preferred. Structure is the spatial arrangement and bonding together of soil particles (aggregation) and is important to drainage, aeration, and erosion resistance. A soil's relative hardness under various moisture conditions is its consistence. Density, specifically bulk density, refers to the soils relative compactness and is important to root distribution and water retention (Ballard 1979).

The natural bulk density of forest soils is relatively low, normally increasing with depth. An optimum compactness has a pore-size distribution that allows water and air movement suited to plant growth. Vegetation and related soil biological processes are probably most important to the development of a soil's physical properties. Development of the soil's organic matter contributes to water-holding capacity, maintains aggregate

Figure 4-7. A general soil model presented as a storage silo of three horizons (A, B, C), with the processes of destruction, accumulation, and translocation. (after Proctor et al. 1980)



stability, and improves a soil's resistance to erosion. This organic matter is the main energy source for the micro- and macroorganisms that play an active role in controlling both chemical and physical soil properties. Any change in the quantity or quality of vegetation, air temperature, water regime, or a host of other environmental variables will cause a change in the soil's physical properties. The most direct change to physical properties caused by forest practices is probably compaction which increases the soil's bulk density and disrupts its structure. Soil compaction is the topic we address.

Chemical Properties

Soils are primarily comprised of 15 chemical elements. Of these, seven (iron, calcium, potassium, magnesium, phosphorus, sulfur, and manganese) are important plant nutrients derived from soil weathering. Nitrogen, one of the most essential nutrients, is not derived from soil weathering, but is obtained from nitrogen gas in the atmosphere. This process, called nitrogen fixation, is primarily a biologic one. There are several other soil-derived nutrients sparingly present in most rocks but required by plants in only trace amounts.

The clay-sized minerals and the organic fraction are the most chemically active parts of the soil. They are responsible for retaining exchangeable cations against leaching while making them available for uptake by plants. Most soil nitrogen is contained in the organic fraction and is converted by microorganisms to the mineral forms, ammonium and nitrate, used by plants. Nitrogen availability is a balance between fixation from the atmosphere, accumulation in organic matter, mineralization, and denitrification back to the atmosphere. Nitrogen is most often the limiting nutrient in Washington's forest soils, although response to phosphorus and sulfur fertilization has been noted (Heilman 1979).

The soil's chemical properties can be affected by any forest practice that tends to change the quantity of organic matter and its related nutrients, the rate of mineral weathering, or the dissolved ionic composition of the soil water. We are particularly interested in nutrient removals or losses at rates in excess of replenishment and in persistent changes to chemical processes that control rates at which soil nutrients are made available to plants.

Biological Properties

Soil biology generally refers to the organisms that inhabit the soil. These organisms include viruses, bacteria, fungi, algae, protozoa, nematodes, microarthropods, macroarthropods (insects), earthworms, and slugs and snails. Most contribute to beneficial processes such as weathering of parent material, soil aggregation, organic matter decomposition, nitrogen transformation, gaseous nitrogen fixation, phosphorus and micronutrient solubilization and uptake, capture of nutrients that would otherwise be lost by leaching, and protection of tree roots from pathogens. Others are detrimental to productivity, they aid in formation of iron pans and highly acid raw humus, immobilize nitrogen, or are disease organisms (Trappe and Bollen 1979).

Growth and activity of soil organisms are affected by water, temperature, aeration, pH, food supply, and biological factors. In an undisturbed forest, populations of soil organisms reach a dynamic equilibrium, seasonal changes occur but annual populations are relatively stable. Fire, insect attack, disease, blowdown, timber harvest, fertilization, or any other major site disturbance will upset this equilibrium.

EARTH SUMMARY

It is difficult to separate surface erosion from mass movement, or to distinguish between physical, chemical, and biological soil processes. All of these factors contribute to soil formation and the development of soil fertility and are intimately connected. While it would be ideal to discuss in detail the effects of forest practices on each of these processes, we concentrate on surface erosion, debris avalanches, soil compaction, soil fertility, and soil microbiology. Forest practices affect these processes through physical soil disturbance and modification or removal of vegetation.

WATER

Precipitation ranges from about 5 inches in the driest part of central Washington to over 200 inches in the Olympic Mountains. Statewide, 68 percent of this precipitation ends up as streamflow with the majority of Washington's streams and rivers originating from forested watersheds. These are the important rearing areas for resident and anadromous fish. The quantity and quality of most fifth order and smaller streams (all but a few of the largest Washington rivers - Figure 4-8) are strongly influenced by forests. Forest practices affect both water quantity and quality.

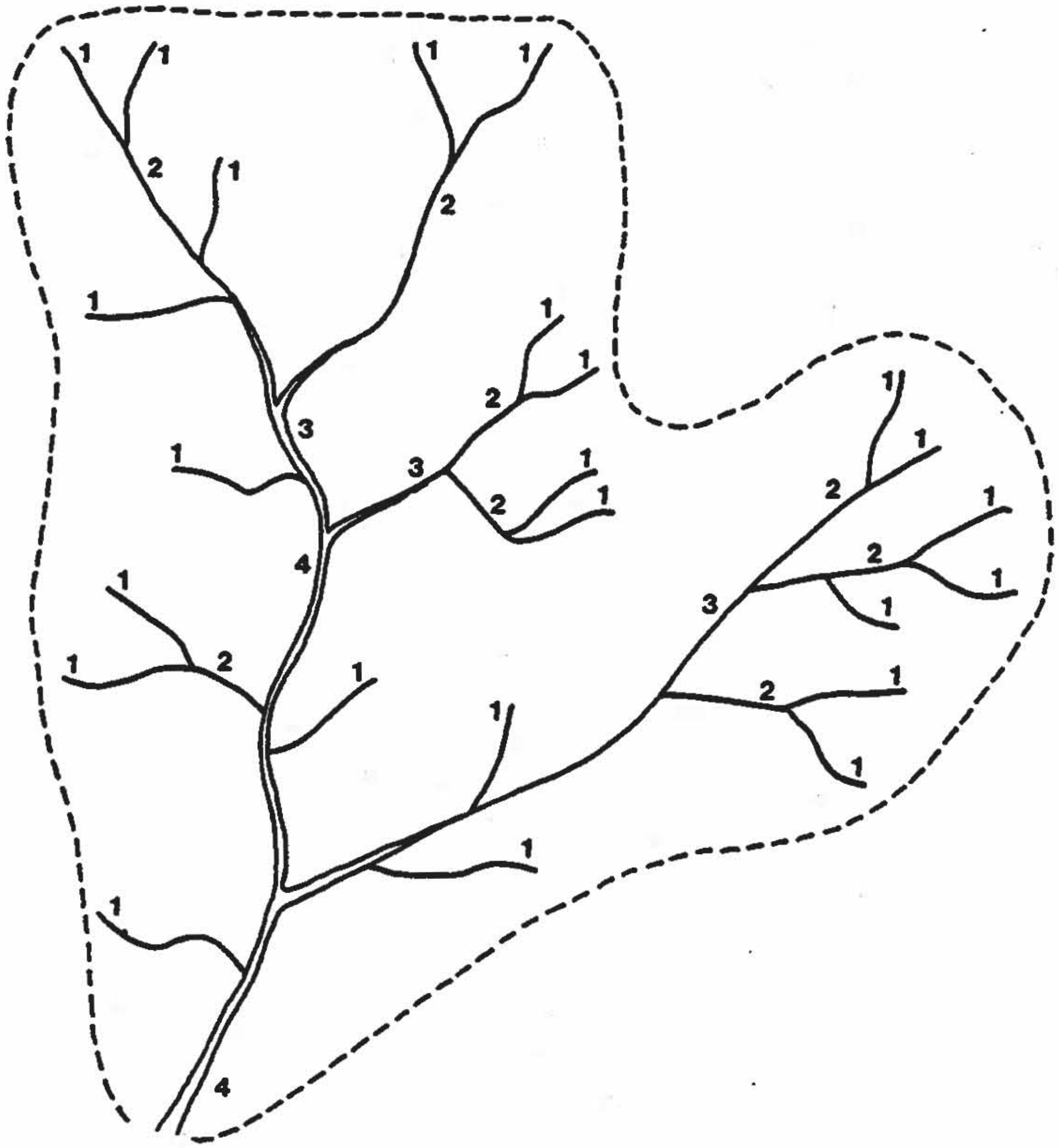
QUANTITY

Water enters the forest in four ways; as rain, snow, intercepted atmospheric moisture, and condensation. Some of this water adheres to the leaves and branches of the vegetation and is either adsorbed, drips to the forest floor, or evaporates. The difference between precipitation and what reaches the forest floor as throughfall is the interception loss.

Precipitation reaching the forest floor contributes first to surface storage, that is water on the forest litter, ponded in soil depressions, or held in the snowpack. It then infiltrates the soil or runs off as overland flow. In the undisturbed forest it is generally conceded that overland flow is rare even during flood-producing rainfall. Water infiltrates, flows laterally, and eventually surfaces as streamflow. It may surface quickly, as in headwater areas with steep topography, or not for many years, as in major groundwater basins at lower elevations.

Infiltrating water is detained temporarily by the soil as it percolates toward groundwater or streams but a portion is retained, eventually to be evaporated or transpired. The amount of water retained and available for use by vegetation depends on soil density, structure, depth, and organic matter content. Of the annual soil water evapotranspiration (ET), 60-80 percent is lost via transpiration with the remainder primarily evaporated from the forest floor or snow surface. The annual ET from a forest is controlled by available

Figure 4-8. Hierarchy of stream ordering. Numbers indicate ordering of respective segments. The watershed is fourth-order.



energy which is related to the regional climate and to the micro-climate as controlled by local slope, aspect, elevation, and vegetation.

The water not evaporated, transpired, or retained by the soil to satisfy future ET needs, is the forest's water yield. It includes both surface runoff as streamflow, and subsurface losses to groundwater. Because commercial forests in Washington are generally located in mountainous areas, our primary emphasis is on streamflow. However, the importance of the forest's contribution to groundwater aquifers, especially in eastern Washington, is recognized (Urie 1967). Streamflow from forest lands is a balance between precipitation, consumption by ET, losses to groundwater aquifers, and the capacity of the soil to store water.

While it is generally apparent that water, usually the lack of it, exerts a major control over vegetation, the control that vegetation has over water is not always appreciated. Natural or man caused modification of the forest watershed has the potential for affecting all segments of the forest hydrologic cycle. Forest practices can change (Chamberlin 1982):

1) the distribution of water and snow on the ground
2) the amount intercepted or evaporated by foliage
3) the amount that can be stored in the soil or transpired from the soil by vegetation
4) the physical structure of soil governing the rate and pathways of water movement to stream channels

In turn, any of these changes can have a major effect on streamflow. Streamflow characteristics potentially altered include annual yield, timing, low flow, and peak flows.

QUALITY

The water that enters the forest ecosystem as precipitation is not pure. Atmospheric moisture contains dissolved gases and mineral ions as well as chemicals that are either man-made or industrial byproducts. Generally, however, precipitation is low in dissolved ions and streamflow quality is largely determined by the forest ecosystem. Water quality variables of importance include stream temperature, dissolved ionic composition, and suspended sediment.

Stream water temperature is controlled by the exposure of the stream to direct solar radiation and the temperature of inflowing tributary or ground water. Air and ground temperatures exert only minor influence on water temperature once it has surfaced. Stream temperature may be affected by forest practices which remove shade from streamside areas or alter channel morphology. Smaller streams generally have a greater potential for temperature modification than do larger streams.

The ionic composition of stream water includes pH, cations, anions, and organic nutrients. The concentration of the majority of cations and anions increases rapidly from their values in precipitation to near constant values by the time a stream has reached third order (Larson 1983). These mineral constituents and pH are controlled by mineral weathering of the parent material and forest soil. Quantities of the important elements nitrogen and phosphorus are usually low in most of Washington's streams and rivers and their concentrations vary more than the common ions. Their levels in stream water are strongly influenced both by the forest and by processes taking place in the aquatic environment.

Dissolved oxygen is another important constituent of stream water. A balance between consumption and accrual determines the dissolved oxygen concentration of stream water. The former via respiration by aquatic organisms, and the latter related to the turbulence of the water leading to reaeration from the air. A stream's maximum capacity for dissolved oxygen is controlled by its temperature with colder water having potentially greater dissolved oxygen content. Forest practices that change the quantity or quality of the water within the forests vegetation or soil, or add chemicals to the ecosystem, have the greatest potential for affecting the dissolved composition of stream water.

The sediment load of a stream (both suspended and bedload) is determined by such characteristics of the drainage basin as soils, vegetation, precipitation, topography, and land use. The sediment enters the stream system by a variety of erosional processes (see EARTH). To achieve stream stability, an equilibrium must be sustained between sediment entering the stream and sediment transported through the channel. Any forest practice that changes sediment load can upset this balance and result in physical and biological changes in the stream system.

WATER SUMMARY

Since water yield is the final product of the forest hydrologic cycle, reflecting all water-soil-vegetation interactions, discussion of water focuses on forest practices and streamflow. We are interested in its runoff characteristics and its quality as indexed by temperature, dissolved composition, suspended sediment, and bedload. Other components of the forest hydrologic cycle (Figure 4-9) are discussed only as they influence stream water. While lakes, ponds, and estuaries are recognized as important habitat for fish and wildlife, they are not included in this study.

FLORA

Flora is the term used to describe all plant life. Flora of a particular area is expressed as a list of plant species arranged in families and genera. The study of flora and its surrounding environment is plant ecology which is subdivided into autecology and synecology. Autecology is the study of the inter-relations between the individual plant and its environment. Synecology is the study of the structure, development, and causes of distribution of plant communities. Our discussion of flora is restricted to the synecology of terrestrial vegetation in Washington State. It includes endemic, indigenous, and exotic plants found in the commercial forest zones of the state's eight physiographic provinces (Franklin and Dyrness 1973 - Figure 4-10). Plants are subdivided into photosynthetic (green plants) and non-photosynthetic (non-green) plants.

Figure 4-9. The hydrologic cycle. (after Proctor et al. 1980)

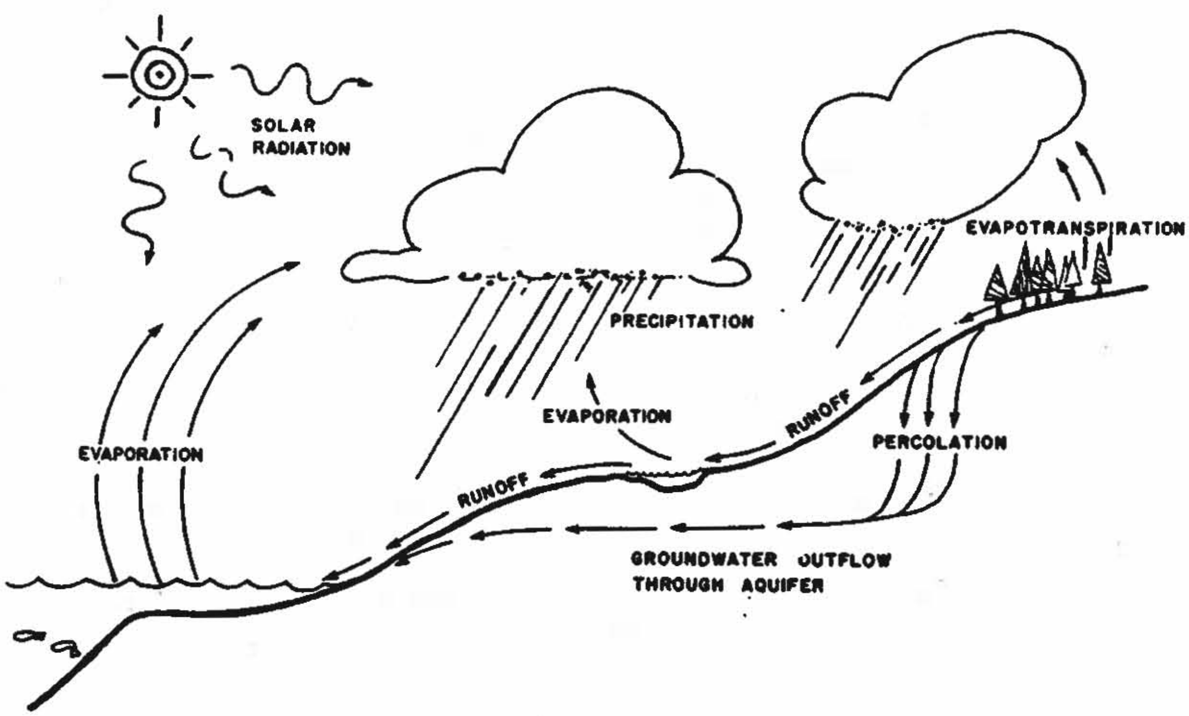
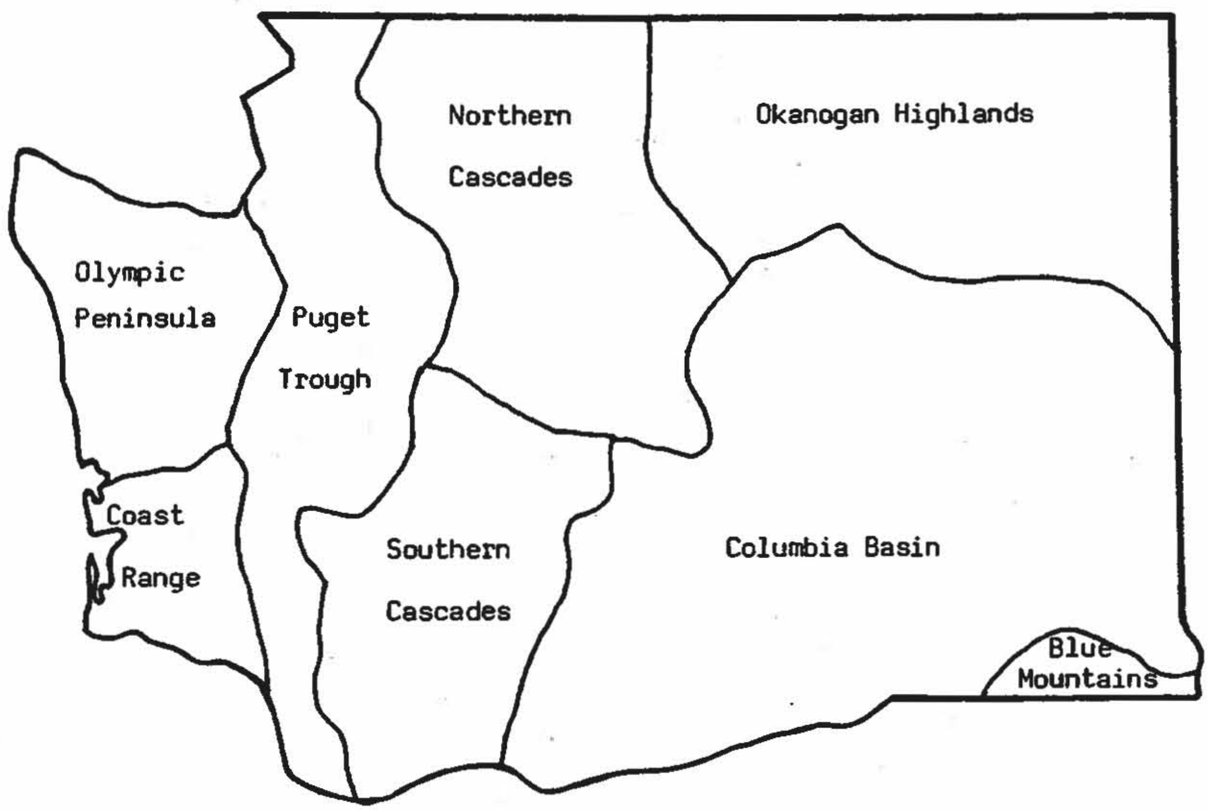


Figure 4-10. Physiographic and geological provinces of Washington. (after Franklin and Dyrness 1973)



Species of non-green plants are numerous, ranging from bacteria and fungi to angiosperms such as the Indian pipes. Non-green plants play three roles in the ecosystem: 1) decomposers, 2) parasites, or 3) symbionts. Of the non-green plants, fungi, especially root-inhabiting mycorrhizae, are very important to most trees. Obligatory symbiotic relationships exist between epigeous and hypogeous mycorrhiza, and most higher plants. The mycorrhizal fungi translocate fungal-absorbed ions from the soil to the host root and host-produced photosynthates to the fungus. Neither the fungus nor the host tree can complete their life cycles independently. Saprophytic fungi are also important for their role in decomposing vegetation.

The green vascular plants of Washington are divided into pteridophyta (ferns) and spermatophyta (seed plants). Seed plants are divided into angiosperms and gymnosperms. Angiosperms are the true flowering plants and include such trees as alder, maple, oak, willow, cottonwood, aspen, etc. Coniferous gymnosperms include the pine, fir, juniper, and cedar families. Non-coniferous gymnosperms are represented by the yew family.

This report stresses trees, primarily conifers because in the Pacific Northwest conifers outnumber hardwoods 1000:1 (Kuchler 1946). A tree is defined for our purposes as a woody plant having one well-defined stem and a more or less definitely formed crown and attaining somewhere in their natural or planted range a height of at least eight feet and a diameter of not less than two inches (Sudworth 1967). Figure 4-11 lists the major Washington tree species with their scientific and common names.

The forests of Washington are divided by the Cascade Range into two general geographic areas - eastside and westside Cascades. The eastside Cascades are composed of the Blue Mountains, Columbia Basin, Okanogan Highlands, and eastern slopes of the Northern and Southern Cascade physiographic provinces and contain six forest zones. The westside Cascades are composed of the Olympic Peninsula, Coast Range, Puget Trough, and western slopes of the Northern and Southern Cascades and have four forest zones. In general, each forest zone is named for the tree species that most likely will occur naturally as the climax species (Franklin and Dyrness 1973):

<u>Forest Zones</u>

<u>Eastside</u>	<u>Westside</u>
ponderosa pine	Sitka spruce
lodgepole pine	western hemlock
Douglas-fir	Pacific silver fir
grand fir	mountain hemlock
western hemlock	
subalpine fir	

Forests are characterized by their:

1) Composition: the array of plant species to include abundance as well as presence and absence of a species. This also includes endangered, threatened, and sensitive plants.

Figure 4-11. Major Washington tree species, with their scientific and common name. (after Mosher and Lunnum)

Scientific Name	Common Name
Abies amabilis [(Dougl.) Forbes]	Pacific silver fir
Abies grandis [(Dougl.) Lindl.]	Grand fir
Abies lasiocarpa [(Hook.) Nutt.]	Subalpine fir
Abies procera [Rehder]	Noble fir
Acer circinatum [Pursh]	Vine maple
Acer macrophyluum [Pursh]	Bigleaf maple
Alnus rubra [Bong.]	Red alder
Arbutis menziesii [Pursh]	Pacific madrone
Betula papyrifera communtata (Reg.) Fern	Western paper birch
Celtis reticulata [Torr.]	Netleaf hackberry
Chamaecyparis nootkantensis [(D. Don) Spach]	Alaska-cedar
Cornus nuttalli [Audubon]	Pacific dogwood
Fraxinus latifolia [Benth.]	Oregon ash
Juniperus scopulorum [Sarg.]	Rocky mountain juniper
Larix lyalli [Parl.]	Subalpine larch
Larix occidentalis [Nutt.]	Western larch
Picea engelmannii [Parry]	Engelmann spruce
Picea sitchensis [Bong.) Carr]	Sitka spruce
Pinus albicaulis [Engelm.]	Whitebark pine
Pinus contorta [Dougl. ex Loud.]	Lodgepole pine
Pinus monticola [Dougl. ex D. Don]	Western white pine
Pinus ponderosa [Dougl. ex Loud.]	Ponderosa pine
Populus tremuloides [Michx.]	Quaking aspen
Populus trichocarpa [Torr. and Gray]	Black cottonwood
Pseudotsuga menziesii [(Mirbel) Franco]	Douglas-fir
Quercus garryana [Dougl.]	Oregon white oak
Rhamnus purshiana [De Candolle]	Cascara
Salix species	Willow
Taxus brevifolia [Nutt.]	Pacific yew
Thuja plicata [Donn]	Western redcedar
Tsuga heterphylla [(Raf.) Sarg.]	Western hemlock
Tsuga mertensiana [(Bong.) Carr.]	Mountain hemlock

2) Structure: the size and spatial arrangement of vegetation.

3) Function: the production of organic matter and the cycling of nutrients through pathways and compartments to include the secondary role vegetation plays in providing habitat to fauna.

Changes in composition, structure, and function as vegetation passes through the various life stages of establishment, growth, and mortality are referred to as plant succession (Odum 1971). Succession is directional and predictable and results from modifications of the physical environment by the community. Daubenmire (1968) describes succession as any unidirectional change that can be detected through changes in proportions of species in a stand or the complete replacement of one community by another.

Succession is either primary or secondary. Primary succession involves the amelioration of extreme site conditions by gradual alterations brought about by the organisms over long periods of time. The colonization and development of vegetation on bare rock, sand, or talus surfaces is an example of primary succession. Secondary succession occurs when plants grow in an area from which a plant community was removed or when plants succeed from relatively shade intolerant species to more shade tolerant ones. An example of secondary plant succession would be the invasion of clearcut or burned areas by opportunistic, shade-intolerant herbaceous species which are replaced in turn by shrubs and ultimately, a stand of shade-intolerant, pioneer tree species (Franklin 1978). General successional stages for some Pacific Northwest forests are illustrated in Figure 4-12. In this study, we are primarily interested in secondary plant succession and the changes in <u>composition</u>, <u>structure</u>, and <u>function</u> of coniferous forests as they pass through the various life stages of establishment, growth, and mortality.

Establishment

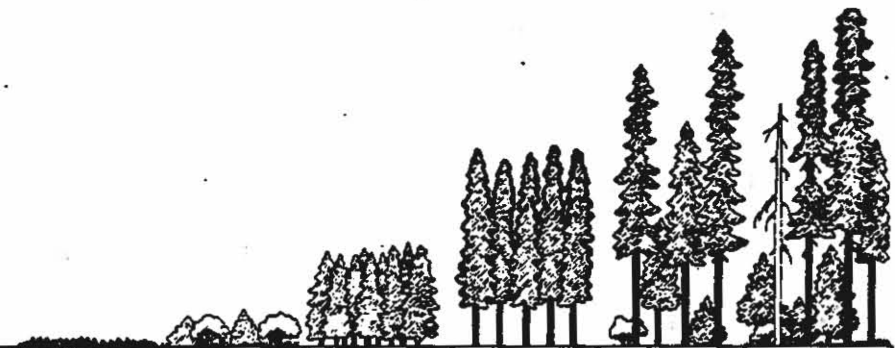
Trees are established naturally either by seed or vegetatively from sprouts or layered branches.

Seed is the principal means for perpetuating most trees and many woody species from one generation to the next. The life of a seed is a complex series of biological events beginning with initiation of the flower and concluding with germination of the mature seed. Trees produce large quantities of seed at infrequent intervals, and the more favorable the conditions of soil and climate for plant growth, the more frequent are good seed crops. Seeds are displaced by gravity, wind, birds, mammals, insects, and flowing water.

Seedfall and dispersion for most trees occurs from August to November and germination usually occurs the following spring. The most critical stages in the life of a tree are when it is an embryo in a seed and when it is a tender young seedling. Losses result from seed eating animals, insects, pathogens, adverse microclimate, fire, or unsuitable seedbed. Mortality during the first few weeks after germination is usually far greater than that throughout the remaining life of a stand (Smith 1962).

Vegetative reproduction from sprouts usually occurs when the parent tree

Figure 4-12. Successional stages of flora in some forest zones of Washington.



FOREST ZONE	DBH in inches	Grass-forb	Shrub-seedling	Pole-sapling	Young	Mature	Old growth
		0-0.4	0.5-4.9	5-8.9	9-20.9	21+	

WESTERN HEMLOCK	AGE in years	0 - 6	7 - 20	21 - 35	36 - 70	71 - 120	121+
		Douglas-fir →		Western hemlock → western red cedar		Western hemlock (Douglas-fir in seral stands or on dry sites)	

TRUE FIR MOUNTAIN HEMLCOK	AGE in years	0 - 20	21 - 35	36 - 65	66 - 100	101-140	141 +
		Douglas-fir and/or Noble fir →		Western hemlock Pacific silver fir →		Pacific silver fir	

Successional Stage Definitions 1/

Grass-forb: Shrubs and/or tree regeneration less than 40 percent crown cover and less than 5 feet tall; unit may range from largely devoid of vegetation to dominance by herbaceous species.

Shrub-seedling: Shrubs greater than 40 percent crown canopy; of any height; trees less than 40 percent crown canopy with small diameters.

Pole-sapling: Tree crown canopy less than 60 percent.

Young: Crown canopy cover exceeding 60 percent.

Mature: Crown cover may be less than 100 percent; little decay or defect present;minimal occurrence of understory trees; dead and down material residual from previous stand.

Old growth: Stands with at least two tree layers (overstory and understory); at least 20 percent of the overstory layer composed of long-lived successional species; standing dead and down material; decay in some trees.

1/ Adopted from Hall, F. et al. 1982.

is unhealthy or recently killed. Sprouting can occur from dormant buds at the root collar of stumps (stump sprouts), dormant buds higher up on the bole (epicormic branches), and adventitious buds on the bole and roots. No Washington conifers produce stump sprouts, but alder, aspen, maple, and oak are examples of hardwoods that do. Vegetative reproduction by layering arises from living, low-hanging branches that have been partially buried in moist organic matter. In addition to producing seeds, western redcedar, western hemlock, Sitka spruce, and subalpine fir can reproduce by branch layering.

Growth

Forests in the Pacific Northwest differ markedly in composition, structure, and function from the deciduous forests that dominate most mesic segments of the world's temperate zones (Franklin and Hemstrom 1981). There are relatively few major tree species, and most are conifers. Forest recovery following disturbance typically requires several decades, and is substantially slower than deciduous forests (Borman and Likens 1979).

Most tree species in the Pacific Northwest play multiple successional roles. It is important to distinguish ecological roles from species' shade tolerances. Species colonizing a site early in a sere are playing a pioneer role. Species capable of perpetuating themselves on a site in the absence of disturbance are playing a climax role. Several intolerant species can form a stable type of climax if environmental conditions exclude their more tolerant associates. An example is the development of self-perpetuating stands of Douglas-fir on habitats that are too dry for western hemlock or grand fir. In other cases, environmental conditions need only favor the less tolerant associate, such as snowpack favoring reproduction of Pacific silver fir over that of western hemlock.

Similarly, many shade-tolerant species can and do play pioneer roles on most sites where they are also climax. Western hemlock is conspicuous early in seres on cut-over forest lands in the Sitka spruce zone, as is Pacific silver fir on many high-elevation burns. This can be due to an absence of seed source for faster-growing intolerant species, or the growth rate of tolerant species may equal or exceed that of the intolerant species (Franklin 1981).

Mortality

Natural mortality can occur at any age to individual trees or stands. Causes of natural mortality include both active and passive agents. Active mortality arises from causes readily evident to the casual observer, such as fire, wind, flood, and volcanoes and is usually of a large magnitude for a short duration. Passive mortality is not readily evident, may cover small or large areas, have a small or large magnitude, and is usually of a shorter frequency and longer duration. Examples include insects, disease, drought, and suppression.

Predicting mortality in Pacific Northwest conifers is complicated by the long-lived character of many species. Two to four generations of shorter-lived species may germinate, mature, and die during the life span of one

Douglas-fir, redcedar, or Alaska-cedar tree (Franklin and Hemstrom 1981).

When a tree dies and remains standing it is called a snag. When it falls to the ground it is called dead and down woody material. As much as 60 percent of the annual litter fall of a mature forest may be woody debris (Grier and Logan 1978). In a mid-elevation, unmanaged 470 year-old Douglas-fir stand, MacMillan et al. (1977) found 53-265 tons/acre of dead and down woody material.

A tree undergoes a series of successional changes from the time it dies and becomes a snag until it fully decomposes and becomes incorporated into the soil as humus. The size, tree species, and condition of a log along with moisture and temperature, determine the rate of decomposition. Different species and parts of a tree within a species vary in susceptibility to decay. For example, Douglas-fir needles may require 10-14 years to decompose, branches one inch in diameter require 36-50 years, and the bole, up to several hundred years (Bartels et al. 1983, Maser et al. 1979 - Figure 4-13).

As a log decomposes, the plant community and life forms inhabiting it gradually change. These changes result from internal and external succession (Figure 4-13). Internal succession is related to the persistence of the log over time (residence time) which normally is determined by the rate of decay. External succession is the change in the plant community surrounding the log.

As logs decay they increase in moisture content maintaining a high moisture content throughout the process of decomposition. This is the basis for three ecosystem functions of down woody materials:

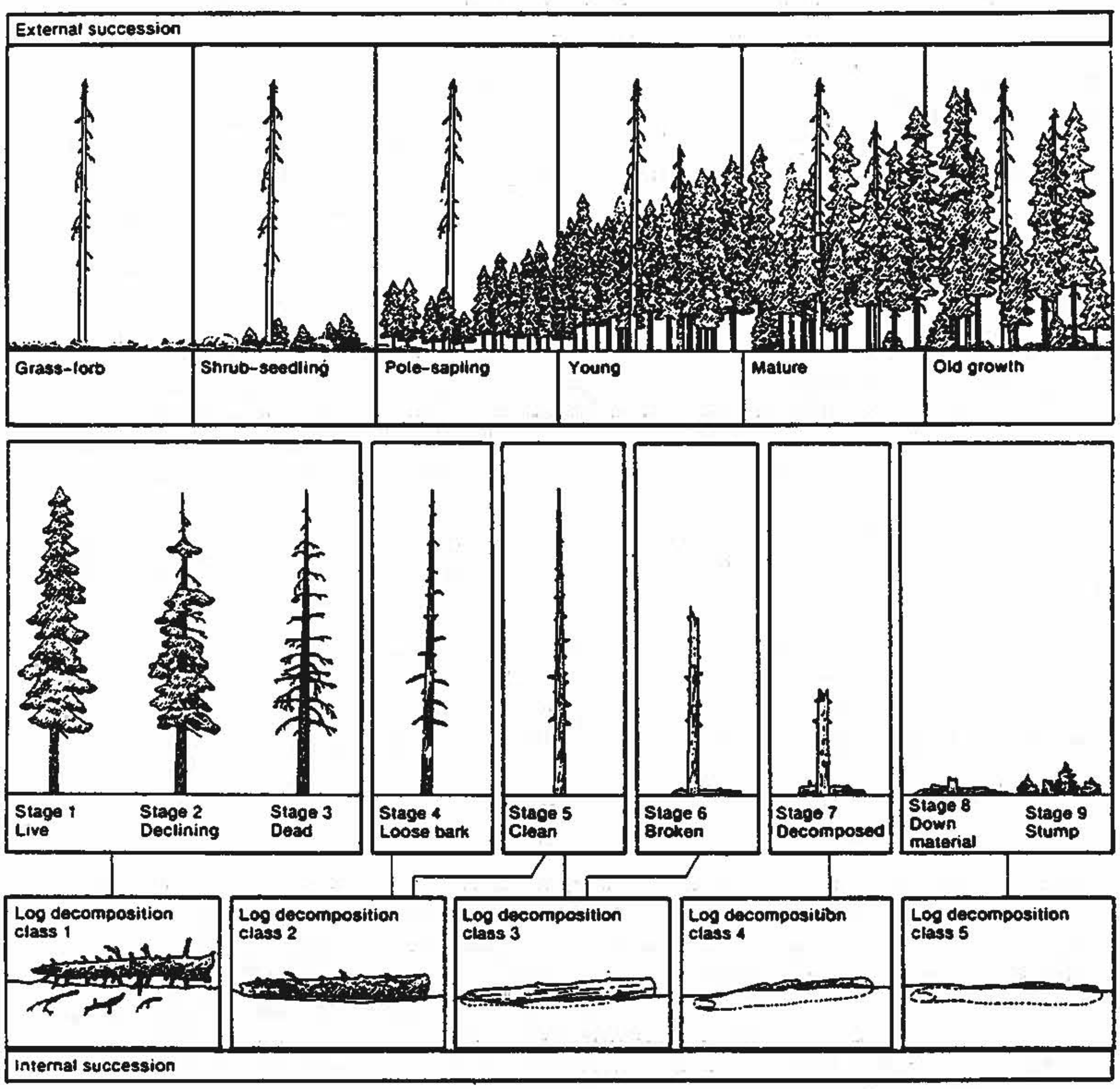
1) provide moist and cool microhabitats for some or all life history functions of many reptiles, amphibians, and small mammals
2) serve as sites for nitrogen fixation by nonsymbiotic bacteria
3) serve as sites for regeneration by some tree species

FLORA SUMMARY

For any given habitat there is a distinct progression in a plant community structure toward a climax (stable, mature) community. These communities are formed by the replacement of a species by others more adapted to the prevailing conditons. Often these conditions are in turn modified by other plants provoking new replacement. The sequence of species replacement, however, is thought to be determined to a large extent by the tolerance to shading of the individual taxa. For this reason, once a community reaches the forest stage of development the sequence of events is predictable because trees are established and grow according to their tolerance to shading. The more tolerant species replace the less tolerant ones until the most tolerant individuals within the region have established a climax forest. This does not mean, however, that the climax forest is composed of only the most tolerant species because the uneven-aged nature of a mature forest permits the presence of many species with a broad spectrum of shade tolerance characteristics (West et al. 1981).

The westside Cascades is discussed here as an example of plant succession within various forest zones. Topography is typically mountainous with gentle

Figure 4-13. Successional stages of snags and dead and down woody material.



Snag condition translated into log decomposition class

Snag stage	Snag condition	Log class
1-3	Hard snag	1
4-5	Hard snag	2
5-6	Soft snag	3
7	Soft snag, 70% + soft sapwood	4

A 5-class system of log decomposition based upon work done on Douglas-fir (adapted from Fogel et al. 1973, used with permission, see also Minore 1966)

Log characteristics	Log decomposition class				
	1	2	3	4	5
Bark	intact	intact	trace	absent	absent
Twigs <3 cm (1.18 in)	present	absent	absent	absent	absent
Texture	intact	intact to partly soft	hard, large pieces	small, soft, blocky pieces	soft and powdery
Shape	round	round	round	round to oval	oval
Color of wood	original color	original color	original color to faded	light brown to faded brown or yellowish	faded to light yellow or gray
Portion of log on ground	log elevated on support points	log elevated on support points but sagging slightly	log is sagging near ground	all of log on ground	all of log on ground

intermountain regions such as the Puget Trough. Forests extend from sea level to over 5,000 feet elevation. Mild, wet winters and relatively warm, dry summers are a major factor in the dominance of conifers over deciduous hardwoods. The mildest climates are in the coastal sitka spruce zone. The coolest environments are in the subalpine zones above 3,000 feet elevation. Synecological studies in the region have shown that moisture and temperature are the primary environmental controls on plant community composition (Zobel et al. 1976 - Figure 4-14). These relationships most likely hold true in Washington. Temperature and moisture vary sharply over short distances in the broken mountain topography, and consequently, similar contrasts occur in the composition and structure of forest communities (Franklin 1981).

Several general succession sequences have been described in coastal Pacific Northwest forests (Franklin and Dyrness 1973). A typical sere in the western hemlock zone would be:

```
Douglas-fir ---> western hemlock and ---> western hemlock
                 western redcedar
```

In the Sitka spruce zone a normal sere would involve:

```
Sitka spruce and ---> western hemlock
western hemlock
```

Red alder stands could conceivably occur as the first stage in either of these seres although its successional replacement by conifer stands is still unproven.

In the lower subalpine areas of the Cascade Range a normal sere would be:

```
Douglas-fir and/or ---> western hemlock ---> Pacific silver
noble fir               and Pacific silver fir       fir
```

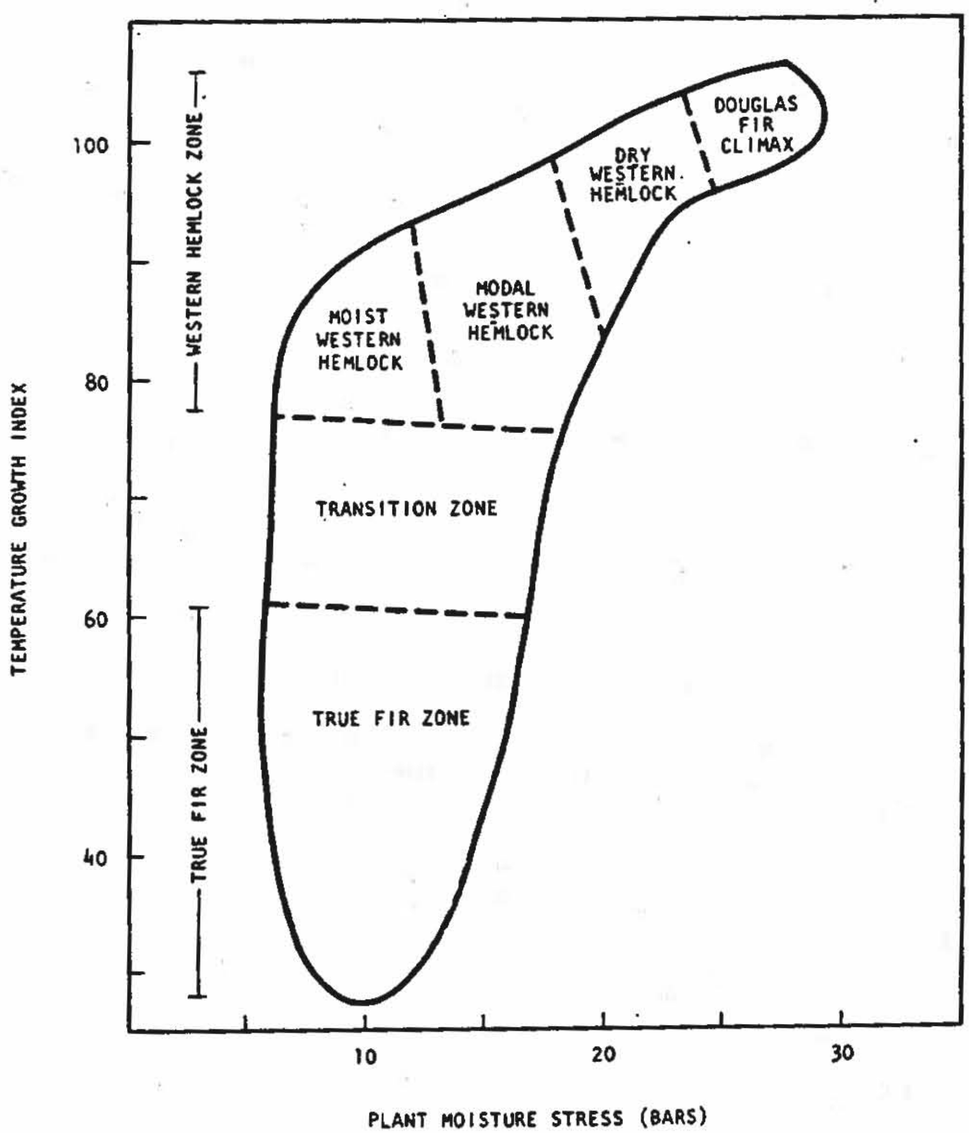
Throughout most of the westside Cascades, western hemlock and Pacific silver fir are the major potential climax species. Special habitats are exceptions, such as the dry sites where Douglas-fir is self-perpetuating. Some species of moderate shade tolerance, such as western redcedar and Alaska-cedar, typically reproduce poorly in old growth stands. This may indicate subclimax status in a stable age class distribution despite an apparent sparsity of reproduction.

Forest practices are superimposed on these complex successional patterns with the intent of influencing the composition and structure of the vegetation. Chapter five addresses the changes to composition, structure, and function caused by forest practices.

FAUNA

The term fauna means all animals of a specific region and includes mammals, fish, shellfish, reptiles, amphibians, birds, insects, and protozoa. Fauna function as either consumers or decomposers. As consumers, they are either onmivores (eat both plants and animals), herbivores (eat green plants),

Figure 4-14. Distribution of two climax vegetation zones in relation to moisture and temperature, defined by plant response indices. (after Zobel et al. 1976)



or carnivores (eat animal tissue).

Producers are eaten by grazers which are in turn eaten by carnivores. Dead plants and animals provide the chemical energy for decomposer organisms and microorganisms, including some insects, worms, fungi, bacteria, etc. These organisms are usually concentrated in or near soils and sediments and they ultimately break down decaying organic materials into basic nutrients to again support plant growth, thus completing the cycle. Since the decomposers are seldom able to break down organic materials completely, there is a continuous accumulation of organic detritus which remains as part of the substrate and contributes to the formation of soils and sediments.

Although groups of organisms can be classified into major functional units and basic food chains for conceptual purposes, the actual trophic or food-energy relationships between individuals, populations, and communities of organisms in ecosystems is much more complicated. When the trophic interrelationships of individual populations within a community are considered in detail it becomes obvious that they are better represented as complex food webs rather than simple food chains (Figure 4-15). All converters (fauna), unable to trap the sun's energy on their own, are dependent on other organisms or organic material for nourishment. These food webs or roadmaps are composed of many interrelated sequences of who eats whom (Proctor et al. 1980).

Washington has four major faunal habitat types: steppe and shrub-steppe, alpine-subalpine, water, and forests. We are specifically interested in freshwater (aquatic), forests (terrestrial), and riparian habitats (the transition area between aquatic and terrestrial). Freshwater habitats include all perennial or intermittent streams, lakes, and wetlands.

Forests include the vegetation within the commercial forest zone of Washington described in the FLORA section of this chapter. This zone includes special habitats such as caves, talus, cliffs, old growth snags, and riparian zones. The term "riparian" is used in a variety of ways. For our purposes we use the expression riparian ecosystem to refer to all living organisms interacting with their non-living environment bordering water. The geographic area in a riparian ecosystem includes the riparian and aquatic zones and the adjacent upland areas which directly influence the quality and quantity of faunal habitat (Figure 4-16). The riparian zone composes about 3-5 percent of the forest area.

For purposes of this study, we have separated fauna into two categories: aquatic and terrestrial. The discussion of aquatic fauna refers primarily to habitat of the aquatic zone and discussion of terrestrial fauna refers to habitats of the riparian zone and the upland forest zone.

FAUNA - AQUATIC

Aquatic fauna includes all animals dependent on bodies of water for all or part of their life cycle. We have limited this category to fish found in Washington's freshwater systems and invertebrate insects important to fish. Fish include 14 species of salmonids (Family Salmonidae) and more than 50 species of nonsalmonids. The study addresses only salmonids which are divided into anadromous and resident based on life-history patterns (Figure 4-17).

Figure 4-15. A simplified food web in an ecosystem. Arrows show the direction of energy flow. (after Proctor et al. 1980)

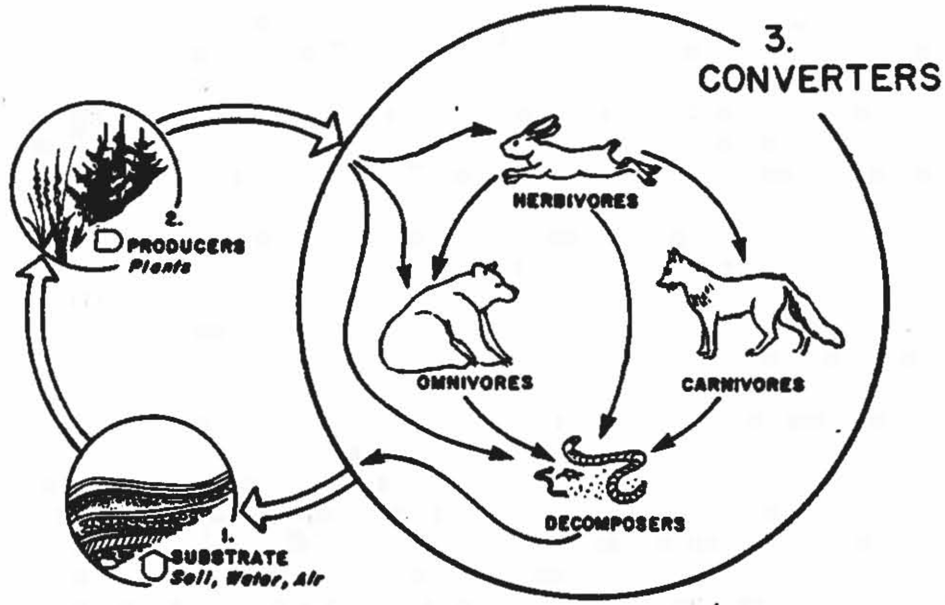
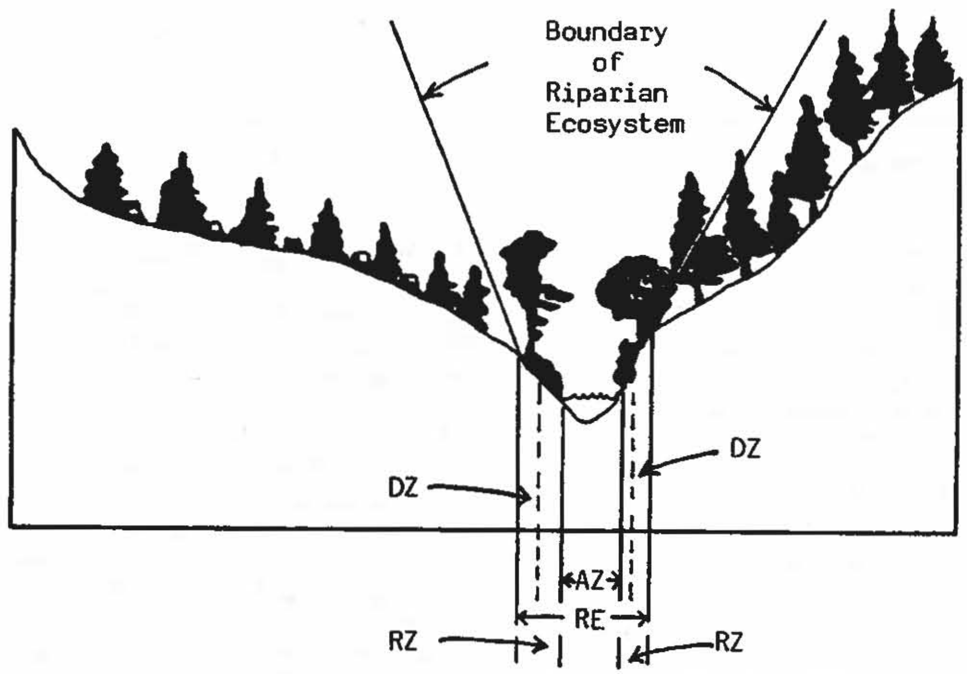


Figure 4-16. Boundaries of a riparian zone and riparian ecosystem.



Aquatic zone (AZ) is the area below the mean annual high water mark of surface waters including the water, banks, beds, organic and inorganic materials.

Riparian zone (RZ) is the area bordering streams, lakes, tidewaters and other bodies of water. Riparian zones are transitional areas which lie between aquatic and terrestrial environments. They have high water tables and may contain plants which require saturated soils during all or parts of the year.

Direct influence zone (DZ) is the zone located adjacent, but outside the riparian zone containing vegetation which directly shapes the physical structure of the aquatic environment, or contributes organic material to aquatic and riparian zones through the forces of gravity or wind.

Riparian ecosystem (RE) is the area bordering streams, lakes, tidewaters, and other bodies of water that include elements of the aquatic and terrestrial ecosystems. They have a high water table and may contain plants that require saturated soils during all or part of the year. Riparian ecosystems include aquatic and adjacent terrestrial areas which directly influence the quality of fish and wildlife habitat.

Figure 4-17. Common and scientific names of anadromous and resident salmonid fish of Washington. (adapted from Reiser and Bjornn 1979).

	Common name	Scientific name
PACIFIC SALMON	Pink salmon	Oncorhynchus gorbuscha (Walbaum)
	Chum salmon	Oncorhynchus keta (Walbaum)
	Coho salmon (silver)	Oncorhynchus kisutch (Walbaum)
	Sockeye salmon (kokanee)	Oncorhynchus nerka (Walbaum)
	Chinook salmon	Oncorhynchus tshawytscha (Walbaum)
TROUT	Cutthroat trout	Salmo clarki (Richardson)
	Rainbow (steelhead) trout	Salmo gairdneri (Richardson)
	Golden trout *	Salmo aquabonita
	Brown trout *	Salmo trutta (Linnaeus)
CHAR	Brook trout *	Salvelinus fontinalis (Mitchill)
	Dolly Varden	Salvelinus malma (Walbaum)
	Lake trout	Salvelinus namaycush (Walbaum)
	Mountain white fish	Prosopium williamsoni
	Artic grayling	Thymallus arcticus

* Introduced species

Anadromous salmonids spawn in fresh water but spend most of their adult lives in saltwater and include the Pacific salmon, various sea-run trout (steelhead and cutthroat), and char (Dolly Varden) (Figure 4-18). Resident fish remain in fresh water throughout their life cycle and include cutthroat, kokanee, silver salmon, grayling, lake trout, brook trout, golden trout, rainbow trout and brown trout.

Major steps in the life cycle of salmonids are:

1) Spawning: includes the deposition and fertilization of eggs in redds, egg incubation, and emergence. The period from egg to alevin to fry emergence ranges from two months for spring-spawning trout to nine months for some Pacific salmon. Salmon and char usually spawn in the fall, on declining water temperatures whereas trout spawn in winter or spring, generally on a rising water temperature regime. Pacific salmon die after spawning while trout and char may survive to spawn more than once (Fisheries & Oceans 1980). Egg incubation is a sensitive stage of the life cycle of salmonids and egg survival is dependent upon sediment-free spawning gravel and clean, well-oxygenated water.

2) Rearing: the growing stage for fry and juveniles. Stable stream conditions are important to those species that spend part or all of their early life in fresh water. Chinook and coho young spend the greatest time of all salmon in streams, ranging from a few months to a year or more.

3) Migration: the deliberate movement of fish from one habitat to another and includes the downstream movement of young salmonids from streams to sea and upstream movement of adult spawners to spawning areas. All anadromous salmonid species, except coastal cutthroat and Dolly Varden, undertake extensive feeding migrations in the Pacific Ocean, between northern California and the Gulf of Alaska. Fry and juveniles move to different habitats as they grow older, and hence require unobstructed access up and down the stream and into side-channels and tributaries.

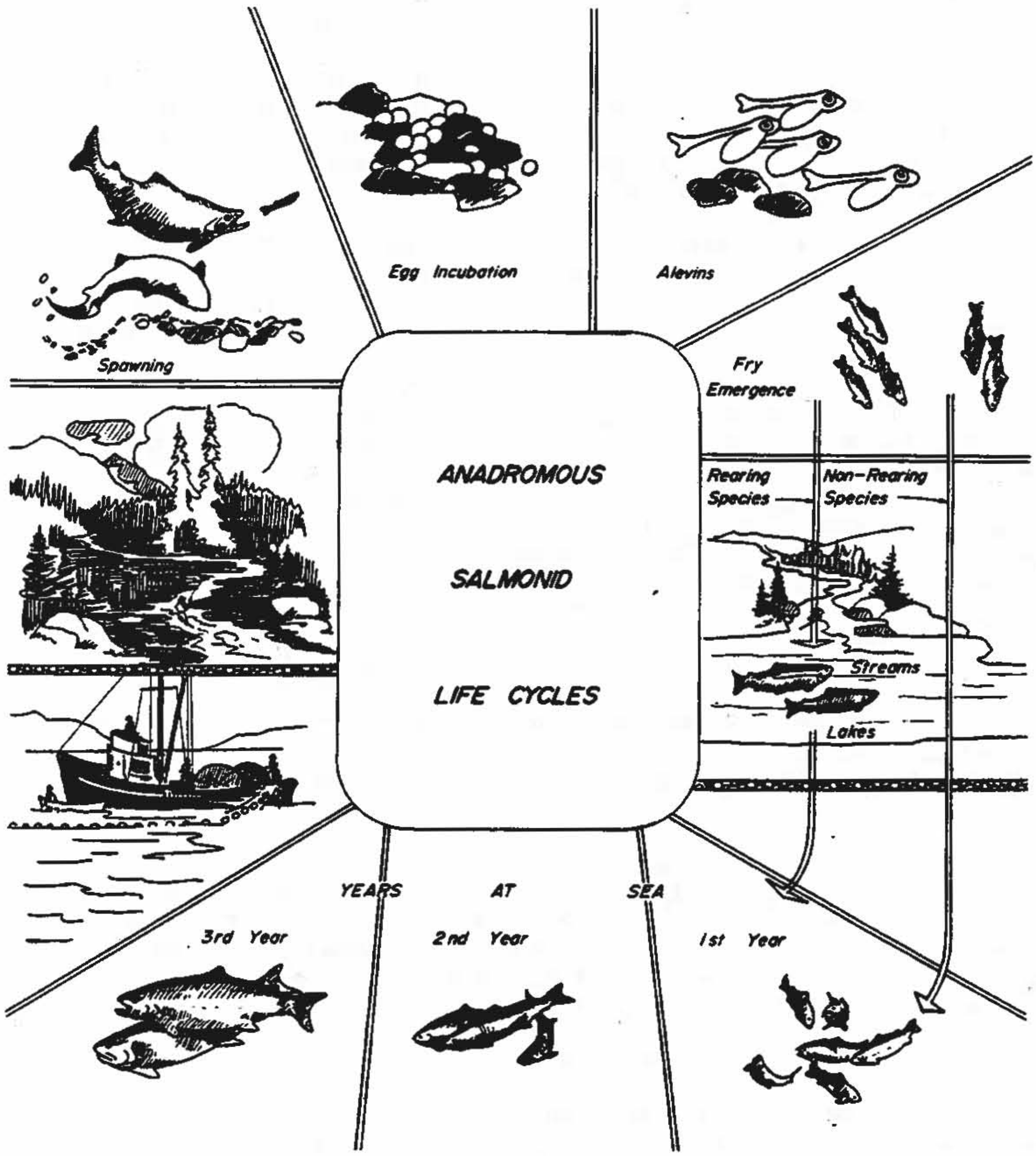
Salmonids require special conditions for successful spawning, egg development and hatching, growth, and survival of their young. In general, salmonids require cool, well-oxygenated water, a clean gravel substrate, and abundant cover and shade. Salmonids are much more demanding in the these respects than are many of the so-called coarse fish such as carp, squawfish, and suckers.

Specific habitat requirements for salmonids vary with species. Requirements of certain species may be in direct conflict with others. For example, a small log jam may create a nursery area for coho salmon but remove a spawning area from chum or pink salmon. Recognizing these differences, we have generalized about the optimum habitat for salmonids using two categories, physical characteristics and water conditions.

There are four basic physical requirements:

1) Access: the opportunity for movement by adult salmonids upstream to spawning and nursery areas, and by fry and juveniles seeking rearing habitat.

Figure 4-18. Anadromous salmonid life cycles.



2) Streamflow: the volume of water carried in a stream. Relatively stable streamflows without extreme freshets and droughts characterize the best salmon and trout streams.

3) Substrate: the bedrock, boulders, cobbles, gravels, sand, and silts making up the streambed. Spawning requires clean, stable gravel varying between 0.4 and 6 inches in diameter, depending on fish size, and permitting an intragravel flow of water adequate to provide each embryo and alevin with high concentration of dissolved oxygen and to remove metabolic wastes.

4) Cover: the plants, rocks, deep water, turbulence, shade,and organic debris used by fish for shelter and protection from adverse conditions and predation. Cover also provides feeding stations and food sources.

There are three basic water condition requirements:

1) Temperature: young of all salmon species prefer water between 53 and 57 degrees F. Temperatures above 59 degrees F are avoided and temperature may become lethal above 77 degrees F. For example, if water temperature rises much above 68 degrees F to 77 degrees F for very long most salmonids, especially in early stages, are seriously stressed or will die. Coarse fish, however, can adapt or tolerate water temperatures approaching 90 degrees F.

2) Dissolved oxygen: high concentrations are required in both intragravel and surface waters. Low concentrations will seriously stress or kill salmonids, especially in early life stages.

3) Clarity: the transmission of sunlight to the stream bottom and the algal community where most of the primary food production occurs. Salmonids are dependent on vision for locating their food supply and usually feed and grow better in clear waters having adequate cover and protection. Coarse fish locate their food chiefly by smell or feel and can therefore tolerate murky water and less cover better than trout and salmon (Toews and Brownlee 1981).

An additional, and obvious, requirement for fish that use streams for nursery purposes is an abundance of terrestrial and aquatic invertebrates (insects). During their fresh water rearing phase, salmonid juveniles feed mainly on the larvae of aquatic insects and to a lesser extent, on terrestrial insects, depending on stream size and flow level. Aquatic insects important to juvenile salmonids can be classified into four basic orders of invertebrates and five functional feeding groups responsible for processing organic matter in the stream.

The food web leading to these insects is extremely complex with many links and pathways, all connected to the surrounding land, particularly the vegetation along stream banks.

Food for invertebrates comes from four basic sources:

1) Detritus: particulate organic matter. Fine particulate organic matter

(FPOM) is smaller than 1mm in diameter and consists of plant and animal fragments, and feces of large invertebrates. Coarse particulate organic matter (CPOM) is greater than 1mm in diameter and consists of logs, branches, large twigs, bark, fruits, etc. that have breakdown times greater than one year.

2) Periphyton: an assembly of attached algae, particularly diatoms, and associated detritus.

3) Macrophytes: mosses, flowering plants and macroalgae.

4) Animals: preying invertebrates.

It is also important to understand that as one moves downstream, habitat and food relationships change (Figure 4-19). As a stream system progresses from headwater to mouth:

1) it changes from heterotrophic to autotrophic and back to heterotrophic

2) there is a shift in the proportion of invertebrates from shredder-collector (1st-3rd order), to collector-grazer (4th-6th order), to mostly collectors (7th-12th order)

3) fish populations shift from cold- to warm-water invertebrate feeders

4) terrestrial inputs of CPOM decrease (1st-3rd order) and the transport of FPOM increases (4th and greater order)

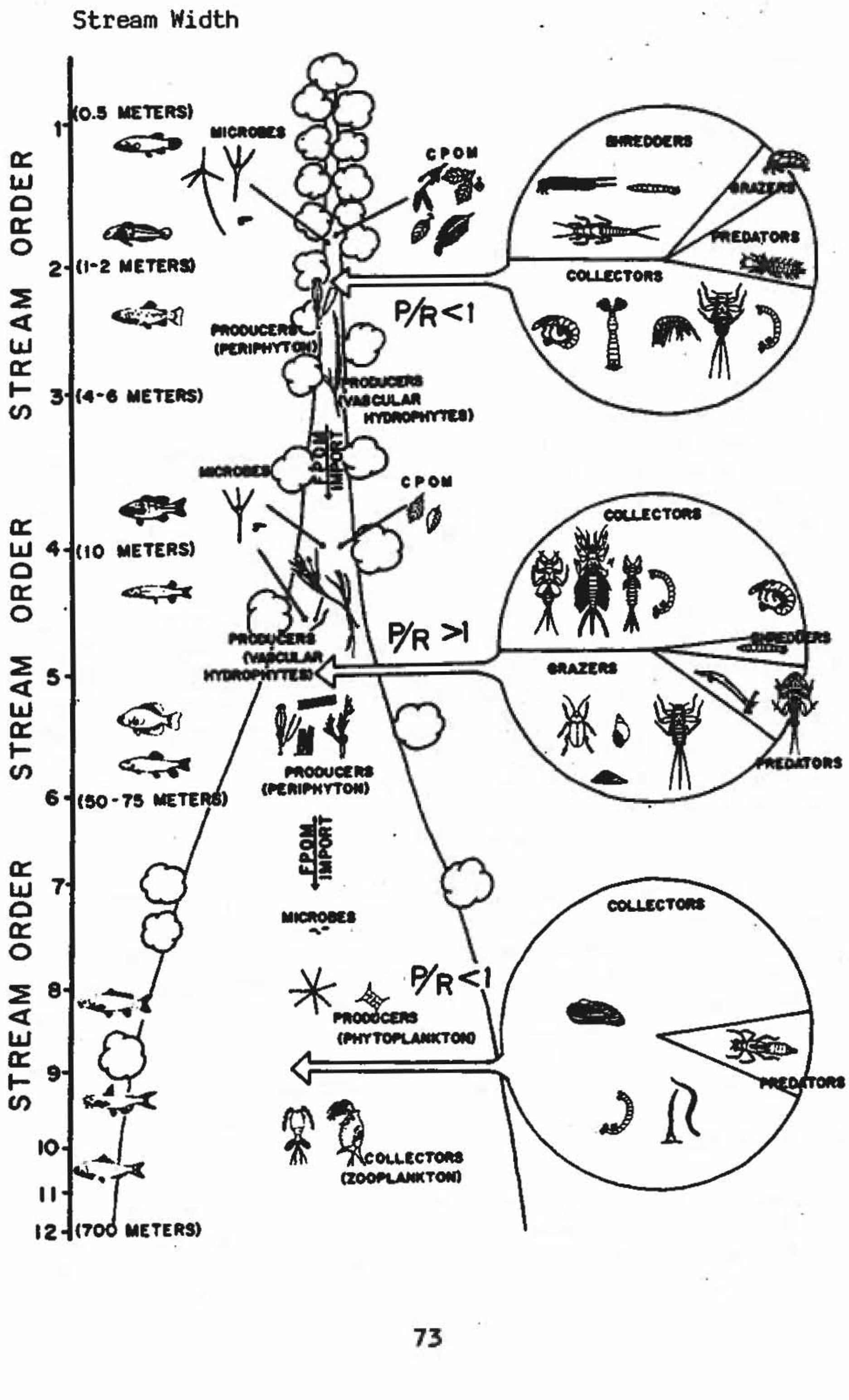
5) the food source for insects shifts from organic matter coming from surrounding watershed to algae produced in riffle areas

A typical salmon stream is composed of two alternating and contrasting habitats - riffles and pools. Riffles are areas of swift streamflow, usually shallow, with rocky and gravelly bottoms. Riffles are important because they contain the majority of the stream insects. When these insects dislodge from the stream bottom and move downstream it is called "drift". Drift occurs mainly at night and is the primary method of making invertebrates available as food for fish.

Pools are areas of deep, slow water, with a bedrock, sandy, or silty bottom. Pools are settling basins with more organic matter than riffles, contain burrowing insects, and are resting areas for fish awaiting drift (Toews and Brownlee 1981). The ratio of pools to riffles is one expression of fish habitat quality.

In determining effects of forest practices on aquatic fauna (Chapter 5), the primary emphasis is on potential changes to this salmonid habitat. Habitat may be altered by physical changes to the channel, or by changes in biologic components necessary for salmonid production.

Figure 4-19. Functional feeding groups of aquatic insects in relation to stream order and width. (adapted from Cummins 1979).



FAUNA - TERRESTRIAL

Terrestrial fauna includes all animals that dwell primarily on land. We have limited this category to nondomesticated vertebrates (wildlife) such as mammals, amphibians, reptiles, and birds. Terrestrial insects are recognized as a significant food source for wildlife, but are not included as wildlife in this study. There are approximately 432 wildlife species that spend all or part of their life cycle in Washington forests (Guenther and Kucera 1978).

Wildlife Category	Total
Mammals	
* small	67
* medium	18
* large (9 ungulates)	11
Amphibians & Reptiles	27
Birds	309

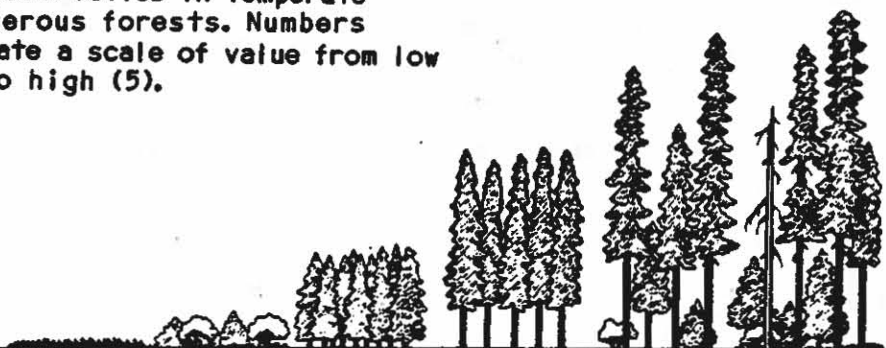
We have not selected any one species as more important than another nor have we categorized species according to status such as game, nongame, varmints, predators, furbearers, etc. Instead we concentrated on habitat as the element of interest. Where specific information is available on a species, however, we have identified it where it was helpful in explaining a process or an effect.

Wildlife habitat provides food, cover, water, and space. Habitat is used by wildlife for foraging and watering, breeding and brooding, hiding and resting, travel, and protection from extremes of heat and cold. We focus on vegetation because it is the primary element defining the number and type of wildlife habitats present in a given area. We are specifically interested in the reliance by mammals and birds on vegetation for food and cover in riparian zones and commercial forests. Although reptiles and amphibians are important to the food web, documentation of their role in relationship to forest practices is not as extensive as for warm blooded animals.

Forest vegetation is characterized by its composition, structure, and function. Succession provides for changes in the structure and composition of vegetation over long periods of time (decades), whereas seasonal changes, due in part to emergence and die-off of annual plants, cause short-term changes in composition and structure. The patterns of vegetation succession depend primarily on the frequency of disturbance and the substrate of a given area. These patterns play a dominant role in controlling the diversity of vegetation and, hence, the number and type of niches or microhabitats provided various wildlife species. The role a particular wildlife species plays in the environment is referred to as its ecological niche.

The six successional forest stand conditons, as described earlier in the FLORA section, provide unique environmental conditions that are ecologically important as niches for wildlife species (Figure 4-20). The niches are a product of the plant community, its successional stages, and other

Figure 4-20. Stand conditions and environmental characteristics in temperate coniferous forests. Numbers indicate a scale of value from low (1) to high (5).



STAND CONDITIONS	Grass forb	Shrub seedling	Pole-sapling	Young	Mature	Old growth
Plant diversity	2 / 3	5 / 4	3 / 4	1 / 1	2 / 3	3 / 5
Vegetation height	– / 1	1 / 2	2 / 3	3 / 4	4 / 5	5 / 5
Canopy volume	– / 1	1 / 2	2 / 3	3 / 4	5 / 5	4 / 4
Canopy closure	1 / 1	2 / 2	4 / 3	4 / 5	4 / 4	3 / 4
Structural diversity	1 / 1	4 / 2	1 / 4	1 / 2	2 / 3	5 / 5
Herbage production	5 / 5	3 / 4	1 / 3	1 / 1	2 / 2	3 / 3
Browse production	1 / 1	5 / 5	1 / 3	1 / 1	2 / 2	3 / 3
Animal diversity */	3 / 2	4 / 5	1 / 4	2 / 1	5 / 3	4 / 4
Woody debris **/ (natural)	– / 5	– / 4	– / 3	– / 2	– / 3	– / 5
Woody debris **/ (intensive mngt.)	– / 1	– / 1	– / 1	– / 2	– / 2	– / 5

Source: Thomas 1979. Wildlife Habitats in Managed Forests-The Blue Mountains of Oregon and Washington.

Source: Hall et al. 1983. Chapter 2- (Draft) Plant Communities and Stand Conditions. Forest Wildlife Habitat Relationships in Western Washington and Oregon.

*/ Plant and animal diversity is based on the number of species associated with a stand condition.

**/ Woody debris can be quite variable depending on treatment following clearcutting (Maxwell and Ward 1976).

environmental factors; including soil type, moisture regime, microclimate, slope, aspect, elevation, and temperature. The plant community type can be considered an integrator of the many factors interacting on a site (Thomas 1979).

We have separated the forest into five types of wildlife habitats:

1) riparian zones
2) edges
3) snags
4) dead and down woody material
5) old growth

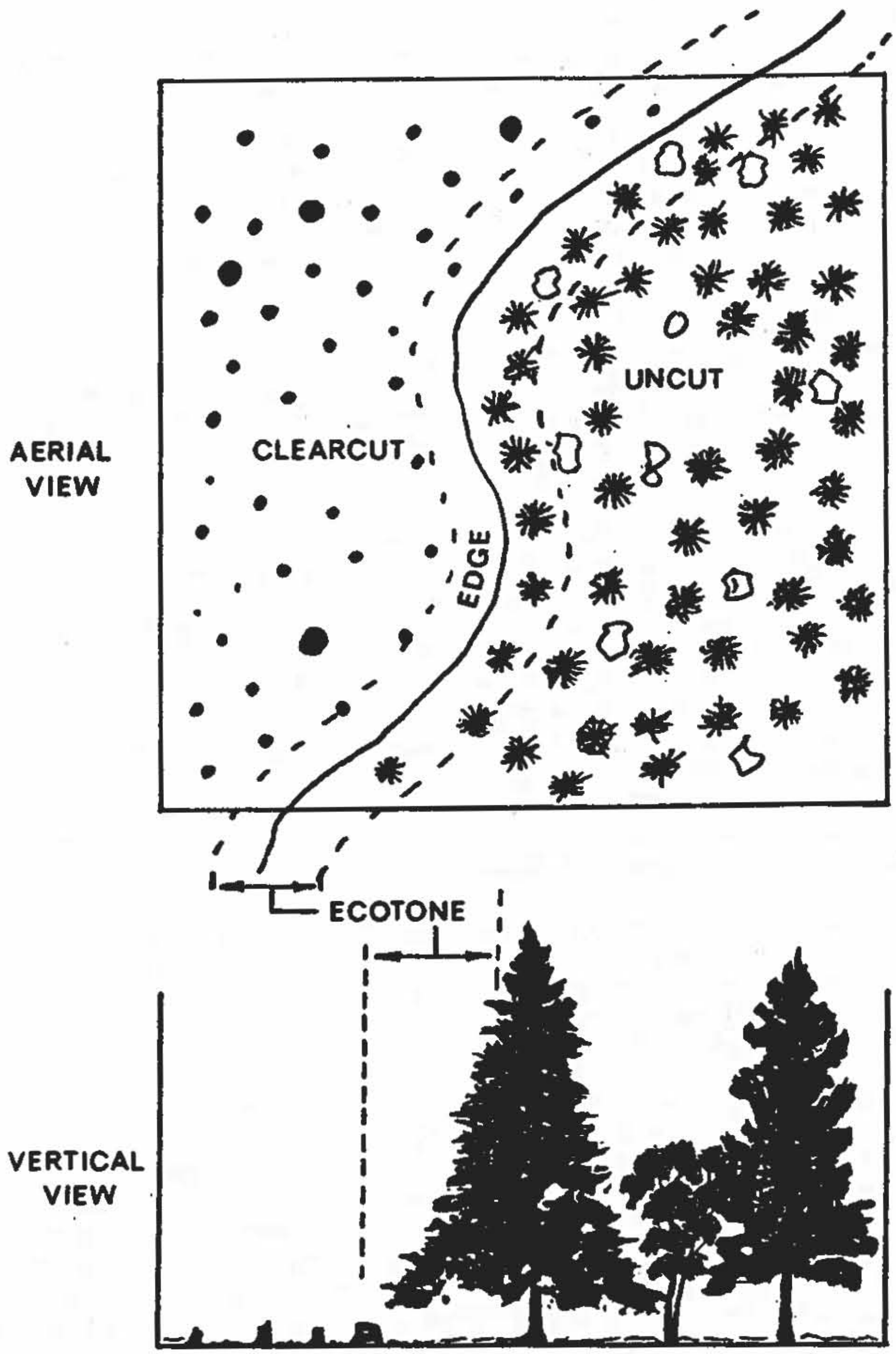
The riparian zone is the environment bordering water. Wildlife use riparian zones disproportionally more than any other type of habitat. More than half of all aquatic and terrestrial fauna known to occur in western Washington and Oregon depend on riparian areas and wetlands (Oakley et al. 1982). We assume that this relationship also holds true for eastern Washington (Thomas 1979). Although not all wildlife require riparian/wetland habitats for survival, more species would be displaced if riparian/wetland habitats were destroyed than if other habitats were eliminated.

Habitat requirements of wildlife in forested riparian ecosystems are being studied concurrently for the Forest Practices Board by the Washington State Riparian Habitat Technical Committee (Sachet 1982). Therefore, no further explanation of riparian wildlife habitats will be given in this section of the report.

Edges are places where plant communities meet or where successional communities meet or where successional stages or vegetative conditions within plant communities come together. For example, edge occurs at the border of a cut and uncut forest. The area influenced by the transition between communities or stages is called an ecotone (Figure 4-21). Edges and their ecotones are usually richer in wildlife than the adjoining plant communities or successional stages (Thomas 1979). Two phenomena help explain the importance of edges. First, dispersion, or the pattern and density of distribution of individuals in an animal population, is proportional to the amount of edge. The greater the length of edge, the greater the potential density of animals. Second, interspersion, the mixing of plant species and animal communities, influences the number of animal species requiring edge. Interspersion and community size are inversely related. As the mixture of communities or successional stages within an area increases, sizes of the communities or stages decrease. Edge animal species benefit from more interspersion, whereas interior species are favored less (Thomas 1979).

Snags are standing dead trees void of leaves and branches. A snag for wildlife use is dimensionally defined as being at least four inches in diameter at breast height (d.b.h.) and at least six feet tall. This definition is based on the minimum dimensions for nesting birds. Additionally, snags provide food and cover for many species of mammals, invertebrates, and plants. Animals either excavate their own cavities or use existing cavities. Snags are used by birds for foraging, drumming, singing posts, food caching, nesting, hunting perches, loafing, lookouts, anvils,

Figure 4-21. Edge and ecotone.



plucking posts, landing and roosting (Miller and Miller 1980).

Cavity-nesting birds usually account for about 30-45 percent of the bird population in forested areas, but can account for as much as 66 percent. Cavity-nesting birds are primarily insectivorous and may play an important role in the control of forest insect pests (Scott et al. 1980). Thirty nine of the 85 species of cavity-nesting birds in North America (excluding Mexico) occur in the Blue Mountains of Oregon and Washington (Thomas 1979).

Dead and down woody material is woody material that is dead and lying on the forest floor (Thomas 1979). This material is recruited from standing live and dead trees. Insects, disease, wind, fire, landslides, and floods are natural factors causing trees to die and become dead, down woody material. Similarly, forest practices produce dead and down woody material.

Dead and down woody material functions as wildlife habitat providing cover and sites for feeding, resting, and reproducing for many species. The size and decomposition stage determines the usefullness of dead and down material. In general the larger the diameter and the greater the length of a log, the more useful it is. However, small material is better than none as small logs provide habitat for some wildlife species (Maser et al. 1979).

An example of the function of dead and down woody material is the role it plays in the dissemination of the spores of hypogeous fungi- mycorrihizal-forming fungi. These fungi fruit below ground and their fruiting bodies are eaten by small animals such as chipmunks. The spores resist digestion and are defecated on or within the soil where precipitation and infiltration bring them into contact with plant roots (Trappe and Maser 1978). The fungi translocate fungal-absorbed ions from the soil to the host root, and host produced photosynthates to the fungus. This obligatory symbiotic relationship is necessary for the major forest tree species - including Douglas-fir, pines, hemlock, and alder (Maser et al. 1979). Dead and down woody material serve as the transportation routes and cover for chipmunks, and nursery sites for new colonies of hypogeous fungi (Trappe and Maser 1978).

In western Oregon and Washington more than 150 species of terrestrial wildlife use dead and down woody material as either a primary or secondary component of their habitat requirements (Bartels et al. 1983). Maser et al. (1979) listed 179 species of vertebrates making use of dead and down woody material in the Blue Mountains of Washington and Oregon.

Old growth coniferous forests are the last stage in forest succession. Some animals find optimum breeding or foraging habitat in old growth ecosystems (Figure 4-22). Whether these species are totally dependent on old growth is not documented, however, the occurrence of a wildlife species in younger stands does not assure its survival in the absence of old growth. Much of the distinctiveness of animal communities in old growth ecosystems relates to large live trees, large dead snags, and large logs on land and in streams (Franklin et al. 1981). The relationship of old growth to wildlife habitat is currently being studied by the US Forest Service, Forestry Sciences Laboratory in Olympia, Washington (Ruggiero and Carey 1982).

Figure 4-22. Vertebrate animals that find optimum habitat for foraging or nesting or both in old growth Douglas-fir- western hemlock forest ecosystems in Washington.

Group	Common Name	Scientific Name
Birds	Goshawk	Accipiter gentillis
	Northern spotted owl	Strix occidentalis
	Vaux's swift	Chaetura vauxi
	Pileated woodpecker	Dryocopus pileatus
	Hammond's flycatcher	Empidonax hammondii
	Pine grosbeak	Pinicola enucleator
	Townsend's warbler	Dendroica townsendi
Canopy mammals	Silver-haired bat	Lasionycteris noctivagans
	Long-eared myotis	Myotis evotis
	Long-legged myotis	Myotis volans
	Hoary bat	Lasiurus cinereus
	Red tree vole	Arbarimus longicaudus
	Northern flying squirrel	Glaucomys sabrinus
Ground mammals	California red-backed vole	Clethrionomys californicus
	Coast mole	Scapanus orarius
	Marten	Martes americana
	Fisher	Martes pennanti

FAUNA SUMMARY

Fauna are the biological integrators of the physical and chemical changes in air, earth, water, and flora. All species of aquatic and terrestrial fauna have particular habitat requirements and preferences. Some species are more general in their requirements than others, but all have an optimum habitat where they live and reproduce best. These optimum habitats, however, are not the same for all species. A change in the structure and composition of the vegetation can change the habitat for some species and not others.

Forest practices change many of the structural, compositional, and functional aspects of aquatic and terrestrial ecosystems and in so doing, favor some faunal species over others. This potential of forest practices to alter faunal populations through shifts in habitat is of major interest to the subject of cumulative effects.

5. CUMULATIVE EFFECTS OF FOREST PRACTICES

This chapter discusses the circumstances arising from forest practices that lead to cumulative effects. It is founded on Chapter 4 and the principles of systems ecology. Using the definition of cumulative effects we explain the potential for forest practices interacting with the five physical elements of the environment to cause direct and indirect cumulative effects. Although cumulative effects can be temporary or persistent, we have emphasized the latter. The matrix on page 82 is a guide to Chapter 5.

The first principle of systems ecology, germane to this discussion, and discussed in Section 4.3, is that all elements of the environment are connected and influenced by all other elements of the environment. This means that changing one element of the environment, such as flora, will change one or more other elements of the environment, such as fauna and other flora.

To simplify a complex subject, we have gradually narrowed our scope of concern to discuss what we perceive to be the more important aspects of cumulative effects. We do this at the risk of missing some critical process or element of the environment that may later prove to be as important as those we discuss here. This violates, in part, the first principle of systems ecology, however, we believe this level of detail is appropriate for a first approximation of cumulative effects.

Do cumulative effects of forest practices exist? If so, what are they? These are the primary questions we are trying to answer in this report. Current Washington State forest practice regulations look at each forest practice individually considering only its potential individual effect on the environment. The forest practice application process does not require that consideration be given to potential interactions of individual effects and their conversion to cumulative effects. The answers to the above questions are a first requisite to determining whether present regulatory procedures are adequate or require modification to cover cumulative effects.

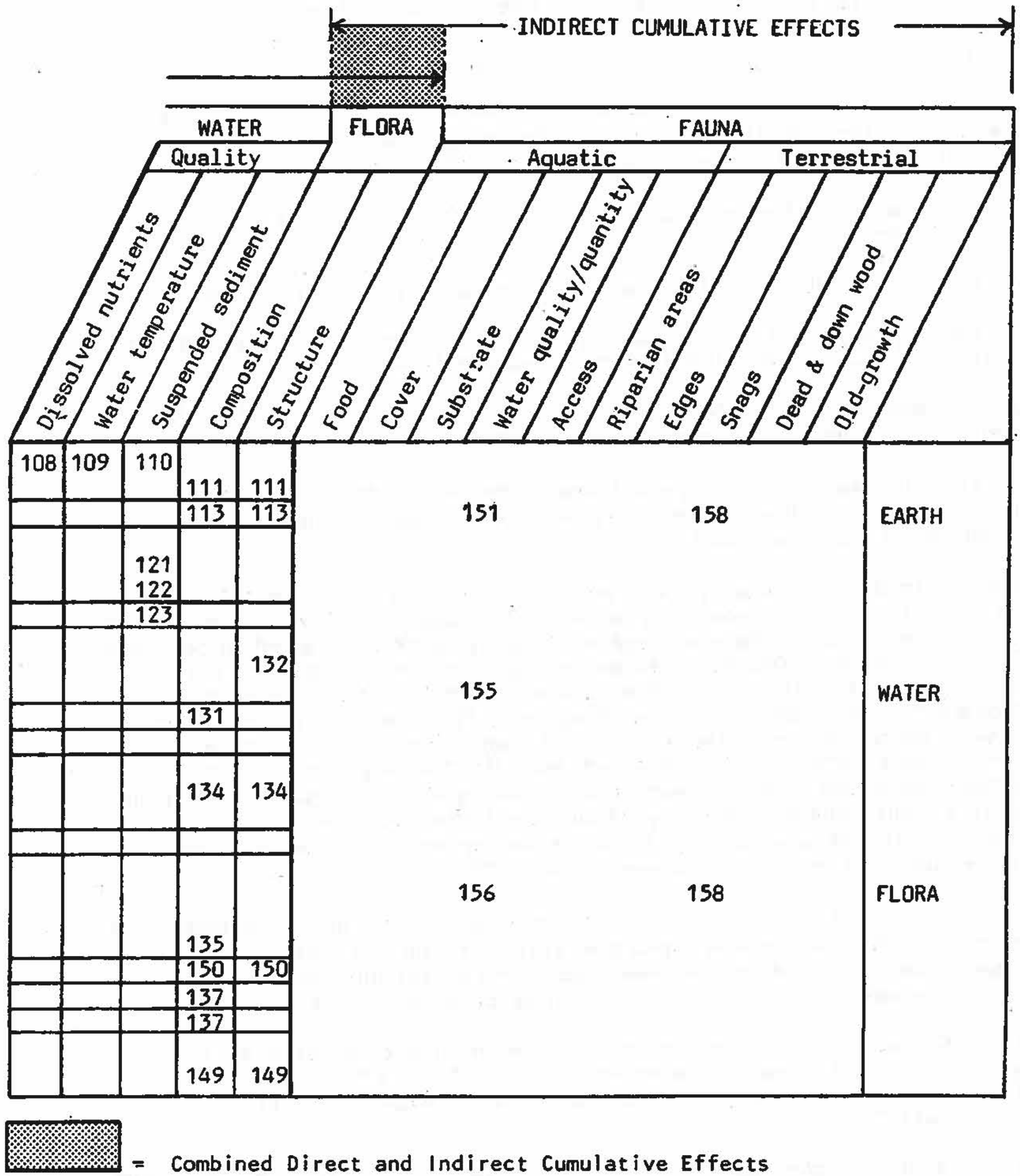
Whether an individual change in the environment becomes a cumulative effect depends on three variables:

1) the magnitude of change
2) its rate of recovery
3) the frequency (in both time and space) of recurring forest practices

The cause-effect relationships between forest practices and cumulative effects are much more complex than those of individual effects. Because of this complexity, there are few, if any, cumulative effects that will universally occur. To determine whether a proposed sequence of forest practices will result in a cumulative effect requires that the practices be exactly defined as to time of occurrence and recurrence and as to location on the landscape. Similar environmental changes will recover at different rates under different site and climatic conditions; whether recovery occurs before interaction with another practice depends on where and when this next practice occurs. This means that all cumulative effects are "potential" changes that

This matrix is offered as a guide to Chapter 5 for locating, by page number, cumulative effects of specific forest practices on specific elements of the environment.

ENVIRONMENTAL ELEMENTS	DIRECT CUMULATIVE EFFECTS										
	AIR	EARTH					WATER				
		Erosion		Forest soil			Quantity				
FOREST PRACTICES	Quality	Surface erosion	Mass movement	Physical properties	Chemical properties	Biological properties	On-site	Water yield	Low stream flow	Peak stream flow	Snowmelt
TIMBER HARVEST		87	88	92	94	97	99	100	101	102	106
Intermediate											
Final											
ROADS		118	119					120			
Construction											
Maintenance											
SITE PREPARATION		127	128								
Prescribed burning	126			128	129	130	130				
Mechanical											
Chemical											
REFORESTATION											
Natural											
Artificial											
STAND MAINTENANCE AND PROTECTION											
Vegetation control											
Wildfire											
Fertilization											
Animals and diseases											
COMBINED FOREST PRACTICES		141	141	145	145	147		147			



INDIRECT CUMULATIVE EFFECTS
WATER
FLORA
FAUNA
Quality
Aquatic
Terrestrial
Dissolved nutrients
Water temperature
Suspended sediment
Composition
Structure
Food
Cover
Substrate
Water quality/quantity
Access
Riparian areas
Edges
Snags
Dead & down wood
Old-growth
108
109
110
111
111
113
113
151
158
EARTH
121
122
123
132
155
WATER
131
134
134
156
158
FLORA
135
150
150
137
137
149
149
= Combined Direct and Indirect Cumulative Effects

can be controlled by proper application and scheduling of forest practices.

Thus, in this study, determining whether or not a change in the environment would become a cumulative effect required answering several questions:

1) What ecosystem properties or processes are changed by the forest practices? Changes include direct effects, generally occurring on-site, and indirect effects, usually to some off-site or mobile component.

2) What is the relative magnitude of this change, and the direction in which it occurs?

3) What is the ability of the ecosystem to assimilate this change?

4) What is the duration of the effect (i.e., its recovery period) and is this related to the "intensity" of the practice?

5) Do these changes interact with changes from other forest practices resulting in changes to other components of the environment?

6) What is the time and space frame under which the forest practices occur? That is, how often are practices repeated, and how are they dispersed on the landscape?

Answers to questions one, two, and (occasionally) three and four were found in the literature. However, answers to questions five and six were rarely addressed in the literature and were obtained from personal interviews or our own experiences. Questions three through six remain the most difficult to answer and the uncertainty in these answers restricts our discussion to the most "common" forest practices as they are "generally" applied and to cumulative effects that are likely to result under "typical" site and climatic conditions. Where data are available, we describe the magnitude and direction of expected change and specific conditions under which they occur. We do not attempt to discuss the probability of cumulative effects occurring or not occurring, nor the threshold that a cumulative effect must surpass before it becomes a cumulative effect of concern to the FPB.

The determination of potential cumulative effects is based on extrapolation of the literature, interpretation of the personal interviews, and our own experience. Where we have made interpretations from limited data our reasons are best expressed by a quote from Lundgrun (1978).

> "It is not so much the fact that the risk of site deterioration is very real which should cause anxieties, but rather the very widespread lack of recognition among forest managers that it is a risk at all."

In the previous chapter, we defined the term "cumulative effect" and introduced our interpretation of "forest practices" and "elements of the environment". In this chapter we will describe the chain of events that tie forest practices as the cause to the environmental elements where the "effect" resides. As outlined earlier, cumulative effects have been divided into <u>direct</u> and <u>indirect</u>, and these are the major divisions of this chapter.

The summary of each sub-section is formulated into a concluding statement. We did this using the rationale that "no conclusions" leads to "no debate". If assigned cumulative effects later prove to be in error, the attempt to rectify these conclusions will lead to pointed discussions which otherwise might not take place.

5.1 DIRECT CUMULATIVE EFFECTS

The FPB regulates forest practices, therefore we have organized this section around forest practices rather than the elements of the environment (Figure 5-1). Direct cumulative effects are closely associated with forest practices and are appropriately discussed under individual forest practice headings. In this section we discuss direct cumulative effects resulting from application of an individual type of practice repeated either on the same site over an extended time period, or on separate sites over a short time period. The final forest practice category, COMBINED PRACTICES, discusses direct cumulative effects caused by interactions of diverse practices. Direct cumulative effects are primarily changes to the air, earth, water, and flora elements of the environment. Cumulative effects on fauna are always indirect and are discussed under INDIRECT CUMULATIVE EFFECTS.

Direct cumulative effects can occur on-site within the forest practice activity area or away from the activity if the changed component moves off-site. To determine whether a change should be considered a direct cumulative effect we used two general guidelines:

1) It is a potential cumulative effect if the change occurs on-site and does not recover during the rotation.

2) It is a potential cumulative effect if a change has a good chance of moving off-site and interacting with other changes.

The risk of the off-site cumulative effect varies with the intensity of harvest activity, the lower the activity level per acre or the greater the time between activities the less the potential for cumulative effects.

TIMBER HARVEST

Harvesting timber has unavoidable direct individual effects on the earth, water, and flora components of the forest ecosystem. But, as we use the term, it has no direct effect on either air or fauna. Potential changes to air resources caused by harvesting are beyond the scope of this review, and changes to fauna are indirect through changes in habitat. Because direct cumulative effects result only when two or more individual effects from separate timber harvests interact, the potential for harvest related direct cumulative effects is also limited to earth, water, and flora.

There is little argument that a change in the forest results when timber is harvested (McLintock 1972). The question is, does the effect of one harvest still persist when the next harvest is initiated? Thus, the

Figure 5-1. The relationship between direct and indirect cumulative effects, forest practices, and elements of the environment.

FOREST PRACTICES SUCH AS:	THAT CAUSE CUMULATIVE EFFECTS IN:					
	AIR	EARTH		WATER		FLORA
		erosion	soils	quantity	quality	
Timber harvest		●	●	●	●	●
Road construction		●		●	●	
Site preparation	●		●	●	●	●
Reforestation						●
Stand maintenance						●
Combined practices	●	●	●	●	●	●

WHICH IN TURN CAUSE INDIRECT CUMULATIVE EFFECTS IN:	EARTH	WATER	FLORA
FAUNA-aquatic	●	●	●
FAUNA-terrestrial	●		●
FLORA	●		●

difficulty in determining cumulative effects of timber harvest is not in identifying change, but the rates at which this change is modified by recovery processes and recurring harvests.

Cumulative effects resulting from timber harvest can occur on the site where the harvest takes place, or off-site away from the harvest activity. On-site cumulative effects are associated with repeated timber harvest on an individual site. Off-site cumulative effects are primarily associated with interactions of timber harvests applied relatively close in time but spread out in some fashion over the landscape. The affected component of the environment must be mobile to move off-site and is usually some product of erosion or other air- and/or water-borne material (fauna are discussed in Section 5.2).

Recovery that must occur to eliminate the potential for an on-site cumulative effect is closely related to the rotation length. Recovery that must occur to reduce potential off-site cumulative effects is related to spacing and timing of the harvest activities. To reduce the potential for off-site cumulative effects, recovery of the air- or water-borne individual effect must occur within a set distance. This distance must be less than the travel distance between harvest-units where individual effects might interact to cause cumulative effects. Therefore, in this discussion we can ignore neither rotation length nor how the harvest operations are grouped.

With respect to cumulative effects, time and space are inescapable components of a timber harvest description. Clearcutting after a 120-year rotation with a well dispersed age class distribution is not the same forest practice as clearcutting after a 60-year rotation where age classes are grouped in large contiguous blocks. Realistically, however, we can not discuss all conceivable manipulations of time and space that are possible in a continuing timber harvest program. Thus, we are forced to generalize on the most common timber harvest scenarios, knowing full well that there are many exceptions. The following narrative describes the cumulative effects of timber harvest on earth, water, and flora.

EARTH

Discussion of cumulative effects of timber harvest on earth resources has been restricted to effects on erosion and soil properties.

Erosion

Within the context of erosion, timber harvest has an effect on both surface erosion and mass failures. The connection between the harvest and the erosion process differs for each. The disturbance related to the yarding portion of harvest is the primary contributor to surface erosion, while it is the reduction in living vegetation and its associated effects on root strength and water distribution that contribute to mass failures.

* Surface Erosion

Timber harvest may increase surface erosion by exposing mineral soil and through soil compaction. These effects are largely related to yarding operations which disturb the soil, expose mineral soil to raindrop impact, and reduce infiltration capacity by compaction. In general, the soil disturbance is related to the amount and force of ground contact by the yarding system. Maximum disturbance is caused by tractor logging and least by full log-suspension systems (Clayton 1981, Dyrness 1970, 1967, 1965; Wooldridge 1960). Logging systems causing the least disturbance result in least surface erosion. However, the type of harvest method is often less important than whether or not it is appropriate to the local terrain (Chamberlin 1982).

The amount of erosion is also related to the quantity of vegetation removed. Vegetation cover, and its associated litter, are the best defense against soil erosion. With identical yarding techniques, clearcut harvest probably has greater effect than a single selection cutting. However, the multiple entries required for repeated selection harvest may cause greater soil disturbance in the long-term.

Some surface erosion will result from any harvest operation, no matter how careful the application. However much of the eroded soil will only be redistributed elsewhere on the site. Except where disturbance is severe and overland flow occurs, soil movement occurs primarily as dry ravel, especially on steep dry slopes (Swanson and Grant 1982, Mersereau and Dyrness 1972). Stabilization of bare soil occurs within a year or two as the site is revegetated.

For surface erosion to result in a direct on-site cumulative effect, the magnitude of erosion must be greater than the soil's ability to replace the lost matter. We are not concerned with the simple lowering of the land surface.

CONCLUSION: With current rotation lengths of 60 years and longer, and where yarding techniques are used that minimize disturbance, we believe there is little potential for soil erosion loss (from harvest alone) exceeding the rate of soil replenishment. Consequently there is little potential for such on-site losses to accumulate harvest after harvest.

* Mass Movement

Many field studies conducted over the past two decades in the Pacific Northwest, northern California, and the northern Rocky Mountains have established relationships between timber harvest (clearcutting) and mass-wasting. The 1964-65 storms on the H. J. Andrews Experimental Forest (HJA) in Oregon generated 3.9 failures/1000 acre of clearcut, compared to 0.4 failures/1000 acre of undisturbed forest (Dyrness 1967a). Over about 24 years, clearcuts in the "unstable terrain" of HJA experienced about 2.8 times as many landslides as undisturbed areas in the same terrain (Swanson and Dyrness 1975). As a result of a major storm in 1975 in the Oregon Coast Range, 77 percent of the landslides occurred in clearcuts and only 9 percent on undisturbed forest (Gresswell, Heller, and Swanston 1979).

Discussion in the literature has dealt primarily with debris avalanches and any resultant debris torrents, but studies have also connected changes in soil creep and earthflow rates to vegetation removal. Decay of the root system and increased soil moisture decrease soil stability (Brown and Sheu 1975).

The effect declines within 15-30 years if deep-rooted vegetation is re-established (R. Beschta pers. comm.). Creep is important in moving soil into stream channels and refilling debris avalanche scars, but since rates are slow and accelerating effects last such a short time we do not believe accelerated creep by itself is a potential cumulative effect under current harvest practices. It is not considered further.

Slump-earthflows typically involve thick bodies of weathered rock and soil and are little influenced by vegetation removal that effects only root strength. However, harvest can occasionally cause renewed or accelerated slump movement, especially on shallow earthflows, by increasing subsurface drainage (resulting from decreased transpiration) thus changing the strength of soils (R. Beschta pers. comm.). A shift from deep-rooted to shallow-rooted grasses was blamed for part of the increase in earthflow activity in the northern California Coast Range (Kelsey 1978). Earthflows are considered further under ROADS.

Debris avalanches are the type of mass movement most affected by timber harvest. The decay of tree roots after harvest causes a decrease in soil strength, especially in shallow, low-cohesion soils, (Ziemer and Swanston 1977). For inherently unstable soils, this tree-root cohesion is commonly the fastener that is holding the soil on the hillside. The effects of debris avalanches include loss of soil from the hillside and deposition of sediment in stream channels. Rice (1977), in California, found that 2-6 percent of an area may be bared in an extreme storm. When debris avalanches become channellized, they turn into debris torrents.

Timber harvest affects debris avalanche occurrence through changes in the forces acting on the soil, specifically changes in the weight and root strength of the mass as a result of harvesting. The change in susceptibility is cyclical, and the cycle seems to have three parts.

1) For the first year after cutting, susceptibility to debris avalanching is reported to be slightly below that of uncut areas. This is supposedly the result of the removal of the overburden of trees, decreasing the downslope force and wind stress on the soil (Brown and Sheu, 1975). The effect is not universal, though, and in some cases increased mass failure may start the winter after harvest (Sidle 1983).

2) Following this period of reduced susceptibility, potential for avalanching rises dramatically in shallow soils on steep slopes, largely as a result of the decay of roots. O'Loughlin (1974) measured a 50 percent reduction of tensile strength of roots in 3-5 years; Burroughs and Thomas (1977) found 86 percent loss of tensile strength in 36 months; and Ziemer and Swanston (1977) observed one-third to one-half loss of strength in 2 years. Root decay continues for at least 10 years after harvest as the larger roots take longer to rot. In addition, roots seem to decay more quickly in wetter climates (F. Swanson pers. comm.). This period of decay corresponds to a period of increased debris avalanche activity observed in many field studies. Swanson and Dyrness (1975) wrote that most slides at HJA occurred within 12 years of harvesting; Megahan et al. (1978) found a 20-year period of increased activity, with a peak from 4-10 years after cutting, in north-central Idaho. Gresswell et al. (1979) stated that 63 percent of the slides in their study in the

Siuslaw National Forest occurred within 3 years, and only 6 percent on cuts over 11 years old. Examples of overall increases in mass movement activity were five times on HJA (Swanson and Dyrness, 1975) and about 24 times in the Oregon Coast Range (Gresswell et al. 1979).

These researchers recognize the role played by large storms in triggering debris avalanches. Heavy rains, especially in combination with rapid snowmelt, can cause rise of pore-water pressures in suitable situations, resulting in loss of shear strength. Many of the papers reviewed dealt with the effects of the great storms of December 1964 and January 1965; for example, Pitlick (1982) estimated that half of the sediment delivered to Redwood Creek by mass movement over 27 years was moved as a result of these storms.

However, it does not take a storm of the magnitude of the '64-'65 events (estimated recurrence interval up to several centuries in some basins) to initiate debris avalanches. Fredriksen (1970) discovered that high-runoff events have a recurrence interval of 3-4 years at HJA and Rothacher and Glazebrook (1968) speculated that large storms are probably even more common than the data from lowland meteorological stations indicate. Thus, it is probable that the frequency of storms that can produce debris avalanches within a 1st or 2nd order basin is of the order of 5-10 years (though the recurrence interval of debris avalanches on an individual piece of ground is more likely several centuries; Kelsey 1982).

If the period of increased susceptibility to debris avalanches is of the order of 10-20 years, it is very probable that a storm capable of causing debris avalanches will occur within that period (89-99 percent chance of a 5-year storm in 10-20 years), and there is a significant possibility of a larger storm (about 10-20 percent chance of a 100-year storm).

3) It is thought that debris avalanche potential should decrease after a decade or two. Most of the marginally stable areas will already have failed, growth of new vegetation will have re-established root strength and soil moisture will be near pre-cutting levels. This supposed decrease has not been adequately observed or measured, partly because most studies have been conducted in areas logged less than 20 years ago. Kelsey (1982), however, pointed out that most debris avalanches triggered by the 1964 storm in the Van Duzen basin affected "older" slopes, those without evidence of movement in the previous decade to century. He cited this as evidence of a period of decreased susceptibility after failure, and estimated the rate of recharge of avalanche scars at about 100-1000 years. In the Pacific Northwest where debris avalanches seem to occur mostly in topographic hollows or headwalls and in inner gorges along streams, similar amounts of time may be necessary to recharge a site after failure (Swanson and Fredriksen 1982).

The long-term and cumulative effects of timber harvest on hillslopes will depend upon the physical processes that control slope stability, and especially the rates of processes that trigger debris avalanches and prepare avalanche sites for further activity (soil formation, and filling by creep and ravel). Swanson and Fredriksen (1982) pointed out that the "effect of clearcutting on the rate of debris avalanche erosion....is related to the rate of recharge of these sites and the effects of management practices on processes that recharge the sites".

The primary on-site effect of debris avalanches is loss of soil from hillslopes, commonly the loss of the entire soil layer from the scar. Based on several studies in California, Rice (1977) placed the area bared by large storms at 2-6 percent; Kelsey (1982) estimated that 2-3 percent of the hillslopes in the steep uplands of the Van Duzen basin are bared each year. Since these figures are of the same order as the amount of area disturbed by road construction in a year (Rothacher and Glazebrook 1968), it does not seem to be a significant effect. However, since debris avalanche scars can continue to remain bare, shed sediment, and undercut adjacent slopes (for up to 100 years, according to Kelsey 1982), future examination of the time scale of debris avalanche activity is warranted.

Increased debris avalanche activity leads to an obvious increase in the area undergoing active re-filling. So although the area recovers before it fails again, the area has a decreased productivity during the recovery period. If the quantity of recovering scars is increased then forest productivity of the landscape as a whole will be reduced.

CONCLUSION: Timber harvest (in conjunction with road construction and fire) causes an increase in debris avalanche susceptibility and activity on steep terrain lasting a decade or two, followed by a period of decreased (at or below background levels) activity. The length of time of these two periods depends on rates of root decay, revegetation, soil formation, and filling of slide scars. Revegetation seems to stabilize the soil within a few years, thus on-site effects of increased debris avalanche activity, at least as far as surface erosion is concerned, do not last long enough to be considered cumulative effects. But this has yet to be proven. The primary potential for cumulative effects is if the increase in debris avalanche frequency over a large area affects the frequency of debris torrents that move off-site (Discussed under COMBINED PRACTICES).

Forest Soils

Timber harvest causes rapid changes to many forest soil properties. Whether changes last long enough to become cumulative effects depends primarily on the rotation length. An on-site cumulative effect will occur if changes caused by harvest continue into the subsequent rotation and are thus additive with changes from such subsequent harvest. In forestry, second-rotation declines in growth have been documented, particularly on poor sites or where poorly adapted species were introduced (Ulrich 1981, Alban 1977, Pelisek 1974).

A rotation length within which recovery occurs is identical to the "ecological rotation" outlined by Kimmins (1974), and the preferred rotation described by Bormann and Likens (1979). An ecological rotation permits return of the site to the ecological condition that existed prior to that rotation. To maintain the soil's physical, chemical, and biological properties, "rotations should not be shorter than the ecological rotation, except possibly when converting climax old growth forests into second-growth forests, and subsequent rotations should be ecological rotations" (Kimmins 1974). We used this concept to determine the potential cumulative effects on the forest soil resulting from timber harvest. The concern is whether old growth harvest and subsequent young growth harvests cause changes detrimental to repeated production of young forests.

We believe permanent changes to the forest soil will result when an old growth forest is converted to a continuous cover of younger, smaller trees. Once the soil has stabilized under this new regime, the forest floor will be thinner, proportionally more nutrients will reside in the mineral soil, nutrient cycling will be faster, and the size of organic debris will be reduced (Long 1982, Turner 1975). In short, continual repetition of young growth forests will result in a loss of soil characteristics related to old growth. We have only limited interest in these changes except where they are detrimental to continued productivity or related faunal habitat. It is understood that old growth soil characteristics are not necessarily required for continued production of trees.

* <u>Physical Properties</u>

Logging systems that drag the logs along the ground cause changes in soil physical properties. The severity of the change varies from one logging system to another and from one landscape to another. Physical change includes a reduction in the soil available for tree growth, soil disturbance, and soil compaction. Disturbance by plowing of the soil during yarding is not usually detrimental. Some shallow disturbance is often required to improve seedbed condition. Undesirable deep disturbance, exposing less fertile and denser soils, is generally limited (Froehlich 1978, Hatchell et al. 1970). The most serious physical change is compaction (Froehlich 1978, 1974, 1973). Compaction is usually expressed as a change in bulk density and is related to losses in pore space, permeability, and resultant infiltration (Campbell et al. 1973, Froehlich 1973). These elements are closely related and serve as an index to each other and an expression of compaction (Froehlich 1978).

The logging system, rather than the silvicultural system, controls the amount of soil disturbance and compaction. Although harvest of a given volume of timber by clearcutting disturbs less area than when done by selection cutting (Smith 1979), when equal areas are considered, soil compaction is similar between a selection cut (including thinning) and a clearcut (Cromack et al. 1979). This is so because, regardless of the timber volume removed, there is a need to reach all areas of the harvest unit. Any potential decrease in compaction by selection cutting is offset by the need for frequent re-entries (Hatchell and Ralston 1971).

Increases in bulk density are most directly related to the yarding technique and to the soil's condition when logging occurs. These include pressure and vibration from harvesting equipment, repeated dragging of logs, and the soil moisture content, degree of aggregation, and organic content (Switzer et al. 1979, Froehlich 1978). Compaction is most severe following extensive use of tractor-type machinery for final harvest or thinning (Froehlich 1973). As much as 25-33 percent of a clearcut area may be disturbed or compacted by tractor logging, compared to 3-9 percent from highlead or skyline systems (Dyrness 1965, Wooldridge 1960, Steinbrenner 1955). The high density of skid trails required for tractor thinning can result in bulk density increasing 13-21 percent (Aulerich et al. 1974). Compaction decreases in more sophisticated yarding systems with partial or full log suspension (Aulerich et al. 1974). Also, compaction is greater and penetrates deeper under wet soil conditions, and the more porous the soil the greater the potential change in soil density due to compaction (Miles 1978, Steinbrenner 1955).

The extent of surface disturbance and the degree of compaction are readily measured and published for several combinations of yarding techniques and site conditions. However, the meaning of these values is not completely understood. Compaction decreases growth in height; impedes root penetration, gaseous exchange, and nutrient and moisture movement; and retards growth of residual trees (Switzer et al. 1979, Froehlich 1973, Youngberg 1959). Although seedling establishment is often good on compacted soils (Youngberg 1959) due to an initial flush of available nutrients, further growth is impeded (Curry 1973). Subsequent growth reduction is dependent on the intensity of compaction (Froehlich 1978) and the ability of the species to cope with compacted soils (Cromack et al. 1979). Although initial growth is retarded, the effect that compaction has on tree growth over a complete rotation is not easily observed.

Recovery from soil compaction is slow and can result in a reduction in timber yield during the rotation (Hatchell et al. 1970). The rate of recovery has received little study, but varies with the severity of the initial treatment, depth of compaction, and the rates of processes tending to decompact the soil such as expansion due to freeze-thaw, wetting-drying, and biological activity of flora and fauna (Cromack et al. 1979, Miles 1978, Froehlich 1973). Froehlich (1978) believes that there is a threshold of compaction beyond which recovery by natural processes is very slow. Below this density threshold, enough pore space and structure remains to allow biological activity and climatic factors to proceed at a significantly faster rate.

Based on the severity of compaction and the specific soil type, compaction may last only a few years, or up to several decades (Froehlich 1978, Hatchell and Ralston 1971). Heavily compacted spur roads, primary skid trails, and landings are land areas commonly lost from subsequent timber production.

Timber harvest results in some level of compaction. Whether this leads to decreased site productivity depends on how much land is disturbed as compared to the density of stems required to fully occupy the site. We believe that only tractor logging is of present concern, and probably only if repeated entries are planned. The potential for a cumulative effect is high if the recovery (decompaction rate) is less than the frequency of equipment entering the stand and recompacting the soil. For compaction to be a cumulative effect on the soil, the condition must not recover before the next harvest. It is doubtful that compaction resulting from a single entry for final harvest will last longer than the 60+ years of a rotation. On the other hand, it seems likely that commercial thinning(s) using present tractor systems may result in compaction that carries over to the final harvest, and will thus persist from rotation to rotation. The factors that can be controlled are the skid trail location, type of equipment used, soil conditions when yarding is allowed, and the time interval between entries.

Even without a carry over in compaction, the initial effects of tractor yarding can result in a cumulative effect on the flora. If the soil is compacted each time the site is harvested (even though the soil recovers), a decrease in timber production may occur if early growth is retarded. This has not been demonstrated.

CONCLUSION: A cumulative effect on soil compaction is unlikely from a single tractor entry for final harvest if initial retardation of tree growth is ignored. Where repeated tractor entries are made, either for selective harvest or thinning, it is highly likely that a cumulative effect on soil compaction will result.

* Chemical Properties

In addition to changes in physical properties, the cutting and removal of trees drastically affects soil chemical properties. Our interest is whether these changes persist and are great enough to limit vegetation growth. We restrict this discussion of chemical properties to nutrients, their addition, removal, and transfer within the soils, the rates at which these occur, and how they are changed by harvest. Nutrient budgets in forest ecosystems, whether harvested or not, are conveniently examined within a framework of nutrient cycles (Stone 1975).

Harvest disrupts the nutrient cycle, but the question is, does it decrease the nutrients available for tree growth? If so, do effects last longer than one rotation? The main concern is nutrient loss, either through direct removal in the harvested timber or by accelerated decomposition of organic matter and leaching (Hornbeck 1977). Although much of the literature is specific to nitrogen because of its relative importance to tree growth, we make no distinction among nutrients in this general discussion.

The most obvious nutrient loss is removal in the harvested wood. Such nutrient losses can cause reduced productivity unless long-term nutrient availability is maintained by natural replacement or artificial measures. The loss of nutrients via removal is proportional to the volume of timber removed and not how it was cut (Stone 1975, Jorgensen et al. 1975). In addition to volume, species is also important. Deciduous trees usually have greater nutrient concentrations than most conifers and their harvest will cause greater loss (Alban 1977, Stone 1975).

Whether timber removal results in a cumulative effect on soil nutrients can not be determined unless utilization standards are outlined and rotation lengths specified. Lost nutrients are replaced naturally, and no long-term depletion will occur if subsequent harvest is delayed sufficiently. As Kimmins (1977) points out, "the shorter the rotation, the greater the risk of soil impoverishment for a given level of utilization and rate of nutrient replacement. And, the greater the utilization, the greater the risk of impoverishment for a given rotation and rate of nutrient replacement." To conserve nutrients effectively, the quantity of biomass removed must be carefully balanced against the rotation length and rate of natural replenishment of nutrients (Johnson et al. 1982, Kimmins 1977, Jorgensen et al. 1975). If soil recovery does not occur during the rotation, we have created a cumulative effect in the next rotation.

Conventional harvest of stemwood, whether clearcut or selection, does not usually deplete soil nutrients at rates greater than can be replaced by natural processes (Ulrich 1981, Stark 1980, 1979, Stone et al. 1979, Nebe 1979, Swank and Waide 1979, Alban 1977, Brown et al. 1973, Gessel et al. 1973). Timber removal at time intervals of 50-70 years appears within replacement rates for all but the most infertile soils. The key here is the term "appear", some believe that today's knowledge is inadequate to predict effects of nutrient losses caused by clearcut timber harvest (Rehfuess 1981, Curry 1973). Knowledge of soil weathering rates is apparently the weakest link in setting appropriate rotations. These rates are generally unknown for all but a few soils (Stark 1980, 1979, Alban 1977, Gessel et al. 1973).

Although current practices of stem-only harvesting, with relatively long rotations, does not appear to affect the nutrient cycle cumulatively, "intensive forestry", including shorter rotations and greater utilization, greatly increases the risk. Whole-tree harvesting, thinning, and shorter rotations all remove increasing quantities of nutrients from the forest.

Whole-tree harvesting removes all the above-ground portion of the tree, including topwood, branches, and foliage and can increase fiber yield as much as 300 percent. The consensus is that nutrient deficiencies will result on most sites within a short time period under whole-tree harvesting (Ulrich 1981, Stark 1980, Bormann and Likens 1979, Swank and Waide 1979, Nebe 1979, Hornbeck 1977, Kimmins 1977, Alban 1977, Stone 1975, Jorgensen et al. 1975, White 1974). Removing the entire above-ground stand can increase nutrient loss rates 2-5 times (Stone et al. 1979, Alban 1977). The foliage and branchwood left as slash in stem-only harvest often contains 1/3-2/3 of the tree's above-ground nutrients (Stone 1975). For example, 10 percent of the available soil nitrogen was found to accumulate in the trees of a 35-year old Douglas-fir stand. However, of this nitrogen, only 24 percent was in wood and 15 percent in bark; the majority was in the needles, twigs, and branches (Cole et al. 1968). Whole-tree harvesting, unless the rotation is extended greatly, removes nutrients faster than replacement rates. Rotation lengths of 75-100 years or greater may be necessary on sites where biomass is intensively utilized (Berg 1981). Whole-tree harvest may not actually increase long-term production, but rather increase biomass from one harvest while lengthening the time required for the soil to recover. The occurrence of nutrient deficiencies is not universal; some sites show no ill effects after repeated whole-tree harvesting (Boyle et al. 1973). Much depends on site quality and whether appropriate rotation lengths are maintained (Johnson et al. 1982).

Even if whole trees are not removed from the site, the yarding of whole trees to the landing for de-limbing will remove fine slash from the site, concentrating it in a few locations. Effects on average nutrient levels may be similar to whole-tree harvest (Ulrich 1981, Stone 1975).

Shortening of rotations (30-40 years) will increase nutrient withdrawals in a manner similar to whole-tree harvesting (Berg 1981, Lundgren 1978, Kimmins 1977, Hornbeck 1977, Alban 1977, Stone 1975). Because maximum nutrient accumulation occurs during early stages of stand development, the average nutrient removals will be greater from repeated short rotations than from longer ones. Berg (1981) believes rotation length has a greater effect on nitrogen loss than does utilization intensity.

Reductions in forest canopy by harvest lead to increased soil temperatures, increased water flow (due to decreased transpiration and interception), and increased decomposition of organic matter (Ulrich 1981, Alban 1977, Stone 1975, Cole and Gessel 1965). Changes are proportional to the amount of canopy removed, and are greater for clearcutting than selection harvest. These changes, when combined with supplies of new organic litter and reduced uptake by vegetation, result in increased carbon dioxide in soils and a higher availability of nutrients in ionic form (Gessel et al. 1973). Since carbon dioxide is the source of a major mobile anion in forest soils (McColl 1972), potential exists for soil acidification and rapid loss of nutrients by leaching.

High nutrient availability often results in rapid regeneration and initial growth, but it can also cause high nutrient loss from the site in drainage waters. The more complete and frequent the harvest, the greater the leaching loss (Hornbeck 1977). Relatively large losses can occur, particularly if slash burning is also practiced (Brown et al. 1973). Generally, however, soil nutrient losses are believed small (Miller and Newton 1983, Fredriksen 1971, Gessel and Cole 1965). Nevertheless, small nitrate losses have been noted 10-17 years after harvest, indicating persistent changes to biological processes controlling the output of nitrogen (Swank and Douglas 1975).

The small leaching losses that occur after timber harvest are considered to have more serious consequences for the aquatic ecosystem than for forest soil productivity (Kimmins 1977). Gessel et al. (1973) believe the probability is low for extensive nutrient losses through leaching caused by accelerated production of carbon dioxide. Losses are most likely if decomposition results in conversion of organic nitrogen to nitrate, another mobile anion. However, nitrate increases cannot occur when the total quantity of accessible nitrogen is small, conversion of organic nitrogen to ammonium is slow, or nitrification of ammonium is restricted. Because of one or more of these constraints, clearcutting will increase nitrate losses only slightly (Stone 1975).

Nutrient outflow declines as vegetation is re-established and soil water levels drop. As with harvest removals, we believe nutrient leaching losses associated with stem-only harvest at rotations in excess of about 60 years are replaced during the rotation on most sites.

Given the potential for loss, the determination of whether nutrient removals will result in a cumulative effect requires answers to the following (Kimmins 1977):

1) What proportion of the site nutrient capital is removed in harvested material?

2) How available are the remaining nutrients to plants?

3) How rapidly are losses replenished, and by what mechanisms? Are these mechanisms affected by harvest treatments?

4) What is the nutrient requirement of the subsequent crop? How does it vary during the life of the crop?

5) What is the magnitude of other harvest-induced losses of nutrients (leaching)?

6) How frequently will harvests occur (rotation length)?

Answers to these questions are site specific and we can only generalize about the potential for cumulative effects.

CONCLUSION: Stem-only harvest at rotations in excess of about 60 years will probably not cause persistent changes to the nutrient cycle that will reduce tree growth. However, repeated whole-tree harvest and shortened rotations will likely deplete soil nutrients of most Washington soils. On poorer sites, lower utilization or longer rotations will be necessary to maintain productivity.

* Biological Properties

The effects of timber harvest on soil biological processes has received less attention than its effects on soil physical and chemical properties (Jurgensen et al. 1977). Organisms contributing to decay processes, nitrogen fixation, and ectomycorrhizal activity provide soils with valuable biological characteristics (Harvey et al. 1981, 1980). These microflora are primarily responsible for the mineralization or release of nutrients from organic matter, a process supplying a large part of the nutrients required for tree growth (Jurgensen et al. 1979, 1977). Soil microflora are of special importance in the cycling of nitrogen.

The energy source or substrate for all microflora is the soil's organic matter. Decaying wood is a major site of nitrogen fixation (Jurgensen et al. 1980), and the activity of nitrogen fixers is 5-10 times greater in organic versus mineral soil horizons (Harvey et al. 1981). Although the organic matter may be less than 20 percent of the soil, it supports up to 95 percent of the ectomycorrhizal activity required for growth and survival of conifers (Harvey et al. 1981).

Harvest will affect these microflora in two ways, directly by removal of carbon and nutrient supplies in logs, and indirectly through changes in chemical and physical properties of the soil (Jurgensen et al. 1979,1977). Because of the importance of soil organic matter, effects of harvest on biological activity can be evaluated by considering potential changes to forest residues (Harvey et al. 1980, Jurgensen et al. 1980). Any change in the quantity or quality of forest residue (organic debris) will cause rapid changes in microflora populations (Bollen 1974). A shift from old growth to young growth may cause a shift in populations of fungi from a type adapted to old growth heartwood to one adapted to sapwood (Aho 1974). Reducing woody debris will alter the activity of fungi and other microflora associated with wood decay, while any removal of foliage would affect microfloral activity in the forest floor.

With respect to timber harvest, there are two concerns; the immediate effects on microflora following disruption of the normal organic debris cycle, and the long-term effects of repeated removal of organic material, including a trend to smaller diameters. Harvest, no matter how clean, leaves some residue, and (as discussed under Chemical Properties), leads to increased decomposition and carbon dioxide production. This is largely a result of increased microbial activity (Jurgensen et al. 1979, 1977). In addition to contributing to nutrient leaching, accelerated decomposition may produce higher levels of ammonium and greater nitrification, with resultant increased nitrate loss. As a balance, however, the accompanying changes to soil chemistry, especially pH, should tend to raise nitrogen fixation rates (Jurgensen et al. 1979).

Changes in biological processes following harvest, if not unduly aggravated by slash burning, are generally short-lived, declining as new vegetation becomes established. Thus, unless major changes are made to composition of tree species, little potential exists for a cumulative effect to result from the short disruption in debris accumulation.

The effects of repeated removal of organic material is our primary concern. Within limits, productivity increases with the accumulation of organic matter (Harvey et al. 1980). The reserves of organic soil material determine how much wood can be removed without decreasing future soil productivity. Intensive wood utilization may decrease the supply of appropriate quantities and types of organic material. Any large loss of organic reserves is likely to reduce tree growth (Harvey et al. 1981).

Excessive residue reductions may require periods well in excess of 100 years for replacement (Harvey et al. 1981). The poorer the site, the more important it is to maintain the proper amount of organic matter. The risk with any timber harvest is that too little, too much, or the wrong kind of residue will result. Too much residue is often a problem with old growth harvest. However, this is not expected to be a continuous problem with young growth management. What we are concerned with is the potential for too little residue resulting from intensive management. Intensive utilization of fiber can potentially remove sources of soil-wood necessary for ectomycorrhizal activity, thus reducing growth until this wood is replaced. Again, this may require 150-200 years (Harvey et al. 1980). The key is defining "intensive". Harvest should leave quantities and sizes of material necessary to maintain a balanced biological activity.

In the Rocky Mountains, Harvey et al. (1981) believe organic matter is deficient when it covers less than 15 percent of the surface of the soil. They calculate that 10-15 tons/acre of residue should be left after any cutting, burning, or other site treatment. Also, since larger woody sizes are most useful, they recommend this material be 6 inches in diameter and larger. Similar recommendations are not available for Washington, but residue from old growth Douglas-fir harvest is several hundred tons/acre of material with a median diameter of 15 inches (Bollen 1974). This is probably well in excess of biological requirements. Thus, residue treatment to reduce fire hazard or for other purposes is probably acceptable from a biological standpoint. The unanswered questions relate to repeated harvest of young growth.

CONCLUSION: No detrimental effects on soil biological properties have been found where stem-only harvest is practiced and rotations approach 100 years. However, the long-term implications of less woody material returned to soils is not known. We believe that more intensive practices such as whole-tree harvest which removes the crown wood, or rotations less than 60-80 years, will not be beneficial to the soil ecosystem. Likewise, thinnings that remove suppressed and dying trees that would eventually become residue may be detrimental.

Determining site-specific residue requirements requires careful examination of individual stands and a knowledge of expected utilization and rotation lengths. Although hard data is lacking for Washington, we believe it likely that intensive harvest practices will cause cumulative effects on soil biological properties.

WATER

The removal of live vegetation through timber harvest causes immediate changes to the hydrologic cycle by altering interception and transpiration. Yarding of the timber causes additional disturbance that can further affect runoff as well as water quality. The magnitude and duration of these changes to water quantity and/or quality determine whether or not they become cumulative effects.

Water Quantity

Our discussion of timber harvest and water quantity is divided into sections about its effects on on-site hydrology and off-site or downstream effects. Off-site effects include potential changes in water yield, low streamflow, peak streamflow, and snowmelt runoff.

* On-site

Changes in interception, soil water, and snow distribution occur on-site, but accumulate only when a practice is repeated on the same site or after another practice with a similar effect is performed on that site. Considering the time involved, primarily the rotation period between harvests, these effects are not considered cumulative.

For example, the decrease in interception following timber harvest declines as trees are reestablished. Also, increases in soil water following harvest decline to pre-harvest levels as the canopy closes with regrowth (Ziemer 1964, Anderson 1963) and changes in snow accumulation and melt in forest harvest openings decline as the new stand matures. Since crown closure and full site occupancy by vegetation occur prior to the next harvest, changes to the forest hydrologic cycle return to pre-harvest levels as the site is re-occupied by trees. Even water losses from reduction in fog interception (Harr 1980) may be regained after regrowth.

Exceptions to these generalities may occur where soils are compacted, or where permanent changes are made in the forest's successional stage or structure, as when old growth is harvested or the site converted from hardwood to conifer species. Evidence that an old growth forest consumes a different amount of water than a fully stocked second growth forest was not found in the literature. After canopy closure, additional stocking does not result in higher water consumption, but only in increased competition for available water (Zahner 1968). Whether interception is greater in old growth than young growth forests is unknown. On the other hand, conversion will reduce the site's water yield because conifers intercept more water than deciduous trees and unlike hardwoods, continue transpiring during the dormant season (Swank and Douglas 1974, Helvey 1971, Swank and Miner 1968). Hardwood conversion, however, is not a major forest practice, and like the permanent change from an old growth to young forest, is rarely repeated on the same site (DNR 1982).

CONCLUSION: On the majority of sites, timber harvest will not result in a persistent cumulative effect to the on-site water balance. Exceptions are where natural hardwood stands are converted to conifer, and where fog-drip (associated with tall, old growth canopies) was an important part of the pre-harvest water balance.

* <u>Water Yield</u>

Timber harvest, whether by selection, shelterwood, or clearcut practices, removes a portion of the overstory vegetation. In so doing, interception is reduced, the amount of rain or snow reaching the ground increased, and the transpiration of the forest reduced. These impacts combine to make more water available for soil storage (Heikurainen 1967) or streamflow. Timber harvest therefore results in increased annual streamflow (Patric and Aubertin 1977, Cline et al. 1977, Swanson and Hillman 1977, Bateridge 1974, Harris 1973, Verry 1972, Lynch et al. 1972, Hornbeck et al. 1970, Rothacher 1970, Hibbert 1967). Little argument remains on this general point (Golding 1981, Berndt and Swank 1970), even though exceptions are known where fog drip was eliminated (Harr 1980).

Harvest increases the annual water yield in proportion to the reduction in forest cover, with clearcut harvest producing greatest yield (Harr et al. 1979, Rothacher 1970, Hibbert 1967). Attendant slash burning does not increase water yield above that from clearcutting alone (Rothacher and Lopushinsky 1974). Water yield increases in Oregon Douglas-fir forests ranged from 36 percent in a 100 percent clearcut watershed, to 16 percent in a 30 percent clearcut watershed (Rothacher 1970). Increased water yield is greatest the first year after harvest, declining thereafter, with the rate of decline related to the rate of vegetation regrowth (Hibbert 1967, Kovner 1957). Where soils are deep and revegetation rapid, the length of impact may be 10 years or less (Anderson et al. 1976); it may last up to 30 years on slowly revegetated sites (Leaf 1975, Kovner 1957). In either case, increases in streamflow from a single harvest unit return to pre-harvest levels as the new forest matures. Thus, there is little potential for a cumulative effect on water yield of 1st and 2nd order streams from repeated cutting of an individual harvest unit, except where heavy precommercial thinnings and intermediate harvests are scheduled.

However, there is a logical cumulative effect on annual streamflow from larger watersheds. Many 3rd order and larger watersheds containing numerous cutting units harvested on short rotations will never reach full site occupancy by vegetation. Some unit within the watershed is always regrowing and the watershed as a whole will never reach its full evapotranspiration potential. The water yield from a 4th or 5th order watershed managed through continuous cropping will probably have a permanently increased water yield. The question remains, is this increased yield of interest or concern?

Increased water yield from annual timber harvest of small portions of a watershed may not be easily measureable (Anderson et al. 1976). Current stream gaging techniques cannot detect the effects of forest density reductions less than about 10-20 percent of basal area (McMinn and Hewlett 1975, Hibbert 1967). A study of the Naselle River drainage in southwest Washington found no measureable change in streamflow over the period 1930-1956 during which the watershed was logged at a rate of 2 percent of area per year (Martin and Tinney 1962). In contrast, a similar study on a 295 sq. mi. drainage in central Oregon over 45 years found that after restocking with second growth, and with sustained (although reduced) timber harvest activities, a small water yield increase of about 1 inch persisted (Berndt and Swank 1970). Rothacher (1970) estimated that in western Oregon an 18-inch on-site increase in water yield would be equivalent to only about 0.8 inch increase from an area patch cut on a 100-year rotation. Also, the magnitude of increase in streamflow from any forest practice is directly related to the amount of annual precipitation which varies greatly from year to year (Hewlett and Helvey 1970, Hibbert 1967). During dry years, increased yields will be lower than in wet years, and the normal variability in streamflow from large watersheds will greatly exceed the amount of additional water yield from a small harvest unit (Bethlahmy 1974, 1972). Harr (1983) concludes that harvest of large watersheds under sustained yield will augment flow by only 3-6 percent.

CONCLUSION: A cumulative effect of timber harvest, in particular clearcut practices, applied on a continuing rotational basis is an increased water yield from larger forested watersheds (4th and 5th order). The increase will only be a few percent.

* <u>Low Streamflow</u>

In western Oregon and Washington, about 20 percent of the increased water yield from timber harvest occurs during the summer growing season (Rothacher 1970). Although water yield increases in the rainfall zone are greatest during fall and winter, the smaller increases in summer flow, when streams are at their lowest, may be of greater consequence (Harr 1980, Rothacher 1971, 1970). Transpiration during the growing season maintains soil moisture at a low level with subsequent slow drainage and minimum streamflow. The water savings from a reduction in transpiration following harvest may increase the soil moisture (Klock 1981, Harr 1976a,b, Hibbert 1967), making more water available for streamflow. Low flows were increased 300-400 percent following clearcutting and slash burning of a small watershed in the western Cascades of Oregon (Rothacher 1971, 1970). Summer low flows were three times greater following clearcutting of a southwest Oregon watershed (Harr et al. 1979), and also increased significantly after clearcutting and burning 82 percent of an Oregon Coast Range watershed (Harr and Krygier 1972). Cutting a smaller portion of a watershed results in a much smaller increase in low flow (Harr and Krygier 1972).

An increase in summer low streamflow following timber harvest is the general case, but it is not without exception. Where canopy interception of cloud moisture and resultant "fog drip" is an important source of water during spring to early fall, a reduction in this component by harvest can result in a decrease in low flow (Harr 1980).

Timber harvest in Washington will, with the exception noted, probably cause increased summer streamflow. Increases will be greatest where clearcutting is practiced and less where some type of selection cut is used. These increases will be primarily in small 1st and 2nd order streams draining individual harvest units. Rapid regrowth, particularly by riparian vegetation, will decrease these low flow increases in a few years (Harr et al. 1979, Rothacher 1971). Thus, low flow will return to its pre-harvest level before the next harvest, and no cumulative effect on flow from 1st and 2nd order streams will exist.

The result is different for streams draining larger, 3rd-5th order watersheds. As is the case with water yield, continual timber harvest in a watershed will maintain increased low flows from some portion of the basin. Theoretically the basin as a whole will have a permanently increased low flow, and thus experience a cumulative effect of timber harvest. In practice, however, the short duration of an individual increase and the normal variability of streamflow, both from year to year and between watersheds, will effectively mask these small increases (Harr 1976b). While it may be possible to measure annual increases in water yield from a managed watershed, normal variation will make it very difficult to isolate changes in seasonal low flows, particularly with intensive reforestation and rapid regrowth of riparian vegetation.

CONCLUSION: In most of Washington's larger forested watersheds (4th and 5th order), where timber harvest followed by rapid regeneration is common, persistent increases in low flow will occur. This cumulative effect will be small and difficult to measure.

* Peak Streamflow

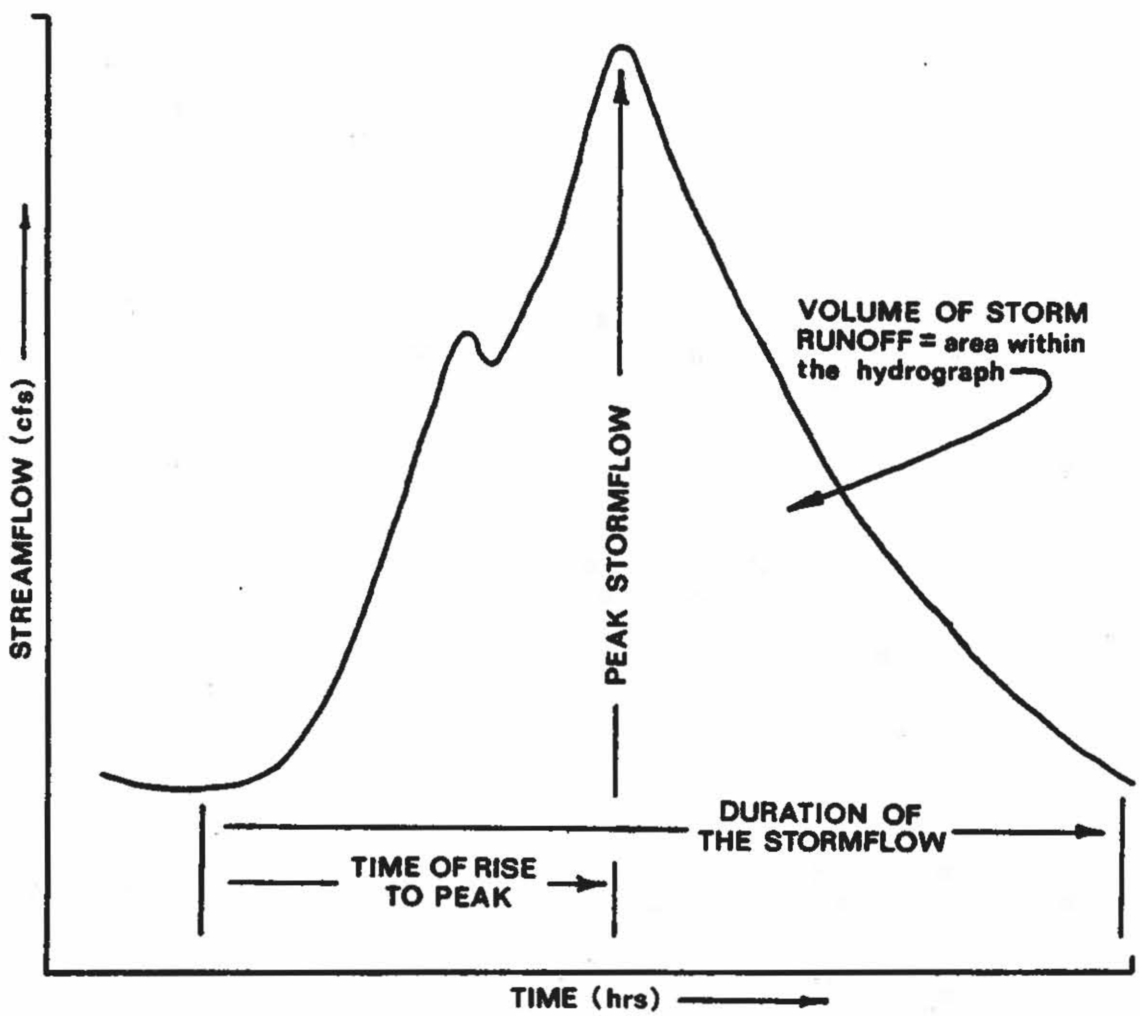
Considerable controversy exists about whether or not timber harvest causes increased flood peaks. Much of the confusion arises from the definition of flood peak. Is it the average annual peak flow, or only the major floods occurring at relatively rare intervals, but causing major erosion and downstream flooding? The average fall or winter peak flow is considerably lower in magnitude than the large flood events. We discuss both.

About 80 percent of the water yield increase arising from forest harvest in the Douglas-fir region occurs during October-March (Rothacher 1970). This additional water means that some component of the normal winter hydrograph must change. Changes to the hydrograph from forest practices, however, are possible even without an increased water yield. The hydrograph of a stormflow event has four components (Figure 5-2):

1) the magnitude of the peak flow
2) the time of rise to peak
3) the duration of the stormflow
4) the volume of storm runoff

These components control the energy distribution of the runoff and its resultant potential for erosion, flooding, and related damage. For any storm event, a change in one component will result in a corresponding change in others. For example, any activity increasing peak stormflow must increase the storm runoff volume, or else change the stormflow timing to pass the same water volume at higher magnitude in a shorter time. Conversely, increasing the storm runoff volume may result in increased peak flow or only an increase

Figure 5-2. Components of a typical storm hydrograph.



in the duration of the runoff. The difficulty in predicting these responses is that timber harvest changes many stages of the forest hydrologic cycle and, in doing so, alters one or more of these four components in an infinite variation of combinations and magnitudes. Although some general conclusions may be inferred from the literature, there are many exceptions.

Most studies of streamflow following timber harvest of 1st and 2nd order basins in the Pacific Northwest have found that stormflow peaks increase during the fall and early winter (Chamberlin 1982, Harr 1979, 1976b, 1975, Harr et al. 1975, Rothacher 1973, 1971). As might be expected, increases after clearcut harvest are greater than when less timber is removed (Harr et al. 1975). However, the size of the increase in peak flows may be related to the amount of soil compacted by logging as much as to the quantity of vegetation removed. In Oregon, a shelterwood cut with 13 percent of the soil compacted had a greater increase in peak flow than a nearby clearcut (Harr 1979).

Storm peaks are increased in three ways (Swanson and Hillman 1977):

1) by forcing some ordinarily subsurface flow to a surface path
2) by increasing the efficiency of precipitation delivery to the subsurface system
3) by increasing the area of wetted stream perimeter

Increased surface runoff is generally not the case on harvested land where disturbance is not severe and subsurface flow continues to dominate (Swanson and Hillman 1977, Hewlett and Hibbert 1967). Rather, in early fall storms, the efficiency of the subsurface flow system is increased by wetter soils in the clearing than under the forest canopy (Harr et al. 1975, Rothacher 1971). Transpiration by the forest during the summer growing season depletes the soil water, reducing it to a lower level than in a clearing. Wetter soils require less water to fill remaining storage capacity and fall rains in the clearing result in more water available for storm runoff and higher peak flows. The higher flows result from the greater water volume, with no apparent change in the time to peak (Bethlahmy 1972). Even after all soil storage capacity is filled, and soil water in the clearing and under the canopy are similar, winter streamflow can be increased by surface runoff from compacted soils or from a lack of interception in clearings (Harr et al. 1975).

In all reports of increased peak flows, fall increases were proportionally greater than winter increases. Although winter peaks are generally higher, they are not changed as much as fall peaks because the difference in soil wetness between cut and uncut areas is less. These general results from most studies are not unanimous; the evidence that forest harvest increases peak flows is conflicting (Bethlahmy 1974). Under certain conditions, peak flows following timber harvest can be reduced. Disturbance of the larger soil channels (root channels) by harvest can force infiltrating water to move through the smaller microchannels of the soil matrix. The result is an attenuation of the storm event, with a longer time for streamflow to peak, and a smaller peak flow (DeVries and Chow 1978, Cheng et al. 1975). The reduction in snow interception when timber is harvested also can reduce the peak flow associated with rain and snow events (Harr and McCorison 1979). The elimination of snow normally caught and held in the forest canopy reduces condensation and convection melt, lowering the water immediately available for runoff and thus the storm peak. Slower snowmelt also delays the time to peak.

Whether forest harvest increases or decreases peak flows is relevant to cumulative effects only when the impacts are felt off-site. Changes in storm flows of 1st and 2nd order basins, like changes in water yield, diminish rapidly with regrowth of the vegetation, and probably disappear before a stand matures and a site is again harvested. Thus, the only potential for cumulative effects is if these changes in peak flow within 1st and 2nd order watersheds combine to change the peak flows from 3-5th order watersheds. The question to be answered is: does rotating timber harvest throughout a 5th order watershed with a mix of age classes persistently increase peak flows?

Like peak flow from harvest of a 1st order watershed, small increases in fall peak flows and average winter peaks should be evident on larger managed watersheds. The probability is high that continuous cutting on a rotational basis will result in increased fall and early winter storm peaks from many Washington watersheds. The effect will probably be most noticeable in western Washington where larger frontal systems approaching from the Pacific Ocean cause relatively uniform rainfall over large areas. Resulting stormflows from all sub-basins peak at close intervals and desynchronization of flood peaks is rare.

The magnitude of these increases on 4th order and larger basins with mixed age classes will likely be small. They will certainly be smaller than research findings from 100 percent clearcut 2nd order watersheds, and probably less than results reported for larger watersheds clearcut over a short time period and having only a few young age classes during the study period. This assumes future cutting schedules within 3rd-5th order watersheds are adjusted to maintain a mix of age classes.

Fall peak flows, however, are not the large flood events (Rothacher 1973), and the average winter peak flow is much less than the less frequent major flood. These so called "wet mantle" floods are generally responsible for accelerated erosion, stream channel damage, and loss of real property, and are thus of particular interest. These floods occur when long duration Pacific storms result in heavy rainfall over several days. Under these conditions soils are completely wetted whether in a clearing or under the forest and interception losses become negligible. Thus with an absence of road effects and only small non-contiguous soil compaction from harvest, runoff should not differ between a clearcut and forest. Adequate data, however, are not available for these rare flood events on mountainous watersheds. Because they are rare they do not often coincide with short study periods, and when they do they often destroy or damage the gaging facility, wiping out all record of their magnitude. Controversy remains over the effects of harvest on major floods.

Our understanding of large flood events is further clouded by the issue of rain-on-snow. Maximum flows in the Pacific Northwest result from rapid snowmelt during prolonged rainfall (Harr 1979). The primary manner in which harvest could cause increased flood peaks is through its impact on snow accumulation. If harvest results in more snow on the ground when major rain-on-snow events occur, then there is a potential for increased floods. However, the major rain-on-snow storm events are mostly a function of rainfall, with only about 17 percent of the runoff from snowmelt (Harr 1978).

Since rain storms rarely coincide with the maximum snow accumulation, the impact of increased snow in clearings is questionable. A slight increase in snow on the ground may not greatly affect the timing or synchronization of runoff. But again, not enough is known about these events.

In summary, timber harvest increases the small fall-storm peaks, but this impact becomes less as the magnitude of the storm increases and is believed small or non-existent for wet mantle floods (Harr 1976a,b, Harris 1973, Rothacher 1973, 1971). If these results appear inadequate, we can only say that much remains to be learned. A final answer is necessary on whether, or under what conditions, harvest changes the stormflow volume or peak from infrequent larger storms. Should stormflow volume for major runoff events be increased on many 1st and 2nd order watersheds of a 4th or 5th order basin, stormflow volume might be sufficiently increased on the parent watershed to cause downstream flooding (Harr 1976b). Also, if increases in the fall and early winter storms interact with some other impact of forest practices, for instance debris avalanches, then these runoff increases may be more important than reported here. In effect, changes in the runoff would increase the frequency of these events.

CONCLUSION: Continual harvest of small watersheds (1st and 2nd order) within a larger basin will result in a persistent increase in fall and average winter stormflow peaks of the larger mainstem. This is a cumulative effect of many scattered harvest activities, each causing only a short-lived change to the 1st or 2nd order stream stormflow, but combining to cause a persistent change in the mainstem. As the magnitude of the stormflow becomes greater the cumulative effect from harvest declines and harvest impacts on wet mantle floods are believed small. Nevertheless, additional research is necessary, particularly with respect to rain-on-snow, before the magnitude of this change is finally determined.

* <u>Snowmelt Runoff</u>

In addition to changes that timber harvest cause in the distribution of rainfall, are the effects that harvest has on the accumulation and melt of snow. More snow accumulates in harvest clearings than under the surrounding forest (Golding 1981, Gary 1979, 1975, 1974, Cline et al. 1977, Haupt 1972, Hoover 1969, Anderson and Gleason 1959, Anderson 1956), and harvest increases the snow pack in proportion to the timber cut (Leaf 1975). This is not caused by more snow falling over the clearings than over the forest (Gary 1975, Hoover and Leaf 1967), but rather, in some areas snow is blown off the trees and redeposited in the clearings (Gary 1979, 1975, Hoover and Leaf 1967, Anderson and Gleason 1959). In other areas the forest intercepts and evaporates snow from its canopy, resulting in less snow under the trees (Golding 1981, Cline et al. 1977, Haupt 1972).

Redistribution is most prominent in high elevation zones, such as the central Rocky Mountains, where cold dry winds are common (Cline et al. 1977). Interception melt dominates in Washington where forests are generally lower in elevation and snow caught in the forest canopy is melted by warm wind or rain. Evaporation of intercepted snow is a direct loss of water from the forest and snowmelt drip causes an immediate outflow of water rather than retention as snow (Haupt 1972). Both result in a smaller snowpack under the forest. Although the magnitude of increased snow accumulation in clearings differs greatly by year, aspect, and elevation, its occurrence is generally accepted (Cline et al. 1977).

The greater snowpack in a harvested unit results in an increased annual water yield, similar to that following harvest in the rainfall zone (Gary 1979, Hoover and Leaf 1967, Bates and Henry 1928). However, rather than increased fall and winter runoff, the greater water yield usually occurs as increased streamflow during the spring snowmelt (Golding 1981, Swanson and Hillman 1977). The clearings also result in advances in the time of snowmelt (Chamberlin 1982, Swanson and Hillman 1977, Leaf 1975) because the snow melts sooner in openings than under the forest (Rothacher and Lapushinsky 1974, Goodell 1959). Although it may persist longer in openings because there is more snow to be melted, the result is an earlier and more rapid melt. The rapid melt maintains high soil water levels assisting the melt water to run out faster (Chamberlin 1982). Melt runoff from an individual harvest unit may be earlier by as much as a month and increased 1-3 times (Chamberlin 1982).

The increased water yield arises from a reduction in evaporation loss, either because of reduced transpiration, little snow interception in the clearing, or the more rapid melt and runoff from the clearing compared to the forest (Hoover and Leaf 1967). A rapid melt means less time is available for evaporaton. Whatever the process that results in greater snow accumulation, the end product remains as greater water yield.

The greater snowpack and water yield after timber harvest persist for several years due to reduced transpiration, less snowpack evaporation, and higher soil water levels (Gary 1979, Hornbeck et al. 1970, Hoover 1969). In high elevation forests where regrowth is slow and snow is an important component of streamflow, the increased water yield may last 30 years or longer (Swanson and Hillman 1977, Leaf and Alexander 1975, Leaf 1975).

Although an increased water yield from 3rd or 4th order snow-zone watersheds managed under sustained yield is the general case, whether this results in higher peak flows during snowmelt is questionable. Increased peak flows would require synchronization of the rapid snowmelt in clearings with melt under the forest (Anderson et al. 1976). Cutting only part of a watershed will probably desynchronize snowmelt and produce reduced peak flows (DeWalle and Lynch 1975, Verry 1972). Desynchronization results when snow in the clearings melts before that under the forest. This is further accentuated when harvesting on southern aspects.

CONCLUSION: Greater water yield from larger watersheds during spring snowmelt is a cumulative effect of continued timber harvest in the snow zone. Although this may cause increased snowmelt peaks from small watersheds, increased peaks from larger (3rd-5th order) basins would probably be small.

Water Quality

Timber harvest can cause several changes to stream water quality. We are interested here in changes in dissolved nutrients, water temperature, and suspended sediment.

* Dissolved Nutrients

Timber harvest causes higher nutrient concentrations in streams (Tiedemann 1981, Hewlett 1978, Hetherington 1976, Snyder et al. 1975, Aubertin and Patric 1974, Fredriksen 1971). As previously discussed, harvest accelerates the release and mineralization of plant nutrients in the forest soil. Subsequent leaching can move a portion of these nutrients to the stream system. Reported increases range from near zero to several times baseline concentrations. The actual value is site specific, varies between individual nutrients, and depends on the amount and species of vegetation removed and any subsequent site treatment.

Greatest streamflow nutrient increases occur directly adjacent to the harvest unit and decrease downstream. Increased concentrations are usually highest during low flows and lowest during high flows (Snyder et al. 1975, Tiedemann 1974). Low flow concentrations are related to high soil respiration and nutrient availability during summer. Dilution by high flows causes lower concentrations.

Since most Washington forest streams have naturally low nutrient concentrations, increases following harvest can be proportionally large, doubling or tripling nutrient levels. These changes in nutrient levels may cause changes in stream flora and fauna within the harvest unit (Fredriksen 1971). There is also concern over potential nitrogen eutrophication of streams and lake systems (Tiedemann 1981). However, as the vegetation returns, tying up mobile elements, nutrient concentratons in streams decline (Hewlett 1978, Marks and Bormann 1972). Baseline nutrient concentrations are usually re-established within a few years.

The relatively rapid decline in nutrient increases from an individual harvest means that dissolved nutrients are highly unlikely to become an on-site cumulative effect. Downstream extrapolation, however, indicates that with continual harvest throughout the basin, nutrient enrichment will repeatedly occur somewhere within the stream system. First and 2nd order tributaries with increased nutrient concentrations will be scattered throughout the watershed, closely following the harvest pattern. A cumulative effect will occur if these scattered increases combine to continually increase the nutrient level of the 3rd order or larger stream.

Whether or not a cumulative effect related to dissolved nutrients is probable depends upon the water's travel distance between harvest units and the frequency of harvest. As the water moves downstream, nutrients are rapidly diluted, adsorbed by sediments, and taken up by primary producers. The rate of these processes and the resultant travel distances necesssary to effectively reduce nutrient concentrations have not been studied. We believe downstream mixing with other affected tributaries probably occurs, but that resultant nutrient increases in 3rd order and larger streams are negligible.

The importance of increased dissolved nutrients to aquatic ecosystems is unknown. Scattered increases in overall stream productivity could result but studies in Alaska found increased nutrient levels were too low to affect stream periphyton or macroinvertebrates (Everest and Harr 1982).

CONCLUSION: Timber harvest may cause a downstream cumulative effect by permanently increasing nutrient levels as harvest progressively affects 1st and 2nd order tributaries within a 3rd-5th order watershed. However, because of the water's travel distance between harvest units such nutrient accumulations in the mainstem will be small.

* Water Temperature

Timber harvest that removes streamside vegetation, eliminating shade, will change the temperature regime of forest streams. The result is often increased summer water temperatures, and occasionally decreased winter temperatures (Brown et al. 1971, Swift and Messer 1971, Brown and Krygier 1970, Brown 1970, Meehan 1970, Brown and Krygier 1967, Levno and Rothacher 1967). Temperature increases during summer low flow are of greatest concern; changes in winter temperatures are less likely due to greater water volumes, lower sun angles, and topographic shading.

The major source of heat for small forested streams is solar radiation (Brown 1969), and increased exposure to solar radiation following removal of streamside vegetation is the primary cause of increased water temperatures. Harvest along streams may increase solar radiation 6-7 times resulting in summer temperature increases from as little as 3-4 degrees F. to as much as 24 degrees F. (Anderson 1973).

The magnitude of increased summer temperatures is directly related to the amount of shade removed and the surface area of stream exposed to direct sunlight (Swift and Messer 1971). Small streams are particularly sensitive to changes in shade as they have less capacity for heat storage than larger streams (Brown 1969). Maintaining shade is the key to control of water temperature. Where streambank vegetation is not cut during harvest, summer temperatures remain unchanged (Swift and Messer 1971, Brown and Krygier 1970).

Heated streams are cooled by the inflow of cooler groundwater and tributaries, and by downstream shade. Groundwater inflow results in greatest temperature reductions; shade is only of limited value in cooling where the air temperature is greater than the stream's (Swift and Baker 1973, Brown et al. 1971). With the re-establishment of streamside vegetation increased water temperatures begin to decline. As revegetation along streams is usually rapid, temperature increases are relatively short-lived. The recovery time varies with the width of stream requiring shade but is usually less than 10 years (Brown and Krygier 1970).

Since shade cannot be relied upon to cool heated water, large temperature changes should be avoided in the first place. This is the intent of present forest practices regulations requiring buffer strips along temperature-sensitive type 1, 2, and 3 streams. However, the smaller 1st and 2nd order streams that are most sensitive to increased exposure are usually typed as class 4 or 5. Thus many tributaries may not receive adequate protection from solar loading. Maintaining shade on these smaller channels as well as the larger ones would probably eliminate most temperature increases.

There are two ways that increases in water temperature can become cumulative effects:

1) by remaining elevated along the harvest reach for longer than one rotation

2) by continuously raising the temperature of a downstream reach, either by separate contributions from individual harvests over time, or by combined effects of several harvests

The first is unlikely, but the second is highly likely unless care is taken in the harvest planning. Brown and Krygier (1967) noted "the integrated effect of numerous clearcuttings on small tributary streams of larger stream systems may be as significant as dams, etc."

In the past, cumulative temperature increases resulted when larger (4th or 5th order) watersheds were progressively harvested over a short time span. Shade was rapidly removed from a large portion of the tributary stream system. Future control of stream temperature requires gradual removal of shade over time so temperatures do not exceed desired levels in any one reach (Brown et al. 1971).

If, because of current age-class distributions, contiguous harvest is repeated from the bottom of the watershed to the top, then a cumulative effect is probable on water temperature. However, if harvesting is distributed in space and time within 4th order and larger basins, temperature changes will probably dissipate. Given a mix of temperature-sensitive and non-sensitive reaches, shaded reaches with cooler inflow, and streamside management zones along 3rd order and larger stream segments, the additive effects of temperature increases would be minimized where affected 1st and 2nd order tributaries are scattered rather than grouped.

CONCLUSION: A cumulative effect on water temperature is likely in 4th order and larger watersheds if they are harvested within a short time frame resulting in large contiguous harvest-blocks with their contained 1st and 2nd order streams lacking shade. If, however, future harvests are scheduled over a longer time span and/or spread out in space, then a cumulative effect is unlikely.

* <u>Suspended Sediment</u>

Timber harvest can increase sediment in streams in proportion to altered surface erosion rates. It may also increase sediment in streams by causing debris avalanches. With respect to surface erosion, harvesting techniques that disturb soil the most are generally responsible for greatest increases in suspended sediment concentrations. The amount of eroded soil reaching streams is proportional to the amount of soil exposed and the proximity of the disturbed area to the channel (Rice et al. 1972).

Tractor logging, with its related network of skid trails, is responsible for the highest concentrations of suspended sediment reported in the literature. Harvest using cable systems causes little increase in stream sediment levels except where yarding across streams disturbs the channel (Klock 1975, Brown and Krygier 1971, Fredriksen 1970). Techniques that least disturb soils and vegetation in the vicinity of channels are most effective in minimizing the harvest's contribution to suspended sediment (NCASI 1979). Where surface erosion is the primary cause of increased stream sediment concentrations, maximum increases follow soon after harvest and gradually decline as new vegetation controls erosion (Beschta 1978).

Since harvest, especially clearcutting, can reduce slope stability, sediment production from steep slopes is more probable from debris avalanches than from surface erosion. Debris avalanches can result in long-term availability of readily suspended sediments in stream channels. Where debris avalanches do not result and stream channel integrity is maintained, harvest-related surface erosion does not contribute enough sediment to streams on a continual basis to cause a long-term increase in downstream sediment concentrations.

CONCLUSION: An increase in suspended sediment concentrations caused by surface erosion following timber harvest does not constitute a cumulative effect, even when the interactions of many harvest activities are considered. On-site recovery is usually rapid and downstream accumulations are short-lived.

Sediment from accelerated debris avalanche or slump-earthflow occurrence is a greater concern. Debris avalanches can deposit large volumes of sediment in channels, drastically modifying the sediment supply for a considerable period. The increased frequency of debris avalanching within a managed watershed (using clearcut harvest) increases the probability of higher than normal sediment concentrations during stormflows. The related potential for a persistent cumulative effect is high.

FLORA

Discussion of cumulative effects of timber harvest on flora addresses the influence of harvesting on the composition and structure of the forest. Our approach will emphasize the overstory because vastly more material is available regarding the effects on trees, as opposed to the minor vegetation comprising the understory,

Composition

The type of timber harvest and the particular forest zone where applied control the species compositional changes following harvest. The following discussion addresses the applications of harvesting types to forest zones.

Pre-commercial thinning (PCT) is applied in all zones with the greatest occurrence in western Washington, though recently it has been increasingly used in eastern Washington as well. The goal of PCT is to space the remaining trees to achieve increased growth. Emphasis is placed on spacing with acceptable species and rarely are any species, other than hardwoods, directly selected against; and even hardwoods are no longer undesireable in the stand as long as they are not in a position to overtop or crowd the desired conifers. Composition change by PCT is reported to be less than ten percent, and by itself, pre-commercial thinning is not expected to cause a permanent change in species composition.

Commercial thinning has the goal of controlling stocking with an emphasis on increasing growth on the residual trees. Additionally, there is the goal of receiving a positive economic return from the trees harvested. The need to remove marketable quantities of any species favors minor species in the stand, as often there are insufficient quantities of minor species to remove in the merchantable size range (Worthington and Staebler 1961). No long-term effect on composition is envisioned from commercial thinning.

Partial cutting has the greatest potential for causing a cumulative effect of any harvesting method; particularly in eastern Washington. Most species are seral in one or more of the major zones in which they occur, western larch and western white pine occur only as seral species. In stands of mixed species, harvesting favors the more tolerant species and has the potential for eliminating the seral species from the stand. The rate of change will be dependant upon the species mix present and the level of harvest applied to each species (Seidel and Cochran 1981, Barrett 1979, Barber 1979, 1978, Franklin and DeBell 1972). During the four year period between 1977 and 1980 approximately 90 percent of the Forest Practice Applications in eastern Washington listed partial cutting as the method of harvest, with over 95 percent of the acres (approximately 175,000 acres annually) partial cut (Bucknell 1981). Although data are not available to document in which forest types the harvesting occurred, it is apparent that the trend is toward the reduction of seral species such as western larch and lodgepole pine, and toward an increase in the climax species such as white fir, grand fir, and mountain hemlock. The impacts of such changes include a reduction of grasses and annual forbs and an increase in shrubs (Seidel and Cochran 1981), leading to a reduction in the habitat for grazing animals, and an increase in the habitat for browsers. Also, the build-up of residue occurring under these climax types is greater than under their more seral counterparts, resulting in an increase in fire hazard reduction costs and/or an increase in the occurence of wildfires.

Shelterwood cutting removes the overstory in two or more stages to stimulate regeneration, as well as to provide some amelioration of temperature and light reaching the ground. While shelterwood is not an ecological requirement of any species in Washington (Franklin and DeBell 1972), it serves a similar role to partial cutting, favoring climax species over seral ones, particularly in the absence of artificial regeneration. The harvest percentages in the previous paragraph include shelterwoods. The results of shelterwoods are similar in direction to partial cuts, though shelterwoods, through their more open canopy, have less influence on the understory composition than partial cuts.

Seed tree cutting takes place very little if at all and therefore we will not address it further in this report.

The effects of salvage cutting on composition will vary with the intensity of the operation. During the 4-year period, 1977-1980, cedar salvage applications averaged 130,000 acres per year, while salvage other than cedar averaged in excess of 16,500 acres per year (Bucknell 1981). Cedar salvage is generally done following clearcutting and the effects on composition, if any, would certainly be masked by the effects of the clearcutting itself. Other remaining salvage operations generally follow some natural disaster such as fire or windstorm or insect infestation, or to recover the otherwise naturally occurring mortality. When salvage follows natural disaster the effects on composition do not accrue from the harvesting itself. The same cannot be said for those salvage cuts that recover the occasional mortality. The effects of salvage operations are similar to those of partial cutting, favoring the climax species over the more seral ones (Seidel and Cochran 1981). The nature of salvage operations makes their effects limited and therefore we will not discuss them further.

Conversion is designed to achieve an immediate effect on forest composition. In western Washington thousands of acres of hardwoods have been converted to conifer production. These hardwood stands developed from early-century harvesting followed by inadequate reforestation. This reforestation was in part a result of poor site preparation, stand maintenance, and stand protection practices. One analysis of state and private lands in western Washington for the 20 year period 1955-1975 indicates conversion took place on over 180,000 acres, or about 38 percent of the total acres in brush and hardwoods (Dimock et al. 1976). An additional 375,000 acres were slated for conversion, with a planned retention of approximately 35,000 acres in hardwoods, or 7 percent of the brush and hardwood base in this study. This scale of conversion will return conifers to large expanses of western Washington forest lands, with a resultant reduction of hardwoods. Hardwoods will continue to be part of the riparian area and will occur throughout the forest despite this conversion effort. Because most hardwood conversions are reclaiming previous conifer sites, its impact on species composition is not considered a cumulative effect.

Rehabilitation returns understocked conifer or hardwood acres to full stocking through harvesting and subsequent replanting. Its impact is similar to that of conversion and no additional detail will be developed here.

Overstory removal, the final stage of shelterwood harvest, has minimal impact on the resulting species composition if adequate regeneration has occurred and the resulting regeneration is still small enough not to be damaged by the harvest operation. Delay of only a short time period in the overstory removal can result in large losses to the advanced reproduction, thereby altering the balance of conifer regeneration, or even resulting in the loss of the stand to shrubs (Seidel and Cochran 1981, Barrett 1979, Schmidt et al. 1976). The status of shelterwood overstory removals is not documented. To the extent it is properly applied, overstory removal does not result in a cumulative effect on composition.

Clearcut harvesting is the dominant method used in western Washington, and, with an increased emphasis on even-aged silviculture, its use has grown in eastern Washington as well. Applications for clearcutting comprised three-fourths of the acres proposed for harvest in western Washington between 1977 and 1980, while comprising only 5 percent of the acres in eastern Washington (Bucknell 1981).

Clearcutting, itself, has had little effect on the species composition of the forest zones in western Washington. The exceptions are primarily related to poor seed crops and high seedling mortality on the more severe sites (Franklin and DeBell 1972). Following enactment of the 1945 Forest Practices Act, it has been a requirement to achieve a specified reforestation level after clearcutting. Generally this requires the use of subsequent forest practices, and therefore we will address this topic further under COMBINED PRACTICES.

CONCLUSION: Partial cutting has the greatest effect of all timber harvests on species composition and results in a cumulative effect by changing stands of seral species to climax species.

Structure

Potentially the greatest effect in scope and intensity related to timber harvesting is that of changes in forest structure. Structure is related to species size and their spatial arrangement within the plant communities. The results of changes in structure are felt primarily by the "users" of the forest; fauna, both terrestrial and aquatic are the primary reactors to structural changes. Therefore, the environmental significance of structural change related to flora will be dealt with under FAUNA.

Four structural components are recognized in old growth systems (Franklin 1981):

1) large standing live
2) large standing dead
3) large down, dead on ground
4) large down, dead in streams

One necessarily follows from the other, with the exception of organic matter in streams which does not derive necessarily from dead trees on the ground, but rather from standing trees in the riparian area.

The size component and spatial arrangement are related both to species and age, with older trees generally being taller and having greater crown size than younger trees. Examples of the massiveness of trees common to the Pacific Northwest are shown in Figure 5-3. In addition to the impressive sizes listed, the relative sizes of various species are also exhibited. From these one may infer the structural components related to various forest zones. For example, typical heights range from 90 feet for Alaska yellow-cedar and ponderosa pine to 240 feet for Douglas-fir. Alaska yellow-cedar is a high elevation species found in the mountain hemlock zone, and ponderosa pine is an eastside species. Douglas-fir is found in all except the mountain hemlock and lodgepole pine zones, but reaches its greatest size in the western hemlock zone. Eastside trees tend to be of lesser size than westside species or their westside counterparts.

Similar comparisons may be made between the typical diameters: 30 inches for ponderosa pine and mountain hemlock, the principal species of the mountain hemlock zone, and 100 inches for western redcedar, a principal constituent of the Sitka spruce and western hemlock zones of western Washington.

The time required to reach these sizes is variable, depending upon the specific site quality, location, and species in question. An expression of the natural growth rates of various species may be obtained from yield tables (McArdle 1930, Meyer 1938, Barnes 1962). These tables illustrate relative diameters over time. One can readily infer the lack of very large trees when

Figure 5-3. Typical and maximum ages and dimensions attained by selected tree species on better sites in the Pacific Northwest.

TREE SPECIES	TYPICAL			MAXIMUM	
	Age (years)	Diameter (inches)	Height (feet)	Age (years)	Diameter (inches)
Pacific silver fir	400+	35-43	144-180	590	81
Noble fir	400+	39-59	148-224	500+	106
Port-Orford-cedar	500+	47-71	196		141
Alaska yellow-cedar	1000+	39-59	98-131	3500	116
Western larch	700+	55	164	915	92
Incense cedar	500+	35-47	148	542+	144
Engelmann spruce	400+	39+	148-224	500+	91
Sitka spruce	500+	71-91	230-246	750+	207
Sugar pine	400+	39-49	144-180		121
Western white pine	400+	43	196	615	78
Ponderosa pine	600+	30-49	98-164	726	105
Douglas-fir	750+	59-87	230-262	1200	171
Western redcedar	1000+	30-118	196	1200+	248
Western hemlock	400+	35-47	164-213	500+	102
Mountain hemlock	400+	30-39	115+	800+	87

operating with a shortened rotation length.

Yield tables for managed stands illustrate tree sizes which can be expected to develop during a rotation (Curtis et al. 1982, Cochran 1979a,b, Chambers and Wilson 1978, 1972, Schmidt et al. 1976, Hoyer 1975 - Figure 5-4), and again, it is obvious that the sizes developed during conventional rotations are substantially smaller than in old growth forests.

CONCLUSION: Rotation lengths currently practiced preclude the development of large live trees and subsequent dead structural components of the old growth system. This changes the horizontal and vertical structure of the canopy reducing canopy layers to one dominant layer. These results are persistent cumulative effects.

FOREST ROADS

Construction and use of forest roads result in obvious changes to the forest. Their existence directly affects earth, water, and flora while indirectly affecting fauna (ignoring road kills). Many of the effects of forest roads are related to their construction, while others are only related to maintenance and use. Where possible, we make this distinction.

The permanent forest road system when completed will occupy about 8-10 percent of our forested lands (Froehlich 1978). How close the system is to completion is unknown, but the general consensus is that many miles of road remain to be constructed. Also, some believe that because of continued reconstruction, road building activities will never end and may not even decline.

Lands occupied by roads are essentially removed from the forest land base. They are maintained bare of soil and most flora and fauna species. As the road system is expanded there is one obvious cumulative effect, the removal of the soil and its related resources from use by forests and their wildlife. The discussion of direct cumulative effects related to forest roads does not address this issue further. The importance of an 8-10 percent reduction in forests and related habitat was not explored.

We consider roads a type of land conversion. Our interests are in effects of roads on EARTH and WATER. Roads affect frequency, rates, and quantities of surface erosion and mass failure. Roads also disrupt the natural drainage of water and affect water quality via the erosion process. These are the issues we discuss.

EARTH

Accelerated erosion is the greatest effect that roads have on the earth component of the environment. Although the removal of soil from the right-of-way during construction results in a long-term reduction in soil available for timber production, we do not discuss this change or any other effect of roads on forest soils. For the most part, roads permanently reduce the forest land base, and the cumulative reduction in the total available soil resource with each mile of new road is obvious.

Figure 5-4. Typical characteristics for Douglas-fir at age 60 years under various natural conditions and silvicultural treatments.

Treatment	Height(ft)	Dia.(in.)
Natural regeneration-no subsequent treatment	92	11
Planting 400 trees per acre-no subsequent treatment	95	13
Planting 300 trees per acre-no subsequent treatment	96	14
Natural-precommercially thinned to 400 trees per acre	96	13
Natural-precommercially thinned to 300 trees per acre	97	14
Natural-commercially thinned	92	11
Planting 400 trees per acre with commercial thinning	97	14
Planting 300 trees per acre with commercial thinning	99	15
Natural-precommercially thinned to 400, commercial thin	98	14
Natural-precommercially thinned to 300, commercial thin	100	17
Natural-precommercially thinned to 300, fertilized	100	15
Natural-precommercially thinned to 300, commercially thinned with multiple application of fertilizer	107	20

Erosion

Forest roads (especially unpaved logging roads) present considerable erosion potential. Road surfaces, cut-banks, ditches, and sidecast fills often remain exposed for long periods of time. Erosion from forest roads is divided into two categories, surface erosion and mass movement.

* Surface Erosion

Surface erosion results from construction, use, and maintenance of forest roads. The potential for erosion within any given area increases with the miles of road involved. Though dry ravel and rainsplash erosion are important processes on cut-banks, especially where needle ice helps prepare sediment for movement, probably the most important process involved in surface erosion is sheetwash of the road surface. Reid (1981) found that sediment production increased 3.4 and 4.9 times as a result of logging roads on two basins on the Olympic Peninsula; 19 percent and 28 percent of the sediment was derived from road surfaces (58-59 percent was from road-related landslides, which are discussed later). Roads increased production of fine sediment (2 mm and less) by 4.5 and 7.2 times, with 43 percent and 49 percent contributed by road surfaces. In both cases, only a few percent were contributed by cut-banks and sidecast fills.

The potential for erosion of the road surface is greatest for roads undergoing heavy use during rainfall (Wooldridge 1979a, Wooldridge and Larson 1978). The grinding of the road surface by traffic, even during dry weather, produces fine sediments which are transported off the road surface by rainfall. Sediment concentrations of road runoff may be 15 to 100 times greater from heavily used roads than from lightly used gravel roads or paved roads (Reid 1981, Wald 1975).

This loss of surfacing material from the road is an economic rather than an environmental concern. However, sediment beginning as road erosion can enter stream systems affecting water-related resources. Despite the fact that mass movement accounts for most of the road-related erosion, road-surface erosion may be a problem of longer duration on a given site. Landslides from roads may decrease in time as construction techniques improve, as the road system is completed, and as unstable areas fail (Reid 1981). As long as the roads remain active, however, they will continue to produce sediment. The quantities of sediment involved are not large when compared to that produced during construction, or even when compared to the natural variation in suspended sediment concentrations. Nevertheless, the potential is high for a persistent increase in sediment made available for transport by streams, especially where roads are not adequately maintained. Because the real issue of interest here occurs after the sediment leaves the road surface and enters the drainage or stream system, discussion of the effects of road erosion will be continued in the section dealing with water quality.

CONCLUSION: Accelerated surface erosion from new construction will continue until the permanent road network is fully developed. Even with the best construction techniques bare soil will continue to erode. Once the permanent road system is complete, use of unpaved roads by trucks and maintenance by graders, etc. will cause erosion of the road surfaces. Within the forseeable future, surface erosion from forest roads will continue as a cumulative effect. The amount of future surface erosion will reflect, to a great extent, how well roads are maintained.

* Mass Movement

Where terrain is steep and soils unstable, mass failures related to forest roads are an important type of erosion. Road failures are largely a result of improper location, sidecasting and addition of road fill, inadequate or poorly designed road drainage, and over-steepened back slopes (Burroughs et al. 1973, Larse 1971). Road construction in steep mountainous areas results in increased cut and fill slope gradients with a concomitant increase in debris avalanche potential. Excavation for roads and landings, compaction, changes in surface drainage patterns, and changes in soil moisture can alter the soil hydrology enough to allow more frequent and/or intense episodes of soil saturation, which are usually the triggers for debris avalanches. While increased sediment from surface erosion may occur over long periods of time, mass soil movements add large quantities of soil, rock, and organic debris to the stream very quickly.

Debris avalanches from roads have been identified as the most serious erosion process contributing to reduced water quality on forest lands (EPA 1975). Roads were found to be associated with 30 times as many avalanches as took place in undisturbed terrain in western Oregon (Swanson and Dyrness 1975). Fredriksen (1970) reported that periodic debris torrents from logging roads increased annual sediment losses by 100 times those observed from an undisturbed watershed. Dyrness (1967c), in the Cascades of Oregon, found that slumps and earthflows caused by fill failures, cut-bank failures, and failures due to road drainage were the most frequently occurring events during a period of high landslide activity in the winter of 1964-1965. Fill failures constituted the greatest single source. Megahan (1967) reported that 90 percent of the soil mass movements, occurring along the South Fork of the Salmon River in Idaho during a storm in April 1965 resulted from soil failures along the road right of way.

The association of roads with debris avalanches is not specifically related to the construction phase or to road use, but rather to the fact that roads exist. Once constructed, both the soil and bedrock structure and the hydrologic properties in the vicinity of roads are permanently altered. Unlike failures within harvest units, the potential for debris avalanches from roads does not appear to decline with time except as the more susceptible areas fail.

CONCLUSION: Accelerated erosion from mass movement of the forest road system, principally by debris avalanches, is a persistent cumulative effect. The potential for failure, although highly related to bedrock, soil type, road location, and quality of construction, does not appear to decline with time. Additional roading or re-construction will maintain or increase overall instability.

WATER

Major effects of forest roads on water are rerouting, which alters the timing and volume of runoff, and the exposure of large areas of soil to erosion leading to accelerated stream sedimentation. The magnitude of these effects is a function of road gradient, topography, and soil and bedrock type.

Water Quantity

Forest roads are constructed by cutting into the hillslope. They may be completely (full-bench) or only partially cut into the hill with the remaining road width developed by fill. In either case, the inside road edge is cut through the soil into subsoil and often into bedrock. An additional depth of cut is usual for an inside ditch. Outsloped roads without ditches are uncommon. Of course, this is not the case where lands are flat or roads are kept to ridge tops, but these are not the most common locations in upland forested watersheds.

Road drainage ditches follow the gradient of the road and lead either to cross-culverts forming new channels (dry except during rainfall), or to 1st and 2nd order streams. These ditches and their associated roads intercept the subsurface flow of water and rapidly route it to surface channels. Ditches also cut across small channels that carry water only during storms, in effect capturing their upslope drainage areas. Often this rerouting of both surface and subsurface water increases the watershed area of the tributary receiving the ditch runoff. This affects both the quantity and timing of storm runoff from these 1st and 2nd order watersheds. Peak flow from a 2nd order watershed increased 50 percent in the fall and 21 percent in winter following road construction in western Oregon (Krygier and Harr 1972).

The interruption of subsurface flow is least serious with ridgetop and valley bottom roads. Ridge roads have little if any watershed area above them and water intercepted by valley roads has little distance left to travel before entering the main channel, thus rerouting is slight. Potentially, the greatest rerouting of water occurs on midslope roads and roads climbing from valley to ridge. It is not uncommon for a road to traverse one side of a watershed, curve around the headwaters, and continue along the other side. Such roads will effectively separate subsurface flow of the upper watershed from the lower basin.

A fully developed road network necessary to implement forest practices increases the surface drainage density of a watershed (Chamberlin 1982, Harr et al. 1979, Hsieh 1970). The additional surface channelling shortens the time necessary for water to reach the outlet of a stream. Decreasing runoff time generally leads to an increase in peak flows. How much the drainage density is increased and what effects this has on peak storm runoff depend, in part, on the density of roads per area of watershed.

An often-quoted study in Oregon found a measurable change in peak flow from a small watershed only after at least 12 percent of the area was converted to roads (Harr et al. 1979, Harr et al. 1975, Hsieh 1970). No change in total water volume was found and changes in peak flow were not detectable when only 3-4 percent of the area was in roads.

Probably of greater importance than the amount of road is its location within the watershed and the number and placement of culverts. We believe that peak flows will usually increase from 1st order tributaries directly receiving ditch runoff; if not from upland soil water capture, then at least from rapid drainage of the impervious road surface. We also expect that the magnitude of change declines as the size of stream increases. Whether increased peak flows in 1st and 2nd order watersheds combine to increase peak flows in 3rd order and larger basins is another question.

The storm peak of the mainstem of a river results from the convergence, often synchronized, of flows from its many sub-basins (Bethlahmy 1974). Whether the timing of this convergence is changed as a result of roads depends on the size of the parent watershed, its steepness, the road pattern, and the design of the road drainage system. Synchronization usually requires uniform precipitation over much of the watershed. The watershed size receiving relatively uniform rainfall differs between western and eastern Washington. Large Pacific storm systems commonly cover several hundred square miles of western Washington with long-duration, moderate-intensity rainfall. This results in tributaries of 3rd, 4th, and even 5th order rivers peaking at about the same time. In eastern Washington where storms are more localized, smaller areas are generally affected by individual storms.

Desynchronization is possible where tributaries draining roaded areas join with tributaries draining unroaded areas or with tributaries not receiving precipitation. Earlier peaking of stormflow from the roaded sub-basin than from the unroaded sub-basin can cause a lower peak flow in the downstream reach. However, because few 3rd-5th order watersheds in Washington are presently unroaded, we believe it is the exception rather than the rule for most basins.

CONCLUSION: The cumulative effect of a road system covering about 10 percent of the watershed area, is an increase in peak fall and winter streamflow in 1st-4th order watersheds. Increased peak flow will be proportionally less as the size of watershed increases, and the magnitude of increase will depend greatly on the amount of road located in hydrologically sensitive areas. Because roads primarily reroute surface water, their effect of increasing peak flows should be similar during a wet mantle flood and during a normal winter storm.

Water Quality

The increase in sediment concentrations (and deposition of this sediment) is the only important effect of forest roads on water quality. Suspended sediment is generally considered the most significant pollutant in forest streams (Brown 1973, EPA 1973, Brown and Krygier 1971, Krygier and Hall 1971, Haupt and Kidd 1965). Road construction, maintenance, and use have been labeled as the primary source of accelerated erosion and sedimentation caused by forest practices (Swanston and Dyrness 1973, Brown and Krygier 1971, Fredriksen 1970, Packer 1967). A report on forest management in the Bull Run watershed near Portland indicates that on the basis of regional statistics, 70 percent of the sedimentation in streams resulted from road construction rather than logging (Frewing Committee Report 1973).

Sediment is produced from forest roads by two processes, surface erosion and mass movement. While mass failure probably delivers the most sediment to stream channels, we have not separated the water quality impacts from these two processes in this discussion.

There are many reports that road construction results in increased sediment concentrations in streams. Studies in Washington, Oregon, California, and Idaho have all found varying magnitudes of increased sediment yield from newly roaded basins, either during or immediately after road construction (Wooldridge 1979a,b, Rice et al. 1979, Krammes and Burns 1973, Megahan and Kidd 1972a,b, Brown and Krygier 1971, Fredriksen 1970, 1965). The magnitude of increase depended on specific site and climatic factors but was usually several to many times greater than undisturbed levels. Fredriksen (1970), reporting on 1.65 miles of road construction in a steep 250-acre watershed in the Oregon Cascades, found that storms occurring immediately after construction caused the stream to carry 250 times more sediment than in a nearby undisturbed watershed. A similar study in the Coast Range of Oregon reported surface erosion rates during the first year following road construction double those expected without roads (Brown and Krygier 1971).

Large increases in sediment yield following construction are relatively short lived, however. Megahan and Kidd (1972a,b) estimated that approximately 85 percent of all sediment produced for several years following construction of new roads occurred during the first year. Most of this sediment is produced by rainsplash and sheetwash erosion of bare soil (Wooldridge and Larson 1978).

Sediment from new roads decreases as the road ages and compacts, and as the non-running surface revegetates. If the roads were abandoned at this point revegetation would most likely stabilize the surface within a relatively short time, and surface erosion would return to pre-disturbance levels. Thus, the impacts of road construction on water quality would be direct, but not cumulative, as long as road construction is not continuous within the watershed.

Forest roads, however, are built to be used, primarily for hauling forest products and secondarily for management and recreation access. Many roads, particularly mainline roads, receive considerable use the year around. Additionally, they are generally maintained with the running surface and ditch lines free of vegetation. Although maintenance practices (including proper grading, surface gravelling, and ditching) are designed to reduce erosion of the road surface, continued road use produces sediment and prevents suspended sediment concentrations from ever returning to pre-disturbance levels in nearby streams. Fredriksen (1970) found that suspended sediment levels in streams due to roads and skid trails remained about five times pre-disturbance levels for over 11 years without landslides. Wald (1975) reported that re-surfacing and grading increased ditchline suspended sediment 3.6 times during rainfall immediately after grading, and that heavy truck traffic increased it 13 times over an unused road.

The permanency of the forest road system raises the concern that as long as the roads remain active they will continue to be a source of sediment in streams (Reid 1981, Megahan 1981). Sediment yields from old roads have been reported as greater than from undisturbed basins (Megahan 1975, 1974). On the Olympic Peninsula, Reid (1981) found that road segments used by more than 16 trucks per day contribute 130 times as much sediment as roads not subject to truck traffic, and 1000 times as much as abandoned roads. Paved roads decreased the quantity of sediment reaching streams through road culverts by a factor of 240. Reid (1981) also concluded that in comparison to road surface erosion, cut-bank erosion is insignificant if roads are in use. Although these are site specific values, truck use of the study roads increased annual sediment production 3-5 times.

Sustained low concentrations of suspended sediment are a conspicuous impact of hauling on forest roads and result from surface erosion even during low-intensity rainfall (Wooldridge 1979a). Suspended sediment concentrations in tributary streams draining forest roads remain at low levels during rainless periods, even with moderate to intense rain but no truck traffic. However, truck traffic during periods of rainfall causes rapid increases in sediment concentrations.

Obviously it takes water to move the sediment from the road surface to the stream and the resultant impact on water quality will be considerably less in the drier areas of eastern Washington and greatest in wetter areas, such as the Olympic Peninsula. Generation of dust from forest roads during rainless periods may affect water quality, but this has not been documented, nor do we believe it is of serious consequence; it is not considered further.

While acknowledging that suspended sediment may increase in 1st and 2nd order tributary streams following road construction or use, it is uncertain what effect this has on larger streams. A study of the Middle Fork Santiam River in western Oregon found no measurable increase in suspended sediment concentration during 9 years of road construction and logging (Sullivan 1983). Over this period, 100 miles of road were constructed and 1400 acres of old growth forest were harvested. The study was admittedly "insensitive to lower magnitude but undoubtedly more persistent increases in sediment from sources such as gravel road surfaces".

In summary, new construction or truck hauling on unpaved forest roads produces suspended sediment during rainfall, which subsequently increases sediment concentrations in nearby streams. Sediment is primarily contributed by active haul roads, but even infrequently used roads are compacted, have low infiltration, and are susceptible to sheet and rill erosion, and mass failure.

As an access road is constructed, an individual harvest unit logged, and timber hauled away, suspended sediment increases for a short time (in response to rainfall) in adjacent 1st and 2nd order streams. These increases are transferred downstream to the parent stream. When the activity is complete, sediment concentrations decline within a few years but continued surface erosion from maintenance, management, or recreation traffic may preclude a complete return to baseline levels. On 3-5th order watersheds, as activity shifts to another part of the basin other small tributaries are affected. Effects on individual 1st and 2nd order tributaries may be minor and short-lived but the parent stream is repeatedly (seasonally) receiving a higher quantity of sediment. The increase is not constant but varies with the general level of activity in the basin. As long as construction or truck hauling continues somewhere in the basin a cumulative effect on sediment within the main stream will result. The magnitude of the change depends on the watershed's size and the intensity of logging activity. Increases will be greatest in 1st and 2nd order streams but only transient in duration, while changes in 3-5th order parent streams will be smaller but persistent. Considering the move toward intensive management and shorter rotations, we believe changes in 3rd order and larger watersheds are both perceptible and measurable.

CONCLUSION: Construction, use, and maintenance of forest roads repeatedly increase suspended sediment concentrations in the various 1st and 2nd order tributaries receiving ditch drainage. Increases are greatest where roads are new or in active use. The combined effect of these increases distributed in both space and time over a larger 3-5th order watershed is a persistent increase in average sediment concentrations, or associated sedimentation, within the mainstem. We consider this a potential cumulative effect of forest roads. Whether sediment increases are measurable at any given point in time depends upon the quality of the road system and the level of forest practice activity within the watershed.

SITE PREPARATION

Site preparation includes the use of mechanical scarification and herbicides as well as prescribed burning. However, our discussion is primarily limited to burning. While mechanical chopping or scarification may disturb soils in the same manner as harvest, these practices are not as common as burning and literature pertinent to Washington was not found on the subject. Also, we do not believe scarification would normally be repeated on the same site or be widespread within a given area (watershed). If this is incorrect, potential cumulative effects on soil and water could be similar to those of intense tractor logging. In any case, we concentrate here on fire.

Fire is a natural process and most of the major ecosystems in Washington reflect the effects of fire. Wildfires cause drastic changes to the forest, altering air and water quality, soil properties, and changing floral composition. These changes, however, do not necessarily cause permanent changes to the ecosystem. Many conifer species have evolved under, and are adapted to periodic wildfire and in some cases benefit from its occurrence (Mueggler 1976). Thus, as realized by most natural resource managers, fire is not necessarily bad.

While suppressing wildfires, forest managers have introduced prescribed burning for site preparation and fire hazard reduction. In some ways, this burning may substitute for natural wildfires, at least that is one of the goals of its use. We are interested in whether changes to the environment caused by prescribed burning differ from changes following natural wildfire. Many environmental changes follow prescribed burning but if they mimic the effects of wildfire they are not of interest here.

In addressing this question we had to develop a rudimentary understanding of 1) the acreage and location presently burned by prescribed fire compared with previous wildfire, 2) changes to the frequency of fire occurrence, and 3) differences between effects of prescribed burning and wildfire. These topics were beyond the simple "Effects of Fire" presented in the majority of the research literature, and available information allows us only to propose an appropriate level of concern.

Because of the natural prevalence of wildfires in eastern Washington and the relatively small area of state and private ownership burned annually, our discussion focuses on western Washington. Also since pile burning is limited in western Washington (Carnine 1982), impacts considered are primarily related to broadcast burning.

Wild and prescribed fires in western Washington currently burn about the same acreage as prehistoric wildfires (50,000 acres/year - Fahnestock and Agee 1983). However, different lands are being burned. The commercial forest land base has been reduced by various conversions to only two-thirds of the original forest lands and burning is now confined to this smaller area. Burning the same number of acres over a one-third smaller landbase also reduces by one-third the average interval between fires on a given site. Whether this average is arrived at by combining frequent burning of some sites and infrequent burning of others is unknown. This increased burning frequency on commercial forest lands is balanced somewhat by a decrease in the tons/acre of residue burned. Prehistoric wildfires burned about 44 tons/acre while current burning consumes only 33 tons/acre (Fahnestock and Agee 1983). Thus, the same number of acres are being burned at a one-third greater frequency but with a 22 percent lower fuel consumption rate per acre.

Other differences between prescribed fire and wildfire also exist. Prescribed burning is carried out over a longer burning period than were wildfires. Lightning was probably the principal cause of fire prior to Euro-American settlement and fires were restricted to the drier parts of summer. Lightning fires were also unevenly distributed over the landscape, most often occurring at higher elevations while prescribed burning follows a pattern set by land use (Burke 1979). Additionally, the amount of annual burning is more stable than random pre-settlement wildfires when dry years of extensive burning were separated by longer wet periods with little or no burning.

Our interest in this information is in determining whether prescribed burning greatly changes the frequency of fire on an individual site. We have not been able to completely answer this question. We question whether burning will follow harvest at the end of each young growth rotation. Slash burning is used most often after harvest of old growth timber with its high quantities of residue. Young growth forests have substantially less residue than forests with large amounts of old growth. It is unlikely that all such sites will be burned at the end of every future rotation, and when burned, lower residue levels should result in less intense burns. We believe younger forests, lower mortality, and increased utilization indicate a downward trend in the amount of slash burned. This will result in an average fire frequency in western Washington of several rotations. The frequency of fire in eastern Washington also does not appear to be accelerated. If anything, many areas are burned less frequently than under a wildfire regime.

Inherently, there are few differences between wildfire and prescribed fire. The environmental effects that result are more related to climatic and site conditions during the burn than the type of fire. Specific effects attributable to a majority of slash burns cannot be found in the literature. The complexity of the forest ecosystem, when combined with varying harvest intensities and burning conditions, make conclusions difficult (Feller 1982). Effects of prescribed fire reported in the literature are highly variable, depending on fire intensity, temperature, vegetation type and amount, soil moisture, and other factors (Wells et al. 1979).

Based on this information, we cannot determine whether changes to the ecosystem from prescribed burning differ from changes following wildfire. We believe that the extent of lands currently burned coupled with future burning of decreased residue levels indicates that controlling wildfire will have a greater potential environmental effect than prescribed fire. Much of our discussion on effects of prescribed burning on AIR, EARTH, WATER, and FLORA reflects this belief.

AIR

Potential effects of forest practices on AIR are limited to air quality, specifically the production of air pollutants and their transportation off-site. Prescribed burning is a source of particulates, hydrocarbons, and carbon monoxide emissions, and may contribute to temporary violations of health-related air quality standards. Combustion products, including heat, water vapor, particles, and gasses, are emitted into the atmosphere from a fire and form a cloud which moves in a downwind direction (GEOMET 1978).

Within the context of cumulative effects, however, we are interested in air quality changes only if they differ from changes that occur due to natural wildfire. This includes the quantity of smoke and its persistence, the smoke's composition, and the frequency of occurrence.

Fahnestock and Agee (1983) conclude that because of wildfire suppression the annual production of smoke has decreased about 22 percent. They also suggest that although the quantity of smoke is less, the wider seasonal distribution of current burning slightly to moderately impairs visibility more often now than prehistorically. While visibility is generally considered an air quality parameter, we believe it is a social rather than environmental concern and do not discuss it further. We are concerned with any change to the quantity, frequency, and composition of smoke in large airsheds on an annual or long-term basis.

It appears that the frequency of smoke has been increased slightly while the total quantity has been reduced. Since the quantity of smoke is most important in affecting physical air quality, it is probable that air quality has improved overall. This is particularly probable if smoke from a prescribed fire has no more objectional composition than smoke from wildfire. In fact, smoke from a prescribed fire is often cleaner, and thus less degrading, than smoke from a wildfire. Sandberg et al. (1979) indicates that particulates from wildfire exceed those from prescribed fire. They believe the particulate fraction is the single most important category of smoke emissions.

Visibility is apparently the greatest concern of prescribed fire on air (Feller 1982). Hall (1972) in summarizing thermal and chemical processes, concluded that adverse effects of prescribed burning are limited to visibility. Present concern over management is to reduce incidents of visibility impairment, other air quality parameters are only temporarily degraded (Sandberg et al. 1979).

CONCLUSION: The combination of reduced wildfires and use of prescribed burning has resulted in a cumulative improvement in air quality. An exception is the frequency of visibility impairment, which has increased.

EARTH

The effects of prescribed fire on earth resources do not differ, except in magnitude, from those of timber harvest or forest roads. All three practices can disturb forest soils and cause accelerated erosion. The magnitude of change caused by fire is related to the frequency of burning and the intensity of the burn.

This discussion is predicated on the assumption that the minimum time between burning on any site is the rotation length, currently 60+ years. In addition, we believe burning each site after every rotation will not be common, the intensity of the burn will usually be less than a wildfire, and burning will decline as young growth residue replaces old growth.

Erosion

Intense burning, whether from wild or prescribed fire, increases erosion on most sites (Wells et al. 1979). Erosion following prescribed burning is related to removal of the forest floor and exposure of mineral soil, and to reductions in infiltration capacities causing overland flow (Feller 1982). Of course, the importance of slope cannot be overlooked. These are the same disturbances that contribute to erosion after timber harvest; burning simply increases their severity.

* <u>Surface Erosion</u>

Serious surface erosion requires the overland flow of water, and one effect that is caused by fire but not harvest is formation of hydrophobic (water-repellent) soils. This is most common in drier climates (Feller 1982) under hot-burning piles of residue. Broadcast burning should not induce sufficient water repellency to be of concern (DeByle 1973).

Pile and burn has a greater effect on erosion potential than does broadcast burning, probably due to combined effects of tractor disturbance and the more intense heating of soils under piles (Feller 1982). Whether following harvest or fire, re-establishing ground cover is the critical factor in reducing accelerated erosion. Regrowth occurs rapidly in most of Washington except at higher elevations.

For burning to accelerate erosion enough to cause a cumulative effect requires an intense burn. Usually, however, severely burned spots are limited to a small part of the total burn (3-8 percent - Anderson et al. 1976). Thus erosion following moderate burns will be small, not move far off-site, and decrease rapidly during the early part of the rotation. Inappropriate burning, however, especially in steep terrain, can cause excessive dry-ravel, accelerating erosion and slowing revegetation.

CONCLUSION: We believe prescribed burning will not greatly accelerate surface erosion. Some surface erosion will occur, but not to the extent necessary to cause a persistent cumulative effect. On forest lands where wildfire is controlled and prescribed burning not used, or used only lightly, erosion may even be reduced. Our major concern with prescribed burning is that if inappropriately combined with other intensive forest practices on steep or poor sites, the combined effects might be cumulative.

* Mass Movement

Fire is not an important factor in mass erosion except as it indirectly affects vegetation and the water balance (Wells et al. 1979). Probably its greatest effect is killing residual trees thus delaying the establishment of a stabilizing root sytem. This is partly offset where hand planting occurs soon after burning. Fire also affects infiltration, surface detention, and overland flow of water (Anderson et al. 1976) which indirectly may increase the potential for debris avalanches.

CONCLUSION: Fire occurs naturally and has only limited affect on slope stability when prescribed after harvest. Thus, we believe the potential for fire causing an increased frequency of debris avalanching from burning every 60 years or so is low. The potential is even lower where prescribed burning occurs less often than did natural wildfire. Our concern with prescribed fire is as an additional disturbance to vegetation on unstable sites already impacted by harvest and road construction.

Forest Soils

Burning affects most soil properties. The magnitude of change depends on the fire intensity and the amount of mineral soil exposed to heat (Wells et al. 1979). Since fire is a natural process we are interested in only those changes that would not occur from wildfire and that last longer than a few years. We do not believe that temporary changes will cause any cumulative effect on soil properties. Changes must last long enough to raise or lower current productivity, or cause a gradual decline in productivity during future rotations.

* Physical Properties

Intense fire can break down soil structure (DeBano and Rice 1971) but prescribed fires are not usually intense enough to cause serious direct effects on soil structure (Wells et al. 1979, Switzer et al. 1979). Probably the most important change is an increase in bulk density due to combustion of fine organic material incorporated in the soil (DeByle 1981) and to puddling of bare soil by raindrop impact (Switzer et al. 1979).

Fire changes physical properties in proportion to its intensity, the amount of vegetation destroyed and forest floor consumed, the area burned, and the frequency of fire occurrence. Fire intensity and frequency are the most important aspects in terms of its cumulative effects potential. Since prescribed fire intensively burns only small areas we do not believe changes to physical properties are great.

The effects of fire moderate with time as vegetation returns to the site. Recovery is slowest on poor sites at high elevations and fastest on moist sites at low elevation. Since remnant vegetation is usually well established within 3-5 years (Wright and Bailey 1982), we believe recovery of soil physical properties will occur during the rotation as long as rotations are not inappropriately shortened and fire repeated more frequently than at present. A study of soils in the western Cascade Mountains of Oregon and Washington found no effects of broadcast burning on physical properties 25 years after burning (Kraemer and Hermann 1979).

CONCLUSION: Prescribed burning, primarily broadcast burning, will probably not result in a cumulative effect on soil physical properties when applied at current frequencies of 60+ years. As young growth management continues, levels of residue and related fire intensity should decrease (as will the need for fire) and the potential for causing a cumulative effect will also decline.

* Chemical Properties

Prescribed burning affects the chemical properties of soil primarily by ashing the organic materials contained in the above ground vegetation and organic residue (Wells et al. 1979). Consumption of organic matter is proportionately greater on unproductive and submarginal forests where organic matter is not incorporated into the soil or where there is only a thin layer of organic matter over parent material. Normally, however, we do not expect fire to be prescribed on these sites.

Burning the surface organic matter decreases the forest floor, volatilizes large amounts of nitrogen and smaller amounts of other elements, and forms soluble ions (Wells et al. 1979). While most of the released nutrients remain on-site (at least initially) some, including nitrogen, sulfur, and potassium are lost in smoke and flyash (Kimmins 1977). These losses are relatively small in comparison to removals by harvest.

The consumption of organic matter and its associated nitrogen may be the most important consequence of fire (Kraemer and Hermann 1979). Subsequent rainfall dissolves readily soluble compounds in the ash and leaches them into the soil. This usually results in an increase in pH and in available phosphorus, and cations (DeByle 1980, 1976, Grier and Cole 1971). Most of the released ions are retained within the soil with only small losses (Grier and Cole 1971). Nutrient losses are, however, several times greater following slash burning than after clearcutting alone (Cole et al. 1973).

Nutrient losses are important only if they are not resupplied to the soil to meet vegetation growth needs. While nitrogen loss is probably greater than for other nutrients, available nitrogen often increases after fire due to enhanced nitrification, nitrogen fixation, and leaching of nitrogen into the soil (Feller 1982, Wells et al. 1979). Because of such reactions soil chemical changes following prescribed burning are highly variable both in kind and magnitude. There remains considerable debate whether nutrient losses following fire are important because fire usually increases the availability of nutrients.

The important questions are not whether changes in nutrient status occur, but whether they differ from changes following wildfire and how long do they persist? Consumption of the forest floor and understory vegetation by prescribed burning is usually less than that caused by wildfire because prescribed burns are usually made during periods when burning conditions are moderate (Anderson et al. 1976). Thus, intensity of fire is probably not increased but the frequency of future prescribed burning remains an unknown. As long as nutrient changes do not last longer than the interval between burns, cumulative effects will not occur. The controlling variable is the frequency of future burning.

Recovery of changes in chemical properties is rapid. Jurgensen et al. (1981) found increased ammonium and nitrification lasted only one year and any long-term depletion of soil nitrogen reserves was not apparent. Likewise, Kraemer and Hermann (1979) found no measurable difference in nutrient status of burned and unburned soil plots 25 years after burning. The potential for serious effects of burning on soil productivity appears limited to the small portion of the area that is severely burned (Wells et al. 1979). Only here do we expect the change in nutrient status to last more than a few years (Stark 1980).

CONCLUSION: Nutrient losses and shifts in soil chemical properties caused by prescribed burning will recover rapidly on most sites and not carry over to the next rotation. Thus, a cumulative effect is unlikely. But on poor sites, where harvest removals of nutrients are relatively large, slash burning and associated nutrient losses may increase the recovery time constituting a cumulative effect.

* <u>Biological Properties</u>

Burning can cause increases, decreases, or no effects on populations of microorganisms depending on fire intensity, degree of destruction of organic matter, soil temperature regimes, soil moisture during burning, and occurrence of rain after burning (Feller 1982). Intense fire affects microorganisms most, often temporarily sterilizing the soil surface (Bollen 1974). Such drastic changes are usually confined to a small proportion of the burn and recovery of directly affected populations is rapid where moisture is sufficient (Harvey et al. 1976).

Probably of greater importance than the immediate killing of organisms is the indirect effect of reducing the organic matter available for future biological activity. Severe burning can reduce organic matter as much as 75 percent, consuming surface residue that would eventually be incorporated in the soil. The impact this has on soil biology is similar to that of excessive biomass removal during harvest (see TIMBER HARVEST). The magnitude of this on-site change is related to the frequency of prescribed fire and the quantity of organic matter each fire consumes.

CONCLUSION: Whether or not prescribed fire has a cumulative effect on soil biological properties is dependent on the frequency of fire use and the intensity of the burn. As concluded earlier, we do not believe either of these aspects of fire are great enough by themselves to cause long-lasting change. Only where fire is combined with intensive biomass utilization and/or short rotations do we believe a cumulative effect is probable (see COMBINED PRACTICES). However, little is presently known about the optimum amount and kind of residue needed to maintain soil quality.

WATER

Fire has always been a natural occurrence in forests and the normal hydrologic behavior of watersheds incorporates some effects of fire (Anderson et al. 1976). Thus again, we must be careful in interpreting the changes following prescribed burning. Much depends on the frequency and intensity of prescribed fire on any site or within a watershed as a whole.

Prescribed burning causes temporary changes to the hydrologic cycle (Tiedemann et al. 1979). The cause, similar to timber harvest, is primarily the destruction of vegetation. Unlike wildfire, however, prescribed fire follows timber harvest where large fuels are removed and small fuels distributed over the site. Therefore, effects of prescribed burning on hydrology are probably much less than those of wildfire, and also less than those of timber harvest. Because of the small magnitude of on-site hydrologic change, we do not believe prescribed fire has any cumulative effect on streamflow.

Also, as concluded earlier, we believe that prescribed fire does not cause any long-term changes in either surface erosion or soil nutrient losses. Therefore we can only conclude that it also does not cumulatively affect water quality.

CONCLUSION: Repeated use of prescribed fire on an individual site at the end of a 60+ year rotation or annual burning on scattered harvest units will not, by themselves, cause a cumulative effect to either water quantity or quality.

FLORA

Site preparation is designed to achieve one or more of several purposes:

1) reduce logging slash or other debris
2) reduce vegetative competition
3) prepare a mineral seedbed
4) reduce compaction
5) create more favorable microsites on harsh sites
6) control disease

By its very design site preparation will have immediate impact on existing vegetation. These impacts include removal of the vegetation through scarification, scalping, burning of slash and residual vegetation, and killing or retarding growth with herbicides. These practices convert the site to a successional stage which favors the establishment and growth of shade-intolerant early successional tree species (Feller 1982). The degree of reversion is related to the practice used, and to some degree, its intensity. Fire has a pronounced effect on shrub production, with marked reduction of shrub occurrence following burning, while grass and forb occurrence is often similar whether burned or unburned (Wright and Bailey 1982, Dyrness 1973). The particular species occurring may vary depending on whether or not the site was burned, however (Dyrness 1973).

Physical destruction of residual forest species through soil disturbance, such as scarification or machine piling, has been noted to have a greater impact than that of prescribed fire (Wright & Bailey 1981). The extent of such practices are not well enough documented to establish relative impacts. Bucknell (1981) provides an estimate of scarification between 1977 and 1980, and the range is from less than one percent of the total acres harvested to slightly greater than two percent, and was less than 10,000 acres in any year reported. These figures do not account for machine slash piling, though. Carnine (1981, 1982) estimates pile burning at 7,600 acres in 1981 and 9,900 acres in 1982. The 1981 figure is approximately three percent of acres harvested for the same period. Nearly all prescribed burning reported for eastern Washington is pile burning, and approximately 60 percent of the total acreage of pile burning occurs in eastern Washington.

Another aspect of site preparation is the sanitation effect of removing suppressed understory or advanced regeneration already infested or subject to infestation by insect and disease. Prescribed burning to reduce the source of food for spruce beetles and to remove advanced reproduction susceptible to the Balsam woolly aphid are two examples of such activities (Wright & Bailey 1982). Dwarf mistletoe is similarly controlled through the application of prescribed broadcast burning (Baranyay and Smith 1972). Such sanitation will not solve all insect and disease problems, however, because such organisms as *Phellinus* (*Poria*) *weirii* and *Armillaria mellea* are not substantially reduced by prescribed burning. Direct control is required usually by some other method such as stump removal (Wallis 1976).

For site preparation impacts to reach cumulative effect proportion with respect to flora they must change species composition or structure of the site for a period longer than a rotation. There is evidence to support a change in the rate of successional development, and even apparent absence of the shrub stage following prescribed burning (Dyrness 1973), but this does not arise from the absence of the shrub species themselves, only the loss of their period of dominance.

CONCLUSION: We conclude that site preparation, alone, does not result in a cumulative effect on flora; rather, it is through combined effects or through functional impacts measured on terrestrial fauna that a cumulative effect may be evident.

REFORESTATION

Reforestation is usually separated into natural or artificial regeneration. Natural regeneration of conifers in the Pacific Northwest is obtained from three sources (Roe et al. 1970):

1) seedlings/saplings established under the overstory prior to harvest; referred to as advance regeneration

2) seeds stored in the soil prior to harvesting

3) seeds disseminated from residual trees following harvest, or from trees adjacent to the harvested unit

The success of natural regeneration relies upon adequate seed, a suitable seedbed, and a favorable environment for establishment and growth. A suitable seedbed and favorable micro-environment can be prepared, to some extent, by the harvest operation or subsequent site preparation activities, but adequate seed is dependent on the frequency of good seed crops. This frequency is variable, especially among species (Lavender 1978):

Species	Frequency of good seed years
Douglas-fir	infrequent
ponderosa pine	infrequent, 2-6 years
lodgepole pine	regular, 1-2 years
grand fir	regular, 2-3 years
noble fir	infrequent, some each year

Sitka spruce	regular, 2-5 years
western hemlock	regular, 3-4 years

Given the erratic nature of seed production for such species as Douglas-fir, ponderosa pine, and noble fir, it is unlikely that harvests can be scheduled to take advantage of good seed years. The failure to obtain adequate regeneration early in the century was often attributed to a combination of lack of adequate seedbed and loss of regeneration and seed source to fires.

Natural regeneration is used successfully under even-aged management regimes in the higher elevation zones of the North Cascades (Deer 1981). Success appears to depend upon the occurrence of advanced regeneration and its protection during harvest, adequate seed source either in the duff on the site, or in adjacent stands, and timely evaluation of regeneration success. Natural regeneration continues to be the primary means of reforestation under partial cut systems, and may be the only practical means in many instances (Cleary et al. 1978).

The result of poor reforestation following some early century harvesting led to the 1945 Forest Practices Act which was essentially a reforestation act. Natural regeneration was, and still is, an acceptable reforestation practice. But the requirement of achieving satisfactory regeneration in five years following harvest, coupled with an economic interest for securing prompt reforestation, particularly on the more productive sites where vegetation competition is greatest, encouraged the increased use of artificial regeneration.

Artificial regeneration is accomplished through direct seeding or planting. Success with Douglas-fir in early nursery trials, along with the greater economic value associated with it at that time resulted in most plantations being stocked with Douglas-fir. Aerial seeding trials began in the late thirties (Goodyear 1941). These early trials met with limited success. Seed eating animals and birds often were the primary contributors to failure. Development of various chemicals for seed protection, such as endrin and tetramine, enhanced the success of aerial seeding. The use of aerial seeding grew throughout the sixties as a potential means of reforesting at a low cost. Decline of its use occurred as result of erratic performance, inefficient use of seed (often one established seedling per 100 seeds sown) and the susceptibility of new seedlings to environmental stress (Cleary et al. 1978).

Planting of bare root seedlings is the principal artificial reforestation practice. Recently this has been partially replaced by container plantings. Several species, notably hemlock and some true firs, were difficult to grow and plant successfully as bare root stock. Additionally, the time required to produce seedlings can be reduced through use of containerized seedlings. Virtually all important timber producing species in the Northwest have been successfully raised in containers (Cleary et al. 1978).

Reforestation practices primarily affect the flora component of the environment. Although choice of species to regenerate may have some future affect on forest soils or water, we have ignored these potentials and restrict further discussion to FLORA.

FLORA

Reforestation has a direct effect upon the floral component of the ecosystem. For changes associated with regeneration to be cumulative they must either persist from one reforestation period to the next on a particular site, or the changes must interact among various reforestaton efforts across the landscape. Recovery necessary to eliminate the potential for either type of cumulative effect is most closely related to the type of regeneration practiced. Floral characteristics most closely associated with reforestation practices are species composition and genetic variablity. Discussion of cumulative effects of reforestation has been limited to these topics.

Species Composition

The use of natural regeneration has definite implications for species composition when used with selection harvesting of seral species. Many authors have documented the changes in stand composition due to "economic highgrading" or partial cuts (Olson and Hatch 1981, Aho 1981, Seidel and Cochran 1981, Franklin and Dyrness 1973). Where a seed source for the more tolerant species exists the more tolerant species replace the seral species through successive cuttings.

Artificial regeneration has been credited with producing monocultures, or single species plantations. Evidence to support this is lacking. The interview process particularly pointed this out, as person after person described their attempts to achieve full stocking with Douglas-fir only to be confronted with mixed stands requiring stocking control. Even efforts to modify mixed stands through species preference in precommercial thinnings resulted in little or no measurable effect on species composition.

CONCLUSION: The use of natural regeneration under selection harvesting will result in a cumulative effect on species composition where selection favors shade-tolerant species. Artificial regeneration does not result in a cumulative effect on species composition.

Genetics

Of greater importance than species composition may be the impact of artificial regeneration on genetics. As recently as three decades ago the natural gene pool was essentially intact (Silèn 1976). The Seed Certification program is one attempt to provide a match between seed source and planting sites. A definition of "local" seed source is difficult to impose as evidenced by Ching's (1978) description of the Oregon coast range, where extreme north to south differences are exhibited but so gradually as to defy specific siting, while in the eastern Oregon the more variable climate and topography suggests defining "local source" as the same aspect, same drainage, and same elevation. Silen (1982) agrees that species adaptability may be "template like", and that moving a species to a different aspect may have detrimental effects on survival and development.

Another element of genetics is the effort to increase growth and tree form through tree improvement programs. The IFA-PNW Cooperative Tree Improvement Programs are examples. In Washington there are seven such programs involving approximately two million acres, three species of trees, and 18 cooperators, including federal, state, and private forest land owners (Wheat and Bordelon 1980). While such characteristics as survivability, growth, form, and insect and disease resistance are the principal attributes being studied, it is recognized that attempts to improve any tree characteristic by genetic selection must be done without sacrificing general adaptability (Silen 1982, Ching 1978).

CONCLUSION: The potential exists for cumulative effects on trees due to genetic selection; however, documentation is lacking to prove its effect on adaptability and survival.

STAND MAINTENANCE AND PROTECTION

Stand maintenance and protection measures are designed to encourage development of desired forest stands and to insure their survival and growth. Because of this we have concentrated our discussion on flora.

FLORA

Stand maintenance and protection encompass the control of competing vegetation, growth enhancement, animal, disease and insect control, and wildfire control. The first two are related to increases in survival, growth, and timber volume. The last two are more directly related to protecting the resource than to its development, though not wholly so, as animal, disease and insect control enhance survival and growth in many instances.

Vegetation Control

Control of competing vegetation is accomplished primarily through the use of herbicides to reduce or eliminate non-coniferous vegetation. Whether the particular target is a grass or broadleaf shrub, herbicides are most commonly applied aerially. The degree of success is measured by the survival of the preferred species, the conifers, and the amount of reduced growth of the target vegetation.

Timing is critical in assessing the need for vegetation control. The juvenile growth rate of desired conifers is frequently slower than that of competing vegetation. Consequently the ability of a tree seedling to outgrow its competitors depends upon the development of both (Cleary et al. 1978). Young conifers are reported to require three to five years of unimpeded light and good moisture conditions to outgrow their competitors and achieve permanent release (Gratkowski 1975). Just as timing is critical to young conifers from the standpoint of being overtopped by competing vegetation, herbicides are most effective when used on small, young vegetation (Stewart 1978).

Timing is also important from the standpoint of achieving effectiveness on competing vegetation while avoiding damage to the conifers. Budbreak occurs on brush species earlier than such conifers as Douglas-fir and western hemlock, and permits late winter or early spring application when the brush is most susceptible and the conifers are still relatively resistant. Late summer sprays have proven more effective for release of ponderosa and other pines which are susceptible to earlier treatments (Gratkowski 1975).

The choice of herbicide depends upon the vegetation complex to be treated, with treatment keyed to the dominant species. Various studies of the effectiveness of herbicides for plantation maintenance demonstrate that total kill is not often achieved at the application rates commonly used (Minore et al. 1982, Dimock 1981, Stewart 1974a,b,c, Gratkowski 1968).

The particular conifer species also determines the amount of control needed. The higher the tolerance to shade the less control required for release. The relative shade tolerances of selected Washington conifers are (Spurr 1964):

Degree of Tolerance	Conifer species
Very tolerant	western hemlock mt. hemlock western redcedar
Tolerant	spruces, true firs
Intermediate	western white pine Douglas-fir
Intolerant	ponderosa pine lodgepole pine
Very intolerant	western larch

The objectives of releasing young conifers are to increase the light reaching seedlings in the understory and decrease competition for soil moisture and nutrients. It is not necessary to kill competing vegetation to achieve these objectives (Greaves et al. 1978).

The herbicide most commonly used for release from woody plants is 2,4-D (2,4-diclorophenoxy-acetic acid), while release from grasses is achieved with atrazine (2-chloro-4 ethylamino-6-isopropylamino-5-triazine). When control is for grasses and broadleaf forbs in combination 2,4-D and atrazine are used in combination (Greaves et al. 1978).

According to Bucknell (1981), for the period 1977 through 1980 the total acreage included in planned spraying application was approximately 412,000 acres, or slightly less than 1 percent of the non-federal commercial forest land annually.

The result of conifer release is a reduction in the growth rate of target vegetation and an increase in the rate at which conifers become established and proceed through the early successional stages toward becoming saplings. The elimination of target species is rare, thereby creating little change in species composition. The increased rate of succession speeds up the structural change which would occur in the stand.

CONCLUSION: There is no cumulative effect on either species composition or structure as a result of control of competing vegetation. The changes in structure will not persist from one rotation to another.

Fertilization

Growth enhancement is accomplished by the addition of fertilizer, most commonly nitrogen (N) in the form of urea. Other sources of N have been used as well as other nutrients such as phosphorus, and sulfur.

The purpose of fertilization is to remove one of the limiting factors for tree growth. Miller and Fight (1979) discuss the concept of growth-limiting factors and conclude that fertilization with nitrogen is a reliable means of increasing growth of Douglas-fir.

Growth response of other species to fertilization has not been studied as long, and results appear to be more variable. Webster et al. (1976) discuss the broad range of response for western hemlock fertilized with nitrogen. Their general conclusions are that coastal hemlock does not respond positively to fertilization, while inland hemlock shows a positive response. Lodgepole and ponderosa pines have also been shown to respond to fertilization (Cochran 1977, 1975). In addition to nitrogen, fertilization of pines has included the nutrients phosphorus, sulfur, and boron.

Response in volume growth peaks at three to five years following fertilization and gradually approaches zero within 8-15 years (Miller and Fight 1979, Cochran 1977). For the period 1977-1980 the acres fertilized averaged 148,000, or approximately 1.5 percent of the commercial forest land base (Bucknell 1981).

CONCLUSION: The change in tree and stand structure related to fertilization is an increase in rate of tree diameter and height development. That is, the individual tree is larger and the stand as a whole is taller. These growth characteristics accumulate during the rotation but do not persist following harvest.

Animals, Diseases, and Insects

The techniques of animal, disease and insect control vary depending upon the organism being controlled. Of interest to coniferous forests are such diseases as _Phellinus (Poria) weirii_, _Armillaria mellea_, and dwarf mistletoes (_Arceuthobium_ spp.); insects such as the mountain pine beetle (_Dendroctonus ponderosae_) and the spruce budworm (_Choristoneura occidentalis_); and a wide variety of animals.

The endemic impact of many of these pests to any particular stand may be minimal, but they often constitute serious threats to successful forest production. The controls used in the past generally have been directed at the particular pest. Greater emphasis is currently being placed upon controlling populations or stand conditions through silvicultural means which have the opportunity for both indirect and direct effects on flora.

In the case of _Armillaria_ root rot, it has become common to use mechanical means to reduce residual infection centers. The attempt to control _Armillaria_ is by uprooting stumps which serve as sources of innoculum in the soil for long periods following harvesting or death of the tree. The removal of the stumps allows reforestation with the original species, ponderosa pine for example in Klickitat county, which is otherwise susceptible to reinfection. The direct result of this control effort is the ability to maintain a preferred species. The increased level of occurrence of Armillaria is directly related to fire control and partial cutting in these stands (Barrett 1979). It is not as easy to use this same method of control for Phellinus. A suggested method for control of Phellinus is the use of an alternative species such as red alder, lodgepole or western white pine which are less susceptible to the disease (Wallis 1976). This will result in a temporary change in species composition over a portion of the stand, and will not become a persistent cumulative effect.

In the past, selective cutting and fire control have contributed to mistletoe spread (Baranyay and Smith 1972). Dwarf mistletoes are usually treated during site preparation by broadcast burning of residue and residual trees infected with the disease. Such control efforts have not been demonstrated to have an effect on species composition or stand structure, except as the reduction of dwarf mistletoe reduces the brooming effect common on diseased trees. This reduction in disease population may carry over to subsequent or adjacent stands and may therefore result in a decrease in the disease over time.

Insects have generally been controlled through the use of aerial applications of insecticides at such times as epidemic populations occur. Greater emphasis is being placed upon maintaining stands in healthier condition or at a different stage of development to avoid population buildups. Evidence has been offered supporting tree size and vigor as factors in the recent mountain pine beetle epidemics in lodgepole pine. Suggested silvicultural controls include: removing the larger trees and holding the stand at smaller tree sizes; thinning or other stocking control measures to maintain stand vigor; converting the entire stand in pure stands, or removing the susceptible component in mixed stands (Shrimpton 1982, Cole 1978, Hamel et al. 1977, Cole and Cahill 1976). Several of these changes may result in temporary or persistent changes to species composition or stand structure.

Control of animal damage has been by direct population reduction through trapping and hunting, mechanical protection of seedlings with plastic netting, and chemical methods (anti-palatives). None of these control measures has a direct effect on the flora. Habitat control to reduce population potential through reduction of understory or residue following harvest does not result in an effect on species composition or structure, as previously discussed in SITE PREPARATION.

CONCLUSION: Animal, disease and insect control results in direct effects on species composition and stand structure. Replacing susceptible species with non-susceptible species and maintaining stands in smaller size classes to reduce infection potential have persistent cumulative effects on both structure and species composition.

COMBINED PRACTICES

Thus far the discussion of direct cumulative effects has focused on repeated application of a distinct type of forest practice. Most types of forest practices, however, are implemented in conjunction with other practices. Road construction and use are usually closely associated in time and space with timber harvest, and if slash is burned it follows soon after harvest. While cumulative effects can occur from interactions of repeated harvest of an individual site or continual harvest throughout a watershed it is probably more common to have effects of roads, harvest, and slash burning, etc. combine into a cumulative effect. These interactions are probably the common direct cumulative effects envisioned by most people.

Effects from combined practices are primarily additive rather than multiplicative. Multiplicative or synergistic interactions are usually associated with indirect effects on living elements of the environment, principally fauna. The magnitude of a direct cumulative effect of several practices equals the sum of the effects of the practices if applied separately. The increased magnitude of effect, however, may greatly extend the time necessary for recovery. This leads to a cumulative effect when recovery from one practice is interrupted or set back by application of a later practice. This can occur when timber harvest is followed by burning or some other site preparation treatment. These grouped practices can increase the probability of cumulative effects.

EARTH

Here as elsewhere, we have divided earth into erosion processes and forest soil properties.

Erosion

Practices found to be most conducive to erosion are road construction and use, timber harvest (especially clearcutting), and slash burning. These activities change the hydrologic and physical properties of earth materials and thus, the balance between forces tending to promote and to resist erosion. The extent of damage in any particular place and time depends on local conditions of geology, climate, etc.

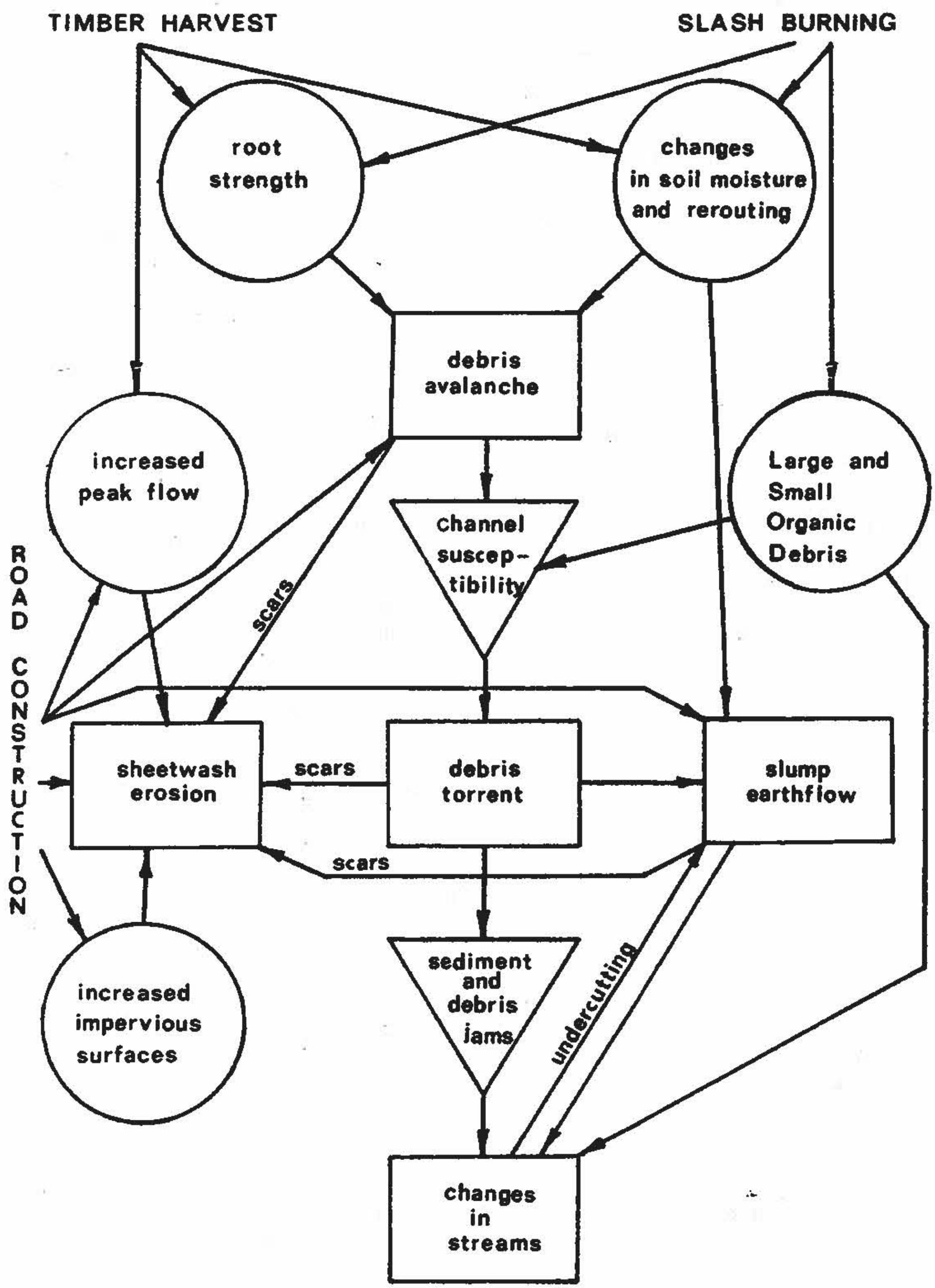
Figure 5-5 summarizes the major erosive processes active in Pacific Northwest forest lands, their interrelationships, and the forest practices that may have long-term or cumulative effects upon them. Whether or not cumulative effects result depends on the details of the linkages between processes and practices.

Past research has done much to explain the mechanics and dynamics of erosion processes, and to establish a correlation between certain forest practices and increases in the magnitude and frequency of erosion. But although these erosional processes are fairly rapid as geological processes go, they have not been studied long enough to observe the long-term (several decades) effects, let alone the "permanent" or cumulative effects. As a result, few of the studies reviewed make long-term observations or predictions and only a few speculate about permanent changes. None of the papers use the term "cumulative effects".

Examples:

1) "Major climatic events are now likely to trigger more frequently both small landslides directly attributable to land use, as well as large landslides only indirectly related to land use." (Kelsey 1982)

Figure 5-5. Summary of the interactions between forest practices, effects of forest practices (circles) and erosion processes (boxes), and transitional areas (triangles).



2) "Unless the ecosystem is consciously managed otherwise, the net effect of intensive forest management is likely to be a gradual, widespread decrease in large organic debris (LOD) in streams. The sediment-storage capacity of high-gradient, low-order portions of channel systems would decline greatly, and travel time of coarse particulate matter through such stream reaches presumably would be reduced. Reduced diversity and areas of prime aquatic habitat is also a likely result." (Swanson and Fredriksen 1982)

* Surface Erosion

Combining practices intensifies the activity level within the watershed or forest. Truck hauling, yarding, and site preparation are conducted at various locations and on different time schedules. The combined effect of forest practices on surface erosion is the sum of their individual contributions. However, even though there is little potential for either timber harvest or site preparation in themselves to result in a cumulative effect on surface erosion; when combined with road related erosion the potential for a cumulative effect is increased.

CONCLUSION: While roads are often the primary contributors to surface erosion, road construction and use combined with timber harvest, slash burning, and other harvest related activities in a watershed has a greater potential for causing a surface-erosion cumulative effect than does any single practice.

* Mass Movement

Since roads and timber harvest have already been identified as causing debris avalanches, combining these practices will also increase the probability of debris avalanches. Also, debris avalanches can cause debris torrents. While a debris avalanche can be traced to an individual harvest unit or road section, the trigger for a debris torrent can not always be easily determined. Debris torrents often result from several debris avalanches, some natural and some caused by forest practices. Thus, we discuss debris torrents under combined practices rather than under individual practices.

The effects of debris avalanches reach beyond hillslopes, because many become channellized and change into debris torrents, which are powerful agents of erosion. For example, 81-87 percent of debris avalanches became torrents in one area of the Oregon Cascades (Swanson and Lienkamper 1978), and 71 percent of the erosion caused by road-related mass movement in Reid's (1981) study came as a result of the avalanche-torrent combination. Debris torrents can also start within channels, as the result of quick movement of channel sediment and debris. Thus, the question becomes, how might forest practices increase the chances of a debris avalanche becoming a debris torrent, or of a torrent being started in the channel?

Whether or not forest practices increase the risk of debris torrents depends on how they alter the susceptibility of small channels to torrent initiation and transmission. There are many ways that the sensitivity may be increased:

1) A debris avalanche must be charged with water to become a torrent. If it does not contain enough water initially, it can get it by flowing into

a live stream. Thus, any process that increases the amount of water in the channel or the length of live channel, at a time when debris avalanches might occur, will increase the proportion of avalanches that become torrents. Timber harvest, and roads that intercept subsurface flow and direct it to surface channels, can increase peak runoff in autumn storms.

2) The ability of channel material to resist becoming part of a debris torrent depends on the interlocking strength of the channel sediment which is provided mostly by LOD and roots of streamside vegetation. Many workers have studied the effects of LOD on channel form, sediment storage, and stability. Megahan and Nowlin (1976) in central Idaho, Swanson and Lienkamper (1978) in the Oregon Cascades, and Mosley (1981) in New Zealand are some of the primary sources of information. Swanson and Lienkamper, especially, have discussed how large logs and stumps fall into stream channels, become incorporated into their beds, and thus stabilize their banks and beds, forming a stair-step profile of pools and falls that consumes energy that otherwise would have gone into erosion and sediment transport. Any reduction in LOD content, size, or stability will make it easier for an incoming debris avalanche to scour the channel, or for the channel sediment itself to begin moving quickly enough to become an erosive slurry. Forest practices that can affect LOD in these ways include:

a. Shorter rotation --> smaller trees --> smaller LOD

b. Intensive utilization --> less deadfall --> less and smaller LOD

c. Slash burning --> consumption of LOD

d. Stream cleanout

3) While LOD tends to stabilize channels, small, floatable debris seems to have the opposite effect. Small organic debris (SOD - size undefined) can enter tributary streams, form debris jams that partially or completely dam them, only to burst later. As suggested by Klock and Helvey (1976) this may be the major cause of debris torrents originating within the channel itself. The forest practices that decrease LOD will also increase SOD in the form of logging slash and debris, slash from thinning, and material broken up by fire.

4) Greater availability of erodible sediment and debris of any kind can increase the risk of debris torrents in steep channels and their ability to grow and scour once started. Forest practices can increase the amount of loose sediment in 1st order channels through ravel from bared slopes, road-cuts, sidecast, skid trails across streams, and especially road fill placed across streams. The latter can be a major source of torrent sediment, but on occasion can also stop it by damming.

The effects of forest practices upon channel stability have been stressed by several workers. Swanson and Fredriksen (1982) believe that sediment availability and changes in channel storage are far more important than changes in basin hydrology. They contend that, since annual export of sediment from a small basin is only about 5-10 percent of the volume of channel storage, even small changes in storage can cause large changes in sediment yield. These findings echo Swanson and Lienkamper's (1976) contention that forest practices, especially the change from old growth to 80-100 year old forests, is causing permanent changes in 1st-3rd order streams by changing their LOD content and stability. Part of that change will occur as generally faster throughflow of sediment by stream transport. Much of it will probably occur as more frequent debris torrents which commonly do most of the erosional work in small streams.

Several studies have estimated the time scales involved in debris torrent activity. Klock and Helvey (1976) estimated the recurrence interval of torrents in the Entiat Range (north-central Washington) from sediments and trees on alluvial fans and found that they occurred every 80-150 years, probably following wildfire (as debris torrents in 1972 followed the fire of 1970). In the northern California Coast Ranges, Kelsey (1982) estimated a recurrence interval of 300-2000 years for a single channel. The interval is about 100 years for a storm capable of generating a debris torrent in "some" basins in the region and 500 years for a storm capable of triggering torrents in "many" basins.

No one has quantified the degree to which forest practices may have altered the recurrence intervals. Kelsey (1982) states that "disturbance frequency in a basin increases as the proportion of the basin in early vegetative recovery (from logging, grazing, fire, or landsliding) increases" - but no one has yet been able to put numbers on this "disturbance frequency".

Thus, there are many ways in which forest practices can increase the susceptibility of headwater channels to debris torrents. The primary effects of an accelerated debris torrent activity include an increase in erosion of the channels themselves and an increase in sediment deposition downstream. Secondary effects include the shedding of sediment from the torrent tracks for many years and a more rapid throughflow of sediment from hillslopes to channels, as the storage capacity of the channels is severely reduced. If the time scale of debris torrent activity in undisturbed basins is on the order of one or two centuries, an increase in activity could make them frequent enough to occur at least once within each rotation preventing complete recovery. Certainly the effects can add up in higher-order channels which receive sediment from debris torrents on several tributaries, perhaps frequently enough to undergo permanent change.

Because of their density, viscosity, and inherent internal strength, debris torrents require fairly steep slopes to keep moving. Commonly the main mass of a torrent will stop when it reaches a larger stream having a flatter gradient. Therefore, debris torrents are most common on 1st and 2nd order channels, rare on 3rd and 4th order streams, and very rare on larger streams.

This does not mean, however, that debris torrents do not affect larger streams. When it stops, the torrent mass is typically fronted by a lobate tangle of logs, root-wads, and rocks, which traps a lot of muddy sediment. The total volume of the debris may be 10-100 times the volume of the initial failure (Swanston and Swanson 1976). Much of the sediment is immediately injected into the larger stream while the remainder is reworked over time. The debris jam can obstruct the flow of the parent stream or force it against the opposite side causing bank and hillslope erosion.

Kelsey (1982, 1980) studied the effects of debris torrents triggered by the 1964 storm on 1st-4th order reaches of the Upper Van Duzen and South Fork Van Duzen in northern California. Initially, 81 percent and 67 percent (respectively) of the sediment from nine torrents was deposited in headwater channels with the remainder transported downstream during the flood. The deposition caused aggradation of up to a few meters in these streams, which subsequently allowed them to flow across the fills and undercut hillslopes that had been protected by old terraces. Within two years, 75 percent of the volume of the new fills was moved downstream and continued to move as waves of sediment at speeds of 8.9 and 13.7 km/decade. As these waves progressed they caused aggradation and lateral corrasion along the valleys and triggered new slope failures by undercutting.

A major storm triggered a few debris avalanches and torrents; the torrents converged in 2nd, 3rd and 4th order channels and temporarily deposited most of their load. The sediment slugs then moved downstream about 10 km in 10 years, causing aggradation, bank erosion, undercutting of hillslopes, reactivation of old landslides, and general habitat degradation. The effects of this kind of event are (Kelsey 1982):

1) Additive: torrents from many tributary channels combine in the master channels.

2) Synergistic: large-scale mobilization of channel fills seems to occur only during storms that generate debris torrents; the effects of floods plus torrents is greater than the effects of either - undercutting, creation or reactivation of landslides downstream.

3) Long-term: sediment slugs are active for decades after the triggering event. Kelsey estimated channel recovery time at 25-100 years. New/reactivated slides can keep moving for a long time.

In the example of the Van Duzen River basin, the debris avalanches came from fairly undisturbed terrain, so these are not necessarily cumulative effects of forest practices. However, if forest practices increase the likelihood of any of the processes involved, then they can be responsible for the acceleration of some major erosional and depositional processes.

Forest practices on hillslopes are less likely to affect slump-earthflow than debris avalanches. Since the former characteristically have deeper soils they are less influenced by changes in root strength or practices that alter short-term soil hydrology. Nevertheless, slump-earthflows can be accelerated by increased water, by road drainage, or lowered transpiration following harvest. Road construction, which can undercut slopes to depths of several meters can also cause or reactivate slumping or earthflow. Upslope forest management practices that permanently change soil hydrology may affect slump-earthflow activity over a long time period. Debris torrents triggered by large storms have caused channel changes that initiated and reactivated landslides, sometimes many years after the storm, as in northern California (Kelsey 1980, 1978). When forest practices affect debris avalanche activity and susceptibility to debris torrents, they may also affect the likelihood of slump-earthflow activity on steep slopes adjacent to stream channels (inner gorges). Events in isolated parts of the headwaters can be amplified in these lower channels, which may become subject to sediment and debris deposition, channel alteration, and landsliding on a more-or-less continual basis.

CONCLUSION: In steep, geologically unstable watersheds, ongoing harvest activities combined with an extensive road network will result in a greater frequency of multiple debris avalanches and related debris torrents. We consider this a cumulative effect that is in part caused by changes to the forests hydrologic regime. (see WATER this section).

Forest Soils

Most forest practices have some effect on the soil. Harvest disturbs physical soil properties, removes organic material, alters the nutrient cycle, and changes the composition of flora and fauna. Roads remove land from tree production and change soil-water conditions in surrounding soils, especially downslope. Prescribed burning and scarification disturb the soil and redistribute organic matter over the site. Even herbicides and fertilizers can affect soil properties.

Of these forest practices, combinations of timber harvest and site preparation probably cause the greatest disruption to soil properties. Whether these disturbances evolve into cumulative effects depends on the resiliency of the specific site and the frequency with which these practices are repeated. Persistent cumulative effects occur where changes to soil properties do not recover during a rotation. Such changes will most likely affect the future distribution and growth of vegetation.

* <u>Physical Properties</u>

The primary concern with the soil's physical structure is compaction. Timber harvest, prescribed burning, scarification, etc. all cause some degree of soil compaction. Tractor logging combined with tractor thinning will cause a cumulative effect if the time between entries and the time between the last entry for thinning and final harvest does not allow for soil decompaction. This is aggravated where fire or scarification add their disturbance to that of harvest.

To document whether cumulative effects occur in fact as well as in theory requires knowledge of the natural rate of decompaction (soil recovery) which varies from site to site. Also one must know whether intensive combinations of practices are restricted to the sites where recovery is likely or also occur on more sensitive sites. Neither the recovery rate for most soils nor the intensity of forest practices applied to that soil are known in any detail. Thus we can only describe the conditions where we believe the risk of a cumulative effect is great.

CONCLUSION: We believe the combined effects of timber harvest and site preparation have the potential for causing a cumulative effect on soil compaction where the logging technique is inappropriate to the terrain, fire is prescribed when only a thin forest floor exists or the forest floor has already been extensively disturbed, and tractor thinning occurs at intervals that do not allow soil recovery.

* <u>Chemical Properties</u>

Several forest practices in combination can affect the chemical properties of soils. Effects of timber harvest and site preparation are properties of soils. Effects of timber harvest and site preparation are closely connected. In addition, maintenance of forests in young age classes (by repeated harvest) adds other effects. In all cases a concern with chemical properties is that continual application of forest practices could drain more nutrients out of the ecosystem than weathering and atmospheric input can supply. A progressive decline in the size of nutrient pools and an eventual decline in forest productivity would result. This is a serious concern on nutrient-poor sites.

Nutrient losses occur via both removal and leaching. Rather than increase these losses, particularly through leaching, maintenance of a forest as young growth may decrease them. An old growth ecosystem loses more nutrients than a rapidly growing young forest (Vitousek 1977). Compared to old growth, a young forest accumulates and returns nutrients at a faster rate and has a tight nutrient cycle. While cutting young growth forests temporarily disturbs the nutrient cycle, maintaining young growth stands may conserve nutrients over many rotations (Vitousek and Reiners 1975). The rotation length (age) necessary for this conservation to offset losses by harvest removal is unknown. Nevertheless, expected future shifts in age classes by themselves do not appear deleterious to the nutrient cycle if excessive quantities of biomass are not removed.

Forest practices where the risk of deterioration of site productivity is greatest include whole tree harvest, short rotation even-aged management, and mechanical site preparation, and particularly combinations of these. Damage is most probable on poorly buffered (pH) sites with low organic matter.

As previously concluded, we believe that conventional stem-only harvest (clearcut or selection) at rotations in excess of 60 years does not usually remove nutrients faster than they are replenished during the rotation. This includes both nutrient removal in the stem and leaching losses. We also believe that the addition of prescribed fire will not seriously extend the recovery period of the disrupted nutrient cycle. However, we identify combinations of shorter rotations and greater utilization as a concern on all but the best sites. By shorter we mean rotations less than about 60 years and by greater utilization we mean removal of anything but stemwood.

While we agree with the conclusion reached by Alban (1977) that the present knowledge of the soil's ability to provide for nutrients lost as a result of timber harvest activities is inadequate. Better information on nutrient inputs and outputs as well as on soil changes over time will be needed for many sites before broadly applicable generalizations can be made concerning the effect of timber harvesting on soil productivity. We nevertheless agree with Stone et al. (1979):

> "Results from long-term agricultural experiments of continuous cropping without nutrient replenishment suggest the likely response of forests: Wherever net annual rate of removal exceeds replacement of available nutrient pools, yields decrease, either gradually or steeply, towards a new level determined by the annual supply of the most critical element. In forests, reduced growth would be reflected in longer rotations or cutting cycles."

CONCLUSION: Short rotations and/or greater utilization of biomass represent a convergence of forestry with modern agricultural practices. Application of these practices on sites where soil nutrient levels and replacement rates do not allow recovery will result in a cumulative effect.

* Biological Properties

Changes to biological properties directly follow changes to physical and chemical properties. Where cumulative effects on physical and chemical properties occur related effects on soil biology will undoubtedly follow. Discussion of these effects would be a reiteration of previous comments. However, one change to the forest soil caused by forest practices stands out. It is the alteration in the forest floor where large logs are continually removed (or not allowed to develop). This has an effect of unknown magnitude on soil biology.

In undisturbed Douglas-fir forests the forest floor stabilizes at about 125 years (not including large logs) with litter accumulation balanced by decomposition (Long 1982). In the absence of fire large woody material accumulates indefinitely and may be three times greater in an old growth forest than in one less than 100 years in age. Thus maintenance of younger forests combined with prescribed burning or other intensive practices will change the composition of the forest floor. While the forest floor will be "in harmony" with its younger forest it will have undergone major change. Fine litter, where the majority of nutrients are concentrated, may not be greatly different, but the forest floor will most likely be thinner, undergo a more rapid turnover, and have a reduced large-log component.

We consider this change in composition of the forest floor to be a cumulative effect of continual young growth management. While the loss of low nutrient logs may have little apparent effect on the soil's ability to produce repeated generations of trees, it will reduce habitat for some soil microflora and terrestrial fauna.

CONCLUSION: A cumulative effect of timber harvest with rotations between 60-100 years and/or greater utilization is a gradual decline in the quantity of large woody material in the forest floor. This will be accelerated by prescribed burning. While the transition may be slow where large logs are already incorporated in the soil, the lack of recruitment of additional large logs makes it inevitable. This will cause long-term changes to both micro and macro species of flora and fauna. Which species will be most affected and what importance this has to the forest ecosystem is unknown.

WATER

Timber harvest and forest roads probably have the greatest affect on water of any combination of forest practices. Both practices remove vegetation and alter the flow of water through the system. In so doing they change the quantity and quality of streamflow by increasing the erosion potential.

Water Quantity

The greatest change to the hydrologic regime resulting from timber harvest and forest roads is an increase in peak streamflow during winter storm events. As concluded earlier, continual timber harvest of small 1st and 2nd order watersheds within a larger basin will cause a persistent increase in the average fall and winter stormflow peaks of the parent stream. We also stated that as the magnitude of the flood increases the effects of harvest decline and are probably small for wet mantle floods.

These comments however did not include the added effects of forest roads. We also concluded that forest roads will increase peak flows in 1st-4th order basins where they occupy over 10 percent of the land area. Roads and drainage ditches extend the channel network thus capturing and rerouting water and contributing to faster runoff. However, the added volume attributable to roads will be small when compared to the total volume of a wet mantle flood.

CONCLUSION: Timber harvest combined with forest roads (and with any other practice that tends to speed up the delivery of water to streams) will increase the size of peak flows from affected 1st-4th order watersheds. The change will be greatest for smaller storms and least for the larger storms. Hewlett (1979) reached a similar conclusion:

> "the cumulative effects of forest operations (including harvest, roads, roller chopping, and machine planting) on the Piedmont watershed (Georgia) more than doubled small stormflow volumes and peaks, but were proportionately less influentual in large flood-producing flows".

This change to the hydrologic regime will also increase the frequency of occurrence of flood flows. What was once a 10-year (or 100-year) flood will now occur, on average, slightly more often. This change to the frequency of flood peaks will accelerate erosional processes. This could include an increased frequency of debris avalanches and torrents, and acceleration of other forms of channel erosion. While these changes will likely be small, they may be important in the future.

Water Quality

Forest roads and timber harvest both accelerate erosion. This causes variable increases in suspended sediment and associated sedimentation in forest streams. Although we concluded earlier that harvest related surface erosion does not constitute a cumulative effect to either earth or water, we believe that when added to surface erosion from roads (and site preparation) a cumulative effect is probable. Also, both timber harvest and roads increase the frequency of debris avalanches and thus the erodible material in channels. The water quality degradation that results from forest practices distributed throughout a watershed is a cumulative effect, but we believe that forest roads are by far the largest single cause of this effect.

CONCLUSION: A cumulative effect of continual timber harvest, construction and use of forest roads, and other site disturbing forest practices is an increase in the sediment quantities delivered to and transported by forest streams. This results from both accelerated surface erosion and an increased frequency of debris avalanches. Sediment concentrations will be greatest (but short lived) in 1st and 2nd order streams draining recent forest practices and least (but more persistent) in the larger 3rd-5th order streams. The magnitude of this change will vary from watershed to watershed and is currently unknown for any basin in Washington.

FLORA

Here, as previously, we have divided flora into species composition and stand structure.

Composition

Virtually all forest practices have immediate individual effects on species composition. Practices found to have potential for cumulative effects included timber harvest, reforestation, and stand maintenance and protection.

Timber harvest by partial cutting in seral stands increases the opportunity for more tolerant species to gain dominance. Continued partial cutting with reliance upon natural reforestation will result in a change in species composition in such stands (Seidel and Cochran 1981, Barrett 1979, Franklin and DeBell 1972).

Harvesting to control insect damage combined with reforestation using less susceptible species will also result in a change in species composition.

CONCLUSION: The combined practices of harvesting and reforestation can result in a cumulative effect on species composition.

Structure

The result of managing young growth forests through a variety of even-aged silvicultural methods - timber harvest, artificial reforestation, stand stocking control, stand maintenance and protection is a change in stand structure. Young growth rotations preclude the development of large trees associated with old growth stands. The absence of large live trees eliminates the opportunity for large snags, and large dead and down material(Franklin 1982).

Prompt reforestation following harvest, coupled with the control of competing vegetation shortens the time span required for succession to proceed from the earliest grass-forb stage, through the shrub-seedling stage, to the pole-sapling stage. This truncation of succession combined with the elimination of the mature and old growth succession stages is a persistent cumulative effect of combined forest practices.

CONCLUSION: Even-aged, short rotation forest management will result in a persistent cumulative effect on stand structure.

5.2 INDIRECT CUMULATIVE EFFECTS

This section discusses the INDIRECT cumulative effects on flora and fauna resulting from direct cumulative effects on earth, water, and flora (discussed in section 5.1). No indirect cumulative effects of air on flora and fauna were found and are thus not discussed. Additionally, no indirect cumulative effects of earth and water were found on terrestrial fauna and flora (Figure 5-1).

FLORA

Forest practices that result in direct cumulative effects on flora can also result in indirect effects. Similarly, forest practices which are not intended to affect flora may result in indirect effects to them. Forest practices having the greatest potential for indirect effects on flora are stand maintenance and protection.

Wildfire control in eastern Washington stands subject to high fire return frequencies has resulted in changes to species composition and stand structure. In many of these stands fire was the dominant factor shaping stand development (Wright and Bailey 1982, Gruell et al. 1982, Day 1972). The frequent occurence of low intensity fires reduced the grass and shrub layers, and eliminated or retarded the development of less fire resistant species. This is particularly evident in ponderosa pine and western larch stands. The successful application of fire prevention and suppression in these stands caused an increase in understory development and invasion by shade tolerant species such as grand fir (Dell 1977).

In addition to changing the species composition these invading species frequently develop longer crowns which result in a "laddering" of fuels, previously absent (Wright and Bailey 1982). With this change in structure comes a buildup of higher fuel levels. These higher fuel levels contribute to an increased fire intensity when fires do occur. The result is the replacement of low intensity fires with higher intensity, potentially catastrophic, fires.

Fire exclusion has also been attributed with increasing the risk of insect and disease infestations (Shrimpton 1982, Cole 1978, Baranyay and Smith 1972). The outbreaks of the Douglas-fir tussock moth (*Orgyia pseudotsugata*) and the mountain pine beetle (*Dendroctonus ponderosae*) are two examples of increased susceptibility to outbreaks due to fire reduction. The development of stands with a higher percentage of grand fir and Douglas-fir than existed without fire control and the increased tree size and reduced tree vigor of lodgepole pine stands are thought to create the opportunity for epidemics of these insects.

CONCLUSION: The indirect effect of fire prevention has been a change in species composition and stand structure where stands with previously high fire frequencies have been successfully protected. Continued fire prevention and control without some stand management changes will maintain these cumulative effects.

FAUNA-AQUATIC

Forest practices that cause direct cumulative effects on earth, water, and flora can in turn cause indirect effects on aquatic fauna, especially salmonids. The cumulative effect of forest practices on salmonids stems primarily from alterations in aquatic habitat. Effects of these habitat alterations are manifested through changes in the number of fish a drainage system can produce (carrying capacity) and changes in the reproductive efficiency of the stream system. These alterations can accumulate creating conditions that cause a shift in baseline levels of fish growth, survival, abundance, and species composition.

Aquatic habitat is composed of physical, chemical, and biological elements and processes. Of these, changes in water temperature, organic energy inputs, LOD, cover, and substrate composition present the greatest potential for causing indirect cumulative effects to fish.

EARTH

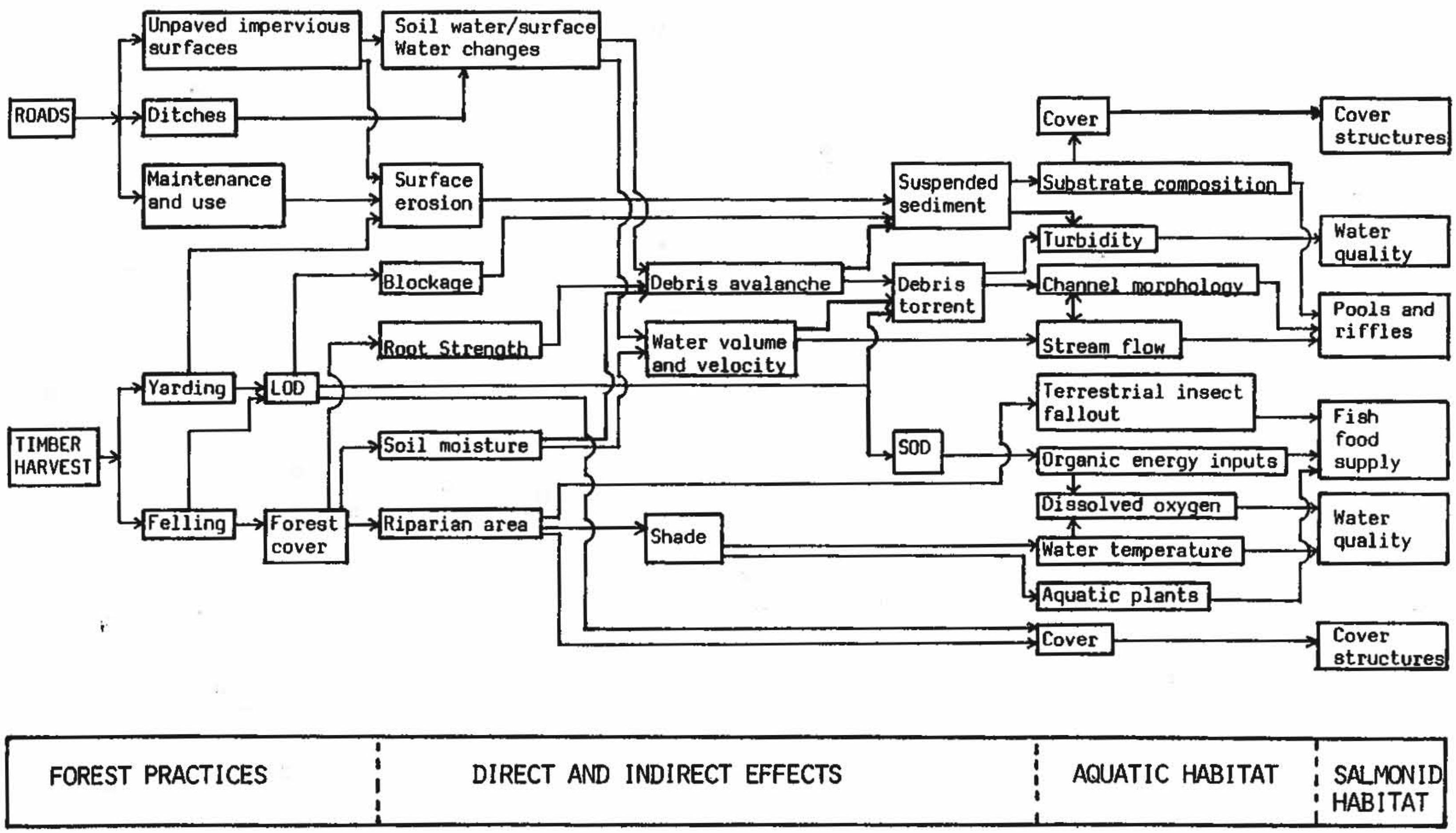
Results of erosion important to aquatic habitat consist of turbidity, substrate composition, channel morphology, and debris dams, all of which have potential for causing indirect cumulative effects to fish as a result of forest practices (Figure 5-6).

The focus of this discussion will be on debris avalanches, debris torrents, and suspended sediment. Debris avalanches and torrents cause major alterations in salmonid habitat both on-site and downstream. Debris torrents usually begin in steeper 1st and 2nd order channels and move downstream into low gradient 3rd-6th order channels where they commonly stop. The torrent track is characterized by channel scouring that removes all material down to bedrock or boulder pavement; undercutting of valley sides that stimulates erosion and additional landsliding, and a massive accumulation of sediment and organic debris at the terminus of the torrent tracks (Swanson and Lienkaemper 1978). The direct effect on fish is the complete or partial destruction of the population within the directly impacted reach, plus mortality of eggs and rearing juveniles downstream as a result of the large pulse of suspended and bedload sediment. The indirect but longer term impacts of a debris torrent often include: a barrier to fish migration, a change in spawning gravel quantity and quality, a reduction in the quantity and quality of rearing habitat, a reduction in the fish food supply, and a reduction in water quality. To balance these negative aspects, the natural frequency of debris torrents also creates rearing habitat by forming pool areas; delivers coarse inorganic and organic material; and creates habitat diversity.

The large debris pile that is deposited at the end of a torrent track is often impassable for migrating adult or juvenile salmonids. The physical size of a debris pile can be 10-100 times the volume of the initial failure (Swanston and Swanson 1976), and causes an obstruction to fish migration as a result of height or dewatering of the stream. The effects of a migration blockage on a stream's carrying capacity can vary from minor to significant depending on how long the block persists and how much stream area is cut off from the parent stock. Also, the blockage of small tributaries can have a large effect on a mainstream fish population because small streams are frequently used as refuge by juveniles during the winter freshet period (Cederholm and Scarlett 1982). Some material deposited in the next higher order stream (at the torrent terminus) can have beneficial effects by creating pool habitat. The blockages that are frequently caused by debris torrents should be distinguished from the random input of LOD from the riparian area, as the latter infrequently results in a blockage to fish migration.

The channel within a debris torrent track has a steeper gradient and greater stream velocity as a result of bed scouring and the removal of retention structures. Therefore, stream gravels are not retained, resulting in a reduction in the quantity of suitable spawning sites. Further, spawning

Figure 5-6. The relationship between timber harvest, roads, aquatic habitat and salmonid habitat.



gravel is restricted to small pockets and is of lower quality as a result of increased sedimentation. Also, the loss of retention structures causes a reduction in the sediment storage capacity of the channel and results in a greater throughflow of sediment from hillslope to channels and an increase in sediment deposition downstream. The accumulation of sediment in spawning gravels downstream reduces gravel quality and may result in a decrease in survival to emergence, and fitness of salmonid embryos and fry, respectively (Phillips 1971, McNeil 1966, Cooper 1965). Similarly an increase of sediment in spawning gravels below landslide-impacted areas is known to cause a significant reduction in the survival of incubating coho salmon (Cederholm and Salo 1979). An exception to this would be the deposition of spawning gravel in areas lacking gravel. Such would be the case in some streams damaged many years ago by splash dams.

The primary effect of a debris torrent on salmonid rearing habitat is the severe reduction in topographic heterogeneity, that is, the channelization of the stream. The scouring of the channel, removal of retention structures, and removal of sites for energy dissipation results in a channel with a steeper gradient, greater water velocity, increased area of riffle and cascade, decreased pool area and volume, larger substrate, and an absence of debris related cover structures. Rearing habitat quality and quantity within the torrent track is greatly reduced, and results in a reduction in reproduction efficiency and habitat carrying capacity (Vince Poulin pers. comm., C. Jeff Cederholm pers. comm.). The recovery of pool habitat associated with LOD will depend on the surrounding forest. If there is no forest to provide this debris, the stream may be permanently changed. Also, the change from a pool-dominated habitat to an elongated riffle-type habitat, will cause a shift in species composition and age structure of the salmonid population. Juvenile coho and older cutthroat trout decline in number, whereas underyearling steelhead and cutthroat populations increase in abundance (Bisson and Sedell, in press).

Downstream, a debris torrent causes significant alterations in channel morphology and channel destabilization that can reduce salmonid rearing habitat. For example, the accumulation of sediment downstream causes channel widening and braiding (Lyons and Beschta 1983), resulting in decreased water depth and corresponding decline in habitat quality. Heavy sediment accumulations can result in increased rates of stream channel dewatering and subsequent rearing and spawning fish loss (Vince Poulin pers. comm.). In addition, the initial slug of sediment produced by the debris torrent continues to move downstream at a slow rate causing aggradation, bank erosion, undercutting of hillslopes, reactivation of old landslides, and general habitat degradation. Consequently, the effect of a debris torrent can be a long term problem. Kelsey (1980) estimated channel recovery time at 75-100 years for the effects from a sediment slug moving through the channel in the Van Duzen River in northern California. Habitat recovery within the debris torrent track will likely require decades to a century before sufficient quantities of LOD accumulate in the channel to provide stability and structural diversity.

Lesser, but potentially important effects of a debris torrent on the aquatic ecosystem include the long-term increased yield of suspended sediment and reduction in water quality. Turbid waters can reduce the feeding capability of juvenile salmonids (Noggle 1978) or cause returning adults to avoid migration into a disturbed system (Martin et al. in prep.). The degree of effects of suspended sediment on fish can vary seasonally. Fish are least tolerant in the spring and summer and most tolerant in the fall and winter (Noggle 1978). The loss of channel stability and reduced habitat heterogeneity that affects fish populations also causes a change in the aquatic invertebrate community. If the stream can not retain organic matter and maintain a diversity of physical habitats then, biologically, it may be unable to process organic matter from the adjacent forest. Large functional and structural components of the stream ecosystem could therefore disappear (Triska et al. 1982).

In summary, an increased frequency of debris avalanches and torrents caused by forest practices can have a cumulative effect on the survival of salmonids. The occurrence of more than one disturbance in a basin can have a cumulative effect on the carrying capacity of the stream system. The effect of a disturbance on salmonid habitat causes an incremental reduction in the population during each life-history phase. Blockage of an area can cause returning adults to spawn in another location, where there is likely to be competition from other adults resulting in spawners utilizing sub-optimal areas or superimposition of another adult's redd (nest). Consequently, fewer eggs are deposited or embryos experience higher mortality during incubation. Similar population responses could also occur where the quantity of spawning gravel is reduced by a debris torrent. During incubation a further reduction in survival below undisturbed levels occurs as a result of sedimentation of the redd and/or unstable gravel environments, leading to scouring of the redds. Next, survival during summer and winter rearing is reduced further as a result of an unstable environment with limited quantities of cover for escape from predators and refuge from freshets. Finally, the accumulation of mortality at each successive life stage results in a population that is significantly smaller at time of ocean entry than if the population were produced in an undisturbed stream system. During ocean residency and during migration of the returning adults, the smaller population is likely to lose the same number of individuals to natural predation and fishing as an undisturbed population. Consequently, the proportion of the population lost is now much larger than when the population was undisturbed, resulting in fewer adult spawners returning to the natal stream. Since the efficiency for reproduction within the disturbed stream system has been reduced, the natural population will require more adults to produce an equivalent number of spawners in the next generation (Cederholm et al. 1982). Thus, unless mortality is reduced or habitat conditions are improved, the population may continue to decline and could be depressed to the point of extinction.

The occurrence of more than one disturbance in a basin could result in an accumulation of impacts that collectively will have a greater impact on fish habitat and populations than a single disturbance. Many small landslides or debris torrents in non-fish bearing streams can cause an accumulation of sediment in larger fish-bearing streams that is sufficient to reduce fish survival and hence lower the system's carrying capacity. Salmonid populations have evolved in an ecosystem where environmental disturbances occurred less frequently in time and in space and spawner escapements were very large. When forest practices increase the frequency of habitat disturbance and fish harvesting decreases spawner escapements, the effects of habitatdegradation are magnified and even small reductions in reproductive efficiency translate into large effects on the salmonid resource.

A stream that has received habitat degradation as a result of a debris torrent or landslide may never recover to pre-disturbance levels when forest management activities continue to aggravate the system. Furthermore, the incremental accumulation of effects can reach a threshold where biological responses become critical. For example, sediment inputs that exceed sediment export from the drainage will cause an accumulation of sediment in spawning grounds. Small accumulations of sediment above baseline levels can be absorbed by the system and may or may not cause a reduction in egg survival to emergence. However, when intragravel sediment concentrations reach a critical threshold (e.g., 20 percent for coho salmon in Clearwater River, Cederholm et al. 1982, Tagart 1976) the egg survival to emergence is greatly reduced.

Forest management activities that maintain sediment inputs above baseline levels will increase the risk of the system to accumulate sediment above the critical threshold. The buffering capacity of the stream to absorb sediment is reduced, thus frequent small natural or man-caused events that would likely cause minor impacts under pre-harvest management conditions are more likely to result in major effects on the fish population. A reduction in egg survival to emergence causes a reduction in the reproductive efficiency of the stream to produce salmonid fry. Consequently, if subsequent rearing habitat is not filled to capacity, then more adult spawners will be needed to generate a population equivalent to baseline levels. As long as sediment concentrations exceed threshold levels, this cumulative effect will persist.

CONCLUSION: A cumulative effect of forest road construction and use, accelerated landslides and debris torrents, and accelerated streambank degradation is an increase in fine sediments in spawning gravels. Cumulative effects of accelerated landslides and debris torrents, removal and depletion of LOD, changed drainage pattern, and accelerated sedimentation are changes in stream channel morphology and cover structures that form rearing habitat for juvenile salmonids.

A cumulative effect of past splash-dams and channel clearance for log transport, debris torrents, and management related losses of gravel retention structures (reductions of large organic debris (LOD) as a result of stream cleanout, wood salvage, and shorter stand rotations) is an increase or decrease in the quantity of spawning gravel. Increases and decreases in gravel quantity are relative to baseline conditions. In a stream that is gravel-poor an increase in gravel quantity from debris torrents may be beneficial to spawning areas. However, most streams in western Washington are gravel-rich and retention of gravel rather than supply is of greater concern.

WATER

Streamflow, temperature, dissolved oxygen, and clarity are water conditions important to aquatic habitat. Of these, we believe only water temperature has the potential for causing indirect cumulative effects to fish as a result of forest practices (Figure 5-6). Death or removal of riparian vegetation by either herbicides or clearcutting increases the potential for elevated water temperature by exposing the water surface to solar radiation and increasing heat input into the groundwater and soil heat reservoirs. Changes to streamflow, either augmented low flows or significant variations in the "flashiness" of streams, could indirectly affect fish. Low flow augmentation is potentially beneficial through the increase in living space and moderation of summer water temperatures. Flashiness may be detrimental to fish, particularly during fry emergence. However, we do not believe that these changes are large enough or last long enough to cumulatively affect the mainstem, the primary rearing habitat of a drainage.

In Chapter 5.1 we concluded that forest practices would probably not result in a persistent cumulative effect on water temperature. This does not preclude temporary increases in water temperature from causing indirect cumulative effects on aquatic fauna. If scheduling of future timber harvest on Type 4 and 5 waters (1st and 2nd order streams) results in long reaches without shade, temporary water temperature increases could affect fish production. Dispersed changes in fish productivity could result in a change in the overall watershed fish population. Overall watershed productivity could be changed through many dispersed changes in fish productivity.

The elevation of water temperatures in summer can cause positive and negative effects on fish growth depending on productivity of fish food supply. Generally, when fish populations are at capacity the individual growth rate is limited by the available food supply. Consequently, even small temperature increases will reduce food conversion efficiency and result in a lower growth rate. Alternatively, when a population is below capacity (as a result of low adult escapement or poor egg survival to emergence), a moderate increase in temperature can improve growth rate.

CONCLUSION: The direction and magnitude of the effect of an increased temperature regime on fish is difficult to predict given the stochastic nature of storm events and the population process. Nevertheless, cumulative effects do occur and the significance of this impact on stream carrying capacity needs to be investigated.

FLORA

Floral characteristics important to aquatic habitat consist of organic energy inputs, structuring of channel habitats, and cover, all of which have potential for causing indirect cumulative effects to fish as a result of forest practices (Figure 5-6).

Organic energy inputs consist of large organic debris (LOD) and small organic debris (SOD). The presence of LOD and streamside vegetation plays a major role in controlling channel morphology and the formation of cover habitat (Keller and Swanson 1979, Swanson and Lienkaemper 1978). Within channels LOD accumulations control the routing of water and sediment through the stream system, resulting in the creation of riffles, pools and protected backwater areas. Debris causes the channel to have a stepped profile that creates zones of concentrated stream turbulence (plunge pools), where potential energy is dissipated along short steep reaches rather than more uniformly along the stream (Keller and Tally 1979, Heede 1972). Therefore, much of the streambed will have gradients less than the overall gradient of the valley bottom, resulting in less erosion of bed and banks, more sediment storage in the channel, slower routing of organic detritus, and greater habitat diversity than in straight, even-gradient channels (Swanson et al. 1982).

Small organic debris consists of coarse particulate organic matter (CPOM) and fine particulate organic matter (FPOM). LOD functions as a retention structure for SOD and as a substrate for the development of aquatic invertebrates (Sedell and Triska 1977). The retention and processing of small organic matter is critical for the energy supply and production of aquatic communities in small mountain streams (Triska et al. 1982).

The distribution and abundance of stream salmonids is a function of the distribution and quality of pools, riffles, and cover habitat. Habitat quality indices that incorporate geomorphic parameters (e.g., pools and riffles), hydrologic parameters (e.g., depth and velocity), and vegetative parameters (e.g., in-stream debris and overhanging vegetation) have been closely correlated with population size (Binns and Eiserman 1979, Nickelson 1979, Wesche 1976). Therefore, when cover is removed the population of salmonids has been demonstrated to have a corresponding reduction in abundance (Lestelle 1978, Boussu 1954) and in experiments where cover habitat was added salmon abundance was increased (Ward and Staney 1979, Chapman and Bjornn 1969).

Juvenile salmonids require the structural diversity created by pools, riffles, in-stream debris, undercut banks and overhanging vegetation for rearing and resting habitat (reviews by Reiser and Bjornn 1979, Hall and Baker 1975, Giger 1973). During summer, when stream flows are low, the deep pools and associated vegetative complex function primarily as escape shelter from predators. But during winter, when streamflows are high, cover also provides a refuge for physical displacement. Logs, undercut banks with tree roots and root wads act to dissipate the energy of flowing water and create pockets of velocity shelter that are utilized by juvenile salmonids (Tschaplinski and Hartman 1983, Bustard and Narver 1975, Hartman 1965). Furthermore, when stream discharge exceeds bankfull levels, fish move out onto the floodplain where LOD and standing vegetation create slack water refuges (Bisson pers. comm.).

CONCLUSION: A cumulative effect of a permanent change in structure (smaller trees) in riparian areas is the loss of large organic debris necessary for aquatic habitat, i.e. organic energy inputs and cover. Organic debris will still exist in young growth forests, however, it will be reduced in size and quantity. The quantity of pools and riffles will be reduced and the quantity of rapids and shallows will increase.

FAUNA-TERRESTRIAL

Forest practices that cause direct cumulative effects on earth and flora can in turn cause indirect effects on terrestrial fauna. The cumulative effect of forest practices on terrestrial fauna (wildlife) is similar to aquatic fauna (fish) in that it stems primarily from alterations in habitat. Changes in food, cover, water, and space are manifested through changes in the number and species of wildlife. Earth elements such as caves, cliffs and talus, and vegetation are the primary elements controlling food, cover and space. Indirect changes in wildlife resulting from direct changes in water quantity and quality are not considered important and thus not discussed here. The majority of the important forest faunal changes discussed here are related to a change in forage, cover, and space resulting from combined forest practices.

EARTH

Forest practices generally do not physically affect caves, cliffs, and talus slopes. Road construction, however, can occassionally disrupt existing cliffs and talus areas or create new ones. Timber harvesting near these specialized habitats can also affect the overall habitat in many of the same ways as described later in this section under FLORA.

Of special interest is the indirect cumulative effect on elk caused by direct changes in earth, i.e., forest roads. Numerous studies show that forest roads cause a decline in the use of adjacent habitat by elk. (Rost and Bailey 1979,1974, Lyon 1979, Thomas 1979, Perry and Overly 1977, 1976, Hershey and Leege 1976, Marcum 1976, Ward 1976). These studies show that vehicular traffic on forest roads evokes an avoidance response by elk. However, data are lacking to show that logging traffic rather than recreational traffic was the sole reason for this avoidance. Additionally, there are no data to show that the decline in habitat adjacent to roads persisted more than five years after road closure (Lyon 1983). In other words, what effect does the physical presence of the road have on elk? To qualify as a persistent cumulative effect, elk populations would have to continue to decrease as road miles per section increased or logging traffic increased.

CONCLUSION: The literature reviewed failed to show that changes in earth resulting from road construction and use produced a cumulative effect on wildlife habitat.

FLORA

The category of flora includes conversion, forest plant succession, snags, dead and down woody material, and space.

Conversion

Conversion includes the change in floral <u>composition</u> (hardwoods to softwoods) and <u>structure</u> (old growth to young growth).

* <u>Composition</u>

In regards to converting from hardwoods to softwoods, Taber et al. (1980) concluded that the number of animal species changes:

> "Because industrialized societies have a need for softwood over hardwood in a ratio of 9:1, the cumulative trend of forest management has been to eliminate broad-leaved hardwoods from the forest, with consequent serious loss of habitat heterogeneity and faunal diversity. The number of forest bird species and mammals is greatest in mixed forests. Mixed forests provide more types of food, nest sites, etc., than do either pure conifer or hardwood forests."

DNR 1982 concluded that on their managed lands:

> "The cumulative effects of hardwood forest conversion will be to

reduce populations of animals associated with broadleaf and mixed conifer/broadleaf forests, and to increase populations of those adapted to coniferous forests. Converting deciduous woods in the habitat of Columbian white-tailed deer would be extremely harmful to this endangered species. Nor could western gray squirrels tolerate a change in their oak woodland habitat to coniferous forest. Over a wider area, bird species such as warbling vireo, black-headed grosbeak, ruffed grouse and screech owl would also be adversely affected, while animals like the chestnut-backed chickadee, Douglas squirrel, and red-backed vole should become even more numerous."

CONCLUSION: The indirect cumulative effect of hardwood conversions will be changes in habitat that will affect both the species diversity and populations of wildlife.

* Structure

Converting from old growth to young growth will bring a permanent change in forest structure through the loss of large live trees, large standing dead trees, and large dead and down woody material. Any wildlife species needing or preferring mature and old growth forest habitats will be selected against through a reduction in species diversity and possibly through a change in population (Lange 1980, Sanderson et al. 1980, Thomas 1979, Meslow and Wright 1975).

CONCLUSION: The magnitude of this potential change has not been documented but may be long-term and irreversible under current young growth management policies; thus constituting a cumulative effect.

Forest Plant Succession

Forest succession exerts a large influence on animal populations and species diversity by controlling canopy closure, plant community composition and structure, nutrients, temporary shelter, habitation, escape cover, and space (Bunnell and Eastman 1976). Intensive forest management predetermines forest composition and structure by controlling tree species and spacing.

Food energy is closely related to the stage of tree canopy development. Early successional stages provide more forage potential than other successional stages. These early successional stages will occur more frequently (once every 60 years for Douglas-fir under forest management) but last for shorter periods of time than in undisturbed forests (once every 400 years). Escape cover and shelter for wildlife are also related to tree canopy development. Early successional stages lack the structure to provide cover for animals, mid-successional stages are best, followed by late stages.

Forest succession affects the number of bird species and nesting sites. Bunnell and Eastman (1976) found that early successional stages favor ground and shrub nesters while mid-stages favor woodducks in cottonwood and late stages favor nuthatches and pileated woodpeckers in conifers.

In riparian areas bird species diversity varies between hardwood and softwood stands (conifers) and as forest succession proceeds (Guenther and Kucera 1978). Bird species using conifer-dominated riparian areas respond positively to forest openings, assuming that well developed stands are adjacent. Diversity in conifer-dominated riparian areas is greatest in shrub-dominated stages. It drops about 35 percent by the time the stand is mature, increases to about 70 percent as the stand becomes overmature, and then reaches its lowest point (60 percent of potential) when overmature. In hardwood dominated communities bird species diversity is greatest in older stands and species numbers fluctuate at low levels in younger stands. When a hardwood stand is clearcut, bird species diversity may decrease 20 percent, increase to over 90 percent of potential during the shrub-dominated stage, and then decline to about 65 percent during the pole-sapling stage. The number of bird species using hardwood-dominated riparian areas is greatest in mature stands and decreases when the stand is overmature.

The role of birds in regulating forest insects has been reviewed by Bruns (1960), Franz (1961), Thomas et al. (1975), and Wiens (1975). The conclusion of these reviews is that insectivorous birds in general, and perhaps hole-nesting birds in particular, play an important role in the reduction of insect populations at endemic levels. Birds are probably important, therefore, in damping the number and size of insect outbreaks (Mannan 1980).

In riparian areas mammal species diversity varies between hardwood and softwood stands as forest succession proceeds (Guenther and Kucera 1978). Mammals respond positively to openings in the forest environment with the largest number of mammalian species found in natural openings or new clearcuts The relationship between mammalian species diversity and forest succession is complicated by the preference many species have for a variety of successional stages. In a conifer-dominated riparian area the number of mammalian species may decrease 20 percent by the time the stand is mature and an additional 3 percent when the stand is overmature. The maximum number of mammalian species in forest openings is influenced by adjacent canopy and understory conditions. Large openings may have very little interior use. In a hardwood-dominated riparian area the number of mammalian species during the pole stage may be 30 percent less than that present in openings. The number of species returns to 85 percent of potential as the stand reaches maturity.

In riparian areas amphibians respond similarly to hardwood and softwood forest succession (Guenther and Kucera 1978). Amphibians are tied to riparian habitat more closely than any other group of species due to their reproductive requirements. The aquatic system usually provides their reproductive substrate and the tree canopy and sub-canopy maintain the cool, moist microclimate necessary for thermo-regulation and respiration. Amphibians find optimum habitat in stands older than 100 years. When a forested riparian area is clearcut the number of amphibian species using the area will drop by about 20 percent until the canopy of the new, young stand begins to close. A further 5 percent reduction in number of amphibian species occurs during the sapling-pole to young forest stages. As the stand becomes mature, more amphibian species reinhabit the area bringing the number of species back to 87 percent of potential. Full use by the entire amphibian group is not achieved until stands become overmature. The total number of reptile species changes little in response to changes in forest succession, however, species composition varies. Some reptile species are dependent on the aquatic system for feeding. Also many species will not use openings without adjacent closed canopy areas for thermoregulation.

The animal responses to forest succession described for riparian areas, above, are also applicable to non-riparian areas, however, the number of animal species for mammals, birds, etc. would be greater (Sachet 1982).

CONCLUSION: Short rotations and intensive forest practices will increase the frequency and area of early successional stages but decrease their duration. This change in habitat will cause a shift in animal species diversity from baseline conditons. We believe animal species diversity and populations will probably remain altered in succeeding rotations thus resulting in a persistent cumulative effect.

Snags

Snags are common in old growth stands and less common in young stands. Conversion of old growth stands to young stands, continuous cropping of the forest using short rotations, salvage logging, and thinnings reduce the current number of snags and prevent the future recruitment of snags. These reductions in snags could accumulate over time thus programming snags out of existence (Miller and Miller 1980, Thomas 1979).

The continuous reduction in the quantity and quality of snags will effect snag dependent wildlife. Unless these animals can adapt to other habitats, their numbers will continually decrease. This is especially true for cavity nesting birds where even small snags can not be substituted for large snags. The reduction of hole-nesting birds and other insectivorous species via elimination of older forest age classes may thus reduce the stability of managed forest systems. Potential effects of reducing or eliminating forest raptors such as spotted owl and goshawk and such mammals as flying squirrels, bats, etc. are unknown (Mannan 1980, Maser pers. comm.).

CONCLUSION: Short rotations and intensive forest practices will reduce the quantity and quality of snags resulting in a persistent cumulative effect on snag dependent wildlife.

Dead and Down Woody Material

The main habitat functions of dead and down logs are cover and as sites for feeding and reproduction. In general, the larger the diameter and the greater the length of a log the more useful it is; however, small material is better than none (Maser et al. 1979). The largest quantities of dead and down woody material are found in old growth stands, in western Washington, and at lower elevations. Short rotations, intensive forest management, and improved utilization reduce the quantity of dead wood on the ground. Continuous cropping of the forest using these practices will reduce the opportunity to have large dead and down woody material in the future. In each succeeding rotation this quantity of woody material on any particular site will decrease. Large pieces of old growth residue become fully incorporated into the soil after 200-300 years.

CONCLUSION: The cumulative effect of reduced dead and down woody material is the reduction in the quantity and quality of habitat for some birds and mammals. This effect will persist so long as the rate of woody material removed (through natural decay, logging, fire, etc) exceeds the rate of recruitment.

Space

Space as a component of wildlife habitat refers to amount of edge and openness in the forest. Edge created by contrasting stages of forest succession, such as a clearcut adjoining an uncut stand, tends to improve species richness for most wildlife. Species richness is additive and increases with increasing edge, however, the diversity of an area can not be increased indefinitely. At some point the open areas become so numerous and close together that heterogeneity turns into homogeneity. Thomas (1979) made a "best guess" that the species richness for birds in the Blue Mountains increased with stand size to about 84 acres. Beyond this size it is assumed that species richness would decrease both for birds and other vertebrate wildlife. There are exceptions to nearly all such relationships, as in the following example: Golden eagles are found in the open arid habitats of eastern Washington but less commonly in western Washington. In recent years, the number of known golden eagle nests has increased. Most nests were found on or near the edge of the forest stand at or below the average canopy height. This increased golden eagle population may be due to clearcut logging that creates large open areas supporting prey species (Bruce et al. 1982).

CONCLUSION: A persistent cumulative effect would occur when the changes in the quantity of edge and openness cause wildlife species richness and/or populations to shift to a new baseline. There is no documentation to show how changes in edge and openness resulting from forest practices have changed species richness over time in Washington.

6. DISCUSSION AND CONCLUSIONS

We conclude that current forest practices in Washington have the potential for causing cumulative effects. However, few of these cumulative effects are universal nor will they occur automatically. Whether or not a cumulative effect (on a particular environmental component) occurs depends on the intensity of the initial forest practice (the magnitude of change it causes to the environmental component) and the time allowed for recovery before the next forest practice (that also affects the same environmental component). A given sequence of forest practices can cause a cumulative effect on one site and not on another more resilient site.

Intensity and resiliency are key concepts to understanding cumulative effects. Intensity refers to the magnitude of change caused by a forest practice, and resiliency refers to the time necessary for the ecosystem to recover. The variability in these two parameters means that few, if any, cumulative effects will "always" occur. A cumulative effect only results when the change is so great that the resiliency of the ecosystem does not allow full recovery before the occurrence of additional forest practices. A persistent cumulative effect results only if this change will not recover without a modification of the forest practices causing the change.

In Chapter 4 of this report we defined cumulative effects and described what constitutes a forest practice, and the basic properties and processes of the environment that are most likely affected by forest practices. The two factors, forest practices and elements of the environment, were joined and contrasted in Chapter 5 where we discussed the potential for forest practices resulting in cumulative effects. Each subsection of Chapter 5 ends with a concluding statement.

Rather than reiterate the specific conclusions formed in Chapter 5, we summarize only those forest practices that we believe will most likely cause cumulative effects. These practices can be grouped into three broad categories:

1) The first category is forest practices that physically disturb or alter the soil. Forest roads and timber harvest are practices that cause greatest disturbance to the soil Both accelerate surface erosion and increase the frequency of debris avalanches. Increased erosion decreases water quality and degrades aquatic habitat. These forest practices also alter the hydrologic cycle affecting the timing and volume of runoff. Because of the permanency of forest roads, the persistence of associated erosion processes, and the continual nature of timber harvest, we conclude that persistent cumulative effects on erosion, water quality and quantity, and aquatic habitat and associated aquatic fauna will result. The magnitude of these cumulative effects are site specific and depend on the amount of road involved, the intensity of harvest activities, the resiliency of the individual sites, and the scheduling of the activities. We also believe, as did many people interviewed, that environmental changes caused by construction, use, and maintenance of forest roads

constitute the greatest contribution to these cumulative effects, especially to persistent alterations of aquatic habitat (substrate and clarity).

The remaining two categories of forest practices primarily affect the terrestrial elements of the environment and not the aquatic components. Exceptions are practices that change the structure and composition of flora affecting the aquatic habitat through alterations in the riparian zone and especially changes in LOD recruitment.

2) The next category is forest practices that remove excessive quantities of biomass from the forest. Removal of biomass by harvest, or harvest related practices (site preparation), directly removes nutrients, disrupts the nutrient cycle and accelerates leaching, and reduces the size and quantity of dead and down woody material. These in turn affect the productivity of both the floral and faunal components of the forest.

Forest practices that can result in removal of excessive biomass from the forest include whole-tree harvest, prescribed fire, and short rotations. Of these, we believe that whole-tree harvest combined with short rotations has the greatest potential for causing cumulative effects. We also believe that ultra-short rotations (less than about 40 years), even without increased utilization, would probably result in cumulative effects. Cumulative effects likely to result include a gradual decline in available nutrients and other alterations in forest soil properties, a reduction in growth of forest trees causing changes to both forest structure and composition, and a decline in quantities of woody material in the soil causing changes to microflora populations. These changes will in turn cause additional changes to all living components of the environment that rely on any of these habitat components.

3) The final category is forest practices that change the composititon and structure of flora. They are primarily practices involved in converting unmanaged forests to managed forests and include even-aged management using short rotations, selection harvest, artificial regeneration, and animal and disease control. These practices cause a shift from old growth forests maintained by wildfire, windthrow, insects and disease; to young forests maintained by repeated harvest, site preparation, and hand planting. Cumulative effects that result are mostly related to reductions in large, old trees, changes in dominant species, and maintenance of a large land base in younger (smaller) trees. Changes to soil physical, chemical, and biological properties which depend on some aspect of mature vegetation (litter, large logs, nutrient cycle, microflora) are one effect. Also, the loss of old growth forest structure, both within the canopy (crown types, snags) and near the ground (LOD, subordinate vegetation) is another cumulative effect. These changes will cause additional changes to flora and fauna that depend on habitat provided by a mature forest. In most cases extinction of any species is not likely, but decreases in some species, and increases in others are likely. Forest practices in this last category, in particular those related to the old growth issues, are not easily modified. The long time necessary for a forest to develop old growth characteristics precludes the use of most intensive forest management activities.

The determination of persistent cumulative effects resulting from these categories requires a knowledge of three forest practices variables; HOW the practices are applied, WHERE on the landscape they are located, and WHEN in time they are carried out. A description of the HOW, WHEN, and WHERE of a forest practice constitutes its full definition. Only after forest practices are described in this manner can the probability of causing the previously described cumulative effects be determined. Furthermore, only by being in control of all three of these forest practices variables can cumulative effects be controlled.

It should be clearly understood that zero environmental impact can never result from forest practices. Whereas it is possible to control cumulative effects, it is impossible to eliminate them. The necessary steps to control cumulative effects include (adapted from McLintock 1972):

1) Structure broad categories of possible cause-effect relationships.

2) Identify specifically which forest practices cause what cumulative effects.

3) Rank each of these cause-effect relationships for importance as an environmental hazard.

4) Assess the importance of forest practices having adverse environmental impacts and evaluate the cost, if any, of using a "cleaner" or more acceptable alternative.

5) Balance the trade-offs between environmental quality, alternative forest practice procedures, and the social benefits derived from resource use.

6) Decide what level of environmental change is acceptable and regulate accordingly.

We have addressed steps one, two, and three in this study, it remains for others to address steps four, five, and six. In Chapter 7 we offer recommendations that will assist the FPB in making continued advances in these latter steps.

7. RECOMMENDATIONS

As a result of this study we concluded that the potential for cumulative effects exists. Changes in the environment can accumulate through the actions of man. The following recommendations are designed to assist the FPB in answering the obvious questions of: What is the probability that cumulative effects will occur? What is the magnitude of cumulative effects in Washington? What can be done to control cumulative effects? What are the advantages and disadvantages of controlling cumulative effects? These are just a few of the many questions we believe surround the subject of cumulative effects.

The first recommendation is that the FPB uses this report to construct a list of significant cumulative effects issues. This is necessary to alert the research community and the forest industry to the important topics. We believe it is appropriate for the FPB, as representative of the public, to evaluate this significance. The term "significance" as used here, refers to the importance of these issues to society. If the FPB believes that certain cumulative effects issues are of no interest to society, then these issues should not be included in the list. The legal jurisdiction of the FPB might be used as a first test of what is included. For example, is the FPB concerned with changes in soil productivity occurring on private lands? Is the FPB concerned with cumulative effects related to old growth?

The second recommendation is that the FPB, having listed significant cumulative effects, now arrange them in order of priority. Those cumulative effects of greatest concern to society and requiring the most timely response by the FPB should be given highest priority. In prioritizing cumulative effects the FPB should balance the beneficial cumulative effects against the detrimental ones and include the economic and social benefits of forest practices. However, we believe there is no denying the fact that detrimental cumulative effects are of greatest concern and should be the FPB's highest priority.

Prioritizing the cumulative effects issues will allow the FPB and the research community to determine where research is most needed. However, a certain amount of research may be necessary before complete prioritizing of the issues can be completed. Additional information may be needed by the FPB before determining the importance of an issue. We believe adequate assessment of several cumulative effects issues may first require answers to such questions as:

1) What is the magnitude and extent of forest practices that are causing cumulative effects? Some practices causing cumulative effects may be relatively rare and thus, may be given a lower priority until other more pressing issues are addressed.

2) Will these forest practices continue in the foreseeable future? Practices such as harvest of old growth may need to be addressed sooner than other issues. Conversely, addressing forest practices that are

expected to decline in the near future, for example slash burning, might be deferred. Long-term emphasis should be placed on addressing those forest practices that are foreseen as continual, or as increasing in extent or magnitude.

3) What is the spatial and temporal extent of cumulative effects identified as significant? This is closely related to the extent of forest practices causing the effect.

Answers to these questions will allow the FPB to complete the prioritization of cumulative effects issues. A completed list will point out to the the research community where research is desired.

The third recommendation is that the FPB define appropriate baselines for each issue. While we investigated cumulative effects based on an "undisturbed" baseline, this is not necessarily the appropriate baseline for all lands or even most lands. As a guide to selecting appropriate baselines, we suggest the FPB consider the thoughts of Tombaugh (1984):

> "Our primary responsibility as professional resource managers must be to maintain or enhance the quality and productivity of those resources on which other resources depend - - particularly soil and water resources. Options can be left open for a great range of manipulations of forests and wildlife only if soil fertility and water quantity and quality are maintained."

The goal of these recommendations is to improve the management of natural resources to assure sustained yields of timber and non-timber resources. Additional recommendations are offered in four categories; RESEARCH, BASIN EXAMINATIONS, DATA MANAGEMENT, AND INSTITUTIONAL. Recommendations for research and basin field examinations are directly applicable to cumulative effects. Such projects could test the hypotheses advanced in this literature review. The other two categories are indirectly applicable in that they are necessary for implementing research findings and documenting temporal and spatial changes in the environment.

Recommendations follow three themes; making efficient use of existing information, gaining new knowledge, and cooperation. These are the basic ingredients for improving the understanding of the nature, source, and extent of cumulative effects.

7.1 RESEARCH

The FPB serves in an advisory capacity to the DNR in annually determining the state's research needs. The Forest Practices Act (RCW 76.09.270) states:

> "The department (DNR), along with other affected agencies and institutions, shall annually determine the state's needs for research in forest practices and the impact of such practices on public resources and shall recommend needed projects to the governor and the legislature."

The FPB should annually review their needs for research information appropriate for promulgating forest practices regulations. The FPB should be aware that the quest for knowledge is a never ending journey and that today's research information is a product of past research priorities and perceptions. These priorities and perceptions have greatly changed in the past and will most likely continue to change in the future. The goal of research is to anticipate future information needs far enough in advance to have the results available before an issue becomes uncontrollable. The subject of cumulative effects is such an issue.

The FPB cannot afford to be a responder to issues. The FPB must take the lead in identifying key issues and the accompanying research necessary to address these issues. The list of all needed research is endless, and in order to keep the list focused on cumulative effects we have organized our research recommendations into two broad categories, old growth and young growth. Research should answer the long-term questions about cumulative effects. It is no longer adequate to know only what the effects of forest practices are, researchers must determine how long these changes last and how the recovery period can be modified by improved practices or additional mitigative practices.

OLD GROWTH

Acreages of old growth forests are decreasing rapidly in Washington with no replacement in sight. These forests present unique opportunities for studying natural ecological processes. Two old growth studies are currently in progress and we recommend the FPB encourage their completion.

The first one is the US Forest Service Region 5 Douglas-fir Wildlife Successional Stages Research program at the University of California and Oregon State University. The purpose of the program is to draw preliminary conclusions regarding the old growth habitat obligate relationship of certain species suspected of requiring old growth habitat for the maintenance of continuing populations.

The second one is the US Forest Service Pacific Northwest Forest and Range Experiment Station (Olympia, Washington) Pacific Northwest Old Growth Wildlife Habitat Program. The purpose of this program is to provide detailed information about the ecological relationships of wildlife to old growth habitats, but will leave unanswered questions regarding a species' obligate or facultative relationship to old growth (or other) habitats. Further research on the ecological relationships of wildlife species to all successional stages will be necessary. The geographical range of this program is the Douglas-fir region of the Pacific Northwest.

YOUNG GROWTH

Young growth forests are the future forests of Washington. Research is needed to improve the understanding of ecological processes manipulated by man. Major advancements were made in understanding natural processes through the International Biological Program (IBP) from 1964 to 1978. The IBP was initiated in 1964 for the purpose of coordinating international research on a worldwide scale to better understand ecosystems. The US Ecosystems Analysis program was begun in 1965 and organized into five biomes: grassland, desert, tundra, eastern deciduous forest, and western coniferous forest. The Coniferous Forest Biome program spanned the period 1971 to 1978. Its goal was to better understand the composition, structure, and function of western coniferous forest ecosystems and associated aquatic ecosystems. Another goal of this program, but to a lesser degree, was the assessment of man's actions on natural ecosystems. While the IBP made great contributions towards understanding natural processes, it did little to understand the composition, structure, and function of repeated rotations of young coniferous forest.

Special attention should be given to determining the recovery periods necessary to returning the environment to the appropriate baseline following multiple forest practices. These research findings could be the basis for developing methods for reducing negative cumulative effects. Research should focus on persistent cumulative effects resulting from repeated or combined forest practices. In general, a better understanding is needed of the magnitude or intensity of the effects of forest practices, the resiliency of representative sites with respect to these changes, and how this resiliency might be increased and the recovery time shortened by alternative forest practices.

7.2 BASIN EXAMINATIONS

The goal of basin examinations is to understand how forest practices are distributed throughout the commercial forest zone of Washington. The objectives are to quantify and qualify the location and timing of forest practices causing direct cumulative effects on earth, water, and flora. Such an examination will allow the FPB to better determine which cumulative effects and their associated forest practices are most widespread in Washington and would therefore require greatest attention by the FPB. The emphasis would be to make maximum use of existing data to develop an overview of how forest ecosystems have changed in structure and composition over time.

To accomplish this we propose dividing the state into seven regions. The regions would be a product of merging the seven physiographic provinces delineated by Franklin and Dyrness (1973) and the 62 water resource inventory areas (WRIA). One basin from each region should be selected as representative of the biogeoclimatic conditions and forest practices, and compile, analyze, and display all resource data associated with forest practices conducted in the past 40 years or as far back in time as records allow. The following list is offered as an example of important information needed:

Harvest: silvicultural systems (even- vs. uneven-aged) and yarding systems (tractor).

Roads: quantity and quality of roads constructed, reconstructed, and used; active, inactive, and abandoned status; surface erosion potential (drainage and road use); mass movement (actual and potential debris avalanches and torrents according to drainage patterns, construction methods, and road use).

Site Preparation: snags removed; debris consumed and quantities of residue remaining.

Reforestation: control of competing vegetation (shrub layer); fertilization (nutrient budget); stocking levels; thinning regimes; present composition; residual species vs. planted species; tree diameters.

The purpose of these basin examinations is to document the major cumulative effects that are actually occurring in Washington's forested watersheds and to determine what level of forest practice activity resulted in these changes. Using this information, the FPB can continue its priorization of cumulative effects issues, and begin the task of deciding what level of forest practice activity will allow future recovery of detrimental cumulative effects. We believe it is within the FPB's mandate to propose appropriate forest practice levels to protect public resources, this may include scheduling in time and/or space of future forest practices.

7.3 DATA MANAGEMENT

The goal of our data management recommendations is to make more efficient use of new and existing data. The decade of the 1980's is one of data control and technology transfer. Through the aid of computers and other high technology it is possible to collect, store, analyze, and exchange information faster than ever before. However, this increased efficiency is only useful if the correct information is collected and stored. To this end we recommend a greater standardization of data collection methods for inventorying and monitoring habitat, and the increased use of permanent plots (long-term) and photography to document changes in forest and aquatic ecosystems over time.

We also recommend the establishment of a central clearing house for coordinating research programs and synthesizing existing research and data on the environmental effects of forest practices in a format useable by forest managers and resource planners. This can be accomplished in many ways, however, the prompt publication and distribution of research findings coupled with management guidelines is recommended.

An example of one publication that brings research findings on wildlife and forestry together in an easily understood format is Jack Ward Thomas's WILDLIFE HABITATS IN MANAGED FORESTS: THE BLUE MOUNTAINS OF OREGON AND WASHINGTON. It is a model publication for developing similar documents for the western Sierra Nevada, the North Coast-Cascades (Siskiyou Mountains) region of northwest California, the eastern Rocky Mountains, the northwest Rocky Mountains and the western Pacific Northwest.

The geographical scope of the western Pacific Northwest study covers the Pacific Coast to the Cascade Crest, and from the Canadian to the California borders including the San Juan Islands and the Siskiyou Mountains (Brown 1982). The report is scheduled for completion in 1984.

7.4 INSTITUTIONAL

The goals of our institutional recommendations are to improve the administration of agency programs, interagency cooperation, and general understanding of cumulative effects. We have divided our recommendations into laws affectng forest management, planning, and human elements of the environment.

LAWS

The FPB should determine the environmental effects of laws regulating forest practices. It is important to know what effect present laws have on changing the forest environment and quality of human life before contemplating a change in these laws or creating new laws. It should be recognized that individual laws or combinations of laws can create environmental problems greater than the ones they were designed to solve. We offer the following examples as conceptual problems created by some existing laws:

1) What effect have reforestation laws had on the gene pool of Northwest conifers?

2) What effect have air pollution laws for visibility had on the soil resource?

PLANNING

Planning is an essential step in all aspects of natural resource management. Most planning programs concentrate on predictable or controllable events. What is needed is a plan for addressing unexpected or uncontrollable events. These events are usually catastrophic and consist of wildfires, insects, wind, floods, or volcanic eruptions. Floods are included here only when man's activities do not contribute to the environmental problem. The eruption of Mount St. Helens is offered here as an example. The Toutle-Cowlitz Watershed Management Plan is Washington's first multiple use watershed management plan developed through the cooperation of all land owners and state, federal, and local agencies.

It is reasonable to expect that a major wildfire, comparable to the pre-1850's, will occur in our life time. Likewise, another Columbus Day wind storm (1962) or major flood could occur. Such events have caused major changes in the baseline condition of the environment. These changes can greatly affect the alternatives available for managing forests in the future and the risk of their occurrence should be included in the planning process.

HUMAN ELEMENTS OF THE ENVIRONMENT

The reader may have noted the absence of value judgements regarding the significance of cumulative effects. This is a direct result of considering only the physical elements of the environment. Whether an environmental effect is positive or negative cannot be determined until man's goals and objectives for forest management are balanced with environmental change. We recommend the Forest Practices Board, in the process of evaluating cumulative effects, consider the trade-offs between environmental quality, forest practices alternatives, and the social benefits of resource use.

7.5 SUMMARY OF RECOMMENDATIONS

From the literature search and interviews on cumulative effects we defined cumulative effects, explained the status of knowledge on the subject, and provided a variety of recommendations. This information can now be used by the FPB to develop a framework for guiding any future consideration of cumulative effects.

In regards to research, there is no missing link that when discovered will serve as a cure for cumulative effects. Research is an ongoing process essential for refining the data base and perception of cumulative effects. The analysis and understanding of existing data to improve perceptions is probably more cost effective, initially, than additional uncoordinated research.

Basin examination of forest practices are needed to quantify the magnitude and temporal and spatial changes in vegetation and earth resources. Data management is essential for achieving consistency and accuracy in collecting data appropriate for addressing cumulative effects. Up-to-date information needs to be organized, summarized, and disseminated to people who are responsible for changing the environment (this includes both regulators and forest managers). Institutional changes need to be recognized as potential sources of cumulative effects as well as their control.

Positive cumulative effects accrue to human elements of the environment and need to receive consideration equal to negative cumulative effects. The quality of life in Washington is a function of choice.

7.6 DIRECTION

The following recommendations are specific in that they represent actions that the Forest Practices Board can take now:

1) Develop a state-wide overview of the magnitude, duration, and frequency of forest practices. Examine small scale aerial photography or satellite imagery, timber harvest reports, forest practices applications, public timber sale records, etc. to determine the general landscape changes over time. This information can then be used in the basin examinations.

2) Concurrent with the above step, commence an examination of methods used in the Pacific Northwest to analyze cumulative effects. The US Forest Service, US Fish and Wildlife Service, and some private firms have developed methods for looking at the effects on earth and water. Other methods may be available or adaptable for addressing cumulative effects

on other environmental elements. Each method should be examined by asking, at a minimum, the following questions:

a. Do the methods address the issue of concern, i.e. air, earth, water, flora, or fauna?

b. Are the methods and procedures theoretically correct?

c. Are the data available now or readily available in the near future?

d. Are the results socially and economically practical?

3) Conduct basin examinations in Washington to determine past, present, and future distributions (scheduling) of forest practices. This recommendation is the same as Task #2 in the FPB's request for proposal dated June 1981.

4) Based on the results of the above three tasks, the FPB would then be ready to determine if new methods or modifications of existing methods are appropriate for controlling cumulative effects.

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GLOSSARY

Autecology: The study of interrelationships between the individual plant and its environment.

Baseline: The desired state or condition of the environment. The condition of the forest or watershed we wish to maintain now and into the future and from which we measure the changes caused by forest practices.

Brooming: An abnormal growth of small branches caused by fungi or viruses.

Change Agent: The apparent cause of an environmental impact.

Composition: The array of plant species to include abundance as well as presence and absence of a species.

Conversion: The removal of an undesirable timber type, frequently hardwoods, and replacement by a preferred crop.

Decomposers: Organisms which break organic material into simpler compounds or constituent elements.

Direct Effect: Those in which the change agent impinges directly upon the responding environmental component. Synonymous with primary impact.

Direct Cumulative Effect: Those caused by direct individual effects of two or more forest practices. Practices can be the same type spread out in time and space, or different types also distributed through time and space.

Ecosystem: An ecological system composed of living organisms interacting with their non-living environment.

Endemic: Native to a particular area or region and present in usual numbers.

Environmental Impact: A change in the environment caused by an act of man. The change must be perceptible, measureable, and relatable through a change agent to an action.

Epigeous Fungi: Fungi which grow and fruit above ground.

Even-aged Silviculture: Maintaining a stand so that all trees are the same age, or so the difference between the oldest and the youngest trees does not exceed 20 percent of the length of the rotation.

Exotic: Introduced from another country or region.

Function: The production of organic matter and the cycling of nutrients through pathways and compartments to include the secondary role vegetation plays in providing habitat for fauna.

Hypogeous Fungi: Fungi which grow and fruit below ground.

Indicator: An element of the environment affected, or potentially affected, by a change agent. An indicator can be a structural component, a functional process, or an index.

Indigenous: Produced, growing, or living naturally in a particular region or environment.

Indirect Cumulative Effects: Those traceable to a prior cumulative effect or to two or more indirect individual effects.

Individual Effects: Changes resulting from a single action of man, without further intervention.

Intensity: The magnitude of change caused by a forest practice. An "intense" forest practice causes a large environmental change.

Multiple Forest Practices: Includes combined practices: all possible combinations in time and space of the many types of forest practices; and repeated practices: repetition of a single type of forest practice in time and/or space.

Mycorrihizal Fungi: Fungi which form a symbiotic association with the roots of a seed plant.

Parasites: Organisms which are biologically dependent upon a host, which is usually injured by the association.

Persistent Cumulative Effects: Those that result in a persistent change in the equilibrium or average baseline of the affected component.

Plant Succession: Changes in composition, structure, and function as vegetation passes through the various life stages of establishment, growth, and mortality.

Recovery: A return to the baseline condition.

Regolith: The unconsolidated earth materials that overlie bedrock.

Rehabilitation: The replacement of a desirable timber type that is severely understocked or otherwise incapable of utilizing the site throughout the planned rotation.

Resiliency: The ability of an ecosystem to recover from an induced change, generally measured by the time necessary for recovery.

Saprophytic Fungi: Fungi which live on dead or decaying organic matter.

Secondary Effect: Those in which the change agent causes one or more intermediary effects in a chain of events leading to the observed impact. Synonymous with indirect impact.

Sere: One of a series of ecological communities succeeding one another in the biologic development of an area.

Stream Order: A hierarchy wherein streams are ranked. Fingertip tributaries at the head of a stream system are designated as 1st-order streams. Two 1st-order streams join to form a 2nd-order stream; two 2nd-order streams join, forming a 3rd-order, and so on. It takes at least two streams of any given order to form a stream of the next highest order.

Structure: The size and spatial arrangement of vegetation.

Symbionts: Two dissimilar orgainisms living together in a mutually beneficial relationship.

Synecology: The study of interrelationships among all kinds of organisms in an ecosystem in relation to the environment.

Temporary Cumulative Effects: Those for which we can forsee at some point in the future the reestablishment of a baseline condition without the need to change current management practices.

Threshold: A maximum or minimum number, or other value, for an environmental impact which, if exceeded, cause that impact to take on new importance.

Uneven-aged Silviculture: Maintaining a stand with at least three intermingled age classes.

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APPENDIX A

CUMULATIVE ENVIRONMENTAL EFFECTS:
AN HISTORICAL REVIEW

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for

ECOSYSTEMS, INC.

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TABLE OF CONTENTS

INTRODUCTION

The stated goals of the Cumulative Effects of Forest Practices study as proposed to the Washington State Forest Practices board are to:

1. Define what is meant by the term "cumulative effects"...

2. Develop a first approximation of the nature, source, and extent of cumulative effects on the environment arising from forest land management activities on lands regulated by the State of Washington...

3. Provide a basis for directing future scientific studies on the significance of cumulative effects...

The general purpose of this report is to set a context for initiating and carrying out the Cumulative Effects study program by:

+ reviewing the history of pertinent environmental protection legislation and its interpretation and implementation;

+ reviewing a sampling of environmental impact analyses for compliance with cumulative effects analysis requirements, analytical techniques, and level of detail;

+ presenting preliminary conclusions regarding the nature of potential cumulative effects of forest practices.

This preliminary "screening" or over-view study is restricted to selected activities in the Pacific Northwest.

SECTION 1 - WASHINGTON STATE LEGISLATION AND REGULATIONS

The Washington State Environmental Policy Act (SEPA; Chapter 43.21C RCW), the basis of Washington State environmental protection legislation, was passed by the state legislature in 1971, with the stated purposes of:

> 1) To declare a state policy which will encourage productive and enjoyable harmony between man and his environment; 2) to promote efforts which will prevent or eliminate damage to the environment and biosphere; 3) and stimulate the health and welfare of man; and (4) to enrich the understanding of the ecological systems and natural resources important to the state and nation. (REC 43.21C.010)

This mandate was to be carried out principally by integrating the natural and social sciences and the environmental design arts into the planning and decision making process, the development of methods and procedures for consideration of natural amenities along with economic and technical considerations in decision making, and to include in every recommendation or proposal for actions significantly affecting the environment, a detailed statement of environmental impacts and design alternatives (RCW 43.21C.030 (a), (b), (c)). The legislature made no specific mention of "cumulative effects," but the language of RCW 43.21C.030 (f) suggests such a concern:

> (f) Recognize the worldwide and long-range character of environmental problems and, where consistant with state policy, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment;

Implementation of SEPA was unregulated during the early years following passage of the act. In 1972, the Washington Department of Ecology (WDOE) issued some non-regulatory guidelines for the preparation of environmental impact statements (EIS). These guidelines were vague by contemporary standards, and were merely advisory, not mandatory. They therefore failed to provide any consistant assistance to the process of compliance with the SEPA legislation. The 1972 Guidelines contained no direct reference to cumulative effects. However, the suggestions for assessment of ecosystem impacts (p 19), if fully complied with and carried to their logical conclusion, would have resulted in at least a cursory review of cumulative effects.

By 1974, the lack of regulatory direction and the resultant confusion prompted the legislature to direct the temporary establishment of a Council on Environmental Policy (CEP), and for the CEP to adopt rules of interpretation and implementation for the SEPA legislation (RCW 43.21C.110). Also, agencies were directed to adopt rules pertaining to the integration of the policies and procedures of SEPA into their various agency programs (RCW 43.21C.120).

From the beginning, there was controversy regarding the application of SEPA to forest practices. The Washington Department of Natural Resources (WDNR) and the forest industry in general quite naturally desired to remain free of the regulatory constraints of SEPA regarding EIS preparation. Environmentalist interest groups, of course, desired to have the intent of SEPA fully applied to the forest industry.

The Forest Practices Act (FPA; RCW 76.09) of 1974 defined three classes of forest practices (I,II,and III), and exempted all of them from the requirement to prepare an EIS under SEPA (RCW 76.09.050). After much debate, the 1975 amendments to the FPA created the Class IV forest practices which were discretionarily to be subject to SEPA.

> Class IV. Forest practices other than those contained in Class I or II: (a) On lands platted after January 1, 1960, (b) on lands being converted to another use, (c) on lands, which, pursuant to RCW 76.09.070 as now or hereafter amended, are not to be reforested because of the likelihood of future conversion to urban development, and/or (d) which have a potential for a substantial impact on the environment and therefore require an evaluation by the department as to whether or not a detailed statement must be prepared pursuant to the state environmental policy act...(RCW 76.09.050 (d)).

The CEP completed their work in 1975, and on January 16, 1976, the new 1976 SEPA Guidelines (WAC 197-10) became effective. The 1976 Guidelines contained two pertinant provisions regarding forest practices and cumulative effects.

Forest practices, in general, were granted a categorical exemption from the threshold determination and EIS requirements of SEPA, affirming the similar provisions of the FPA:

> (19) Natural resources management. In addition to the other exemptions contained in this section, the following natural resources management activities shall be exempt:
> (a) All Class I, II, III, and IV forest practices as defined by Chapter 200, Laws of 1975, Ex. Sess., or regulations promulgated thereunder, and except those forest practices designated by the forest practices board as being subject to SEPA evaluation. (WAC 197-10-170 (19)).

The required contents for impact analysis in an EIS was defined in some detail, and included references to cumulative effects:

> (8) The impact of the proposal on the environment. The following items shall be included in the subsection: (a) The known impacts resulting from the proposal within any element of the environment listed in WAC 197-10-444, the effects of which are either known to be, or which may be significant (whether beneficial or adverse), shall be discussed in detail; impacts which are potential, but not certain to occur, shall be discussed within reason.
> (b) Elements of the environment which will not be significantly affected shall be marked "N/A" (not applicable) as set forth in WAC 197-10-444 (1).
> (c) Direct and indirect impacts of the total proposal, as described in subsection (8) (a) above shall be examined and discussed (for example, growth-inducing impacts).
> (d) The possibility that effects upon different elements of the environment will inter-relate to form significant impacts shall be considered. (WAC 197-10-440 (8)).

The charge to analyze cumulative effects is contained not only in the direct statement in subsection (c), but is also implied by the language in subsection (d).

Closely following the issuance of the general SEPA Guidelines in January 1976, WDNR issued their own WDNR SEPA Guidelines (WAC 332-40) in May 1976. These WDNR guidelines were virtually an adoption by reference of the CEP guidelines with no significant changes.

In July 1976, the Washington Forest Practices Board (FPB) issued their FPA guidelines: the Washington Forest Practice Rules and Regulations (FPR; WAC 222). In coordination with the 1976 SEPA Guidelines, the FPR created and defined the Class IV-Special forest practices which were to be subject to SEPA:

> (1) "Class IV-Special". Application to conduct forest practices involving the following circumstances may require submission of additional information as they have been determined to have a potential for a substantial impact on the environment. It may be determined that a detailed environmental statement is required before these forest practices may be conducted.
> (a) Harvesting, road construction, site preparation, or aerial application of pesticides on lands known to contain the nest or breeding grounds of any threatened or endangered species of wildlife as designated by the Department of Game in accordance with federal criteria and procedure, and approved by the Board.
> (b) Widespread use of DDT or a similar persistant insecticide.
> (c) Harvesting or road construction on landlocked parcels within the boundaries of any National park, State park or any park of a local governmental entity. (d) Utilization of an alternate plan except those involving field evaluation of a new forest practice technology or any reforestation practice. (WAC 222-16-050 (1)).

It is important to note that the provisions of this subsection merely identify those Class IV-Special forest practices for which an EIS may be required. All that is required is that Class IV-Special forest practices be reviewed for environmental significance. There is lacking even a clear requirement for conformance with the SEPA Threshold Determination process (WAC 197-10-300 et seq) to formally determine if the proposed action is sufficiently significant to require preparation of a full EIS.

There was dissatisfaction with the 1976 SEPA Guidelines among most interest groups and affected parties, and petitions to the legislature and WDOE began soon after implementation of the 1976 Guidelines. Environmentalist groups in particular were working to require a greater compliance with the EIs provisions of SEPA by the forest industry and WDNR. Forest interests defended their position.

The CEP had been abolished by design in July 1976 following the completion of their development of the 1976 Guidelines. During 1977 WDOE developed guideline amendments, and in January 1978, the revised 1978 SEPA Guidelines became effective. The categorical exemption provisions for forest practices were essentially unchanged, and were merely rewritten to bring the language of the SEPA Guidelines into conformance with the language of the FPR:

> (a) All Class I, II, III, and IV forest practices as defined by chapter 76.09.050 RCW, or regulations promulgated thereunder, except those class IV forest practices designated by the forest practices board as being special forest practices and therefore subject to SEPA evaluation. (WAC 197-10-170 (19) (a)).

That portion of the SEPA Guidelines directing the content of EIS impact analysis (WAC 197-10-440 (8)) remained unchanged.

In May 1978 WDNR revised their WDNR SEPA Guidelines to bring them into conformance with the WDOE guidelines with no substantial alterations.

The adoption of SEPA in 1971 occurred during a period of nation-wide concern about environmental affairs. The Washington State legislation was modeled on the National Environmental Protection act of 1969 (NEPA; Public Law 91-190). A review of the pertinent aspects of NEPA is contained in Exhibit A.

SECTION 2 - FOREST PRACTICES ENVIRONMENTAL LITIGATION

There is only one significant court decision affecting forest practices and environmental affairs in Washington State. However, there are a number of other filed cases which have been settled out of court or which are dormant, all of which had or have the potential for raising interesting issues, particularly that of cumulative effects.

The one significant decision was in the case of Noel et al. vs. Cole et al., popularly known as the "Classic U" case. At litigation here was WDNR's sale of timber on the Classic U tract to Alpine Excavation, Inc., in July 1977. The proposed 25 acre clearcut for which a forest practice permit was issued in August 1977 included the cutting of some old growth timber. The plaintiff's arguments did not raise the issue of cumulative effects with respect to old growth harvesting, as such. However, implicit in any concern for the loss of old growth timber stands is the source of the loss: the cumulative effect of timber management policies which permit or encourage the harvesting of old growth stands.

A Memorandum Opinionin Noel vs. Cole was issued by the Island County Superior Court in June 1978, and a final Order Granting Summary Judgement was issued in January 1979. The principal decisions of interest were:

1) The exemption of all timber sales from SEPA (WAC 197-10-175 (4) (g) and WAC 332-40-175 (2) (g) was declared invalid. Therefore, all timber sales are subject to environmental review for determination if they constitute a "major action" under SEPA. The Classic U sale was determined by the court to constitute a major action, therefore requiring a Threshold Determination under SEPA for determination of environmental significance and the necessity of preparation of a full EIS.

2) The definition of Class IV-Special forest practices was declared invalid:

> The Forest Practice Board's definition and classification of Class

> IV forest practices as contained in WAC 222-16-050 is so narrow and restricted as to almost totally thwart the purpose and intent of the Legislature as set out in 76.09.010, 76.09.050 and the provisions of SEPA.

In a parallel decision, the court found the classification of the Classic U sale as a Class III forest practice invalid.

3) The court further found that not only did the Classic U sale constitute a major action, but that the facts showed:

> that there existed a reasonable probability that the clear-cutting of the Classic U tract would have more than a moderate effect on the quality of the environment.

The summary comments of the court are also worth noting:

> The court is compelled to comment that a suit such as the instant one was inevitable in view of the over-zealous actions of some State agencies in removing forest practices from SEPA considerations. It is undeniable that the State has a legitimate interest and concern in carefully controlling the impact of environmental considerations as they pertain to the vast forest industry of this state. Certainly the economics and peculiar problems of the forest industry must be considered in determining what appropriate and practical environmental controls can be imposed. However, in both SEPA and the Forest Practices Act it is clearly the intent of the Legislature that environmental factors will be considered. The effect of the various regulations involved in this action promulgated for the alleged purpose of interpreting, implementing and defining both SEPA and the Forest Practices Act, is to remove almost all environmental consideration from forest practices. This is not in keeping with either the intent of the legislature or this State's policy of endeavoring to balance environmental and non-environmental interests. In effect, administrative agencies have done what the legislature would not do, and have nearly completely exempted DNR and the timber industry from the provisions of SEPA. If the legislature wishes to exempt forest practices from SEPA it must say so. In the meantime, those state agencies empowered to implement the legislative mandates must do so in keeping with the purpose and intent of the legislation. The elimination of nearly all environmental considerations is not in keeping with legislative purpose and intent and leads directly to litigation of this kind.

As a direct result of this court decision, an environmental impact statement was prepared for the Classic U timber sale, with the Final EIS being issued in 1981. Also, WDNR instituted a study of Class IV-Special forest practices. The Class IV- Special Technical Committee issued their final report in 1980. The Class IV-Special issue is discussed in detail in a separate chapter of this report.

Flooding along the Green River in King County prompted a suit by a citizens group from Greenwater against the principal timber operator in the upper watershed of the Green River, the Weyerhaeuser Company (Greenwater vs. Weyerhaeuser). The principal contention of the Greenwater plaintiffs was that the cumulative effects of all forest practices in the upper Green River basin were directly responsible for the damaging flood flows that had caused property destruction and loss in the community. This litigation was settled out of court in 1980. In settling out of court, the plaintiffs agreed to not reveal the nature of the settlement.

The issue of the potential cumulative effects of forest practices on fisheries resources was raised in a case filed in 1980 (Steelhead Trout Club of Washington et al. vs. Cole). This case has not been followed through on by the plaintiffs and is functionally dormant.

The Washington Department of Natural Resources' 1979 Forest Land Management Plan (FLMP) and FLMP Final EIS is the subject of a lawsuit filed by the Washington Environmental Council and others (2.1 Million Acres of Trees vs. Cole). The plaintiffs contend that the FLMP is excessively broad in geographic scope in its attempt to deal with the entire state of Washington, that the long term nature of the plan is also excessive, and that the Final EIS is inadequate in its analyses. The litigation, if brought to court, would certainly raise a variety of cumulative effects issues. Presently, this case is somewhat dormant and the possibility exists for an out of court settlement.

Separate from the direct issue of litigation regarding forest practices and Washington state environmental protection legislation, is the issue of the Indian treaty fishing rights federal court decisions. In 1974 Judge Boldt issued his decision affirming the treaty rights of the western Washington treaty tribes to share equally in the state's salmon fishery (US vs. Washington). Subsequent litigation resulted in Judge Orrick's 1980 decision in US vs. Washington, Phase II which opinioned:

> Implicitly incorporated in fishing clause of treaties between United States and several Pacific Northwest Indian tribes was the right to have fishery habitat protected from man-made despoliation.

The full meaning of US vs. Washington,Phase II is yet to be determined, particularly with regard to the environmental protection clause cited above. A useful review of this issue in contained in Anadromous Fish Law Memo, Issue 12, April 1981 published by the Natural Resources Law Institute of the Lewis and Clark Law School, Portland, Oregon (distributed by the Oregon State University Extension Service Sea Grant Marine Advisory Program, Corvallis, Oregon).

SECTION 3 - CLASS IV-SPECIAL FOREST PRACTICES

When in 1978 the Island County Superior Court declared the then current definition of Class IV-Special forest practices to be invalid, the Forest Practices Board responded by directing the WDNR to "undertake a factual review of all forest practices with the purpose of identifying those groups of forest practices which have a 'potential for a substantial impact on the environment.'" The study was to be carried out by:

> (1) State-wide public hearings to provide an opportunity for members of the public and interested groups to present oral and

written testimony; and
(2) Solicitation of written input from other state and local governmental agencies; and
(3) Solicitation of written input from interested industry, environmental and citizen groups and individuals. (Forest Practices Board Resolution No. 1, 17 July 1979)

The Department of Natural Resources convened a Class IV-Special Technical Committee to carry out the study. The Technical Committee (TC) issued their final report to WDNR in May 1980. Fourteen issues relating to forest practices and substantial environmental impacts were identified and examined by the TC between October and December 1979. Certain issues received further investigation between January and April 1980. The TC's final report concluded that:

> The impacts and causal relationships of forest practices on the environment have not been well documented in the State of Washington. In the time allowed for this study, the TC was limited in obtaining extensive information or data on the frequency, impact, and extent of the problems inherent to the fourteen issues. Sufficient information was available when combined with the TC's expertise to conclude that:
>
> 1. Some forest practices on unstable slopes can substantially impact high value resources. In addition, changes in the regulations are necessary to adequately protect water quality.
>
> 2. Communication between water purveyors and forest land owners is a key element in preventing water quality problems in industrial and domestic watersheds.
>
> 3. Some fish hatcheries and artificial rearing areas can be adversely impacted by some forest practices when conducted on unstable slopes. Further, better communications between owners, combined with a longer period for application review, is key to preventing water quality problems for those water users.
>
> 4. Some forest practices conducted on moderate to steep slopes, in high snowfall areas, above capital improvements or areas of frequent public use, have the potential to impact the improvements or endanger life.
>
> 5. Certain harvesting operations can substantially impact aesthetics. When harvesting is conducted along certain scenic corridors, the operations may have the potential for substantial impact on the environment.
>
> 6. Harvesting timber in the sub-alpine zone is ecologically similar to but silviculturally different from traumatic natural events. Improvements are needed in practices and reforestation planning in these areas.
>
> 7. There needs to be a comprehensive study of the environmental aspects of cumulative effects of many forest practices in one area

in a short period of time and of the cumulative effects of forest practices where many impact thresholds are approached, but none reached.

8. Forest practices may adversely affect the habitats of unique populations. There is no common list or process which identifies the species populations or habitats.

9. The data available did not establish a relationship between forest practices and changing big game populations or winter range habitat.

10. The act of converting forest land to another use is not a forest practice. DNR and the affected local government have specific responsibilities as lead agencies under SEPA.

11. The data available did not establish a relationship between the application of chemicals and significant environmental impacts. Some need for further regulation was deemed necessary to better protect Type 4 water and possible small domestic water supplies.

12. The data did establish a relationship between prescribed burning and significant environmental impacts on fragile soils which can be adequately addressed through the burning permit process. No comparable relationship was found on fertile soils. Air quality is adequately regulated by the Smoke Management Program and the Clean Air Act.

13. Effective communication between the DNR and the State Historic Preservation Officer will help prevent damage to archaelogical and historic sites.

14. Some forest practices conducted within the boundary of public parks can have the potential for substantial impact on the environment within the park. Effective communication between DNR and the State Parks and Recreation Commission will help prevent damage to state park areas.

The TC made certain specific recommendations regarding changes in regulations, additions to the Class IV-Special forest practices list, and issues needing further study. A summary of those recommendations is outlined in Table 1.

In reviewing these conclusions of the TC, it is important to remember that the TC report prefaced the findings with the qualifying remark that not only have impacts and causal relationships not been adequately documented, that the TC was limited in the time available to conduct the study. In fact, to a large degree the study depended on the fortuitous observation of effects by persons from whom the TC solicited information. The fact that the TC failed to find evidence of significant environmental effects in a number of instances is not necessarily an indication of no significant environmental effects, but may merely be a reflection on the level of funding and time devoted to the study. Some of the TC subcommittees depended entirely on anecdotal reporting in what amounts to opinion polls, resulting in findings which have no scientific validity except possibly as a preliminary screening device.

To a limited degree, the FPB acted on the recommendations of the Class IV-Special TC. In October 1981 a number of changes and amendments to the Forest Practice Rules and Regulations (FPR) were proposed, including changes to the Class IV-Special provisions.

The introductory language of the Class IV-Special section was amended to clearly require compliance with SEPA for all Class IV-Special forest practices. The provisions of WAC 222-16-050 (1) (a) regulating forest practices affecting threatened and endangered species was modified to bring those provisions into conformance with federal definitions and to remove discretionary powers of the FPB to deny threatened or endangered status to any species. The provisions of WAC 222-16-050 (1) (c) concerning forest practices within park boundaries was clarified. These proposed changes, in amendatory format are:

> WAC 222-16-050 CLASSES OF FOREST PRACTICES. There are four (4) classes of forest practices created by the act. These classes are listed below in the order most convenient for the applicant's use in determining into which class his operations fall. All forest practices (including those in Classes I and II) must be conducted in accordance with the Forest Practices Regulations.
>
> (1) "CLASS IV - SPECIAL." Application to conduct forest practices involving the following circumstances (may) requires an environmental checklist in compliance with the State Environmental Policy Act (SEPA), and SEPA Guidelines, as they have been determined to have potential for a substantial impact on the environment. It may be determined that additional information or a detailed environmental statement is required before these forest practices may be conducted.
>
> (a) Harvesting, road construction, site preparation or aerial application of pesticides.
>
> (i) On lands known to contain a breeding pair or the nest or breeding grounds of any threatened or endangered species; or
>
> (ii) Within the critical habitat designated for such species by the United States Fish and Wildlife Service.
>
> (b) Widespread use of DDT or a similar persistent insecticide.
>
> (c) Harvesting (or) road construction, aerial application of pesticides and site preparation on all lands within the boundaries of any national park, state park, or any park of a local governmental entity, except park managed salvage of merchantable forest products.
>
> (d) Utilization of an alternate plan except those involving field evaluation of a new forest practice technology or any reforestation practice.

In summary, the TC did a better job than might be expected under the circumstances. That the FPB failed to act on the advice of the TC, but made only minor changes to the definitions of the existing Class-IV-Special Forest Practices will likely result in further legal challenges.

Table 1. RECOMMENDATIONS OF CLASS IV-SPECIAL TECHNICAL COMMITTEE

Issue	Change 1/ Regulations		Class IV Special		Further Study
	Yes	No	Yes	No	
1. Unstable Slope Conditions	X		X		
2. Industrial & Domestic Watersheds		X*		X	
3. Fish Hatcheries	X		X		
4. Snow Chutes & Slide Areas		X	X		
5. Scenic Transportation Corridors		X	X		X
6. Sub-Alpine & Harsh Climates		X*		X	X
7. Cumulative Effects		X		X	X
8. Unique Species & Habitats	X		X		
9. Key Big Game Winter Range		X		X	
10. Conversions		X		X	
11. Chemical Applications	X			X	
12. Prescribed Burning	X			X	
13. Archaeological & Historic Sites	X*			X	
14. Public Parks		X*	X		

Note: An asterisk (*) denotes recommended changes in DNR administration of forest practices regulations.

1/ Change in regulations means changing any part of the forest practies regulations except WAC 222-16-050, Classes of Forest Practices.

SECTION 4 - FOREST MANAGEMENT EFFECTS ANALYSIS REVIEW

A random selection of 15 forest management impact statements, assessments, and supplemental impact statements (see Exhibit B) were reviewed for impact analysis level of detail and professional and public commentary reaction. No systematic procedure was used to select the 15 analytical documents' the documents most readily available under the time and budget constraints of this phase of the Cumulative Effects study were more-or-less self-selective. Likewise, no statistically rigorous method of analyzing these documents for level of detail and commentary reaction was employed; the conclusions offered here are simply a comparative review of analytical techniques and a report of semi-quantitative tabulations of commentary reactions.

Impact Analysis: The impact statements, with specific exceptions, can generally be characterized as:

1) qualitative, or at best, semi-quantitative;

2) often euphemistic and self-serving;

3) restricted to direct effects and only the most obvious secondary effects;

4) having only inadvertant consideration of cumulative effects, and then not identified as such;

5) lacking in scientifically valid support for many assertions or analyses;

6) often so superficial as to make intelligent review and comment virtually impossible.

Exemplary exceptions to the above characterizations are the 10-year Timber Management Plan impact statements of the US Bureau of Land Management, particularly the Roseburg Timber Management EIS, and to a lesser degree the Ceder-Tolt Watershed Management Plan EIS. The USBLM documents actually attempt to consciously account for cumulative effects, particularly with regard to:

1) the management of both BLM and non-BLM lands within the management area;

2) old growth timber harvest and associated old growth type wildlife habitat;

3) spotted owl habitat management;

4) wildlife habitat age groups in general;

5) snag density management for wildlife habitat;

6) selected wildlife population levels;

7) fiscal and economic issues.

While not flawless, the USBLM impact statements can be characterized as being very quantitative, clearly written, well documented, and comprehensive in comparison to other forest management impact analyses as well as all impact analyses in general.

Commentary Response: Grouping of commentary responses may readily be subdivided into two generic categories, impact issues and procedural issues. The latter is not directly germane to the Cumulative Effects study, but is nonetheless instructive.

The principal impact issues which repeatedly came up in all or most of the sets of commentary responses were:

1) Old Growth/Wilderness Elimination: respondents commented on their concern for the continued elimination of this habitat type, the lack of analysis of the cumulative effects of its elimination or reduction, and the perceived ecological and cultural or heritage resource value.

2) Herbicide and Pesticide Use: respondents are principally concerned with the human health aspects of herbicide/pesticide use, and secondarily with the ecosystem/wildlife aspects; in general, the public has no trust in the ability or willingness of forest managers to honestly evaluate the environmental effects of the use of forest chemicals.

3) Fish and Wildlife: no clear patterns emerge from the comments, but some issues are: riparian zone managment, fisheries habitat degradation, old growth wildlife habitat reduction, and rare, endangered and sensitive species.

4) Douglas-fir Monoculture: respondents question the wisdom and cumulative effects of transforming substantial areas of the forested regions of the state into ecologically simplistic Douglas-fir monocultures.

Procedural comments were directed towards impact statements issued by the Washington Department of Natural Resources under the previous administration of Bert Cole. The principal issues were:

1) Draft EIS commentary period too short;

2) Superficial impact analyses;

3) Inadequate data to support assertions, analyses, or decisions;

4) Self-serving nature or tone of impact statement.

SECTION 5 - CONCLUSIONS

Clear requirements for the analysis of cumulative environmental effects have existed since 1971 in federal regulations, and since 1974 in Washington state regulations. These requirements are based on implied mandates in the federal and state environmental protection legislation.

There has been little or no conscious attempt to address cumulative effects in forest management environmental impact analyses with the exception of recent documents issued by the USBLM. While specific research quantitatively identifying the exact nature and magnitude of the cumulative effects of forest practices is yet lacking, basic ecological theory is an adequate basis for at least acknowledging the existance of certain likely cumulative effects. The SEPA Guidelines direct that "impacts which are potential, but not certain to occur, shall be discussed within reason" (WAC 197-10-440 (8) (a)).

The following discussion is illustrative, not inclusive, of some issues in cumulative effects.

Wildlife species exhibit varying degrees of habitat preference, including successional stage preference (Odum 1959, Hutchinson 1959, Berger 1961, Thomas et al 1979). Alterations of the distribution and abundance of habitat types and successional stages will therefore have effects on the distribution and abundance of wildlife species to varying degrees. Forest management policies and practices which affect the distribution and abundance of climax old growth forests, seral managed Douglas-fir forests, and select against early succession red alder woodland seres will unquestionably have cumulative effects on the distribution and abundance of wildlife populations. Only the magnitude is debatable.

The hydrologic regime of a watershed is affected by the nature, density, and succesional stage of the vegetation growing on it acting through the processes of rainfall interception, evapotranspiration, absorption, and runoff (Kittredge 1948, Colman 1953, Dunne and Leopold 1978). It has been determined that forest practices do affect both runoff and erosion (R-5 Watershed Management Staff 1980). The principal questions remaining focus on the relative importance of different forest practices and the extent to which an individual watershed may be altered.

It is generally agreed that the natural production of salmon is lowered under extremely high sedimentation levels in stream gravels, and that forest practices can and do contribute to these effects (Gibbonsand Salo 1973, Dlugokenski, Bradshawand Hager 1981). The beneficial effects of spawning gravel cleaning on egg-to-fry survival rate has been demonstrated (Allen, Seeb and King1981). The cumulative effects of forest practices on fisheries resources may be difficult to quantify, but it is clear that the effects exist. Other issues include streamside habitat and water quality.

Ecosystem processes have evolved by natural selection much as have individual species (Connell and Orias 1964; Collier et al 1973:530). Selection operates to improve patterns of adaptation of the species to the ecosystem, thus affecting ecosystem patterns.

> The old growth forests existing today are complex ecosystems which have evolved by natural selection through successional stages during the vegetative community development process. Evidence now points to the simultaneous evolution of mycorrhizal tree hosts, hypogeous fungi, and small mammals that function as a transport mechanism.
>
> Considerable research is required to fully understand the relationships and importance of these processes to long-range timber production. It now appears that dispersal of mycorrhizal fungi by

small mammals may be a critical factor in forest plantation establishment and survival in some instances (Maser et al 1978). The functioning of the old growth forest as a system, however, has not yet been studied in depth. As recent as 10 years ago, nothing was known about sources of nitrogen in old growth stands. Since then, epiphytic lichens and wood-dwelling bacteria have been identified as significant sites of nitrogen fixation (Franklin et al 1981)
Roseburg Timber Management Draft EIS, USBLM, 1982

Similarly, what are the ecosystem properties of the old growth forest that have co-evolved with the Douglas-fir Tussock Moth (DFTM), that allows their relatively successful coexistance, but which properties are lacking in the seral managed Douglas-fir forest that leaves the Douglas-fir forest so devastated by population outbreaks of the DFTM?

EXHIBIT A

NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act of 1969 (NEPA; Public Law 91-190) grew out of legislation proposed by Senator Henry M. Jackson which would have directed the Secretary of the Interior to develop a comprehensive and continuing program of study, review, and research for the purpose, among other things, of promoting and fostering means and measures which would prevent or effectively reduce any adverse effects on the quality of the environment in the management and development of the nation's natural resources. In committee, the proposed legislation was transformed into something very different which broadened the scope of the legislation from just the Secretary of the Interior, to include all federal government agencies. It was at this time that provisions requiring an environmental impact statement were added.

NEPA, as passed by Congress on 1 January 1970, had a stated purpose of

> Sec. 2. The purposes of this Act are: To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.

This mandate was to be carried out primarily through a series of measures to be adopted by all Federal agencies to integrate the natural and social sciences and the environmental design arts into the planning of all major Federal projects, to develop methods and procedures for the consideration of natural amenities along with economic and technical factors in decision making, and to include in every recommendation or proposal for actions significantly affecting the environment, a detailed statement of environmental impacts and design alternatives (91-190 Sec. 102). The legislation made no specific mention of a concern for "cumulative effects", but the language of Sec 102 (E) suggests such a concern:

> (E) recognize the worldwide and long-range character of environmental problems and, where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment;

The importance of NEPA to a discussion of SEPA and cumulative effects lies in the fact that SEPA is modeled on NEPA with much of the language of NEPA borrowed, unchanged.

> It is a well settled principal that when a state borrows federal legislation it also borrows the construction placed upon such (federal) legislation by the federal courts. (Juanita Bay Valley Com. v Kirkland, Wn App. 59, 68-69 (1973))

This principal of applying interpretations of the federal law to interpretations of the state law is diluted somewhat by the adoption of subsequent, differing interpretive regulations.

Implementation of NEPA is by means of master guidelines adopted by the Council on Environmental Quality (CEQ) and subsidiary guidelines adopted by the various federal agencies. The CEQ guidelines issued on 23 April 1971 contained a specific requirement for the consideration of cumulative effects in the instructions for the content of an environmental statement:

> (v) The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity. This in essence requires the agency to assess the action for cumulative and long-term effects from the perspective that each generation is trustee of the environment for succeeding generations (6.(v))

In succeeding years, the procedural policies of the various federal agencies implementing NEPA became increasingly divergent. In 1978 CEQ issued a set of revised and more detailed Regulations For Implementing The Procedural Provisions of The National Environmental Policy Act (40 CFR Parts 1500-1508). In defining the "scope" of an environmental impact statement, CEQ directed that:

> Scope consists of the range of actions, alternatives, and impacts to be considered in an environmental impact statement. The scope of an individual statement may depend on its relationships to other statements (1502.20 and 1508.28). To determine the scope of environmental impact statements, agencies shall consider 3 types of actions, 3 types of alternatives, and 3 types of impacts (40 CFR 1508.25)

The three types of impacts are defined as:

> (c) Impacts, which may be: (1) Direct. (2) Indirect.
> (3) Cumulative. (40 CFR 1506.25 (c))

Cumulative impact is further defined as:

> "Cumulative impact" is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably forseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. (40 CFR 1508.7)

Cumulative impacts are differentiated from direct and indirect impacts which are defined as:

> (a) Direct effects, which are caused by the action and occur at the same time and place.
> (b) Indirect effects, which are caused by the action
> and are later in time or farther removed in distance, but are still reasonably forseeable. Indirect effects may include growth-inducing

effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

Effects and impacts as used in these regulations are synonymous. Effects includes ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative. Effects may also include those resulting from actions which have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial. (40 CRF 1508.)

EXHIBIT B

IMPACT STATEMENTS AND ASSESSMENTS REVIEWED

Willamette National Forest Multiple Use Land Management/Timber Management Final EIS, Parts 1 & 3. USDA Forest Service, 1975.

Kittitas Land Management Plan (Wenatchee N. F.) Draft EIS. USDA Forest Service, 1978.

Canal Front Planning Unit (Olympic N.F.) Final EIS. USDA Forest Service, 1978.

Cedar-Tolt Watershed Management Plan Draft EIS. Seattle Water Department, 1979.

Forest Land Management Program Draft & Final EIS. Washington Department of Natural Resources, 1979.

Classic "U" Timber Sale, Whidbey Island Draft & Final EIS. Washington Department of Natural Resources, 1980-81.

South Coast & Curry Sustained Yield Unit 10-year Timber Management Plan Final EIS. US Bureau of Land Management, 1981.

Westside Salem 10-year Timber Management Plan Draft & Final EIS. US Bureau of Land Management, 1981.

Quartz Cedar Timber Sale Draft & Final Supplemental EIS. Washington Department of Natural Resources, 1981.

Eastside Salem Sustained Yield Unit 10-year Timber Management Plan Draft EIS. US Bureau of Land Management, 1982.

Quarter Mile Timber Sale Final Supplemental EIS. Washington Department of Natural Resources, 1982.

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APPENDIX B

CUMULATIVE IMPACT ASSESSMENT IN CALIFORNIA

Prepared by

BRUCE R. GROGAN

for

ECOSYSTEMS, INC.

August 30, 1982

TABLE OF CONTENTS

INTRODUCTION

This report attempts to provide an overview of present efforts in California to address the cumulative impacts of management activities on watersheds. The information contained herein was obtained from the available literature, through numerous telephone conversations with involved professionals, in conversations with resource managers, and in written communications with other experts.

SECTION 1 - STATE OF CALIFORNIA ACTIVITIES

1.1 - EDGEBROOK CONFERENCE (JUNE 1980)

The conference, which was attended by the author while he was a member of the Washington State Forest Practices Technical Advisory Committee, was sponsored by the Department of Forestry and Resource Management and Cooperative Extension, University of California at Berkeley. The purposes of the Conference, according to the report, were:

"1. to attempt to refine conceptual understanding of how to define and measure cumulative effects;

2. to assess the present state of scientific knowledge about cumulative effects of forest management practices and programs; and

3. to identify the critical information gaps that must be filled in order to provide a basis for formulating approaches and policies for managing cumulative effects."

Note should be made that "The Conference was not specifically designed to address or resolve policy issues involved in the mitigation, control, or management of cumulative effects of forest management practices." In fact, "the guiding premise was that before such policy issues can be defined and resolved, a systematic effort to better understand the nature of cumulative effects is a necessary first step." The following papers were presented:

1. The Topology of Impacts (Luna Leopold)

2. Cumulative Impacts on Watershed Processes and Soil Productivity (Paul Zinke)

3. A Perspective on the Cumulative Effects of Logging on Streamflow and Sedimentation (Raymond Rice)

4. Vegetation Dynamics and Intensive Forest Management (James Rydelius)

5. Some Cumulative Effects of Forest Management on Wildlife (Richard Taber, Stephen West and Kenneth Raedeke)

6. Cumulative Effects of Forest Management on Watersheds... Some Aquatic Considerations (E.O. Salo and C.J. Cedarholm)

7. A Brief, Incomplete, and Heuristic Guide to Thinking About Legal and

Institutional Aspects of Regulating Cumulative Effects of Silvicultural Practices on Fragile Watersheds (Sally Fairfax)

8. The Economics of Cumulative Effects (John Zivnuska)

9. A Summary of the Edgebrook Conference on Cumulative Effects of Forest Management on California Watersheds (Harry Camp)

The results of the conferences were of primary value in that they emphasized that state of professional confusion characteristic of attempts to deal with the emerging issue of cumulative effects. The fact that a select group of professsionals could not arrive at an acceptable direction for future efforts is indicative of the complexity of the issue and the undetermined magnitude of the problem. Aside from information sharing, the general opinion of professionals contacted recently is that the Conference was not of much value. But one must remember that this is the opinion of individuals who are and have been working with the issue at technical and management levels. And they represent a small, somewhat elite sub-grouping of resource managers who have familiarity with the issue. For the others - the overwhelming majority - the ideas expressed by the conference participants are invaluable background materials for the development of an understanding of the cumulative effects issue.

1.2 - CUMULATIVE EFFECTS TASK FORCE (FORMED MARCH 18, 1981)

Henry Vaux, Chairman of the State Board of Forestry, invited select individuals to participate as members on the Cumulative Effects Task Force. The membership included one industry forest hydrologist, one industry civil engineer, one United States Forest Service hydrologist, a member of the State Water Quality Control Board, and an environmental consultant. (For names and contact points, refer to Exhibit 4) The need for a formal review of the cumulative effects issue became apparent during review of the Board of Forestry's report which was submitted to the State Water Resources Control Board in June 1980 pursuant to Section 208 of the Federal Water Pollution Control Act. It was noted therein that the cumulative effects of timber harvesting are inadequately considered in the regulatory system. The report also noted that "development of best management practices for control of cumulative effects requires further research and may need different institutional and regulatory mechanisms than the Board of Forestry now has available". Chairman Vaux defined the duties of the Task Force as follows:

"1. Provide a working definition of the cumulative effects of successive harvesting operations. Since existing literature uses the term 'cumulative effect' to designate what appear to be generically different phenomena, more than one definition may be necessary.

2. Review and summarize research and other empirical work that has been done relative to cumulative effects, such as that of the United States Forest Service.

3. Delineate approaches that the Board can use to address the issue, including educational and analytical tools to help foresters evaluate cumulative effects, and regulatory approaches that, if needed, the Board could implement.

4. Set forth critical research and information needs."

The report of the Task Force was completed in January 1982. The group's efforts "focused on changes in the beneficial uses of water due to increased sedimentation and stream bank erosion resulting from the combined off-site effects of multiple silvicultural operations." Proceeding under severe time and financial constraints, the Task Force did not perform an in-depth literature review of all aspects of the cumulative effects issue. They chose, instead, to rely heavily on the four primary references cited on page 16 of The Report of Cumulative Effects Task Force.

The Task Force appears to have accomplished at least a partial resolution of the problem in that they agreed on definitional and analytical frameworks from which to proceed. Although reference was made to more inclusive definitions of cumulative effects, the following is the working definition developed by the group and the reference point for their subsequent recommendation:

> "Changes in the the beneficial uses of water due to increased sedimentation and stream bank erosion resulting from the combined off-site effects of multiple silvicultural operations, particularly timber management harvesting and related road construction."

The report provided a "Vocabulary of Cumulative Effects" which was developed to provide additional descriptive terminology. The terminology is as follows:

1 California Board of Forestry, Report of The Board of Forestry to the Water Resources Control Board, resolution 80-5-6, June 11, 1982.

Additive vs. Synergistic:

"Cumulative effects are additive if the effects of multiple actions are independent of each other. If no interactions occur, additive effects are measured as the simple sum of the effects of separate projects taken together. In contrast, effects are synergistic if they interact such that the resultant outcome is greater than the sum. Some additional increment of change results from a synergistic process because of interactions taking place between the effects."

Thresholds:

"Thresholds mark points where conditions change; that is, where rates of change accelerate or decelerate.... Thresholds are properties of systems; of concern in impact assessment are those thresholds where effects begin to cause harm, to activate feedback mechanisms, or become irreversible..."

Feedback Mechanisms:

"Feedback mechanisms are those which cause interactive reinforcement of ongoing processes. A feedback loop exists when a chain of events circles around to reactivate the chain..."

Baseline:

"The effect of an action must be measured in relation to some reference point, or baseline. When assessing cumulative effects it must be clearly stated what baseline has been chosen for analysis: the condition of the system as it is now (the static baseline); the condition of the system if natural conditions were to continue over time (the dynamic baseline); or the condition as it was at some time in the past (the historic baseline). Impacts measured from a dynamic baseline may be quite different from those measured from the static, especially when mitigation measures are considered, and may affect the determination of which project has the overall lesser effect."

Resiliance and Attenuation:

"Natural systems are resiliant and, within limits, can return to equilibrium conditions after disturbance... The concept of resiliancy and attenuation is important since management options can make use of this capacity to mitigate cumulative effects and maintain them below thresholds of long-term damage."

The Task Force was mandated to consider regulatory approaches to resolve cumulative effects problems. The report stated that "the cumulative effects under the current rules (effective 1975) are not clear. However, a great many problem areas exist from past (pre-1975) activities. The group concluded that:

"...potentially harmful cumulative effects may be present to a greater or lesser degree in numerous smaller-ordered streams and that the primary mitigation against such effects is diligent control of sediment-producing activities."

The Task Force considered regulatory options according to the following criteria:

"1. appropriateness of the solution to the scale of the problem;

2. workability within the present regulatory framework of the timber harvesting plan; and

3. effectiveness in responding to public, industry and state concerns."

The options which were recommended for adoption by the Board of Forestry are:

1. Support the use of on-site best management practices to minimize cumulative effects.
("The Task Force strongly agrees that the use of on-site best management practices is the single most effective means to protect water quality.")

2. "...the mitigation of cumulative effects may be possible within the present framework of individual timber harvest plan review, without the

development of a larger planning system involving timber harvest scheduling."

3. Two areas of concern regarding on-site practices merit special attention: improper management of sensitive land types (SMZ's, unstable slopes, inner gorges) and the quality and completeness of available geologic-geomorphic information.

4. Require consideration of the immediately adjacent and downstream channel conditions in the feasibility analysis.
("In order to determine whether a THP will cause or aggravate cumulative effects, there must be a procedure at the time of plan review to allow the larger environmental setting to be examined. Ideally, the hydrologic conditions of a watershed would be understood before harvesting was conducted. In this way, the impact of a proposed harvest operation could be measured against the capacity of the system to absorb additional impact.")

The group recognized the deficiency of the available data base and the attendant problems. When state mapping programs are completed, the situation will change, but, for now, the recommendation is that "common sense" assessments be made by the owner/operator within either the RPF or the Board deciding on the appropriate methodology. Appropriate measures to prevent significant cumulative effects "would remain limited to those now in use: conformance with forest practice rules and on-site mitigation". This option "is the best interim alternative until further information is available".

The options which were rejected by the Task Force are:

1. Allocate timber harvest operations over time and space.
   Reason rejected: insufficient information at present time.
   Major Issues:
   a. watershed threshold limits
   b. multiple ownerships
   c. multiple land uses within a watershed
   d. antitrust regulations

2. Master design of road system.
   Reason rejected: unfeasible.
   Unresolved Issues:
   a. individual THP's provide no overview of the road system.
   b. necessary disclosure of proprietary information regarding future harvest locations and timing.
   c. forest practice standards are being revised and should be evaluated.

The Task Force recommended that the following Research/Education needs be met in order to develop necessary information regarding the cumulative effects of forest management activity and to foster an increasing awareness of the issue among those concerned with responsible forest resource management.

1. A study should be conducted to measure the effectiveness of the current forest practice rules, as actually implemented, and their effect

cn preventing significant cumulative effects.
NOTE: At the time which the Report of the Task Force was issued, the forest practices regulations were under revision. They have subsequently been revised and approved by the Board of Forestry. It is the effectiveness of these revised regulations which is referred to.

2. A study could be conducted to evaluate the condition of lower ordered (smaller) streams... As an outgrowth of this study, a system and/or criteria for assessing stream and water conditions could be developed for use by RPF's.

3. The majority of the Task Force believes that there is a need for a reliable data base to be used to identify critical sensitive areas within watersheds.
NOTE: There presently is an ongoing California Watershed Mapping Program which stemmed from the Board of Forestry's Best Management Practices Program under Section 208. Concentrating in northern California, the "purpose of the program is to apply additional geological expertise to indentifying unstable areas prior to the time an RPF sets to work developing a timber harvest plan". It is mostly an aerial photo effort. This is a highly controversial program which focuses on "management guidelines" associated "with each of the mapped land forms and suggested management practices which should be applied when those features are encountered in timber harvest plans. The issue is the regulatory status of the guidelines. California Department of Forestry takes the position that they are merely suggested and not binding. The State Water Resources Board wants them to be transformed into regulations. The issue is still unresolved!

4. The Task Force identified a need of foresters and geologists for further education. It recommends that this educational need be met in two ways. "First, we would request that the Board point out the need for further field-applied engineering/geology/geomorphology education to those universities in California with forestry programs. Second, we feel that these needs can be met for foresters out of school by having the University of California Extension sponsor an applied field-oriented course."

The Report of the Task Force was completed in January 1982 and presented to the California Board of Forestry in April 1982. It was referred to the Forest Practices Subcommittee which briefly discussed it on April 6, 1982. At this time only one member of the subcommittee had read the report. It was therefore decided to wait until a later meeting to discuss it. It is unlikely that the report will be seriously addressed before late 1982 or early 1983 as the Board of Forestry is busy addressing other tasks outlined in the 208 Report.

DISCUSSION

The Task Force has made some definitive steps in the direction of issue clarification if not problem resolution. These results are quite different from those achieved at the Edgebrook Conference (June 1980) where confusion and disagreement characterized the condition of a cumulatively intelligent body. That conference was valuable primarily because it demonstrated blatant conditions of "warped reality" and "perverted perceptions". In spite of a great deal of rhetoric, nothing concrete or tangible was developed. No definitions were proposed and accepted. No relationships between theory and management received majority support. At least this Task Force went that next step and provided a chopping block which, when viewed in concert with some of the efforts being undertaken by federal land managers, may be fairly substantial! But the report is still controversial. Industry representatives contacted to date are sufficiently comfortable with the "general" terminology employed. Enviromentalists believe that the report has not gone "far enough". Some believe that at least one major issue is not sufficiently touched upon, so to speak. That focuses on the impact of repeated operations on a single site. Paul Seidelman agreed with myself that the Task Force missed the boat on that one.

Wherever it goes from here, it is clear that the principles applied will be resurfacing in other arenas. Some major ones are:

a. hazard mapping/identification
b. off-site assessment of impacts
c. threshold determinations for larger units (i.e., watersheds)
d. resiliance as a management tool
e. cross-discipline training and experience
f. baseline assessments
g. stringent on-site control
h. relationships of number of activities within a given area vs. timing and location of activity
i. relative importance of sediment increases vs. increases in large storm flow peaks (See Exhibit 1)

1.3 - WATERSHED MAPPING

As previously mentioned, there is presently an ongoing Watershed Mapping Program in progress. This program was initiated prior to the development of the Task Force's recommendation for mapping and subsequent to the Edgebrook Conference. I have been told by several people that in 1980, there was 208 money available but in need of an issue. The rest is history. This particular hazard mapping project "is a joint agency watershed project which has interagency agreements between the State Water Resources Control Board (SWRCB) and the Department of Forestry (CDF); CDF and the California Department of Mines and Geology (CDMG); and, WRCB and the Environmental Protection Agency (EPA)". The long-range goals of the project are to:

"1. Retain productive forest soils, reduce sedimentation of North Coast streams and protect fish habitat;

2. Achieve compliance with the 1983 clean water goals of the Federal Water Pollution Control Act; and

3. Achieve the objectives set forth in the State's water quality control plans (basin plans)." 1

1 Department of Forestry Interagency Agreement No. 0-090-418-0, Exhibit B to Water Resources Control Board, p. 1.

The methods to be used include:

"1. Map physical characteristics that can be correlated to landslide potential, soil erosion potential, and stream bank erosion potential;

2. Develop maps that show the relative potential of each of the geologic, soil or hydrologic constraints;

3. Make the maps available to land managers in order that they manage land more efficiently and reduce the cost of erosion control;

4. Incorporate use of these maps into the Agency's Timber Harvesting Plan (THP) review procedure; and for developing recommendations to the Board of Forestry for integration into the regulatory process;

5. Determine the feasibility of computer digitization of basic data maps;

6. Examine alternative means of increasing landowner interest and participation in watershed studies; and

7. Seek funding to map other North Coast watersheds." (Ibid.)

The product for the project should:

"1. Develop a set of reproducible hazard maps and legends with a map scale no smaller than 1:24,000."

The California State Department of Forestry shall:

"1. Integrate the maps into the Agency Timber Harvesting Plan (THP) review process for protection of soil and maintenance of water quality and aquatic habitat.

2. Propose rule changes based on the compiled data and completed maps to the Board of Forestry (BOF) for its consideration.

3. Seek additional funding for mapping other watersheds not covered by this or other similar projects."

Note should be made that this project is directed primarily at large industrial timberlands. To date the work has consisted of mapping based on aerial photographs with ground truthing being impossible due to industrial refusal to permit entry onto their lands. The industrial resistance - or in the land of "Pole-timber", the word "Solidarity" may be appropriate - is not to individuals, but to the objectives of incorporating the products (maps) into the Timber Harvesting Review Process and of developing recommendations for the Board of Forestry to integrate into their regulatory process. It's a hell of a mess! Needless to say, one must judiciously review the results of unverified photo interpretation. (One industry representative told me of one person on the mapping team who identified a soil movement on a photo only to be told later that it was a landing!)

NOTE: The recommendation of the Task Force appears to dove-tail well with at least the intent of this project but they also go further in that stream channel analyses are called for.

1.4 - STREAM CLASSIFICATION

The new classification system which the BOF adopted in 1981 is in a holding pattern. "Once the new system of classification goes into effect, watercourses [note: not streams] will be classed based on beneficial uses of the water, aquatic habitat and channel condition. Additionally, the degree of protection will be based on the slope and classification given." The implementation of the system has been delayed by ambiguity in the referencing of the words "beneficial use" and "deleterious".

SECTION 2 - FEDERAL ACTIVITIES

2.1 - FEDERAL LAND MANAGEMENT AND CUMULATIVE EFFECTS - AN OVERVIEW

Involvement of the United States Forest Service in cumulative effects discussions precedes the Edgebrook Conference and has continued actively into the present. Both regional managers and responsible professionals on numerous forests continue struggling with the issue. In March 1980, an interdisciplinary team of Forest Service experts convened in Redding, "for the purpose of developing a methodology for determining the potential for cumulative watershed impacts, resulting from the implementation of forest planning alternatives to adversely affect soil or water resources". The basis for present Forest Service efforts may be traced to the work of Paul Seidelman, formerly the Region 5 Geologist, as presented in "Methodology for Evaluating Cumulative Watershed Impacts", dated February 1981. Herein is contained the components of his Equivalent Road Area Methodology which both the Region and individual forests are modifying in response to their peculiar needs. The range includes application within cumulative effects assessment and management options in timber harvesting regions to application in regions concerned with both wildfires and prescribed burning. The methodology was also employed in the Grider Creek Area Drainage Development Plan and Environmental Assessment performed by Larry Seeman Associates for the Klamath National Forest.

Since Seidelman's methodology forms the basis for federal land managment efforts, a brief review of it is desirable. Seidelman proposes that "Cumulative watershed impacts include all impacts on beneficial uses of water and soil occurring away from sites of primary land use. They are the result of the additive effects of land disturbing activities...The focus [of this paper] is on the effects of vegetative management (primary timber management) and roads on cumulative watershed impacts." Seidelman focuses on sensitive watershed lands (floodplains, wetlands, active landslides, valley inner gorges and streamside management zones) which represent the areas "most susceptible to damage by man's activities". The methodology presented, and subsequently employed in a number of locations, is "for tracking the rate of development on normally manageable watershed land, and assessing the degree of damage to sensitive forest lands". The management philosophy behind the approach "is that sensitive watershed lands should be managed primarily for protecting water resource values while the rate of development on other lands is kept within certain thresholds so that cumulative effects do not cause an overall decline in watershed condition".

Seidelman's approach reflects his conclusion that the location of vegetation manipulation and road construction is the most important variable in the determination of cumulative effect impact levels. Other important variables focus on how an operation is performed and how much activity occurs within a given area in time and space. These relevant factors were grouped into two categories:

1. indicators of most sensitive watershed lands
2. indicators on other watershed lands

Sensitive watershed lands are defined as "lands having an extreme tendency towards producing high levels of watershed impact...". They are indentifiable by analyses of the following factors:

"1. streams with valley inner gorges
2. active landslides
3. slopes greater than 80%
4. riparian areas
   a. floodplains
   b. wetlands
   c. riparian ecosystems
   d. streamside management zones."

It is within these sensitive watershed land areas that the management of silvicultural activities for water quality appears to be most important. Activities on non-sensitive lands are of relatively minor concern in the methodology. Seidelman, in order to relate theory to management practices and to both compare watersheds and develop thresholds of allowable disturbance, developed a system of equating timber management disturbances and roading within a watershed into "EQUIVALENT ROAD ACRES (ERA'S)". The ERA's were determined through literature reviews and professional judgement. Accurate ERA values would reflect physical watershed conditions specific to geomorphic areas. One would therefore expect variance in values to refect on-site differences within a region of concern. ERA values are used in conjunction with time periods which reflect hydrologic and root strength recovery and rotational periods. Note that this "ERA analysis relates only to the accumulated effects of peak flows causing off-site impacts to sensitive watershed lands"!

The ERA methodology is an attempt to help managers plan the timing and magnitude of activities in ways which will prevent cumulative off-site negative impacts on water quality parameters. Prior to application, two types of indices are needed for each watershed:

"1. Natural Sensitivity -
   a. Acres of sensitive watershed land per square mile of watershed, i.e., acres of inner gorge, active slides, slopes exceeding or equal to 80%, and riparian areas.
   b. 'Other' watershed lands in square miles per square mile of watershed.

2. Present Condition -
   a. of sensitive lands:
      - Percent of sensitive watershed land disturbed by past actions, i.e., roads (acres); vegetative management history amount

(acres); year of treatment; type of treatment; age and success of revegetation.

b. of other watershed lands."

A key point in the methodology is the incorporation of a RECOVERY FACTOR for each treatment type by watershed. Based on field experience, the recovery factor represents the temporal variation in severity of impact and sensitivity of site which is necessary for evaluation of future allowable operation.

The development of watershed maintenance thresholds is based on "percent of sensitive watershed lands disturbed and the ERA occurring on other watershed lands". Thresholds are used to indicate the point at which irreversible cumulative impacts occur. Remember, the goal is to establish "...the relative sensitivity of watersheds and the maximum disturbance thresholds necessary to mitigate cumulative effects". The author claims that the system, presented in overview here, "allows for a rational approach to answering the following questions:

1. Which watersheds are most sensitive to disturbances?
2. Which watersheds have had the greatest amount of disturbance in sensitive zones?
3. In which watersheds is it most desirable to initiate watershed improvement projects?
4. In which watersheds are timber management activities least likely to be constrained due to sensitive ground conditions or past management practices?
5. In which watersheds is the implementation of BMP's most urgently needed?"

Note should be made that the report recommends that thresholds should be developed on an individual forest base and during the planning process. As Seidelman stated:

> "An important aspect of this system is the flexibility provided in highly developed or over-developed watersheds where watershed improvement projects could be utilized to allow for additional land disturbances from vegetative management and roading. Such watersheds could also undergo additional vegetation management under highly constrained management practices. Thresholds should serve to trigger various levels of constraining or mitigating management practices and should not be considered as 'shut down' barriers."

The preceding discussion attempted to present a simplification of the concept upon which the present efforts of the U.S. Forest Service in Region 5 are based. One should study the Seidelman Report to acquire a greater familiarity with the methodology and its attendant issues. Now let's review what some of the individual forests have done with the concept...

2.2 - CUMULATIVE IMPACT ANALYSIS IN FOREST PLANNING SHASTA-TRINITY NATIONAL FOREST

The Shasta-Trinity National Forest appears to be one of the most progressive in the field of performing cumulative effects analyses for inclusion in forest planning processes. The following represents a synthesis of the approach, the results and the problems which have been encountered.

Cumulative effects are viewed as a "function" of:

"1. the amount of sensitive ground and its hazard level within a watershed;

2. the level of management activities; and

3. the location of impacts relative to hazardous areas." (Exhibit 11)

In the Forest Plan, an evaluation of both the "amount of sensitive ground present within a watershed and the level of past and present harvesting activities" has been performed. The effort started with an assumption that the potential of any watershed to produce sediment is a function of:

mass wasting hazards
surface erosion hazards
slope gradients
drainage density
channel gradient
precipitation
elevation
peak flow characteristics

Now, in order to translate these into a meaningful characterization of relative sensitivity of watersheds to cumulative impacts, the following factors were weighed through a calibration process and combined in a simple equation to yield a SENSITIVITY INDEX: slope gradient, soil erodibility, mass wasting potential and peak flow characteristics. Appropriate watersheds, a function of stream order, were grouped into low, moderate and high sensitivity classes.

In conjunction with a sensitivity analysis, the level of management activity was determined using the EQUIVALENT ROAD AREA methodology which was developed by Paul Seidelman and approved by the Regional Watershed Management Staff.

Finally, a MANAGEMENT LEVEL THRESHOLD, or THRESHOLD OF CONCERN, was developed for each watershed based upon inherent sensitivity. These are expressed in % ERA. Working thresholds for the three sensitivity classes on the Shasta-Trinity National Forest are:

14% ERA for highly sensitive watersheds
16% ERA for moderately sensitive watersheds
18% ERA for low sensitivity watersheds

What forest Planners do with these data is to assess the future situation in a given watershed by projecting each proposed management alternative in terms of Equivalent Road Area. "This, when added to the existing ERA level, which was modified by an anticipated recovery factor, would yield a projected impact level for each of the watersheds. This was expressed in terms of ERA acres below threshold." (Author's Note: I have seen some projections which exceed thresholds, thereby indicating that such activity is not acceptable at this time!) "The number of acres below threshold is a comparative measure of the effects of the different alternatives on water quality. From a water quality viewpoint, the alternative which is farthest below threshold is the most desirable."

In summary, the Shasta-Trinity approach builds upon the Seidelman methodology by developing thresholds of concern for all 5th Order watersheds and sensitivity indices and translating those into actual management options. It represents a "unified way of looking at management", according to Don Haskins, the Forest Geologist. It is being applied at the individual watershed level as well as for the entire area. The Forest used FORPLAN to assist in the broader, forest-wide analysis and directed management to commit to specific sub-thresholds of concern. This provides general guidance to on-site managers whereas site-specific, project-level information will be the determining factors in a final assessment.

The biggest problem which has surfaced revolves around multiple ownerships in a given watershed and how a manager/planner accommodates them in this analytical framework. The new policy on the Shasta-Trinity is that, where multiple ownerships exist in the same watershed, the Forest Service "will not be our watershed's keeper". In other words, this methodology can only be made applicable on Forest Service lands. Before, consideration of what had been done on other ownerships in a watershed was included. But issues were unsuccessfully resolved. Future attention should be directed toward analyzing this lack of continuity throughout a multiple-ownership watershed.

Many other National Forests in the Region are struggling with the cumulative effects issue as it relates to their resource base and management needs. Among them are the Klamath, Mendocino, San Bernardino and Los Padres. In view of the fact that all forests in Region 5 have been directed to develop an analytical framework within which cumulative effects can be effectively assessed, all forests should be contacted and their progress evaluated. Regional Geologist, John Chatoian, the staff person responsible for directing the Region's overall efforts directed at the cumulative effects issue, intends to convene appropriate Forest Service individuals from within the Region to assess progress on forests and to grapple with a Region-wide methodology. A great deal of useful information will undoubtedly be generated at such a convocation.

2.3 - THE LOS PADRES EXPERIENCE

The Los Padres National Forest stands out as an example of progressive and innovative thinking relative to the assessment of cumulative impacts. The management concerns on the Los Padres differ sharply from those of the Forests in northern California where timber harvesting and related activities are the major concerns. The two most visible issues on the Los Padres which have been assessed relative to cumulative effects are:

1. wildfire and prescribed burning
2. oil, gas, and mineral exploration

Wildfire and Prescribed Burning

On July 30, 1981, representatives of the Los Padres, Angeles, and San Bernardino National Forests met with representatives of the Regional Watershed Staff to discuss the use of cumulative watershed impacts on South Forests. It was the consensus of the Regional Office staff that South Zone Forests should use cumulative watershed impacts (as proposed by Region 5 with some minor changes to meet conditions and activities of the South Zone) to determine the effects of management activities and wildfire within these watersheds. NOTE: In other words, they should apply the Seidelman methodology. The five basic requirements needed for compliance were identified as:

"1. Development of an adequate data base of most sensitive watershed lands.

2. Development of coefficients to convert land management activities to equivalent road acres (ERA's)...

3. Development of recovery factors used in obtaining adjusted ERA's.

4. Development of watershed maintenance thresholds based on percent of sensitive watershed lands disturbed and ERA's occurring on other watershed lands.

5. Inventory of sensitive watershed land area disturbed and of other watershed land area disturbed by such things as wildfire, prescribed burns, type conversions, roads, campgrounds, etc."

The specific data needs were identified and available sources of data delineated. The most recent developments are reflected in the yet-to-be-released Management Plan. A specific section of that document addresses "Cumulative Watershed Effects" and is quoted, subject to change, as follows:

> "Current management policy emphasizes that sensitive watershed lands should be primarily for the protection of the soil and water resource values while keeping the impacts from activities within the quantity and quality standards. Implementation of this concept is needed so that cumulative effects do not cause an overall decline in watershed condition. Ultimately, coordination of management activities is required in order to mitigate cumulative watershed effects."

> "To develop cumulative impacts for Los Padres National Forest, it was necessary to inventory existing land disturbances. Acres of disturbance were inventoried and then converted to an adjusted equivalent roaded acre (AERA) base, similar to that developed by Paul Seidelman in Methodology for Evaluating Cumulative Watershed Impacts..."

> "Watershed maintenance thresholds were developed, based on potential peak flows and sedimentation for a two-year storm following a wildfire and the portion of the watershed having an extreme geologic stability hazard rating..." (end of available document)

During 1981-82, efforts were made to comply with the Regional directives. The process employed on the Los Padres is resulting in the emergence of guidelines for the management of cumulative effects. These are due, in rough draft form, in January 1983. Reflecting the primary emphasis on wildfire and prescribed burns, the Seidelman methodology was adapted to suit the Forest-specific needs. Wildfire data used were published in 1949, supplemented with data subsequently collected. The area upon which the methodology was developed is the Monterey District. Thresholds were then established. Inventories were performed of slope stability, sediment generation peak flows, and sensitivity to impacts. Watersheds were grouped according to sediment loading capability. Working assumptions were that a complete burn occurred and that peak flows were obtained in a two-year storm event. Watersheds were then ranked for sensitivity as follows:

10% ERA......most sensitive
12% ERA
15% ERA......average
17% ERA
20% ERA......most stable

This methodology, proposed in the Land Management Plan which is currently under review, could be employed to demonstrate the relative cumulative impacts of wildfire vs. prescribed burning. That is a big issue in this part of the country! One fear of those responsible for developing the methodology is that the Threshold of Concern may become guidelines as opposed to standards, which is how they were written.

The major problems which have surfaced in this process on the Los Padres are:

1. an inadequate data base;
2. mixed ownership and management policies within a given watershed;
3. cost-effective and adequate monitoring programs have not been indentified; and
4. the adequate consideration of non-sensitive lands, and activities thereon, within a watershed which has received a "sensitive" ranking. In other words, even in a sensitive watershed, not all lands will have equivalent potential for negatively impacting such parameters as water quality. The methodology, as developed, does not appear to respond to relative potential impacts within previously classified "sensitive" watersheds.

2.4 - NON-FORESTRY CUMULATIVE EFFECTS ISSUES

There is growing awareness of cumulative effects issues in areas of resource management other than forestry. Energy development is, perhaps, the most visible one in California with water allocation following closely in public perception. Both of these areas need to be explored with the California Resources Agency and the desired contact has been identified. Norman Hill is the staff person who was responsible for the administration of California's Environmental Quality Act for many years. This is the legislation which is one of the "principal bases from considering cumulative effects in forest practices".

Of all areas confronting the environmental issues associated with oil, gas, and mineral development in California, the Los Padres National Forest may be the most visible from the national perspective. The demands upon the resource base for exploration have been the subject of recent articles in, among other places, The New York Times. Even the Secretary of the Interior has referred to the Los Padres as his prime example of intensifying demands. The Forest itself is backlogged with applications for leasing rights by exploring companies and is struggling to develop an effective system of impact assessment. The objective is to develop a Forest-wide classification scheme which would expedite the assessment process.

Historically - and it's not that historical - the Forest reviewed each application in a haphazard fashion which had no effective relationship to either cumulative effects within a given watershed or to the management of the overall Forest resource base. More recently, as demonstrated by the recently published Draft Environmental Impact Statement for the Lomex Corporation's Proposed Mineral Explorations in the Navajo Vicinity of San Luis Obispos County, efforts have been made to consider more extensive ramifications of development activites. In summary, the process involved:

1. Estimating impacts expected to occur over ten years including exploration, development, productions, and abandonment:
    a. number of wildcats, acres of roads, acres of pads
    b. potential quantity of oil to be found on 243 leases (the current number of applications) which is converted to acres of disturbance and associated activites which generate air, water, land, wildlife, and usual impacts.
2. Analyze the EXPECTED and RANGE of impacts.
3. Perform physical examination of all lease sites and develop/recommend alternatives:
    a. sediment yield expected and the range discussed. (Quantified in terms of cubic yards produced per the 35-year anticipated lifetime of the development.)
    b. expected emissions of CO, HC, NO, SO_x and TSP were quantified by ranges in terms of tons/year.
4. Socioeconomic analyses:
    a. Both the recommended activity and all 243 leases were evaluated in terms of the number of jobs produced and translated into dollar benefit estimates.
5. Biological assessment:
    a. Changes were estimated, in both narrative and qualitative descriptions, for range, Fish and Wildlife, etc.

The major problem is that the available data were insufficient to allow for more than "best guesses" based on professional judgements (conversation with Forest Service Geologist). A more effective method of evaluating impacts is, however, in the proposed Land Management Plan which is under review. Under discussion is the specific assessment of the cumulative effects of oil and gas leasing. The Forest's Soil Scientist proposes "a method which demonstrates the cumulative effects of oil and gas activities on a watershed basis,...." This is in contrast to preceding efforts which were relatively limited to assessing oil and gas leasing activities on a site-specific basis. The specific proposal is "to compare impacts of A, B and C of the Oil and Gas EA on each NFS watershed" using the following available information:

"1. Existing acres of disturbance by NFS watershed including roads, campgrounds and special uses.

2. Watershed thresholds.

3. Recovery coefficients for disturbances such as fire."

It is noted that assessment activities may be focused on sub-watersheds within larger units.

The ultimate disposition of this proposal is unknown at the present time. Conversations with involved individuals indicate a high degree of optimism concerning both its adoption and its value in accurately assessing the cumulative effects of oil and gas leasing activities on the Los Padres National Forest. In essence, the proposed methodology is an application of Seidelman's methodology made applicable to a non-forestry resource management issue.

SECTION 3 - OTHER ACTIVITIES

3.1 - GRIDER CREEK STUDY; KLAMATH NATIONAL FOREST

The Grider Creek Drainage Development Plan and Environmental Assessment, performed by Larry Seaman and Associates of Berkeley, was precedent-setting in that it was the first project of its size and kind to be contracted out by a National Forest. The drainage is:

> "...sensitive by virtue of its biophysical and possible cultural resources, its geographical and socioeconomic setting, and the management objectives stated for it. Grider Creek drains an extremely steep watershed at least two-thirds of which is characterized by high or extreme erosion hazard. Fishing resource values over a 100-year rotation could be on the order of $5 million, the spotted owl and peregrine falcon inhabit portions of the watershed, and a large number of sensitive plant species reported in the surrounding area have general habitat requirements that suggest their likely occurrence within the project area.
> ... Several possibly conflicting resource values and objectives must be analyzed and balanced. This analysis and balance is particularly important given that the sales in the drainage area would contribute part of the volume harvested in a departure from non-declining even-flow timber management."

Bob Coats of the Center for Natural Resource Studies in Berkeley was a subcontractor to the Seaman group. He was responsible for the hydrology and watershed analyses. In a letter, Dr. Coats explained:

> "We applied that method [Seidelman's] (in a revised form) in the Grider Creek work.... The method expresses all land disturbance in equivalent road acres. As you can imagine, many questionable assumptions are involved, and the results, if not interpreted properly, may be misleading. There seems to be considerable room for abuse of the method - it becomes an enormous numbers game very quickly."

SECTION 4 - SUMMARY

At the time of the Edgebrook Conference in June 1980, professional resource managers in California were more aware of, and discussing more actively, the issues associated with cumulative effects than were their counterparts in Washington State. The Conference itself represents a progression in the awareness of the issue to the point where cooperative efforts were directed toward achieving an understanding of the issues. Although the conference produced no definitions or management directions, it did serve as a catalyst for the unification of professional effort and for the initiation of additional work by both state and federal land managers. The Cumulative Effects Task Force was commissioned in March 1981 and achieved a certain amount of necessary progress toward the responsive management of the issue. Contained within the Task Force's Report, which was submitted earlier this year, are recommendations for:

1. an acceptable working definition of cumulative impacts;
2. mapping of existing and potentially sensitive land areas;
3. applied research designated to bridge existing data gaps;
4. providing necessary educational programs to resource managers so that they can more accurately identify and assess cumulative effects of management activities;
5. the assessment of the recently revised California State Forest Practice Regulations to determine their effectiveness in mitigating against cumulative impacts.

The report presently rests in the hands of the Forest Practices Subcommittee of the California Board of Forestry. The timing of its review and ultimate disposition remain uncertain.

Another effort which will eventually be supportive of specific cumulative impact assessments is being sponsored by Water Resources Control Board under the direction of the California Department of Forestry. It is the mapping, primarily based upon aerial photographs, of unstable slopes in the coastal regions of northern California. The process is a slow one which, in the face of industry resistance, is controversial. The primary concern is that the project will result in the development of regulations instead of guidelines. Interestingly enough, the California Department of Forestry is supporting the "guidelines" concept while the Water Resources Control Board desires that regulations be developed based upon the work. Industry is sitting back and watching from their offices while the gates to their lands are closed to the field teams.

An additional effort is the development of the Stream Classification System which, when completed, will result in watercourses being classified according to, among other things, beneficial uses. This merits attention!

The United States Forest Service appears to be the most pro-active participant in the emergence of effective cumulative effects assessment. The proposed methodology of Paul Seidelman forms the basis for efforts on most, if not all, Forests in the Region. It is an official Region 5 policy that individual Forests will adapt the methodology to respond to their specific needs. The Shasta-Trinity, for example, is employing a modified version of Seidelman's methodology to assess the impacts of timber management activities on the Forest. The Los Padres National Forest, on the other hand, is also using a modified version of the Seidelman methodology to assess the impacts of wildfire, prescribed burning, and oil and gas leasing activities. The content may be different throughout the Region, but the principles being employed remain the same. Interestingly enough, a modified methodology was also applied by a private consultant to an assessment of impacts and the development of management plans for the Grider Creek Drainage on the Klamath National Forest. Indications are that the application of the methodology resulted in the recommendation that at least certain management options not be pursued.

And, finally, Region 5 is gearing up to convene individuals from their Forests to synthesize the diverse efforts in order to develop a coordinated, regional approach. This is tentatively scheduled for the latter part of 1982.

SECTION 5 - DISCUSSION

This report represents an overview of a situation which has many participating elements and substantial amounts of ongoing effort. A substantial battle looms in the distance if the results of the present state mapping effort are linked too closely with the reocmmendations of the Cumulative Effects Task Force. In theory, the information is similar with the addition of stream surveys being requested by the Task Force. But the methodology and results to date of the mapping have already incurred the wrath of industry on both technical and political grounds. This reality, coupled with the extremely slow pace at which the maps are being produced, may counterbalance any efforts to translate the watershed mapping results into regulation. The rate at which maps are being produced is so slow that, conceivably, many of the sensitive land forms may have already stablized - either hydrologically, vegetatively, or both - by the time that the information becomes available.

Other questions beg to be asked. What will the Board of Forestry do? If data gaps are to be bridged, who will pay for the work? Who will do the work? And, the big one, "Then what?"

Conversations with principal participants in both the public and private sectors have revealed several recurrent themes which merit attention:

1. One of the biggest problems which continues to haunt resource managers concerned with cumulative impacts in watersheds is that of multiple ownerships in the same watershed. There is no viable solution - or even integration of partipating factions - to this problem.

2. The "professional judgement" is that the most effective protection against harmful cumulative effects in watersheds are on-site best management practices.

3. The Seidelman Methodology, and the modified forms which have been applied, need to be critically examined. Application of the methodology can rapidly become a big "numbers game" and, as such, it can be abused quite easily. There also are many questionable assumptions made which can produce misleading results. The simplification, in the process of modification and translation, may have become oversimplified. (The relative importance on activities on non-sensitive lands located within a

sensitive watershed is an example necessitating further analysis).

4. Efforts to date have generally ignored the issues associated with multiple operations on a single site. This deficiency needs to be corrected.

5. The relative importance of sediment increases vs. increases in large storm flow peaks needs further analysis.

6. The cooperative efforts and/or additional education of resource professionals needs to be explored. Foresters are not geologists and geologists are not foresters!

7. A cost-effective and technically sound monitoring system needs to be developed.

8. Insufficient data exist upon which responsible cumulative impacts-related decisions can be made.

APPENDIX C

MAJOR KEYWORDS USED IN COMPUTER-AIDED SEARCH

Cumulative Effects

secondary impact/effect
synergistic/impact
long-term/impact/effect

water quality
storm runoff
flooding
watershed
water temperature
sediment
stream
river
water
nutrients/chemistry

soils
compaction
nutrient deficiency
productivity
mass/slope/stability
dust
air
smoke
visibility

fish
salmon
trout
habitat

wildlife
fauna
game

forest management
forestry
forests
timber/tree

logging
timber harvest
clearcutting
aforest

forest roads
road construction
road maintenance

site preparation
slash/disposal/burning
residue
fire
reforest

forest chemicals
herbicides
fertilization

Ecosystems, Inc.
4224 6th Ave. SE
Lacey, WA 98503
(206) 456-1758

APPENDIX D

SAMPLE OF CUMULATIVE EFFECTS QUESTIONNAIRE

INTERVIEWS
DISCUSSION OUTLINE
April 1983

CUMULATIVE EFFECTS PROJECT

Introduction:

Ecosystems, Inc. (EI) is performing a study of Cumulative Effects for the Washington Forest Practices Board (FPB), a state agency responsible for developing forest practices regulations for all nonfederal forest land in Washington State. Acting through the Washington Department of Natural Resources (DNR), the FPB conducted a detailed review of forest practices having a potential for significant impact on the environment (during 1979-1980). Such forest practices are considered Class IV-Special practices and are subject to the State Environmental Policy Act (SEPA). SEPA is a regulatory process designed to protect the physical and human elements of the environment.

The FPB's review showed that few forest practices when analyzed individually have a potential for significantly impacting the environment. However, when viewed collectively, over time and space, some forest practices may have a cumulative effect on the environment.

Desiring more information on this relatively unstudied subject, the FPB contracted with EI in August 1982 to investigate the nature, source, and extent of cumulative effects on the environment arising from forest land management based on a review of current knowledge. This review consists of examining published and unpublished literature plus interviewing key researchers, forest managers, administrators, and other interested organizations and people.

To successfully complete this endeavor, we have necessarily placed limits on its scope. We have selected for review, only those environmental elements and forest practices that we believe significantly interact, and knowledge of which will provide useful information for the Washington Forest Practices Board.

Goals:

The goals of this study are to:

1. Define "cumulative effects" as related to our selected forest practices and as restricted by our selected environmental elements.

2. Answer the question: Do forest practices impact the environmental elements in such a way as to be considered "cumulative effects"?

3. Point out areas where our knowledge does not allow an answer to this question and recommend needed research.

Definition:

For the purpose of conducting the literature search and personal interviews with researchers, forest managers, administrators, and other interested people, Definition cont ....

we have developed the following draft definition of cumulative effects:

> Cumulative effects are the net additive or synergistic impacts caused by the interaction of one or more forest practices.

It is inherent in this discussion of cumulative effects that the impacts are changes to the environment resulting from man's actions. Furthermore, they are perceptible and measurable. These changes may be the result of:

1. One forest practice repeated through time &/or space.

2. Multiple forest practices.

3. Any combination of these.

Selected Forest Practices:

This review addresses primarily those forest practices outlined in the Washington Forest Practices Rules and Regulations. In particular, road construction and maintenance, timber harvesting, reforestation, and forest chemicals. These categories are of obvious interest to the FPB. We have added two other categories which we consider of interest to the FPB, the issues of old growth forests, and fire prevention. Minor forest practices, if not included in the above categories, may be mentioned briefly or not at all. This review will concentrate on changes to environmental elements resulting from:

1. Roads
   - Construction
   - Use
   - Maintenance
2. Timber harvesting
   - Logging
   - Site preparation
   - Slash disposal
3. Reforestation
   - Natural and/or artificial
4. Chemicals
   - Application
5. Old growth forests
   - Flora and Fauna associations
6. Fire prevention
   - Reduction in natural wildfire

Selected Environmental Elements:

This review is limited to the elements of the physical environment, in particular air, earth, water, flora, and fauna. Although difficult, the physical and biological elements are easier to collect and quantify, and are the basic components for elements of the human environment, such as social, economics, aesthetic, recreation, etc. We have concentrated on understanding the physical elements as a first step in future assessment of elements of the human environment. The specific categories within these major elements that are of particular interest are:

1. Air
   - Quality
     - Particulate - smoke, dust
     - Gas - smoke
     - Visibility

2. Earth
   - Erosion and sedimentation
     - Surface erosion
     - Sediment transport
       - Suspended sediment, bedload
       - Debris avalanches
       - Debris torrents
       - Slump earthflows
     - Sediment deposition
       - Streambed gravel
   - Soils
     - Compaction / infiltration
     - Soil nutrient cycling
     - Forest productivity

3. Water
   - Quantity
     - Annual water yield
     - Low streamflow - timing, magnitude
     - Peak streamflow - timing, magnitude
     - Snow distribution and melt
   - Quality
     - Sediment - bedload, suspended
     - Temperature
     - Dissolved chemistry - nutrients, forest chemicals

4. Flora
   - Structure
   - Composition
   - Function
   - Threatened/endangered species

5. Fauna
   - Aquatic
     - Fish - anadromous, resident
     - Food supply - terrestrial, aquatic
     - Stream productivity - heterotrophic, autotrophic
     - Threatened / endangered species
     - Habitat / behavior
   - Terrestrial
     - Mammals - big game, small game, Non-game
     - Amphibians
     - Reptiles
     - Threatened / endangered species
     - Habitat / behavior

General Discussion questions:

1. What other specific forest practices or activities should be added to this review?

2. What other specific components of the environment should be added to this review?

3. Do you believe that there are any interactions between forest practices and the elements of the environment that result in cumulative effects? If so, what are they?

4. Are you required to understand or address cumulative effects in your work?

CUMULATIVE EFFECTS PROJECT
Interview Questions

Forest Managers

1. Are you a forest manager?
2. What is forest management?
3. How many acres of forest land do you manage?
4. Do you believe cumulative effects exist? Why?
5. What is your definition of cumulative effects of forestland management activities on the environment?
6. When did you first become aware of cumulative effects?
7. Do cumulative effects exist on your land? What are they?
8. How do you manage to (prevent or) control cumulative effects?
9. How successful are your management practices?
10. What new research is needed to assist you in better managing your forestland to control cumulative effects?

Researchers

1. Are you a researcher?
2. What do you study?
3. What is the geographical coverage of your research?
4. Do you believe cumulative effects exist? Why?
5. What is your definition of cumulative effects of forestland management activities on the environment?
6. When did you first become aware of cumulative effects?
7. How does your research address cumulative effects?
8. How long have you been conducting this research?
9. How are the results of your research applied in the forest to control cumulative effects?
10. How effective is your applied research in controlling cumulative effects?
11. What new research is needed to improve your understanding of cumulative effects?

Administrators

1. Are you an administrator?
2. What program(s) do you administer?
3. What is the geographical coverage of these program(s)?
4. Do you believe cumulative effects exist? Why?
5. What is your definition of cumulative effects of forestland management activities on the environment?
6. When did you first become aware of cumulative effects?
7. Do the program(s) you administer prevent or control cumulative effects?
8. What is the origin of these programs? i.e. law, policy, guidelines, etc.
9. How effective are these programs?
10. What new research is needed to assist you in better administering your your programs to control cumulative effects?

Additionally, we are interested in any other information you may feel is appropriate to this subject.

APPENDIX E

LIST OF PEOPLE INTERVIEWED DURING THE STUDY

The following persons were contacted and interviewed by Ecosystems, Inc. from August 16, 1982 to July 16, 1983 for information on the cumulative effects project.

CODE

CATEGORY OF PEOPLE	AREA OF EXPERTISE
R = researcher	A = air
FM = forest manager	Eg = earth, geology
A = administrator	Es = earth, soils
	W = water
	F = flora
	Fa = fauna, aquatic
	Ft = fauna, terrestrial

NAME	ORGANIZATION	CODE
Verry, Elon S.	USFS, North Central Forest Exp. Stn. Grand Rapids, MN	R-W
Perala, Donald	USFS, North Central Forest Exp. Stn. Grand Rapids, MN	R-Es
Wright, David	USFS, Chippewa National Forest	A-F
Ohmann, Lewis	USFS, North Central Forest Exp. Stn. St. Paul, MN	R-F
Chamberlin, Tom	Ministry of Environment Victoria, British Columbia	R-Fa
Brown, Reade	USFS, Olympia, WA	A-Ft
Nelson, William	Dept. of Game, Non-game Program Olympia, WA	A-Ft
Herman, Steve	The Evergreen State College Olympia, WA	A-Ft
Hart, George	Utah State University Logan, UT	R-W
Long, James	Utah State University Logan, UT	R-F
Farmer, Gene	USFS, Intermountain Forest & Range Experiment Stn., Logan, UT	R-W

Danials, Ted	Utah State University Logan, UT	R-F
Gifford, Fred	Utah State University Logan, UT	R-W
Pimental, Richard	Utah State University Logan, UT	R-Fa
Engeby, Orville	USFS, Region 4 Ogden, UT	A-F
Wheeler, Richard	USFS, Mt. Hood National Forest Gresham, OR	A-W
Christner, Jere	USFS, Willamette National Forest Eugene, OR	A-W
Golding, Doug	University of British Columbia Vancouver, B.C.	R-W
Sziklai, Oscar	University of British Columbia Vancouver, B.C.	R-F
Franklin, Jerry	USFS, Forestry Sciences Lab Corvallis, OR	R-F
Minore, Don	USFS, Forestry Sciences Lab Corvallis, OR	R-F
Swanson, Fred	USFS, Forestry Sciences Lab Corvallis, OR	R-Eg
Harr, Dennis	USFS, Forestry Sciences Lab Corvallis, OR	R-W
Sedell, James	USFS, Forestry Sciences Lab Corvallis, OR	R-Fa
Silen, Roy	USFS, Forestry Sciences Lab Corvallis, OR	R-F
Sorenson, Frank	USFS, Forestry Sciences Lab Corvallis, OR	R-F
Hall, Fred	USFS, Region 6 Portland, OR	A-F
Edmonds, Robert	University of Washington Seattle, WA	R-F
Klock, Glen	Klock & Assoc. Wenatchee, WA	A-W

Sheehan, Mark	Washington Natural Heritage Program Olympia, WA	A-F
Kunze, Linda	Washington Natural Heritage Program Olympia, WA	A-F
Webster, Steve	Weyerhaeuser Company Tacoma, WA	R-Es
Duncan, Stan	Weyerhaeuser Company Tacoma, WA	R-Eq
Bisson, Pete	Weyerhaeuser Company Tacoma, WA	R-Fa
Rochelle, James	Weyerhaeuser Company Tacoma, WA	R-Ft
Biddle, Robert	Weyerhaeuser Company Tacoma, WA	R-W
Lawrence, William	Weyerhaeuser Company Tacoma, WA	A-Ft
Wilson, Boyd	Dept. of Natural Resources Olympia, WA	R-F
Kammenga, Jerry	Dept. of Natural Resources Olympia, WA	R-F
Ryan, James	Dept. of Natural Resources Olympia, Wa	R-F
Cederholm, Jeff	Dept. of Natural Resources Olympia, WA	R-Fa
Hartwell, Harry	Dept. of Natural Resources Olympia, WA	R-Ft
Anderson, Harry	Dept. of Natural Resources Olympia, WA	R-Es
Carlson, Dan	Oregon Dept. of Fish & Wildlife Portland, OR	A-Fa
Simons, Gregg	USDI, Bureau of Land Management Portland, OR	A-F
Stahl, Andy	National Wildlife Federation Portland, OR	A-Fa
Swank, Jerry	USFS, Region 6 Portland, OR	A-W

Grant, Gordon	Oregon State University Corvallis, OR	R-Eg
Wolf, Mitch	USFS, Region 5 San Francisco, CA	A-W
Schroeder, Lee	Oregon State University Corvallis, OR	R-Eg
Beschta, Robert	Oregon State University Corvallis, OR	R-W
Benda, Lee	Oregon State University Corvallis, OR	R-Eg
Bella, David	Oregon State University Corvallis, OR	R-Eg
Hanson, Nels	Washington Farm Forestry Assoc. Olympia, Wa	FM-F
Overton, Peter	Tree Farmer	FM-F
Rockwood, Al	International Paper Co. Gardner, OR	FM-F
Hallenger, William	Longview, WA	FM-F
Ward, Jack	St. Regis Corporation Tacoma, WA	FM-F
Dick, Robert	Washington Forest Protection Assoc. Olympia, WA	A-F
Berg, Scott	Industrial Forestry Assoc. Olympia, WA	A-A
Wheat, Joe	Industrial Forestry Assoc. Olympia, WA	A-F
Bordelon, Mike	Industrial Forestry Assoc. Olympia, WA	A-F
Deusen, Millard	Dept. of Fisheries Olympia, WA	A-Fa
Sachet, James	Dept. of Ecology Olympia, WA	A-W
Coon, Jack	USFS, Olympic National Forest Olympia, WA	A-F
Beckstead, Maureen	USFS, Olympic National Forest Olympia, Wa	A-Fa

Henderson, Jan	USFS, Olympic National Forest Olympia, WA	A-F
Lee, Harry	University of Idaho Moscow, ID	R-F
Stszek, Karel	University of Idaho Moscow, ID	R-F
Bennett, David	University of Idaho Moscow, ID	R-Fa
Johnson, Fred	University of Idaho Moscow, ID	R-F
Ahlstrom, Jerry	Assistant Executive to Board of Forestry, CA	A-F
Haskins, Don	USFS, Shasta-Trinity National Forest California	A-Eg
Chatoian, John	USFS, Region 5 San Francisco, CA	A-Eg
Kennedy, Jon	USFS, Region 5 San Francisco, CA	A-Eg
Rector, John	USFS, Region 5 San Francisco, CA	A-Eg
deHoll, Fritz	USFS, Los Padres National Forest California	
Record, Hollis	USFS, Los Padres National Forest California	
Blecker, Bob	USFS, Los Padres National Forest California	
O'Hayre, Jim	USFS, Los Padres National Forest California	
O'Leary, Sue	Georgia Pacific Company California	
Melo, Jerry	Georgia Pacific Company California	FM-F
Seidelman, Paul	Seidelman Associates Lafayette, CA	A-Eg
Miller, Taylor	Center for Natural Resource Studies California	

Coates, Bob	Center for Natural Resource Studies California	
Burd, Robert	U. S. Environmental Protection Agency Seattle, WA	A-W
Miller, Richard	USFS, Forest Sciences Lab Olympia, WA	R-Es
Ruggiero, Len	USFS, Forest Sciences Lab Olympia, WA	R-F
Cary, Andy	USFS, Forest Sciences Lab Olympia, WA	R-F
Gibbons, Dave	USFS, Region 10 Juneau, AK	A-Fa
Bryant, Mason	USFS, Region 10 Juneau, AK	A-Fa
Haugen, Gordon	USFS, Region 6 Portland, OR	A-Fa
Townsend, Lyn	Soil Conservation Service Spokane, WA	A-F
Schamberger, Melvin	US Fish & Wildlife Service Ft. Collins, CO	A-Ft
Armour, Carl	US Fish & Wildlife Service Ft. Collins, CO	A-Ft
Meyer, Don	USFS, Region Ft. Collins, CO	A-F
Williams, Owen	USFS, Region Ft. Collins, CO	R-W
Hawks, Cliff	USFS, Region Ft. Collins, CO	R-Fa
Stednick, John	Colorado St. Univ. Ft. Collins, CO	R-W
Smith, Dwight	Colorado St. Univ. Steamboat Springs, CO	R-Ft
Horak, Gerry	Dynamac, Inc. Steamboat Springs, CO	R
Christensen, Alan	USFS, Region Kootenai Nat'l F, MT	A-Ft

Youmans, Clifton C.	Econ, Inc. Forsyth, MT	R-Ft
Feigley, Peter	Scholz Minerals Engineering, Inc. Lead, S. Dakota	R-Ft
Hickey, Dwight	IEC Beak Richmond, B.C.	R-Fa
Doyle, Jim	USFS, Region 6 Mt. Baker/Snoqualmie	A-Fa

May 31, 1983

APPENDIX F

PARTICIPANTS ATTENDING JUNE 24, 1983 WORKSHOP

Dear

This is a letter of personal invitation seeking your participation in a closed workshop to discuss the subject of CUMULATIVE EFFECTS of forest land management activities on the environment. This workshop will be held at:

DATE: JUNE 24, 1983 FRIDAY
TIME: 9 AM - 5PM
LOCATION: THE EVERGREEN STATE COLLEGE
COLLEGE ACTIVITIES BUILDING
(CAB) ROOM 110
OLYMPIA, WASHINGTON

This workshop will consist of about 50 key researchers, forest managers, and administrators (see the enclosed list). Most of these people were interviewed by Ecosystems Inc. from February to March. From the interviews we gained insight to peoples' perception of the definition of cumulative effects, state-of-the-knowledge, and needed research or field investigations.

Our nine-member team has taken this information, in combination with our literature search, and formulated hypotheses about the nature, source, and extent of cumulative effects. The purpose of the workshop is to discuss these hypotheses with you.

In the morning sessions, discussion groups I through V will discuss hypotheses on earth, air & water, flora, and fauna (aquatic and terrestrial). In the early afternoon, discussion groups A, B, and C will meet. This double array of professions and elements of the environment will provide for ample interaction between all participants.

4224 6th avenue s.e., building 5. lacey. wa. 98503 (206) 456-1758

workshop cont....

From the workshop we will attempt to refine the following:

+ the definition of cumulative effects,

+ the state-of-the-knowledge on cumulative effects, and

+ needed research and/or field investigations to confirm or reject hypotheses on the subject.

I look forward to your participation. PLEASE CALL ME BY JUNE 10 to confinm your attendance. Thank you.

Sincerely,

ECOSYSTEMS, INC.

Rollin Geppert

Rollin R. Geppert
President

RG/jb
Enclosures

CUMULATIVE EFFECTS WORKSHOP
THE EVERGREEN STATE COLLEGE
COLLEGE ACTIVITIES BUILDING (CAB) ROOM #110
JUNE 24, 1983

AGENDA

9:00 AM	WELCOME & INTRODUCTION
9:15 AM	DISCUSSION GROUPS I THROUGH V
10:00 AM	BREAK
10:30 AM	CONTINUE DISCUSSION GROUPS
12:00 NOON	LUNCH (AVAILABLE AT TESC CAFETERIA)
1:00 PM	FORM NEW DISCUSSION GROUPS; A, B, & C
2:30 PM	BREAK
3:00 PM	WORKSHOP SUMMARIES
5:00 PM	END

June 24, 1983
CUMULATIVE EFFECTS WORKSHOP
Final List of Persons
Attending

* Ecosystems Inc. discussion group leader

<table>
<tr><th>DISCUSSION GROUPS</th><th>A
RESEARCHERS</th><th>B
FOREST MANAGERS</th><th>C
ADMINISTRATORS</th></tr>
<tr><td>I EARTH
* M. Brunengo</td><td>Stan Duncan, WC
Steve Webster, WC
Walt Shields, CZ</td><td>Nels Hanson, WFFA
Al Rockwood, IPC
Jack Ward, SRC
Raph Coon, FS</td><td>John Chatoian,R5FS
Noel Wolff, SPC
Wm. Lawrence, WC</td></tr>
<tr><td>II AIR & WATER
* Art Larson</td><td>Robert Beschta, OSU
Tom Chamberlin, MOF
E. Hetherington, CFS
George Ice, NCASI</td><td rowspan="4">OTHER

B. Boyle, DNR
C. Pinnix, DNR
A. Olson, DNR
B. George, FPB
C. Michalke, FPB
M. Smith, FPB
B. Hayes, FPB
J. McMahon, FPB
H. Brunstad, FPB
J. Thomas, DOE
M. Meacham, WEF
M. Golde, NWFE
J. Pavletich,NWSSC
S. Bledsoe, WFPA
K. Nordin, IRM
C. Skillman, WCLA</td><td>Jim Sachet, DOE
Scott Berg, IFA
Arne Skaugset, STC</td></tr>
<tr><td>III FLORA
* R. Geppert</td><td>Richard Bigley, UBC
Dave Scott, UW</td><td>Dave Handley, COFI
Bob Dick, WFPA</td></tr>
<tr><td>IV FAUNA
(aquatic)
* Doug Martin</td><td>Pete Bisson, WA
Vince Poulin, FFIP
Jeff Cederholm, DNR
Leslie Powell, DFO</td><td>Millard Deusen, WDF
Andy Stahl, NWF</td></tr>
<tr><td>V FAUNA
(terrestrial)
* Doug Canning</td><td>Joe Fox, UW
Robert Anderson, WC</td><td>Chris Drivdahl, WDG
Reade Brown, WDG</td></tr>
</table>

CUMULATIVE EFFECTS WORKSHOP -June 24, 1983
Participants Employer Code

FSL	Forest Sciences Lab., US Forest Service, Corvallis, OR
WC	Weyerhaeuser Company, Tacoma, WA
CZ	Crown Zellerbach, OR
OSU	Oregon State University, Corvallis, OR
UBC	University of British Columbia, Vancouver, BC
CFS	Canadian Forest Service
UW	University of Washington, Seattle, WA
DOE	Department of Ecology, Olympia, WA
NCASI	National Council of the Paper Industry for Air and Stream, Corvallis,OR Improvement, Inc.
DNR	Department of Natural Resources, Olympia, WA
MOF	Ministry of Forests, British Columbia, Canada
WFFA	Washington Farm Forestry Assoc., Olympia, WA
PC	Private Consultant
WFPA	Washington Forest Protection Association, Olympia, WA
IPC	International Paper Company, Coos Bay, OR
IFA	Industrial Forestry Assoc., Olympia, WA
R5FS	Region 5, US Forest Service, San Francisco, CA
R6FS	Region 6, US Forest Service, Portland, OR
WDF	Washington Department of Fisheries, Olympia, WA
NWF	National Wildlife Federation, Portland, OR
FS	Forest Service
SRC	St. Regis Corporation, Tacoma, WA
WDG	Washington Department of Game, Olympia, WA
DFO	Department of Fisheries and Oceans, British Columbia, Canada
SPC	Scott Paper Company
FFIP	Fish Forestry Interaction Program, Bristish Columbia, Canada
COFI	Council of Forest Industries of British Columbia, Canada
STC	Simpson Timber Company, Korbel, CA
IRM	Institute of Resource Management, Moscow, ID
NWSSC	Northwest Steelhead and Salmon Council of Trout Unlimited, Olympia, WA
NWFE	Northwest Fund for the Environment, Seattle, WA
WEF	Washington Environmental Foundation, Seattte, WA
FPB	Forest Practice Board
WCLA	Washington Contract Loggers Assoc., Olympia, WA

FROM

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Olympia, WA 98504

To