Appendix 3

Independent Multidisciplinary Science Team Report

INDEPENDENT MULTIDISCIPLINARY SCIENCE TEAM (IMST)

1859

State of Oregon

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September 14, 1999

The Honorable John A. Kitzhaber
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Enclosed is Technical Report 1999-1 from the Independent Multidisciplinary Science Team on the forestry project that we just completed. The report contains 19 specific recommendations. Most are directed to the Oregon Department of Forestry (ODF), but there are also recommendations for Oregon Department of Fish and Wildlife (ODFW) and the Forest Research Laboratory (FRL).

This report focuses on topics involving the management of (a) riparian areas, (b) large wood (sometimes referred to as large woody debris), (c) sedimentation from roads and landslides and (d) fish passage at road-stream crossings. While there are other forestry issues that could impact the recovery of wild salmonids, we felt these were most important, and were within the scope of what the IMST could do given the rest of our responsibilities.

The geographic scope of our report is forested lands west of the Cascades and in the Siskiyous. We excluded forest lands on the east side in part because grazing and forestry are so strongly intermingled on these lands and in many instances it will be difficult to segregate the effects on aquatic habitat of one land use from the other. I anticipate that IMST will address this intermixed land use on the eastside and their different policies in a separate project. For now we note that the concepts articulated for the westside forestlands can likely be extended by ODF, ODFW and the FRL to the eastside forests.

Concerning this report, the IMST finds that some specific aspects the Oregon Forest Practices Rules and the Measures of the Oregon Plan need improvement in dealing with riparian buffers, large wood management,

Appendix 3

sedimentation and fish passage at road-stream crossings. We believe these changes can all be accommodated within the existing policy framework. However, even with these changes, the current site-specific approach of regulation and voluntary actions is not sufficient to accomplish the recovery of wild salmonids. A landscape scale approach with flexible or adaptive management will be needed. Our report recommends this for forestlands (see recommendations I and 2), but we believe this will require a change in the forest policy framework of the State before it will be feasible, equitable and attractive. Given that salmonids extend across most of the lands of the State, I anticipate that in the future the IMST will conclude the landscape approach will need to extend across this larger landscape as well.

To conclude, as you study our report keep in mind there are two levels of resolution and two general time scales involved. One level of resolution is at the operational level involving changes to existing Rules and Measures and their implementation. This level of resolution can be accomplished in the near-term future. The second level of resolution is at the policy level, as reflected in recommendations I and 2. This issues involved at this level will require a longer period of time.

The IMST will discuss this report with the ODF Advisory Committee on Forest Practices on September 23. 1 will discuss this report with the Board of forestry on October 22.

The IMST remains committed to the mission of the Oregon Plan and hope our work is helpful. We would be pleased to discuss this report or any of our other work with you at your convenience.

Sincerely Yours,

Logan A. Norris

Logan A. Norris, Chair
Independent Multidisciplinary Science Team

<u>LAN:grs</u>

cc: IMST
JLCSRSR

Appendix 3

Recovery of Wild Salmonids in Western Oregon Forests:

Oregon Forest Practices Act Rules

and the Measures in the

Oregon Plan for Salmon and Watersheds

Technical Report 1999-1

Independent Multidisciplinary Science Team

September 8, 1999

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Appendix 3

Table of Contents

Executive Summary

Section I - Introduction

Section II – Concepts for the Recovery of Stocks of Wild Salmonids in Oregon that Involve Forests and Forestry

Section III - Science Questions and Answers

Section IV – Conclusions and Implications for Policy

Section V. Recommendations

Section VI. References

Appendix. Summary of the State of Knowledge

PREFACE

The recovery of wild salmonids in Oregon depends on many factors, including quality freshwater and estuarine habitats. Freshwater habitat extends across all the lands of the State, and includes lands in urban areas and lands devoted to agriculture, forestry, and other uses. Estuaries provide a transition between fresh water and the ocean, and are a critical part of the habitat of anadromous wild salmonids. The Independent Multidisciplinary Science Team (IMST) is evaluating the science behind the management practices and policies that affect all of these freshwater and estuarine habitats.

We have subdivided the work to focus on major types of land use (forestry, agriculture, and urban land uses). The subdivisions correspond to the different policy frameworks within which these lands are managed. Although the policies differ, these land uses interface and intermingle, and the aquatic environments on which the fish depend traverse and link them all. We emphasize that the boundaries we make between these areas in our reports are entirely artificial.

IMST is conducting its analysis of land-use practices within a framework made up of three fundamental concepts. Although not testable in a practical sense, we believe each concept is consistent with generally accepted scientific theory. The concepts are as follows:

1. ***Wild salmonids are a natural part of the ecosystem of the Pacific Northwest, and they have co-evolved with it.*** The contemporary geological landscape of the Pacific Northwest was established with the formation of the major river/stream basins of the region, approximately two to five million years ago. The modern salmonids of the region largely developed from that time (Lichatowich 1999). The abundance of these species at the time of Euro-American migration to Oregon is a reflection of more than 10,000 years of adaptation to the post-glacial environment and 4,000 to 5,000 years of adaptation to contemporary climatic and forest patterns. There is some indirect evidence from anthropological studies that salmon in Oregon's coastal streams may not have reached the high levels of abundance that the first Euro-Americans saw until about 1,000 to 2,000 years ago. The point is that the salmonid stocks of today evolved with the environment (co-evolved) over a relatively long period compared with the length of time since Euro-Americans entered this landscape.

2. ***High quality habitat for wild salmonids was the result of naturally occurring processes that operated across the landscape and over time***. These same processes occur today, but humans have altered their extent, frequency, and to some degree, their nature. Humans will continue to exert a dominant force on the landscape of the Pacific Northwest, but current ecosystems need to better reflect the range of historic conditions.

3. ***The environment and habitat of these species is dynamic, not static***. At any given ***location***, there were periods of time when habitat conditions were better and times when habitat conditions were worse. At any given ***time,*** there were locations where habitat was better and locations where it was worse. Over ***time*** the ***location*** of better habitat shifted. Salmonid habitat in the Pacific Northwest has been a continuously shifting mosaic of

disturbed and undisturbed habitats. One of the legacies of salmonid evolution in a highly fluctuating environment is the ability to colonize new or recovered habitat.

These concepts apply regardless of the land use, and are the basis for the evaluations in this report that focus on forestry, as they will be in subsequent reports on other patterns of land use as well.

Wild salmonid stocks historically accommodated changes in their environment through a combination of three strategies**.** ***Long-term adaptation*** produced the highly varied life-history forms of these species, providing the genetic diversity needed to accommodate a wide range of changing conditions. ***High fish abundance distributed in multiple locations (stocks)*** increased the likelihood that metapopulations and their gene pools would survive. ***Occupation of refugia*** (higher quality habitat) allowed for recolonization of poor habitat as its condition improved over time.

Since the mid 1850s, the rate and extent to which habitat conditions changed has sometimes exceeded the ability of these species to adapt; therefore, stock abundance currently is greatly reduced. Although refugia exist (at a reduced level) today, population levels of wild salmonid stocks are seriously depressed because of other factors (ocean conditions, fisheries and hatchery management, land-use patterns and practices), that limit the rate and extent to which recolonization can occur. In addition, some harvest and hatchery practices have diminished the genetic diversity of salmonids, limiting their ability to cope with climate fluctuations. It is the combination of these factors and their cumulative effects since 1850 that have produced the depressed stocks of today.

The historic range of ecological conditions in the Pacific Northwest, both of habitat and of salmonid stocks, is important because it provides a framework for developing policy and management plans for the future. The performance of salmonids under historic ecological conditions is evidence that these habitats were compatible with salmon reproduction and survival. Land uses resulting in non-historical ecological conditions may support productive salmonid populations, but the evidence for recovery of salmonids under these circumstances is neither extensive nor compelling.

Therefore, we conclude that the goal of management and policy should be to emulate (not duplicate) natural processes within their historic range. The recovery of wild salmonid stocks is an iterative process. Just as policy and management have changed in the past they will continue to change in the future, guided by what we learn from science and from experience.

Executive Summary

The forests of Oregon are an important part of the landscape used by wild salmonids. How these forests are managed is important in attaining the goals of the Oregon Plan for Salmon and Watersheds (Oregon Plan) and Oregon Executive Order 99-01. Agricultural, urban, and other environments are addressed in other projects of the Independent Multidisciplinary Science Team (IMST).

Forested landscapes include both aquatic and terrestrial components. The linkage between aquatic and terrestrial components has been recognized for a long time and has been prominent in the Oregon Forest Practices Act (OFPA) since its creation in 1972. The OFPA and its Administrative Rules were developed primarily to protect resource values, including water quality and, indirectly, habitat for salmonids. They were not specifically directed towards the recovery of wild salmonids, which is the mission of the Oregon Plan. However, it is through the Administrative Rules of OFPA and the Measures in the Oregon Plan that the mission of the Oregon Plan and Executive Order 99-01 are to be accomplished. The goals of the IMST forestry project are to

(a) articulate the scientific basis for the recovery of wild salmonids as it relates to the forests of Oregon, and
(b) recommend actions concerning the Rules and the Measures as they contribute to accomplishing the mission of the Oregon Plan.

The geographic scope of this Technical Report is the portion of Oregon forests that provide habitat for wild salmonids west of the crest of the Cascade Range and in the Siskiyou Mountains. However, it also provides the fundamental concepts and relevant science questions and findings for a much broader area. Topically, it covers riparian buffers, large wood, sedimentation, and fish passage at road-stream crossings because IMST believes these are the most important aspects for the recovery of wild salmonids. The Report focuses on broad scientific issues and concepts. It is not a review of each OFPA Administrative Rule or Measure of the Oregon Plan, although some are addressed primarily as examples. The scientific direction provided by this Report can guide ODF staff (working with other panels of experts as needed) in formulating rules for OFPA and measures for the Oregon Plan that are needed as part of accomplishing the recovery of depressed stocks of wild salmonids.

This is a long and complex report addressing some issues with broad policy implications that will take time to resolve, and some other issues that are more operational and can probably be dealt with more rapidly. The Report includes a preface in which the fundamental approach to recovery of wild salmonids is outlined. Briefly, the approach is emulation (not duplication) of the historic range of conditions across the landscape. This approach is appropriate for all lands, although the extent to which it is applied is a matter of policy, to be determined in part by the extent to which wild salmonid recovery is to be achieved. The report is divided into six sections with an appendix. The details of the organization of the report are in Section 1, The Introduction.

The report addresses three science questions:

Question 1. What is the scientific basis for maintaining fish habitat/water quality in forested ecosystems with respect to riparian buffers, large wood, sedimentation, and fish passage at road-stream crossings?

This question is applied to four broad subject areas:

Riparian Protection

Managing riparian areas differently than upslope areas as a strategy for protecting fish habitat is scientifically valid only if it is done with the goal of maintaining the dynamics of landscape structure and function. Sharp demarcations between riparian forest and upslope forest, and between fish-bearing and nonfish-bearing streams are not consistent with the historic pattern.

Large Wood Management

Large wood is a key structural and functional component of aquatic systems. Most models of large wood recruitment focus on riparian areas as the source, ignoring the important contributions made by upslope sources, especially from landslides. There is a critical need to restore the ecological processes that produce and deliver large wood to the streams from riparian as well as upslope areas.

Sedimentation

Sediment is a natural part of forest stream systems, as are the more coarse elements of stream structure, such as large wood, boulders, and gravel. Roads and landslides increase the amount of fine sediment in streams, but do not always add the more coarse elements. In addition, fine sediment production from roads is chronic rather than episodic. Management of sedimentation from roads and landslides at the watershed level is more difficult, and the scientific basis for it is less well developed, although the concepts are known and provide a basis for reasonable conjecture on how to proceed. In essence, the concept is to vary the extent and intensity of disturbance in a watershed over space and time, emulating the historical pattern of disturbance.

Fish Passage at Stream Crossings

The road-stream crossing guidelines developed by ODFW (ODFW 1996) are based on science, although often not the result of explicit experimentation. They provide a scientifically sound basis for management of such crossings, although better information should result from monitoring.

Question 2. Are current forest practice Rules and Measures with regard to riparian buffers, large wood, sedimentation, and fish passage at road-stream crossings adequate to achieve the mission of the Oregon Plan?

IMST concludes that current rules for riparian protection, large wood management, sedimentation, and fish passage are not adequate to reserve depressed stocks of wild salmonids. They are not adequate because they are dominated by site- and action-specific strategies. While these are important as an initial step in accomplishing the mission of the Oregon Plan, they are not sufficient for the recovery of critical habitat for wild salmonids.

Question 3. What strategies are needed in the management of forest resources to achieve the mission of the Oregon Plan?

Recovery of wild salmonids requires, among other things, habitat that is functional across the landscape. This means that policy, management, regulation, and voluntary actions must also work across the landscape. Current State forest policy focuses on specific actions occurring within defined periods of time at specific sites. As an example, the rules provide for riparian protection on a site-by-site basis, rather than at the landscape level. Sharp distinctions in the management of riparian zones (as compared to upslope forests), based on the size of the stream and the presence or absence of fish, will result in a failure to maintain the dynamics of structure and function of riparian zones across the landscape. In other cases, hazardous sites on forest roads and railroad grades are exempt from current OFPA Rules because the actions occurred before the Rules were in effect. Mechanisms are needed to solve these problems on critical sites that are exempted from current rules. Similar examples can be drawn from conclusions about the recruitment of large wood and the management of sediment and fish passage. A policy framework that incorporates landscape perspectives and makes regulation, management, and voluntary actions possible at this scale is needed.

There are three major areas in which shifts in policy are needed:

1. Incorporate the objectives of the Oregon Plan and Executive Order 99-01 into the OFPA. This will place an emphasis of regulation on the protection and enhancement of habitat needed for the recovery of wild salmonids.
2. Develop policy that extends the management of forest resources to the landscape level. This does not delete the site-specific aspects of current rules, but applies them in a different context. It will entail a shift from prescriptive rules applied uniformly across the landscape to site-by-site regulations that take into account cumulative disturbance in the watershed, landscape features, and climatic variation.
3. Develop policy that brings roads not constructed to current standards and other hazardous settings in critical locations into compliance with current standards. This means having the current OFPA Rules applied to actions taken before the current Rules were in force. In many cases, the operator acted in good faith and within the rules of the day, but the outcome is not scientifically consistent with the mission of the Oregon Plan; thus, a provision by which remediation is accomplished is needed.

Evaluating policy options within the complexity of contemporary forestry is a challenge. Extending these options to the landscape level and over time makes the job enormously more difficult. Fortunately, there are analytical approaches and models that can help. Examples of these are in the CLAMS research project, the Umpqua Land Exchange Project, and others.

The following are the specific recommendations of IMST. The first two recommendations will be difficult or impossible to implement within the existing policy framework. These we identify as Recommendations that May Require a Modified Policy Framework. Although these recommendations will take a longer period of time to implement, work on the revised policy framework should begin immediately. The other 17 recommendations can be accommodated within the existing policy framework of the Oregon Forest Practices Act or the Oregon Plan. These we identify as Recommendations Consistent with the Existing Policy Framework, and we believe they can be addressed in the near future. In aggregate, our recommendations are intended to both reinforce and enhance the site-specific Rules of the OFPA and Measures of the Oregon Plan and provide a bridge to management that incorporates a landscape perspective.

Recommendations for ODF

Recommendations that May Require a Modified Policy Framework

Recommendation 1. Explicitly incorporate the policy objective of the Oregon Plan and Executive Order 99-01 into OFPA.

Recommendation 2. ODF should develop a policy framework to encompass landscape (large watershed) level planning and operations on forests within the range of wild salmonids in Oregon.

> IMST recommends that the following elements be included in this modified forest policy framework:
>
> *Long-term landscape level assessment* of the upslope and riparian forest and associated aquatic systems to ensure that the desired condition is maintained across the landscape and through time.
>
> *Identified goals* for the characteristics of aquatic systems and riparian and upslope forests across the landscape to ensure the integrity of salmonid habitat.
>
> *Monitoring* that will provide the information needed to evaluate the aggregated outcomes of management at the landscape level.
>
> *Coordination* among agencies and watershed councils to facilitate landscape level planning and management at scales that extend beyond the forest.

Recommendations Consistent with the Existing Forest Policy Framework

Recommendation 3. Treat non-fish-bearing streams the same as small, medium, and large fish-bearing streams when determining buffer-width protection.

Recommendation 4. Provide increased riparian protection for the 100-year floodplains and islands.

Recommendation 5. Increase the conifer basal-area requirement and the number-of-trees requirement for RMAs, with increases in these requirements for medium and small streams regardless of fish presence.

Recommendation 6. Complete the study of the effectiveness of the OFPA rules in providing large wood for the short- and long-term.

Recommendation 7. Provide enhanced certainty of protection for “core areas”.

Recommendation 8. Develop and implement standards or guidelines that reduce the length of roadside drainage ditches that discharge into channels.

Recommendation 9. Implement the standards and guidelines for the length of roadside drainage ditch between cross-drainage structures, especially on steep-gradient roads.

Recommendation 10. Require the flow capacity of cross-drainage structures and stream-crossing structures and culverts to meet current design standards.

Recommendation 11. Provide for the stabilization of roads not constructed to current standards (including "old roads and railroad grades") in critical locations. Stabilization means reduction or elimination of the potential for failure. It includes a variety of strategies ranging from removal to abandonment, entirely or of sections, by which specific roads and railroad grades become a much less important source of sediment.

Recommendation 12. Require durable surfacing on wet-season haul roads and require that hauling cease before surfaces become soft or "pump" sediment to the surface.

Recommendation 13. Retain trees on "high risk slopes" and in likely debris torrent tracks to increase the likelihood that large wood will be transported to streams when landslides and debris torrents occur.

Recommendation 14. Continue to apply the current best management practices (BMP) approach to the management of forest lands with significant landslide potential, and develop a better case history basis for evaluating the effectiveness of BMP in this area.

Recommendation 15. Modify culverts and other structures to permit the passage of juvenile and adult salmonids upstream and downstream at forest road-stream crossings.

Recommendations for or with other agencies

Recommendation 16. ODFW and ODF should develop a collaborative program of monitoring to quantify the linkages between parameters of ecosystem condition and wild salmonid recovery.

Recommendation 17. ODFW should complete "core area" designation for all wild salmonids in Oregon and identify high priority protection/restoration areas that are not covered by current "core area" designations. ODFW should work with the Oregon Plan Implementation Team in prioritizing habitat for enhanced levels of protection and/or restoration.

Recommendation 18. ODFW should include consideration of practices (forestry, agriculture, urban, other land uses) above and below core areas, as these may affect the conditions and processes critical to maintenance of core area function in forestry areas.
Recommendation 19. The Oregon Forest Research Laboratory (FRL), in collaboration with ODFW, should develop forest road-stream crossing strategies that facilitate the passage of large wood at road-stream crossings.

SECTION 1
INTRODUCTION

The forest lands in Oregon are an important part of the landscape used by wild salmonids. How these lands are managed is important in accomplishing the mission of the Oregon Plan for Salmon and Watersheds (Oregon Plan) and the goals of Oregon Executive Order 99-01. This Technical Report of the Independent Multidisciplinary Science Team (IMST) focuses on western Oregon forests and their management while noting, however, that all of the habitats used by wild salmonids are important. Non-forested environments are addressed in other projects of IMST.

Forested landscapes include both aquatic and terrestrial components. The aquatic components are critical to the survival of salmonids in Oregon, and they are strongly linked to the terrestrial components of these landscapes. This linkage has been recognized for a long time and has been prominent in the Oregon Forest Practices Act since its creation in 1972. The Oregon Forest Practices Act and its Administrative Rules were developed primarily to protect resource values, including water quality and, indirectly, habitat for salmonids. They were not specifically directed towards the recovery of wild salmonids, which is the mission of the Oregon Plan and the goal of Executive Order 99-01.

The Oregon Plan includes two approaches in forestry that together are intended to contribute to the mission of the Plan. These are the application of the Administrative Rules of the Oregon Forest Practices Act and the Measures related to forestry in the Oregon Plan. The focus of IMST on the forestry project is two-fold:

1. The scientific basis for the recovery of wild salmonids as it relates to the forests of Oregon, and

2. The Administrative Rules and the Measures in the Oregon Plan as they contribute to accomplishing the mission of the Oregon Plan.

History and Scope of the Project

The 1997 Memorandum of Agreement (MOA) between the National Marine Fisheries Service (NMFS) and the State of Oregon contemplated that Oregon forest practices would be adjusted to provide a high probability that aquatic habitat on Oregon forest lands would be protected and restored. Such adjustments were to be considered through a cooperative process with the Oregon Board of Forestry. Towards this end, the Oregon Department of Forestry (ODF) formed the MOA Committee to develop recommendations to the Board of Forestry by late fall of 1998. As part of this process, NMFS produced a draft proposal on February 17, 1998, concerning Oregon forest practices (NMFS 1998).

The IMST initiated the design of a review of forest practices (the forestry report) in the spring of 1998, with the intention of completing the project about the time the MOA Committee completed their work. Because of the legal challenges to the NMFS decision not to list the north coast coho, the work of the MOA committee was suspended. IMST also suspended work on the forestry report in order to complete work on the IMST predation and hatcheries projects.

Executive Order 99-01 redirected work to be done on Oregon's Forest Practices Act Rules, with recommendations for changes to be made to the Board of Forestry. IMST reestablished its forestry project in January 1999, adjusting it to the State's new relationship to NMFS and the expanded scope of the Oregon Plan.

The geographic scope of this Technical Report is the portion of Oregon forests that provide habitat for wild salmonids west of the crest of the Cascade Range and in the Siskiyou Mountains. Yet it also provides the fundamental concepts and relevant science questions and findings for a much broader area. Topically, the scope of the Report deals with riparian buffers, large wood, sedimentation from roads and landslides (but not harvesting or reforestation), and fish passage at road-stream crossings. Although other topics could be included, IMST considered these the most important to the recovery of wild salmonids.

This Report addresses some issues that are quite broad and involve substantial changes in policy. We expect these will take longer to resolve and the recommendations associated with them will take longer to implement. Some other issues are quite operational in scale and can be dealt with within current policy. The recommendations related to these issues may be more rapidly addressed.

This Report focuses on broad scientific issues and concepts. It is not a review of each of the individual administrative rules that are part of the Oregon Forest Practices Act (OFPA), or the measures that are part of the Oregon Plan. In some cases it does focus on specific rules or measures, but these are used primarily to illustrate examples. Lack of inclusion of a specific rule or measure does not imply either approval or rejection of it by IMST. The scientific direction provided by this Report can guide ODF staff (working with other panels of experts as needed) in formulating administrative rules for OFPA and measures for the Oregon Plan that are needed as part of accomplishing the recovery of depressed stocks of wild salmonids.

Organization of This Report

This is a long and complex report, reflecting the breadth and complexity of the issues involved. It is divided into six sections with an appendix. The following explanation of its organization is to help readers direct their attention to the elements that are of greatest interest. Figure 1 is a schematic representation of the report's organization.

Figure 1. Report Organization Flow Chart

Preface

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Introduction

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Concepts for the Recovery of Stocks of Wild Salmonids in Oregon that Involve Forests and Forestry

- Changing Views of Salmonids and Habitat
- Landscape Ecology

↓

Science Questions and Answers

1. What is the scientific basis for maintaining fish habitat/water quality in forested ecosystems with respect to riparian buffers, large wood, sedimentation, and fish passage at road-stream crossings?
2. Are current forest practices Rules and Measures with regard to riparian buffers, large wood, sedimentation, and fish passage adequate to achieve the mission of the Oregon Plan?
3. What strategies are needed in the management of forest resources to achieve the mission of the Oregon Plan?

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Conclusions and Implications for Policy

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Recommendations

- Recommendations for ODF
- Recommendations for other Agencies

Section I. Introduction

∃ The introduction provides the history and context for the report, and identifies the major science questions addressed by the report.

Section II. Concepts for the Recovery of Stocks of Wild Salmonids in Oregon that involve Forests and Forestry

∃ The recovery of wild salmonids in Oregon depends on more than the forested portion of the landscape of the state. The purpose of this section, however, is to address the specifics of recovery that are particularly relevant to forests and how they are managed.

∃ Landscape ecology — basic concepts. This is a review of fundamental concepts of ecology as they operate at the large landscape level. These concepts are central to the recovery of depressed stocks of salmonids in Oregon, regardless of the type of landscape. In this section, we focus on concepts in forest settings.

Section III. Science Questions and Answers

∃ This section includes the specific questions IMST addresses, and our answers to them.

Section IV. Conclusions and Implications for Policy

∃ This section draws the major conclusions from the answers to the science questions and addresses them in the context of their implications for policy. This section is at the interface between science and policy. It is meant to help those addressing policy to do so in ways that are as consistent as possible with what is known from science.

Section V. Recommendations

∃ These are the specific recommendations of the IMST.

Section VI. References

Appendix. Summary of the State of Knowledge

∃ Interactions between forests and forest practices as they affect water quality and aquatic habitat. This is a review of much (but not all) of the knowledge from the literature as it relates to the topic. This section is organized around four topics: salmonid habitat, riparian management, large wood, and sedimentation. It provides the technical background and many of the references for the answers to the science questions.

Science Questions

There are a great many science questions that could be part of this project. From these, we selected three broad questions, which IMST considers to be most important in accomplishing the mission of the Oregon Plan. These questions contain sub-elements in which more specific issues are addressed. We include the three broad questions here to provide direction in reading the balance of this report:

1. What is the scientific basis for maintaining fish habitat/water quality in forested ecosystems with respect to riparian buffers, large wood, sedimentation, and fish passage at road-stream crossings?

2. Are current forest practices Rules and Measures with regard to riparian buffers, large wood, sedimentation, and fish passage adequate to achieve the mission of the Oregon Plan?

3. What strategies are needed in the management of forest resources to achieve the mission of the Oregon Plan?

Resource Materials

The forestry area is challenging because of the large number of summary and analytical documents relevant to Oregon forests and forestry. These are the result of the regulatory framework and history of the State of Oregon, the development of the Northwest Forest Plan for federal forest properties (FEMAT 1993), and the proposal developed by NMFS (NMFS 1998) concerning modifications of the Oregon Forest Practices Act Administrative Rules.

Both Washington and California have been reviewing their forest practices in attempts to accomplish the recovery of salmonid stocks. These efforts produced two major reports in 1999 (California [SRP 1999] and Washington [DNR 1999]). While differing in terminology and specifics, both reports cover many of the same issues addressed in this report of the IMST.

In aggregate, the documents from these various efforts are voluminous. IMST was not able to review and comment on these documents in detail. In some cases, we comment on their particular findings, but note that our doing so is not the result of a thorough evaluation. Although these documents have both strengths and weaknesses, they generally provide a reasonable basis for considering the technical issues involved.

We have included additional documents in the reference section of this report (identified with an asterisk) which were not cited in the report. These documents, along with the cited material, provide the technical basis for guidance in matters relating to changes in forest practices as they affect salmonid habitat.

SECTION II
CONCEPTS FOR THE RECOVERY OF STOCKS OF WILD SALMONIDS IN OREGON THAT INVOLVE FORESTS AND FORESTRY

CHANGING VIEWS OF SALMONIDS AND HABITAT

Our understanding of what constitutes aquatic habitat for salmonids has changed considerably with time, as have the conditions of streams in the Pacific Northwest over the past 150 years. From early descriptions found in Army journals, diaries, and some technical reports, we can reconstruct a description of salmon habitat in streams before the mid-1850s. It is to these conditions that salmonids are adapted and to which their spatial-temporal patterns of habitat use have evolved (Sedell and Luchessa 1981). A review of the sources of historical information clearly demonstrates that most stream channels and salmon habitat were more complex than they are today (Sedell and Luchessa 1981; Sedell et al. 1988; Brenner 1991). Salmonid habitat is associated with structural elements such as large wood, which create complex channels with a diversity of micro and macro habitats from headwaters to the ocean (Swanson et al. 1976; Sedell et al. 1988). Large wood is an important part of the structure of the stream channel. It creates pools, regulates sediment storage and distribution, provides nutrients and substrate for aquatic insects, and creates pockets of cooler water (thermal refugia) in warm streams (Gregory et al. 1991; Sedell and Swanson 1984; Sedell et al. 1988; Bilby and Bisson 1998). But healthy salmon habitat is more than the physical presence of those structural elements at a given spot. Salmon habitat is also the processes that create, alter, and maintain those elements across whole watersheds (Naiman 1992).

Major changes in salmonid habitat began with the arrival of large numbers of Euro-American settlers to the Pacific Northwest during the mid-nineteenth century. To accommodate the economic growth of their communities through trade and other means, settlers began to significantly alter streams. Obstructions were removed from channels to facilitate the passage of boats (Sedell and Luchessa 1981). Large logs and root wads were also removed from rivers to accommodate the gillnet fishery for salmon.

Timber harvest intensified the impacts of development on stream channels. By the end of the 1880s, every river that could float a log during high flows was being used to transport them downstream to the mills (Cox 1974). In 1884, the first splash dams were built to augment the natural flow of rivers and permit log transport through most of the year (Beckman 1970). Before logs could be moved downstream from a dam, however, the main channel had to be cleared of all obstructions, including large wood and boulders, and all side channels and backwaters had to be blocked to keep the logs in the main stem. After the rivers were cleared of debris, continued logging from riparian zones removed trees that might eventually have replaced the large structural elements lost from streams.

By the turn of the century, many river channels had already been converted from their natural state of complex tangles of logs, side channels, and surrounding wetlands to unobstructed highways for boats, gillnets, and logs. Thus, when biologists began making the first habitat surveys in the 1920s and 1930s, they believed that channel complexity, including large pieces of wood or any kind of roughness in the stream channel, was not part of salmon habitat. This belief stemmed partly from the highly altered state of rivers that existed at that time. When biologists began to focus their attention on stream habitat, this altered condition was viewed as the norm. In fact, some biologists equated streams to highways: “Just as automobiles need smooth roads to operate on, fish need clean unobstructed rivers and streams if they are to live, move and propagate” (Schoettler 1953). Although the removal of large logjams that completely blocked the migration of fishes was justified, the vision of a clean unobstructed stream led biologists to support the aggressive removal of large wood from the stream channel and the destruction of important structural elements of habitat.

The vision of clean, unobstructed river channels and simplified habitat that prevailed before 1970 was matched by an equally simplified view of how salmon used that habitat. This view was based on an overly simplified perception of the life history of salmonids—generic patterns of migration, spawning, and rearing that were assigned to salmon species and races. The main stem and lower reaches of watersheds, which had already been cleared for splash damming and transportation, were viewed as merely conduits to carry salmon smolts to the sea. In their degraded state that was probably the only function these streams were capable of carrying out.

Our understanding of what constitutes aquatic habitat for salmonids has changed considerably in the past 25 years. We now recognize that stream habitat for salmonids resemble those pre-1800 stream conditions and not the unobstructed “highways". Just as our concept of what constitutes healthy aquatic habitat has changed, so has our understanding of how the salmonids used that habitat. W. F. Thompson (1959) visualized salmon habitat as “a chain of favorable environments connected within a definite season and place, in such a way as to provide maximum survival.” He went on to state that a given watershed and population of salmon would be composed of bundles of several of these chains of favorable places.

Thompson’s model introduced three new ideas that have subsequently been elaborated on by others: First, healthy stream habitat is complex and diverse. Salmon, due to their extensive migration throughout the various stages of their life histories, utilize multiple segments of the stream, selecting differing habitat types during each life history stage. Therefore, there are several possible chains of favorable places or life history pathways (habitat types/location combinations for any particular species/stock) from headwaters to the ocean. A healthy population is capable of using multiple pathways through the freshwater habitat when available. Salmon have evolved diverse life histories in response to habitat diversity and complexity. Life history diversity has been identified in chinook salmon (Reimers 1973; Schluchter and Lichatowich 1977; Carl and Healey 1984), in pink salmon (Gharrett and Smoker 1993), and in coho salmon (Lestelle et al. 1993).

Second, the interaction between salmonids and their habitat has a space and time dimension. The same habitat may be used by successive waves of salmonids at different times or seasons or for different purposes (Mobrand et al. 1997). Third, salmonids and their habitat comprise a single coevolved unit that cannot be separated for management purposes. We cannot meaningfully think of salmonid life histories without considering the habitats those life histories require. Conversely, we cannot think of salmonid habitat without considering the life histories that make use of it. The fundamental management unit is the fish and its habitat (Healey and Prince 1995). Each species and its resulting populations have evolved additional diversity in response to the diversity and complexity in the local habitat they encounter (Healey and Prince 1995).

The recovery of life history diversity is important to long-term productivity and persistence of a species. The salmonids' environment is continually fluctuating: droughts, floods, fires, and changing ocean conditions are continually testing the resiliency of each species. Life history diversity is the strategy salmonids have evolved for survival in a fluctuating environment (Thorpe 1994). This strategy is successful because it spreads the risk of mortality in a changing environment (Den Boer 1968). Wild salmonid restoration requires the restoration of habitat complexity to allow the expression of life history diversity (Healey and Prince 1995). This approach requires at a minimum a watershed scale mapping of life history on habitat and reconnection of the "chains" of habitats and life histories from headwaters to the ocean.

Our understanding of what constitutes salmonid habitat is still evolving. It is currently shifting from site-specific structures and ecological functions to landscape-scale processes that shape and maintain salmonid habitat. These changes in what we consider stream habitat and how salmonid use that habitat have important and sometimes overlooked implications. Restoration of habitat must consider the whole watershed and its ecological processes and it must consider the entire chain of habitats required for salmonid to complete their life histories. For example, habitat restoration that focuses on public land in the upper watersheds will only permit the restoration of a limited range of life histories. Habitats through the entire watershed must be addressed if salmonid are to recover their full range of life history diversity. To accommodate our increased understanding of salmon habitat, land-use practices including forestry, agriculture, and urban and industrial development must all be evaluated and examined from the perspective of the entire landscape.

LANDSCAPE ECOLOGY: BASIC CONCEPTS

> *The study of landscapes as a system expands the focus from predictions about exact future states to predictions about the relationships between large-scale properties of landscapes (i.e., climat,e topography, and channel networks) and the long-term behavior of aquatic systems.* Benda et al.1998, p. 261.

Salmonids have evolved to depend on many interrelated components of the terrestrial landscape during several phases in their life histories. Since streams are tightly linked to the terrestrial landscape they flow through, when reviewing land-use practices and their effects on salmonid habitat, it is necessary to analyze impacts on both adjacent and distant components of the landscape. Analysis and adjustment of management practices in riparian forests has received a lot of attention. However, considering the interrelated components of the entire landscape, a similar analysis and adjustment in management practices must occur in upslope forests throughout the watershed. As outlined by Schlosser (1991), the science of landscape ecology (Forman and Godron 1986) offers an opportunity for this type of analysis by using landscape dynamics to analyze impacts of land-use and strengthen land-use decisions.

Taking only a site-specific approach to regulate landscape-level processes can be counter-productive and in some cases catastrophic. For example, fire suppression has been very successful in reducing the number of wildfires per year, but the subsequent accumulation of fuels and changing forest structure have increased the risk of severe or catastrophic fires and/or insect and pathogen outbreaks. From a landscape perspective, periodic fires that burn the forest understory (underburns) are critical to reducing fuel loads and stand density. Without these more frequent—but less intense—burns, the fire regime has switched to less frequent but more intense fires. This example is echoed in many land-use decisions. Failure to account for unintended consequences at specific sites often leads to unintended and therefore unplanned for results at the landscape level.

Structure, function, and change

The structure and functional interactions of the components in a landscape, along with their dynamic nature, form the conceptual basis for landscape ecology. Structural components include the physical habitat occupied by salmonids along with the materials that maintain the integrity of that habitat. Functional interactions include the flows of energy (food) and materials within the ecosystem. As with any living organism, landscapes are dynamic: both structure and function change across time and space. Even with change, stability is ensured as long as ecosystem structure and function are maintained within certain bounds and all required components remain within the landscape. By examining the landscape components and how they interact to provide good salmonid habitat, we can make better land-use decisions.

Landscape patterns

Landscapes form distinctive patterns influenced by geological, climatic, and hydrological processes, vegetative responses, and land-use history. Understanding landscape patterns and how they influence function (physical, chemical, and biological interactions of ecosystems) is important when evaluating impacts of management on aquatic habitat. As summarized in Naiman and Bilby (1998), the width of a forested riparian zone and the extent of the forest influence are related to stream size and morphology. Small upslope streams—the primary downstream conduit for water, sediment, organic material, and nutrients—are heavily influenced by upland forests with very limited riparian vegetation. The channels are generally steep and filled with unsorted sediments, boulders, and wood that exceed the streams' transport capabilities. In contrast, midslope streams typically have a distinctive band of riparian vegetation whose width is determined by geomorphology, long-term hydraulic forces, terrestrial disturbance, and successional patterns. The stream channels are characterized by moderate to steep gradients, substrates of boulders, gravel, and sands, and frequent large wood jams. Their connection with the upslope forests is buffered by the presence of riparian vegetation and more frequent, less intense, hydrological disturbance.

Landscape patterns result from the dynamic interaction between structure and function, and provide the heterogeneous habitats required by the numerous life-stages and species of salmonids. Establishing a quantitative link between fish habitat requirements and landscape patterns and processes is key to designing land-use practices that work within the range of forest conditions that encourage the recovery of salmonids. However, it should be recognized that providing habitat similar to historical levels must be coupled with the spatial arrangement and landscape dynamics allowing for function (Wimberly et al., in press).

Disturbance

Periodic disturbance plays an important role in maintaining the integrity and variability of salmonid habitat, since the extent, magnitude, and frequency of disturbance are key components in shaping landscape structure and functions. For example, within the Oregon Coast Range, historic patterns of disturbance are dominated by climatic events that result in heavy precipitation, windstorms, and lightening-caused fire (Benda et al. 1998; Agee 1993). The frequency, intensity, and magnitude of the response to these disturbances vary widely, depending on the structural components of the landscape (i.e., topography, channel networks). These structural components ultimately determine the impact of disturbances and their effect on habitat integrity. For example, input of large wood into streams involves an interaction between disturbances that kill trees (e.g., fire) and floods that are of sufficient magnitude to transport them. Variation in the frequency of fires affects the rate of wood input to streams, as well as its potential size. Along the northern Coast Range, for instance, the fire frequency exceeds 400 years (Agee 1993), allowing time for forests to produce very large trees.

Although fire is not the only cause of tree mortality, the synergy created when a catastrophic fire is followed by intense storms leads to massive inputs of sediment, rock, and wood into aquatic systems (Benda et al. 1998). The variability in the amount of wood and sediment added to streams over time and space is just one part of landscape dynamics that should be considered when developing management strategies to protect salmonid habitat. Although we may never be able to recreate the historic patterns of landscape disturbance, they can be used as a guide to choosing management options which may ultimately maintain habitat integrity and function across the current landscape.

Wild salmonids in relation to landscape ecology

The National Research Council’s (1996) recommendation is to view salmon from the broader, metapopulation perspective, as well as by local populations. Metapopulations are groups of local populations that are distributed across a heterogeneous landscape and genetically linked by dispersal of individuals (Hanski 1991; Hanski and Gilpin 1991). Metapopulation theory has only recently been used to interpret salmonid population structure and ecology and to formulate management strategies (Reiman and McIntyre 1993, 1995; Gresswell et al. 1994; Li et al. 1995; Mundy et al. 1995; Schlosser and Angemeier 1995; National Research Council 1996; Independent Scientific Group 1996). Since it is relatively new, its application to salmonid populations should be viewed as a hypothesis that must be tested through effective monitoring and evaluation (Independent Scientific Group 1996).

Metapopulation theory directly links populations to the natural disturbance regimes that shape landscape structure and function. The linkage is the balance between the extinction of local populations after severe habitat disturbance and the subsequent recolonization of previously disturbed habitats as they recover. This extinction-colonization balance depends on the dispersal of individuals and the connectivity between habitats occupied by populations making up the metapopulation. If the frequency of disturbance—whether human caused or natural—that degrades a species' habitat exceeds its ability to maintain a balance between extinction and recolonization, the individual populations and eventually the entire metapopulation will go extinct.

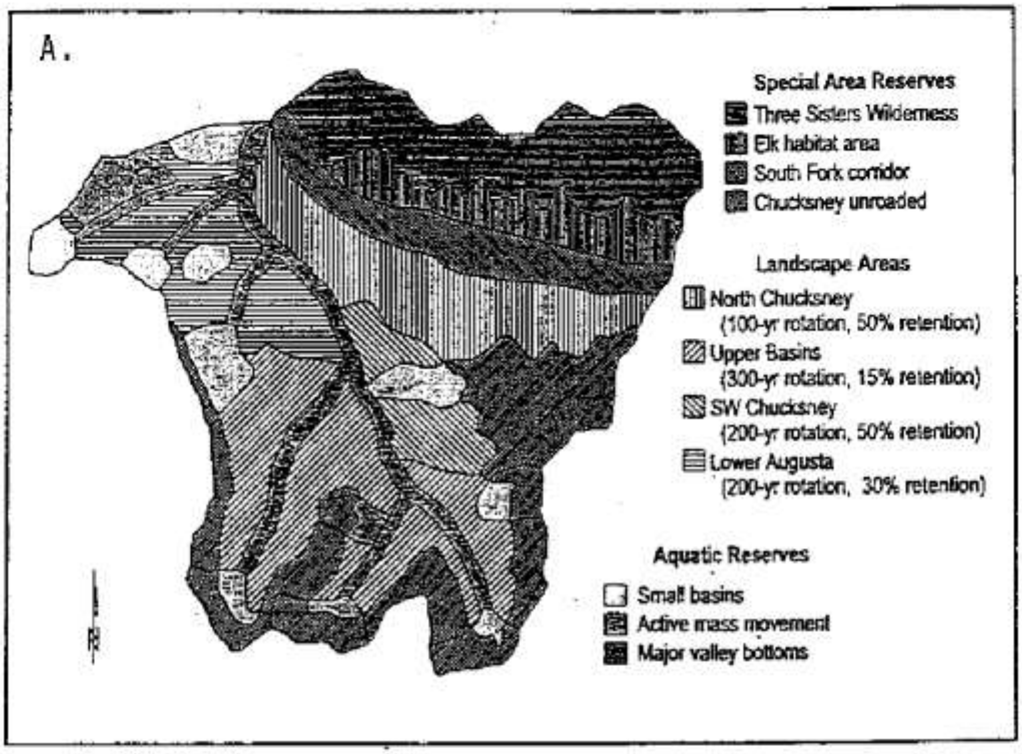
Several models of metapopulation structure have been presented (e.g., Schlosser and Angermeier 1995), but the core-satellite model appears to describe the structure of Pacific salmon metapopulations (Li et al. 1995; Schlosser and Angermeier 1995; Independent Science Group 1996). Core populations are large, usually occupying extensive and productive habitats; under natural conditions, the core population is expected to persist indefinitely. Satellite populations often occupy marginal habitat. Their abundance may fluctuate widely in response to changes in climate, and they may go extinct after severe disturbance events. Dispersal of salmon from a large core population will colonize vacant habitat, reestablishing satellite populations and generally minimizing the possibility of total extinction of the metapopulation (Harrison 1994). If core areas identified in the Oregon Plan were associated with core populations, then it would be critical to protect those habitats to prevent the extinction of the metapopulation and ensure the possibility of recovery.

A LANDSCAPE APPROACH

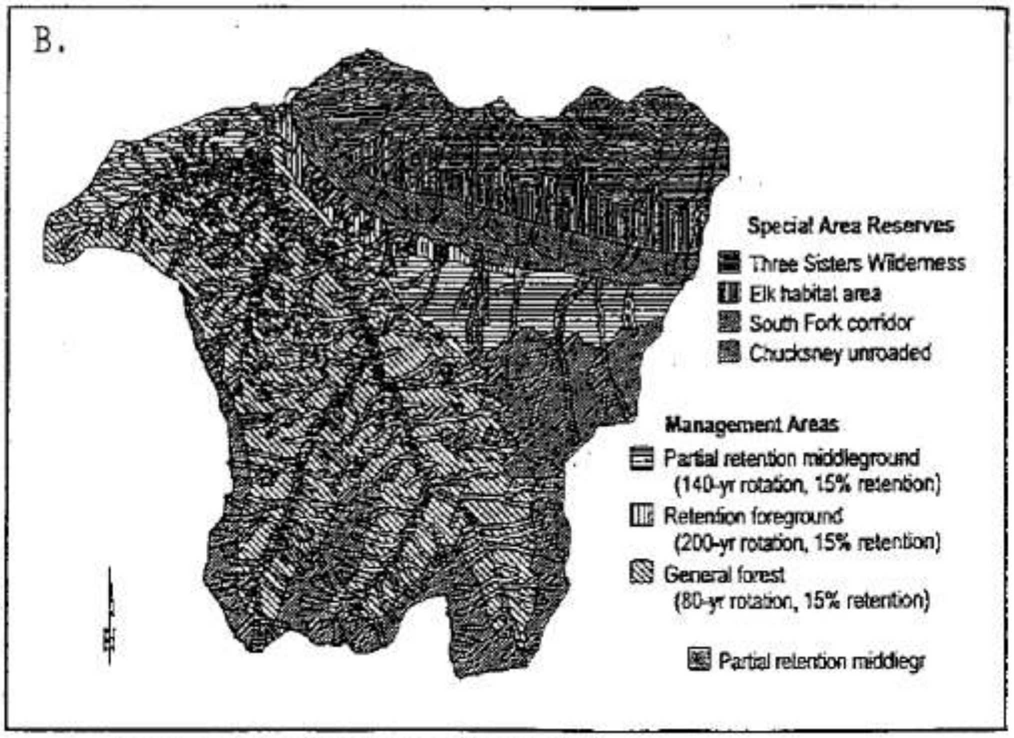
IMST believes the principles of landscape ecology should be used in managing salmonid habitat at both the site-specific and landscape level. When concepts of landscape ecology are applied to forest land-management decisions (throughout the forested watershed), the focus shifts from individual stream reaches or habitat components to the dynamics of landscape patterns and processes. Using historic patterns as a guide, a link between fish habitat requirements and landscape patterns and processes can be established. Currently, OFPA riparian buffer strategies are applied uniformly across the landscape. But a landscape strategy emulates disturbance patterns in both the upslope and riparian areas.

The Augustus Creek Study (Willamette National Forest) provides a useful example to illustrate what we mean by managing to better emulate natural disturbance patterns (Cissel et al. 1998). This study produced a landscape plan based on historical fire regimes. Figure 2 contrasts the land use allocations based on historic disturbance (A) and the Interim (Federal) Northwest Forest Plan (B). In (A), aquatic habitats include areas of both late-successional forest and younger forests, creating more diversity, resulting in higher productivity. In (B), use of a riparian reserve network provides for some functions, but it lacks the connection to the upslope forests, is homogenous, and does not emulate historic conditions.

At the larger landscape scale, there would be an aggregation of basins like the Augustus Creek study area. In the absence of a major natural disturbance, management would proceed as "planned" in all the basins. When a major disturbance (i.e., debris flow, fire) occurs in one of the basins and salmon habitat is negatively impacted, then management practices in an adjacent, less impacted basin may need to change.



Management categories for the Augusta Creek Landscape Plan.



Management areas for the Augusta Creek Interim Plan.

Figure 2. Contrasting land use allocations for the Augusta Creek Basin. A. represents landscape areas based on historic disturbances. B. represents management areas based on the interim (Federal) Northwest Forest Plan.

The landscape approach will be quite difficult to implement because it will require that we think and act in some different ways. It will require a level of collaboration that will be challenging

- *Philosophically* – Some of the "decision space" and accountability we have historically held closely will need to be shared more widely.
- *Legally* – Some existing laws and policies make collaboration at this level impossible, difficult or at least unattractive.
- *Practically* – How can it be done at the practical operational level?

The landscape approach is not something that can begin immediately, or be implemented uniformly, or that will yield results immediately.

- It will take time to (a) develop the policy framework that makes it possible and attractive, (b) improve the scientific base of understanding on which it rests, (c) refine the tools and techniques that are needed for assessment, planning, monitoring, and analysis, and (d) educate the various publics to the role this approach can play in natural resources management.
- Implementation will not be possible everywhere. For instance, there may be insurmountable policy barriers between actions at the private/state and federal levels, or there may be no feasible way to include many of the small woodland owners.
- It will take time for this approach to yield clearly discernable results in salmonid recovery because of the many factors (beyond the forest) that are involved, and the period of time it will take the landscape to respond and reflect these different approaches to practice. Monitoring of ecosystem and fish responses are essential.

Despite these challenges, IMST believes it is important to start, and do what can be done where it is possible. Smaller scale efforts (for instance in the ODF Northwest Forest Plan Area) may be a useful initial scale. This could be treated as a trial effort, in which techniques are developed and refined. While not a replicated experiment in the traditional sense, it is a life-scale case history experiment from which a great deal can be learned.

SECTION III
SCIENCE QUESTIONS AND ANSWERS

Question 1. What is the scientific basis for maintaining fish habitat/water quality in forested ecosystems with respect to riparian buffers, large wood, sedimentation, and fish passages at road-stream crossings?

A. Riparian Buffers

(1.) Riparian buffers as a strategy.

Limiting forest management practices adjacent to aquatic areas is the most common site-specific strategy applied on forested lands. There is a large body of scientific literature on the riparian buffer widths required to retain various aquatic functions. However, there is little discussion about the scientific basis for riparian buffers as a landscape structure, particularly, their resiliency and role in maintaining landscape-level processes. Riparian vegetation often differs from upslope vegetation because its environmental conditions, disturbance histories, and successional patterns are distinctive, especially on low-gradient higher-order streams (Pabst and Spies 1998). When riparian protection strategies have been designed on the basis of buffer width, there has been little consideration of the interaction between riparian and upslope forests or the historic patterns created by riparian forests and their role in maintaining ecosystem heterogeneity. Although riparian buffer strips have been found to be sufficient for maintaining many physical structures and processes, this is not sufficient. Aquatic systems include a unique blend of both physical and biological components that interact with historic and current disturbance (Beschta 1997).

Recommended riparian buffer width should vary according to the ecosystem function under consideration, as well as the attributes of the ecosystem. For example, a relatively narrow strip of vegetation may provide shade, but maintaining relative humidity in the riparian area may require a buffer in excess of 100 m (Dong et al. 1998). Currently, most measurements of changing riparian and aquatic function, as influenced by buffer width, are made on forested buffers adjacent to cutover forests or young regenerating stands (Hibbs and Giordano 1996; Brosofske et al. 1997; Dong et al. 1998). This is quite different than comparing a riparian forest with an adjacent upslope forest of similar age or older.

Since the current riparian strategies on forested lands have not been in place long enough for long-term monitoring, a look at historic conditions is the best indication of future success in restoring stocks of wild salmonids. Historically, the Coast Range disturbance regime was dominated by frequent storms and infrequent but intense fires (Benda et al. 1998). From this we would expect to find a heterogeneous mix of riparian and upslope forests across a watershed. In a given basin, the riparian forests contrasted with upslope forests could be younger, older, or the same age, and could vary in their density.

The current regulatory framework has an implicit goal of maintaining older conifer forests with varying tree densities along the stream, surrounded by younger conifer forests in the upslope. In addition, current rules are based on the attainment of old forest structure, as represented by 120-year-old forests. The frequency of disturbance in riparian forests is highly variable. Fire return intervals of 300 years and/or 50-year flood events created a dynamic heterogenous mixture of young and very old forests. The remnants of these old conifer forests are represented by the large stumps found adjacent to many streams. The current strategy, although functional in the short-term, will not create a landscape pattern based on historic disturbance. Therefore, it would not be based on our best understanding of ecosystem structure and function. The riparian buffer approach creates a sinuous, sharply demarcated landscape pattern that has a limited historical basis.

Riparian management zones are thus being defined by management needs, and not in accordance with natural processes and the maintenance of riparian biological and physical functions. We conclude that in the long term, riparian buffer strategies, as a single landscape feature with sharp upslope demarcations, will not provide sufficient protection for the recovery of salmonids.

Riparian buffers as a strategy.

On the basis of scientific evidence, we conclude that managing riparian areas differently than upslope areas as a strategy for protecting fish habitat is scientifically valid only if done with the goal of maintaining the dynamics of landscape structure and function. Riparian buffer strategies, as a single landscape feature with sharp upslope demarcations are not consistent with historic pattern.

(2.) Riparian buffer management based on stream size.

As outlined in the appendix of this report, stream size impacts aquatic structure and function. Smaller streams in upper reaches transport material such as large wood down into lower, more productive reaches. Depending on the morphological conditions of the stream, transport is either in small steady flows or in large pulses associated with floods. Larger streams in lower gradient portions of the watershed are areas of deposition and organic material processing, making them some of the most productive reaches for some salmonids.

Floodplain development is also influenced by stream size. Floodplains are geomorphic surfaces created and shaped by alluvial processes during floods. These depositional surfaces are created by the stream and are part of the stream channel. These riverine surfaces then form the templates for floodplain forest development. Vegetated floodplains are stabilized by rooting and are lateral refuges of lower velocity and structural complexity for fish. When vegetated floodplain refuges are available, flood disturbances potentially provide many benefits, such as pool formation, riffle deposition, complex wood accumulation, sediment flushing from gravels, and exchange of food between terrestrial and aquatic ecosystems. Riparian protection for the floodplain is needed for it to perform these functions.

Given the distinctive differences between stream function based on size, we conclude it is scientifically sound to vary riparian widths with stream size. On a landscape basis, care should be taken to maintain a variety of forest types and ages on all stream reaches, including small and intermittent streams, and in the floodplain.

Riparian buffer management based on stream size.

Because stream size affects aquatic structure and function, it is scientifically sound to vary riparian widths with stream size. On a landscape basis, care should be taken to maintain a variety of forest types and ages on all stream reaches, including small and intermittent streams, and in the floodplain.

(3.) Riparian buffer management based on fish presence.

Non-game fish and other aquatic organisms play a role in the functioning of stream systems locally, and contribute to downstream processes. In addition, distribution of salmonids will change as populations adjust to dynamic landscape and ocean conditions. Therefore, unlike stream size, the presence or absence of game fish is not a scientifically sound basis for managing riparian buffers.

Riparian buffer management based on fish presence.

There is not a scientifically sound basis for managing riparian buffers based on the presence or absence of game fish.

Conclusion

Overall, the current strategy of riparian buffers does not emulate historic conditions at the landscape level. Although some strategy of buffering is likely to be necessary, even with landscape level management, we believe it should be much different than the highly prescriptive approach reflected in current OFPA Rules.

B. Large Wood

The scientific literature on the importance of large wood to aquatic habitat is considerable and continues to expand (Spence et al. 1996; Bilby and Bisson 1998). It provides a clear scientific basis for the need to manage forest practices to ensure a continuous supply of large wood to the aquatic habitat. The specific level of large wood needed to bring about recovery of listed salmonids is still uncertain, however.

The scientific basis for the need to manage large wood and the current management strategies come from three sources. *Research* into recruitment and function of large wood in aquatic habitats has contributed to the development of management strategies. *Stream surveys* give the status of large wood in Oregon’s streams relative to current benchmarks. Finally, *historical reconstruction* of aquatic habitats provides important information on the volume of wood in stream channels at the time of Euro-American settlement.

(1). Functions of large wood.

The literature on the importance of large wood on the structure of stream habitat was recently reviewed in Spence et al. (1996) and Bilby and Bisson (1998). Large wood accounts for much of the pool formation in streams draining forestland, and pools are the preferred rearing habitat for coho and other salmonids in Oregon’s coastal streams (Nickelson et al. 1992). Other functions of large wood include (a) trapping and regulating the flow of sediment, (b) providing substrate and nutrients to the aquatic food web, (c) creating complex patterns of hydrologic flow, (d) keeping salmon carcasses in the stream (their nutrients can be an important part of the food web), and (e) providing thermal refugia.

Functions of large wood.

Large wood is critical to the proper functioning and condition of aquatic systems, and it is essential in the recovery of wild salmonids in areas where it existed historically.

(2.) The status of large wood in streams and the landscape.

Historical reconstruction of aquatic habitats clearly shows that large wood in the stream channel was a major feature of Oregon's watersheds. Prior to the early 1800s, Oregon's coastal rivers contained a large volume of wood that created complex habitat structure, including large pools, backwaters, and associated wetlands (Swanson et al. 1976, Sedell and Luchessa 1981, Sedell et al. 1988, Brenner 1991, Brenner and Sedell (1994). It was this condition—habitat and channel complexity imparted by significant volumes of large wood—to which salmonids adapted and to which their spatial and temporal patterns of habitat use evolved (Sedell and Luchessa 1981). In addition, portions of the forested landscape were dominated by extensive older forests, large snags, and the associated accumulation of large downed wood (Teensma et al. 1991).

Shortly after the arrival of the first Euro-American settlers to the Pacific Northwest, stream channels were radically altered. Not only was large wood removed from the channel to facilitate the use of rivers for transportation, potential wood replacements were harvested from riparian and upslope forests. This altered state of inner channels was maintained by continued logging in the riparian zone and the problem was compounded by removal of wood from streams into the 1970s.

As part of the Oregon Plan and other efforts, extensive surveys of large wood in forest streams are being conducted in Oregon's coastal rivers. Surveys of about 2,000 stream- miles on non-Federal lands show there are fewer pieces of large wood in the stream channels than specified in the current Oregon benchmarks. About 40 percent of the stream-miles surveyed are considered adequate or good with regard to the presence of large wood, but 60 percent are considered poor. Probably more important to the long-term recovery of wild salmonids is the finding that 94 percent of the riparian areas (a potential source of future large wood in streams) are themselves ranked as poor with regard to the presence of large conifers (ODF 1999).

We conclude that Oregon streams and adjacent forests currently contain much lower levels of larger wood than they did historically, and under the current management practices, the potential for recruitment will not result in its replenishment.

The status of large wood in streams and the landscape.

Oregon streams currently contain much lower levels of larger wood than they did historically.

(3.) Managing for recruitment of large wood.

The riparian zone is an important source for large wood. The trees that fall into the stream from the riparian zone come predominantly from within 98 feet of the channel edge. However, large wood can also be recruited from as far as 165 feet from the stream bank. A riparian buffer consisting of taller older trees contributes large wood from greater distances than do younger forests with shorter trees (McDade et al. 1990; Van Sickle and Gregory 1990; Fetherston et al. 1995). In unconstrained stream reaches, large wood from the floodplain also can eventually reach the stream because of floods or lateral migration of the stream channel (Bilby and Bisson 1998).

Upslope areas adjacent to headwater streams are also an important source of large wood. In intermediate-sized stream channels, large wood may originate on the slope above a headwater tributary and be delivered to the lower stream reaches through a debris torrent. First- and second-order headwater streams provide a large amount of the wood that forms habitat in larger channels downstream (Prichard et al. 1998).

We conclude that both riparian management areas and unstable upslope areas are important for the recruitment of large wood to streams in the future. While harvesting has reduced the amount of large wood available for recruitment, it must also be recognized that the level of mortality in forested systems has also been reduced. Fire suppression, limitations on pathogens, and thinning have reduced the production of snags on the landscape. Therefore, even if old forests are allowed to develop, management will have to also facilitate the recruitment of snags.

Managing for recruitment of large wood.

Both riparian management areas and unstable upslope areas are important for the recruitment of large wood to streams.

Conclusion

The current status of large wood in Oregon streams is far outside the historic range and we believe this is seriously hindering the recovery of wild salmonids. Management strategies that more nearly emulate the historic range of condition are possible and can contribute to the attainment of the mission of the Oregon Plan.

C. Sedimentation

Sediment occurs naturally in forested stream systems. Although this is part of the natural disturbance regime for this region, the processes of erosion have accelerated with the increase in forest management activities.

Fine sediment is a natural part of stream systems, as are the coarser elements of stream structure, such as large wood, boulders, and gravel. The trick in achieving quality habitat for salmonids is to keep these various elements in balance with one another. There is no definitive scientifically based “tolerance” for fine sediments, but in the absence of introductions of boulders, large wood, and gravel, it is prudent to minimize the introduction of fine sediment.

(1.) Managing chronic sedimentation from roads at the site level.

Scientific investigation and analysis have produced a sound scientific basis for site-level management of the production of road-related sediment and its movement to streams. The volume of literature is such that a point-by-point analysis of it by IMST is impractical, and can be done by ODF staff. Briefly:
Fine sediment production increases with road construction, use, and maintenance. The scientific principles that govern sedimentation are well documented in the literature:

- Actions that decrease the size of soil particles increase the amount of fine material available for water transport. An example is the production of fine particles from the mechanical action of vehicular traffic on forest roads.
- Actions that expose the soil surface or disturb road or ditch surfaces increase erosion potential. Some examples include excavating road cuts, clearing vegetation from roadsides and ditches, and scraping road surfaces with road graders or other bladed vehicles.

Once fine particles have been produced, they are available for transport to streams where they can impact the quality of salmonid habitat. The key issues concern the effectiveness of road-drainage systems and the dispersal of ditch-drain water.

We accept that drainage from road ditches into streams cannot be completely eliminated, but we believe that it can be greatly reduced. Dispersing road drainage water onto stable slopes rather than into channels will minimize the movement of sediment from roads to streams. Science has shown that undisturbed forest floor has a high infiltration capacity. Although it has not been explicitly tested, logic indicates that sediment transported to such areas will be trapped in the soil profile and will be less likely to enter the stream.

The volume and velocity of the water determine its erosive and sediment transport power. Crossroad drainage culverts are used to limit the distance over which the volume of road-drainage water can accumulate. On steeper roads, the distance between crossroad drainage culverts is decreased to prevent the accumulation of large volumes of rapidly flowing water. Empirically derived guidelines for crossroad drainage systems have been part of the literature for many years, but often have not been rigorously followed. Systematic validation of these guidelines should be incorporated into the monitoring program to determine their adequacy. In the meantime, however, implementation of the guidelines should reduce the introduction of chronic sediment from roads.

Managing chronic sedimentation from roads at the site level.

Fine sediment production increases with road construction, use and maintenance. There is a strong, scientifically sound basis for site-level management of sediment production and movement to streams.

Some reports argue that chronic sediment particles from roads are too small to be entrained in gravel, and therefore have little impact on salmonid production. Although this is likely true in the sense of salmonid egg survival and emergence of fry, we find this view too narrow. More suspended sediment will deposited in areas where water velocity is slower, and chronic sediment production and transport will occur even during periods of lower stream flow. The result will be increased sediment deposition in pools, backwaters, and other areas critical for rearing. In addition, suspended sediment reduces the transmission of light, which reduces the primary productivity of the stream. Suspended sediment also decreases visibility, which may alter foraging and territoriality behaviors and perhaps the ability to evade predation.

We conclude that chronic sediment production can be managed and mitigated and that there is a scientifically valid basis for doing so. The technical literature (some of which is reviewed in the appendix) provides the scientific basis for this. Examples include the use of rock to armor a road surface, reduced tire pressure, revegetation of exposed soil surfaces, and retention of vegetation on roadsides. Technical specialists can use the literature to develop specific practices for reducing chronic sediment production from roads. Minimizing the amount of road drainage water that flows directly into streams and channels can reduce the movement of fine sediment from roads to streams. This can be accomplished by decreasing the distance between crossroad drainage structure and by diverting more road drainage water onto stable slopes.

(2.) Managing chronic sedimentation from roads at the landscape level.

There is a sound scientific basis for the management of chronic sediment production and transport to streams at the site level, but there has been less analysis at the landscape level. There are relationships in the literature showing the quantity of sediment production as a function of the number of roads in a watershed. In general these relationships suggest that sedimentation increases with road density, but as a practical matter these are empirical or intuitive relationships and are not the result of critical experimentation. There are many site-specific factors that influence these relationships and their empirical nature makes it difficult to apply them (quantitatively) to other areas.

We conclude the reported relationships between road density and sedimentation provide only qualitative guidance for landscape-level planning and management. Monitoring and more case history analyses will provide a stronger basis for policy.

Managing chronic sedimentation from roads at the landscape level.

The reported relationships between road density and sedimentation provide only qualitative guidance for landscape-level planning and management. Monitoring and more case history analyses will provide a stronger basis for policy.

(3.) Managing episodic road failure.

The literature on sedimentation from roads is dominated by the impact of catastrophic road failures. The topic is complicated by the episodic nature of storms and changing road construction and maintenance standards. Among the various operations that occur on forest lands, the scientific base of knowledge and experience over the past two decades have increased the most with respect to road construction and maintenance. This increase in knowledge provides a sound basis for the development of guidelines and standards that will greatly reduce sedimentation from road failures. The base of information has been summarized effectively in presentations to ODF and in the issue-analysis documents prepared by the Department. Technical staff (in the Department and elsewhere) can use this information and these documents in refining rules and measures to help accomplish the mission of the Oregon Plan.

Road-failure related sedimentation is best addressed in three parts: 1) location, 2) design and construction, and 3) maintenance and abandonment.

Road Location

Our knowledge of the relationships between geology, soils, topography, and climate is well developed and scientifically sound. Much of the improvement in road location standards over the past few decades have come from this knowledge. Continued adherence to these best management practices (BMP) will result in a markedly fewer failures of new roads than of so-called "legacy" or "old" roads (meaning roads not covered by OFPA, often those constructed before current rules were in force). The literature and experience support the value of using BMP to locate roads such that they

- minimize stream and channel crossings
- do not cross wetlands or areas with a high likelihood of slope failure

Road design and construction methods

Current road design and construction methods are well documented in the literature and are well reflected in ODF documents. The scientific and engineering principles on which they rest are sound.

Road Maintenance and Retirement

Road location, design, and construction establish the limits of the potential impact of a road on salmonid habitat. Maintenance (short- and long-term) often determines the degree to which the potential impact (for protection or damage) is achieved. Scientific and technical analyses show that roads not constructed to current standards are involved in a disproportionately large number of road-related slope failures. We believe that a systematic program of road retirement and stabilization of hazardous sites can minimize both the catastrophic and chronic sources of sediment from roads no longer in active use.

The strategies for road retirement and stabilization have evolved from experience and from adaptation of the principles associated with road maintenance. Specifically:

- remove culverts and stream crossings that are more susceptible to catastrophic failure during heavy storms
- prevent channelization on road surfaces
- stabilize fills

- limit access
- encourage revegetation

These strategies have not been scientifically tested for effectiveness, but they have a sound theoretical basis. A more systematic basis for judging the effectiveness of various road retirement strategies can be developed through case history analysis and monitoring.

We conclude that the scientific and technical basis for what is needed in road maintenance and retirement is well developed and known. Refinements in this knowledge can occur through the monitoring and event analysis programs that are already part of ODF programs.

Managing episodic road failure.

The scientific and technical basis for what is needed in road maintenance and retirement is well developed and known. Refinements can occur through the monitoring and event analysis programs that are already part of ODF programs.

(4.) Managing slope failure and the movement of material to the stream system.

Landslides occur in both disturbed and relatively undisturbed forests. Available evidence from central and northwestern Oregon indicates that forest management activities increase the frequency of landslides within a period of one to two decades after disturbance. Results from the ODF study (ODF 1998b) are consistent with the suggestion that harvesting may shift the timing of occurrence of slope failure and concentrate it within the two decades after harvest. Although a provocative idea, we do not consider this a rigorous test, and caution against adoption of this as a paradigm without further testing. We do not consider it an adequate technical basis for policy formulation.

Slope stability problems need to be considered at the site and the landscape level. The logic for managing slope failure is (a) to identify sites where significantly elevated risks of slope failure exist, and (b) to moderate or limit management activities believed to increase the occurrence of slope failure. The ability to characterize (or predict) the risk of slope failure is not uniform across the scale of risk. At the extremes of the risk of slope failure, the ability to predict accurately is greater, e.g., for a given set of geological soil and climatic conditions, shallow slopes are unlikely to fail but very steep slopes are more likely to fail. Prediction of slope failure must be done in the face of uncertainty about weather patterns over the first two decades after disturbance.

The ability to predict slope failure is limited by

- the difficulty of accurately predicting inherent slope stability, except at the extremes of condition (including steepness)
- limited knowledge of how a given management tactic might interact to increase or decrease inherent slope stability, and
- inability to predict pattern of extreme weather events over a subsequent period of one or two decades.

These points apply at both the site and the landscape level, but some degree of averaging occurs at larger scales, with an increase in the accuracy with which slope failure can be predicted (at the landscape level). The consequence is a greater ability to "manage" in the face of slope failure at the landscape level. The concepts for this are illustrated in Figures 3 and 4 (Benda et al. 1998).

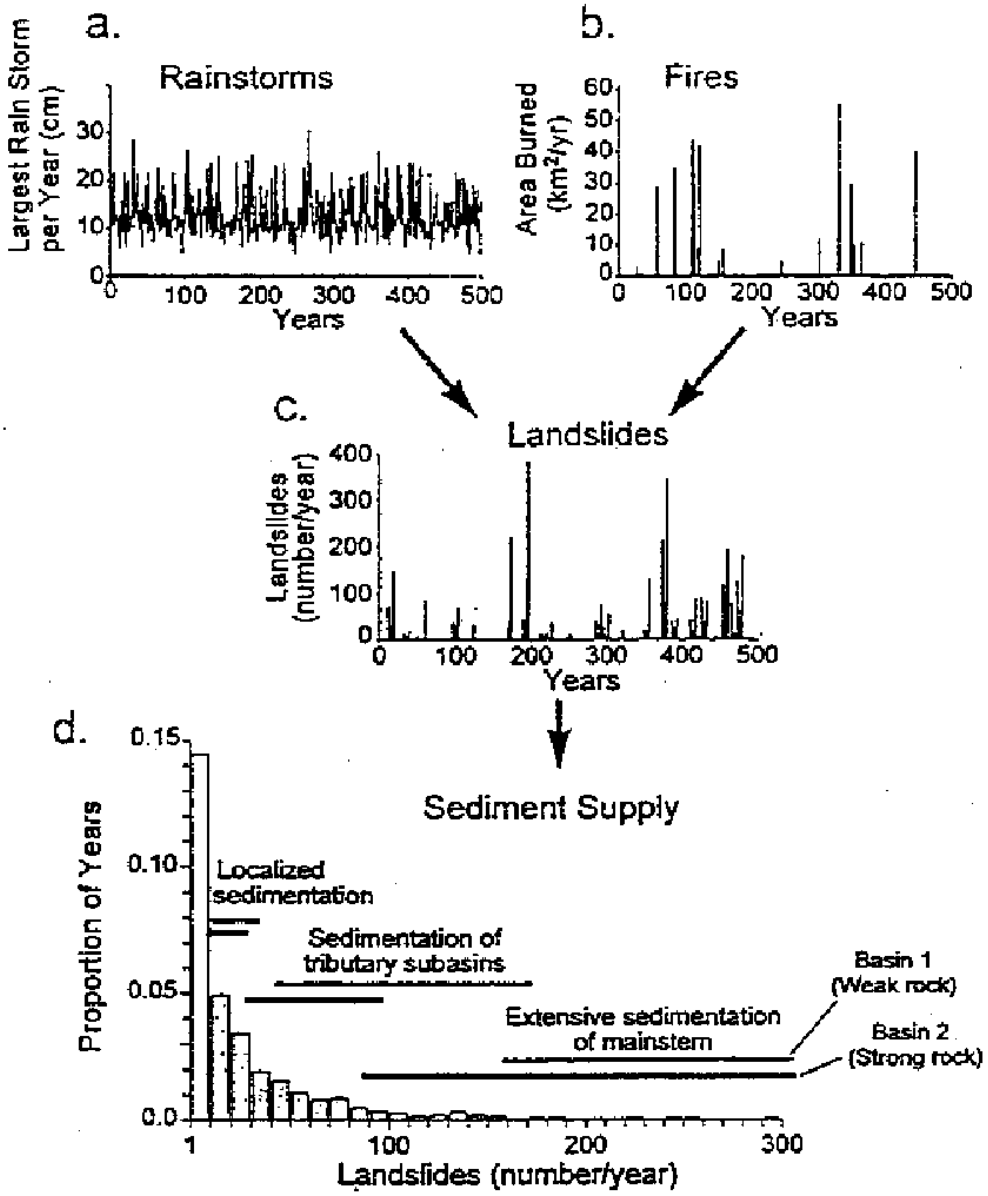


Figure 3. A sequence of rainstorms (a) and fires (b) generates a sequence of landscapes within a basin (c) which results in an intermittent sequence of sediment delivery to the channel system. The time sequence of sediment supply is represented as a distribution (d) indicating how likely various magnitudes of sedimentation occur. Channel response depends on the size distribution and durability of the sediment delivered. (From Benda et al. 1998, p. 275.)

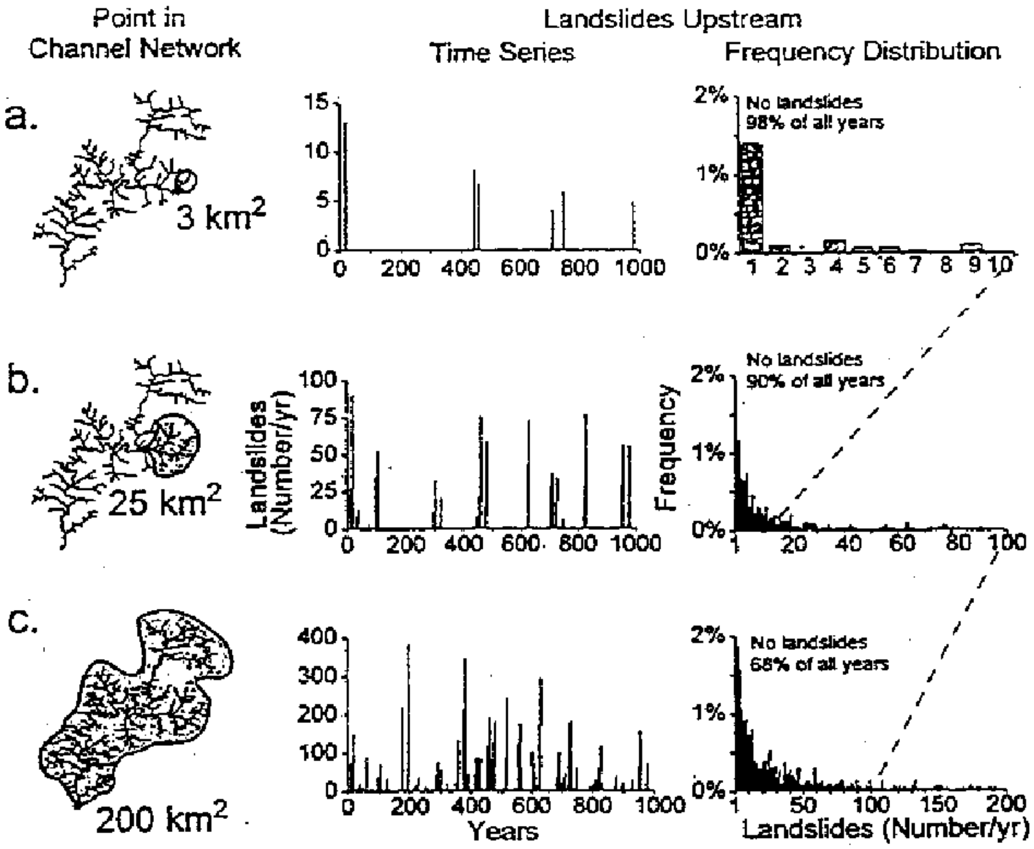


Figure 4. A 1000-year simulation of landslides in a 200-km^2 basin in the Oregon Coast Range indicates that the likelihood of landslides and associated sediment and wood delivery to the channel system increases with increasing basin area. (a) a 3-km^2 headwater basin experiences infrequent landslides. (b) a 25-km^2 tributary subbasin contains a greater total number of potential landslide sites and is more likely to include a fire: hence, landslides occur more frequently and in greater numbers within this larger area. (c) Numerous subbasins and a vary large number of potential landslide sites are contained within the entire 200 km^2 basin. Landslides occur somewhere within the basin a third of all years. On rare occasions, when large fires are followed by intense storms, well over 100 landslides can occur within the basin in a single year. (From Benda et al. 1998, p. 278.)

Although the ideas in these figures are conceptually strong, they must be validated through monitoring and analysis based on the continued use of BMP. There is some risk in continuing the present approach (because in some cases slope failures will be underestimated), but the long-term gain in benefit for management across large areas may be worth the risk. This is a policy question.

Not all landslides result in transport of material (debris torrents) to streams. When they do, the consequences vary. In some cases, stream channels and riparian zones have been completely scoured, leaving the system in a highly unproductive state, at least over the near future. In other cases, landslides have significantly enhanced fish habitat by adding structural complexity and spawning materials or creating off-channel refugia. As with most other elements of resource management, there is no single simple solution.

Although specific evidence is limited, we believe that functional riparian zones may be an important factor in diminishing the adverse effects of debris torrents. Riparian zones can contribute large wood and other debris to the torrent, maintaining some balance between the amounts of sediment, gravel, boulders, and large wood. This idea requires validation through monitoring and analysis of BMP. It may be premature as a basis for policy formulation, but we believe it is conceptually correct.

We conclude that the geology, engineering, and geotechnical concepts for addressing slope failure are reasonably well developed and are described in Benda et al. (1998), Swanson et al. (1987), and in ODF (1998b). We conclude, however, that except where inherent slope stability is at its extremes (either very great or very low), regulatory or voluntary measures have little certainty of reducing sedimentation from non-road-related slope failure at the site level.

Managing slope failures and the movement of material to streams.

Slope failure is a natural process and it can have both positive and negative effects on fish habitat. The technical basis for managing roads to reduce or minimize slope failure is well developed. The technical basis for managing non-road-related slope failure is much less well developed, except under extremes of site conditions. Although speculative, we believe maintenance of functional riparian zones along channels where debris torrents may occur can mitigate their destructive force, and increase the positive effects they may have.

D. Fish Passage at Road-Stream Crossings

Road/stream crossings impact salmonids through blockage of access to upstream habitat, as sources of chronic sediment input, and as sites of catastrophic failure and subsequent debris torrents. Fish passage at forest road crossings is reported to be a major factor in loss of habitat suitable for fish (ODF 1998a). Studies in Washington documented loss of coho summer rearing habitat from culverts at 13 percent of the total decrease in habitat. This decrease was considered to be greater than the combined effect of all other forest management activity related causes (ODF 1998a). Conroy (1997), noted that as many as 75 percent of culverts in given forested drainages in Washington were either outright blockages or impediments to fish passage. The technical basis for solution of this aspect of the habitat problem is well established. Strategies include minimizing the numbers of such crossings, reducing the erodability of exposed soil surfaces, making them stable during periods of high water, and providing for upstream and downstream fish passage.

Specific best management practices must be adopted on a site-by-site basis. A set of road-stream crossing guidelines have been developed by ODFW (ODFW 1996). The guidelines were adopted in 1996–1997 by memorandum of agreement among several state agencies, including ODF and

ODFW. These are based on science, although specific design elements are the result of extrapolation from scientific principles and often are not the result of explicit experimentation.

Fish Passage at Road-Stream Crossings

The ODFW guidelines are believed to be scientifically sound (although not thoroughly tested) and provide an adequate basis for managing fish passage at road-stream crossings.

Question 2. Are current forest practices Rules and Measures with regard to riparian buffers, large wood, sedimentation, and fish passage adequate to achieve the mission of the Oregon Plan?

The current OFPA Rules and Measures in the Oregon Plan are predominantly prescriptive and site specific, and deal with specific actions. Our analysis of the scientific basis for management (see question 1) provides the basis for an analysis of the adequacy of the Rules and Measures. While this report is not a review of the Rules and Measures, we provide the following evaluation of adequacy to highlight some examples.

Riparian Buffers as a Strategy

The current Rules will result in buffers with characteristics that are quite different from adjacent upslope forests, resulting in sharp demarcations and a landscape condition that does not emulate the historic range of conditions.

Riparian buffer management based on stream size

Current OFPA rules correctly allow for varying buffer width and stand density based on stream size, with smaller streams receiving less protection compared to larger streams.

Riparian buffer management based on fish presence

The OFPA Rules and the Measures outlined in the Oregon Plan are not scientifically sound for the recovery of wild salmonids because they only consider game fish and do not adequately address the contribution of non-fish bearing streams to many downstream processes.

Riparian buffers on floodplains

OFPA rules for riparian management provide no protection for floodplains outside the RMA. This means that floods in floodplain reaches may extend beyond the RMA and increase the risk of erosion and channel change on the outer margins of floodplains. These areas will not provide the ecological functions associated with stream riparian systems.

Functions of large wood

OFPA Rules and the Measures of the Oregon Plan acknowledge the importance of large wood in aquatic systems.

Managing for the recruitment of large wood

Within existing RMAs, the width is adequate for recruitment of large wood but the density of large conifers is not, especially on small streams. RMA protection must be extended to stream reaches not currently included and trees must be retained on unstable upslope to increase the potential for large wood recruitment.

Managing chronic sedimentation from roads

OFPA Rules provide an adequate basis for addressing several of the chronic sources of sediment from roads at the site level. Specific attention in implementation needs to be given to enforcement with respect to road drainage directly into channels, cross-road drainage frequency, road surfacing, tire pressure, wet season operations, revegetation of exposed surfaces, and vegetation retention on roadsides. The Rules do little to address roads at the landscape level except to encourage strategies that reduce the construction of new roads.

Managing episodic road failure

Current road design and construction methods are scientifically sound and well documented in the technical and operational literature, providing a sound basis for OFPA Rules and Measures in the Oregon Plan. The Rules and Measures are adequate in this regard, with attention to implementation.

Managing road maintenance and abandonment

OFPA Rules provide an adequate basis for regulation of road maintenance. In the implementation of the Rules, it is important to retain culvert design discharge capacity.
OFPA Rules require that culvert replacements conform to current standards, including providing for passage of 50-year flow events. However, this requires complex judgements on the part of operators and landowners, often under emergency conditions. The challenge is to ensure the information necessary for making the right decision is readily available, and that appropriate regulatory oversight is provided.

Managing slope failure and the movement of material to the stream system

Continued use of BMP as permitted under the Rules is appropriate, but it needs to be combined with monitoring and case history analysis to provide a better basis for management of slope failure in the future.

Fish passage at road-stream crossings

Pending better information and the results of monitoring, the ODFW guidelines provide a sound basis for managing fish passages at road-stream crossings.

The changes noted above, combined with their effective implementation, will improve the effectiveness of site-specific Rules and Measures. We conclude, however, that site specific rules alone, even with these changes, will not result in the emulation of the range of historic condition at the landscape level needed for salmonid recovery. The problems with site specific rules include the following:

A. Each site or action is treated as if it is independent of any other. This ignores cumulative effects and it ignores other related processes occurring in other parts of the landscape.

> Cumulative effects are often difficult to explicitly measure at the landscape level, but they are consistent with logic. For example, roads produce fine sediment and culverts and stream crossings modify the movement of water, sediment, and large wood. Although difficult to demonstrate at the watershed level, logically, the production of fine sediment increases with the length of a road system and number of stream crossings, and the movement of water, sediment, and large wood is increasingly influenced as the number of culverts and stream crossings increase.
>
> The relationships between riparian and upslope areas provide examples where current rules ignore related processes occurring in other portions of the landscape. As an example, current OFPA riparian rules relating to large wood recruitment are based on achieving 58 to 92 percent of the large wood that results from a mature forest riparian zone. Relying primarily on recruitment from riparian buffers, watersheds that historically had significant contributions of large wood from upslope positions have much lower levels of large wood recruitment than the historic range of condition. ODF acknowledges that currently the rules do not address the issue of potential large wood inputs from upslope sources.
>
> As a second example, the riparian forest is treated as distinct from the upslope forest. The result of current riparian protection is a strip of mature forest between the upslope forest and the stream. Since the upslope forest is managed primarily for harvest of trees, and the riparian forest is managed to develop into mature forest for stream protection, larger demarcations between the two forest types could/will develop. This will almost certainly result in a riparian forest structure and function (perhaps an upslope as well) that is different from historic conditions (Murphy 1995). Landscape level goals for riparian and upslope conditions must be developed and implemented to allow for the full complement of physical and biological structures and functions, while minimizing risk to the aquatic system. We believe the key is emulation of the historic range of condition.

B. Application of uniform riparian rules results in a relatively uniform outcome throughout a landscape. A principle outlined in the Preface is that heterogeneity of ecosystem conditions across time and space is the pattern to which wild salmonids adapted. The application of uniform rules tends to reduce the heterogeneity.

> As an example, the current riparian management rules require specific widths and basal area retention for streams of specific sizes. Over time the result will be an increasingly uniform condition in the riparian zones of a landscape. There will be little variation in the entry of sunlight, organic material, nutrients, insects, large wood, and other materials to the aquatic system. This will poorly emulate the historic range of condition.

We conclude that the current site-specific Rules and Measures contribute to achieving the mission of the Oregon Plan, but they are insufficient. In the short run, they must be incorporated into a landscape approach. Over the long run, the site-specific Rules and Measures may be able to be simplified and become less prescriptive as management, policy, regulation, and voluntary measures are developed at the landscape level.

Adequacy of site-specific strategies for achieving the mission of the Oregon Plan.

The current site-specific Rules and Measures contribute to achieving the mission of the Oregon Plan, but they are insufficient. They must be incorporated into a landscape approach.

Question 3. What strategies are needed in the management of forest resources to achieve the mission of the Oregon Plan?

Based on our understanding of the science, we believe a landscape approach to policy, resource management, regulation, and voluntary actions is needed to accomplish the mission of the Oregon Plan. The current approach is primarily a site- and action-specific prescriptive approach. Other approaches are at the conceptual or landscape level only. It is likely that a blend of these approaches is best.

A. Prescriptive Approaches

Prescriptive approaches are the dominant strategy for the regulation of practices on forestlands. They typically specify the actions that should (or should not) occur at any given site. An example is to leave a buffer strip of some specific width (or widths) along streams. The Oregon Forest Practices Act, the federal Northwest Forest Plan, and the Forest Practices Rules in Washington and other states are all prescriptive in their approach.

As outlined in the Preface to this report, we believe emulation of the historic range and distribution of conditions at the landscape level is essential to accomplishing the mission of the Oregon Plan. This is the criterion we apply in our analysis of the capacity of several prescriptive approaches to this goal.

(1.) Oregon Forest Practices Act and Administrative Rules

The contemporary version of the Oregon Forest Practices Act was enacted in 1972, with substantive revisions in 1987 and 1994, and the latest modifications in 1998. The OFPA Rules regulate forestry activities, and were developed to protect forest-related resource values, including waters of the state. They provide benefit to salmonids through protection of water quality and habitat, but they do not include the recovery of wild salmonids.

The OFPA rules focus on specific activities as they occur on specific sites. Examples include timber harvest, use of pesticides and other chemicals, reforestation, and the design, construction, and maintenance of roads. They incorporate a landscape perspective with respect to some aspects of timber harvest (for instance by limiting the size and adjacency of clearcut harvest units) and some aspects of roads (encouraging the use of existing roads rather than building new roads where practical).

The OFPA rules include Water Protection Rules, which include specifics for Riparian Management Areas (RMAs). Vegetation retention along streams follows a protocol that is designed to meet criteria for "desired future conditions". The purpose of these requirements is to provide for the establishment or re-establishment of functioning riparian habitat along streams, which will benefit water quality of fish habitat. These rules are designed to minimize or avoid adverse effects to the waters of the state, but are action and site specific. They do not include a landscape perspective.

(2.) The (federal) Northwest Forest Plan

The Forest Ecosystem Management Assessment Team (FEMAT) developed the Northwest Forest Plan (ROD). It is based on the analysis of 10 options for management of federal forests within the range of the northern spotted owl, and it focuses on wildlife species that are associated with late-successional and old-growth forests. Allocation of land to a system of “reserves” interspersed with lands where timber harvest can occur and Adaptive Management Areas (where new approaches to management can be tried) is central to the Northwest Forest Plan. Specific Standards and Guidelines for Management provide prescriptive elements.

Key watersheds were also identified and prioritized within each land allocation. The Aquatic Conservation Strategy, under the Northwest Forest Plan, was designed to protect and restore salmon and steelhead habitat by maintaining and restoring ecosystem health at the watershed scale. This includes watershed analysis. The current measures are conservative, and may be changed as additional information providing a better basis for management options becomes available.

The Northwest Forest Plan includes both a site-specific and a landscape perspective, although it does little to include lands outside of federal ownership, even when they are key parts of the landscape to be managed. A variety of policies and laws (some of which are conflicting) have made it difficult to achieve the full array of federal management objectives or the elements of adaptive management that are a critical part of the Northwest Forest Plan.

(3.) Washington Forest Practices Act and Rules

The State of Washington has regulated forestry activities on state and private lands since 1974 through the Washington Forest Practices Act. Under the Act, the Washington Forest Practices Board (WFPB) issues Rules (WFPB 1995) and a Board Manual as guidance for regulation of forestry activities. The rules have gone through many changes, with the most current legislation directing futures rules to be based on the April 1999 “Forest and Fish Report” (DNR, 1999).

The Forest Fish Report articulates four goals:

- Provide compliance with the Endangered Species Act for aquatic and riparian-dependent species on non-federal forest lands.
- Restore and maintain riparian habitat on non-federal forest lands to support a harvestable supply of fish.
- Meet the requirements of the Clean Water Act for water quality on non-federal forest lands.
- Keep the timber industry economically viable in the State of Washington.

Priorities include riparian protection (buffer zones with regional variations) for fish and non-fish habitat, road maintenance and construction and protection for unstable slopes, adaptive management, watershed analysis, and other issues. The approach includes prescriptions designed to achieve desired future conditions, based on scientific criteria that are believed will provide appropriate ecological functions required for water quality and stream habitat.

The Washington State approach is similar in many respects to the OFPA approach, although it incorporates more contemporary, strategies including watershed analysis and a landscape based approach. However, as with OFPA, the Washington State strategies do not adequately incorporate the landscape perspective needed to accomplish the mission of the Oregon Plan.

We find that regulatory frameworks for managing natural resources are often focused on single factors and present a simplified view of complex ecosystem interactions. The goal of regulation may be multifaceted (i.e., water quality), but the rule designed to obtain the goal is often singular (i.e., a 100-ft riparian management zone). A "one-size-fits-all" approach, while an attractive regulatory framework, is not capable of reflecting the dynamic nature of landscape structure and function. In addition, by limiting the application of scientific concepts, managers are often discouraged from adapting the regulatory framework to coincide with changing ecological conditions.

We do not consider the prescriptive approaches included in the Oregon and Washington forest practices rules to be consistent with the direction provided by science for the recovery of Oregon’s wild salmonids. To meet the objective of long-term ecosystem function, a conceptual-based management approach may be more successful.

B. Conceptual Approaches

The science of landscape ecology forms a good conceptual basis for meeting the goal of enhancing and maintaining salmonid habitat (Schlosser 1991). By developing a policy framework that encourages landscape patterns that reflect the historic conditions under which salmonids evolved, the entire landscape can play a role in achieving properly functioning aquatic conditions. A mosaic of conditions across the landscape was once achieved through natural disturbances. Although we can never recreate the same dynamic system on our current landscape, we can use our current understanding and monitoring of results to better tailor our management activities towards the same end.

There are difficulties inherent in applying a landscape-based management strategy. The lack of large-scale quantitative relationships makes it hard to predict the impact of management decisions on desired outcomes. There are models available that simulate disturbance history (Benda et al. 1998), sediment transport (Benda and Dunne 1997a, b), and large wood recruitment (Meleason and Gregory 1999); however, these models remain to be validated across larger landscape scales. In addition, the regulatory framework of such a complex approach would be difficult to monitor, although satellite imagery and projects such as the Coastal Landscape Analysis and Modeling Study (CLAMS) indicate that the required technology is rapidly becoming available.

We conclude that the science of landscape ecology provides the appropriate concepts for landscape level management, but it is not sufficiently well developed and tested to permit its widespread use now. In addition, the policy framework (a combination of regulation, voluntary action, incentives and other approaches) required to make it workable has not been developed.

C. A Blended Approach

The Oregon Department of Forestry is preparing a management plan for over 600,000 acres in northwestern Oregon. The plan is a blend of the prescriptive approach (because it does not violate the OFPA rules) and a conceptual approach (because it uses principles of landscape management).

This plan has the goal of maintaining properly functioning conditions in both terrestrial and aquatic systems, including a variety of habitats and forest conditions across the landscape and over time. Aquatic systems are further considered with a goal to provide stands that are diverse in size, type, and arrangement, both adjacent to riparian areas and across the landscape. In addition to these landscape-based goals, the plan will be implemented under the current regulatory framework established by the Oregon Forest Practices Rules. The aquatic strategies outlined in the plan attempt to take a blended approach by including both an overall landscape management element, as well as more specific prescriptive elements, to be applied when different forest activities are conducted.

In a review by several scientists (Hayes 1998), the plan was recognized for having a strong conceptual basis rooted in science. However, the scientists agreed that individual management approaches (such as riparian buffer widths) were not well supported with scientific data.

D. Emulating Historic Patterns — A Challenge

Designing a management strategy that emulates historic patterns of disturbance at the landscape level is a useful framework, but we need to recognize that we are managing from current conditions, and these do not fully reflect historic landscape patterns. Historically, the major disturbances in the forests of western Oregon included fires and hydrological (i.e., landslides, debris flows, floods), climatic (i.e., drought, wind), and pathogenic (i.e., insects and disease) events. Although they are often discussed as separate incidents, it should be recognized that these disturbances are interrelated and often have synergistic effects on terrestrial and aquatic systems.

These disturbances and their interactions change aquatic systems and add to their spatial and temporal heterogeneity. The degree of change depends on the frequency extensiveness, and intensity of the disturbance and the condition of the ecosystem. For example, a severe fire, followed by a 50-year storm will provide the aquatic system with sediment, rock, and large wood at a time when the hydrologic forces are present to transport and deposit it (Benda et al. 1998). The effects of fire also interact with the age class of the forest. For example, in younger stands, fire may kill many trees because their bark is relatively thin; smaller material is also more likely to burn completely, leaving less wood to be transported into streams. The frequency or return interval of a disturbance can have major impacts on forest composition and density. For example, frequent disturbances that provide light and an adequate seedbed would favor short-lived species such as red alder, whereas less frequent gap-formation events (such as root rot or patchy blow-down) would favor shade-tolerant conifers. Maintaining the riparian forest heterogeneity based on historic patterns should be considered when designing riparian protection strategies.

Conclusion

We conclude that the current OFPA Administrative Rules and the Measures of the Oregon Plan are designed to meet our forest management goals, but are not adequate for accomplishing the mission of the Oregon Plan. To better meet the goal of properly functioning aquatic systems, we believe an approach that retains prescriptive elements but incorporates landscape level perspectives is needed. The blended approach taken by Oregon Department of Forestry in their Northwest Management Plan with a few modifications is an example. The modifications include 1) the immediate protection of all existing core habitat while implementation occurs; 2) taking a broader perspective to include adjacent private lands; and 3) the implementation of a scientifically valid monitoring program.

Strategies needed in the management of forest resources to achieve the mission of The Oregon Plan.

The current OFPA Administrative Rules and the Measures of the Oregon Plan are designed to meet our forest management goals, but are not adequate for accomplishing the mission of the Oregon Plan.

To better meet the goal of properly functioning aquatic systems, a blended approach that retains prescriptive elements but incorporates landscape-level perspectives is needed. The blended approach taken by Oregon Department of Forestry in their Northwest Management Plan with a few modifications is an example. The modifications include the immediate protection of all existing core habitat while implementation occurs, and taking a broader perspective to include adjacent private lands, and the implementation of a scientifically valid monitoring program.

SECTION IV
CONCLUSIONS AND IMPLICATIONS FOR POLICY

The science-based conclusions and implications for policy are drawn from our answers to the science questions and are grouped in four areas: riparian protection, large wood management, sedimentation, and fish passage at stream crossings.

Conclusions

Riparian Protection

Managing riparian areas as a strategy for protecting fish habitat is scientifically valid only if it is done with the goal of maintaining the dynamics structure and function across the landscape. Sharp demarcations between riparian forest and upslope forest, and between game-fish-bearing and non-bearing streams, are not consistent with the historic pattern.

Large Wood Management

The current status of large wood in western Oregon streams and the future recruitment potential for large wood are not adequate to ensure recovery of depressed stocks of wild salmonids. Most models of large wood recruitment focus on riparian areas as the source, ignoring the important contributions made by upslope sources, especially from landslides. There is a critical need to restore the ecological processes that produce and deliver large wood to the streams (riparian as well as upslope). Correcting this problem will take a long time, several decades. We do not believe the current OFPA rules will achieve the desired levels of large wood in the stream channels and in the forested riparian zones. A rigorous coast-wide monitoring and evaluation program and an adaptive management process is needed to detect and solve problems.

Sedimentation

Forestry operations increase the amount of chronic and episodic production of fine sediments. Disproportionately high amounts of fine sediment, compared with the coarser elements of stream structure (large wood, boulders, gravel, and cobble), diminish the quality of habitat for wild salmonids. In many instances, excess fire sediment can be reduced or the balance between finer and coarser material improved through actions at the site, using existing knowledge. Examples include designing, locating, constructing, and maintaining roads to minimize failure and to prevent road drainage from entering streams; maintaining trees on areas with a high risk of slope failure; and maintaining fully functional riparian zones to reduce the extent of disturbance of debris torrents.

Management of sedimentation at the watershed level is more difficult, and the scientific basis for it is less well developed, although the concepts are known and provide a basis for reasonable conjecture on how to proceed. In essence, the approach is to vary the extent and intensity of disturbance in a watershed over space and time, emulating the historical pattern of disturbance.

Fish passage at stream crossings

The stream-road crossing guidelines developed by ODFW (ODFW 1996) are based on science, although often not the result of explicit experimentation. They provide a scientifically sound basis for management of such crossings, although better information should result from monitoring.

Implications for Policy

Current forest policy for the state of Oregon focuses on forest management and environmental protection, but not the recovery of wild salmonids. The Rules and Measures by which current policy objectives are sought focus on specific actions occurring within defined periods of time at specific sites. It is precriptive: the rules provide for protection on a site-by-site basis, rather than at the landscape level. The rules make sharp distinctions in how riparian zones are managed, which may result in a failure to maintain the dynamics of structure and function of riparian and aquatic zones across the landscape. In other cases, hazardous sites on forest roads and railroad grades are exempt from current rules because the actions occurred before the rules were in effect. Mechanisms are needed to solve these problems on critical sites that are exempted from current rules. Similar examples can be drawn from conclusions about the recruitment of large wood and the management of sediment and fish passage.

There are three major areas in which shifts in policy are needed to achieve scientific consistency with the mission of The Oregon Plan.

∃ Incorporate the objectives of the Oregon Plan and Executive order 99-01 into the OFPA. This will place an emphasis of regulation on the protection and enhancement of habitat needed for the recovery of wild salmonids.
∃ Develop policy that extends the management of forest resources to the landscape level. This does not delete the site-specific aspects of current rules, but applies them in a different context. It will allow a shift from the current more prescriptive rules applied uniformly across the landscape to site-by-site regulations that take into account cumulative disturbance in the watershed, landscape features, and climatic variation.
∃ Develop policy that identifies, prioritizes and brings roads not built to current standards and other hazardous settings in critical locations into compliance with current standards. This means having the current rules applied to actions taken before the current rules were in force. It is remediation of particularly hazardous situations. In many cases the operator acted in good faith and within the rules of the day, but the outcome is not scientifically consistent with the mission of the Oregon plan; thus, a provision by which remediation is accomplished is needed.

Evaluating Policy

Evaluating policy options within the complexity that characterizes contemporary forestry is a challenge. Extending these options to the landscape level and over time makes the job enormously more difficult. Fortunately, there are analytical approaches and models that can be useful. Although it is not as simple as just "getting and running the model", these approaches from research can help. Examples of these are currently in use in the CLAMS research project and the Umpqua Land Exchange Project, both in western Oregon. Another example is illustrated by the work of Bettinger et al. (1998), who analyzed policy options involving aquatic habitat and timber production over time in a 15,000-acre watershed in eastern Oregon.

During the policy transition, regulatory actions will have to be treated as hypotheses that must be tested through adequate monitoring and evaluation. ODF will need to respond rapidly to new information obtained through the monitoring and evaluation program.

SECTION V.
RECOMMENDATIONS

This Report focuses on broad scientific issues and concepts. It is not a review of each of the individual Administrative Rules that are part of the Oregon Forest Practices Act or the Measures that are part of the Oregon Plan. In some cases it does focus on specific Rules or Measures, but these are used primarily to illustrate examples. Lack of inclusion of a specific Rule or Measure does not imply either approval or rejection of it by IMST. The scientific direction provided by this Report can guide ODF staff (working with other panels of experts as needed) in formulating Administrative Rules for OFPA and Measures for the Oregon Plan that are needed as part of accomplishing the recovery of depressed stocks of wild salmonids.

The following are the specific recommendations of the IMST. Some of our recommendations can be accommodated within the existing policy framework of the Oregon Forest Practices Act or the Oregon Plan. These are identified as Recommendations Consistent with the Existing Policy Framework, and we believe they can be addressed in the near future. Some other recommendations will be difficult or impossible to implement within the existing policy framework. These we identify as Recommendations that May Require a Modified Policy framework. Although these recommendations will take a longer period of time to implement, work on the revised policy framework should begin now. In aggregate, our recommendations are intended to both reinforce and enhance the site-specific Rules of OFPA and Measures of the Oregon Plan and provide a bridge to management that incorporates a landscape perspective.

Recommendations for ODF

Recommendations that May Require a Modified Policy Framework

Recommendation 1. Explicitly incorporate the policy objective of the Oregon Plan and Executive Order 99-01 into OFPA.

The policy objective of OFPA includes (among other things), the protection of water quality and aquatic habitat. Site-specific rules that protect aquatic habitat and water quality are necessary to achieve the policy objectives of the Oregon Plan. However, they are not sufficient because they do not specifically address the recovery of the depressed stocks of wild salmonids covered by the Oregon Plan and Executive Order 99-01. The objectives of the Oregon Plan and Executive Order 99-01 should be a specific objective of the OFPA if OFPA is to be scientifically consistent with them.

Recommendation 2. ODF should develop a policy framework to encompass landscape (large watershed) level planning and operations on forests within the range of wild salmonids in Oregon.

The current forest policy framework focuses on individual actions at specific sites. Although this is critical to accomplishing the mission of the Oregon Plan, IMST does not find that it is sufficient. There is a strong scientific basis for believing that achieving the mission of the Oregon Plan requires management of habitat for wild salmonids at the landscape (large watershed) level.

Large watersheds (such as the Willamette River, Alsea River, and others), include both forested and non-forested lands. Given that forests tend to predominate in the upper reaches of watershed areas, it is logical to provide for landscape (watershed level) management of forestlands within the framework of OFPA. Other policy frameworks will need adjustment to accomplish this same recommendation on other lands. The landscape level approach that is recommended for forestry will be prominent in IMST reports on other land uses as well.

IMST recommends that the following elements be included in this modified forest policy framework:

Long-term landscape (watershed) level assessment. Watershed level assessments of the conditions of upslope and riparian forest and associated aquatic systems are needed to determine the changes necessary to achieve the desired future conditions. This is believed to be an important mechanism for decisions and planning for management on the landscape scale. Remote sensing, digital elevation models, and a variety of modeling and analytical tools are available for this purpose. (Examples particularly relevant to forestry are found in the CLAMS project and the Umpqua Land Exchange Project.)

Identified goals. Goals that ensure the integrity of salmonid habitat should be identified for the characteristics of aquatic systems and riparian and upslope forests across the landscape. An important part of this is establishing quantitative links between fish habitat requirements and landscape patterns/processes. The ODF Northwest Forest plan is an example of one approach to this, although the goals of this plan are more explicit to forest stand structure than they are to aquatic and riparian system characteristics.

Monitoring. Monitoring is necessary to provide the information needed to evaluate the aggregated outcomes of management at the landscape level. Accomplishing monitoring from the landscape perspective will require additional monitoring, or perhaps can be accomplished with better coordination of monitoring and analysis of data across agencies to include the landscape perspective. There is a specific need for collaboration between ODFW and ODF to explicitly examine and evaluate the links and relationships between fish and ecosystem conditions (see Recommendation 16).

Coordination. Coordination among agencies and watershed councils is needed to facilitate the expansion of landscape level planning and management at scales that extend beyond the forest. The purpose of this element is to improve the coordination of forest lands with other lands.

We believe landscape analysis can be used in designing forestry practices that result in an emulation of the historic patterns of landscape disturbance on the current landscape. Among strategies that may be effective and advantageous from several perspectives are the following:

- defining the number stream crossings in a given basin
- defining the length of road system in a given basin
- defining the amount and distribution of stand age-classes in a given basin.

Utilization of such strategies may, among other things,

- permit a shift from the current, rigid buffer-width strategy to a more flexible one providing the historic array of condition at the landscape level
- provide the ability to achieve water temperature goals through control of the proportion of the landscape in various forested conditions
- provide greater flexibility in scheduling the extent and frequency of management related disturbance (i.e., concentrate clearcut timber harvest in a sub-basin and then provide longer periods for the watershed to stabilize and recover).

Recommendations Consistent with the Existing Forest Policy Framework

Recommendation 3. Treat non-fish-bearing streams the same as small, medium, and large fish-bearing streams when determining buffer-width protection.
Current rules reduce buffer-width requirements if game fish are not present. It is recommended that all large, medium, and small streams, regardless of fish presence, receive a riparian management area (RMA) of 100, 70, and 50 feet, respectively. Currently, there is no lower size limit for what constitutes a small stream. Given the increased level of protection, a lower limit to define a small stream should be developed. The lower limit should allow for a sufficient level of aquatic protection, paying particular attention to the role small streams play in wood delivery and carbon inputs during storms. On a landscape basis, a portion of intermittent or ephemeral streams will require the 50- foot buffer in order to retain aquatic function.

Table 1. Summary table based on ODF Rules regarding current requirements for minimum retention of streamside trees. Requirements are for numbers and basal area (BA) of conifer trees (exceptions are allowed under certain circumstances to substitute appropriate hardwoods for conifers) in riparian management areas (RMA) for clearcuts in Coast Range and South Coast geographic regions. Required minimum diameter at breast height of trees retained in the RMA for both Type F and Type N streams is 11 inches for large streams and 8 inches for medium streams.

		Number of conifers		Standard target		Active management target	
Stream type/size	RMA width (ft)	Trees/1000-ft stream length	Trees/acre	BA/1000-ft stream length	BA/acre	BA/1000-ft stream length	BA/acre
Type F (fish)							
Large	100	40	17	230	100	170	74
Medium	70	30	19	120	75	90	56
Small	50	0	0	40	35	20	17
Type N (non-fish)							
Large	70	30	19	90	56	—	—
Medium	50	10	9	50	44	—	—
Small	0	0	0	0	0	—	—

Recommendation 4. Provide increased riparian protection for the 100-year floodplains and islands.

Floodplains are low-gradient, unconstrained stream reaches where a strong connectivity exists between the aquatic and terrestrial ecosystems. To maintain this important landscape function, the 100-year floodplain should receive increased protection over that provided by current OFPA Rules or Measures in the Oregon Plan. The goal of this protection is to create the same type of mature forest condition that is the goal of current RMA management.

The entire 100-year floodplain should be included (including on islands). This would include the RMA and the areas beyond it to the edge of the floodplain. This may result in a larger zone of protection on one side of the stream. For example, if a stream is currently against the east side of a floodplain, the protection zone to the east may extend only as far as the upslope edge of the RMA, but on the west side, the protection may be 250 feet or more, depending on the floodplain width. The only time the floodplain protection zone should be equal on each side is if the stream is in the center of the floodplain.

Recommendation 5. Increase the conifer basal-area requirement and the number-of-trees requirement for RMAs, with increases in these requirements for medium and small streams regardless of fish presence.

This recommendation is based on the expected volume and number of trees in the riparian forest under current rules. In the Coast Range, current OFPA rules have *active* management basal area targets in the RMA on “Type 2 or 3” harvest units of 56 ft^2/acre and 17 ft^2/acre for medium and small streams, respectively. Standard targets are 75 ft^2/acre and 34.7 ft^2/acre for fish-bearing medium and small streams, respectively. These targets are too low and should be increased to at least the level required for large streams. In addition, these rules should be applied to all streams regardless of fish presence. The current required minimum trees-per-acre should also be increased on medium and small streams to meet the levels required on large fish-bearing streams. As in Recommendation 3, the lower limit defining small streams must be developed, with attention given to a similar level of protection for a portion of intermittent or ephemeral streams.

Recommendation 6. Complete the study of the effectiveness of the OFPA Rules in providing large wood for the short and long term.

One of the goals of riparian management is to generate a supply of large wood of diverse character and size to meet several different functions in the stream. Oregon Plan measure ODF 11S is to determine the effectiveness of the 1994 forest practices rules in providing for short-term and long-term sources of large wood. According to Measure 11, "If this monitoring effort identifies that the Water Protection Rules are not achieving the protection or LWD recruitment goals, the department will recommend rule changes." The depleted status of large wood throughout Coast Range watersheds makes completion of measure ODF 11S critically important.

There are several important questions this ODF study will be able to address. For example, what role will thinning of conifers in the riparian zone contribute to achieving a mature riparian forest condition sooner? When, where, and how should active management of hardwood-dominated riparian zones be done? Are basal area credits (in RMAs) for large wood placement in streams a useful and appropriate strategy for achieving large wood goals?

Recommendation 7. Provide enhanced levels of certainty of protection for “core areas”.

The term "core area" was used by ODFW in identifying specific areas critically important to the recovery of coho in the original Oregon Plan. This term may be replaced in the future. It is our intention that, regardless of the term used, this recommendation be applied to areas specifically designated by ODFW as critical to achieving the mission of the Oregon Plan and the intention of Executive Order 99-01.

The OFPA Rules should be changed to eliminate language that equivocates on resource protection in favor of forest operations. This equivocation inappropriately puts the risk of operations in core salmonid areas on the habitat. Examples of such language are found in the Road Location rules, 629-625-200 (3) "where *viable alternative exist"*, (5) "*where practical*", and "*investigate options*", in Road Maintenance rules 629-625-600 (8)(b) "*As reasonably practicable*".

These equivocal statements and similar types of statements in other rules should be replaced with language that clearly gives priority to the protection of core areas.

Recommendation 8. Develop and implement standards or guidelines that reduce the length of roadside drainage ditches that discharge into channels.

Surveys of road systems find that 30 to 70 percent of road drainage points discharge water and entrained sediment into channels. Although it is impractical to eliminate such drainage points, the amount of sediment discharged can be reduced by reducing the length of the segments of roadside drainage ditches that feed into channel discharge points. The shorter the distance of such channels, the less sediment that will be come entrained in the flowing water. This recommendation should be implemented for all new road construction and any road reconstruction covered by the OFPA Rules.

Recommendation 9. Implement the standards and guidelines for the length of roadside drainage ditch between cross-drainage structures, especially on steep gradient roads.

Surveys of road systems find that the distance between cross-drainage structures usually exceeds established guidelines. Decreasing the distance between such structures will reduce the volume of water discharged to the slope and will reduce the amount of sediment that becomes entrained in the discharge flow. The consequence of these changes will be a reduced likelihood of discharge-related slope or road failure and a reduced level of road-related sediment entering stream systems.

Recommendation 10. Require the flow capacity of cross-drainage structures and stream-crossing structures and culverts to meet current design standards.

This recommendation addresses two issues: maintaining the flow capacity of cross-drainage structures and culverts during maintenance, and emergency culvert replacement.

Maintaining flow capacity. ODF surveys show that a large percentage of ditch-relief culverts have reduced flow capacity because the ends of the culverts are damaged and/or the culverts are obstructed with debris. These culverts may cause water to be diverted, increasing the potential for catastrophic road failure. An effective program of drainage system maintenance will reduce the potential for road failure from this source. As part of this system of maintenance, equipment operators should be trained to prevent damage to the ends of culverts.

Emergency culvert replacement. OFPA rules require that culverts replaced during a road “reconstruction” meet current standards, i.e., the 50-year rule. Unfortunately, culverts that are undersized by current standards may fail and need to be replaced on an emergency basis during intense storms. Operators may not have the level of knowledge needed to determine the correct culvert size for this reconstruction. ODF needs to develop a program to predetermine appropriate culvert size for critical sites to ensure that this information is readily available to operators.

Recommendation 11. Provide for the stabilization of roads not constructed to current standards (including "old roads and railroad grades") in critical locations. Stabilization means reduction or elimination of the potential for failure. It includes a variety of strategies ranging from removal to abandonment, entirely or of sections, by which specific roads and railroad grades become a much less important source of sediment.

Analysis of road failures shows that roads not built to current standards dominate road-failure statistics in sensitive locations. IMST finds compelling evidence that road failures present sedimentation risks that are inconsistent with achieving the recovery of wild salmonids. OFPA rules can require that roads being used for forestry purposes be stabilized. We believe this rule should be vigorously enforced, with highest priority attention given to roads in core areas identified by ODFW, but with attention to forest roads at all locations over time.

"Old roads and railroad grades" on forestlands, sometimes called legacy roads, are not covered by the OFPA rules unless they are reactivated for a current forestry operation or purposes. IMST believes the lack of a mechanism to address the risks presented by such roads is a serious impediment to achieving the goals of the Oregon Plan. A process that will result in the stabilization of such roads is needed, with highest priority attention to roads in core areas, but with attention to such roads and railroad grades at all locations on forestlands over time.

As part of the Oregon Plan, voluntary efforts by forest industry are underway in northwestern Oregon to identify and stabilize or reduce the risk of failure on "old roads". ODF should document and report on the progress of this effort, and should extend it to other forest areas where wild salmonid habitat exists. Highest priority should be given to core areas identified by ODFW.

Recommendation 12. Require durable surfacing on wet-season haul roads and require that hauling cease before surfaces become soft or "pump" sediment to the surface.

Road surfaces are a source of fine sediment when they are used for hauling during the wet season. The surfacing characteristics of the road and the intensity of use influence the production of these sediments. Research has shown that a durable surface, such as rock of sufficient hardness and depth, will markedly reduce the production of sediment. In some cases the road surface or base may be soft, or traffic may cause a pumping action that causes sediment to move to the surface, where it can be transported to streams. A cessation of hauling will reduce sediment production from this source.

Recommendation 13. Retain trees on "high risk slopes" and in likely debris torrent tracks to increase the likelihood that large wood will be transported to streams when landslides and debris torrents occur.

Landslides and debris torrents may be an important mechanism by which portions of the aquatic system are revitalized. Landslides and debris torrents that emulate the historical quality and quantity of debris delivered to the stream system are believed to be most effective. The key elements of landslides and debris torrents are their composition (wood, rock, and sediment) and the size of material (large wood, boulders, cobble, gravel). The composition and size of rock and sediment is largely defined by the characteristics of the site, but the presence of trees to serve as a source of large wood is largely determined by management decisions.

IMST concludes that retention of trees on high risk slopes and in likely debris torrent tracks will provide an important source of large wood for stream systems that drain these areas. Science does not provide guidance on the density of tree retention in such areas. The "Benda wood accumulation model" and the debris "run-out model" provide scientifically sound guidance. We suggest an adaptive management approach, using monitoring of landslides and debris torrents to identify the tree retention density that will be effective.

Recommendation 14. Continue to apply the current best management practices (BMP) approach to the management of forest lands with significant landslide potential, and develop a better case history basis for evaluating the effectiveness of BMP in these areas.
Recent research experience and ODF’s documentation and analysis of landslides provide an initial basis for management of areas with significant landslide potential. A continuation of these efforts and the periodic analysis of findings offer a scientifically sound approach to identifying management strategies that will be consistent with the mission of the Oregon Plan.

Recommendation 15. Modify culverts and other structures to permit the passage of juvenile and adult salmonids upstream and downstream at forest road-stream crossings.
Surveys of forest road-stream crossings show that a significant number of sites have culverts or other structures that prevent the passage of adult and/or juvenile salmonids. This prevents the full use of potentially productive salmonid habitat. OFPA Rules (629-625-600 (8)(a) provide for fish passage for roads constructed after September 1994, however a significant number of fish passage barriers exist on roads not covered by this rule. Voluntary efforts to solve this problem are being conducted on other roads in northwestern Oregon by forest industries, as part of the Oregon Plan. ODF should document progress on the voluntary efforts to solve this problem, and implement voluntary or regulatory programs on other lands to achieve the goals of the Oregon Plan. If there are situations on forest lands where OFPA Rules or Oregon Plan measures do not address fish passage problems, ODF should notify the Manager, Oregon Plan, so that remediation may be implemented by the appropriate agency.

Recommendations for or with other Agencies

Recommendation 16. ODFW and ODF should develop a collaborative program of monitoring to quantify the linkages between parameters of ecosystem condition and wild salmonid recovery.

Validation of the effectiveness of various strategies of both site specific and landscape level management on the recovery of wild salmonids can only come through effective monitoring. Both ODF and ODFW conduct monitoring that are or can be useful for this purpose. In some cases, modification or expansion of programs may be needed. A collaborative effort between the Departments in the design, conduct, and analysis of monitoring programs is a critical step in quantifying the links between forest condition and the welfare of the fish. Historically these links have been very difficult to establish but are needed for future policy and planning activities. ISMT believes well designed, adequately funded, and carefully coordinated monitoring efforts involving both Departments are essential for this purpose.

Recommendation 17. ODFW should complete "core area" designation for all wild salmonids in Oregon and identify high priority protection/restoration areas that are not covered by current "core area" designations. ODFW should work with the Oregon Plan Implementation Team in prioritizing habitat for enhanced levels of protection and/or restoration.

The term "core area" was used by ODFW to identify specific areas critically important to the recovery of coho in the original Oregon Plan. This term may be replaced in the future. It is our intention that, regardless of the term used, this recommendation be applied to areas specifically designated by ODFW as critical to achieving the mission of the Oregon Plan and the intention of Executive Order 99-01.

Core area designations are incomplete for winter steelhead and are completely lacking for sea-run cutthroat trout and other salmonids covered by the Oregon Plan and Executive order 99-01. Core areas for other species may need revision in light of new information obtained since completion of the first core area designations.

Recommendation 18. ODFW should include consideration of practices (forestry, agriculture, urban, other land uses) above and below core areas, as these may affect the conditions and processes critical to maintenance of core area function in forestry areas.

The concept of a core area needs to extend beyond the specific location of a core area. A core area cannot continue to function in the recovery of wild salmonids unless upstream and downstream portions of the system are also functioning effectively. For forested portions of the landscape, this means explicitly considering the effects of forest practices under OFPA, as they may influence the core area. The same concept must be applied to non-forested portions of the landscape for the same reason. For instance, the functionality of core areas in the forested portion of the landscape will be reduced if water quality and habitat conditions in downstream agricultural or urban areas are not conducive to salmonid recovery.

Recommendation 19. The Oregon Forest Research Laboratory (FRL), in collaboration with ODFW, should develop forest road-stream crossing strategies that facilitate the passage of large wood at road-stream crossings.

Stream crossings, especially in upper reaches of stream systems, can provide significant impediments to the downstream passage of large wood and other elements of habitat structure. Alternatives to bridges or culverts may be more effective, and in some instances, perhaps less expensive. Forest managers currently have few options to consider in the design of stream crossings. The development and testing of additional alternatives may provide a better mixture of solutions to stream crossing problems. An initial step in this could be a jointly sponsored (FRL and ODFW) workshop to establish key design parameters and performance criteria.

SECTION VI
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APPENDIX. SUMMARY OF THE STATE OF KNOWLEDGE

The following section provides a summary of the state of knowledge and an entree to the literature dealing with key areas of this report: relationships between forests and aquatic habitat, forest practices, and water quality**.**

ATTRIBUTES OF SALMONID HABITAT

Ecological processes influencing the quality of habitat attributes and their relationship to forest practices are discussed in various sections of this report. This discussion of the attributes of salmonid habitat has been adapted from Bjornn and Reiser (1991) unless noted otherwise.

Salmonid Life Histories

Pacific salmon need chains of favorable places connected at the appropriate season to complete their life histories. To be considered favorable, those places must include attributes that match the environmental requirements of the fish and the aquatic community at the appropriate time. The importance, quality, and location of critical attributes of salmonid habitat may vary through the life stages of migration, spawning, incubation, and rearing.

Migration. For anadromous species such as salmonids, the stream channel must be free of barriers from the estuary up to the spawning areas (adult upstream migration) or from rearing areas down to the estuary (juvenile downstream migration). The most obvious necessity of the migration corridor is appropriate stream flow. Low flows can block or delay movement of fish, as can excessive flows or conditions that create high velocities. Other physical barriers such as excessive debris can also block migration. High turbidity may delay or block migration entirely. Physiological barriers can also impede migration. For example, excessive temperatures or low concentrations of dissolved oxygen can also effectively block migration.

Spawning. Each salmonid species requires gravel of the appropriate size for spawning (substrate), as well as stream flow at a depth and velocity that are within the preferred range. Temperatures at the time of spawning can be a key habitat attribute. In adapting to its local environment, each salmonid population has evolved a unique time and temperature for spawning that maximizes the survival of the offspring (Miller and Brannon 1982; Bjornn and Reiser 1991).

Incubation. Because the incubating eggs are immobile, they are particularly vulnerable to changes in habitat. For example, the eggs need continuous flows of well-oxygenated water to thrive. Although eggs may survive in water with oxygen concentrations that are below saturation, they may develop abnormally. Heavy siltation during incubation can smother the eggs. High levels of fine sediment can fill in the interstitial spaces in the gravel cutting off the supply of oxygenated water. As indicated for spawning, natural temperature regimens are important regulators of salmonid life histories. That is especially true for the incubating egg, because the length of incubation is directly related to water temperature.

Rearing. Attributes associated with rearing habitat of salmonids are complex. In addition to flow, temperature, substrate, and dissolved oxygen, juveniles need to be able to move between habitat types. Cover that allows them to avoid predators is a critical habitat attribute from the time the juveniles emerge from the gravel until their migration to sea. Cover can take several forms including deep pools, undercut banks, boulders, large wood, and root wads. Productivity (food base for salmonids) is an important attribute of rearing habitat and is determined largely by nutrients and energy available to the stream community.

RIPARIAN FORESTS AS A KEY FACTOR INFLUENCING SALMONID HABITAT

Role of Riparian Forests in Regulating (Influencing) Stream Temperature

Where riparian vegetation intercepts solar radiation it serves a role in moderating the quantity and quality of light reaching the stream (Beschta et al. 1987). In well-stocked forests, depending on aspect and slope, the amount of solar radiation reaching a forested stream channel is 1 to 3 percent of the total incoming radiation for small streams and 10 to 25 percent for mid-size streams (Naiman 1992). Removal of trees near a stream causes increases in water temperatures and daily temperature fluctuations (Hetrick et al. 1998; Beschta et al. 1987; Hall and Lantz 1969; Brown and Krygier, 1970; Brown, 1980; Hall et al. 1987). Newton and Cole (1998) report interesting research suggesting that retention of vegetation cover on the south side of streams was adequate to maintain temperature in the situation they studied. However, depending on ambient climatic and down-stream conditions, the increase may only be temporary (Hetrick et al. 1998; Caldwell et al. 1992). The work of Brown (1970) provides a scientific basis for predicting stream temperature based on an energy balance model.

On a landscape basis, the relationship between stream temperature and riparian vegetation is complex and highly variable. By understanding the processes influencing the amount of radiation intercepted by the riparian forest canopy along with the interaction with disturbance, stand development and geomorphology we can begin to answer the questions concerning the role of forest vegetation in influencing stream temperature. The amount of solar radiation intercepted by a forest canopy is a function of the cumulative leaf area and an extinction coefficient that is determined by the foliar arrangement and reflective properties (Beer-Lambert law as cited in Waring and Schlesinger 1985). Leaf area for deciduous species is often one third of the values for conifer stands (Waring and Schlesinger 1985). Therefore any natural and human-caused factor that reduces riparian leaf area and/or changes species composition can increase the amount of radiation reaching the stream surface and therefore increase stream temperatures. For example, in stands with few remaining evergreens and a high percentage of deciduous trees, more radiation will reach the stream surface when the deciduous trees lose their leaves.

Along with obvious losses in leaf area after timber harvest, there are also changes in forest successional processes. These alter the quantity and arrangement of leaf area in riparian forests. As alder forests decline with age, shrub-dominated communities with lower leaf area develop. As long-lived conifer stands mature, leaf area rapidly increases to about age 40, levels off, and then declines at a rate dependent on self-thinning and disturbance-related mortality (Gholz 1982).

Therefore, as gaps in the forest form and stand densities are reduced, more radiation can be expected to reach the stream surface. Although dense conifer forests are often seen as a goal in managing forests to regulate stream temperature, historically, natural disturbance and successional processes resulted in a forest with a variety of tree and shrub species, ages, and densities (Pabst and Spies 1998; Poage 1995; Avina 1999).

The impact of riparian vegetation on stream temperature depends on riparian landscape patterns, forest conditions, and stream channel characteristics as they influence interception of solar radiation. For example as stream width increases, the forest may no longer be capable of shading the entire stream or river corridor. Thus the potential role riparian vegetation plays in regulating temperatures declines. Aspect and slope may also influence the amount of radiation reaching the water surface. Radiation may increase or decrease depending on the geographic orientation of the stream and the angle of light reaching the basin.

Although forests play a key role in regulating stream temperature, the integration of stream temperature within a basin depends on vegetative and morphological factors that vary widely across the landscape and with time. To list and quantify all the factors involved in maintaining stream temperatures within the range of quality salmonid habitat would be an exceedingly complex undertaking. Because the required landscape variability and complexity are difficult to create through management, managers have defaulted to the use of riparian buffers to minimize impacts of forest management practices on stream temperature. One of the goals of the riparian buffer is to create conditions that will minimize the risk of increasing stream temperatures when the adjacent stand is harvested. There is general agreement that buffers of 100 to 150 feet are sufficient to protect water quality in most situations (Spence et al. 1996). Thus there are few studies that examine what percentage of the landscape must contain these intact riparian buffers and where they should be located to be most beneficial for maintaining quality salmonid habitat.

As an alternative to riparian buffers, maintaining a diverse set of forest conditions — by generating forest harvest patterns that "mimic" historic disturbance patterns (i.e., size, frequency, distribution) — within the landscape will allow natural processes to act in accordance with forest management to balance water temperature. When considering the impact of stand density, successional processes, species composition, and geomorphology on water temperature, the major emphasis shifts from buffer width requirements to the percentage of the landscape in various forested conditions required to maintain water quality. This means that instead of all buffers, there will be stands of different ages and harvest patterns along the stream.

Role of Forests in Influencing Nutrient Inputs and Flux

By understanding the fundamental processes involved in the deposition and processing of organic matter, we can examine how factors that vary across the landscape, such as forest stand age, stand density, tree species, stream size, percent slope, aspect, and stream morphology, influence the location and amount of habitat for salmonids. The deposition and processing of organic materials are major limiting factors in stream productivity. For salmonids, a productive stream has good physical habitat for spawning and the organic resources needed to produce the food required for fry to survive and grow. The stream obtains organic resources from two primary sources: 1) organic matter produced within the stream from photosynthetic algae and other aquatic plants; and 2) organic matter deposited by the terrestrial system, such as leaves, bark, and wood. In forested ecosystems, terrestrial sources provide streams with most of their organic matter. In an eastern U.S. forest, 98 percent of the organic material in the stream came from terrestrial sources (Fisher and Likens 1973).

Deposition of organic materials. The size and morphology of the stream, as dictated by topography, greatly influence the deposition and processing of organic materials. Slope also influences the species composition of the forest, forest biomass production, and in some cases stream temperature. As a forest ages, litterfall increases with increasing biomass. Litter is deposited into small steep-gradient streams in densely forested areas high in a watershed. Steeper slopes with fast-moving streams are less likely to retain deposited organic material until it is decomposed. Thus these small (lower-order) streams are important to the productivity of larger (higher order) streams in lower reaches of the watershed because they are a major source of organic material. Leaves, bark, and wood deposited in these small streams can be rapidly transported downstream if there are no barriers, such as culverts, large wood, and boulders.

Forest age, composition, and season affect the quality, as well as the quantity, of leaf material deposited in streams. For example, alder leaves are noted for their relatively high nitrogen are readily decomposed. But before a leaf or needle is abscised (released and falls), the tree recaptures many of the nutrients; thus leaves deposited in the fall are not as nutrient rich as those deposited from a mid-summer windstorm. With their high lignin content, conifer needles are more difficult to break down and therefore release their organic material more slowly compared with deciduous foliage.

Decomposition of organic materials. After it is deposited in streams, organic material must be processed before it is available as a food source for salmonids. Forest stand age, density, and species composition, along with stream characteristics, such as size, percent slope, aspect, and morphology, all influence the decomposition of organic material.

In small (lower-order) streams on densely forested slopes, large wood can trap organic material, where it may be broken down before it is transported downstream with high flows. However, because many of the biological processes required to decompose organic material are temperature dependent, the process may be slower in cool streams within densely forested riparian zones (Beschta et al. 1987; Hawkins et al. 1982).

Decomposition of organic material occurs in several ways. Some organic compounds are leached from material in the stream. Shredding insects that feed primarily on leaves also process organic materials. Microorganisms colonize material that becomes trapped in the stream, breaking it down into constituents available for microbes and insects. Fine particles are carried downstream and deposited within the channel, becoming available to benthic (bottom) feeding organisms and rooted aquatic plants.

The morphology of the stream largely determines the decomposer species present. Functional groups of these animals correspond to orders of streams. These distinctive relationships are based on the relative availability of different substrates and are used for classification (Cummins 1973, 1974). Shredding insects rely on leaf material and are thus found primarily in small, lower-order (1st through 3rd) streams. Grazing insects rely on instream (primary production) algae attached to rocks and are therefore found primarily in larger, higher-order (5th and 6th) streams. Fine-particulate collectors, which feed primarily on fecal material, are distributed across a wider range (1st through 6th) of stream orders. The ratio of shredders to grazers was found to be more than 100:1 in canopy-covered first-order streams with low incident light levels and was 1:14 in wide, eighth-order streams with high levels of sunlight (Triska et al. 1982).

Forest practices. Where forest practices change tree density and species composition, they will affect the input and processing of organic material. The degree of impact depends on prior stand conditions and the composition of adjacent stands. For example, frequent intense harvest in the presence of an alder seed source will result in a shift toward alder-dominated riparian areas. Low intensity thinning in riparian conifer stands will increase stand stability and the productivity of the remaining trees, while not opening up the stand enough for alder regeneration. Across the landscape, shifts in stand age and species composition will benefit the higher-order streams by providing a variety of materials at varying rates, thereby adding to habitat heterogeneity. The processes controlling the input and processing of organic material are better served by a heterogeneous landscape with varying amounts of forest cover, species composition, and age classes than by the creation of a single forest type across the landscape.

LARGE WOOD AS STRUCTURAL AND FUNCTIONAL ELEMENTS OF AQUATIC HABITAT

The most productive habitats for salmonid fish are small streams associated with mature and old-growth coniferous forests where large organic debris and fallen trees greatly influence the physical and biological characteristics of such streams. Sedell et al. 1988.

Functions of Large Wood in Streams

Large wood is often the primary structural element in the stream channel responsible for forming pools in smaller streams and side channels and backwaters in larger streams (Bilby and Bisson 1998). Both are critical habitats for coho salmon in Oregon’s coastal streams (Nickelson et al. 1992). Over 80 percent of the pools in small streams in southwestern Washington, in the Idaho panhandle, and in northern California were associated with the presence of large wood (Bilby and Bisson 1998).

The function of large wood varies with the size of the stream. In smaller streams, large wood can generally span the channel. There it becomes an important structural element that increases the frequency and volume of pools, traps organic material and slowly releases nutrients to the stream, provides substrate and food for aquatic invertebrates, and traps fine sediments. The smaller stream channels are also the conduits that deliver much of the large wood to the channels lower in the watershed. Large wood increases channel complexity, obstructs and diversifies currents, and creates essential features of salmonid habitat, such as plunge (created by water flowing over logs), lateral (along the bank), and backwater pools (Spence et al. 1996).

Larger streams contain less wood, but the average size (diameter, length, or volume) of the wood is greater because these streams can transport larger materials. The nature of the pools formed by large wood changes from plunge pools in the smaller headwater streams to scour pools in mid-sized streams (Bilby and Ward 1989). In larger channels, large wood tends to accumulate along the margins and on gravel bars or other obstructions. This creates variable depths and complex flow patterns, lateral migration of the channel, and backwaters along the stream margins (Spence et al. 1996).

In the larger low-gradient streams, large accumulations of wood can span the channel and create large pools, secondary channels, and backwaters (Bilby and Bisson 1998). Alcoves, side channels, and beaver ponds are important over-wintering habitat for coho salmon in Oregon’s coastal streams, and it is the availability of this kind of habitat that constrains coho survival in coastal rivers (Nickelson et al. 1992). Large wood also prevents salmon carcasses from washing out to sea after spawning, which allows nutrients from the carcasses to be released to the watershed (Cederholm et al. 1989). Nutrients derived from salmon carcasses can be an important source of nitrogen and carbon for juvenile salmon and can influence their growth (Bilby et al. 1996).

Local temperature regimes may exert more influence on the evolution of life history patterns than do other environmental attributes of stream habitat (Miller and Brannon 1982). Structural roughness imparted by large wood, especially the creation of pools, can retard mixing of warm water and cool water from either tributaries or ground water and create local pockets of cool water refugia (Sedell and Swanson 1984). Studies in the Yakima River, Washington, have shown that adult chinook salmon can locate and will make use of these small thermal refugia (Berman and Quinn 1991).

Sources of Large Wood

The sources of large wood and the mechanisms for their delivery to the stream channel vary with the size of the stream, its gradient, and the surrounding landscape. First- and second-order headwater streams provide much of the large wood that can form habitat in larger channels (Prichard et al. 1998). Over time, fire, blowdown, natural mortality, and bank undercutting deliver wood to first- and second-order streams, where it easily spans the smaller channels. There it traps sediment, sometimes for very long periods of time, even centuries or more. The buildup of wood and sediment continues until it is delivered downstream, along with green wood, through a mass movement of the material. This type of movement is called a debris torrent. The sediment and wood are eventually incorporated into the channel structure of the larger stream where they become part of normal stream function (Prichard et al. 1998).

Trees that fall into streams usually come from within 30 m of the channel edge; 70 to 90 percent of the large wood in streams is derived from this distance. The riparian vegetation of an old-growth forest consists of taller trees, so the source of large wood is from greater distances than for younger forests with shorter trees, since more tall trees reach the stream when they fall

(McDade et al. 1990; Van Sickle and Gregory 1990; Fetherston et al. 1995). In unconstrained stream reaches, large wood from anywhere in the flood plain can eventually reach the channel after floods or lateral migration of the stream channel (Bilby and Bisson 1998).

Both episodic and chronic events deliver large wood to the stream channel. Chronic events include natural tree mortality and natural undercutting of the stream banks. However, these events add relatively small amounts of large wood to the stream. Fires, floods, windthrow, landslides, and debris torrents occur infrequently, but they are the source of large quantities of wood (Bilby and Bisson 1998; Benda et al. 1998).

Impact of Forest Practices on Large Wood

Recent surveys confirm that many of Oregon’s coastal streams in managed forests are deficient in wood (State of Oregon 1998). The amount of wood in streams associated with managed forests has been evaluated by comparing it with two standards: 1) The average amount of wood in reference streams (streams with little or no forestry impacts); and 2) the target amount of wood identified in the Oregon habitat benchmarks (Oregon Plan 1997). Most of the reference streams were in the Cascade Range, with a few located in the Coast Range (State of Oregon 1998). In addition, the surveys reported the presence of wood in two ways: 1) pieces of wood greater than 0.15 m in diameter and 3.0 m in length; and 2) key pieces of wood greater than 0.6 m in diameter and 10.0 m in length. To account for regional differences in salmonid habitat in coastal rivers, the Oregon Coast was divided into five regions: north coast, mid-coast, mid-south coast, Umpqua, and south coast. The north coast and mid-coast stream reaches had slightly more pieces of wood than did the reference reaches. The mid-south coast, south coast, and Umpqua had lower levels of wood (number of pieces) than did the reference reaches. Over 75 percent of the stream length surveyed in the mid-south coast, south coast, Umpqua had fewer than 15 pieces of wood per 100 m of channel. The Oregon benchmark is >20 pieces of wood per 100 m stream length. It should be kept in mind that the benchmark is probably lower than the historical, undisturbed state, especially in the lower elevation stream reaches.

The number of pieces of wood includes smaller sizes that may not have a strong influence on channel process and habitat formation. The status of key (larger) pieces of wood is a better measure of wood that can form habitat in the coastal stream channels. Half of the stream lengths surveyed in all the coastal subregions had less than one key piece of wood per 100 m of channel (State of Oregon 1998). The benchmark is three key pieces of wood per 100 m of channel. Current levels of large wood in coastal rivers are less than the benchmark and far below historical levels.

The amount of large wood currently in stream channels of Oregon’s coastal rivers has been depleted and in the near future, new recruitment is not likely to correct that condition. Over 30 percent of the stream lengths surveyed have no large conifers in the riparian zone. Large conifers are defined as trees >50 cm dbh (diameter at breast height) within 30 m of the stream (State of Oregon 1998). Seventy-five percent have fewer than 60 large conifers per 333 m of stream channel. This is far less than in the reference riparian areas, which had 240 large conifers per 333 m of stream channel.

Timber harvest has reduced the amount of wood in streams, consequently degrading the quality of habitat. For example, in an extensive survey of streams draining unharvested old-growth forests and streams within intensively and moderately logged forests in western Washington State, intensive harvest was associated with increased riffle area, reduced pool area, and reduced pool depth. The total amount of wood in the streams did not change with timber harvest, but the size of wood was reduced (Ralph et al. 1994). Since the size of wood in the channel is directly related to pool size (Bilby and Bisson 1998), this represented a direct loss of critical salmon habitat. Similar results—reduced amounts of large wood— were obtained in surveys of Oregon Coastal streams.

The loss of habitat caused by the decrease in large wood can cause a significant reduction in salmonid standing stocks (numbers of adults returning to spawn each year). Standing stocks in three sections of stream that had been previously cleared of all large wood were compared to four sections of stream that had been undisturbed for 40 years. Pool volume, sinuosity, width, and depth had all decreased in the stream sections from which the wood had been removed. These changes in habitat caused a fivefold reduction in salmonid standing stocks (Fausch and Northcote 1992).

Historically, the quantity and quality of large wood in stream channels reflected the age and species composition of the riparian forests and the occurrence of disturbance. Major disturbance events such as wildfire, catastrophic windthrow, and floods were natural features of watersheds that added massive amounts of large wood to the stream channels or redistributed it downstream within the watershed (Bilby and Bisson 1998). At any given time 15 to 25 percent of the central Oregon Coast Range may have been in early successional stages following disturbance (Reeves et al. 1995).

Even during those periods when the riparian forests were recovering, however, the amount of large wood in the stream would have remained high. That is not true of forests subjected to human-caused disturbance, such as logging, which reduces the quality and quantity of large wood delivered to the stream (Bilby and Bisson 1998). Reeves et al. (1995) identified four differences in natural and human-caused disturbance that affect the quality and quantity of large wood delivered to the stream channels:

1. Disturbance such as wildfire leaves a legacy of large wood that can eventually enter the stream, whereas timber harvest removes that source of wood.

2. The interval between major natural disturbances is usually longer than the harvest cycle—300 years for wildfire and 40 to 80 years for timber harvest.

3. The area disturbed differs. Historically, 15 to 25 percent of the central Oregon Coast Range at any given time may have been in an early successional stage because of wildfires, whereas timber harvest generally affects a larger total area.

4. Disturbance from timber harvest is widely dispersed over the landscape, whereas natural disturbance events may cover a larger area in a single event.

Hicks et al. (1991) reviewed studies that evaluated the effects of habitat change on salmonids and concluded that timber harvest has simplified salmonid habitats and the process of simplification was continuing. Although the loss of stream structure due to reduced levels of large wood has only recently been viewed as a problem, it has contributed to major habitat degradation (Hicks et al. 1991). Some changes in habitat, however, such as increased temperatures and increased fine sediment are more transient and less detrimental than originally believed. Based on their review, Hicks et al. (1991) formulated the following principles that should guide logging operations to protect aquatic habitat:

- *Protection of streamside zones by leaving streamside vegetation intact will help maintain the integrity of channels and preserve important terrestrial-aquatic interactions.*
- *Productivity of streams for salmonid populations tends to be enhanced under conditions of moderate temperatures, low to moderate sediment levels, high light levels, adequate nutrients, an abundance of cover, and a diversity of habitat and substrate types.*
- *Productive floodplain and side-channel habitats should be protected.*
- *Streams should be protected against frequent and extreme episodes of bed-load movement or sediment deposition through careful streamside management and through proper planning and engineering of roads and timber harvest systems.*
- *Management of streamside zones should include provisions for long-term recruitment of large woody debris into stream channels and for protection of existing stable large woody debris.*
- *The geology, geomorphology, and climate of a watershed mediate the response of fish populations to timber harvest. Site-specific management recommendations must consider regional landforms and climatic variation.* (Hicks et al. 1991, p. 518.

It should be noted that the last principle is consistent with a landscape approach to the regulations of timber harvest.

Most studies of the effects logging on salmonids have looked at specific stream reaches and target species. However, when aquatic habitat loses diversity and complexity as a result of timber harvest, there is a corresponding loss of diversity in fish assemblages at the basin scale. For instance, instead of having coho, chinook, and chum salmon in a watershed, as a result of homogenization of the habitat, it now supports only coho. This represents an important loss in biodiversity. In a study of 14 small to intermediate coastal basins in Oregon, Reeves et al. (1993) found lower diversity in fish assemblages in streams with high harvest levels than in streams with low harvest levels. Fish assemblage diversity in a watershed was most highly associated with the percent of the basin harvested. Reeves et al. (1993) attributed this in part to the more diverse habitats in the basin with low timber harvest levels. Streams in those basins had more pieces of wood and more pools than did streams from basins with high harvest levels. Reeves et al. (1993) concluded that basin-level evaluations are needed to fully assess the effects of timber harvest in a watershed. This conclusion is consistent with our recommendation that habitat management and protection should be approached from the landscape perspective.

SEDIMENTATION

Sedimentation is a natural process, occurring in both "unmanaged" and actively managed basins. Swanson et al. (1987) provide excellent overviews of sediment producing processes in forests of the Pacific Northwest. Their review emphasizes the high degree of variability that exists in sediment relationships, across landscapes and over time, and as these interact with natural and human-mediated events. Everest et al. (1987) provides a useful perspective about sedimentation. Their central theme is that sediment is a natural part of stream systems, and that there is an equilibrium between sediment input and sediment routing that needs to be maintained to have healthy stream systems. This means maintaining a balance between the amount of fine sediment, coarser bedload sediment and larger elements of in-stream structure (boulders, large wood). Both the production and routing of suspended sediment and bedload sediment are important.

Reid (1981) reported sediment yields ranging from 13 to 133 tons per square kilometer of basin area per year in systems not under active management (Table 2). Landslides and bank erosion are the dominant sources of sediment in these "unmanaged" systems.

Table 2. Source of sediment in undisturbed 6th order basin

Source of sediment	Sediment production (m^3/ km^2/yr)
Bank erosion	29.0
Landslides	28.0
Debris flows	9.7
Tree throw	8.9
Animal burrows	4.0

Source: Reid, 1981.

The effect of active forest management on sedimentation is a central issue. Benda et al. (1998) summarize the interaction between land management, sedimentation and fish habitat. Numerous efforts have been made to study sedimentation in connection with forest management. As an example, Beschta (1978) reporting on the Alsea watershed studies in the Oregon Coast Range found increases in suspended sediment discharge from two small watersheds occurring over an 8-year post disturbance period. The increase in discharge was episodic, and the author associates periods of elevated discharge with disturbance. In a 25-percent patch-cut watershed, sediment production was elevated for three years, with the elevations dominated by two road failure related events. In the other five years, the level of sediment discharge resembled the pre-treatment pattern. In the second watershed, 82 percent of the areas was clearcut, and slash burned with no stream protection. The highest sediment discharge occurred after burning, with annual reductions in discharge occurring over the next six years until pretreatment levels were attained. Beschta attributes the pattern of the response in this watershed to the degree of vegetative cover, but is not able to determine the influence of soil disturbance close to the stream on the effects measured.

It has been much more difficult to quantify the effects of management on in-stream sediment condition over landscapes larger than those included in the Alsea study. In an analysis of stream gravel composition, Duncan and Ward (1985) surveyed 12 watersheds in SW Washington. They found no statistically significant relationship between the amount of fine sediment in stream gravel and any variable except bedrock geology. Streams draining watersheds dominated by sedimentary rock had a higher level (11.6%) of fine sediment (< 2 mm) than watersheds dominated by volcanic rock (10%). However, they note that when only two variables are considered (and sediment finer than 0.63 mm is addressed), the frequency of road drainage points into streams is a statistically significant factor. Everest et al. (1987) note that studies of the impacts of forest management on fish have generally failed to isolate the effects of fine sediments from the effects caused by other habitat changes, making it impossible to segregate the effects.

Reid (1981) calculated the sediment production from road-related and natural process in two hypothetical sub-basins of the Clearwater basin in northwestern Washington (Table 3). They found that roads accounted for about 75 percent of total sediments, and 82 percent of the sediment that was less than 0.2 mm in size.

Table 3. Calculated road-related and natural process sediment production (assumes no other management actions) in two hypothetical sub-basins of the Clearwater basin.

Source of Sediment	Sediment Production, tons/km^2/year NW Basin Total	NW Basin < 2 mm	SW Basin Total	SW Basin < 2 mm
Road-related, all sources	190	99	308	130
Natural processes, all sources	79	28	79	21
Total, both sources	269	127	387	151

Source: Reid, 1981.

Major storms increase the rate and intensity of landslides and road failures. Initiating landslides may turn into debris flows (movement of material beyond initiation area, on the slope but outside of a channel) or debris torrents (movement of material down a channel), depending on site characteristics and conditions at the time. Debris flows and debris torrents commonly transport much more sediment than the initiating event, due to the scouring action of the movement of the debris on the slope or in the channel. Debris flows stop moving when the slope gradient of the channel decreases. Debris torrents also tend to stop and become debris jams when channels merge, especially where the debris torrent is in a channel that enters another channel at a steep angle. Predictive models (Benda and Cundy, 1990) are useful in analysis and management of such events.

Several investigations of storm-related landslides have been conducted. Following a major storm event in 1975, Gresswell et al. (1979) analyzed mass soil movements associated with roads and clearcuts on the Mapleton District of the Siuslaw National Forest in the central Oregon Coast Range. Their findings indicate slides in harvest units accounted for over three-quarters of the failures and about two-thirds of the landslide volume; however, the average volume associated with road failures was twice as large as in-unit failures. The study results provide guidance on characteristics associated with the failures. Swanson et al. (1977) working in the same general area reported the frequency of landslides was 1.9 to 4.0 times greater in clearcuts than it was in similar areas of unharvested forest. In a study of small unroaded areas, Ketcheson and Froehlich (1978) found a frequency of land sliding that was 3.7 times greater in clearcuts than in undisturbed forest.

ODF conducted an extensive evaluation of storm-related landslides following the 1995-1996 season. ODF concluded that the incidence of road-related failures was smaller and slide volumes were smaller than in past studies, suggesting that the changes in road practices since 1972 is reducing road-related slope failures.

Swanson et al. (1987) summarized data on land sliding and sedimentation from the various watershed level studies of the region, but note serious limitations with them:

- The forest management and harvest strategies used in the study are not necessarily relevant today.
- The results only reflect the complex of weather as it occurred at the time of the study.

The problem is that the interrelationships between treatments, site characteristics, and weather are unique, making each study a case history. There is limited ability to compare the results among such major efforts. This is not suggesting we can't learn from them ? but the uniqueness of what is learned from each study must be appreciated.

In summary, roads, landslides, and bank erosion are believed to be the dominant sources of sediment in managed systems, and there is a strong interaction with storms. Given riparian protection, landslides and roads become the dominant source likely to be influenced by management action.

Roads as a Source of Sediment

According to Luce and Black (1999) road-related erosion is the result of the interaction between how much sediment is available for transport and the power of water to move it. They provide an analytical framework for dealing with both factors, providing a reasonable scientific basis for both evaluating the potential for movement of road-related sediments to the stream, and prioritizing the protective measures that might be taken to address them. Surface-related erosion from roads appears to be concentrated in the first few years after construction, landslide-related erosion and sediment production could occur many years later, and is highly episodic.

Based on their findings, Luce and Black (1999) conclude that substantial amounts of sediment can come from relatively standard roads with little use, and that it is possible to substantially reduce road erosion by targeting those sections with the greatest sediment production. Their paper addresses the sources of variability, which may be able to be incorporated into management guidelines or standards. This study is significant because of its location in the Oregon Coast Range, and the fact it began in November 1995 and ran through the February 1996 storm.

Reid and Dunne (1984) conducted an important study in the Clearwater drainage of the Olympic Mountains in western Washington. Their study of 10 road segments provides helpful relationships between road surfacing materials, intensity of use, and rainfall and its related hydrograph. Their results quantify what logic suggests, i.e.,

- Sediment concentration increases with culvert discharge for active roads, but showed no increase for an abandoned road.
- Sediment concentration is higher during periods of heavy road use compared to periods of light use.
- Sediment yield increased with the amount of rainfall in a storm, and was higher for roads with a higher intensity of use.

Using the relationships developed in their study, they calculated the average annual sediment yield from various types of roads in the study basin. They also estimated the proportion of road miles in various level-of-use categories for a 40 percent clearcut basin being managed on a 60-80 year cutting cycle (Table 4).

Table 4. Sediment yield per kilometer of road, and proportion of the length of unpaved roads in a given level of use category, Clearwater Basin, Olympic Mountains, Washington.

Road type	Average sediment yield (tons/km/yr)	Basin roads in a road type (% of km)
Rock, heavy use (>4 loaded trucks/day)	500	6
Rock, temporary non-use (Heavy-use road not used for 2 days)	66	Not applicable
Rock, moderate use (1-4 loaded trucks/day)	42	5
Rock, light use (no loaded trucks, but some light vehicles)	3.8	39
Paved	2.0	Not applicable
Abandoned	0.5	50

Source: Reid and Dunne, 1984.

The data in this table are the sediment yield at the culvert. How much of this enters the stream system varies with the proportion of road runoff that is diverted to streams. Estimates for this are highly variable, ranging from 75 percent (Reid and Dunne, 1984), to about 33-34 percent (Bilby et al. 1989) and (Wemple et al. 1996).

Based on the data for paved roads, Reid and Dunne (1984) suggest 1.8 tons of sediment per km of road per year comes from cut slopes and ditches, considerably less than might have been anticipated. They note that the armoring of the surfaces that occurs with time since disturbance is a key factor in this process.

The key point from Table 4 is to show the difference in sediment production from roads that are in various levels of use, and paved or unpaved. We do not suggest these are the values to be extended to many other areas, but only show that there is a basis on which estimates can be constructed and decisions made which will influence the sediment production from road systems and road surfaces.

Bilby et al. (1989) followed the generation and fate of sediments from gravel road surfaces in southwestern Washington. Their study shows smallest sizes of sediment (<0.004 mm) comprised about 80 percent of the sediment yield from both the two mainline road sites and the two spur road sites. A settling pond that received runoff from the mainline road was effective in reducing sediment load in the ditch flow during periods when the concentration of sediment was high, and the rate of water discharge was moderate to low. While trapping perhaps only 20 percent of the sediment, the settling pond accumulated more than 1 ton of sediment over the course of the study period. Perhaps significantly in terms of potential impact on aquatic habitat, the settling pond trapped about 97 percent of the sand-sized sediment. This larger sized sediment is more likely to be deposited in streams as stream velocity decreases. The settling pond had no influence on the smallest sized sediment (<0.004 mm) or turbidity. They note this sized material is much less likely than sand-sized sediment to be deposited in spawning substrates in the stream system. Settling ponds may provide some short-term relief, but eventually they will fill, and either no longer be able to serve as a sediment trap, or may require maintenance and disposal of the sediment to a location where it will not erode to streams

The Bilby et al. (1989) study sites differed in the nature of the road base and the rock used as a surface for it. Their article suggests that the depth of the ballast (and the nature of the surfacing materials) was different at the two sites, but they provide no quantitative data on this point. The mainline road was on relatively flat terrain (no cut slopes), while the spur road was much steeper and had cut slopes.

They provide regression equations to illustrate the relationship between intensity of road use (axles per day) and sediment production over the course of a storm. Although this factor alone accounts for (explains) 60 to 70 percent of the variation in sediment production on the spur road, it accounts for very little (<3%) of the sediment production on the mainline road. When the same data set is analyzed on an hour-by-hour basis, however, intensity of use appears to be the dominant factor on the mainline road as well. The regression equation and relationships for only one site are provided in the paper (presumably the equations and relationships for the other sites can be obtained from the authors). For the site illustrated, the combination of axles per hour and accumulated number of axles explain nearly 60 percent of the response (concentration of sediment in runoff from the road system).

Bilby (1985) studied the input of sediment from a mainline haul road in southwestern Washington for one year. He found that at a point 50 meters below the point of road runoff, 21 percent of the total sediment load of the stream at that point was road-related. By weight, 80 percent of the sediment introduced from the road was <0.004 mm in size, and 79 percent was entering the study reach from upstream. In contrast, he reports, that more than 80 percent of the "fine sediments" in the stream bed gravel were from 0.25 to 2.0 mm in size. Analysis of sediment cores from above and below the study sites showed no difference in the proportion of fine sediments (<2 mm) by weight. Bilby concludes that in this case study that the road surface sediment did not make an appreciable contribution to sediment stored in the channel, although this is a reflection of the particular site under study (1% slope, vegetated ditches, deep road prism), and cannot be widely extrapolated. The transport of sediment is clearly influenced by the energy of the water flow, as illustrated by the increasing degree with which sand-sized sediment (0.63-2.0 mm) was transported with increasing steepness of the road gradient. Road gradient accounted for 97 percent of the variation in the data they collected at these five sites (2 mainline, relatively flat road gradients of 2% and 2.5%; and 3 secondary roads with gradients between 3.1% and 14.4%).

Burroughs and King (1989) summarized extensive research on sediment production and control on forest roads in Idaho. They also summarize relevant research findings from other parts of the United States. While the weather patterns and soil properties are remarkably different in many cases from those of the Oregon coast range, the qualitative aspects of the relationships they report are useful. Examples of their findings include the following:

- Heavy vehicle traffic on unsurfaced, rutted roads doubles sediment production.
- 6 inches of crushed rock reduces sediment production by 70 percent, and when combined with grass at the margins of the travel-way, 84 percent (2 inches of rock did not reduce sediment production).
- Bituminous coverings (asphalt) and road oils reduced sediment production by 97 and 85 percent respectively.
- Sediment production from unconsolidated fill slopes is high, but decreases exponentially with time.

Several strategies have been evaluated to quantify their effectiveness in reducing sediment production from both cut and fill slopes. Interestingly logging debris placed parallel to the contour decreased sediment production by 75 percent, suggesting this may be a useful strategy around landings and perhaps skid roads. Seeding alone does little until vegetation is established, and prior to establishment seed is subject to loss from the site with soil from erosion. Although a study in the Oregon Cascades on a 100 percent slope cut-bank showed seeding reduced sediment production by 36 percent.

There are quantitative relationships for the transport of eroded sediment from fill slopes to streams. Although these would need to be evaluated for use in the Coast Range, such characterization would be helpful because it will show the distance over which protective strategies are needed near streams. The specific data reported for an erosive soil in northern Idaho suggests distances of 100 feet or less were relevant. This suggests there is a basis on which protective strategies can be developed for Oregon — and with monitoring, their effectiveness evaluated.

Burroughs and King (1989) show interesting relationships among the various sources of sediment from a road study site in Idaho, where artificial rain was used. Although the quantitative aspects of the relationships probably do not apply in the Oregon Coast Range, qualitatively the relationships may well be valid, and can provide a basis for providing for sediment production management. These relationships are shown in Figure 14 of Burroughs and King (1989).

Many of the ideas developed in Burroughs and King (1989) are evaluated in Luce and Black (1999) in connection with their study of sediment production from forest roads in western Oregon. They established important relationships between sediment production and such parameters as distanced between culverts, road slope, soil texture, and cut slope height. The study appears scientifically sound. Their findings can be summarized as follows:

- Sediment production was a function of road-segment length and slope.
- Rocked roads on silty clay loam produced nine times the sediment as rocked road on a gravelly loam.
- Sediment production was not correlated with the height of the cut-slope.
- Road segments with vegetation cleared from cut-slope and ditch produced seven times the sediment as road segments where the vegetation was retained.

In summary, we conclude that there is significant scientific evidence to show that management actions can influence chronic sediment production from roads. This evidence is well documented and is known to ODF, based on its citation in their reports.

Road Drainage

Road drainage is the process by which road-related sediment might be moved to stream systems. Road drainage issues include (a) spacing between cross road drainage culverts, (b) the effectiveness with which these culverts operate, and (c) the location at which discharge from drainage culverts occur.

ODF (1996) monitoring data show that about one-third of the road systems on State and private forest lands in western Oregon can deliver sediment to streams by ditch delivery. West of the crest of the Cascades in Oregon and Washington, other estimates of road drainage discharged to streams or gullies range from 33 percent (Wemple et al. 1996) to 34 percent (Bilby et al. 1989) to 75 percent (Reid and Dunne, 1984). Paul (1998) reports that road drainage points are associated with about one-third of the road-related landslides, based on surveys in western Washington (Toth 1991) and western Oregon (Mills 1991). Irvin and Sullivan (cited as an unpublished report by Duncan et al. 1987) looking at three watersheds in western Washington and Oregon, note 20 percent of road runoff points discharged onto the forest floor and 80 percent emptied directly into drainage systems (70% emptied into first- or second-order channels). The balance emptied into permanent watercourses. These data show the importance of road drainage systems, and the impact of their discharge of sediment entrained in water on water quality.

We conclude that reducing the amount of road drainage water that flows into channels can reduce sediment delivery to streams. Although it may not be possible to reduce the number of points at which entry occurs, the volume of road drainage water at these points can be reduced by more frequent cross-road drainage. The key is to reduce the length of the road drainage ditch that leads directly to the point where it discharges to the channel. This can be accomplished by installation of a cross-road drainage structure a relatively short distance "uproad" from the channel entry point.

Piehl et al. (1988) studied ditch-relief culverts and low-volume roads in the Oregon Coast Range. As part of their paper they summarized relevant research from two other related efforts, as follows: after the major storms of December 1964 and January 1965, the Forest Service conducted an analysis of storm-related road failures in the Pacific Northwest. They concluded that the failure of road-drainage facilities caused nearly all road damage and those plugged ditch-relief culverts contributed significantly to the problem (Dyson et al. 1966). In the second effort by Krag et al. (1986), the authors reported on an analysis of 31 slope failures on the Queen Charlotte Islands in Canada. Most of the road-associated failures were traced to problems of road drainage (i.e., ditches - absence of ditches or ditches formed from road ballast; or culverts - spaced too far apart, too small, or poorly located).

In their Oregon Coast Range study, Piehl et al. (1988) found ditch-relief culverts spaced on average from 30 to 170 percent greater than the guidelines developed for such drainage by Arnold (1957). The average culvert spacing on Forest Service and BLM roads was closest to the guideline. The greatest average spacing was on private lands (although the sample of sites studied on state and private lands was quite small in comparison to the size of the sample on federal proprieties). Culvert inlet condition was also studied. On average, the cross-sectional opening of culverts averaged 81 percent of original, due to a combination of siltation, debris, denting and slumping of cut banks. This suggests that the ability of the culvert to pass water and material entrained in it was reduced by 19 percent over that envisioned in the design.

Erosion at the outlets of culverts was measurable in 38 percent of the cases studied. Outlet discharge volume increased with increased spacing between ditch-relief culverts. When spacing between culverts exceeded the "Arnold" standards by more than 100 percent, the erosion volume was 3 times as great as it was when the spacing standard was exceeded by less than 100 percent.

The stability of fill slopes below ditch-relief culverts showed some relationship to the degree to which spacing exceeded the Arnold guidelines, but the variability was high, suggesting the importance of a site-specific evaluation. Although the predictive power of the relationship may be low, it shows the correctness of the logic that the specifics of the location of drainage discharge points, and the volume of water they handle, will influence fill-slope stability.

The Arnold spacing guidelines have served as a guideline in this region for more than 30 years, but we caution that they should not be viewed as a standard. The guidelines appeared in a 1957 summary publication on soils of the Douglas-fir region. As nearly as we can determine, the guidelines are based on an unpublished report by Arnold of "studies" of culvert spacing. Piehl et al. (1988) note that the guidelines have not been systematically evaluated.

In absence of better information, we suggest the "Arnold guidelines" continue to be used because they provide a systematic basis for design of ditch-relief culvert drainage patterns. Monitoring culvert/drainage system function over time will provide the basis for refinement of these guidelines.

A difficult issue to manage is low-level sediment production over an extensive area, contrasted with high-level sediment production concentrated in a few areas. For instance, Piehl et al. (1988) in the central Oregon Coast Range evaluated 515 crossroad culverts. There were two such crossings where landslides occurred. These accounted for 72 percent of the sediment production from all 515 crossings. Although it is important to reduce or eliminate such large sources of sediment, the average sediment production at all of the other sites averaged 0.7 cubic meters of erosion per site, for 28 percent of the total.

ODF surveys have found that many landslides are the result of the failure of roads not constructed to current standards. These are roads constructed befosre the current OFPA rules were in place. These so-called "legacy roads" continue to be sources of sediment long after they were constructed, due to their inherently higher rate of failure.

Road Maintenance and Abandonment

Roads with any vehicular use since 1972 are required to meet OFPA maintenance requirements, regardless of when the road was constructed. Effective maintenance is required both for stability of the road, and for its efficient use, however. Maintenance as an activity both produces and influences sediment production.

Luce and Black (1999) comment on the issue of cleaning road drainage ditches. They found that sediment yield on older roads with undisturbed ditch lines is small compared to newer roads, or roads with disturbed ditches (unless the cut-slope is producing a great deal of sediment. They suggest that road surfacing (use of aggregate) and control of the level of traffic could be equally as effective in influencing sediment production. In a further study by Black and Luce (1999), in the same location in the Oregon Coast Range, they monitored sediment production over two years, 1995-1997, following blading of a rocked road surface. They found a 76 percent reduction in sediment yield the second year, which they attribute to revegetation of the cut-slope and ditch, and the armoring of the road surface once the fines exposed due to the blading were removed. Revegetation was thought to play a significant part in the erosion reduction.

Reduced tire pressure (reduced from 620 kPa to 340 kPa) on logging trucks has been shown to reduce sediment production from 45 to 80 percent operated over low quality aggregate (Foltz 1996; Foltz and Elliot 1997), as reported in Luce and Black (1999).

We conclude that when roads are newly constructed or are in use, policies that address road surface composition, tire pressure, and frequency, distribution, and characteristics of cross-road drainage and the maintenance of these systems can influence sediment production and delivery to streams. Limiting maintenance of ditches and roadside vegetation during periods of low road use will reduce chronic sediment production, allowing the system to “armor up”. However, this must be coupled with road design and construction strategies that produce an “inherently stable” road. There are no formulas to completely ensure success in this. However, there is a strong engineering and science conceptual base for it. This makes best management practices (BMP), reinforced with experience, a sound approach. The Luce and Black (1999) and Black and Luce (1999) papers are rich in guidance for scientifically-based approaches to road sediment management in the Oregon Coast Range.

Abandonment (including stabilization) of roads can help reduce road-related sedimentation problems, both chronic and episodic. Weaver and Hagans (undated) provide useful discussion and perspectives for road abandonment. Although much of their perspective is influenced by experience with the redwood region of northern coastal California, the concepts and practices they discuss are useful in Oregon. The many practices they discuss are likely to be helpful, but it is difficult to elect the more cost-effective strategies. The costs of various approaches are outlined in Table 1 of their report. Prioritization of road abandonment strategies at any given location, and the prioritization of general areas in which abandonment strategies should be exercised, is needed.

Harr and Nichols (1993) evaluated decommissioning roads in one case study in Canyon Creek (tributary of the Nooksak River in northwestern Washington). They reported that 17 road-related landslides deposited 191,000 cubic meters of sediment into streams during four periods of rain-on-snow events with recurrence intervals of 2 to 5 years. After decommissioning work, only a single road-related landslide occurred during a record rain-on-snow runoff event of 1989-90, and none of its sediment reached the stream. Decommissioning involved stabilization of fills, removal of stream crossings, recontouring slope, and reestablishing drainage patterns to reduce landslide hazards. Note this is an unreplicated case study, but it suggests decommissioning may be a useful strategy in some cases. Segment decommissioning costs ranged from $1615 per km to $6625 per km. Sixty-six percent of the length cost less than $1615 per km for decommissioning. The average cost for road abandonment was $3500 per km.

Non-road-related Landslides

Slope failure rates are highly variable across the landscape and over time. This is a fundamental problem in the analysis of these events. When superimposed on the question of human-related actions as changing the rate or magnitude of disturbance, relative to historic patterns, it is difficult to make this comparison.

ODF began monitoring landslides in 1988 (ODF 1997). Their findings included the following:

- Very few landslides occurred on areas the Department had determined to be high risk sites.
- Landslides associated with roads (especially those constructed prior to 1983) dominate the statistics.
- Approximately one-third of the landslides investigated were classified as in harvest units (as opposed to related to roads or landings).

Following the major storms of 1995-1996, ODF (1998b) conducted an extensive survey of landslides. ODF stratified the landslide data according to length of time between harvest and slope failure. Although there is variation, the general pattern is that the rate of land sliding was highest in stands 0-9 years post harvest, and lowest in stands 10 to 30 years, and then increased with stand age. Probably of greater importance is the landslide erosion rate (how much sediment is moved). When the same data set is analyzed with respect to soil moved (yd^3/acre) the pattern is similar to that for rate of land sliding, but the variation is higher. As a generalization, the erosion rate is higher in areas shortly after harvest, and then it decreases with stand age. In three of four cases, the erosion rate is lowest in stands more than 100 years of age.

The ODF study provides a clear picture concerning the association of land form and slope steepness with the rate of occurrence of landslides (Table 5). There were no landslides that entered channels where slopes were less than 40 percent.

Table 5. Slope steepness is critical.

Slope class, %	Landslide frequency, % of total	Cumulative landslide frequency, % of total
0 – 60	8	8
60-70	15	23
70 – 90	49	72
90 +	28	100

Landform also appears to be a useful indicator of landslide erosion risk. In those study areas in which more than 20 landslides occurred, uniform slopes and, in all but one case, concave slopes had the greatest incidence of landslides. Convex slopes and irregular slopes were lower. Landslide inventories show that from one-third to one-half of all landslides in the Oregon Coast Range originate in headwall areas. This relationship suggests a higher level of predictability on a site-by-site basis than exists.

The COPE analysis of headwall leave areas in the central Oregon Coast Range (Mapleton Ranger District) showed the Mapleton Risk Rating System is a useful guide in assessing the risk of slope failure in headwall areas (Martin 1997; Skaugset et al. 1993). This is a semi-quantitative checklist system in which field observers assign numerical values to various characteristics of headwall areas. These are based on the degree to which they are believed to contribute to headwall stability. Although this rating system loses predictive power at higher risk rating levels, it remains useful in instances where the goal is to reduce the risk of erosion from slope failure in headwalls. This risk assessment system has not been tested outside of the Central Oregon Coast Range (highly dissected marine sandstone and siltstone). Such testing is needed and can be incorporated into monitoring and adaptive management strategies.

Re-analysis of headwall inventory data in the central Oregon Coast Range showed no statistically significant difference in slope failure rate in clearcut, forested and headwall leave areas. However, this is not a random test of the variables, and the sample size is quite small. We do not consider it a critical test of the hypothesis, and caution against the use of the general findings as indicating that headwall leave areas are ineffective in preventing or reducing slope failures.

Important quantitative relationships between landslide initiation and subsequent behavior were reported by Fannin and Rollerson (1993) following their analysis of 449 debris flows in the Queen Charlotte Islands of British Columbia.

In general, we conclude that, on average, the relationship between slope characteristics (and other factors) and slope failure are helpful for management of the risk of landslide-caused sedimentation on actively managed forest properties, but the variation exhibited on a site-by-site basis is very large. We should not be surprised by this site-to-site variation. If it were not the case, then all steep headwall sites would have failed long ago. Refinements in our understanding of the interaction among site factors and our technical ability to characterize them are needed to permit more accurate predictions of slope failure potential.

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