INDEPENDENT IULTIDISCIPLINARY SCIENCE TEAM (IMST)

August 12, 2002

The Honorable John A. Kitzhaber
Governor of Oregon
State Capital Building
Salem, OR 97301

The Honorable Gene Derfler
Oregon Senate President
State Capital Building
Salem, OR 97301

The Honorable Mark Simmons
Oregon House Speaker
State Capital Building
Salem, OR 97301

State of Oregon

John Buckhouse
Wayne Elmore
Stan Gregory
Kathleen Kavanagh
William Pearcy
Carl Schreck

Enclosed is Technical Report 2002-1, the Independent Multidisciplinary Science Team's (IMST) report on the Recovery of Wild Salmonids, in Western Oregon Lowlands.

Over the last five years, the IMST has developed a series of reports that address over-arching land use and fish management issues that impact recovery of salmonids in Oregon at the landscape level. We view this report as an integral part of this series and especially important to the recovery of salmonids under the Oregon Plan for Salmon and Watersheds.

This is a highly complex report due to the importance of the issues addressed, the nature of lowlands, the many ecological and socio-political ramifications, the overlapping and in some cases, lack of agency authority, and the confounding jurisdictions of city, county, state and federal mandates and practices associated with lowlands, their rivers and streams.

As with all IMST reports, this report results from evaluation of the best available science. The report has been subjected to intense technical review by selected Northwest scientists and by State of Oregon agency representatives. The final report was adopted with full consensus of the Team at our July 15, 2002 meeting.

The report is organized into four sections: an introduction to the report; five science questions with the findings and conclusions; recommendations; and policy implications.

There were 21 formal recommendations generated by this report. Recommendations are directed at one or more State of Oregon agencies or entities that the IMST believes have the ability to implement, or to affect changes in management or regulation that are needed for implementation. Senate Bill 924 requires the designated agencies to respond to each IMST recommendation. Agencies are expected to respond to the Oregon Plan Manager and IMST within six months of the release of the report. IMST then evaluates the responses for scientific merit, and forwards the evaluations to you and Neal Coenen, Oregon Plan Manager.

In making its recommendations, the IMST did not consider the *current* legal, regulatory, or funding situation under which the responding agencies operate; nor does the IMST imply any sort of "performance evaluation" associated with these agency assignments. The IMST's responsibility is to identify issues that we believe are critical to the health and recovery of salmonids, and to advise the State of Oregon. While agency response may, under some circumstances, be that there is no legal authority and/or funding to implement certain recommendations, the IMST believes that these recommendations should be incorporated into long-range planning and impediments to implementation removed.

We hope that this report will be helpful as work on the Oregon Plan for Salmon and Watersheds continues.

Sincerely,

Stanley V. Gregory
IMST Co-Chair

William G. Pearcy
IMST Co-Chair

encl.

cc: Neal Coenen, Oregon Plan Manager
Stephanie Hallock, Director, DEQ
Paul Curco, Director, DLCD
Ann Hanus, Director, DSL
Phil Ward, Director, ODA
Lindsay Ball, Director, ODFW
Lyla Houglum, Dean and Director, OSU Extension Service
Thayne Dutson, Director, OSU AES
Geoff Huntington, Director, OWEB
Paul Cleary, Director, OWRD
Bruce Warner, Director, ODOT
Dan Thorndike, Chair, WRC
IMST

Recovery of Wild Salmonids in Western Oregon Lowlands

A report of the Independent Multidisciplinary Science Team, Oregon Plan for Salmon and Watersheds

Technical Report 2002-1

July 15, 2002

Members of IMST
John Buckhouse, Department of Rangeland Resources, Oregon State University
Wayne Elmore, Bureau of Land Management, U.S. Department of Interior
Stanley Gregory, Department of Fisheries and Wildlife, Oregon State University
Kathleen Kavanagh, Forest Resources Department, University of Idaho
William Pearcy, College of Oceanic and Atmospheric Sciences, Oregon State University
Carl Schreck, Department of Fisheries and Wildlife, Oregon State University

Citation: Independent Multidisciplinary Science Team. 2002. Recovery of Wild Salmonids in Western Oregon Lowlands. Technical Report 2002-1 to the Oregon Plan for Salmon and Watersheds, Governor's Natural Resources Office, Salem, Oregon.

Acknowledgements
The IMST would like to thank former IMST members Logan Norris and Jim Lichatowich, and IMST technical support staff Cynthia Taylor, Leah Gorman, Ellen Deehan, Kathy Maas-Hebner, Suzie Peck, and D. Eric Hanson for their contributions to writing and producing this report. We are grateful to IMST administrative staff, Glenda Serpa, for her administrative support in the production of the report. We also thank Charlie Corranino (Oregon Department of Fish and Wildlife) for data on fish passage, and Doug Parrow (Oregon Water Resources Department) for data on streamflow exceedance. Finally we wish to thank the following technical reviewers who commented on earlier drafts: Bob Beschta, Derek Godwin, James Moore, Ron Miner, Gordie Reeves, Mike Borman, Steve Smith; Neal Coenen, Debbie Colbert, Meg Reeves, John Lilly, Dick Pedersen, Jeff Weber, Ken Bierly, Ray Jaindl, Mack Barrington, Ted Lorensen, Greg Apke, William Fletcher, and Ron Reisdorf.

TABLE OF CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

AgWQM area plans - Agricultural Water Quality Management area plans
AgWQMP - Agricultural Water Quality Management Program
BMPs - best management practices
CAFO - confined animal feeding operations
CLAMS - Coastal Landscape Analysis and Modeling Study
DEQ - Oregon Department of Environmental Quality
DLCD - Oregon Department of Land Conservation and Development
DSL - Oregon Division of State Lands
EPA – United States Environmental Protection Agency
ESU - evolutionary significant unit
GCA - gene conservation areas
GIS - geographic information system
HUC - hydrologic unit code
IMST - Independent Multidisciplinary Science Team
NOAA - National Oceanic and Atmospheric Administration
NMFS - National Marine Fisheries Service
NRC - National Research Council
NRCS - United States Natural Resources Conservation Service
OCN -Oregon Coastal Native (coho salmon)
ODA - Oregon Department of Agriculture
ODF - Oregon Department of Forestry
ODOT - Oregon Department of Transportation
ODFW - Oregon Department of Fish and Wildlife
OSU - Oregon State University
OWEB - Oregon Watershed Enhancement Board
OWRD - Oregon Water Resources Department
OWQI - Oregon Water Quality Index
PFMC - Pacific Fishery Management Council
PNW-ERC - Pacific Northwest Ecosystem Research Consortium
SOER - State of the Environment Report
TMDL - Total Maximum Daily Load
USDA - United States Department of Agriculture
USDI - United States Department of the Interior
USFWS - United States Fish and Wildlife Service
USFS - United States Forest Service
USGS - United States Geological Survey
WRI - Willamette Restoration Initiative

PREFACE

The Independent Multidisciplinary Science Team (IMST) was established by the 1997 Oregon Legislature via Senate Bill 924, signed by Governor John Kitzhaber on March 25, 1997. The Team is to advise the State on matters of science related to the Oregon Plan for Salmon and Watersheds. The Governor, the Senate President and the Speaker of the House jointly constituted the 7-member Team October 10, 1997. The establishment of the Team reflected the 1997 agreement between Oregon and the National Marine Fisheries Service concerning coho salmon. This agreement has been terminated, but Executive Order 99-01,which expanded the scope of the Oregon Plan, specifies the continuing role of the Team in the recovery of wild salmonids in Oregon.

IMST Operational Framework

The operational framework of the IMST is summarized in the Team Charter (available at http://www.fsl.orst.edu/imst/). The primary means of communicating results of the Team's work is through written reports. In IMST reports, the Team assesses the best available science as it pertains to salmonid and watershed recovery and the management of natural resources. Based on these assessments, the IMST makes recommendations to Oregon state agencies or entities.

Recommendations are directed to one or more agencies or entities that have the ability to implement, or to affect changes in management or regulation that are needed for implementation. It should be noted that the IMST looks beyond an agency's *current* ability to implement the recommendations because current legal, regulatory, or funding situations may need to change to accomplish the goals of the Oregon Plan. It is the belief of the IMST that if an agency agrees that a recommendation is technically sound and would aid the recovery of salmonid stocks and watersheds, the agency would then determine what impediments might exist to prevent or delay implementation and work toward eliminating those impediments. The Team also assumes that each agency has the knowledge and expertise to determine how best to identify and eliminate impediments to implementation and to determine appropriate time frames and goals needed to meet the intent of the recommendation. In addition, the IMST recognizes that an agency may already have ongoing activities that address a recommendation. Our inclusion of such an "overlapping" recommendation should be seen as reinforcement for needed actions.

Senate Bill 924 specifies that agencies are to respond to the recommendations of the IMST, stating "(3) If the Independent Multidisciplinary Science Team submits suggestions to an agency responsible for implementing a portion of the Oregon Plan, the agency shall respond to the Team explaining how the agency intends to implement the suggestion or why the agency does not implement the suggestion." Once agency responses are received, the IMST reviews the scientific adequacy of each response and whether further action or consideration by the agency is warranted. IMST reviews of responses are forwarded to the Governor and the State Legislature. State agencies are expected to respond to IMST recommendations within six months after a report is issued.

Conceptual Scientific Framework

The IMST developed the following conceptual scientific framework for the recovery of depressed stocks of wild salmonids in Oregon. It was developed originally as we evaluated Oregon's forest practices (IMST 1999). Since then, it has been expanded to cover all land uses and fish management. Although not testable in a practical sense, we believe this conceptual framework is consistent with generally accepted knowledge and scientific theory.

The recovery of wild salmonids in Oregon depends on many factors, including the availability of quality freshwater and estuarine habitats, ocean conditions, the management of fish harvest, and the adequacy of natural and artificial propagation. Freshwater habitat extends across all the lands of the state, and includes 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 wild anadromous salmonids. The ocean on which salmonids depend extends well beyond Oregon and is subject to fluctuations in productivity that markedly affect adult recruitment. Fish propagation and fish harvest are critical activities in which humans are directly involved with anadromous fish. The IMST is evaluating the science behind the management practices and policies that affect all of these freshwater and estuarine habitats and the management of fish and fisheries.

Wehave divided our work into a series of reports that focus on major types of land use (forestry, agriculture, and urban land uses) and fish management (artificial propagation, harvest, and habitat) that impact salmonid recovery in Oregon at the landscape level. The land use 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; therefore, the boundaries we make in our reports are artificial.

Concepts

IMST is conducting its analysis of land use practices and fish management within a framework made up of the following three fundamental concepts:

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 1999b). 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 (Matson and Coupland 1995). The point is that the salmonid stocks of today co-evolved with the environment 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 terrestrial, freshwater, and estuarine landscape of the Pacific Northwest, but current ecosystems need to better reflect the range of historic conditions (Benda 1994, Reeves et al. 1995).
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, both in fresh water and the ocean.

Fresh water and estuarine 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 and adapt to new or recovered habitat.

The ocean habitat also fluctuates and is dynamic, changing over several time scales. There are inter-decadal variations in climate called regimes (as well as shorter term variations) that affect the ocean productivity for salmonids. One regime that resulted in a shift from favorable to unfavorable ocean conditions, especially for coho salmon, occurred in 1977. Some believe that we are entering a more favorable regime that began with the 1998 La Nina. However, it is important to realize that full recovery of salmonid populations is a long-term process. A major assumption is that improved conditions of freshwater and estuarine habitat are buffers to poor ocean conditions. Without improvement of the condition of these habitats, the return to poor ocean conditions in the future will be more devastating to salmonids than what was experienced in the early 1990s (Lawson 1993).

These concepts apply regardless of the land use or fish management strategy and are the basis for the evaluations in this report.

Operation of the Concepts in Salmonids

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) provided the base for recolonization of poor habitat as conditions improved over time.

History

Since the mid 1850s, the rate and extent to which habitat conditions have changed has sometimes exceeded the ability of these species to adapt; therefore, 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 habitat productivity and the rate and extent to which recolonization can occur. In addition, some harvest and hatchery practices may have diminished the genetic diversity of salmonids (reviewed in Allendorf and Waples 1996, NRC 1996), potentially 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 and the diversity of salmonid stocks in the Pacific Northwest are important because they provide a framework for developing policy and management plans for the future. The persistence and performance of salmonids under historic ecological conditions is evidence that these habitats were compatible with salmonid reproduction and survival. Prior to European settlement of the western United States, artificial propagation was not practiced, yet the level of harvest by Native Americans may have reached the levels of peak harvests by Euro-Americans (Beiningen 1976; Schalk 1986).

Conclusions

Land uses and fish management strategies resulting in non-historical ecological conditions may support productive salmonid populations, but the evidence for recovery of wild salmonids under these circumstances is neither extensive nor compelling. Recovery of wild salmonids also requires fish management (artificial propagation and harvest) strategies that are consistent with the goals of recovery and are compatible with the condition of the terrestrial and ocean landscape within which they operate.

We conclude that:

- The goal of land use management and policy should be to emulate (not duplicate) natural processes within their historic range.
- The goal of fish management and policy should be to produce and take fish in a manner that is consistent with the condition of the environment and how it changes with time.
- The recovery of wild salmonid stocks is an iterative and a long-term 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

This report discusses major characteristics of western Oregon's lowland rivers, streams, and estuaries that the IMST finds to be important to wild salmonids. We describe how landscape scale factors – landscape structure, landscape function, disturbance regimes, and landscape scale biological processes – historically supported salmonid populations in western Oregon lowlands. The report also covers human modifications to these ecosystems that impact salmonids. We assess how lowland land use practices may have altered lowland systems so that the landscape's ability to support healthy salmonid populations was reduced. Finally, we discuss how functioning lowland ecosystems might be protected and restored.

The geographic scope of this report is the lowland portion of Oregon west of the crest of the Cascade Range. This area stretches from the lower Columbia River south to the Siskiyou Mountains and includes estuaries, coastal lakes, and alluvial rivers and valleys that provide potential habitat for wild salmonids. In addition to major rivers, this report covers the many small tributaries and streams in western Oregon lowlands.

Science Questions

IMST addresses five science questions in this report. The answers to these questions form the basis for our findings and conclusions, and for specific recommendations to state agencies and entities.

Question 1. How important are western Oregon lowlands and estuaries to the production and recovery of salmonids?

Question 2. How have conditions in western Oregon lowlands changed from conditions prior to EuroAmerican settlement?

Question 3. What is the scientific basis for maintaining and enhancing fish habitat in western Oregon lowland ecosystems with respect to water quantity and flow modifications, fish passage, and water quality?

Question 4. What is the scientific evidence for the importance of vegetation within riparian areas in enhancing ecological processes and functions critical to salmonid recovery in western Oregon lowland ecosystems?

Question 5. What general actions are needed in the western Oregon lowlands to facilitate recovery of salmonid populations?

Overall Findings

Based on our scientific review of the answers to these five questions, the IMST finds that:

- Lowland river systems and estuaries provided diverse and productive habitats for rearing juveniles, spawning adults, and migrating juvenile and adult salmonids.
- Lowland ecosystems of western Oregon have been greatly altered during the past 150 years by human disturbances resulting from a variety of land uses. The basic processes by which water and sediment move from uplands – via streams, rivers, and estuaries – to the ocean have been highly altered.
- Alterations in flow regimes in western Oregon lowland streams have contributed to alterations in water quantity, hydrographs, and channel and floodplain form and function, negatively affecting salmonid habitat.
- Fish ladders, small dams, culverts, tide gates, irrigation diversions, and some fish hatcheries still block salmonid passage in many streams in the western Oregon lowlands.

In general, salmonids need cold, oxygenated, clean, clear water. Excessive temperature, sediment, inorganic and organic nutrients, and anthropogenic chemicals (including pesticides) impair water quality and impact salmonids.

Riparian vegetation provides many important ecological functions to aquatic systems: habitat diversity, organic matter inputs, large wood input, regulation of channel morphology and streamflow, hydrologic connectivity, temperature mediation, sediment interception, and nutrient uptake.

Key elements to a landscape approach to salmonid recovery include (1) considering landscape scale biological processes such as metapopulation structure, (2) landscape scale research, modeling and planning, (3) inventory and assessment, (4) prioritization, (5) monitoring and adaptive management, and (6) selecting projects that maintain and restore landscape scale processes.

Overall Conclusions

The quality and quantity of native salmonid habitat in lowland rivers, streams, and estuaries has been significantly reduced since EuroAmerican settlement. Recovery of wild salmonids requires habitat that is functional across the landscape. For example, management of lowland riparian zones in conjunction with those on adjacent uplands is needed to maintain the dynamics of riparian structure and function across the landscape. Other areas that need to be addressed both within and beyond the boundaries of the western Oregon lowlands include roads and sediment, large wood, fish passage, pesticides, and nutrient inputs to streams. We conclude that management practices must be considered on a large spatial scale, among agencies, and across different land uses.

Protection of intact, functional aquatic habitats should be the first priority for salmonid recovery efforts. Many land use practices in lowlands can be changed to halt and reverse the degradation of streams, floodplains, and salmonid habitat. Restoration of structure and function of lowland systems – including the geomorphic, hydrologic, and biological processes that create and maintain salmonid habitat – can have beneficial effects on salmonids and on lowland ecosystems in general. Because vegetation and large wood within riparian areas contribute important hydrologic and biologic functions to lowland rivers and estuaries, they should receive protection and be restored toward their historic level of function within river networks.

Addressing salmonid recovery in western Oregon lowlands presents tremendous challenges for a number of reasons, including high human population density, diverse land ownership, and significant reduction in salmonid habitat quality. Creative thinking is needed to move forward in the face of these challenges. In particular, solutions that will work across boundaries of land ownership, agencies, and ecosystems are needed.

Recommendations

Based on the findings and conclusions for these five science questions, the IMST makes the following 21 specific recommendations. The aim of these recommendations is to help Oregon move toward effective protection and restoration of aquatic and riparian ecosystems, and toward reestablishing healthy salmonid populations.

Recommendations are directed to one or more agencies or entities that have the ability to implement, or to affect changes in management or regulation that are needed for implementation. It should be noted that the IMST looks beyond an agency's *current* ability to implement the recommendations because current legal, regulatory, or funding situations may need to change. It is the belief of the IMST that if an agency agrees that a recommendation is technically sound and would aid the recovery of salmonid stocks and watersheds, the agency would then determine what impediments might exist to prevent or delay implementation and work toward eliminating those impediments. The

Team also assumes that each agency has the knowledge and expertise to determine how best to identify and eliminate impediments to implementation and to determine appropriate time frames and goals needed to meet the intent of the recommendation. In addition, the IMST recognizes that an agency may already have ongoing activities that address a recommendation. Our inclusion of such an "overlapping" recommendation should be seen as reinforcement for needed actions.

In the Recommendations section, each recommendation is accompanied by a brief explanation, illustration of the recommendation's context, and/or possible suggestions for implementation.

Recommendation 1. The Core Team of the Oregon Plan for Salmon and Watersheds should develop and implement a landscape approach to manage salmonid habitat in western Oregon lowlands.

Recommendation 2. The Core Team of the Oregon Plan should develop and implement a statewide riparian policy and plan that provides for proper function and condition of riparian areas in Oregon.

Recommendation 3. The Core Team of the Oregon Plan should develop a statewide policy and plan for the management of large wood in and near streams and estuaries.

Recommendation 4. The Oregon Watershed Enhancement Board (OWEB) should develop strategic priorities for protection and restoration activities in western Oregon lowland streams, rivers, and estuaries to enhance salmonid recovery.

Recommendation 5. The Division of State Lands (DSL) should reconnect main river channels to off-channel areas and floodplains to increase available lowland habitat for salmonids.

Recommendation 6. The Oregon Department of Fish and Wildlife (ODFW) should determine fish abundance and establish fish-habitat relationships in western Oregon lowland rivers, streams, and estuaries.

Recommendation 7. The Oregon Watershed Enhancement Board (OWEB) should implement a long-term systematic monitoring strategy to evaluate the status and trends of salmonid populations, the capacity of habitat to produce salmonids and support diverse salmonid life histories, and the effectiveness of protection and restoration. The strategy should represent the diversity of land uses and aquatic ecosystems in western Oregon lowlands.

Recommendation 8. The Oregon Department of Agriculture (ODA) and the Department of Environmental Quality (DEQ) should establish the effects that land use activities in western Oregon lowlands have on salmonid populations and habitat quality.

Recommendation 9. The Oregon Department of Agriculture (ODA) should improve the technical strength of their program under the Oregon Plan and expand its scope to address salmonid habitat requirements.

Recommendation 10. The Oregon Water Resources Department (OWRD), in cooperation with other agencies, should reestablish a more natural hydrograph (timing and magnitude) on an experimental basis in river systems where flow modification is occurring as a result of storage operations.

Recommendation 11. The Oregon Water Resources Department (OWRD) should maintain or increase streamflow where water withdrawals and/or impoundments presently limit salmonid distribution, productivity, or migration.

Recommendation 12. The Water Resources Commission should develop and implement a strategic plan for the long-term management of water in western Oregon.

Recommendation 13. The Oregon Water Resources Department (OWRD) should coordinate with the US Geological Survey (USGS) to establish and maintain hydrologic gaging stations on stream and river systems critical to salmonid recovery where data are not currently available.

Recommendation 14. The Oregon Department of Agriculture (ODA) should reduce sedimentation from agricultural practices in western Oregon lowlands.

Recommendation 15. The Oregon Department of Agriculture (ODA) and the Department of Environmental Quality (DEQ) should prevent adverse pesticide impacts on aquatic systems.

Recommendation 16. The Oregon Department of Agriculture (ODA) and the Department of Environmental Quality (DEQ) should prevent adverse eutrophication impacts of aquatic systems.

Recommendation 17. The Oregon State University (OSU) Agriculture Experiment Station (AES) and the OSU Cooperative Extension Service (CES), working with other state agencies involved in research, should increase understanding of how rural land use activities in the western Oregon lowland systems interact with and affect salmonid recovery.

Recommendation 18. The Division of State Lands (DSL), Oregon Water Resources Department (OWRD), Oregon Department of Fish and Wildlife (ODFW), and Oregon Department of Transportation (ODOT) should reestablish and maintain natural fish passage for juveniles and adults in lowland stream systems.

Recommendation 19. The Division of State Lands (DSL) and Oregon Department of Fish and Wildlife (ODFW) should protect and restore hydrologic function and salmonid habitat in freshwater and tidal wetlands.

Recommendation 20. The Department of Land Conservation and Development (DLCD), in conjunction with Oregon Department of Fish and Wildlife (ODFW), should improve and protect salmonid habitat in Oregon's estuaries.

Recommendation 21. The Oregon Department of Fish and Wildlife (ODFW) should prevent loss of salmonids because of water diversion.

INTRODUCTION

Lowlands in western Oregon are an important part of the landscape used by wild salmonids. The appropriate management of these lands is important to accomplishing the goals of the Oregon Plan for Salmon and Watersheds (Oregon Plan 1997). This technical report of the Independent Multidisciplinary Science Team (IMST) focuses on western Oregon lowlands and their management. We note, however, that all habitats used by wild salmonids are important to recovery.

The focus of IMST on the Western Oregon Lowlands Project is:

- To evaluate the importance of western Oregon lowlands to wild anadromous salmonids;
- To evaluate the scientific basis for maintaining and enhancing western Oregon lowland river and estuary ecosystems; and
- To recommend actions that will facilitate recovery of salmonid populations.

This report is a broad, comprehensive look at management activities within the western Oregon lowlands and how they may affect salmonid recovery. In the report, the IMST addresses some scientific and technical issues that are operational and can be addressed rapidly. Other issues are quite broad and have important implications for policy; we expect these issues will take longer to resolve. The report is not intended to be a review of individual actions by agencies or measures directed to them through the Oregon Plan. Rather, agency actions are used to illustrate examples. The scientific direction provided by this report can guide agencies and landowners in modifying practices to aid recovery of depressed wild salmonid stocks. The main content of the report is divided into four sections:

Introduction. The introduction defines the scope of the report. This section also briefly reviews status of salmonid stocks, and provides an overview of how landscape ecology pertains to salmonid recovery.

Science Questions and Answers. This section presents five broad questions posed by the IMST, which the Team considers to be most important to accomplishing the goals of the Oregon Plan. The answers are used to develop the Team's findings and conclusions.

Recommendations. These are the specific recommendations of the IMST to the State of Oregon and state agencies to facilitate salmonid recovery in western Oregon lowlands.

Implications for Policy. This section puts the science questions, findings, conclusions, and recommendations in the context of how they might affect state policies. This section is at the interface between science and policy and its content is intended to help those addressing policy do so in ways that are consistent with the best available science.

Geographic Scope

The geographic scope of this report is the lowland portion of Oregon west of the crest of the Cascade Range (Figure 1). This area stretches from the lower Columbia River south to the Siskiyou Mountains and includes estuaries, coastal lakes, and alluvial rivers and valleys that provide potential habitat for wild salmonids. We define lowland rivers and streams as those in geologically unconstrained alluvial valleys, with low channel and valley gradients (<2%), either narrow or wide floodplains, and usually a meandering or braided channel network. Typically, channel bed material is smaller than cobble-size and channel morphology is plane-bed, pool-riffle, or dune-ripple. The channel may also contain pools, bars, and steps formed as a result of large wood in the channel (Montgomery and Buffington 1998). In addition to major rivers, this report covers the many small tributaries and streams in western Oregon lowlands. Most areas in western Oregon with higher gradients are forested, and are discussed in our previous report on forest land use (IMST 1999).

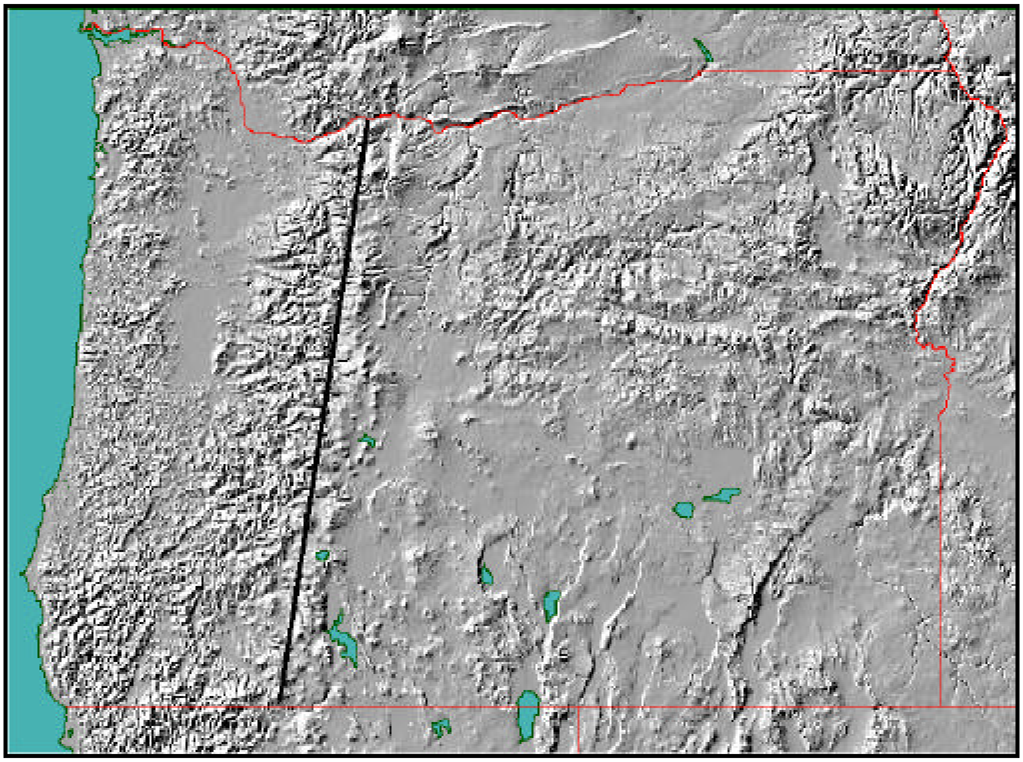

Figure 1. Region of western Oregon covered in this report (left of black line, west of the crest of the Cascade Mountain Range) (after Sterner 2001).

One of the major lowland areas covered in this report, the Willamette Valley, ranges from 400 ft. at the southern end (near Eugene, OR) to sea level (Orr et al. 1992). Other lowland areas in western Oregon tend to have a similar range in elevation; however, elevation is only one of many factors that define the boundaries of ecosystems in lowland areas (Omernik 1995). Principal lowland areas covered in this report include the Willamette Valley – including tributaries to the Willamette River – and broad floodplain valley areas of the Columbia, Siuslaw, and Umpqua Rivers as they cut across the Coast Range. Major coastal rivers with broad floodplains and estuaries include the Nehalem, Wilson, Trask, Nestucca, Siletz, Yaquina, Siuslaw, Alsea, Coos, and Coquille Rivers. Many small coastal rivers have lowland area, including the Sixes and Elk Rivers. Broad, unconstrained alluvial valleys of the Rogue and Illinois Rivers are included in this report, although the elevation of these valleys may be above 400 ft.

This report covers all estuaries in Oregon regardless of size. Oregon has 22 major estuaries (Figure 2) and 17 minor estuaries. Oregon's estuaries have been altered to varying degrees, and the tidal marshes in estuaries have experienced significant changes (see Question 2). The Department of Land Conservation and Development (DLCD) classification of Oregon's estuaries defines the level of development permitted. DLCD classified eleven of Oregon's estuaries as either "natural" or "conservation" estuaries (Table 1; Cortright et al. 1987), and these are managed to preserve estuary functions that have had little alteration (Jackson 1991). The remaining eleven of Oregon's 22 estuaries have been classified as "development" estuaries and have jetty entrances, shipping channels, and extensive shoreline alternations (Jackson 1991). Detailed mapping and habitat information is not available for the minor estuaries (Table 2). These estuaries are located at the confluence of smaller rivers and creeks with the ocean, are valuable as habitat, and support anadromous fish. DLCD requires that minor estuaries be classified during the development of local comprehensive plans or estuary plans (Cortright et al. 1987).

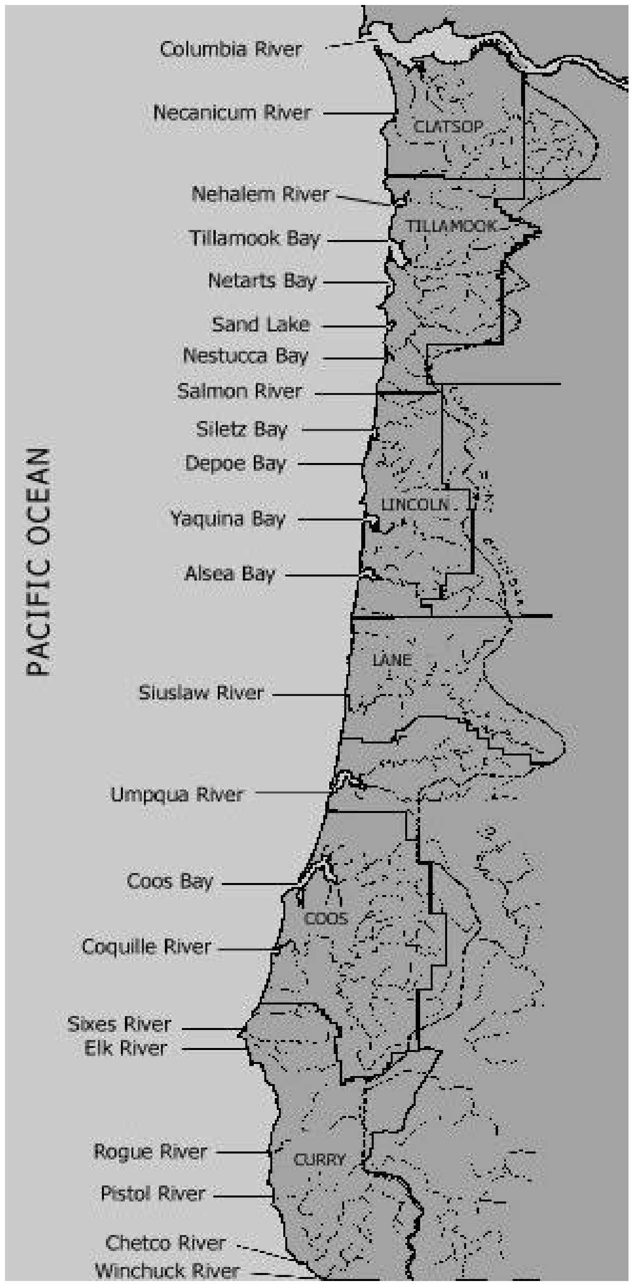

Figure 2. Oregon's estuaries and their drainage areas. Reproduced from http://www.inforain.org/mapsatwork/oregonestuary/.

Table 1. Classification of Oregon's major estuaries (From Cortright et al. 1987).

Natural	Sand Lake Salmon River Elk River* Sixes River* Pistol River*	Estuaries lacking maintained jetties or channels, and which are usually little developed for residential, commercial or industrial uses. They may have altered shorelines, provided that these altered shorelines are not adjacent to an urban area. Shore lands around natural estuaries are generally used for agriculture, forestry, recreation and other rural uses. Natural estuaries have only natural management units.
Conservation	Necanicum River Netarts Bay Nestucca River Siletz Bay Alsea Bay Winchuck River*	Estuaries lacking maintained jetties or channels, but are within or adjacent to urban areas which have altered shorelines adjacent to the estuary. Conservation estuaries shall have conservation and natural management units.
Shallow Draft Development	Nehalem Bay Tillamook Bay Depoe Bay* Siuslaw River Umpqua River Coquille River Rogue River Chetco River	Estuaries with maintained jetties and a main channel (not entrance channel) maintained by dredging at 22 feet or less. Shallow draft development estuaries have development, conservation and natural management
Deep Draft Development	Columbia River Yaquina Bay Coos Bay	Estuaries with maintained jetties and a main channel maintained by dredging deeper than 22 feet. Deep draft development estuaries have development, conservation and natural management units.

- ODFW habitat maps not available (Cortright et al. 1987).

Table 2. Minor estuaries in Oregon (Modified from Cortright et al. 1987).

County	**Estuary**	**Classification**	Size [1]
Clatsop	Ecola Creek	Conservation	50 acres
Tillamook	Neskowin Creek	Conservation	30 acres
Lincoln	Big Creek Beaver Creek Yachats River	Natural Conservation Conservation	20 acres 35 acres 40 acres
Lane	Tenmile Creek Big Creek Berry Creek Siltcoos River Sutton River	Natural Natural Natural Natural Natural	35 acres 35 acres 30 acres 45 acres 45 acres
Douglas	Tahkenitch Creek	Natural	25 acres
Coos	Tenmile Creek Twomile Creek Fourmile Creek / New R.	Natural Natural Natural	35 acres 20 acres 20 acres
Curry	Floras Creek / New R. Euchre Creek Hunter	Natural Natural Natural	125 acres 45 acres 50 acres

Technical Scope

The technical scope of this report includes major characteristics of lowland rivers, streams, and estuaries that the IMST finds to be important to wild salmonids. The report also covers human modifications to these ecosystems that impact salmonids. There are many changes in freshwater conditions contributing to the decline of native salmonids in western Oregon, such as construction of hydropower dams, direct alteration of stream channels, and agricultural and urban development (Nehlsen et al. 1991, NRC 1996). These alterations have resulted in major changes to the landscape of western Oregon including habitat and flow modification, decreased water quality, loss of riparian vegetation, and hindered fish passage. Although other topics could be included in this report, the IMST considered these topics to be the most important to wild salmonid recovery. Agriculture is the dominant land use of western Oregon lowlands, and many of the alterations to lowland ecosystems are the result of land conversion for agriculture (Azuma et al. 1999). Therefore, its impacts on salmonid habitat, populations, and recovery are prominent in this report.

This report does not include other major factors that have contributed to the decline of salmonids. These include overfishing, predation, interactions with non-native and hatchery fish (Nehlsen et al. 1991, Huntington et al. 1996, NRC 1996), and unfavorable ocean conditions (Pearcy 1997). Western Oregon forests, which predominate upland areas in the Coast Range and Cascade Range, are managed under the State's Forest Practices Act (not including federal lands) and were discussed in an earlier report (IMST 1999). Urban and Eastern Oregon land uses and management will be discussed in future reports.

Rural residential home sites are an increasingly obvious feature of the Oregon lowland landscape, and often have some aspect of agriculture associated with them. These home sites are generally on small acreage (0.5 -20 acres). Agricultural practices may include cultivation, small-scale nurseries, vineyards, Christmas trees, hybrid cottonwood plantations, or livestock (most commonly horses, llamas, sheep, cattle, or goats, although poultry, swine, and other animals may be observed). The distinguishing difference between rural residential home sites and commercial agriculture is financial: the rural residential home site occupants do not earn their major source of household income from the land, but rather from an independent source of employment away from the site.

Rural residential home sites promulgate a series of potential land use problems including urban sprawl; increased roads; intensified use on any given acre (corralled horses, for example); potential overuse of fertilizers or pesticides; overgrazing of confined animals; improper or non-existent animal waste disposal; improper cultivation coupled with increased erosion; as well as serious problems frequently associated with individual household sewage disposal. The IMST is aware of the potential hazards associated with rural residential home sites, and we have chosen to address them in our upcoming report on urban land use.

Status of Stocks

Nehlsen et al. (1991) identified 214 native, naturally spawning stocks of Pacific salmon, steelhead or anadromous cutthroat trout that were depleted or at risk of extinction in the Pacific Northwest (Oregon, California, Washington and Idaho). Fifty-eight are located in the Oregon coastal region and 76 in the Columbia River Basin. Since 1991, seven salmonid evolutionarily significant units (ESUs) west of the Cascades have been listed by the National Marine Fisheries Service (NMFS) as Threatened under the US Endangered Species Act. These include: southern Oregon/northern

California and Oregon coastal **coho salmon**[1] (*Oncorhynchus kisutch*); upper Willamette and Lower Columbia River **chinook salmon** (*Oncorhynchus tshawytscha)*; Columbia River **chum salmon** (*Oncorhynchus keta*); and lower Columbia River and Upper Willamette **steelhead** (*Oncorhynchus mykiss*). In addition, the Oregon coastal steelhead ESU is being considered for listing. The State of Oregon has also listed coho salmon in the Lower Columbia as endangered, and it is a candidate for listing by NMFS. The U.S. Fish and Wildlife Service is considering listing the Southwest Washington /Columbia River population of coastal **cutthroat trout** (*Oncorhynchus clarki clarki*) as Threatened under the Endangered Species Act. The status of all these species has been reviewed in NOAA Technical Memoranda (Weitkamp et al. 1995, Busby et al. 1996, Johnson et al.1997, Myers et al. 1998, Johnson et al. 1999). The distribution of these species, and of bull trout, in western Oregon are shown in Figure 3. Comparable distribution maps for cutthroat trout are not currently available.

Based on these listings and on the conclusion that healthy native anadromous salmonid stocks now constitute a small fraction of the historical resource (Huntington et al. 1996), we conclude that the status of both anadromous and resident wild salmonids in western Oregon, including lowland rivers and estuaries, is poor. Abundance and distribution of wild salmonids have been reduced from historical levels, life history types may have been lost, and risk of extinction for some populations has increased. As we will discuss in this report, human caused disturbances and impacts are strongly associated with the status of salmonid stocks in the Pacific Northwest and have decreased both the quality and availability of salmonid habitat (Beechie et al. 1994, Bradford and Irvine 2000).

The western Oregon lowlands have the highest richness of fish species within Oregon, with over 75% of all fish species including non-salmonids (Hulse et al. 2002). There are 60 fish species present in the Willamette River basin alone. Only ten fish species occupy the headwater streams in the basin, indicating the importance of habitat in the lower elevation reaches in the basin. Thirty-one species are native fish and twenty-nine are introduced (Hulse et al. 2002). The state or federal government has listed seven of thirty-one native species in the Willamette as threatened or endangered. Therefore, activities in the western Oregon lowlands affect more species than just salmonids.

[1] Federal listing for Oregon coastal coho was overturned by a U.S. District Court (Eugene, OR) ruling in the case *Alsea Valley Alliance v. Evans*, September 10, 2001. In response, the National Marine Fisheries Service has agreed to review the status of 25 federally listed ESUs of salmonids. Oregon coastal coho remain listed as Sensitive by the State of Oregon.

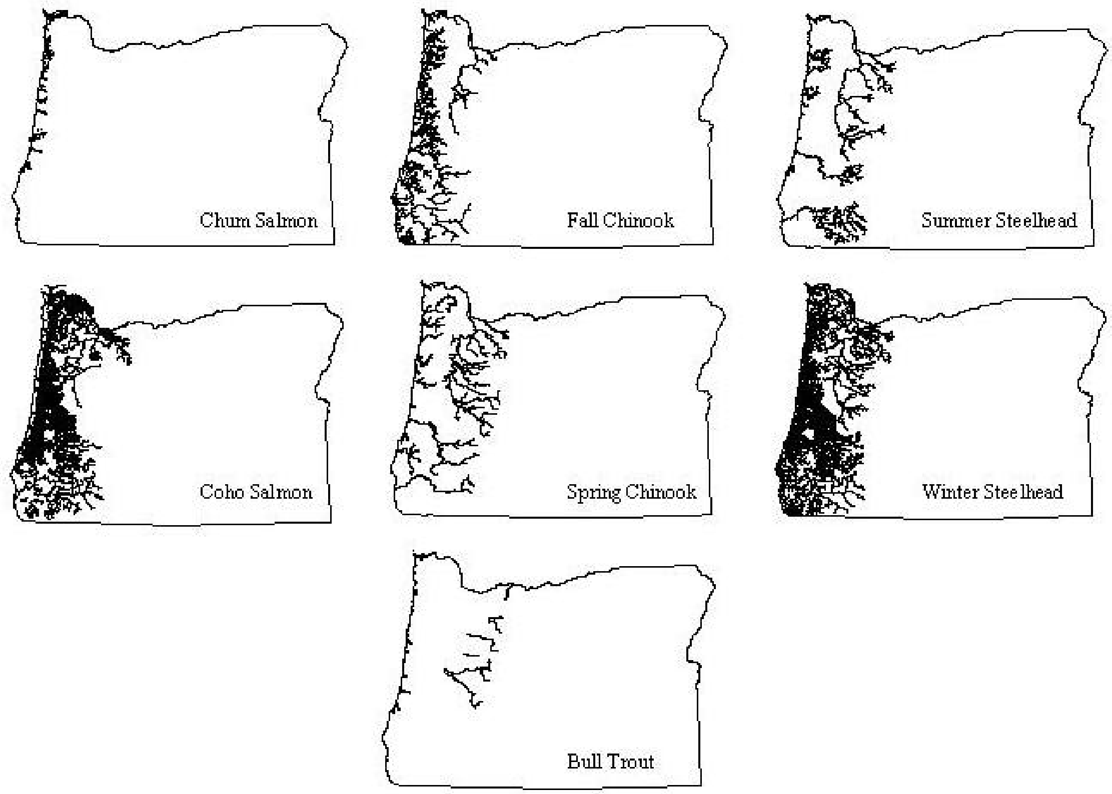

Figure 3. Distribution of chinook salmon, chum salmon, coho salmon, steelhead trout, and bull trout habitat in western Oregon based on survey data, supporting documentation, and the best professional judgment of field biologists.[2]

Concepts from Landscape Ecology

Lowland river, stream, and estuary ecosystems are physically connected to and influenced by upland ecosystems (Naiman et al. 1988, Swanson et al. 1988, Gregory et al. 1991, Naiman and Decamps 1997, Beschta and Kauffman 2000). Lowland landscapes include both aquatic and terrestrial components, which are both affected by the management and condition of the surrounding landscape. In other words, rivers and valleys are inseparable ecologically, and natural functions need to be maintained throughout entire watersheds (Harding et. al 1998). The linkages between uplands and lowlands and between aquatic and terrestrial systems have long been recognized, and have been prominent in the guidance provided by the Oregon Plan.

Human land uses within a watershed can alter landscape conditions and disturbance regimes, and this can affect water quality, water quantity, and/or habitat conditions. Coho, winter steelhead and summer chinook have been observed to be healthier where there are few dams, less agriculture, and lower human populations (Nehlsen et al. 1991, Mrakovcich 1998). Research indicates that land cover characteristics throughout a watershed are important in influencing stream conditions (Richards et al. 1996). A positive correlation was found between the percentage of forested area and coho abundance in the Snohomish River basin of western Washington (Pess et al. 2001), indicating stocks may currently be healthier in upland regions which are often on publicly owned land. Harding et al. (1999)

[2] Data sources: State Boundary: USGS, 1:2,000,000; retrieved from Oregon GeoSpatial Data Clearing House, Oregon Department of Administrative Services (http://www.sscgis.state.or.us/). Distribution data retrieved 2/06/01 from Oregon Department of Fish and Wildlife 1:100,000 salmonid distribution mapping project (http://rainbow.dfw.state.or.us/data.html).

concluded that land use, especially agriculture, can result in long-term changes and reductions in aquatic diversity. Other authors have concluded that the extent of agriculture in a basin may be the best predictor of local stream conditions (Allan et al. 1997, Wang et al. 1997).

When assessing land management practices relative to salmonid recovery, it is important to keep in mind that the ecosystems we are attempting to restore are natural-cultural systems – all of Oregon's watersheds have been altered in some manner by human use. Therefore, assessments of the status of these systems must consider the complex interactions between terrestrial and aquatic systems, disturbance regimes, watershed conditions, and land uses practices. In previous reports, the IMST adopted a landscape perspective for its review of land management practices and certain fishery management programs such as artificial propagation and harvest management. We have also adopted the landscape perspective in this review of the role of lowland land use practices in the recovery of anadromous salmonids.

Spatial and temporal frameworks

By definition, a landscape perspective involves consideration of large spatial extents. A landscape is usually understood to be an area with a diameter of at least a few kilometers (Forman and Godron 1986). Landscape ecologists often consider long time frames because the ecological processes that affect large areas occur infrequently (e.g., floods, earthquakes) or very slowly. Salmonids move long distances throughout their life cycles, occupy diverse habitats, and have great fluctuations in productivity over time. Therefore, in salmonid management, large spatial areas and long time frames need to be considered to understand the cumulative impacts of human activities on fish and fish habitat.

Taking a landscape perspective also involves considering how ecological processes differ at various spatial and temporal scales. To do this, landscape ecologists often look at ecosystems as a hierarchy (Allen and Hoekstra 1992). For example, watersheds can be understood as a series of nested units: stream systems, sections, reaches (constrained, semiconstrained, unconstrained), channel units (pool, glides, riffles, rapids, cascades, and steps), and sub-units (Frissel et al. 1986, Grant et al. 1990, D'Angelo et al. 1995). Examining multiple scales has proven to be very useful in understanding the characteristics of salmonid habitat (D'Angelo et al. 1997; Burnett 2001) and the geological processes that create the stream habitat (Grant et al. 1990).

Structure, function, and change

Ecosystems and the materials and organisms that make up those ecosystems are sometimes called "elements" of a landscape. For the landscape inhabited by salmonids in Oregon, these elements include riparian and upland forest, grasslands, wetlands, floodplains, ground water, gravel, and large wood in the stream channel. Other elements include buildings, roads, sewers, bridges, and parking lots. Important elements described in this report are the physical habitat occupied by salmonids and the materials that maintain the integrity of that habitat.

The structure of a landscape is the pattern or distribution of landscape elements. In other words, the structure of the landscape is the spatial arrangement of organisms, ecosystems, and human impacts. Examples of questions relating to the structure of the landscape are:

- How large are the various patches of habitat?
- What shape are the habitat patches?
- What is the quantity of materials that make up habitat (large wood, gravel)?
- What are the types of ecosystems included in the landscape?
- What is the configuration of these ecosystems?

The function of a landscape refers to the flow of energy (food), materials (water, nutrients, gravel and large wood), and organisms within the ecosystem.

Landscapes are dynamic: both structure and function change across time and space. Even with change, stability of the system is ensured as long as all the relevant elements remain within the landscape and structure and functions are maintained within the bounds of the historical experience of the biotic community. Functions – such as movement of water and gravel – need to be maintained to a degree that habitat continues to be available and biological processes are not interrupted. Maintaining structure may also be necessary in order to maintain function; for example, large enough patches of wetland on the valley floor (structure) are needed to absorb floodwaters and maintain hydrologic regimes (function). The dynamic interaction between structure and function creates the heterogeneous habitats required by the numerous life-stages and species of salmonids.

Disturbance

Frequency, extent, and magnitude of disturbance are key factors in shaping the landscape inhabited by salmonids (Reeves et al. 1995). Disturbances, such as floods, fires, and landslides, play an important role in creating and maintaining diverse salmonid habitats. 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 (Agee 1993, Benda et al. 1998). The frequency, intensity, and magnitude of the response to these disturbances vary widely, depending on factors such as topography and channel networks. These factors 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.

Another example of disturbances that create and maintain salmonid habitat in lowlands is floods. Floods influence channel and floodplain morphology of lowland river and estuary systems. Therefore, floods are important to producing a complex mosaic of habitats for aquatic species (Wolman and Leopold 1957, Welcomme 1995, Brown 1997). Coastal aquatic ecosystems are influenced by interactions between uplands, riparian areas, tidal marshes and marsh channels, the open water of the estuary and the ocean near the shore (Rumrill and Cornu 1995). Daily inflow of tidal currents is important to the development and maintenance of estuarine habitat (Mead et al. 2000).

Landscape scale biological processes: metapopulation structure

The National Research Council (NRC 1996) recommended viewing salmon from a broader, metapopulation perspective, as well as at a local population scale. Metapopulations are groups of local populations distributed across a heterogeneous landscape and genetically linked by dispersal of individuals (Levins 1969). For salmonids, metapopulation structure can be considered a landscape scale biological process because fish move between populations at the landscape scale. Just as understanding the distribution or "structure" of habitat (amount, configuration, connectivity) is important to salmonid recovery planning, so is the structure of populations across a landscape (population size, productivity, dispersal rates). However, as we will describe, the two are closely linked. Adequate habitat to support multiple populations is needed to maintain metapopulation structure.

In a metapopulation, dispersal allows for recolonization of unoccupied habitat patches after local extinction events (Levins 1969, Hanski 1991, Hanski and Gilpin 1991). The extinction-colonization balance depends on dispersal of individuals and connectivity between habitats occupied by populations. If the frequency of disturbance – whether human caused or natural – degrades a species' habitat and exceeds the species' ability to maintain a balance between extinction and recolonization, the individual populations, and eventually the entire metapopulation, will become extinct. Metapopulation structure may also provide a pool of individuals able to recolonize degraded habitat as the habitat recovers. Salmon may become locally extinct (extirpated) after severe disturbance events, such as wildfires or landslides (Reeves et al. 1995). As conditions improve, salmon from other populations will colonize vacant habitat, reestablishing populations and generally minimizing the possibility of the metapopulation's extinction. However, metapopulation structure may not protect populations from regional events (such as periodic downturns in ocean productivity) if all populations are extirpated at the same time (Harrison 1991). Application of metapopulation theory to salmonid recovery is discussed further in Question 5.

Applying landscape ecology to salmonid recovery

IMST believes the landscape perspective should be used in managing salmonid habitat at both individual sites and across the landscape of western Oregon. When concepts of landscape ecology are applied to land management decisions throughout watersheds, the focus shifts from individual stream reaches or habitat components to the dynamics of landscape patterns and processes. In this report, we describe how landscape scale factors – landscape structure, landscape function, disturbance regimes, and landscape scale biological processes – historically supported salmonid populations in western Oregon lowlands. We assess how lowland land use practices may have altered these factors so that the landscape's ability to support healthy salmonid populations was reduced. Finally, we discuss how functioning lowland ecosystems might be protected and restored.

SCIENCE QUESTIONS AND ANSWERS

In this section, we address five science-based questions. Each question is critical to the next question in the sequence. At the end of each science question, we summarize our findings and the conclusions we drew from the findings. The science questions are followed by two sections that include IMST recommendations to facilitate recovery of salmonids in lowland regions of western Oregon and possible implications for state policy.

Question 1. How important are western Oregon lowlands and estuaries to the production and recovery of salmonids?

Understanding the importance of western Oregon lowlands to the production and recovery of salmonids requires examining how salmonids use lowland habitats. In this question, we describe salmonid habitat utilization in western Oregon's lowland rivers, streams, and estuaries, and discuss how utilization varies among species and individuals. We also describe evidence that production and life history diversity of salmonids has been greatly reduced since EuroAmerican settlement, and discuss the relationship of the decline with changes in lowland conditions. The ecological processes that influenced the evolution and diversity of Oregon's salmonids and the changes to lowland rivers and estuary conditions since EuroAmerican settlement are covered in more depth in Question 2.

Life History Diversity of Salmonids

Salmonids interact with a landscape mosaic of habitats during their lives. Different salmonid species may utilize different portions of a watershed or landscape. Anadromous salmonids (coho, chinook, chum, sockeye, pink, steelhead, and cutthroat trout) use lowland rivers and estuaries in several stages of their life history. As young, they move from freshwater rearing habitats (that range from high elevation spawning streams to small lowland tributaries) downstream into estuaries and the ocean. As adults, they return, moving upstream through the same interconnected habitats. Resident (non-anadromous) salmonids such as bull trout, rainbow trout, cutthroat trout, and kokanee also utilize streams in different parts of a landscape at different life history stages.

Salmonid species have various life history strategies. Traits that vary among different species include age, size and date of spawning, time and age of smolt migration, and the number of times an individual reproduces. (Groot and Margolis 1991, Waples et al. 2001). These differences may be closely tied to the physiological status and growth rates of salmonids (Dickhoff et al. 1995, Beckman et al. 2000). Life history "types" are defined by different spatial or temporal utilization of habitats by the same species. For example, life history types may migrate to spawn or migrate to sea at different times or sizes. Reimers (1973) described five life history types in the Sixes River, Oregon that migrated to the estuary, resided in the estuary, and migrated to the ocean at different times of year. Variation in timing of spawning and migration is hypothesized to have evolved in response to environmental conditions (temperature, flow, length of instream migration) experienced by spawning adults (Healey and Prince 1995 and other authors). Differences in life history phenotypes may be plastic, but can have a genetic basis, as with chinook salmon (Carl and Healey 1984, Healey and Prince 1995, Banks et al. 2000). Phenotypic plasticity is thought to operate within the constraints or limits imposed by the genotype (Thorpe et al. 1998), leading to more than one life history strategy. In some cases, life history types may be considered populations within a larger metapopulation.

Salmonid Habitat Use in Lowland Rivers

Low-gradient rivers and streams with active floodplains are ecologically important to anadromous and resident salmonids, as well as other native fish species. Unconstrained, low elevation reaches often have the greatest abundance of salmonids, probably because of the great habitat diversity

(Reeves et al. 1998). In unconstrained stream reaches of lowland rivers, valley walls do not impede lateral channel migration. The resulting complex structure provides important habitats for salmonids.

Unconstrained reaches provide essential habitat for rearing and migration. In addition to mainstem channel habitat, unconstrained reaches of lowland rivers provide diverse slow water habitats to salmonids including side-channels, lakes, backwaters, alcoves, sloughs, and beaver ponds. Unconstrained reaches in the Elk River (Oregon) contained about 15% of the total available habitat, but accounted for 30% of estimated juvenile anadromous salmonids (Reeves et al. 1998, Burnett 2001). Benda et al. (1992) similarly concluded that the majority of stream channels accessible to anadromous salmonids in the South Fork Stillaguamish River in Washington are geologically unconstrained or in wide areas of the main river valley. Sharma and Hilborn (2001) found that lower valley slopes and lower stream gradients were correlated with higher coho smolt densities in 14 western Washington streams.

Juvenile salmonids may spend several weeks in lower portions of rivers during migration from upstream rearing areas before entering estuaries and the ocean. Research has indicated that movements of many juvenile coho, cutthroat, and steelhead within a stream are common during the summer. In particular, they may move if their rearing stream becomes too warm (Chapman 1962; Lindsay 1974). For example, many coho fry leave natal streams and become "nomads", moving downstream into lowland reaches (Chapman 1962, Lindsay 1974, Sandercock 1991.) Contrary to predictions, Kahler et al. (2001) observed that movements were common, "movers" grew faster than "non-movers", and coho "movers" were larger than "non-movers" during the summer in western Washington streams. Rodgers (1986) documented variability in the timing of juvenile coho downstream movement in Knowles Creek (Siuslaw River watershed, Oregon), which he attributed to low streamflow in upper tributaries or lack of winter habitat. If suitable rearing habitat is available in lower elevation streams, river valleys, and estuaries, these outmigrants can make a significant contribution to smolt production and population recovery (Bradford et al. 2000)

As well as being important rearing areas, slow water habitats provide refugia from winter high-flows, especially for juvenile coho salmon (Peterson 1982, Brown and Hartman 1988, Swales and Levings 1989, Nickelson et al. 1992, Nickelson et al. 2001). The largest number of juvenile coho is thought to have once over-wintered in lower reaches of coastal basins (Lichatowich 1989). During fall and winter, juvenile coho change their habitat preference from predominantly main-channel summer rearing areas and move downstream to tributaries, side-channels, and riverine ponds where they avoid high-water winter freshets and flooding events (Peterson 1982, Tschaplinkski and Hartman 1983, Hartman and Brown 1987, Cederholm and Scarlett 1988, Swales and Levings 1989, Giannico and Healey 1998). In the Snohomish River basin (Washington), many of the most productive coho salmon spawning areas are low-gradient stream channels adjacent to wetlands with these off-channel habitats (Pess et al. 2001). The availability of wintering habitat may be an important limiting factor for fish populations; Solazzi et al. (2000) concluded that overwintering habitat limited coho, steelhead, and cutthroat trout abundance in two coastal Oregon streams.

Lakes may function similarly as off-channel habitats, by providing overwinter habitat to salmonids. Over-wintering juvenile coho in the Keogh River system (British Columbia) were more abundant in two small lakes and their adjoining streams than in the main river (Swales et al. 1988). Production of Oregon coastal native (OCN) coho salmon in southern Oregon coast lakes has been very important. Adult coho spawner densities in tributaries to these lakes on average are eleven times higher than those in coastal rivers (1970-2000). Adult spawner escapement into lake systems was especially high in earlier years, 1955-1973, when 20,000-40,000 adults were estimated from survey data (S. Jacobs, pers. comm.[3]; PFMC 1998). In recent decades, several factors may have reduced salmonid habitat quality in coastal lakes. Exotic game fishes have been introduced to these lake habitats, and may be salmonid predators (Dambacher et al. 1999). Other factors that may have reduced habitat quality are eutrophication (which can lead to nuisance aquatic plants), herbicide use, and biological control measures (Dambacher et al. 1999).

"Wall-base" channels have been shown to be another important habitat for overwintering juvenile coho salmon. Wall-base channels flow across a terrace or floodplain, and tend to be adjacent to a valley wall (Peterson and Reid 1983). They often form from abandoned channel meanders, have silt substrates, and drain small areas (>50 ha; Peterson and Reid 1983, Cederholm and Scarlett 1991). Skeesick (1970) first described the use of this type of channels by juvenile coho salmon in the Wilson River (Oregon). Wall-base channels have been shown to contribute significantly to smolt production in some rivers of the Pacific Northwest; Peterson and Ried (1983) estimated that 20-25% of the annual smolt production in the Clearwater River (Washington) comes from wall-base channel habitat.

Chinook salmon also seasonally use off-channel habitat in large rivers systems (Cederholm and Scarlett 1988). Bradford et al. (1990) found that chinook also use backwater habitats in the lower Willamette River. Bayley and Baker (2000) reported that juvenile chinook invaded floodplain ponds along the Willamette River and attained larger sizes than most juveniles over one year of age in the river's mainstem. Both wild chinook and cutthroat trout utilize these restored gravel pits along the Willamette River, especially in the winter and early spring (Bayley and Baker 2000).

Most off-channel habitats in the floodplains of large rivers, such as the Willamette River, have been lost (Sedell and Frogatt 1984, Gregory et al. 2002c). As a result, the importance of the numerous slow water habitats that once existed and were available to rearing salmonids is not completely known. However, in a study that contrasts salmonid production in two adjacent river channels of the Sacramento River (California), Sommer et al. (2001) reported that a primary broad floodplain (the Lolo Bypass) is a better rearing and migration habitat for juvenile chinook salmon than the adjacent free-flowing and heavily channelized Sacramento River. Their study indicates that growth rates, feeding success, and perhaps survival were higher in the floodplain than in the river. One reason for this difference may be because of the channel modification in the lower Sacramento River. USFWS (2000) showed that juvenile chinook densities along constrained, riprapped banks of the Sacramento River were only about one-third of those along natural banks, many of which had large wood, fallen trees or root wads.

Mainstem rearing habitat may currently be more important to coho salmon as a consequence of decreased availability of off-channel habitat (Beechie et al. 1994, Pess et al. 1999). For the Skagit River (Washington and British Columbia), Beechie et al. (1994) calculated that mainstem and associated off-channel habitats provided for 16% to 72% of the basin's total smolt production and concluded that a better estimate of the seasonal use of the mainstem by coho salmon would allow a better evaluation of limiting factors and, consequently, a more focused strategy for habitat restoration and recovery. Mainstem rearing habitat may be important to other salmonid species as well; ODFW biologists often observe juvenile salmonids in lower reaches of Willamette River tributaries (S. Mamoyac, ODFW South Willamette Watershed District, unpublished data).

The importance of small and intermittent streams to salmonids should not be underestimated. Intermittent streams can provide overwintering habitat to rearing salmonids. Summer steelhead were found to overwinter in streams that are intermittent in the summer in the Oregon Coast Range

[3] Jacobs, S. Personal Communication, 2001. Oregon Department of Fish and Wildlife. Corvallis, Oregon. http://www.orst.edu/Dept/ODFW

(Everest 1973). Likewise, rearing coastal cutthroat trout in Washington were found to be more common in small than large streams on Vancouver Island (Rosenfeld 2002). In western Oregon, ODF surveys have found cutthroat trout to be more common than expected in small and intermittent streams along valley margins (T. Lorensen, pers. comm.[4])

Linkages between upland tributaries, lowland rivers and estuarine ecosystems are crucial to the completion of complex anadromous salmonid life histories of anadromous salmonids (Frissell et al. 1993, Ward and Stanford 1995). Lowland rivers provide connectivity between habitats. The examples provided above demonstrate this pattern for coho and chinook salmon. Likewise, steelhead and cutthroat trout utilize Oregon's lowland rivers as migratory pathways, and have complex life history patterns that may involve multiple migrations per individual. A fraction of summer and winter steelhead are repeat spawners, returning to the ocean after spawning (Chapman 1958; Lindsay et al. 1991; K. Kenaston, ODFW, Corvallis, OR, unpubl. data). The Willamette system supports cutthroat trout with a "fluvial" life history pattern: individuals undergo in-river migrations between small spawning tributaries and main river sections downstream (e.g., Dimick and Merryfield 1945, Nicholas 1978, Moring et al. 1986).

Mortality from predation during downstream migration of juveniles and upstream migration of maturing fish can represent a major loss in salmon production (Larsson 1985). At times, predation from birds, mammals and other fishes can be intense (IMST 1998, Roby et al. 1998). Large wood, undercut banks, complex floodplains and channels, and riparian and aquatic vegetation, create complex habitats that provide refuges from predators for salmonids during these transitional periods. Therefore, from a landscape perspective, maintaining habitat complexity in lowland streams is critical to the completion of salmonid life histories.

Finally, Oregon's lowland rivers and streams provide important spawning habitat for several salmonid species. Chum salmon, in particular, spawn in mainstem rivers and lower reaches of tributaries. Juvenile chum then migrate immediately into estuaries (Salo 1991). Fall chinook enter fresh water days or weeks before spawning, and spawn in lower reaches of mainstem rivers or tributaries; coho may spawn in either lower or upper reaches of streams (Groot and Margolis 1991).

Salmonid Habitat Use in Estuaries

Here, we document the importance of estuaries to anadromous salmonids. Modifications to estuaries are discussed in Question 2, and estuary restoration is discussed in Question 5. Estuary conditions are particularly important because all anadromous salmonids from a basin must pass through a single estuary at least twice during their life cycle. If estuarine conditions are not favorable, populations of all anadromous salmonids within a basin could be impacted.

Different species and runs of Pacific salmonids have different behavioral patterns and life history strategies that affect estuary utilization. Estuaries may be used for rearing and may provide a productive foraging environment for juvenile salmonids before they enter the ocean. Alternately, they may simply serve as a corridor to the ocean for out-migrating smolts.

Estuarine habitats, including marshes, forested swamps, eelgrass beds, mudflats, and tidal channels, are important to the life cycles of anadromous salmonids. Juvenile salmonids often utilize estuaries as rearing areas, but preferences vary with life history types and age of juveniles as they pass along the estuary gradient. Low energy, off-channel areas and flooded marshes (tidal channels, backwater sloughs, marshes, and swamps) appear to be important habitats. These slow and backwater habitats in estuaries are sites for the production and accumulation of organic matter that forms the basis for a

[4] Lorensen, T. Personal Communication, 2002. Oregon Department of Forestry. Salem, Oregon.

macrodetrital food web, providing food for juvenile salmonids (e.g., Sibert et al. 1977). Lowland marshes in the brackish zone of estuaries are important habitat for salmonids as refuge and as feeding areas, while the fish adapt to a saltwater environment where they will spend most of their adult life (Iwata and Kotamtsu 1984, Macdonald et al. 1988, Cornwell et al. 2001). Individual fish may use multiple estuarine habitats throughout the day; for example, juvenile chum salmon disperse throughout the estuary, but congregate in the upper inter-tidal area at the fringe of marshes during high tide and retreat to tidal channels at low tide (Healey 1982, Pearcy et al. 1989). Simenstad et al. (2000) concluded that anadromous salmonids have evolved life history strategies that depend on the structure and scale of the diverse estuarine landscape rather than habitat sites.

Residence times in estuaries vary by species, life history type, age, size, hydrologic conditions, and time of year. Among anadromous salmonid species, chum salmon and sub-yearling (ocean-type) chinook are most dependent on estuaries. They move into estuaries at a small size and spend weeks – even months – feeding and rearing (Myers 1980, Healey 1982, Kjelson et al. 1982, Groot and Margolis 1991). Sub-yearling chinook salmon may spend up to five months in Oregon's estuaries, while feeding and adapting to a salt water environment before migrating to the ocean (Nicholas and Hankin 1988). Sea-run cutthroat trout also use coastal estuaries extensively for rearing and feeding, and may spend considerable time in the estuary (Giger 1972, Pearcy 1997). Yearling coho, chinook, and steelhead smolts generally migrate rapidly through estuaries at a relatively large size after rearing a year or more in fresh water.

Life history types within a species may have varying estuarine use patterns that are important to survival. Juvenile chinook demonstrate a great deal of variation in the temporal and spatial distribution of juveniles in estuaries. For example, Reimers (1973) distinguished five life history types of juvenile chinook in the Sixes River Estuary (Oregon). The life history type that grew rapidly in the estuary during the summer and migrated into the ocean in the autumn had the highest survival and adult returns among the five life history types. Reimers (1973) suggested that this indicates the importance of estuarine rearing to subsequent survival. Similarly, Nicholas and Hankin (1988) concluded that optimal survival of juvenile chinook salmon along Oregon coastal rivers was achieved by juveniles that entered estuaries in late summer and early fall, and that the extended estuarine rearing provided a survival advantage.

Coho salmon are a good example of within-species variation in estuarine habitat utilization. Most coho migrate to the ocean as yearlings, but some migrate into estuaries to rear as sub-yearlings (Tschaplinski 1988, Miller and Sadro 2000). Cornwell et al. (2001) reported that coho often enter the Salmon River Estuary (Oregon) in their first six months of life. They found that juvenile coho (and chinook) used marsh channels from February through July or August. Among surviving adult coho salmon, as many as 18% had scale patterns indicative of rearing in the estuary as sub-yearlings. Therefore, this may be an important coho life history type, especially if emigration is caused by a lack of good freshwater overwintering habitat for sub-yearlings.

Research in South Slough (Coos Bay, Oregon) further demonstrates that estuaries can provide important rearing habitat for multiple coho life history types. Based on catches in a fish trap located in the upper estuarine portion of Winchester Creek (a tributary of South Slough), Miller and Sadro (2000) found at least three life history types of coho salmon—age-0 fry that entered tidewater in the spring as fry, juveniles that entered as pre-smolts in the fall and winter, and age-1 smolts that entered in the spring (Figure 4). Age-0 fry in a newly restored marsh in the upper estuary had growth rates almost double that of fish in the upper watershed during the same period. Consequently, coho that enter the estuary as fry may migrate to the ocean as sub-yearlings or rear in the estuary for a year before outmigration. This information confirms that coho sub-yearlings utilize estuaries with some residing in tidal habitats for at least seven months (B. Miller, pers. comm.[5]). Bottom (pers. comm.[6]) found evidence of estuary rearing sub-yearling coho in adult spawners, suggesting that this type survives to spawn.

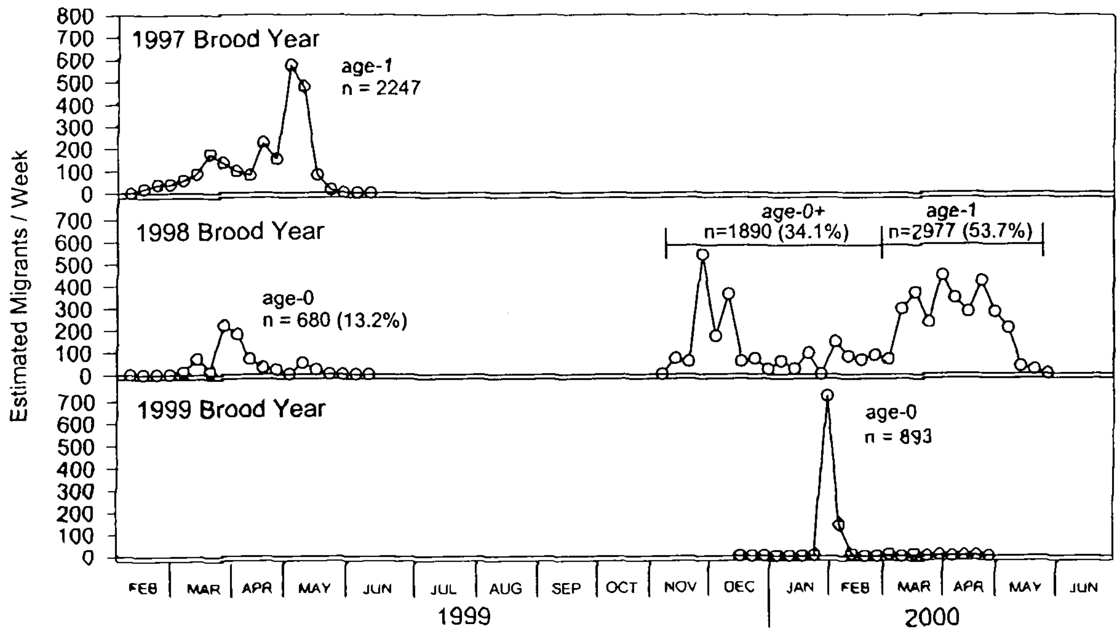

Figure 4. Estimated number and timing of outmigrating juvenile coho for the 1997 brood year (age-1 only), 1998 brood year, and 1999 brood year (age-0 only) in Winchester Creek, Coos Bay, Oregon (Miller and Sadro 2000).

Estuarine residence times may also vary between hatchery fish and offspring of naturally spawning fish. Cornwell et al. (2001) found that hatchery coho and chinook smolts were larger than naturally produced salmon and tended to migrate rapidly through the estuary to the ocean. Few utilized off-channel, restored marshes. Thus, there may be "excess" rearing capacity for wild salmonids in estuaries where large hatchery fry or smolts are released that migrate rapidly through the estuary. Likewise, Levings et al. (1986) found that wild chinook fry used the Campbell River estuary (British Columbia) about 40 to 60 days, whereas larger hatchery fry resided in the estuary only about half as long.

Several studies have evaluated the importance of estuaries for salmonid survival by experimental releases of smolts in freshwater, estuaries, and offshore waters. Although results were equivocal, most studies concluded that estuarine residence enhanced subsequent survival compared with direct ocean releases (Solazzi et al. 1983, Macdonald et al. 1988, Levings et al. 1989). One of the reasons given for better survival in estuarine habitats is reduced predation. Off-channel refugia and in-channel habitats such as large logs, root wads, deep pools, and vegetation can provide refuge from predators (McCabe et al. 1983, Macdonald et al. 1988, Levy et al. 1989, Simenstad et al. 1992, Gregory and Levings 1996). These structural features also may provide refuge from strong tidal and river currents (e.g., NMFS 1999). Smolt abundance in Carnation Creek (British Columbia) and its estuary was positively correlated with large wood, supporting the need to retain and manage large wood for smolt habitat (McMahon and Holtby 1992). The functional role of wood in estuaries is not

[5] Miller, B.A. Personal Communication, 2001. Oregon Department of Fish and Wildlife. Charleston, Oregon.
[6] Bottom, D. Personal Communication, 2001. Northwest Fisheries Science Center, National Marine Fisheries Service. Newport, Oregon.

completely known, although it is assumed to serve a similar role as in freshwater streams (McMahon and Holtby 1992).

Estuarine rearing by juvenile salmonids may be closely related to habitat conditions upstream, in mainstem or tributary reaches. Juvenile salmon may be forced to move from rivers downstream into estuaries, where air temperatures are cooler along the coast and where coastal fog and tidal mixing with ocean water lowers estuary temperatures (Reimers 1973, Healey 1980, Nicholas and Hankin 1988). For example, seaward migration of sub-yearling chinook salmon smolts in the South Umpqua River (Oregon) was earlier when spring water temperatures were high (Roper and Scarnecchia 1999). In the Klamath River (California), Wallace and Collins (1997) found more estuarine rearing of sub-yearling chinook in a low-flow than a high-flow year, possibly because of high temperatures in the mainstem and better, cooler rearing conditions in the estuary. Kjelson et al. (1982) reported that survival of ocean-type (fall run) chinook in the Sacramento River delta (California) was inversely related to water temperature and directly related to flow.

Estuaries serve as important migration corridors for returning mature salmonids. Returning adult salmon, steelhead, and sea-run cutthroat trout spend varying lengths of time in estuaries depending on the species and environmental conditions. In summer and autumn, stream temperatures rise in main river channels and river flow is often low. Therefore, upstream migration of maturing salmonids may be delayed, and estuaries may serve as a thermal refuge for returning adults. Sea-run cutthroat trout reside in estuaries for weeks during summer and autumn, waiting for a freshet and cool water temperatures before upstream migration (Giger 1972).

Comparison of Lowland Systems in Oregon with Less Modified Systems

Historically, how important were lowland river ecosystems to salmonid production in Oregon? Defining historical conditions and how changes in these conditions have affected salmonid production is problematic because most river assessments occurred after major human impacts. This is especially true with highly altered lowland river systems and estuaries (Maser and Sedell 1994, Gregory and Bisson 1997, Bisson et al. 1997), and few relatively unaltered reference areas are available in Oregon. However, studies of reference areas outside of Oregon demonstrate the important contribution of lowland river, stream, and estuary habitat to salmonid productivity.

Some large lowland rivers in Pacific Northwest wilderness areas and National Parks remain relatively intact. In a study of pristine, large coastal rivers in the Olympic National Park (Washington), Sedell et al. (1983, 1984) provided important insights into salmonid habitats in relatively unaltered coastal rivers. They found that virtually all salmonid rearing in the South Fork of the Hoh River occurs in off-channel river habitats and tributaries. This large river had many fallen trees in the channels, and habitat complexity was high because of the numerous side-channels and sloughs. In the South Fork Hoh River and Queets River, large wood was important in all habitats regardless of stream size; large, wood-capped side-channels had eight times the coho salmon densities as side-channels without large wood (Sedell et al. 1983, 1984).

The Kamchatka Peninsula of eastern Russia provides a more distant reference area. The Kamchatka Peninsula is within the range of Pacific salmon, and supports a similar range of salmonid species as the Pacific Northwest. The vegetation on the peninsula is similar to the Pacific Northwest, including coniferous and deciduous vegetation. The lowland rivers of the peninsula are in pristine condition; numerous side-channels and backwaters provide productive and diverse rearing habitats, which support many life history types of salmonids (Stanford, pers. comm.[7]). These lowland rivers are

[7] Stanford, J.A. Personal Communication, 2001. University of Montana, Missoula, MT.

physically complex, with dynamic channels dissecting expansive floodplains and forests, which form a corridor along the river. The floodplains are a mosaic of channels of varying ages, with flows controlled by deposition of large wood and gravel. These floodplains were "full of juvenile salmonids," of six different species. Coho salmon were observed spawning in middle reaches of the floodplain, and the active floodplain contained many redds (Stanford, pers. comm.[4]).

Lost Production from Lowland Systems

Based on historical cannery records, harvest records, and current escapement, the biomass of salmonids returning to rivers of the Pacific Northwest was estimated to be approximately 10 to 20 times less today compared with the biomass prior to EuroAmerican settlement (Gresh et al. 2000), indicating that ecosystems that included salmonids were historically much more productive. The current potential production of coho in Oregon's coastal rivers has been estimated to be about one-half that of the early 1900s (Lichatowich 1989). Chinook escapement has increased since the 1900s, probably reflecting destruction of chinook habitats prior to 1900, followed by gradual recovery.

Surveys conducted by the General Land Office in the 1850's provide a detailed source of information on land (vegetative cover) and rivers (location, configuration) throughout Oregon (Gregory et al. 2002c). However, historic data on fish distribution and abundance are extremely scarce. Some of this information may remain scattered throughout district files, and has not been summarized (C. Cooney, pers. comm.[8]). Extensive fish distribution and habitat surveys were not conducted in the Pacific Northwest until the 1940's (McIntosh et al. 2000), after major human impacts had been initiated, including logging, fisheries, and dam installation. These surveys were also limited in that they were mostly conducted in summer, and emphasized spring chinook habitat (McIntosh et al. 2000). In western Oregon, most of the annual fish counts and fish surveys conducted by ODFW were instituted in the 1950s or after.

Because of the complexity of the relationships and lack of data, information demonstrating causal relationships between habitat modifications and salmonid production declines is scarce. In Question 2, we detail changes in lowland habitats since EuroAmerican settlement. Here, we briefly summarize observed correlations between declines in salmonid productivity and anthropogenic changes to low elevation reaches, floodplains, mainstem rivers, and estuaries of the Pacific Northwest.

The decline in salmonid productivity in Oregon can be attributed to a combination of confounding factors, including over-harvest, habitat alteration, migration barriers, variable ocean conditions, and hatchery practices (Nehlsen et al. 1991). However, the magnitude and duration of the decrease implicates area relationships with decreases in spawning and rearing habitat quality in lowland rivers since EuroAmerican settlement. Approximately 90% of the declines in Pacific salmon stocks are thought to be related to habitat degradation (Nelsen et al. 1991, Gregory and Bisson 1997). Two major lowland land uses, agriculture and urbanization, have been associated with less healthy salmonid stocks of coho, winter steelhead, and summer chinook (Mrakovcich 1998).

Low-elevation, low gradient stream reaches were some of the most productive streams in the Pacific Northwest prior to EuroAmerican settlement (Beechie et al. 1994, Lichatowich et al. 1999, Solazzi et al. 2000). Solazzi et al. (2000) concluded that prior to EuroAmerican settlement, the largest number of juvenile coho salmon probably overwintered in low elevation Coast Range streams, in valleys that are now mainly devoted to agriculture. However, few high quality lowland stream reaches (with habitat that could provide refugia and support good salmonid production) were found in random summer habitat surveys of watersheds in western Oregon by ODFW during 1998 and 1999 (Thom et

[8] Cooney, C. Personal Communication, 2001. Oregon Department of Fish and Wildlife, Corvallis.

al. 1999, Thom et al. 2000). These surveys reported that lowland streams on private, non-forest (largely agricultural) lands had poorer conditions than those on state, federal, or private lands used mainly for timber production. Streams on private, non-forest lands were characterized by a lack of riparian conifers, slightly higher fine sediments, lower volumes and numbers of pieces of large wood, lower densities of deep pools, and lower levels of stream shading than lands primarily managed for timber production. In unconstrained (wide valley floor) streams, only 13 of 55 reaches had high quality habitat (Thom et al. 1999).

The importance of lowland rivers for salmonids has been documented in several studies from the Pacific Northwest. Some of the best evidence of correlations between production declines and habitat degradation comes from studies of large rivers in Washington. Beechie et al. (1994) estimated that hydromodification (or altering hydrology) by diking, dredging, ditching, and draining of ponds of the Skagit River basin in Washington reduced coho smolt production during the summer by 24% and during the winter by 34%. Pess et al. (1999) estimated that winter coho smolt production is about one-third of that prior to EuroAmerican settlement in the Stillaguamish River, due to the elimination of off-channel habitats. Hydromodification accounted for most of the loss of both summer and winter coho smolt production in all habitat types on both the Skagit (Figure 5) and Stillaguamish Rivers (Beechie et al. 1994, Pess et al. 1999, respectively). The major loss of sloughs and off-channel habitat was caused by diking to protect land for agriculture, rural residences, and urban uses. Blockages of culverts preventing fish passage accounted for the second largest decrease in coho salmon smolt production. Forestry activities accounted for a small proportion of the total losses in smolt production.[9]

[9] Note: Culverts may be installed as a part of forest operations, but are considered separately by Beechie et al. (1994).

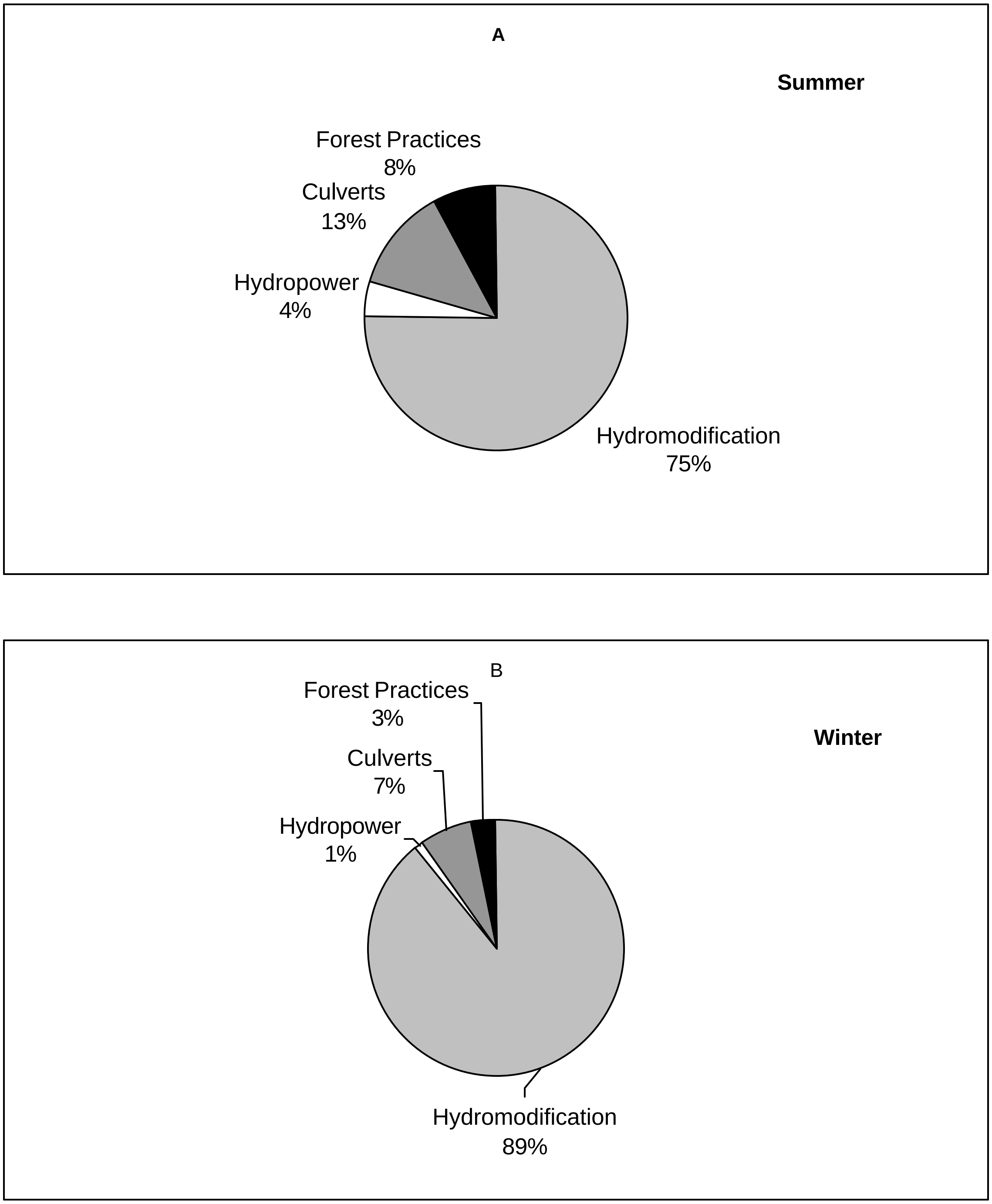

Figure 5. Proportion of total loss in estimated coho salmon smolt production resulting from hydromodification, hydropower, culverts, and forest practices throughout the Skagit River basin for (A) summer habitats and (B) winter habitats (Beechie et al. 1994).[5]

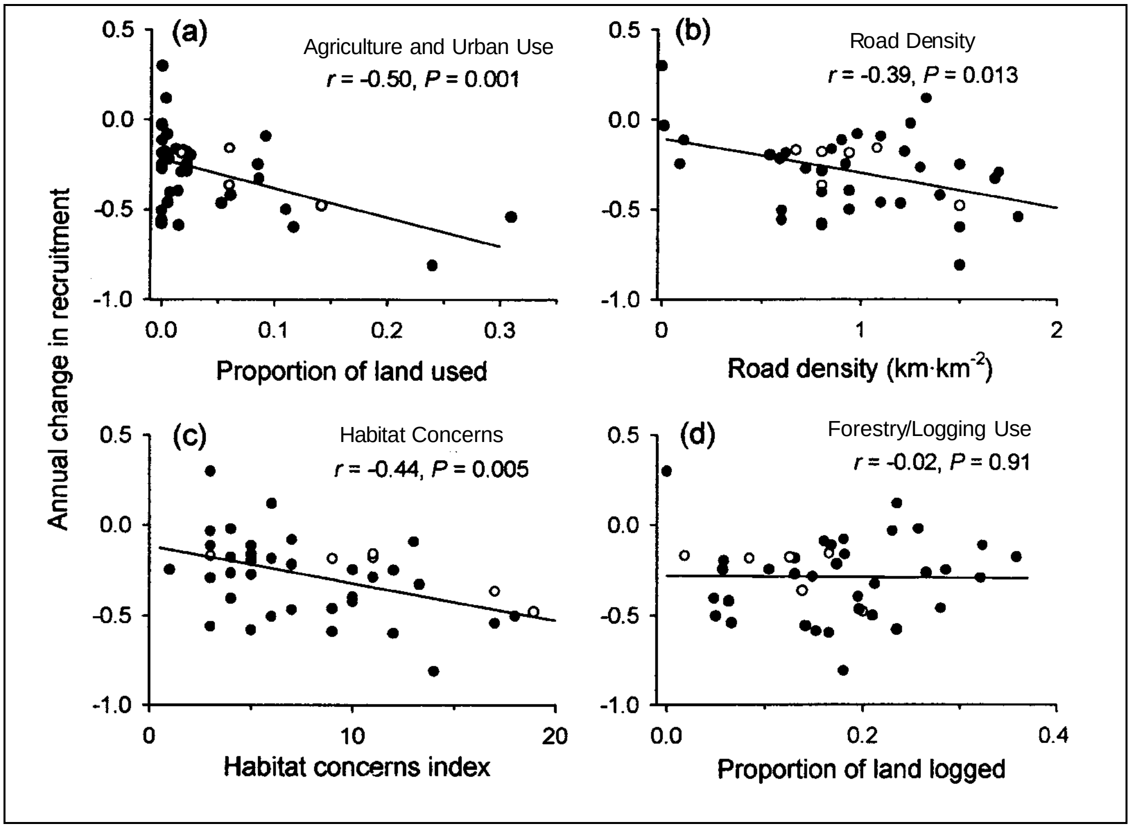

Figure 6. Relationship between the instantaneous average annual rates of change of coho salmon recruitment (1988-1998) and four indices of land use for 40 Thompson River (British Columbia) watersheds (Bradford and Irvine 2000).

In the Oregon Coast Range, Nickelson et al. (2001) observed an estimated four-fold reduction in coho salmon smolt capacity at a low-elevation agricultural site, compared with adjacent state-owned forest land. On the agricultural site, landowners (over many generations) had removed large wood and streamside vegetation, and actively channelized the stream flowing through the site. Bradford and Irvine (2000) found rates of decline of coho salmon in the Thompson River (British Columbia) were correlated with agricultural land use, road density, and stream habitat status, but not with the proportion of recently logged land (Figure 6). Hulse et al. (2002) suggest that changes in lowland reaches of the Willamette River have resulted in poor habitat quality for salmonids, particularly cutthroat trout. Overall, losses of salmonid production correspond with modifications to lowland rivers of the Pacific Northwest and reductions in habitat quality. No quantitative estimates of salmonid productivity losses due to estuary modification are available.

Equally important, the life history diversity of populations that utilized lowland aquatic habitats has probably been reduced because of habitat modification and loss, such as loss of coho salmon overwintering habitat (Miller and Sadro 2000, Bottom et al. 2001). Another example is how the life history diversity of chinook salmon has been affected by unfavorable conditions in mainstem rivers. Downstream migration of juvenile spring chinook in the Willamette River occurs in three overlapping pulses during the spring, summer, and fall. They slowly migrate while feeding and growing until they reach the ocean. However, few juveniles are now observed migrating during the summer, probably because of degraded conditions and high temperatures in the lower river. Hence, they may be restricted to upstream refugia during the summer (Lichatowich 1999a). Similarly, Nicholas and Hankin (1988) believe that migration and rearing of sub-yearling juvenile chinook salmon in Oregon's coastal rivers during the summer is related to water temperature, with "cooler" rivers supporting juveniles for a longer period of time before migration into estuaries. Therefore, life history types that rear in the mainstem rivers may not be expressed if rivers are too warm or degraded.

Evidence suggests that reductions in life history diversity may also have occurred in estuaries. In the Columbia River Estuary, sub-yearling chinook salmon occupied shallow water habitat nearly all year in the early 1900s (Rich 1920), but have shorter residence durations today (Figure 7). This suggests that the expressed population structure of sub-yearling chinook salmon has been greatly simplified (Bottom et al. 2001). Corresponding losses of genetic diversity may be a larger impediment to recovery and long-term adaptation to changing climatic conditions than loss of productivity (Levin and Schiewe 2001). However, several studies in Oregon demonstrate utilization of restored marshes by diverse life history types of juvenile salmon (Miller and Sadro 2000, Cornwell et al. 2001). Therefore, as we discuss in Question 5, habitat restoration may be a means to help restore life history diversity.

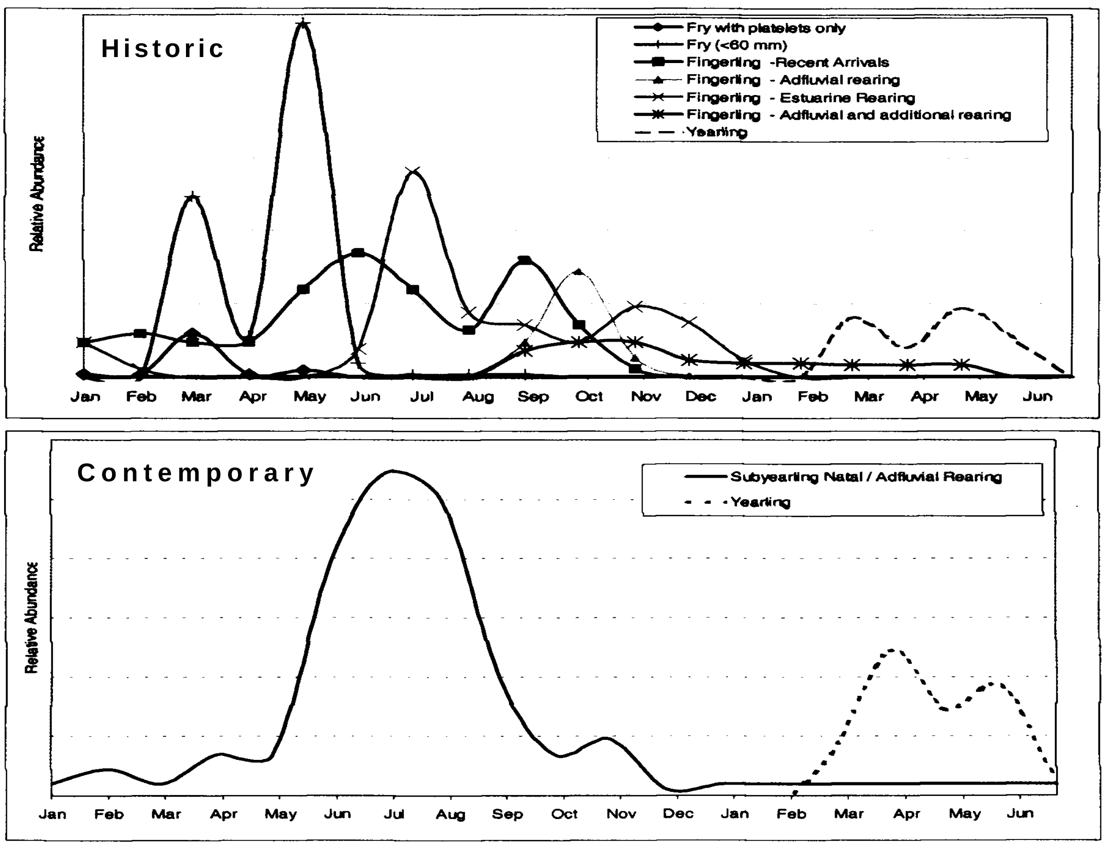

Figure 7. Historical and contemporary early life history types for one brood year of chinook salmon in the Columbia River Estuary. Historical timing and relative abundance were based on historical sampling throughout the lower estuary (Rich 1920). Contemporary timing and relative abundance were reproduced from Dawley et al. (1985) sampling at Jones Beach.

Findings and Conclusions

Findings

Lowland river systems and estuaries provided diverse and productive habitats for rearing juveniles, spawning adults, and migrating juvenile and adult salmonids.

Life History Diversity of Salmonids

Salmonid species have various life history strategies. Traits that vary among species and individuals include:

- Growth rates,
- Time and age of smolt migration,
- Age and size of fish at spawning
- Date of spawning, and
- Number of times an individual reproduces.

Differences in salmonid life history phenotypes tend to be plastic, within the limits established by the genotype.

Salmonid Habitat Use in Lowland Rivers

Lowland rivers and streams provide:

- Spawning habitat for chum, fall chinook, and coho salmon as well as resident salmonids.
- Feeding habitats for rearing juvenile salmonids,
- Refuge from high flows for overwintering juvenile salmonids,
- Connectivity among habitats used by different phases of the salmonid life cycle, and
- Habitat complexity that may protect migrating salmonids from predation.

Complex off-channel and backwater habitats in lowland rivers-- alcoves, sloughs, beaver ponds, and side-channels – are important to rearing salmonids. These habitats are often found in geologically unconstrained reaches of lowlands, and are particularly used by overwintering juvenile coho salmon and chinook.

Juvenile salmonid movements may be driven by temperature and flow, causing juveniles to move into lowland reaches in the summer.

Mainstem habitat is used by rearing salmonids, and can be particularly important to chinook salmon during summer months.

Salmonid Habitat Use in Estuaries

Estuarine habitats utilized by anadromous salmonids include marshes, forested swamps, eelgrass beds, mudflats, tidal channels, and main channels.

Slow and backwater habitats in estuaries (tidal channels, backwater sloughs, marshes, and swamps) are sites for the production and accumulation of organic matter that forms the basis for a macrodetrital food web, providing food for juvenile salmonids.

Diverse estuary habitats are important to anadromous salmonids because they provide:

- Productive foraging environments for juvenile salmonids before they enter the ocean,
- Refuges from predation,
- Refuge from strong tidal and river currents,
- Habitats of intermediate salinity for juvenile salmonids transitioning from fresh water to the ocean,
- Migration corridors for adult salmonids returning from the sea, and
- At times, cooler water temperatures than mainstem lowland rivers.

Residence times in estuaries vary by species, life history type, age, size, hydrologic conditions, time of year, and between hatchery and wild fish.

Different species utilize different portions of watersheds. However, linkages between upland tributaries, lowland rivers, and estuarine ecosystems are essential to completion of the complex life histories of anadromous salmonids (Frissell et al. 1993, Ward and Stanford 1995).

Lost Production from Lowland Systems

Historically, low-elevation habitats tended to be highly productive areas for salmonids.

Unlike land cover data, historic data on fish distribution and abundance are extremely scarce. Historical records that have not been adequately evaluated should be analyzed and summarized.

Studies suggest that the loss and degradation of complex lowland aquatic habitats has been accompanied by a decrease in total salmonid productivity.

Some salmonid life history types that utilized lowland habitats no longer significantly contribute to overall salmonid production.

Conclusions

Lowland habitats likely contribute significantly to overall salmonid productivity. We base this conclusion on historical information, data from less modified lowland river systems, and evidence that salmonid abundances in western Oregon lowlands were much greater in the past.

Habitat modification and land use practices have impaired functions that support productivity in lowland rivers and estuaries.

Because many phases of the salmonid life cycle are dependent on lowland and estuary habitats, protection and restoration of these habitats is important for salmonid recovery.

Preservation of only sections of a watershed or basin may not be sufficient to maintain connectivity between habitats essential to the completing complex salmonid life histories (see further discussion in Question 5).

Some life history types may no longer be expressed in western Oregon lowland systems, probably because of loss of habitat used by these forms. Therefore, restoring habitat diversity in lowlands could be important to salmonid recovery by facilitating the re-establishment of diverse life histories.

There is a need for more extensive baseline data for western Oregon lowlands systems to evaluate:

- Current habitat conditions,
- Utilization of lowlands by salmonids, and
- Trends over time.

Question 2. How have conditions in western Oregon lowlands changed from conditions prior to EuroAmerican settlement?

Lowland river and estuary ecosystems have developed and evolved with natural disturbances, especially those involving flows of water, large wood, coarse debris, and sediment (Poff and Ward 1990, Reeves et al. 1995). Flow patterns shape the natural channels in lowland rivers and estuaries and influence the hydrological connectivity between riparian and aquatic habitats, thus affecting the aquatic ecosystem (Large et al. 1993). Human modification of these natural disturbances, flow patterns, and habitats is a fundamental concern because of the cumulative effects on ecosystem function and salmonid survival and productivity.

The assumption of the IMST is that historical conditions, on average, were more favorable for salmonids than conditions today (Hulse et al. 2002). This assumption is appropriate for managing most of Oregon's terrestrial and aquatic systems, although the extent to which it can be applied is often a matter of policy and determined in part by societal values. Using historic patterns as a guide, a link between fish habitat requirements and landscape patterns and processes can be established.

In this section we will review 1) important physical processes that shape salmonid habitat in lowland rivers, floodplains, and estuaries, and 2) changes in the conditions of these ecosystems since EuroAmerican settlement (approximately the 1840's). As we noted in the answer to Question 1, extensive surveys conducted by the General Land Office in the 1850's provide a sound basis for assessing changes in land and aquatic conditions. However, data on salmonid distribution and abundance from that time period is scarce.

Lowland Rivers

Geomorphic and hydrologic processes

Geomorphic and hydrologic processes, particularly movement of water and sediments, shape rivers and streams in western Oregon lowland floodplains, tidal marshes, and estuaries (Large et al. 1993, Welcomme 1995, Church 1996). These processes have significant impacts on ecological functions and create and maintain a wide range of aquatic and riparian habitats (Beschta and Platts 1986, Large et al. 1993, Welcomme 1995). Streamflows and transported sediments interact with the channel bed and banks to shape channel form and are important for creating physical habitat for salmonids (Schumm 1971, Dunne and Leopold 1978, Beschta 1985, Beschta and Platts 1986, McNamara et al. 2000). In this section, we briefly describe some of the processes that are important to consider when protecting and restoring salmonid habitat in western Oregon lowland streams.

The geomorphic and hydrologic processes of rivers and streams are highly dependent on the context provided by geologic landforms, underlying geology (such as susceptibility of substrates to erosion), and climate (Gregory et al. 1991). Climate influences the frequency and magnitude of water moving through a basin. Western Oregon's lowland streams were historically characterized by peak flows in winter and spring associated with high winter rains and snowmelt (for streams and rivers draining the Cascades), and low flows in late summer and early fall. Changes to these historic flow regimes are discussed in Question 3.

River ecosystems are dynamic. Flows of water and sediment in rivers and streams are variable, and the variability is integral to the development of complex habitat for salmonids and other aquatic species. Variable flows are required to maintain river and stream channels and to transport sediments. These variable events can be classified according to magnitude and frequency: events of greater magnitude generally occur less frequently. "Bankfull" flows generally occur every 1.5 years (Dunne and Leopold 1978, Rosgen 1996). These flows distribute existing gravel and sediment within the channel, and are particularly important to shaping the form of channels.

Events of greater magnitude than bankfull can be considered flood events, occur less frequently, and generally involve movement of water over banks and onto the floodplain. The velocity of water that has flowed out onto the floodplains is lower than the velocity of flows that remain in channel (due to frictional drag and roughness associated with micro-topography, vegetation, and/or wood associated with the floodplain). Therefore, sediment deposition on the floodplain is enhanced. Approximately 80% of storms result in flows that could be classified as "30-year flood events" or smaller. These events may expose new gravel within the existing floodplain. The stability of banks under this magnitude of flow is important to consider when evaluating riparian areas (Elmore, pers. comm.[10]). If banks are not able to withstand flood events, salmonid habitat likely cannot be maintained. Rare events, occurring less often than once every 30 years, can make potentially dramatic changes channels and the floodplain. These events may cut new channels in the floodplain.

Lowland rivers usually have a low gradient and a broad floodplain. The lower gradient of lowland rivers is associated with lower water velocity than in upland rivers and streams, which results in deposition of fine sediments in the channel and on the floodplain (NRC in press). In western Oregon lowlands, most lowland rivers and streams are unconstrained by surrounding landforms, allowing for river meandering. River meandering is important for creating physical and ecological heterogeneity in alluvial valleys (Naiman et al. 2000). Stream channel migration, through lateral movement and periodic flooding, connects the active channel and the floodplain. Lateral channel migration deposits sediment in channel bars, on islands, and on the floodplain, creating sites for vegetation establishment (Rood et al. 1999; Rood and Mahoney 2000). Floodplains along rivers form a mosaic of geomorphic surfaces affecting patterns of riparian forest development (Scott et al. 1997, Dykaar and Wigington 2000). Historically, stream channel migration created complex off-channel habitat for salmonids in Oregon (Beschta and Platts 1986, Gregory et al. 1991, Hill et al. 1991, Welcomme 1995).

Interactions between rivers and their floodplains are significant for nutrient exchange, in addition to the dynamic processes that create physical habitat for salmonids (Healey and Richardson 1996). The importance of surface flooding to riparian ecosystems has been documented (Gregory et al. 1991, Decamps 1993, Naiman and Decamps 1997), as have nutrient dynamics between rivers and floodplains (Stanford and Ward 1988, 1992). Channel migration results in the addition of nutrients to aquatic systems from riparian and floodplain sources (Junk et al. 1989, Bayley 1995, Sparks 1995, Welcomme 1995).

Water storage is another important hydrologic function of lowland aquatic ecosystems. Natural riparian and floodplain wetlands collect and distribute flood flows, recharge groundwater aquifers, and store water for slower releases. If a river has developed a meandering pattern and a well-connected floodplain, the natural complexity of the river and floodplain slows flooding (Leopold et al. 1992). However, many hydrologic interactions between rivers and floodplains – such as surface-groundwater exchange and hyporheic exchange (occurring in the area under the stream channel and floodplain that is connected to the stream) – are not well understood (Stanford and Ward 1992).

Lowland rivers and flood plains are often, but not always, intimately connected to and influenced by streams in uplands. Smaller streams in upper reaches transport material such as large wood, and fine and coarse sediments down into lower reaches. Depending on the morphological conditions of the stream, transport is either in small steady flows associated with high flows, or in large pulses associated with floods. Larger streams in lower gradient portions of the watershed (i.e. in the lowlands) are areas of deposition and organic material processing, making them some of the most historically productive reaches for some salmonids (IMST 1999).

Alteration of lowland river conditions since EuroAmerican settlement

The first lands settled by Euro-Americans were low-elevation, unconstrained river valleys and areas surrounding estuaries, because the lands offered access to commercial waterways and were important for agriculture (Boule and Bierly 1987). Lowland ecosystems of western Oregon have been greatly modified and simplified by human activities associated with agriculture, timber harvest, urbanization, and transportation systems (Sedell and Froggatt 1984, Benner and Sedell 1997, Dykaar and

[10] Elmore, W. Personal communication. 2002. Bureau of Land Management, Prineville, Oregon.

Wigington 2000). This has resulted in a landscape fragmented by many land use activities, jurisdictions, and ownerships. As we describe below, human alterations to lowland river systems include:

- channelization,
- dredging and gravel removal,
- dam and reservoir construction,
- floodplain forest clearing,
- land conversion to agriculture (including wetlands and riparian forest), and
- large wood removal.

Other alterations associated with agriculture and other land uses include water diversions, increased inorganic nutrient input, and toxic chemical pollution, which are discussed in more detail in Question 3. Development on the floodplain, including buildings and roads, is another major alteration, which will be discussed in an upcoming report on urban and industrial land uses. As we discuss in this question and Question 3, these alterations have diminished aquatic habitat quality through:

- channel simplification,
- side-channel elimination,
- floodplain isolation,
- increased sedimentation,
- changes in flow (e.g., reduced flooding, tributary and wetland dewatering),
- water temperature increases,
- eutrophication, and
- barriers to fish passage.

Over the past 150 years, the landscape of western Oregon has undergone numerous changes, both in uplands and lowlands. The percentage of old growth forest has been shown currently to be below the historic range of variability (Figure 8; Wimberly et al. 2000, SOER Science Panel 2000). Humans have modified principal fluvial geomorphic processes of the Willamette River and other lowland river systems. These alterations have included changes in discharge, sediment supply and size, and bank form. The changes have impacted: the processes of sediment deposition that create landforms in the floodplain; the connections between the river, floodplain, and side-channels; and the amount of habitat available to floodplain and aquatic species (Dykaar and Wigington 2000).

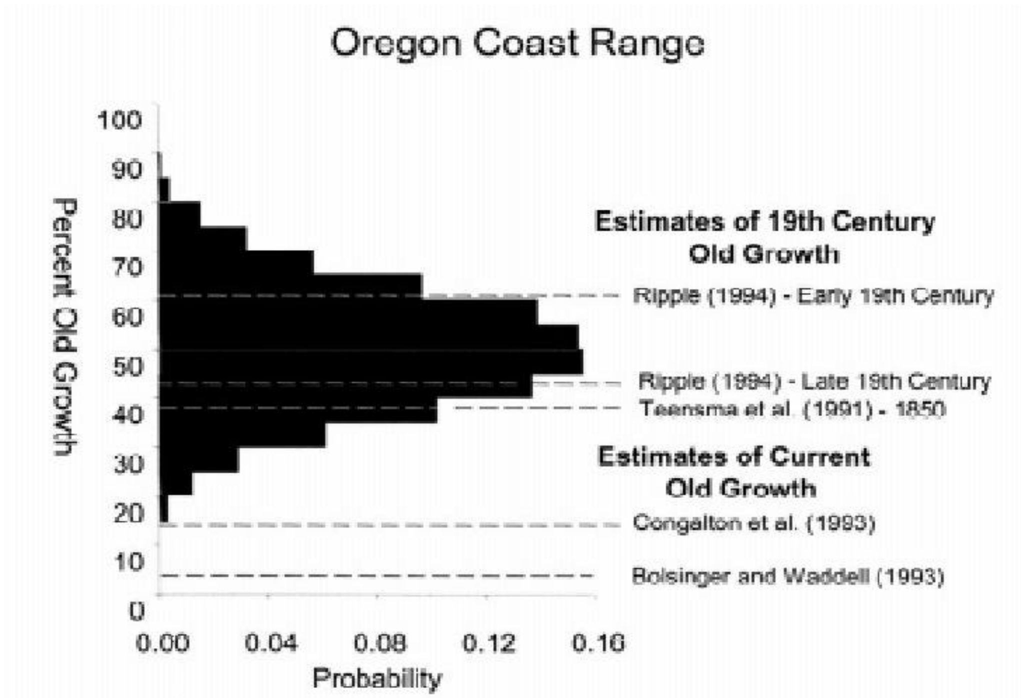

Figure 8. Simulated historical range of variability of old-growth conifer forest in the Coast Range for the last 3000 years. Reproduced from SOER Science Panel (2000).

Changes in the Willamette River since EuroAmerican settlement have been studied more extensively than changes in other lowland rivers in western Oregon. Much of the following discussion and the data presented focus on modifications to the Willamette River system (Table 3), including changes in floodplain and channel form and process and consequent effects on salmonid habitat. Many of these changes parallel changes that occurred in low elevation, unconstrained portions of the Willamette's major tributaries (e.g., the Clackamas, Marys, McKenzie, Molalla, Pudding, and Santiam Rivers), in major coastal rivers (e.g., the Coos, Rogue, Umpqua, Siuslaw, and Nehalem Rivers), and in smaller lowland stream systems of western Oregon in the interior floodplains and coastal tidal marshes.

Table 3. Summary of changes to aquatic systems in the Willamette Valley.

Parameter	Time period	Amount lost	Reference
Gravel bar and island area	1910 – 1988	80% decline in a 22.4 km section (between the confluence with the McKenzie and Harrisburg)	Dykaar and Wigington (2000)
	1850-1995	63.1% reduction (in island area between Portland and Eugene)	Gregory et al. (2002 a)
Length of river edge	1850 – 1995	25.8% reduction (between Portland and Eugene)	Gregory et al. (2002 a)
Emergent wetlands in Willamette Valley	1860 – 1995	57% reduction	SOER Science Panel (2000)
	1860 – 1997	450,000 hectare reduction	Gregory et al. (1998)
Snags removed in the Willamette	1876 – 1912	61 snags/km (upstream from Albany	Sedell et al. (1990)
	1870 – 1950	550 snags/km (upstream from Albany)	Sedell and Froggatt, (1984)
Length of river edge in riparian area	1854 – 1967	74% reduction	Sedell et al. (1990)
Riparian forest area			
Total length	1850 – 1990	72% loss	WRI (2001), Gregory et al. (2002 c)
Small lowland streams	1850 – 1990	40% loss	Gregory et al. (2002 c)
Major tributaries	1850 – 1990	65% loss	Gregory et al. (2002 c)

Channelization and floodplain simplification

Channelization is the process of changing and straightening the natural path of a waterway. Channelization converts rivers from complex, multi-channel, meandering paths to a simplified, narrow and deep channel, cutting off many side-channels and reducing the natural tendency of rivers to migrate laterally, eroding and depositing sediments (Sedell and Froggatt 1984, Sedell et al.1990, Benner and Sedell 1997). Some effects of channelization are illustrated in Figure 9.

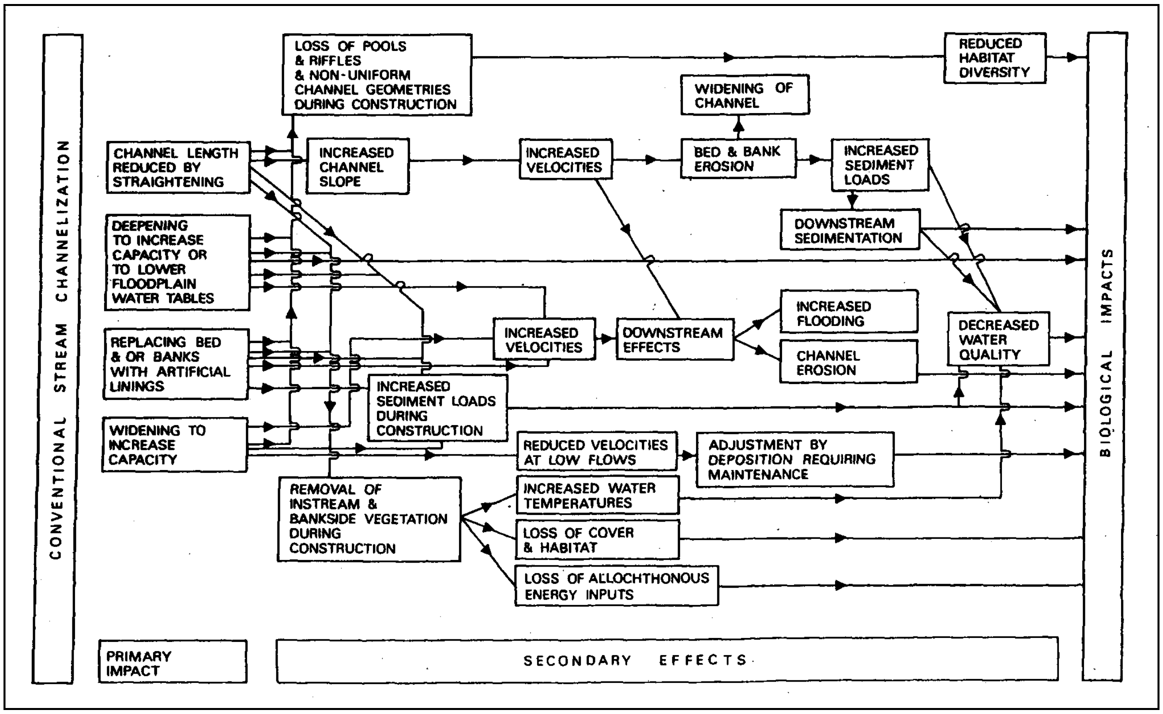

Figure 9. Effects of stream channelization (Brookes 1988, p. 24).

Lowland rivers of western Oregon have been actively channelized to facilitate more rapid runoff and reduce localized flooding. These changes also facilitate draining of floodplain wetlands to make them more suitable for agriculture, residential, and industrial uses. Additionally, longer channel sections can be made more navigable for shipping and transportation, as is the case with lower sections of the Columbia, Willamette, Coos, and Yaquina rivers. Channelization and bank stabilization protect farm, urban, and residential lands, as well as buildings and roads, on the floodplain. However, as we will describe, channelization often adversely affects lowland aquatic ecosystems.

Since 1854, channelization and other modifications have caused the Willamette River to become increasingly isolated from its floodplain (Keeler 1985, Hulse et al. 2002). Many of the first modifications to the river were made to make the river more navigable. Snags, sandbars, and rocks that formed rapids were removed. Sloughs, alcoves, side-channels, and chutes were closed to confine streamflow to the main channel through the installation of dikes and levees. Meanders were straightened to speed water flow in the channel.

Channelization may involve deepening the main channel in order to improve navigability or to increase flow capacity (Brookes 1988). Dredging is one means to deepen the channel. In the Willamette, dredge spoils were often dumped at the mouths and heads of adjacent small side-channels (Benner and Sedell 1997). Wing deflectors were also employed to deepen the channel by directing streamflow toward channel center.

Bank stabilization structures have also contributed to channelization and incision in lowland rivers of western Oregon. Revetments and riprap are common in many lowland rivers, including the Willamette. Revetments are usually made of stone and placed along banks. While revetments are present in other lowland rivers in western Oregon, the Willamette is probably more highly modified than other river systems. Gregory et al. (2002 d) estimate that 12% of the Willamette has revetments on one or both banks, and more than 35% of the bank is revetted in the lower river between Newberg, Oregon and confluence with the Columbia River (Table 4) The lower river, near Portland, has the greatest number of revetments, and the middle river contains the fewest revetments. In the upper Willamette, most of the revetments are adjacent to farm lands and are designed to prevent loss of agricultural land (Table 5; Gregory et al. 2002e).

Table 4. Percent of bank length revetted in the Willamette River (Gregory et al. 2002e).

Percent of River Length			
Reach	**Not revetted**	**One Side**	**Both Sides**
Columbia to Newberg	54.2%	10.2%	35.6%
Newberg to Albany	85.4%	13.5%	1.1%
Albany to Eugene	76.3%	19.0%	4.7%
River Total	73.5%	14.5%	12.0%

Table 5. Number of revetments in the Willamette River and the features they are designed to protect (Gregory et al. 2002e).

Revetments and Land Use					
	Number of Revetments Adjacent to:				
Reach	**Bare**	**Forest**	**Agriculture**	**Built**	**Total**
Columbia to Newberg	7	31	11	89	138
Newberg to Albany	4	39	44	30	117
Albany to Eugene	3	16	69	25	113
River Total	14	86	124	144	368

Even though nearly three-fourths of the length of the Willamette River has no riprap or bank revetments on either bank, some of the most important features of the river have been stabilized along 26% of the river's length (Gregory et al. 2002e). Sixty-five percent of meander bends are stabilized by revetments. Stabilization has eliminated the lateral migration of some of the most dynamic sections of the river, diminishing the river's ability to adjust bed and sediment erosion and storage in response to changes in streamflow magnitude and sediment supply (Gregory et al. 2002e). The interaction between the active channel and the riparian area, which occurs during lateral channel migration (channel meandering) and during floods, is an important phenomenon that creates complex, off-channel and side-channel habitat (Amoros et al. 1987, Gregory et al. 1991).

These changes in channel migration have contributed to reductions in riparian vegetation community complexity. The establishment of riparian vegetation is impaired when sediment deposition is reduced by confining flows to the main channel (Scott et al. 1997, 1998; Dykaar and Wigington 2000). Near Harrisburg (Oregon), in portions of the Willamette River where revetments limited channel migration, a remote sensing study revealed that forest cover and maturity increased and bare ground decreased (1939-1996; Gutowsky 2000). Gutowsky (2000) concluded that channel migration in the upper Willamette River ceased shortly after the construction of flood control dams and the installation of engineered structures to constrain the channel. This cessation in channel migration coincided with a shift in riparian vegetation from a mosaic of exposed soil, herbs, shrubs, and trees in

1939 to a more homogeneous landscape of mature riparian forests unaffected by channel migration (Gutowsky and Jones 2000).

Bare ground, scoured by lateral flows and peak flows and formed by sediment erosion and deposition, can provide important sites for native vegetation to establish. Riparian vegetation may also be removed directly when revetments are installed, reducing shade and the input of large trees. The erosive capacity of streamflow can be exacerbated because the large wood that protects stream banks from erosion has been reduced (Leopold et al. 1992, Coulton et al. 1996b). The effect of revetments on stream ecology and on salmonids is not well known, but Hjort et al. (1983) found that banks with revetments on the Willamette River, were associated with reduced diversity, species richness, and abundance of aquatic organisms compared to natural stream banks.

As a result of all these activities, the channel length of the Willamette River was dramatically reduced during the period between 1850 and 1990 (Figure 10; Table 6). The greatest changes were in the upper (southern) section of the river, between Eugene (at the confluence with the McKenzie River) and Albany (Gregory et al. 2002c). The upper two-thirds of the Willamette River (between Eugene and Salem) is geomorphically unconfined and flows through unconsolidated deposits (Hughes and Gammon 1987, Dykaar and Wigington 2000). Prior to urban and agricultural development along the river, this portion of the Willamette was a braided, gravel-bed river. The river had multiple channels that frequently shifted location, meandering through the floodplain (Sedell and Froggatt 1984). This is a common pattern in unregulated low-gradient rivers; the river channel and floodplain were intimately connected. The channel length between Eugene and Albany was reduced 45-50% between 1854 and 1975 (Sedell and Froggatt 1984, Sedell et al. 1990, Gregory et al. 2002c). For a subsection of this stretch, Benner and Sedell (1997) reported that 60-70% of channel length was lost from the complex section of the river between Eugene and Harrisburg (1854 - 1967; Benner and Sedell 1997). Similarly, Gregory et al. (2002 a) estimated that more than half of the lateral channels have been eliminated upstream from Harrisburg. However, all channel types have been reduced in area, including the main channel (Table 6).

Table 6. Percentage change in river area in the Willamette River between Portland and Eugene in comparison with 1850 (Gregory et al. 2002c).

	Percentage Change in Channel Length				**Percentage Change in River Area**				
	Primary	**Side and Secondary**	**Alcoves and Sloughs**	**Total**	**Primary**	**Side and Secondary**	**Alcoves and Sloughs**	**Islands**	**Total**
1895	-7.3	-0.9	-24.5	-13.8	12.3	-0.9	0.3	-22.1	9.5
1932	-7.1	-27.8	-21.8	-14.7	4.7	-46.5	-14.7	-35.5	-0.9
1995	-6.1	13.1	-57.7	-25.8	-13.3	-35.1	-55.6	-63.1	-22.3

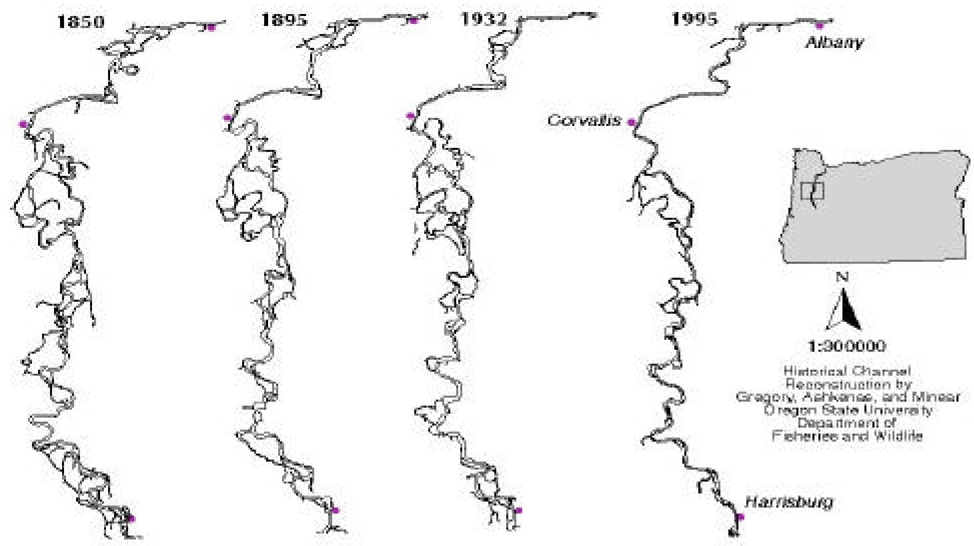

Figure 10.

Willamette River channel simplification between Harrisburg and Albany, 1850 to 1995 (S. Gregory, L. Ashkenas, and P. Minear, unpubl. data).

Sedell and Frogatt (1984) estimated that a significant decrease occurred in surface water volume of the Willamette because of reductions in meandering caused by revetments and reduction in the number of side-channels and sloughs. As a result, more water in the Willamette River system is conveyed in fewer, deep channels instead of moving through multiple, shallow side-channels and wetlands. This change in floodplain and channel morphology contributes to a decrease in groundwater recharge zones on the floodplain. Between 1850 and 1932, small floodplain tributaries, side-channels, and sloughs were eliminated, and a greater percentage of the river length and area (Table 7) have been concentrated in the main channel (Figure 10, Gregory et al. 2002c). These important off-channel habitats, refugia for aquatic biota during winter floods, have been greatly reduced in other lowland rivers as well. Because of this loss of off-channel habitat, low-flow habitats are now mainly found in the main channel (Gregory et al. 2002c).

Table 7. Relative length and relative area of channel features in the mainstem Willamette River between Portland and Eugene, 1850 through 1995 (Gregory et al. 2002c).

	% of Total Length of Channel Types			**Total Length**	**% of Total Area of Channel Types**				**Total Area**
	Primary (%)	Side and Secondary (%)	Alcoves and Sloughs (%)	Miles	Primary (%)	Side and Secondary (%)	Alcoves and Sloughs (%)	Islands (%)	Hectares
1850	51.2	7.8	41.0	355.0	35.2	1.6	8.9	54.2	16543.9
1895	55.1	8.9	36.0	305.8	42.8	1.7	9.7	45.7	15281.7
1932	55.8	6.6	37.6	302.7	45.9	1.1	9.5	43.5	13295.7
1995	64.8	11.8	23.4	263.5	55.0	1.1	7.1	36.0	9197.3

Channelization increases the rate of streamflow and bed scour, which contribute to channel incision (downcutting and channel deepening), increased bank erosion, and bank steepening (Klingeman 1973, Chen and Simons 1986, Nabb and Shankman 1997). For example, diking increases stream bank erosion by increasing water depth and flow velocities between dikes. Channelization also contributes to channel widening because the confined channel and higher banks concentrate streamflow within the channel, rather than allowing floodwater to spill onto the floodplain. Channelization and conversion from natural riparian vegetation continue into recent times (Frenkel et al. 1984).

Dams

Dams and reservoirs have been constructed on multiple major tributaries to the Willamette River. Dams, particularly flood control dams, reduce the magnitude of high flows, extend the duration of flooding, and can alter the entire hydrologic regime of rivers. The resulting modifications of channel form, function, and composition, have caused losses in the quantity and complexity of important salmonid rearing habitats (Sedell and Froggatt 1984, Large et al. 1993, McIntosh et al. 1994, Benner and Sedell 1997). In concert with revetments and dikes, the regulated flows of dams tend to reduce overbank flooding and channel meandering. This disrupts the interactions between lowland rivers and their floodplains, which are essential to supporting a diverse mosaic of riparian communities at various successional stages.

Dams may have altered the quantity of gravel inputs to lowland streams, by changing patterns of gravel transport. Gravel is largely transported as bedload during high flows and floods. Dam and reservoir construction have interrupted bedload transport in many river systems (Kondolf 1995). Dams (including reservoirs with low trap efficiencies for suspended sediment) trap bedload materials, preventing them from moving down stream. This results both in a loss of reservoir storage capacity and in the elimination of gravel supply to downstream reaches (Kondolf 1995). The inability to replenish gravels and sands that have been transported out of lower reaches under high flows and floods can result in the loss of spawning gravels for salmonids and alter communities of aquatic organisms dependent on substrate composition. Dykaar and Wigington (2000) measured an 80% decline in gravel bar and island area between 1910 and 1988 within a 22 km section of the Willamette River, and they attribute this to the effects of dams, riprap, logging, and gravel mining. The effects of dams on lowland rivers are further discussed in the Water Quantity and Flow Modifications section of Question 3.

Reductions in floodplain nutrients and loss of wetlands

Channelization has isolated western Oregon rivers and streams from the surrounding landscape, and drastically altered the ecological function of lowland systems. The physical connections between floodplains and large rivers in North America and Europe have not been well studied; however, research suggests that these connections have diminished significantly (Sedell and Froggatt 1984, Healey and Richardson 1996). Channelization limits over bank flooding and channel migration by confining streamflow within a single channel with rigid banks. Over bank flooding is beneficial because it provides nutrient enrichment to floodplain biotic communities (Benner and Sedell 1997). During flood events, stored nutrients are deposited on the floodplain. With channelization, nutrient and large wood inputs to streams are reduced. These changes reduce backwater and wetland habitat such as sloughs and side-channels. With the separation of the river from the floodplain, aquatic organisms can no longer access off-channel and backwater habitats or the stored nutrients that were once deposited on the floodplain (Sedell and Froggatt 1984). In the Willamette Valley, some of the larger floods in recent history (1964 and 1996) occupied significantly less (152,789 and 194,533 acres inundated, respectively) land area than some of the largest floods recorded (1861/1890 - estimated 320,337 acres inundated), in part because of channelization (Gregory et al. 2002b).

Wetlands are areas that have standing, shallow water or saturated soils at least part of the year because of topography and hydrologic conditions. Wetlands were common along Oregon's lowland rivers and streams prior to EuroAmerican settlement (Mitsch and Gosselink 2000, SOER Science

Panel 2000). The extent of the wetlands in the Willamette and coastal valleys was enhanced by beaver activity. Extensive hunting and trapping, which began with EuroAmerican exploration of the Pacific Northwest, decreased beaver populations in these valleys (Williams 1914, Naiman et al. 1988, Johnston 1994).

Channelization has reduced wetland area and complexity and salmonid habitat quality (Sedell and Frogatt 1984, Benner and Sedell 1997, SOER Science Panel 2000). Flood control and channelization have resulted in the loss of over 450,000 ha (57%) of wetlands in Willamette Valley lowlands between 1860 and 1997 (Gregory et al. 1998, SOER Science Panel 2000). From 1850 to 1990, wetlands decreased from 14% to 1% of the riparian zone along small (1^{st} to 4^{th} order) lowland streams (Grego ry et al. 2002a). Along the Willamette mainstem, wetlands increased from 1.1% to 3.6 % of the river length (Gregory et al. 2002a). Wetland change between 1850 and 1990 for all Willamette lowland streams is shown in Figure 11. Changes in wetlands in coastal streams may not show a similar pattern; wetland loss in coastal estuaries in discussed later in this question.

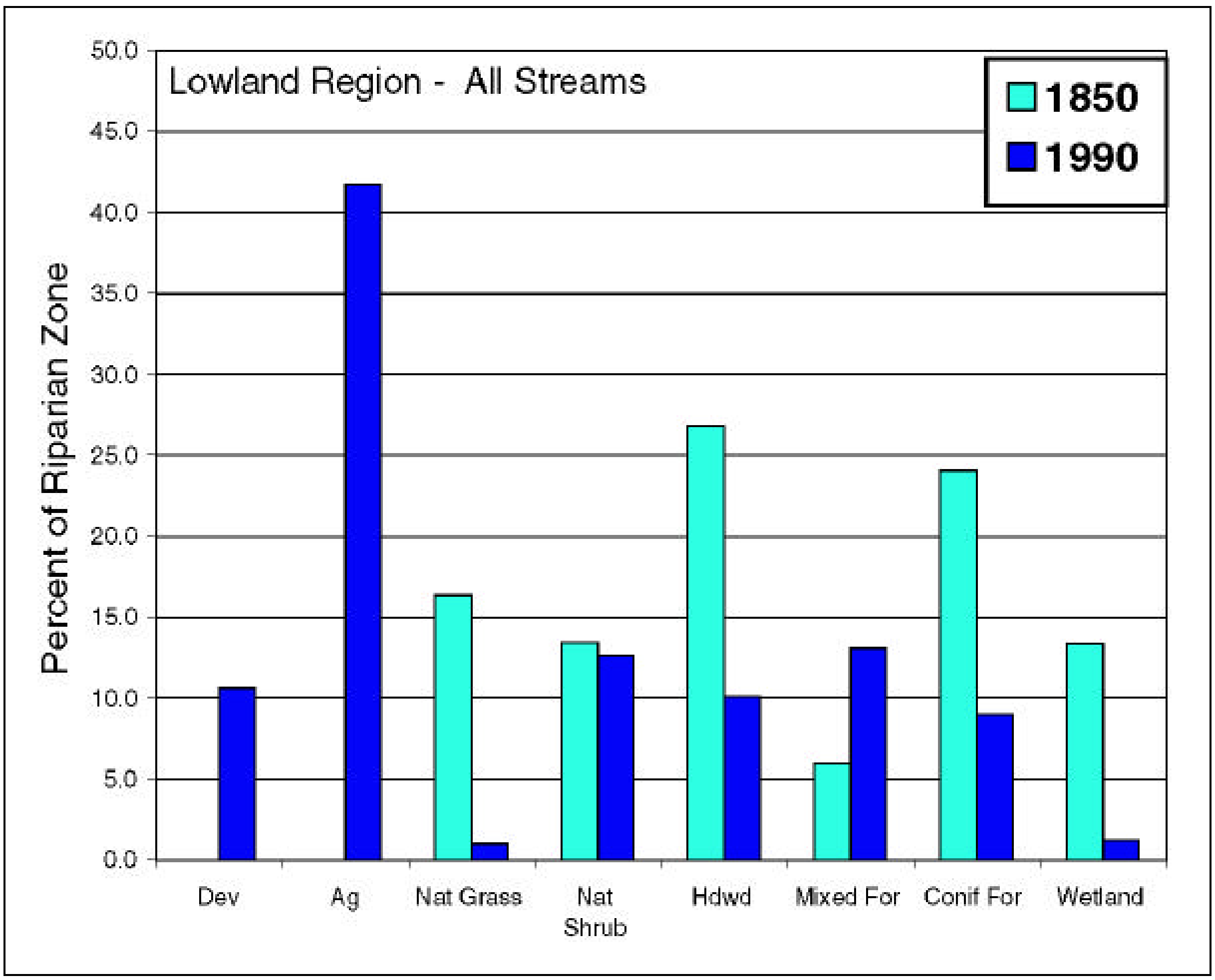

Figure 11. Percentage cover or composition of land use or vegetation types for a 120 m (396 ft) riparian zone along all lowland streams and rivers in the Willamette Basin in 1850 versus 1990. This figure combines data from small streams, major tributaries, and the Willamette River mainstem (Gregory et al. 2002a).

Drainage of agricultural lands, particularly drain tile installation, has been another major source of wetland loss in the Willamette Valley. Between 1937 and 1959, 376,000 acres were drained in the

Willamette Valley; between 1959 and 1964, another 56,000 acres were drained (Soil Conservation Service 1977). Even with legal protection under the Clean Water Act, wetlands continue be lost largely due to agricultural conversion and rural development. Daggett et al. (1998) report that 546 acres per year were lost between 1982 and 1994. Bernert et al. (1999) estimate that a net 2,750 ha of wetlands were lost from the Willamette Valley between 1981 and 1994. Seventy percent of the wetland loss during this period was due to agricultural conversion and six percent to urbanization (Bernert et al. 1999). Urban development and agriculture affect wetlands by contributing to increased sedimentation, water pollution, hydrologic alteration, and fragmentation. Hence, wetlands are less able to filter and cleanse water, to absorb floodwater to release at a later time (see Question 3), and to support wildlife and fish. Losses of wetlands throughout lowlands are of concern because wetland loss contributes to altered hydrology.

Loss of riparian floodplain forests

In the 1850s, the Willamette Valley was dominated by wet prairies and oak savannahs, sub-climax plant communities influenced by frequent fires set by Native Americans. Extensive floodplain forests formed a corridor along the Willamette River and most of its floodplain, including bushy thickets, marshes, and ash openings (Johannessen et al. 1971, Towle 1982, Boyd 1986, Boag 1992, Pearl 1999, Knox 2000). These woodlands were an average of 1-2 miles wide on either side of the river (Johannessen et al. 1971, Sedell and Froggatt 1984, Dykaar and Wigington 2000). At the confluence of the Willamette and the Santiam Rivers, the forests were up to 7 miles (11km) wide (Gregory et al. 2002d). The forests were regularly inundated by floodwaters (Benner and Sedell 1997).

Trees from the floodplain forests were used for timber and firewood in the urban settlements along the river, for fuel by steamboats that navigated the river, and for pulp at a paper mill at Willamette Falls (Towle 1982, Sedell and Froggatt 1984, Keeler 1985).

Between 1850 and 1990, hardwood, conifer, and mixed forests were reduced by over 75% along the Willamette River mainstem (Gregory et al. 2002a), leaving a narrow, discontinuous strip along the river and tributaries, with small isolated patches scattered across the floodplain (Gregory et al. 1998). The patches of original riparian forest that remain in the Willamette Valley today are at most a few hundred feet wide. Along some portions of lowland rivers and streams, riparian forests have been completely eliminated (Benner and Sedell 1997, SOER Science Panel 2000, WRI 2001).

Gregory et al. (2002c) concluded that overall changes in riparian plant communities in the Willamette Valley reflect land use changes that occurred along small streams, as 93% of the total riparian area in the valley is adjacent to small streams. Riparian vegetation was eliminated by clearing and for conversion to other land uses. Not surprisingly, the reduction in riparian forest vegetation (hardwood, mixed forest and conifer) corresponded with an increase in area in agricultural and developed land uses (Figure 11). In 1990, over 40% of the river margin within 120 m of the river margin was in agriculture, and over 10% was developed for urban or rural uses.

Land conversion to agriculture

Agriculture (crops, orchards, pastures, and livestock) has been and continues to be the major agent of change in emergent wetlands and woodlands along lowland rivers. Agricultural activities in western Oregon are concentrated in the valley floors (lowlands) of the Willamette, upper Rogue, Umpqua, and North Coast (Nehalem, Tillamook, and Yaquina) basins (Botkin et al. 1995). In the Willamette basin, almost all the riparian forests were eliminated during land conversion to agriculture (Sedell and Froggatt 1984, Botkin et al. 1995, Benner and Sedell 1997). After the mid-1930s, the construction of flood control dams and more intensive use of irrigation allowed additional land to be converted to agriculture (Dykaar and Wigington 2000), including intensive floodplain forest conversion. By 1990, more than 40% of riparian areas (within 120 m of the river's edge) in lowland valleys of the Willamette Basin were in agricultural use (Gregory et al. 2002a). Conversion to agriculture and other land uses also resulted in changes in bank stability, channel structure, stream discharge, and water quality, as well as spawning gravel quality and quantity (Bottom et al. 1985, Altman et al. 1997).

Other important changes to aquatic systems associated with agriculture include soil erosion, increased water runoff, leaching of agricultural chemicals, lower streamflow due to water diversions and withdrawals, barriers to fish migration, and degradation of riparian and channel habitats (Botkin et al. 1995). The impacts of these activities are addressed in more detail in Questions 3 and 4.

Reductions in large wood

Historically, lowland rivers and streams in the Pacific Northwest contained large wood that often accumulated in debris jams and created deep pools, multiple thread channels, and abundant habitat along channel edges (Collins et al. 2000). Prior to EuroAmerican settlement, large wood and snags were abundant in lowland river channels (Gonor et al. 1988, Sedell et al. 1990). Large wood accumulated along banks of larger streams, routing sediment and floodwaters onto the floodplain and creating a dynamic riparian zone (Collins et al. 2000). At the confluences of major tributaries, the snags accumulated in debris jams, and diverted flow into backwaters, creating and maintaining complex aquatic habitats including gravel bars, shoals, multiple channels, and oxbow lakes. In the Willamette River system, the amount of in-channel wood has been shown to be greater in more complex reaches (tributary junctions and multiple channels) than in single channel reaches (Simmons and Gregory 2000).

Three major factors have contributed to a significant reduction of large wood in Western Oregon lowland streams:

- Reduction in recruitment of large wood to streams,
- snag removal to improve navigation,
- policies encouraging excess wood removal.

First, channelization and bank stabilization in lowland rivers have resulted in a loss of connectivity during flooding between the heavily wooded, low gradient channels along the river. This loss of channel and floodplain connection has drastically reduced the input of large trees and snags into the river. In addition, huge areas of riparian forests, the sources of large wood, have been removed.

Second, from settlement to recent times, land managers removed the large wood from many channels of western Oregon's lowland rivers and streams (Montgomery 1997). The maintenance of navigable channels dictated the removal of most of the large wood in from the main channel of the Willamette River. For example, in the Willamette River upstream of Albany, 61 snags/km were removed between 1876 and 1912 (Table 3; Sedell et al. 1990). From 1870 to 1950, an average of 550 snags/km were removed, representing approximately one downed tree/1.6 m of stream length, compared with the present day removal rate of 1 downed tree/300-400 m of stream length (Sedell and Froggatt 1984).

Third, during the first half of the twentieth century, upland forestry practices loaded logging debris into Pacific Northwest stream and river channels (Gregory 1996). Fishery biologists noticed the subsequent degradation of fish habitat, depletion of dissolved oxygen, hindrance of fish passage, and increase of water temperatures in response to abundant logging debris in streams and rivers (Gregory 1996, Gregory and Bisson 1997). In 1971, the Oregon State Game Commission --and later, the 1974 US Forest Service Manual – stated that logging wood and slash should be kept out of streams, but that stabilized natural wood should be retained (Gregory 1996). However, the Oregon Forest

Practices Act of 1972 suggested clearing all woody material from streams (while retaining natural wood near streams). Although these official recommendations acknowledged the need to retain natural wood either in or near streambeds, Gregory and Bisson (1997) point out that "stream clearing practices often became overly zealous in that it was assumed that if some removal was good, total removal was better."

In summary, the reduction of large wood in western Oregon streams has been a result of channelization, riparian forest destruction, snag removal, and stream cleaning. A 1975 conference on logging debris in streams held at Oregon State University described the natural role and abundance of wood in streams (Gregory 1996). In response to this new information, scientists recognized the biological importance of retaining natural large wood in streams. Reduction of natural large wood in streams and rivers is now understood to decrease pool frequency, pool quality, fish habitat, and stream health due to loss of large wood ecological functions (Myers and Swanson 1996; see also Question 4). Although snags and fallen trees continue to be removed from rivers and streams for safety and navigation purposes, land managers now generally discourage wood removal from streams and rivers (Sedell et al. 1988, Gregory 1996).

Impacts on salmonids

All of the changes described above have reduced the productivity and diversity of aquatic and riparian communities in western Oregon's lowlands. Impacts to salmonids include the decrease and simplification of habitat available for rearing, migration, refuge from high flows and temperatures, and protection from predators. Loss of riparian forests and other vegetation has decreased large wood availability, stream and river channel shading, and bank stability. Loss of side channels, sloughs, and backwaters and large wood reduction (due to riparian forest loss, active removal, and salvage of material transported from upstream forests) have decreased the abundance and complexity of habitat needed to maintain high salmonid productivity.

Estuaries

Geomorphic and hydrologic processes

Estuaries are lowland habitats along the coast, defined as semi-enclosed embayments where fresh and marine waters mix. Estuaries integrate the conditions of the watershed they drain and, through tidal mixing, are strongly influenced by ocean conditions. Estuaries and their wetlands, like lowland river floodplains, have important ecosystem functions. For example, salt marsh vegetation may stabilize shorelines by dissipating energy from storm surges. Porous salt marsh soils can absorb floodwater. In addition, as water flows from uplands through marsh vegetation, nutrients and pollutants are filtered and sediment loads controlled – maintaining water quality. Estuaries also provide important recreational and aesthetic values.

Like rivers, estuaries are dynamic systems. Physical and chemical factors that influence habitat quality for salmonids are likely to change over short time scales. Throughout the day, tidal influences may change the salinity, turbidity, and current at a site. Changes in the morphology of the estuary that affect salmonid habitat occur over longer time scales. For example, sediment discharge may vary seasonally. In winter, western Oregon's seasonal rains result in higher volumes of sediment discharged from watersheds. Flooding and storms may change the structure of marshes (Simenstad et al. 2000). On a geologic time scale, earthquakes may cause the estuary floor to subside by as much as 1 to 2 m; an earthquake large enough to cause a subsidence occurred most recently in 1700 (McManus et al. 1998).

Oregon's estuaries vary depending on geologic history, size, and characteristics of the watershed they drain. The majority of Oregon's estuaries (including Coos Bay, Siletz Bay, and Yaquina Bay) formed when sea levels rose at the end of the last ice age (Cortright et al. 1987). This type of estuary, called a "drowned river estuary", tends to have the branching structure of the flooded river system, and be characterized by large wetland areas with permanently saturated soils (Little 2000). However, estuaries in the Pacific Northwest tend to have less wetlands than other regions of the country, due to steep coastal topography and a history of earthquakes (Simenstad et al. 2000). Some Oregon estuaries (such as Sand Lake and Netarts Bay) were "bar-built", through offshore sand accumulation (Cortright et al. 1987).

The size of the river flowing into an estuary and the depth of the estuary impacts estuary characteristics. Estuaries of larger rivers (with greater freshwater flow) and deep estuaries have less mixing between fresh and salt water. Fresh water tends to float on top of the saltwater layer, in a wedge shaped pattern. The degree of mixing affects patterns of sediment deposition in the estuary. When mixing is limited, fine sediments tend to be carried out to sea, except in areas where course sediment has built up as bars (Little 2000). Other watershed characteristics that can influence an estuary's hydrology include vegetative cover, land use, topography, and soil types (reviewed in Bowman et al. 2000). Flow regimes, sediment loads, and nutrient loads in the estuary may be influenced by watershed characteristics.

As estuaries lie in lowlands at the mouth of rivers, many of the geomorphic and hydrologic processes that occur in lowland rivers are also important in estuaries. Many of the processes and channel alterations in tide-influenced streams are the similar to those in lowland alluvial rivers. Particularly, sediment deposition creates surfaces that are colonized by vegetation and form wetland habitat – in this case, salt marsh habitat. A key difference is that in tidally influenced portions of rivers and in estuaries, water flows both up and downstream on a daily basis as the tide ebbs and flows. In contrast, water only flows downstream in river sections above the influence of tides. Upstream river sections are more influenced by seasonal patterns of precipitation and experience greater seasonal variation in water levels and flows than tidal areas (Mead et al. 2000).

Before humans modified Oregon's estuaries, much of the flat area surrounding the river mouths supported tidal marshes that were dissected by a network of stream channels and regularly flooded by tidal waters. The steep gradient of many coastal watersheds limits the area for tidal marshes, but the broad tidal floodplain of the Columbia River once supported extensive wetlands, including tidal freshwater marsh, brackish marsh, and forested swamp complexes (Simenstad et al. 2000). Rearing salmonids used these flooded areas extensively as refuge and for feeding, while they adapted to the saltwater environment where they spend most of their adult life (e.g., Giger 1972, Myers 1980, Healey 1982, Kjelson et al. 1982, Pearcy et al. 1989, Desmond et al. 2000). The importance of lowland river and estuary habitats to salmonids was discussed in detail in Question 1. Modifications to estuaries that have occurred as a result of human land uses will be discussed in the next section.

<u>Alteration of estuary conditions since EuroAmerican settlement</u>

All of Oregon's 22 major estuaries have been altered to varying degrees, and most of the tidal marshes in Oregon have experienced significant changes. There has been a loss of 68% of the original tidal wetland area in Oregon's estuaries, and about 25% of the total area of estuaries has been lost (Jackson 1991, SOER Science Panel 2000). Tidal marshes have been altered both physically and chemically (Jackson 1991).

Conversion of tidal marshes through diking, draining, and filling

Estuarine wetland and riparian habitats, with their networks of small channels, have been drastically altered and reduced in all of the major estuaries in Oregon and the Pacific Northwest. Since EuroAmerican settlement, all of the estuaries along the Oregon coast have been altered and reduced in size as a result of conversion for a variety of land uses (Hoffnagle and Olson 1974, Pinit 1999). Estuaries have been and are the focus of human activities, such as agriculture, industrial ports, and urbanization (Table 8; Boule and Bierly 1987).

Table 8. Causes and effects of estuary, tidal marsh, and wetland losses from 1870 to the present.

Estuary Change	**Amount of Change**	
Diking for conversion to agriculture	90% loss throughout coastal wetlands	Jefferson (1974), Kentula (1986), Boule and Bierly (1987)
	75% of wetlands isolated by dikes in the Salmon River	Frenkel and Morlan (1991)
Conversion to urban and industrial uses	90% reduction in the tidally influenced area in Coos Bay	Hoffnagle and Olson (1974)
Modification for navigation		Hoffnagle and Olson (1974)
Conversion to dairy operations		Pinit (1999)
Loss of emergent plant production	82% reduction of emergent vegetation production in the Columbia River Estuary	Sherwood et al. (1990)
Loss in benthic macroalgae production	15% reduction in the Columbia River Estuary	Sherwood et al. (1990)
Decreased duration of juvenile salmon residence time	Decreased in Columbia River Estuary between 1916 and 1968	Bottom et al. (2001)

Early settlers recognized the rich agricultural potential of estuarine lowlands, and developed them extensively for agriculture (Boule and Bierly 1987). The settlers' first major activities were diking, draining, and filling vast areas of marshes and forested swamps for agricultural activities. Dikes, tide gates, and jetties in estuaries prevent tidal water from inundating the tidal marshes and speed water run-off. These structures made it possible to convert tidal marshes to pastureland for livestock grazing and to cultivate fields for crop production (Hoffnagle and Olson 1974, Jefferson 1974, Boule and Bierly 1987, Ruprecht and George 1993, Rumrill and Cornu 1995). Today, almost all high marsh areas of Oregon have been diked (Jefferson 1974, Kentula 1986). In addition, tidal marsh channels have been stabilized, dredged, and maintained for navigation (Percy et al. 1974; Rumrill and Cornu 1995, SOER Science Panel 2000).

Loss of tidal wetlands in Oregon estuaries has been high during the past 150 years (Table 9; Dahl 1990, SOER Science Panel 2000). On average, 24% of the estuarine area was lost in 17 of Oregon's largest estuaries between 1870 and 1970, and 68% of tidal wetlands have been lost over the past 100 years (Table 9; SOER Science Panel 2000). Boule and Bierly (1987) reported that 90% of the documented coastal wetland losses in Oregon and Washington are a result of diking for agricultural conversion. These alterations have resulted in significant reductions in the amount of available salmonid habitat. Before restoration began in the Salmon River (Oregon), 75% of the wetlands had been isolated from estuarine circulation by dikes (Frenkel and Morlan 1990, 1991; Morlan 1991). In

Coos Bay, as much as 90% of the tidally-influenced area has been converted to urban, industrial, and agricultural land uses; the changes occurred through dredging (to improve navigation), fill, and diking (Hoffnagle and Olson 1974). Other estuaries, including Tillamook Bay and the Salmon River Estuary, have been altered primarily for agriculture and dairy operations (Pinit 1999).

In the Columbia River Estuary, tidal marshes and swamps, important rearing and nursery habitats for salmonids, now cover only about a third of their former area. This change is due to diking, draining, and filling of wetlands and tidal marshes. Shallow flats have increased while deeper water areas have decreased. This loss of wetland habitats in the Columbia River Estuary has resulted in an 82% reduction of emergent plant production and a 15% loss in benthic macroalgae production, a combined loss of over 50,000 metric tons of organic carbon per year (Sherwood et al. 1990).

Table 9. Changes in estuary wetlands, 1870 to 1979 (From SOER Science Panel 2000, table 3.32, p. 36).

Estuary	Actual 1970 Area (acres)[1]		Diked or Filled	Estimated 1870 Area (acres)[3]		Percent Change (1870-1970)	
	Tidal Wetland	Total Estuary	Tidal Wetland[2]	Tidal Wetland	Total Estuary	Tidal Wetland	Total Estuary
Columbia	16,150	119,220	30,050	46,200	149,270	-65%	-20%
Necanicum	132	451	15	147	466	-10%	-3%
Nehalem	524	2,749	1,571	2,095	4,320	-75%	-36%
Tillamook	884	9,216	3,274	4,158	12,490	-79%	-26%
Netarts	228	2,743	16	244	2,759	-7%	-1%
Sand Lake	462	897	9	471	906	-2%	-1%
Nestucca	205	1,176	2,160	2,365	3,336	-91%	-65%
Salmon	238	438	313	551	751	-57%	-42%
Siletz	274	1,461	401	675	1,862	-59%	-22%
Yaquina	621	4,349	1,493	2,114	5,842	-71%	-26%
Alsea	460	2,516	665	1,125	3,181	-59%	-21%
Siuslaw	746	3,060	1,256	2,002	4,316	-63%	-29%
Umpqua	1,201	6,544	1,218	2,419	7,762	-50%	-16%
Coos Bay	1,727	3,348	3,360	5,087	16,708	-66%	-20%
Coquille	276	1,082	4,600	4,876	5,682	-94%	-81%
Rogue	44	880	30	74	910	-41%	-3%
Chetco	4	171	5	9	176	-56%	-3%
TOTAL	24,176	160,301	50,436	74,612	220,737	-68%	-24%

Channelization and hydrologic alterations

In the process of converting tidal marshes to land, tidal marsh streams were channelized to facilitate water removal. Channelization of marsh streams changes them from a meandering platform to a straight platform, which hastens freshwater run-off (Kentula 1986, Pinit 1999). Channelization has reduced the amount of tidal marshland available for fish habitat.

Freshwater flows from uplands have been reduced by as much as 60-80% during low-flow in peak summer demand periods, due to water withdrawals for out-of-stream uses (SOER Science Panel 2000). This affects not only habitat availability, but also water quality, because freshwater inflows from uplands are important in diluting pollution and flushing nutrients and sediment. Channelization and the consequent changes in hydrologic regimes in tidal marshes may cause changes in sediment chemistry. These changes may include pH changes, which may lead to mobilization of lead, copper, silver, and cadmium, elements that can be detrimental to aquatic life (Anisfeld and Benoit 1997).

Riparian forests and large wood

Prior to EuroAmerican settlement, estuaries contained large amounts of wood (Gonor et al. 1988). Snags were an important structural component of stream channels. Land surveys in Oregon estuaries in the 1850s reported large debris jams in the tidal river channels entering Tillamook Bay; government records from 1889-1920 report the removal of over 24,800 snags (408 snags per mile) in the Coquille and Coos River systems (Benner and Sedell 2000). We can assume that other Oregon estuaries also had riparian forests and abundant large wood, similar to the documented cases of Tillamook, Coos, and Coquille Bays.

Forested upland areas, as well as floodplains, provided large wood to the lower elevation rivers and estuaries. Based on 1857-1872 land surveys of Tillamook and Coquille Bays, lowland vegetation consisted largely of floodplain and tidal forests with extensive marshes (P. Benner, unpubl. data.[11]). The riparian forests, which were removed by early logging, provided shade, stabilized channels and banks, and contributed abundant large trees and wood to the estuaries. The large wood created deep pools and cover for estuarine organisms, including salmonids (Gonor et al. 1988, Maser and Sedell 1994). As we discussed in Question 1, the functional role of large wood in estuaries has not been studied extensively, but is assumed to be similar to the role in rivers. Most of the large wood and snags in estuaries has been removed for flood control and navigation (Gonor et al. 1988), resulting in loss of habitat complexity and refugia for salmonids and other aquatic species. This has reduced the quality and quantity of salmonid habitat in estuaries and tidal marshes.

Sediment inputs

Sediment that accumulates in estuaries comes from marine and riverine sources. The quantity of sediment that is transported from uplands by rivers is likely to be dependent on periodic natural disturbances (floods, landslides, fires, etc.) in the watershed. We would expect that historically, these occasional natural disturbances caused increased sediment to be delivered to estuaries. Sediment inputs to coastal estuaries have also been affected by upland land use practices, dams, and large wood removal (see Questions 3 and 4). Sediment input to estuaries from upland sources has increased due to vegetation clearing for agriculture, forestry, and urban development (SOER Science Panel 2000). Logging of riparian forest adjacent to tidal marshes, as well as in upstream areas, has led to increased erosion and to sediment accumulation in coastal bays and estuaries. Unpaved upland roads can also contribute to raising the amount of sediment in estuaries above pre-settlement levels (Rumrill and Cornu 1995). In addition, hydrologic modifications in tidal marshes have altered sediment distribution patterns in estuaries.

Determining the relative contribution of natural disturbances and land use practices to sediment accumulation in Oregon's estuaries can be challenging. In Tillamook Bay, sediment accumulation from rivers appears to be on average 10 times less in the second half of this century than the first half of the century (McManus et al. 1998). This difference may be attributable to catastrophic forest fires --including the Tillamook Burns of 1933, 1939, 1945, and 1951-- and/or logging related activities in these watersheds. The fine sediments from uplands (silt and clays) usually flush through the Tillamook Bay quickly, making the impact on the Bay less than expected (McManus et al. 1998). Nevertheless, accelerated erosion from upland sources may account for the observed accumulation of fine sediment along the Bay margins (McManus et al. 1998).

[11] Patricia Benner, Corvallis, Oregon. Unpublished analyses of 1) Coquille River historical bottomlands reconstructed from 1857 – 1872 land survey notes data and 2) Tillamook Valley and Bay historical descriptions from 1850s General Land Office original survey notes and 1887-90s U.S. Army Corps of Engineers Reports.

Subsidence of soil surfaces in tidal marshes

The surface level of tidal marshes can change significantly as a result of diking. Diking causes the extent and magnitude of tidal inundation in marshes to decrease (Frenkel and Morlan 1990, 1991; Morlan 1991). This hydrologic alteration has often resulted in the subsidence of the marsh soil surface, as the soil shrinks due to compaction and to increased decomposition of organic material (Mitchell 1981, Frenkel and Morlan 1990, 1991, Morlan 1991, Anisfeld and Benoit 1997, Turner and Lewis 1997); compaction may be accelerated if livestock are grazed on the converted marsh. Frenkel and Morlan (1991) report that a diked pasture in the Salmon River Estuary subsided 35 cm (14 in.) over 17 years. Rumrill and Cornu (1995) estimate that marsh surfaces in South Slough Estuary (Coos Bay, Oregon) are 60-80 cm below their pre-modified level. Subsidence of soil surfaces also has implications for restoration; if dikes are removed, the original quality or extent of habitat may never be fully recovered, or will recover only after many years or decades.

Sediment distribution has also been affected by these changes in land surface levels resulting from hydrologic modifications and the subsequent changes in tidal and flood inundation patterns (Rumrill and Cornu 1995, Reed et al. 1999). After dikes were installed in Smith River Estuary, many channels in the tidal marsh filled with sediment. This occurred through bank erosion due to bank trampling by cattle and through a reduced ability of the tidal streams to remove sediment (Frenkel and Morlan 1990, 1991; Morlan 1991).

Impacts on salmonids

Human modifications have altered estuarine ecosystems. The ecosystems have less hydraulic connectivity between channels and floodplains, more sedimentation, altered bathymetry (water depth relative to sea level), less tidal mixing, more pollution, less large wood, and less tidal slough and marsh area. These changes have reduced the capacity of rearing habitats to support fry and sub-yearling salmonids. This is believed to be a factor in the decline of salmonid populations (Levy and Northcote 1982, Shreffler et al. 1990). Restoration of diked estuarine tide regimes will be discussed in Question 5, but here it is important to note that diking has markedly reduced the amount and spatial extent of habitat.

Findings and Conclusions

Findings

Lowland ecosystems of western Oregon have been greatly altered from historical conditions by human disturbances resulting from a variety of land uses: agriculture, timber harvest, urbanization, and transportation systems.

Lowland aquatic ecosystems have been fragmented and simplified. Human alterations to lowland river systems include:

- Channelization of tributaries and main channels,
- Dredging and gravel removal,
- Dam and reservoir construction,
- Draining and filling of wetlands,
- Floodplain forest clearing,
- Land conversion to agriculture (including wetlands and riparian forest), and
- Large wood removal.

Human alterations to estuary systems include:

- Conversion of 90% of tidal marshes through diking, draining, and filling,
- Channelization,
- Reduced water quality,
- Changes in tidal marsh sediment chemistry (high acidity levels, which lead to mobilization of lead, copper, silver, and cadmium,
- Reduction of large wood,
- Changes in sediment inputs from rivers, and
- Subsidence of soil surfaces in tidal marshes.

Important components and processes in lowland rivers and estuaries that have been modified are:

- Periodic flooding that provides hydrologic connectivity between main channels and complex, off-channel habitats and creates habitat diversity,
- Tidal inundation of salt marshes, leading to subsidence of soil surfaces,
- Area, diversity, and quality of off-channel and instream habitats, particularly habitats supporting rearing juvenile salmonids,
- Channel length and flow regimes,
- Intact, functioning riparian zones with large trees,
- Expansive wetlands in the floodplain and tidal areas, and
- Large wood that modifies and slows streamflow and creates complex habitat.

Floodplains and tidal areas, which provide important salmonid habitat, have often been isolated from lowland alluvial valleys by diking, tide gates, revetments, channelization, wetland drainage, and large wood removal.

Conclusions

Lowland rivers, streams and estuaries of western Oregon, once highly productive salmonid habitats, have been modified greatly during the past 150 years. Much land in these lowland landscapes has been converted to agriculture.

Lowland landscape structure has been fragmented, and the processes that create and maintain salmonid habitat have been impaired. As a result, the quality and quantity of native salmonid habitat has been significantly reduced.

Removal of riparian forests has reduced off-channel habitat complexity and the sources of large wood. Large wood performs valuable functions by providing habitat complexity, dynamic complex channel morphology, and habitat and cover for fish and wildlife. Remnants of intact riparian systems and stream habitats are extremely important and should be conserved.

Much of the productive habitat in estuaries has been lost, largely due to diking and draining of tidal marshes for agricultural purposes.

Reconnecting main river channels and estuaries to off-channel areas and floodplains will increase lowland habitat for salmonids.

Question 3. What is the scientific basis for maintaining and enhancing fish habitat in western Oregon lowland ecosystems with respect to water quantity and flow modifications, fish passage, and water quality?

Water Quantity and Flow Modifications

Anadromous species in western Oregon are adapted to the distinct seasonal hydrologic regimes of western Oregon's lowland rivers. West of the Cascades, Oregon is characterized by wet, cool winters and relatively warm, dry summers. Most precipitation occurs between November and June in the form of rain in the lower elevations of the Willamette Valley and the Cascades Mountains and the Coast Range, and in the form of snow in the higher elevations of the Cascade Mountains. Eighty percent of the mean annual precipitation occurs from October through March (Woodward et al. 1998). Peak run-off and peak streamflows also occur during these months; minimum streamflows occur from July through October (Woodward et al. 1998).

Salmonid life histories are adapted to seasonal variations in streamflow. Adequate water quantity is necessary at critical periods for salmonids to complete their life histories. Both upstream migrations of adults to spawning grounds and downstream movement of juveniles often coincide with higher flows in the fall, winter, and spring. Shallow water and warm water temperatures resulting from low streamflow can prevent migration upstream of adult salmonids.

Low streamflow affects the growth and survival of juvenile salmonids by altering food production, cover, and availability of habitat (Bottom et al. 1985). Reduced streamflow exacerbates water quality problems and may increase aggression, competition, or predation among salmonids (Bottom et al. 1985, Oregon Plan 1997). Instream flow protection and enhancement are, therefore, important to the maintenance and recovery of salmonid populations. The Oregon Plan has identified management of water quantity as an important component in the efforts to restore native salmonid populations to productive and sustainable levels (Oregon Plan 1997).

Due to human alterations, present flow hydrographs in western Oregon have changed from historical hydrographs. Flood control dams, channelization, out-of-stream withdrawals, and wetland drainage have modified stream volumes and the timing of flow in Oregon's rivers. In addition, the impermeable surfaces of paved roads, and roofs in residential and urban areas have increased storm runoff into streams, thereby reducing streamflow during periods between storms.

The amount of water flowing in streams in western Oregon has been reduced, especially by irrigation. In western Oregon, irrigation accounts for over 50% of the water withdrawn from both surface and groundwater sources. Of the water used for irrigation, 8% is from reservoirs (via dams), 78% from rivers and streams (via irrigation diversions), and 14% from groundwater (via wells) (SOER Science Panel 2000). Often irrigation takes place in summer, contributing to already low water levels in streams (Altman et al. 1997). In this section, we discuss the effect of dams and reservoirs, water withdrawals by diversions, and wetlands on water quantity and streamflow in western Oregon lowland streams and rivers.

<u>Dams and Reservoirs</u>

Dams are a major component in the control of river flows, and dams have significant impacts on lowland ecosystems by changing natural flow patterns. By impounding water, these dams modify the hydrology of streams. Where dams regulate flow, rivers are physically and ecologically different from unregulated rivers (Ligon et al. 1995, Petts et al. 1995, Power et al. 1995, Power et al. 1996). Dams can affect the entire hydrologic regime downstream, shifting periods of high and low flow, which may disrupt the timing of some aquatic species life stages, and affect riparian vegetation community structure and distribution.

Benefits of dams to human society include power generation, water for irrigation, and reduction in flooding. Benefits of dams to salmonids include possible enhanced flows and possible lower water temperatures during low-flow seasons and drought years. However, the temperature of water released from dams depends upon whether withdrawals are made from the lower layer of cooler water (hypolimnion) or from the upper layer of warm water (epilimnion) of a reservoir. During fall, when rivers and reservoir levels are low, heated upper waters may be released. For example, ODFW

(2000b) concluded that operation of the Lost Creek Dam on the Rogue River, Oregon negatively impacted wild, spring-run chinook salmon. Accelerated embryonic development, early emergence, increased susceptibility of eggs and fry to dewatering, and increased pre-spawning mortality were due to elevated water temperatures from operation of the Lost Creek Reservoir (ODFW 2000b).

Therefore, dams are not always beneficial to salmonids and other aquatic organisms. In addition to altering water temperature, dams often impede fish passage (even if the dams have fish passage facilities), preventing migration to historical spawning areas, and inundating spawning and rearing habitats. Dams also alter flow and sediment regimes downstream, which affect erosional processes and sediment transport, thereby, modifying channel migration. Flow alterations may strand and kill juvenile salmonids along stream margins (Bradford 1997).

Most large rivers in Oregon have been modified for flood control, irrigation, navigation, hydropower, water supplies and recreation (SOER Science Panel 2000). Although the effects of individual, small hydro-projects may seem insignificant compared to large hydroelectric facilities, cumulative impact of small dams is potentially great (Bottom et al. 1985). The greatest density of dams in Oregon is west of the Cascades, with about 23.5 dams per 1000 sq. mi. (SOER Science Panel 2000). Figure 12 shows the location of 575 of the 1,338 dams in the uplands and lowlands of western Oregon over which the State has authority. Of 1,338 dams in western Oregon, 158 of are used solely for agricultural irrigation with the majority of the other dams operated for multiple purposes (Botkin et al. 1995), such as water for municipal, industrial, livestock pasture, and rural uses.

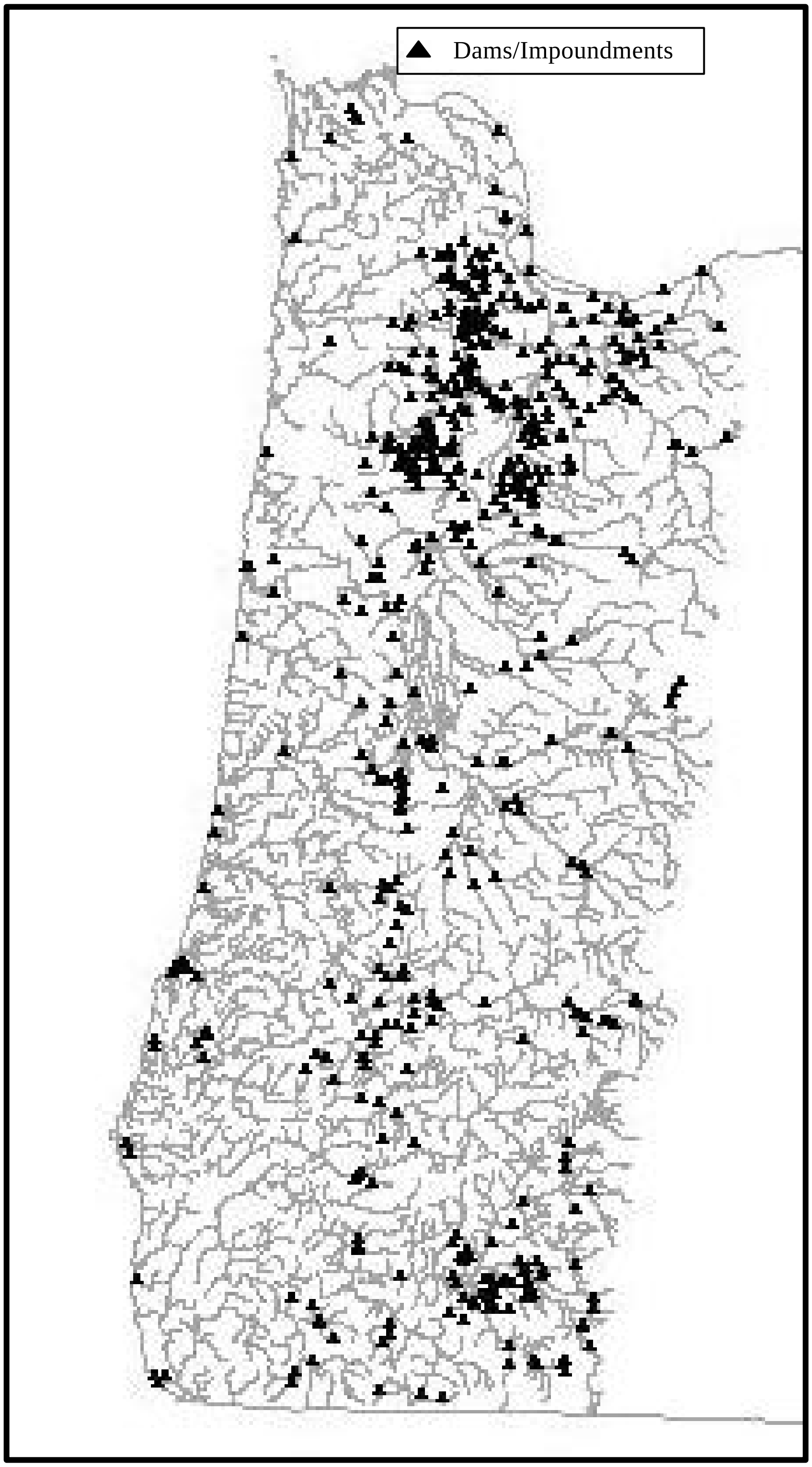

Figure 12. Location of 575 dams out of the 1,338 total dams in western Oregon. (Data Sources: *State Boundary:* USGS, 1:2,000,000, *Rivers:(or rivers)*, EPA, 1:250,000, and *Dams*: Dams regulated by Oregon from the Water Resources Department, 1:24,000. Oregon GeoSpatial Data Clearing House, Oregon Department of Administrative Services: http://www.sscgis.state.or.us/).

Dams have highly modified the Willamette River ecosystem. The Willamette Basin in western Oregon has twenty-five major dams; 13 of these dams are shown in Figure 13 (US Army Corps of Engineers 2000). Most Willamette Basin reservoirs are located in the middle and upper Willamette basin and have significantly altered the flow regime of the Willamette (U.S. Army Corps of Engineers 1980, Gregory et al. 1998,Woodward et al. 1998). The reservoirs in the Willamette system provide 2.3 million acre-feet of water storage, thereby reducing flooding in the basin (Allen et al. 1999).

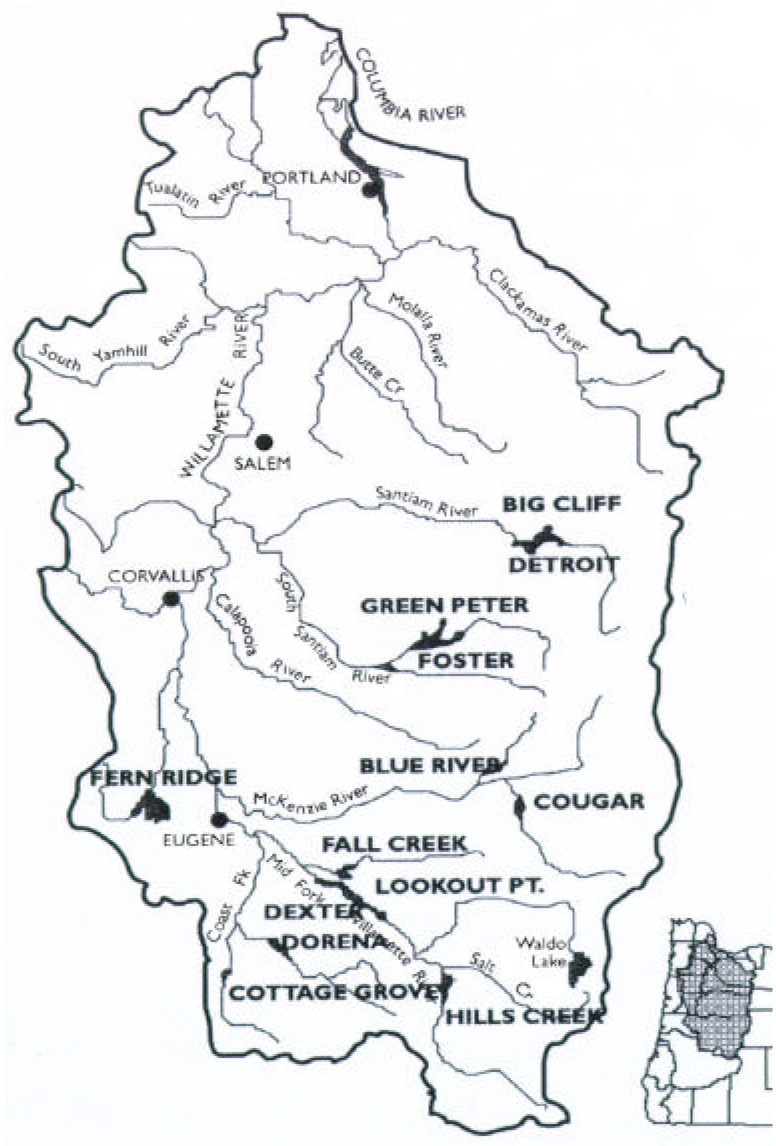

Figure 13. Thirteen of 25 major dams in the Willamette Basin (US Army Corps of Engineers 2000).

Dams modulate flows in the Willamette River system, by storing water during periods of high runoff in the winter and spring, and releasing water during the summer when flows are naturally low. In the Willamette River system, flood control dams and reservoirs have reduced flood-event peak flows in both magnitude and extent (Figure 14). In addition, dams tend to reduce seasonal (winter and spring runoff) peak flows, and tend to increase summer flows (Figures 15 and 16) (US Army Corps of Engineers 1980, Gregory et al. 1998, Dykaar and Wigington 2000).

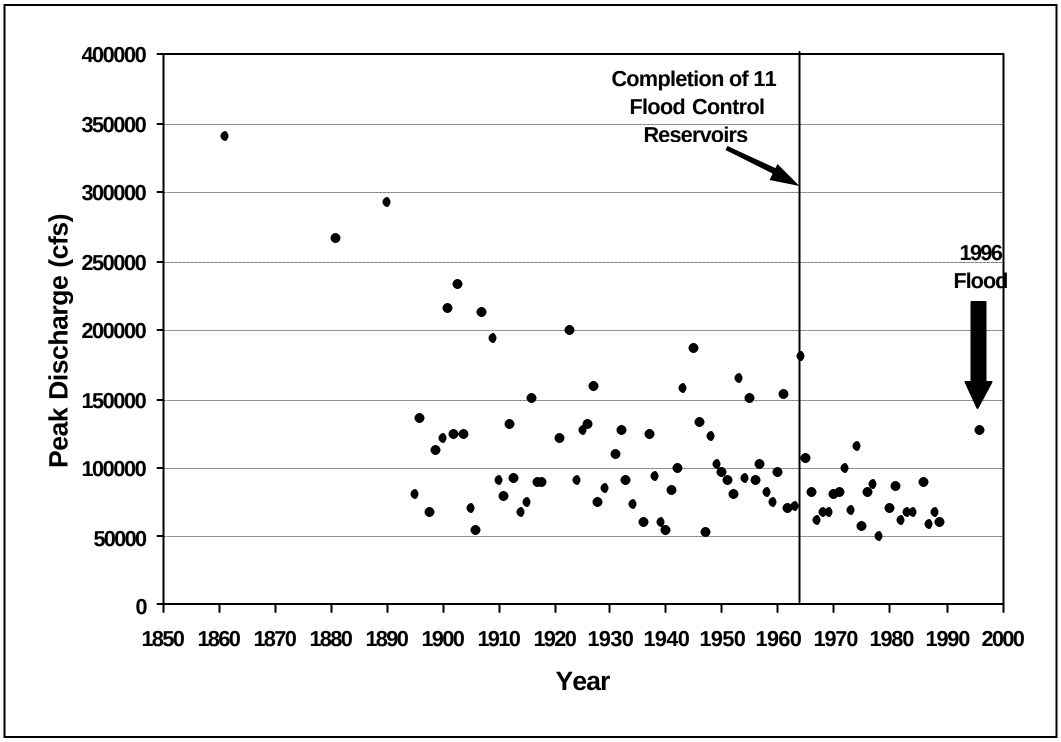

Figure 14. Peak flows in the Willamette River at Albany, Oregon before and after the construction of flood control dams (Gregory et al. 1998). Peak flows for the 1861 flood was recorded at 291,000 cubic feet per second (cfs) compared to the 1964 and 1996 floods, which were recorded at 180,000 and 117,000 cfs, respectively (Gregory et al. 2002b).

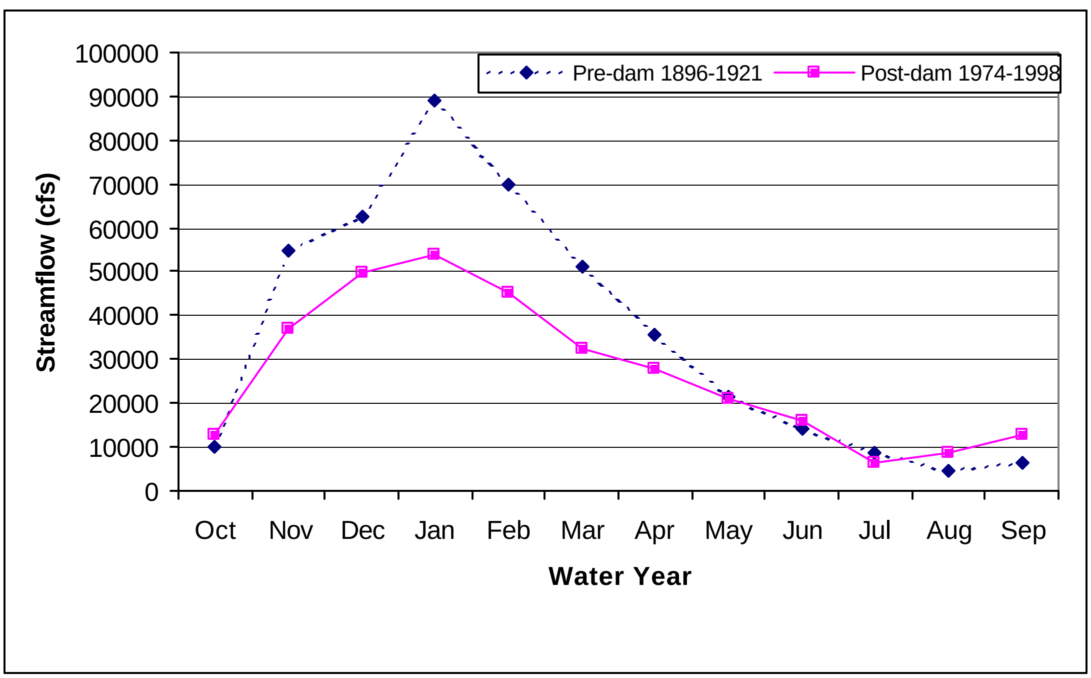

Figure 15. Mean highest monthly flows for the Willamette River mainstem before and after the construction of flood control dams. The more recent hydrograph shows the dampening effect flood control dams can have on late fall and winter flows. (Data from USGS gaging station number 14174000 at Albany, OR, http://water.usgs.gov/nwis/sw).

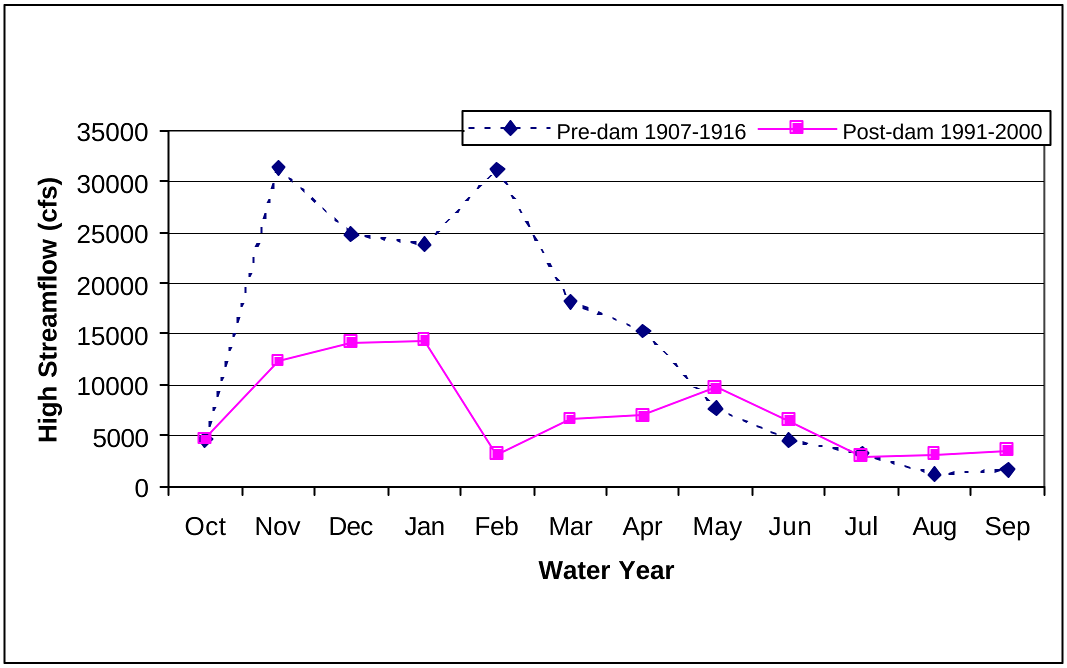

Figure 16. Mean highest monthly flows for the Middle Fork of the Willamette River at Jasper, OR before and after the construction of flood control dams. The more recent hydrograph shows the dampening effect flood control dams can have on late fall and winter flows. (Data from USGS gaging station number 14152000 on the North Fork Willamette River at Jasper, OR. http://water.usgs.gov/nwis/sw).

Reduction of peak flows in the Willamette River system has modified sediment and bed load transport (Wentz et al. 1998). Reduction in peak flows reduces the recruitment of coarse sediment from banks and floodplains, and also reduces the deposition of spawning gravels in mid-channel bars and islands typically found in rivers such as those in the Willamette River system (Williams and Wolman 1984, Benner and Sedell 1997, Dykaar and Wigington 2000, Gutowsky and Jones 2000). In a tributary of the Willamette River (the McKenzie River), peak flows have been reduced by 50% since the installation of two flood control dams (Ligon et al. 1995). The reduction in spawning gravel in the McKenzie River has significantly contributed to fewer redds and to density-dependent salmonid mortality (Ligon et al. 1995).

Peak winter flows are important hydrologic events that wash out fine sediments and scour pools (Milhous 1998). Peak flows expose or deposit gravels that are used for redds, and peak flows maintain the geomorphology and ecological functions of river ecosystems and their associated floodplain wetlands. Peak flows connect the river with the floodplain when high flows overtop the banks, and through channel meandering, which contribute to the formation of backwater habitat, sloughs, and side-channels. Gravels and cobble are transported at high flows. Peak flow deposition of sediment on the banks of a stream creates important sites for vegetation regeneration (Lewin 1978; Scott et al. 1997, 1998; Dykaar and Wigington 2000) and for salmonid egg deposition (Nanson 1980, Ligon et al. 1995). The size and quantity of the gravel and cobble sediment on the channel bed is extremely important to spawning salmonids (DeVries 2000), and significant alterations in gravels and cobble deposition are likely to decrease salmonid survival (Montgomery et al. 1996). Dams also interrupt sediment transport by trapping sediments, gravels and cobbles, thus preventing sediments from moving the length of the river system.

In the Willamette River system, floodplains that were once flooded every 10 years are now flooded only once every 100 years (Benner and Sedell 1997). The large post-dam floods of 1964 and 1996 occupied substantially less floodplain area (inundated 152,789 and 194,533 acres, respectively) in the Willamette Valley than some of the largest pre-dam floods of 1861 and 1890 (each estimated at 320,337 acres of inundation). This decrease in flood size and frequency has resulted in diminished floodplain function (Gregory et al. 2002b). The reduction in peak flows; in combination with reduced channel migration (because of channelization via revetments) has contributed to changes in the community structure of riparian vegetation from a typical riparian vegetation mosaic to vegetation more characteristic of upland forests (Gutowsky and Jones 2000).

Not only do flood control dams and their reservoirs affect the magnitude of fall and winter high flows and flood events but they also affect timing of seasonal peak flows, spring flow levels and summer low flow levels (see Figure 17). The gage on the Middle Fork Willamette River at Jasper, Oregon is below four flood control dams and reservoirs (Fall, Lookout Point, Dexter, and Hills Creek). In preparation of winter flood events, reservoir waters are released in late fall, which shifts the annual peak flow at Jasper to November/December rather than January. The reservoirs are then refilled in late winter and spring for storage which causes a significant drop in river flows from about February through April. Summer and early fall releases from the reservoirs are higher than pre-dam low flows through the rest of the year. These shifts in timing of seasonal flows can affect migration patters, habitat availability, and increase erosion rates particularly through the summer.

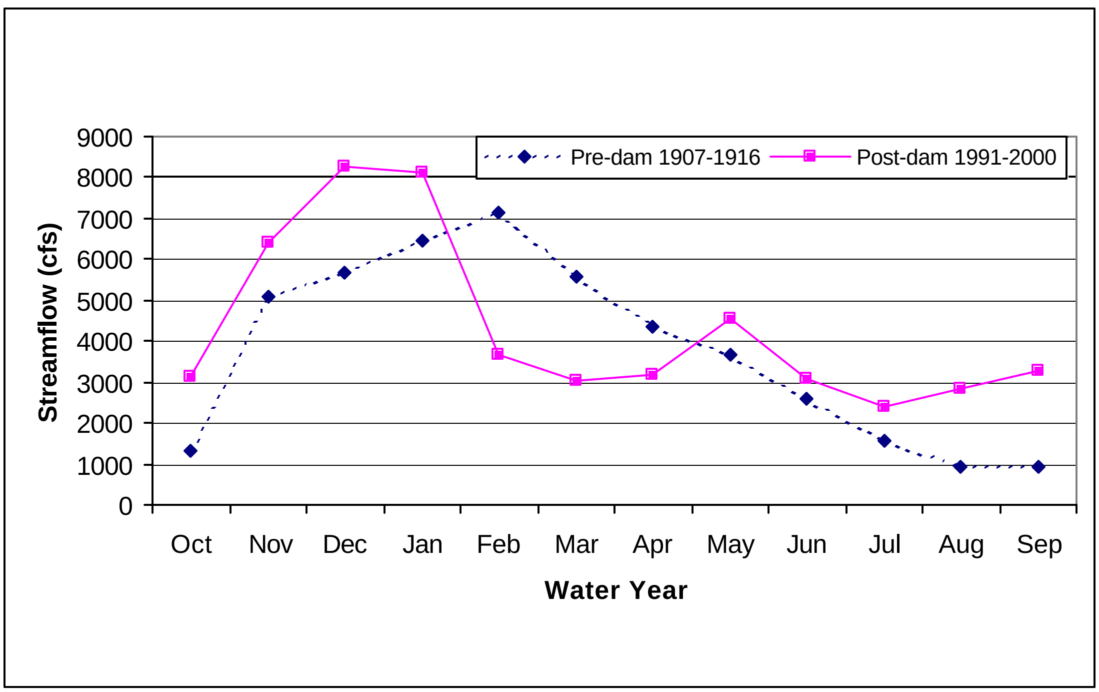

Figure 17. Mean monthly flows for the Middle Fork of the Willamette River at Jasper, OR before and after the construction of flood control dams and reservoirs. The more recent hydrograph shows the shift in the annual winter peak flows when reservoirs are drawn down, the decrease in late winter/spring flows when reservoirs are filled, and an increase in summer low flows. (Data from USGS gaging station number 14152000 at Jasper, OR, http://water.usgs.gov/nwis/sw).

The Columbia River Estuary is also affected by altered flows in both the Willamette River and the Columbia River due to the operation of hydropower and large storage dams. These dams have reduced historical (pre-dam) peak flows from winter snowmelt and runoff in late spring and summer. Prior to the construction of large storage dams, peak runoff from snowmelt occurred in late spring and early summer with lower flows for much of the rest of the year. Since the installation of dams, less seasonal variation in river flow occurs, peak flows have been greatly reduced, and flow amounts can vary within days depending on the human need to generate hydroelectric power. These changes in flow regime in the Columbia River affect the estuary at the mouth of the river (Bottom et al. 2001).

In summary, western Oregon has many dams; consequently, western Oregon Rivers are highly modified systems. Dams alter water quantity and flow in downstream rivers, which directly and indirectly impact salmonid populations in western Oregon.

Water Withdrawals by Diversions

Because the summer and early fall is historically a period of low flows and high stream temperatures, this period is critical for young salmonids in fresh water (Thompson and Fortune 1968). Summer and early fall is also when human demand for water for irrigation and other uses is at a maximum. During these periods of low flow, the availability and quality of instream habitat is reduced, temperatures are elevated, oxygen levels are low, fish are concentrated in pools where competition and predation are more intense, and stress and disease are more prevalent (Bottom et al. 1995). Bottom et al. (1995) concluded that low flows and high temperatures reach stressful levels during the summer in many of Oregon's salmonid streams and rivers, including Tillamook Bay drainages, mainstem of the Alsea, Siletz River, Siuslaw River, streams in the South Coast, and streams in the interior valleys of both the Willamette and Umpqua rivers. The combination of low flow and elevated temperature limits available salmonid habitat, thereby limiting salmonid production (Lichatowich et al. 1996).

In western Oregon, 537 stream miles (out of a total of 9,984 stream miles assessed in western Oregon) are included on the DEQ 303(d) list as *flow modified* because of withdrawals and low-flow conditions (DEQ 1994/1996; Appendix B). These *flow-modified* streams include many streams in the Willamette, Rogue, Umpqua, and coastal basins.

Diversions for irrigation, either by pumps or diversion ditches, are common in agricultural lands of Oregon (Figure 18). About one-half of the water withdrawn west of the Cascades is used for agriculture (SOER Science Panel 2000). In 1990, more than 75% of the water used in the Willamette Basin was from surface water, with irrigation being the largest single use (Wentz et al. 1998). Groundwater from a 3,700 square-mile aquifer system is a significant source of water in the Willamette Valley lowlands and is important in supplying the base flow for streams in the lowlands as well as water for human uses (U.S. Geological Survey 2000). The ground-water/surface-water connections, and the effects of groundwater withdrawals, are not well understood in the Willamette Basin (U.S. Geological Survey 2000), though groundwater withdrawals could reduce base flows.

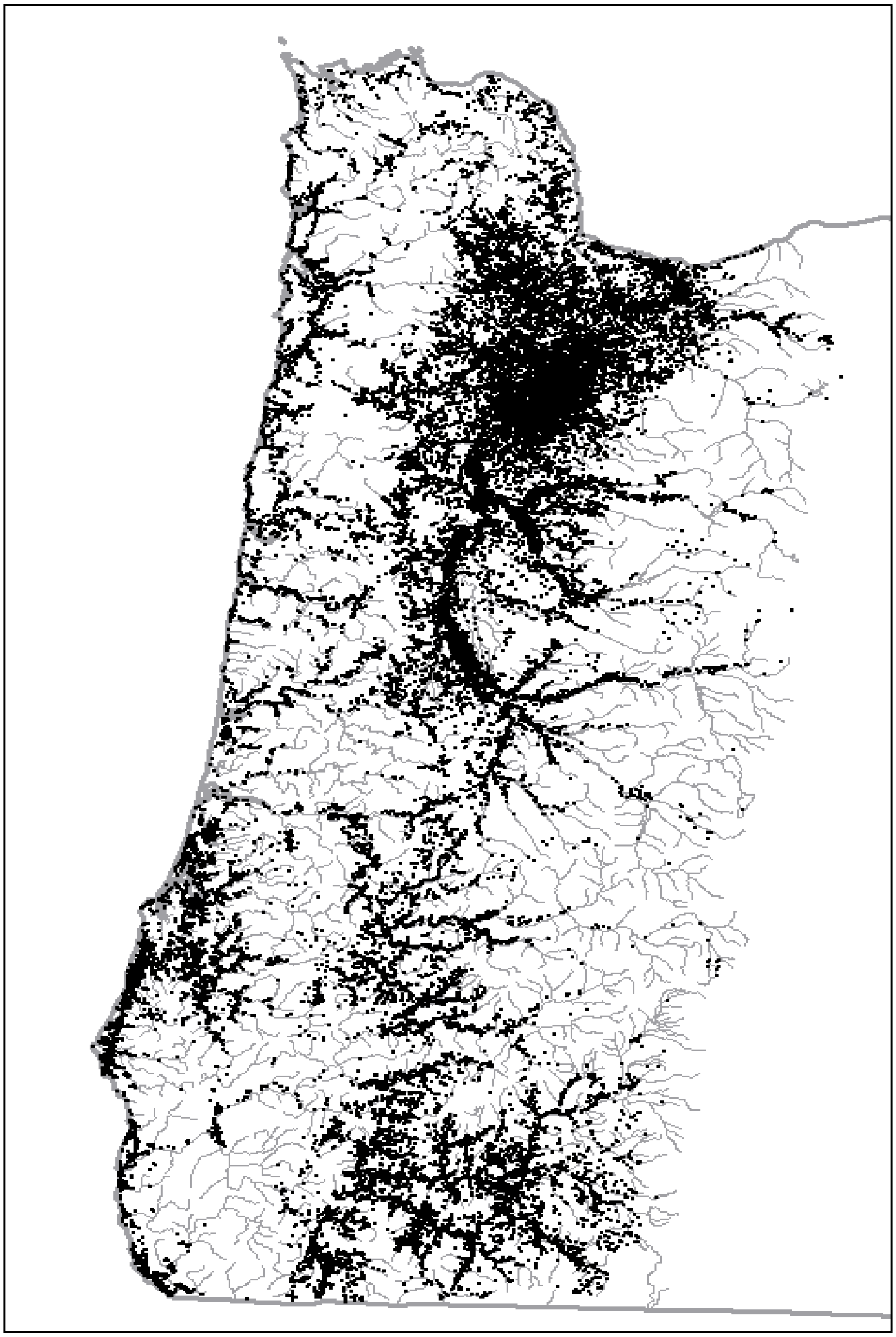

Figure 18. Points of water diversion in western Oregon. Black dotes denote single water divisions. Gray lines are streams and rivers (data from OWRD; http://www.wrd.state.or.us/maps/wrexport.html at http://www .wrd.state.or.us/).

Although only 10 percent of the land in western Oregon is in agriculture, most of that agriculture takes place in lowlands – valley floors of the Willamette, upper Rogue, Umpqua, Nehalem, Tillamook and Yaquina basins (Botkin et al. 1995). Fifty percent of western Oregon agricultural lands are irrigated (Botkin et al. 1995). The area of irrigated land has increased over time; for example, 285,000 acres in the Willamette basin were irrigated in 1987, compared with 27,000 acres irrigated in 1940 (Altman et al. 1997). Over 90 percent of agricultural water use in the Willamette basin is for irrigation (Altman et al. 1997).

During winter and spring months, most streams in western Oregon have enough water available for irrigation and other out-of-stream uses. However, during summer months, demands for water withdrawals for irrigation, municipal, residential, rural and industrial uses exceed available supply because most streams in Oregon are not gaining streamflow during the late summer and early fall low-flow periods (SOER Science Panel 2000). In addition, the amount of water for out-of-stream use is fully allocated, or over-allocated, during the late summer and fall low-flow periods in many Oregon streams (SOER Science Panel 2000).

In the western United States, water law developed in a different manner from the England-based water laws of the eastern seaboard. During settlement of the arid and semi-arid West, water was scarce and settlers and/or miners were few. Consequently, a hierarchical policy of decreasingly senior water rights based upon prior appropriation, the so-called "first in time, first in right" laws, evolved. Under the laws of Prior Appropriation, junior rights are subservient to more senior rights. Consequently, more water than is actually present in a river or stream may be claimed through a hierarchy of decreasingly senior rights, albeit the junior claimants may go unserved. Kiker (1974 p.382) described state and federal powers and authorities as follows: "Although the state governments have the greatest scope of powers relating to water rights, the federal government has substantial influence over water use based upon several constitutional powers (commerce-navigation powers, proprietary powers, war power, admiralty, treaty power, general welfare power and control of interstate relations)".

As we enter the 21st century, the question of *instream water rights* designated for fish habitat is being increasingly discussed. Yet under current law, instream rights are ranked according to their date of establishment. In most, if not all, cases, instream water rights are ranked junior in priority. And not all streams in western Oregon have instream water rights.

Streamflows that meet or exceed the indicated flow in eight out of ten years are referred to as *80% exceedance flow* (SOER Science Panel 2001). In the Willamette Basin, water is available for new appropriations only in the mainstem Willamette River. Other rivers and streams in the Willamette Basin do not have sufficient water to meet all water rights, including instream water rights, on an 80% exceedance basis (Parrow, pers. comm.[12]).

During the summer, many irrigators depend on water releases from upstream dams to meet their irrigation needs. However, water releases from dams do not always result in higher flows in the streams, because diversions of stream water to agricultural crops occur at the peak of the growing season, which is during summer when air temperatures and evaporation and transpiration are also high, resulting in reduced returned flows to streams (Spence et al. 1996). Although return flows from irrigation may recharge the aquifer, sometimes return-flows may be of diminished water quality because returning irrigation water often contains certain dissolved compounds, is a higher temperature than the stream, or contributes to increased erosion.

Although western Oregon agricultural fields are not commonly irrigated to the point of causing surface runoff during the summer, surface runoff from irrigated fields often contains sediments, nutrients and pesticides, and has decreased oxygen concentration (Spence et al. 1996). Irrigation water, withdrawn from streams or shallow aquifers, reduces summer base flows and lowers the water table, which lowers stream water volume and depth, and can also have detrimental effects on streamside trees, reducing growth and increasing mortality (Scott et al. 1998). Small streams used for

[12] Parrow, Doug. Personal Communication, 2001. Oregon Water Resources Department. Salem, Oregon.

rearing of salmonids do not function if channels are completely dewatered, exposing spawning beds, eggs and fry, and causing death of juvenile and adult salmonids.

Wetlands for Water Storage and Flow Mediation

Wetlands play an important role in storing water from winter floods, making water available for recharging groundwater aquifers, and later providing water to surface streams during summer low flows (SOER Science Panel 2000). Hydrologic alterations, such as dams, diversions, drainage-tile installation, and channelization (some discussion of channelization is in Question 2), have re-routed surface flows so that wetlands are no longer part of the hydrologic system in many basins. Drainage tile installation in wetlands may have altered hydrology by accelerating the draining of water in winter. Normally, wetland soils store water from winter rains, and slowly release the water over longer periods of time. Loss of wetlands has reduced the potential recharge of groundwater aquifers and reduced their ability to provide flow during dry summer and fall months, seasons when streamflow is critical to salmonids. Restoration of this water storage function (similar to "water banking") of wetlands in lowland valleys has the potential to augment low summer flows in salmonid streams. Wetlands also are important in slowing surface flow during high flows (Mitsch and Gosselink 2000).

The Willamette Restoration Initiative (WRI) identifies at least 7,000 acres of wetland that could be restored by 2050 with active conservation (WRI 2001). Small emergent wetland sites are scattered throughout the Willamette Valley and should be a focus of protection, along with the forested riparian zones (Titus et al. 1996). The Oregon Natural Heritage Program has identified high quality wetland remnants for protection, including sites on private lands along the Calapooia River, Muddy Creek, the North Santiam River, Luckiamute River, Kingston Prairie, the Mission Bottoms area, and the Bull Run Creek fragment (Titus et al. 1996). The Columbia Bottomlands (at the confluence of the Columbia and the Willamette) have also been identified for conservation (WRI 2001).

Fish Passage

Anadromous fish movement through tributaries to lowland rivers and estuaries, to and from the ocean is necessary for the completion of their life cycles. Botkin et al. (1995) and the National Research Council (NRC 1996) states that impediments to fish passage are an important factor in the decline of salmonids. Impediments to fish passage, including improperly designed fish ladders, push-up dams, culverts, tide gates, irrigation diversions, and fish hatchery barriers limit fish production. These obstructions contribute to loss of spawning and rearing habitats, salmonid population fragmentation (which decreases gene flow), and prevention of salmonid recolonization of headwater streams (Oregon Plan 1997, Mirati 1999, Nicholas et al. 1999).

In Oregon, many dams, culverts, irrigation diversions, and other impediments presently limit fish passage (Oregon Plan 1997). In 1995, fish surveys conducted in the Coast Range revealed that culverts associated with road crossings represented 96% of the barriers identified (Oregon Plan 1997). Between 1995 and 1998, many projects were completed to remove impediments to fish passage including replacement of improperly designed culverts and replacement of pushup dams with other methods of removing water. Thus far, these projects have made an additional 464 stream miles available (DEQ 2000a).

ODFW has also surveyed barriers to fish passage, other than culverts, and found 442 impediments that were impassable in western Oregon (ODFW unpublished data; Corrarino, pers. comm.[13]). In this survey, ODFW identified a number of types of impediments including dams, weirs, natural falls,

[13] Corrarino, Charlie. Personal Communication, 2001. Oregon Department of Fish and Wildlife, Portland, Oregon.

irrigation diversions, ponds, reservoirs, city water supply facilities, fish ways and fish ladders, hatchery intakes, concrete sills, log sills, power diversions, tide gates, logging culverts, lakes, rock cuts at falls, water control facilities, rock cut/blasted pools, and stop logs with screens.

In general, surveys for fish barriers do not investigate barriers located on agricultural lands (Lorensen, pers. comm.[14]). However, the Rogue Basin Fish Access Team did conduct an extensive survey for fish barriers, including culverts on private and federal lands (ODFW 2000a, 2000b). The team (which consists of representatives from state and federal agencies and from several citizen groups who are engaged in watershed restoration activities in the Rogue Basin) identified over 400 passage barriers, many of which were located on roads other than state or county roads (ODFW 2000a, 2000b).

In this section, we discuss the effect of fish ladders, small dams, culverts, tide gates, irrigation diversions, and fish hatcheries on fish passage in western Oregon lowland rivers and streams.

<u>Fish Ladders</u>

Dams without fish ladders are an impediment to fish passage. Large dams in the Willamette River system physically block fish passage and have contributed to losses in spawning and rearing habitat in the Santiam, McKenzie and Middle Fork Willamette rivers. These habitat losses have primarily affected native spring chinook and winter steelhead that historically used the tributaries above the dams (U.S. Army Corps of Engineers 1980, Nicholas et al. 1999).

Functioning fish ladders allow fish to pass dams and swim into upstream spawning and rearing habitat. Ineffective fish ladders become an obstacle to fish passage. Presently, no program assesses fish ladder effectiveness to determine which fish ladders need replacement or modification (Nicholas et al. 1999).

<u>Small Dams</u>

Small permanent dams and seasonal push-up dams are also barriers to fish passage, both for upstream migrating adult salmonids and downstream migrating juveniles. Push-up dams are typically made of gravel and other material from the streambed or banks (but can also include logs, lumber, large rocks, or other material pushed up by earth-moving equipment). They temporarily divert water from the river channel for irrigation. Most push-up dams restrict flows seasonally. Push-up dams may be critical migration barriers, especially for chinook salmon and steelhead, during late summer, low-flow conditions, and for steelhead during spring in low water years. In addition to blocking fish passage, push-up dams can contribute to erosion, changes in stream channel form, degraded water quality (e.g. temperature), and fine sedimentation of redds (Bottom et al. 1985). The use of push-up dams in Western Oregon occurs primarily in southwest Oregon, with more than 300 push-up dams in the Rogue Basin, which limit fish passage (Nicholas et al. 1999).

Many alternatives to push-up dams are available, as has been demonstrated in the Illinois River Valley in southwest Oregon by the Illinois Valley Watershed Council (Nicholas et al. 1999). Some of these alternatives include pumping stations, infiltration galleries, screen boxes, ponds and other water storage adjacent to streams, and single point of diversion for multiple users. In the Illinois River Basin pilot project, eight push-up dams were replaced in 1999, with plans to remove 10 or 12 others (Nicholas et al. 1999). Lack of water resource engineers, funding, and technical support have been identified as obstacles to replacing push-up dams (Nicholas et al. 1999).

[14] Lorensen, Ted. Personal Communication, 2002. Oregon Department of Forestry, Salem, Oregon.

Culverts

In a 1999 survey of all culverts on state and county roads, ODFW and ODOT identified 4,167 culverts in Western Oregon (in Coastal Basins and the Willamette Basin), 2,357 of which are impassable by fish (Table 10). There are over 4,000 stream miles above these culverts presently inaccessible to migrating fish. In addition, ODFW rated the habitat quality and priority for repair or replacement for each impassable culvert. A total of 300 culverts at road crossings were improved for fish passage on private and state forestland in 1998, opening up about 200 miles of streams on private industrial forestland (Nicholas et al. 1999). Fifty ODOT culverts were improved in 1999, providing access to over 130 miles of streams (Nicholas et al. 1999).

Table 10. Culverts on State and Country Roads in Western Oregon (includes Coastal Basins and in the Willamette Basin (Mirati 1999; summarized by ODFW 2000a)

	Fish Passage			Habitat Quality Upstream from Culvert					Priority					Stream Miles Above Culverts
	No	Yes	Total	Good	Fair	Poor	Unk	Total	H	M	L	Unk	Total	
Benton	136	87	223	89	36	7	2	134	21	87	27	0	135	146.15
Clackamas	131	151	282	34	56	4	35	129	16	79	34	0	129	236.2
Clatsop	109	46	155	42	36	15	14	107	22	26	60	0	108	177.3
Columbia	89	80	169	19	49	9	7	84	17	29	38	0	84	144.6
Coos	131	79	210	22	42	59	8	131	25	26	80	0	131	198.05
Curry	61	7	68	3	29	26	0	58	2	9	45	0	56	86.7
Douglas	223	126	349	0	128	92	2	222	64	68	93	0	225	639
Jackson	157	84	241	0	31	62	64	157	4	16	124	0	144	595.5
Josephine	145	40	185	2	51	71	21	145	8	18	114	0	140	246.15
Lane	310	152	462	116	63	21	110	310	96	104	108	2	310	578.39
Lincoln	193	87	280	60	113	20	1	194	52	79	63	0	194	114.9
Linn	124	210	334	36	22	3	63	124	3	64	56	0	123	268.5
Marion	93	205	298	13	44	10	26	93	0	47	46	0	93	125.4
Multnomah	59	47	106	8	45	6	0	59	4	29	27	0	60	97.2
Polk	86	77	163	21	59	6	0	86	3	48	35	0	86	144.8
Tillamook	157	75	232	13	49	67	33	162	10	22	130	0	162	230.4
Washington	51	160	211	6	38	5	3	52	8	17	26	0	51	107.7
Yamhill	102	97	199	27	70	5	2	104	2	55	45	0	102	153.75
TOTAL	**2357**	**1810**	**4167**	**511**	**961**	**488**	**391**	**2351**	**357**	**823**	**1151**	**2**	**2333**	4290.69

Tide Gates

Tide gates are common in diked tidal areas in Oregon’s estuaries. They close when the tide comes in to prevent or retard intrusion of salt water into agricultural land at high tides, and they open when the tide goes out. Consequently, tide gates may impede migration of salmonids and impede use of estuarine habitats and marshes.

Currently tide gates in coastal estuaries have not been inventoried; and few studies have evaluated how tide gate modification will improve conditions for salmonids (Nicholas et al. 1999). ODFW estimates that 90% of the tide gates in western Oregon are in the Coos/Coquille Basin and Tillamook Basin, and suggests a need to better understand their effects and how to improve their function to facilitate fish passage (Corrarino, pers. comm.[15]). Replacement with a type of tide gate that allows fish to pass into previously unavailable habitat has resulted in use of off-channel, marsh habitats by juvenile coho and chinook salmon, and cutthroat trout (Slater, pers. comm.[16]).

Irrigation Diversions

Juvenile and adult salmonids are often killed when they are inadvertently routed through unscreened water intakes at water diversion structures and stranded in irrigated fields. Nichols (1990) identified over 40,000 surface water diversions in western Oregon where surface water is removed from rivers and streams, primarily for agriculture. Unfortunately, the vast majority of diversion structures were found to be unscreened (over 98%), and, as a result, they may have significant impacts on fish populations in western Oregon lowlands. Sixty-two percent of these water diversions were for irrigation. Nichols (1990) identified 1,300 unscreened water diversions on Oregon coastal rivers that potentially affect salmonid rearing streams.

Fish screens on water intakes can prevent hundreds and thousands of fish each year from being stranded by water diversions. Throughout Oregon, about 200 fish screens were installed in irrigation diversions in 1999 (Nicholas et al. 1999). ODFW has a ten-year plan to screen about 3,000 high priority water diversions. An unknown number of diversions above push-up dams are unscreened if they have an old water right. New water rights require screening. Irrigation diversions seem to have a great potential for impacting fish, but little research has investigated these potential impacts.

Fish Hatcheries as Barriers

Electric fences, gates, and weirs have been constructed in association with the operation of some fish hatcheries. These barriers can prevent wild salmonids from migrating to historic spawning grounds and juvenile rearing habitat. As of May 2001, ODFW had conducted an inventory of the barriers associated with fish hatcheries in Oregon, listing which fish hatcheries had barriers, the type of barrier that was constructed, the amount of habitat restricted from use by salmonids, the fish species affected, and the seasons when the fish were blocked (Holt, pers. comm.[17]). This list of barriers will be evaluated and prioritized by ODFW Fish Division staff and incorporated into the statewide barrier process document as identified and consistent with HB 2540. For the whole state of Oregon, barriers associated with fish hatcheries block approximately 800 miles of streams. Most of these hatcheries are in western Oregon lowlands.

Water quality

In general, salmonids need cold, oxygenated, clean, clear water. This portion of the report focuses on stream temperature, dissolved oxygen, pesticide and nutrient inputs, and water turbidity.

Water Quality and the Recovery of Salmonid Stocks

Input of physical and biological substances into streams and rivers can have a positive, neutral, or negative effect. To maintain water quality, consideration must be given to both magnitude and frequency of inputs, as well as to the inherent ability of an aquatic ecosystem to process these inputs.

In natural systems, periodic disturbances contribute large material inputs, such as massive inputs of sediment from large landslides. However, such inputs are generally episodic (i.e. in one location at a time on an infrequent basis). Within natural ranges of variability, one part of the landscape may be affected, while other parts of the landscape are not affected. This type of episodic input allows for a

[15] Corrarino, Charlie. Personal Communication, 2001. Oregon Department of Fish and Wildlife. Portland, Oregon.
[16] Slater, P. Personal Communication, 2001. Coos County Highway Department, Coquille, Oregon.
[17] Holt, Rich. Personal Communication, 2002. Oregon Department of Fish and Wildlife, Portland, Oregon.

stream system to recover from the disturbance over time and can result in a range of habitat conditions for local salmonids.

In contrast, chronic inputs (i.e. inputs that occur most of the time and throughout the entire landscape) can be detrimental to salmonids. Material inputs resulting from some land uses (e.g. road construction, water withdrawals, vegetation removal, or intensive tillage) may be chronic and, therefore, may negatively impact aquatic biota if these alterations result in greater than background levels of organic matter, inorganic nutrients, chemicals, or sediment inputs. In some circumstances, chronic alterations in material inputs overwhelm the ability of the stream ecosystem to process the inputs and maintain adequate water quality.

Status of Water Quality in Western Oregon Lowlands

The Oregon State of the Environment Report states that Oregon's land use laws, coastal zone management, forest practices rules and federal land management rules have aided in upland, coastal, forest and rangeland management, as well as habitat protection, and biodiversity (SOER Science Panel 2000). However, western Oregon lowlands, riparian zones and wetlands still face environmental challenges (SOER Science Panel 2000). The Oregon State of the Environment Report indicates that while water quality in streams throughout Oregon is adequate during high flow periods, water quality is poor or very poor during low-flow periods (SOER Science Panel 2000).

To make waters fishable and swimmable, the U.S. Clean Water Act of 1972 requires states to set quality standards for physical, chemical and biological criteria (including temperature, flow, suspended solids, pH, nutrients, dissolved oxygen, macroinvertebrate and fish abundance and diversity). The U.S. Safe Drinking Water Act defines stricter standards for drinking water, focusing on: microorganisms (fecal coliform), inorganics (nitrates and metals), and organics (volatile organics, petroleum compounds, and pesticides). The quality parameters for drinking water are also important to the health of salmonids because the high standards for water quality can improve ecosystems that salmonids live in, and food sources on which salmonids depend. However, Bauer and Ralph (2001) concluded from their work that habitat indicators (as currently required under the Clean Water Act) do not adequately measure the physical stream characteristics and life history requirements for fish, other biota, and salmonids (i.e., habitat characteristics, sediment substrate quality, stream bank stability, flow, etc).

In Oregon, the Department of Environmental Quality (DEQ) is the state agency responsible for assessing water quality and enforcing water quality standards to comply with the Clean Water Act and the Safe Drinking Water Act. Under the U.S. Clean Water Act, DEQ designates streams as *water quality limited* under the requirements of section 303(d) (water quality standards listed in Appendix A). The Clean Water Act also requires that, for streams designated as *water quality limited*, DEQ must establish Total Maximum Daily Loads (TMDLs) that identify the level of pollution allowed in a stream without violating water quality standards. In the TMDL process, this level of pollutant is allocated to point sources and non-point sources after determining what level of pollutant is considered natural. Some level of pollutant allocation is reserved for a margin of safety, which may accommodate future human developments. Designated management agencies (such as Oregon Department of Agriculture and Oregon Department of Transportation) develop implementation plans to meet these allocations.

Oregon Senate Bill 1010 requires that the Oregon Department of Agriculture assist in the development of Agricultural Water Quality Management Plans (AgWQMAPs) for non-point source pollution control for all streams in agricultural land that are on the EPA 303(d) list, and to address TMDL load allocations (ODA 2000). The Oregon Department of Transportation and Oregon

Department of Forestry also have some responsibility in managing the water quality impacts of their regulated activities.

DEQ monitors water quality at 148 monitoring sites throughout Oregon (six times per year in most sites and twice per year in far eastern Oregon) in order to establish water quality trends (Fonseca, pers. comm.[18]). The monitoring stations are typically in larger rivers and the data collected are reflective of long-term trends. Many of the older monitoring sites are in major rivers and downstream from urban areas and other developed or industrial sites. Monitoring sites are located where the data integrate or reflect upstream conditions. Beginning in the 1970s, monitoring stations have been installed in smaller basins and coastal basins (Caton, pers. comm.[19]).

Data from monitoring sites, along with data from other agencies and organizations, are used to develop the 303(d) listings. The Oregon Department of Environmental Quality, US Forest Service, Bureau of Land Management, US Geological Survey, US Environmental Protection Agency, and watershed councils have contributed data for the 1994/96 and 1998 303(d) lists. Municipalities will contribute data for the 303(d) listings in 2002. As each new assessment is completed, some stream segments may be added or removed from the list for particular water quality parameters. Water quality problems may also exist in streams that have not yet been monitored (Fonseca, pers. com.). In addition to ambient monitoring, Oregon DEQ also conducts "probabilistic" monitoring to investigate biological and habitat conditions, and special studies to provide in-depth investigations of potential water quality (Fonseca, pers. comm.).

A significant number of streams in western Oregon are listed on the DEQ 303(d) list for not meeting water quality standards for toxics, bacteria, dissolved oxygen, temperature, flow, pH, aquatic weeds and algae. In 1994/96, approximately 30% of the stream miles in western Oregon were assessed for their water quality (Figure 19). For each water quality parameter, Table 11 presents the 303(d) listed stream miles, and the stream miles for which data are needed or are of potential concern. Much of the mainstem of the Willamette River and its tributaries do not meet water quality standards for bacteria, dissolved oxygen concentrations, nutrients, pesticides, temperature and toxins (WRI 2001). A detailed summary of listed stream miles by watershed is in Appendix B.

[18] Fonseca, Marilyn. Personal communication, 2001. Oregon Department of Environmental Quality. Portland, Oregon.
[19] Caton. Larry. Personal Communication 2001. Oregon Department of Environmental Quality. Portland, Oregon.

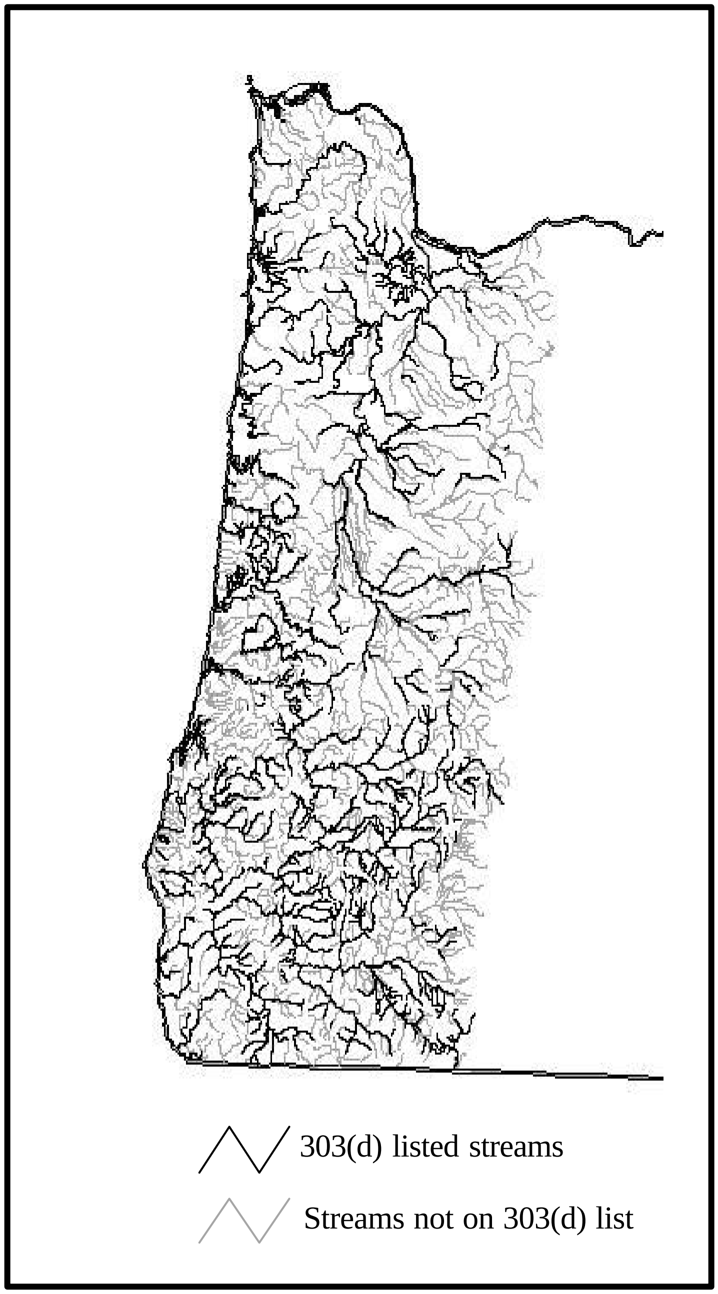

Figure 19. Map of 303(d) listed streams in western Oregon. (Data sources: *State Boundary*: USGS, 1:2,000,000; and *Rivers:* (or rivers), EPA, 1:250,000 Oregon GeoSpatial Data Clearing House, Oregon Department of Administrative Services: http://www.sscgis.state.or.us/; 303d *listed streams*: 1:1,000,000; 2/6/01; USGS, other Federal and State agencies and the northwest Tribes Pacific Northwest River Reach data layer, DEQ http://waterquality.deq.state.or.us/wq/303dlist/D303_98.htm)

Table 11. Summary of water quality for western Oregon streams
(9,984 stream miles assessed out of a total of 32,630 stream miles in western Oregon)
Summarized from 1994/96 Oregon DEQ 303(d) list Database.

Water Quality Parameters (Measured by DEQ)	**303(d) listed (Stream Miles)**	Percent of Total Stream Miles (32,630)	Percent of Stream Miles Assessed (9,984)	**Potential Concern (Stream Miles)**	Percent of Total Stream Miles (32,630)	Percent of Stream Miles Assessed (9,984)	**Meets Standards (stream miles)**	Percent of Total Stream Miles (32,630)	Percent of Stream Miles Assessed (9,984)
Aquatic Weeds	205	0.63%	2.05%	33	0.09%	0.33%	1860	5.70%	18.64%
Bacteria	1724	5.29%	17.27%	327	0.89%	3.28%	2296	7.04%	23.00%
BioCriteria	287	0.88%	2.88%	55	0.15%	0.56%	NE	NE	NE
Dissolved Oxygen (DO)	536	1.64%	5.37%	364	1.00%	3.65%	2347	7.20%	23.52%
Flow Modification	537	1.65%	5.38%	1248	3.41%	12.51%	NE	NE	NE
Habitat Modification	371	1.14%	3.72%	2642	7.21%	26.46%	NE	NE	NE
Nutrients	40	0.12%	0.41%	478	1.31%	4.80%	41	0.13%	0.42%
PH	438	1.35%	4.40%	4	0.01%	0.04%	2574	7.89%	25.78%
Sediment	298	0.91%	2.99%	3214	8.78%	32.20%	NE	NE	NE
Temperature	4000	12.26%	40.07%	1881	5.14%	18.84%	1349	4.14%	13.52%
Total Dissolved Gas (TDG)	142	0.44%	1.43%	19	0.05%	0.19%	NE	NE	NE
Toxics	349	1.07%	3.50%	1242	3.39%	12.45%	NE	NE	NE

Because many stream segments are on the 303(d) list for one or more parameters and are also identified as being of potential concern or for meeting the standards for other parameters, the number of stream miles in each column can not be summed to determine total miles assessed without double counting many stream segments.
NE = Not Evaluated
Note: 1998 data are currently available from DEQ in an unsummarized form. 2002 data will be available later this year at http://www.deq.state.or.us/wq/303dlist/303dpage.htm

Table 11 indicates that 9,984 stream miles out of 32,630 stream miles were assessed in western Oregon. The following stream miles in western Oregon were included on the 1994 DEQ 303(d) list as *water quality limited*:

537 stream miles because of withdrawals and low-flow conditions,
4000 stream miles because of warm water temperatures,
536 stream miles because of low dissolved oxygen concentrations,
349 stream miles for containing high concentrations of toxics,
40 stream miles for containing high concentrations of nutrients,
298 stream miles for being too turbid.

The *Oregon Water Quality Index* summarizes water quality in Oregon. This index is a sum of the scores of eight water quality parameters: temperature, dissolved oxygen, biological oxygen demand, pH, ammonia+nitrate nitrogen, total phosphorus, total solids, and fecal coliform (SOER Science Panel 2000, Cude 2001). Water quality in coastal Oregon streams, as indicated by the Oregon Water Quality Index is summarized in Figure 20 (DEQ 2000a). In the Oregon coast ecoregion, sampling sites with excellent water quality were in the Alsea, Necanicum, Siletz, Winchuck and Youngs River.

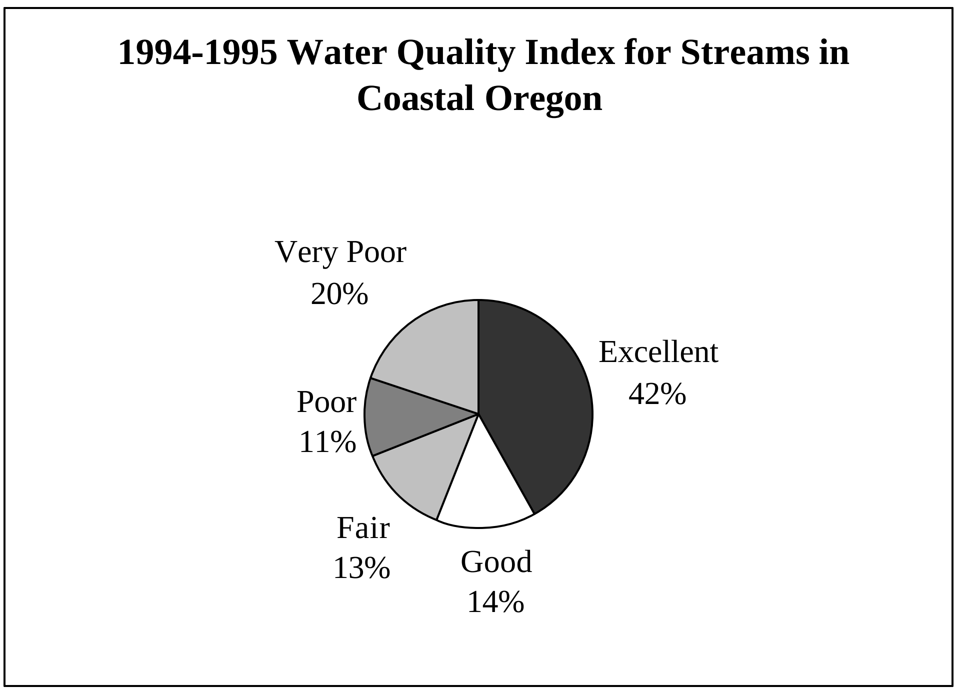

Figure 20. Water quality as determined by the Oregon Water Quality Index for in coastal Oregon streams (after DEQ 2000a).

In the Willamette Valley, 55 sites averaged poor water quality for the *Oregon Water Quality Index* during both low and high flow periods (SOER Science Panel 2000). In the Willamette basin, sampling sites with excellent water quality were in the Middle Fork Willamette, Lower McKenzie, Lower North Santiam, Row, and South Santiam Rivers (SOER Science Panel 2000).

<u>Water Temperature</u>
Scientists are investigating the physical and biological responses of organisms to stream temperatures. This research sets EPA water quality standards for temperature (DEQ 2000d; standards listed in Appendix A). Salmonids inhabit cold-water streams and rivers. EPA currently

sets 303(d) water temperature standards at 55^{o} F for spawning salmonids, and 64^{o} F for juvenile salmonids (DEQ 2000d).

Most *water quality limited* Oregon streams and rivers are listed because, at some point each year, they become too warm to meet EPA temperature standards (DEQ 2000d). Of western Oregon streams assessed for water temperature, forty percent reach temperatures too warm to be optimal for salmonids (Table 11) (DEQ 1994), and some streams occasionally reach water temperatures high enough (mid to high 70^{o} F) to kill salmonids within hours or days (DEQ 1995).

Temperature Tolerances of Salmonids
"Fish are metabolically efficient only at temperatures within their preferred range" (DEQ 1995; p. 2-3). Salmonids are cold-water fish, and require cool temperatures for optimal growth, metabolism, and survival. Very high temperatures sometimes cause all physical activity, such as feeding and swimming to cease, thereby leading to death (DEQ 1995). However, moderately high temperatures also affect salmonid survival, making salmonids more susceptible, for example, to diseases that thrive at temperatures outside the fish's optimal temperature range.

For each salmonid species, temperature requirements vary with the developmental stage. Figure 21 and Table 12 summarize numerous studies and present temperature requirements for each stage in the life cycle of spring chinook: egg incubation, alvelin incubation, fry emergence, juvenile rearing, smoltification (outmigration), adult migration, adult holding, and spawning (DEQ 1995).

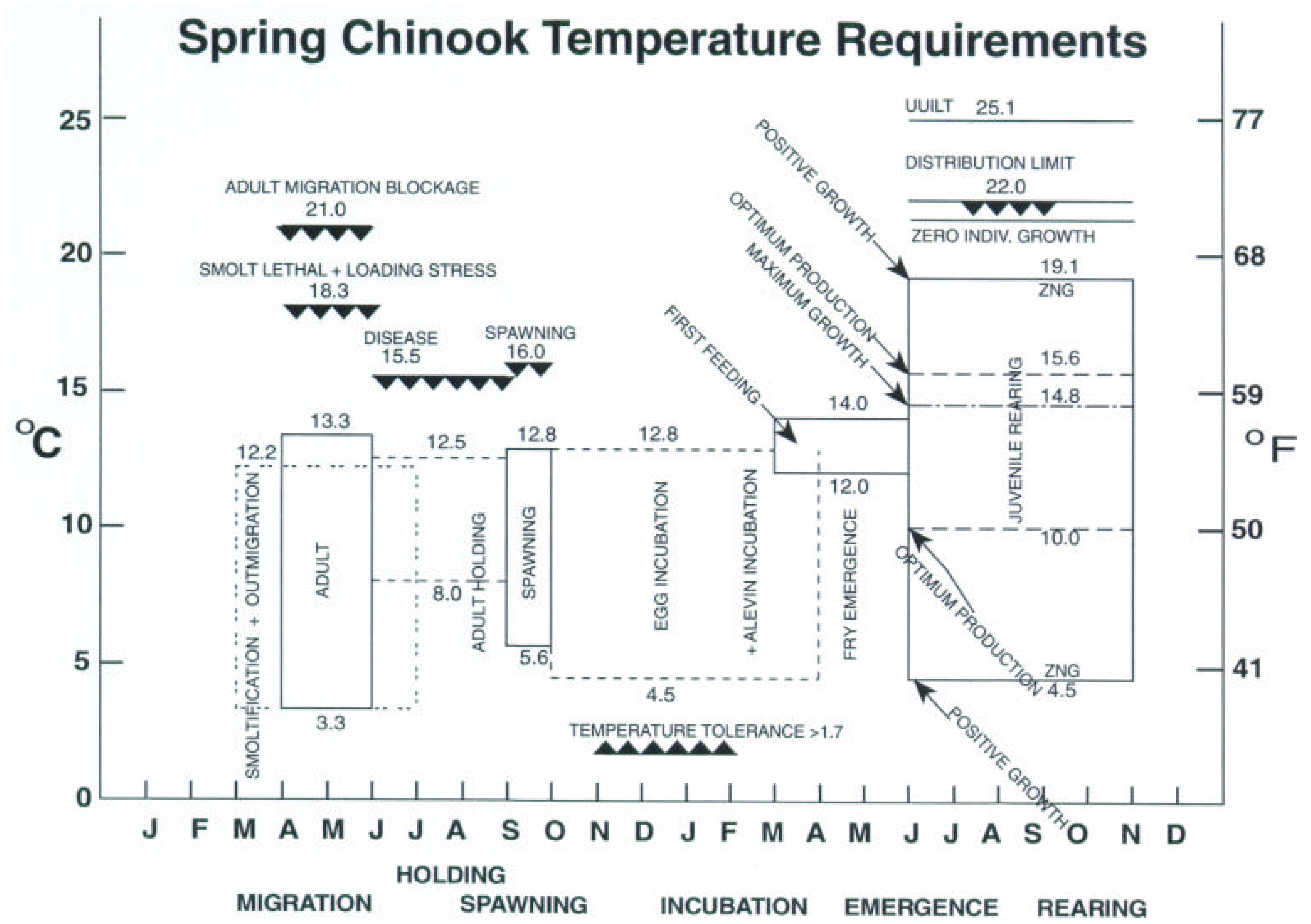

Figure 21. Spring chinook temperature requirements at each life stage – from upstream migration of adults to downstream migration of next-generation smolts (DEQ 1995, McCullough 1999).

Table 12. Temperature ranges for spring chinook salmon at each life stage as modified from DEQ (1995). EPA temperature standards for salmonid streams and rivers are also presented (as listed in Appendix A).

Spring Chinook Developmental Stage	**DEQ Temperature for spring chinook**	**EPA Temperature for salmonids**
Adult migration and holding	Below (55) 56^{o} F	--
Spawning, egg, alvelin	42 -55^{o} F	55^{o} F
Juveniles	50 - 60^{o} F	64^{o} F
Smolt (outmigration)	54^{o} F	--

Coho salmon need cooler temperatures for spawning than chinook salmon; however, other life stage temperature requirements are similar between these two species (DEQ1995). In general, salmonid life stages that occur in summer and early fall (especially adult holding, spawning, and juvenile rearing) are the stages most in danger of encountering stream temperatures that are too warm. Water temperatures exceeding 70^{o} F have been known to cause migration blockages of salmonids (DEQ 1995).

Several mechanisms may explain the ability of some members of salmonid populations to exist at higher than expected water temperatures. The first mechanism is a physiological adaptation (acclimation) of some individual fish to survive exposures to high temperatures. A second possibility is that diel (24-hr period) fluctuations of water temperature may provide an average water temperature below the seven day running average of maximum temperatures needed to designate 303(d) listings for streams. A third possibility is that streams might contain cooler microhabitats to which fish may migrate. Streams and rivers are naturally composed of a mosaic of temperatures; therefore, even if a river is too warm, the river may contain pockets of cool water. However, the availability of cold-water microhabitats may restrict salmonid habitat within the river, thereby increasing competition among fish at microsites and enhancing disease transmission. These three proposed mechanisms are speculative, and substantial experimental research is necessary to determine their influences on fish in different stream systems (IMST 2000a).

Although not indicative of optimal temperatures for salmonids, numerous rigorous laboratory experiments (such as Brett 1952, Hokanson et al. 1977, Bell 1986) have determined the highest laboratory water temperatures tolerated by cold-water fishes, including salmonids (Table 13). In these experiments, fish are acclimated in tanks to survive at high temperatures outside of the optimal range for that fish species. After acclimation, the fish are then plunged into very high water temperatures. The temperature at which 50 percent of the fish die within 24 hours is called the *upper incipient lethal temperature* (DEQ 1995).

Table 13. Lethal temperature limits of cold-water fishes including Pacific salmonids. This table is a composite of three different studies

(Brett 1952, Hokanson et al. 1977, Bell 1986)
(Summarized by ODF/DEQ 2000; p. 15)

Modes of Thermally-Induced Cold Water Fish Mortality		
Instantaneous Lethal Limit – Denaturing of bodily enzyme systems	> 90º F	Instantaneous Death
Incipient Lethal Limit – Breakdown of physiological regulation of vital bodily processes, namely: respiration and circulation	70º F to 77º F	Hours to Days till Death
Sub-Lethal Limit – Conditions that cause decreased or lack of metabolic energy for feeding, growth or reproductive behavior, encourage increased exposure to pathogens, decreased food supply and increased competition from warm water tolerant species	64º F to 74º F	Weeks to Months till Death

Lethal temperatures for fish are a function of the temperature to which the fish were acclimated and the developmental stage of the fish (DEQ1995). The *upper incipient lethal temperatures* for Oregon salmonid species are generally as follows: chinook 77^o F; coho 77^o F; sockeye 74^o F; and steelhead 70^o F (DEQ 1995). The results of these laboratory tests identify water temperatures that would kill most salmonid individuals in a river or a stream unless they migrated out of that stream.

Rather than just avoiding lethal temperatures for salmonids, land managers are encouraged to strive to return rivers and streams to optimal water temperatures. Temperature mediation can be accomplished through restoration of such ecosystem functions as streamside shade, low stream width-to-depth ratios, infiltration of groundwater, and habitat complexity that provides pockets of cool water.

Environmental Influences on Water Temperatures

The average temperature of a stream or river is determined by complex interactions among physical and biological factors in the surrounding environment. In general, four major types of environmental factors affected by land-use practices influence stream temperatures: riparian vegetation, channel morphology, surface and sub-surface flows, and water quantity (IMST 2000a).

Temperature Models

These factors can be incorporated into computer models to examine land-use effects on water temperatures. Modeling of stream temperatures can provide insights on how various factors and their interactions may affect temperature. Models also can be investigative tools for comparing management options.

The TMDL plans for several basins in western Oregon (including: South Fork Coquille, Tillamook Bay, and Tualatin Subbasin) have utilized modeling to predict potential stream temperatures under various management scenarios (DEQ 2000b, DEQ 2000c, DEQ 2001). Riparian vegetation, channel morphology, hydrology, climate, and geographic location all influence stream temperatures. However, because climate and geographic location are outside of human control (and are not affected by human land use activities), they are not manipulated in TMDL stream temperature models. TMDL temperature models focus on predicting changes in stream temperature in response to modification of one or more of the following environmental factors:

1. Riparian vegetation (vegetation height, width, and density)
2. Channel morphology (channel width and depth)
3. Hydrology
    a. Water exchange (temperature of tributaries and groundwater)
    b. Water volume (water quantity)

Riparian Vegetation and Channel Morphology

The current condition of each basin TMDL model was based on field sampling and mapping of stream temperature, riparian vegetation, and channel width. The scientists then developed an estimate of potential riparian vegetation (based on site potential for height, width, and density), and adjusted channel dimensions (width and depth). The TMDL temperature models predict that in a given site as shade increased (due to more riparian vegetation and narrower stream width), stream temperature increase would be moderated (DEQ 2000b, DEQ 2000c, DEQ 2001). Figure 22 presents simulated current and potential water temperature conditions of one river in the Tillamook Bay watershed (DEQ 2000c).

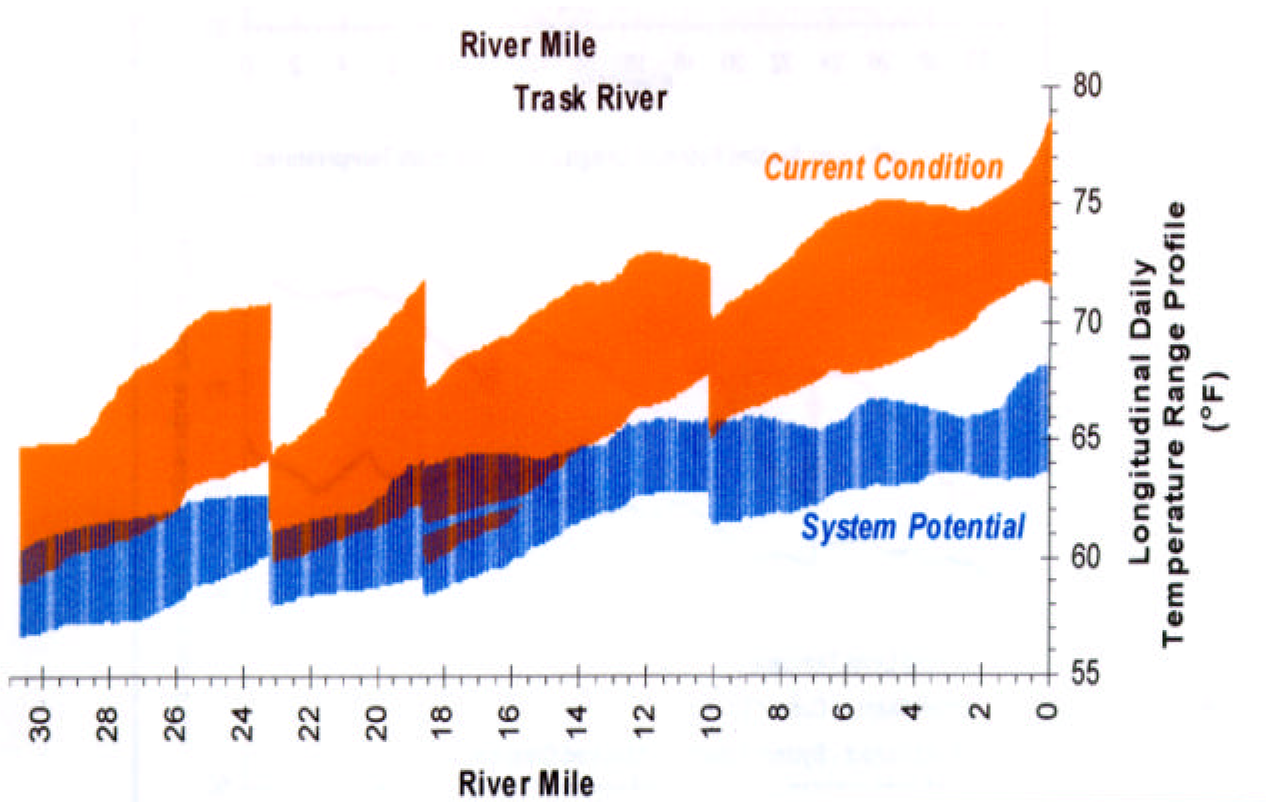

Figure 22. Simulated water temperature range profile for one day (12 August 1998) on the Trask River in Tillamook Bay watershed. Current condition and system potential are modeled and predicted based on riparian vegetation and channel dimension parameters in the TMDL temperature model (DEQ 2000b).

Exchange Between Surface and Subsurface Water
At Oregon's latitude, groundwater remains at a relatively constant temperature (ranging from about 45 to 55^o F) during the course of the year. Therefore, if water can be delivered subsurface through interflow, ground water flow, or hyporheic flow, the water will arrive to the stream at a temperature of approximately 50^o F (Stringham et al. 1998). Since waters generally warm as they travel downstream (and lowland streams tend to be warmer than upland streams due to their gentle gradient and wide valleys), waters entering a stream need to be as cool as possible. Therefore, cool groundwater inputs are an important factor for maintaining cool stream temperatures in the TMDL temperature models. Results of the TMDL temperature models indicate that cool tributary temperatures and improved shading from riparian vegetation are important for maintaining cooler river temperatures (DEQ 2000b, 2000c, 2001).

Water Quantity
The results of these TMDL temperature models indicate that increasing water quantity (due to flow augmentation and restricting water withdrawals) is important for influencing stream temperatures (DEQ 2000b, 2000c, 2001). As water volume and water column depth decrease, penetration of solar radiation and back radiation from the sides and bottom of the channel are more significant in warming a stream. A combination of low-flow and elevated stream temperatures may limit salmonid production by reducing the amount of habitat available (Lichatowich et al. 1996).

Point Sources
Some TMDL temperature models also include point sources. Point sources are any major permitted facility, such as sewage treatment plants and pulp mills (Boyd, pers. comm.[20]). As noted in the Tualatin TMDL temperature model, sewage treatment plants are sources of warm water discharge into lowland rivers (DEQ 2001).

Application
Models, such as the ones developed for the TMDLs, are tools that explore relationships, develop hypotheses, and test the effects of land management decisions on a landscape. However, all ecological models have limitations when applied to a real ecosystem, because models, while attempting to understand the impact or interactions of certain environmental factors, simplify complex ecosystems. However, models can still have managerial value, particularly in pointing out significant landscape factors that affect streams, and testing these effects under various modeled conditions.

<u>*Summary of Environmental Influences*</u>
Stream temperature is a product of complex interactions between geomorphology, soil, hydrology, vegetation, and climate within a watershed (IMST 2000a, IMST 2001). Human activities typically influence stream temperature by affecting one or more of four major components of stream ecosystems: riparian vegetation (humidity, shade, streambank stabilization), channel morphology (channel width/depth), hydrology (water quantity and streamflow), and surface/subsurface interactions (groundwater).

Dissolved Oxygen as Related to Water Temperature
Dissolved oxygen concentrations are a critical feature in salmonid health. Salmonids evolved in and depend on oxygen-rich, cold-water streams (Baker et al. 1995, DEQ 1995, ODF and DEQ 2000, McCullough et al. 2001).

---

[20] Boyd, Matt. Personal Communication, 2002. Oregon Department of Environmental Quality, Portland, Oregon.

Water temperature and dissolved oxygen concentrations are inversely related; as water temperatures become higher, the amount of dissolved oxygen is reduced. This situation causes stress for cold-water fishes (Gordon et al. 1992, Konecki et al. 1995, Beschta 1997, Matthews and Berg 1997). Other factors also affect dissolved oxygen concentrations in stream water, including atmospheric pressure, stream turbulence (wind stress and water mixing), amount of organic matter, and photosynthetic and/or respiratory activity of stream organisms (DEQ 2000a).

As indicated in the previous section on temperature, many streams in western Oregon do not meet water quality standards for temperature. Therefore, given the close association between temperature and dissolved oxygen, dissolved oxygen concentrations are probably low in these high temperature streams. Improving water temperatures in streams will also improve dissolved oxygen concentrations in many streams, especially those streams that do not receive organic matter-rich discharges from industrial, agricultural, and municipal sources (as discussed in the nutrient section of this question).

Vegetation Management and Stream Temperature
Establishing upland and riparian vegetation can be an important management tool for maintaining cool stream temperatures and enhancing overall water quality (see TMDL models). The ecological functions of riparian vegetation are discussed in more detail in Question 4. The influence of upland and riparian vegetation on stream temperature varies substantially across the landscape. Therefore, site-specific information is critical to understanding stream temperature responses to human alteration of riparian vegetation. In general, more extensive riparian vegetation ameliorates solar heating and maintains cool water temperatures (IMST 2000a).

In some circumstances, riparian vegetation directly affects stream temperature by shading the stream, thereby reducing water heating. Additionally, riparian vegetation can indirectly reduce stream temperature by affecting microclimate, channel morphology, streamflow, wind speed, humidity, soil temperature, water use, air temperature, and infiltration (IMST 2000a). The influence of riparian shade in controlling water temperature declines as streams widen in downstream reaches; however, riparian vegetation continues to benefit water quality and fish habitat in downstream reaches, as discussed in Question 4.

Removal of riparian trees causes localized increases in stream temperatures and daily temperature fluctuations through the reduction of shading (Beschta et al 1987, Hetrick et al. 1998). Removal of riparian vegetation can elevate stream temperatures. Salmonids are negatively impacted when the additional sunlight raises water temperatures high enough to alter salmonid physiology, behavior, migration patterns, and egg incubation. However, additional sunlight and warmer water temperatures stimulate aquatic plant and algal growth (Hawkins et al. 1982, Nicholas and Hankin 1988, Beacham and Murray 1990, Bumgarner et al. 1997, Lichatowich et al. 1999). Some increase in primary productivity may benefit aquatic ecosystems that support salmonids.

Researchers have shown that, with increasing levels of terrestrial riparian vegetation and the resulting organics in the soil, infiltration is enhanced and contributes to improved water quality (Buckhouse et al. 1997, Buckhouse 2000). Infiltration is the soaking of water into the soil, technically defined as the passage of water across the air/soil interface. Infiltration of precipitation, as well as water captured in the soil mantle during spring flood events, and delivered via subsurface flows to the stream, may be critical for maintaining cooler stream temperatures. Infiltration is controlled by a number of factors including slope, vegetation, soils, and geology (Buckhouse et al. 1997, Buckhouse 2000). The Natural Resources Conservation Service recognizes that soil organics are the key to infiltration (Federal Interagency Stream Corridor

Restoration Working Group 1998). As precipitation infiltrates organic material in the soil mantle, raindrops lose the kinetic energy necessary for detachment and entrainment of soil particles (erosion), which reduces the downstream problems of sedimentation (Jordan 2000). Vegetation and soil are two riparian features that humans may influence through land management.

Pesticides and Chemical Contaminants

Several fish species native to western Oregon are sensitive to pollution. Chemical contaminants, including pesticides, enter western Oregon lowland rivers and streams from a variety of rural and urban sources such as sewage treatment facilities, septic systems, pulp and paper mills, chemical plants, illegal dumping, accidental spills, and runoff from roads and agricultural fields. These anthropogenic chemicals contaminate water and sediments. Some typical categories of western Oregon chemical contaminants include pesticides (herbicides, fungicides, insecticides), fertilizers, pulp and paper mill chemicals, road chemicals, household cleansers, wood and other preservatives, light-industrial chemicals, personal care products, and human and veterinary medicinal drugs. Although a variety of chemical contaminants enter lowland streams and rivers, this report focuses on pesticides commonly applied to agricultural lands. The other categories of anthropogenic contaminants will be covered in more detail in the report on urban areas presently being developed by the IMST.

Many pesticides are transported into streams and rivers in storm runoff, producing pesticide pulses (Domagalski 1996). Non-point-source pollution accounts for 70% to 80% of the water pollution in the Willamette Basin, and more than 50 different pesticides have been found in the Willamette River (WRI 2001). In the Willamette Valley, pesticide use is greatest in urban and agricultural areas (4.5 billion pounds annually) (WRI 2001). Pesticides are also used in forestry, maintenance of right-of-ways (road and utility), golf courses, and residential areas. While rarely directly applied to aquatic systems, lowland drainage patterns and seasonal precipitation can route fertilizers, pesticides, and their residual products into drainage ditches, streams, and rivers.

Pesticide Impacts

Of major concern to salmonids are chemicals that have the potential to be toxic to fish causing death, deformities, or behavior alteration (Botkin et al. 1995). Very few pesticide chemicals commonly found in aquatic systems have been evaluated in depth for their long-term and short-term impacts on salmonids. The routes of entry (gills, skin, or stomach) of toxicants into fish are also poorly understood. In this report, we focus on a few pesticide chemicals that have been sufficiently studied in relation to salmonids native to the Pacific Northwest.

Excellent research has been conducted on the lethal and sublethal effects of various concentrations of a few individual pesticides on fish (for example: Eisler 1986; Moore and Waring 1996, 1998; Anderson et al. 1997; Waring and Moore 1997; Scholz et al. 2000; Milston 2001). However, because fish live and swim through a veritable “cocktail” of chemical contaminants (which may interact and have synergistic effects) the lethal levels determined for single compounds may not adequately represent pesticide effects in natural systems. Additionally, while evidence indicates that chemicals applied to lowlands can harm salmonids, the amount of harm is dependent on several factors, including the magnitude, intensity and pattern of chemical use (Norris et al. 1991).

Lethal Effects

The term *lethal* refers to direct death of an individual organism; LC_{50} refers to the concentration of a substance that is lethal to 50 percent of the individuals being tested in a laboratory setting. Rarely have pesticides in natural aquatic systems been linked to direct death of fish (except in cases of pesticide spills).

For example, while the acute toxicity of *diazinon* for salmonids has not been determined, concentrations would have to exceed 839 ppb (parts per billion) to 2620 ppb to reach LC_{50} levels for rainbow trout and cutthroat trout, respectively (Scholz et al. 2000, Eisler 1986). Based on the *diazinon* levels detected by Anderson et al. (1997; Table 14), most concentrations in Oregon streams are unlikely to be high enough to cause direct mortality of salmonids.

Table 14. Partial list of aquatic pesticide (herbicide and insecticide) concentrations sampled in the Willamette Basin and to laboratory median lethal concentrations (LC_{50}) of pesticides (Anderson et al. 1997).

Pesticide	**Use of pesticide**	**Pesticide concentration in tributaries 75^{th} percentile (Maximum). (ug/L or ppb)**	**Lethal concentrations (LC_{50}) for rainbow trout, 96hr exposure. (ug/L or ppb)***
Atrazine	Herbicide	0.26 (90)	9900
Desethylatrazine	Herbicide	0.033 (0.24)	NA
Simazine	Herbicide	0.069 (1.0)	2800
Metolachlor	Herbicide	0.14 (4.5)	2000
Diuron	Herbicide	1.5 (29)	3500
Diazinon	Insecticide	.007 (.31)	90-140
Ethoprop	Insecticide	Not detected (0.44)	2100
Chlorpyrifos	Insecticide	Not detected (3.3)	7.1-51
Carbofuran	Insecticide	.012 (9.0)	380

Sub-lethal Effects

The term *sub-lethal* refers to detrimental effects on an organism that do not directly cause death. Many native fish in the Willamette River have deformities (external anomalies), especially in the lower Willamette and in the Newberg pool (DEQ 1999, Wildman et al. 2001, WRI 2001). These anomalies are likely to be related to chemicals entering the river from a variety of sources, including industry, agriculture, and residential pesticide use. However, no direct cause and effect relationship between fish deformities and specific chemicals (or sources) has been established.

Pesticides can induce behavioral alterations in fish, such as changes in response to predators, mating behavior, and migration. The historical assumption of the EPA was, that for various chemicals at concentrations below 1/10 of the median lethal level (LC_{50}), aquatic organisms experience no adverse effect. However, this assumption is now in question. While numerous studies exist on sub-lethal effects of *diazinon* on salmonids (see Moore and Waring 1996), more recent studies have focused on the function of the nervous system, particularly the ability to smell. For example, impacts on salmonid responses to a prostaglandin (odor required for synchronizing male and female spawning) were significantly reduced following short-term exposure to as little as 1.0 ppb of *diazinon* (Moore and Waring 1996). In chinook salmon, anti-predator and homing behavior were inhibited following short-term exposure to diazinon concentrations between 1.0 and 10.0 ppb (Scholz et al. 2000). *Diazinon* levels reported in the Willamette Basin study by Anderson et al. (1997; Table 14) did not exceed 1ppb; however, in another Willamette Basin study by Wentz et al. (1998), values of 1-2ppb were detected.

Carbofuran also may cause behavioral changes in fish. *Carbofuran* levels in the Willamette Basin (Table 14) exceeded those found to cause sub-lethal effects in Atlantic salmon. Following exposure to 1 ppb of carbofuran, a diminished sense of smell and endrocrinological effects reduced the response of male Atlantic salmon to a priming pheromone thought to be involved with the synchronization of spawning between the sexes (Waring and Moore 1997).

Similar nonlethal effects were associated with exposure of Atlantic salmon to *atrazine* in concentrations ranging from.04 to 20 ppb (Moore and Waring 1998). USGS studies conducted in 1993-1995 indicated levels of *atrazine* as high as 4ppb in Willamette basin tributaries (Wentz et al.1998). Ewing (2000) found concentrations of *atrazine* over 400 ppb in the Alsea watershed. These levels were positively correlated with amount of fall rains, timing and amount of spring application, and percentage of watershed in agriculture.

Some chemical compounds that find their way into Oregon waters are readily broken down (transformed) into other persistent and toxic chemicals. For example, the insecticide, DDT, has not been used in the United States for decades, yet its breakdown products can still be measured in sediments, fish, and other animals. Many of these chemical contaminants are stored in fat within organisms, allowing transfer and bioaccumulation of the chemicals up the food chain. In addition, chemical contaminants may be maternally transferred to eggs and progeny.

Milston (2001) reported that short-term exposure of chinook salmon eggs (1 hr) and hatchlings (2 hr) to the estrogenic compound *DDE* induced long-term effects to the immune competence of juvenile salmon one year after exposure. This experiment indicates that even short exposures of such chemicals during critical periods in their life history can have deleterious delayed consequences on salmonids.

Effects on Aquatic Community

Aside from lethal and sub-lethal effects on fish, direct exposure to low-levels of pesticides can impact aquatic community structure; examples include, insecticide-induced decreases in the biomass of aquatic insects (Norris et al. 1991) and herbicide-induced reductions in aquatic chlorophyll concentrations (Hoagland et al. 1993). Although some empirical evidence links pesticide use to adverse impacts on aquatic communities that support salmonids, scientists presently are unable to come to a definitive cause and effect conclusion because of limited data.

Summary of Pesticide Impacts

In summary, while sufficient evidence allows scientists to conclude that pesticides applied to lowlands can harm salmonids, the level of effect is dependent on several factors, including the magnitude, intensity, and pattern of pesticide use (Norris et al. 1991). Pesticides rarely kill fish directly; though altered fish behavior is likely at the levels detected in the Willamette Valley. Adverse impacts on aquatic communities are less clearly established.

Levels in aquatic systems

Several programs have reported on pesticide levels in Oregon aquatic systems (for example: DEQ 1994, Anderson et al. 1997, Wentz et al. 1998, Dent and Robben 2000, Ewing, 2000). A study in the Willamette River surveyed dissolved pesticide in small tributaries in the Willamette Basin (Table 14) (Anderson et al. 1997). In this study, water samples were collected from 16 randomly selected agricultural subbasins and 4 urban subbasins. A total of 29 herbicides and 7 insecticides were detected (10 are represented in Table 14). Since the streams targeted by this study were small (basins of 2.6-13 square miles) and not much dilution occurred relative to larger systems, a large number of unusually high pesticide concentrations (1-90 ppb) were found. None of the pesticides cited in Table 14 were found to be in the range of median lethal concentrations (LC_{50}) for rainbow trout (Anderson et al. 1997).

In another study, Ewing (2000) sampled herbicides from tributaries in forests, agricultural areas, and small municipalities in the Alsea watershed. These samples, which were taken after rainfall during peak run-off events, detected measurable levels of herbicides in runoff from terrestrial sites sprayed with herbicides. The highest levels of *atrazine* and *hexazinone* (483 ±16 ug/L and 188 ±30 ug/L) were found below an agricultural site. These high levels could have potentially harmful effects on aquatic organisms.

Inorganic and Organic Nutrients

Nutrients (including trace elements) provide nourishment to living organisms, and are available in two forms: inorganic molecules and organic molecules.

Plants and algae (as well as nitrifying bacteria) typically acquire nutrients as inorganic molecules (such as nitrate, ammonium, phosphate, and potassium ions) found in soil, fertilizer, and dissolved in water. Although not always originating from rocks, the term *mineral nutrients* is also used to refer to these inorganic molecules. Inorganic nutrients do not provide energy, but do provide elements necessary for plant life.

Animals, fungi, and most bacteria typically acquire nutrients as organic molecules (such as amino acids, proteins, fats, carbohydrates, and vitamins) found in living food and *organic matter* (dead plant or animal material). Organic nutrients provide both energy and elements necessary for animal life.

In general, the form of a nutrient entering an aquatic system determines the initial response of that ecosystem. For example, when inorganic nutrients such as fertilizers enter a stream and stimulate algal blooms, salmonids may initially benefit because stream productivity is increased. When algal blooms die off, or organic matter such as manure enters a stream and stimulates decomposition, salmonids may be harmed if the stream's dissolved oxygen concentration is decreased – as happens during the decomposition process, which requires oxygen consumption (respiration).

Sources and Biological Relationships

Inorganic nutrients (mineral nutrients) enter lowland streams and rivers from three important sources: (1) surface flow and/or groundwater transport of water containing natural dissolved inorganic nutrients and/or anthropogenic fertilizer; (2) erosion of soil sediment which may have inorganic nutrients adsorbed to it; and (3) falling organic material that is subsequently decomposed, thereby releasing inorganic nutrients.

Organic matter (containing organic nutrients) entered Oregon streams prior to Euro-American settlement, from two primary sources: (1) organic matter produced within the stream from photosynthetic algae and other aquatic plants and (2) riparian vegetation (organic matter deposited by the terrestrial vegetation such as leaves, bark and wood). In forested ecosystems, terrestrial sources contributed 98% of the organic material in streams (Fisher and Likens 1973).

Organic Matter

When riparian vegetation drops leaf litter and large wood into streams, this organic material provides food energy and organic nutrients to aquatic invertebrates and, after decomposition, provides inorganic nutrients to algae and aquatic plants. Riparian vegetation also prevents the erosion of soil organic material into streams by holding soil in place. When agricultural practices change the density and species composition of riparian vegetation, leaves and twig input, as well as filtration of organic material is altered (Delong and Brusven 1994).

Forested headwater streams are a major source of organic matter and, therefore, play a major role in productivity for warmer, downstream reaches in western Oregon lowlands (Naiman and Sedell 1979). Organic materials such as leaf litter and small wood deposited in small, steep-gradient streams are rapidly transported to lowland systems; though this organic matter transport is reduced when barriers constrict passage (e.g. culverts are designed to pass flows, but sometimes become clogged with wood). Large wood in lowland streams trap sediments and small organic material, which is broken down and redistributed over the floodplain during high flows, important in supplying inorganic nutrients to plants.

Deposition and processing of organic material can be a limiting factor to natural stream/river ecosystem productivity. Organic material is initially a source of food (organic nutrients) for animals, and later, a source of inorganic nutrients for algae and plants. For salmonids, a productive stream has good physical habitat for spawning and organic resources to produce the food required for fry survival and growth.

An appropriate amount of nutrients in a stream can enhance salmonid production (Johnston et al. 1990b). For example, in nutrient-deficient headwater streams, nutrition derived from salmonid carcasses can be an important source of nitrogen and carbon for juvenile salmonids and can influence their growth (Bilby et al. 1996). Nutrients from salmonid carcasses are in an organic form that can be easily utilized by juvenile salmonids and other wildlife in watersheds, and are also distributed throughout the watershed (Gresh et al. 2000). Juvenile salmonids and other aquatic animals feed directly on salmonid carcasses (Bilby et al. 1996). The research of Gresh et al. (2000) suggests that substantial nutrient deficit in upland streams may occur where salmonid abundance has been in decline.

On the other hand, excessive organic matter can lower dissolved oxygen concentrations in a stream or river. As organic matter is decomposed, the decomposition process (respiration) extracts dissolved oxygen from water, and releases inorganic molecules from organic molecules.

Inorganic Nutrients

Any activity that introduces abundant inorganic nutrients to a stream contributes to enrichment (eutrophication) of the water column. High concentrations of inorganic nutrients, along with abundant light and optimal temperatures, stimulate algal blooms. Subsequent decomposition of large amounts of algae results in dramatic reductions of dissolved oxygen (DEQ 1995). Algal die-offs usually occur when water temperatures are high and, therefore, when dissolved oxygen concentrations are already low. Where conditions exist to allow algal blooms, dissolved oxygen can become limiting to salmonids (Waldichuck 1993).

Eutrophication is an example of cumulative impact where high summer temperatures, low flow, and increased inputs of inorganic nutrients stimulate algal blooms, which lower dissolved oxygen concentrations in the water when they die and are decomposed by bacteria. If these perturbations become chronic, they could result in unfavorable conditions for salmonids.

In addition to causing eutrophication, inorganic nutrients can be directly toxic to salmonids if found in high concentrations. For example, Spence et al. (1996) point out that ammonium ions (often found in anthropogenic fertilizer) can be toxic to salmonids at concentrations of 80 ppb under certain pH conditions, while nitrite (which does not persist in natural surface waters) is toxic at concentrations of 100 - 900 ppb. Two other common fertilizers, nitrate and phosphate, are less toxic to salmonids; however, they both contribute to eutrophication in streams (Spence et al. 1996).

Management of Inorganic Nutrients and Organic Matter

Typically, agricultural croplands and confined animal feeding operations are a greater source of nutrients than forests and pastures (Correll et al. 1992). Fertilizers in agricultural areas are the most common sources of nitrogen and phosphorus in streams. The highest concentrations of these nutrients are in streams and rivers of Willamette Valley agricultural and urban areas (Allen et al. 1999). Manure and fertilizers are typically used as sources of nutrients in agricultural production of crops and pastures (North Coast Basin Local Advisory Committee 2000).

Concerns about agricultural runoff transporting organic material and inorganic nutrients to stream courses have been addressed since the formation of the Soil Conservation Service (now the Natural Resource Conservation Service). Farming practices that allow infiltration of rain where it falls, diminish soil erosion by lessening the amount of soil that is dislodged and washed into waterways (Dunne and Leopold 1978).

Management of fertilizer applications is another effective approach to limiting nutrient inputs into streams and rivers from agricultural lands. Management techniques include application of only amounts of minerals that will be used by specific crop plants, proper calibration and operation of fertilizer application equipment, and managing application timing to avoid potential leaching or runoff (North Coast Basin Local Advisory Committee 2000). Another management technique is to establish riparian management zones (buffers) of perennial vegetation (discussed in Question 4).

Potential nutrient inputs from Confined Animal Feeding Operations (CAFOs) have been a concern in Oregon for some time and are permitted and regulated by ODA. By definition, CAFOs include feedlot operations, dairies, and, at least potentially, corralled horses. In the lowlands of western Oregon, the greatest problems caused by dairies are simply due to the relative abundance of such operations in some regions (Strittholt et al. 2000).

All dairies in Oregon must comply with the Clean Water Act of 1972. Dairies are required to strive for a nutrient balance between crops and animals, leading to no net loss of nutrients from the site (Palmer, pers. comm.[21]). The amount of nutrients applied to a site (e.g. manure from the animals themselves) must balance with the uptake of nutrients by plants on the site. The CAFO program does not monitor the loss of nutrients into groundwater or nearby surface waters of a dairy operation. However, the CAFO program does monitor nutrient application and plant uptake at dairies. If the amount of nutrients applied to a site equals the nutrients captured in plant tissues and in the soil, then no net loss of nutrients has occurred during that period of time. Overall compliance of Oregon dairies and feedlots with the "no net loss of nutrients" regulation in the CAFO permit process is good. Cow-calf winter areas and some poultry operations are not yet involved in this permit process (Palmer, pers. comm. [22]).

Another concern with CAFOs is waste lagoons. Mallin (2000) discussed animal waste lagoons and spray-fields near aquatic environments in the southeastern United States and their potential to degrade water quality and endanger health. The southeastern United States is an area where confined pork raising operations, large-scale lagoons, hurricanes, and humans coexist. In "high-tech" dairies, manure storage tanks and/or lagoons are designed to hold wastes during these wet

---

[21] Palmer, Joel. Personal Communication, 2002. CAFO Program Administrator, Oregon Department of Agriculture, Salem, Oregon.

.

winter months for application of the manure to fields during drier periods (autumn) when crops are grown. Western Oregon does not face the southeastern US hazards of hurricanes breaching CAFO lagoons, but due to Oregon's wet winter climate and saturated soils, western Oregon has similar risks for water contamination from CAFO lagoons.

Phosphorous inputs into streams and rivers are often associated with overland surface flows. The amount of phosphorous transported via surface flow depends on soil type (Ruprecht and George 1993). Both point-source and nonpoint-source pollution potentially contribute phosphorous to aquatic systems above the natural, background phosphorous levels (Ruprecht and George 1993). Nitrogen inputs into aquatic systems are considered to be a groundwater related input. Both methods of inputs for these inorganic nutrients (surface flow versus groundwater transport) are under scrutiny; several interacting factors including volume of flow, timing of precipitation, pH of the system, and type of sediment may be involved (Wolf 1992).

<u>Sediment and Turbidity</u>

Some level of erosion and sediment production is valuable to salmonids. New gravel for spawning beds is recruited during periods of high flows and periodic flooding. Suspended sediments carry nutrients and the raw materials for streambank building and habitat creation. Bed-load sediments can provide spawning gravels. Geologic erosion/sedimentation is natural and inevitable, and is a process to which salmonids have adapted over time. After deposition in streams, sediment affects lowland channel morphology and fish habitat conditions (Coats et al. 1985; Benda et al. 1998). Salmonid productivity is thought to be enhanced at low to moderate sediment levels (see review in Hicks et al. 1991b).

Erosion and sedimentation are natural processes, which are essential to nutrient cycling, habitat, and hydrological and channel morphological dynamics. Geologic erosion operates slowly and is unalterable; however, *accelerated erosion* takes place faster than the normal geologic rate of erosion (Brady 1984). Accelerated erosion and prolonged sedimentation are caused by human activities, and are detrimental to aquatic systems because they may add too many nutrients to the stream, thereby, stimulating eutrophication, and may increase suspended solids in the stream, thereby, contributing to turbidity.

Turbidity (reduction in water clarity) not only reduces the amount and distance light can penetrate the water column, but also may clog fish gills and settle into spawning gravels. High turbidity has the potential to cause physiological stress or lethal effects for fish (Campbell 1954, Noggle 1978, Redding et al. 1987, Newcombe and MacDonald 1991, Wood and Armitage 1997, Lake and Hinch 1999). Non-lethal detrimental effects of too much sediment in water include: changes in fish gill histology and blood physiology, cementation of spawning gravels, and decreased light penetration (Gammon 1970, Servizi and Martens 1992).

Several studies have investigated lethal levels of sediment for salmonids. Caged rainbow trout were killed within twenty days in the Powder River, eastern Oregon, when sediment concentrations were between 1,000 mg/l and 2,500 mg/l (Campbell 1954). Herbert et al. (1961) reported reduced trout abundance at concentrations of 1,000 mg/l in a study conducted in Great Britain, but saw no adverse affects at 60 mg/l. Griffin (1938) observed that juvenile cutthroat trout and chinook salmon continued to feed at suspended sediment concentrations greater than 500 ppm (mg/l).

Noggle (1978) reported that sediment bioassays conducted in summer on juvenile salmonids in streams of the Olympic Peninsula, Washington produced lethal concentrations (LC_{50}) at less than 1,500mg/l (ppm), while autumn bioassays produced LC_{50} at greater than 30,000 mg/l (ppm).

Histological examination of gills by Noggle (1978) indicated structural damage by suspended sediment at concentrations greater than 1,200 mg/l. Noggle (1978) concluded that exposure to suspended sediment has a higher potential to harm juvenile salmonids in the summer than in the autumn, reflecting seasonal differences in sediment toxicity.

Sources of Sediment in Streams

Because sediment production and delivery are processes that connect lowland and upland river and stream systems, a landscape approach is essential to understanding the role of sediment in waterways. Sediment is supplied to stream channel networks from both the adjacent lowlands and surrounding uplands. Historical episodic erosion of sediment into streams is influenced by geology, vegetation cover, landscape position (topography), and weather conditions. The ability of a stream ecosystem at any point in time to accommodate sediment input is impacted by whether the input of sediment is episodic (erosion due to storms) or chronic (consistent erosion from adjacent land).

Natural episodes of erosion such as mass movements from upland hill slopes, and stream channel erosion, deliver fine sediment (silts and clay), coarse sediment (gravel, cobbles, and boulders), and large wood into streams. Large wood in upstream, forested reaches can form important sites for sediment storage (Heede 1981). Marston (1982) found that logjams were usually generated in small streams, and created stable log-steps in somewhat larger streams. Trotter (1990) found that reaches with large wood stored twice the amount of organic matter as reaches without large wood. Sediment storage in upstream reaches reduces the amount of sediment transported from upland sources to lowland streams. Log-steps also reduce water velocities during spring runoff, reducing the potential energy available for erosion, channel incision, and bank scour (Montgomery et al. 1996). The effects of increases in erosion and sediment supply from logging and road building in upland forests in Oregon have been well documented (Botkin et al. 1995).

Chronic erosion from roads, agricultural practices, and upland logging has the potential to increase amounts of fine sediment in streams, but do not always add the more coarse elements (Lenat 1988). Management of sedimentation from land use practices and human-induced landslides at the watershed level is complex; however, a degree of success has been achieved through the implementation of Best Management Practices (BMPs) that limit site production of sediment lost from upland sites. Scientific evidence suggests that managers should, if possible, vary the extent, frequency, and intensity of sediment production processes in a watershed over space and time by emulating historical patterns of sediment input (Benda et al. 1998).

Although urban areas in western Oregon contribute the most sediment on a per acre basis, agriculture contributes more total sediment to the Willamette River than any other activity (WRI 2001). Under certain conditions, cultivation can cause extreme erosion losses on-site with corresponding sediment problems off-site; runoff from agricultural areas is often associated with increased sedimentation (Lenat 1984). Characteristics of an agricultural site (soil type, litter and organic matter content, soil moisture, steepness of slope, soil structure, soil frost conditions, soil colloids, and soil organisms) all influence infiltration and therefore erosion rates.

Of 37,000,000 acres of irrigated land in the United States, 21% (7,770,000) has been affected by soil erosion to some extent (Koluvek, et al. 1993). In the northwestern United States, irrigation-induced soil erosion has been studied since 1940. When irrigation erodes agricultural soils, sediments in the irrigation return-flows can contribute to water quality degradation (Koluvek et al. 1993). The USDA Soil Conservation Service, now known as the Natural Resource Conservation Service, conducted surveys in 1985 and 1986 to estimate the extent of erosion problems in irrigated cropland in the western US, including the Willamette and Rogue River basins of western Oregon (Koluvek et al. 1993). In some fields, annual sediment yield from furrow-irrigated fields exceeded 9 tons/acre and was as great as 45 tons/acre. Sediment yields were 15 tons/acre in irrigation tracts under center-pivot sprinklers. Erosion is often excessive when field slopes are greater than 2% (Koluvek et al. 1993).

Sediment Control

Reducing erosion helps reduce sediment input into streams. The Natural Resource Conservation Service has published extensively on the topic of sediment control through conservation practices. One publication, *Stream Corridor Restoration Principles, Processes, and Practices* (Federal Interagency Stream Corridor Restoration Working Group 1998), published by fifteen federal agencies including NRCS, provides excellent guidance on biological, ecological, and planning approaches to prevent erosion and sedimentation. Farming practices, such as: (1) filter strips in riparian buffers; (2) sediment retention basins; (3) conservation tillage, contour plowing, strip cropping, low-till and no-till cultivation methods; (4) cover crops and vegetation mulching; (5) irrigation management; (6) pasture management; and (7) road/ditch management all play roles in lessening the susceptibility of soils to wash away into streams (Schwab et al. 1966, Federal Interagency Stream Corridor Restoration Working Group 1998). Vegetated filter strips (riparian buffers) installed at the ends of fields or adjacent to streams capture sediment before it is delivered to streams. Vegetation may either be planted (e.g., grasses) or already be present (e.g. riparian vegetation). Vegetated filter strips function by slowing the surface flow of water, which in turn increases sediment deposition. Sediment reduction is related to the ratio of water depth to vegetation height, filter length, slope, and sediment size distribution (Karr and Schlosser 1977, 1978; Magette and Dillaha 1987). Grass filters can reduce sediment loads by over 50% from surface flow (Magette and Dillaha 1987, Parsons et al. 1990, 1994). Riparian management zones (buffers) are discussed in more detail in Question 4.

Studies indicate that certain farm practices can be effective in reducing sediment production. Creating sediment retention basins (small catchment basins where slope is decreased and sediments are precipitated out and captured) is one such method. Edwards et al. (1999) reported sediment retention basins reduced sediment reaching the stream by trapping 94% of the sediment, thereby also trapping 76% of nitrogen, and 52% of phosphorus.

Agricultural texts give encouraging reports of the value of conservation tillage, also known as no-till and low-till systems (D'Itri 1985, Pierce and Frye 1998). Conservation tillage involves less soil disturbance than other tillage methods and leaves residues from the previous standing crop. Conservation tillage practices reduce the number of tillage passes, improve soil quality, and increase roughness of soil surfaces, all of which reduce erosion. Therefore, these practices result in less exposed soil and less erosion.

Other benefits of conservation tillage include greater water infiltration and reduced sediment and phosphorus loads reaching streams. Long-term use of conservation tillage may lead to reduced soil compaction, which increases water infiltration and reduces run-off from high rainfall events, also contributing to decreased erosion.

Cover crops and mulches provide soil cover and reduce runoff during times of high rainfall, thereby reducing or preventing erosion. Permanent cover crops such as perennial grasses are commonly used in orchards, vineyards, and berry fields, while annual cover crops are generally used in crop rotations during the off-season. Cover crops can also take up nutrients and may reduce the levels of nutrients that reach groundwater (Table 15).

Table 15. Erosion control technology examples (Source: Pimental et al. 1986, Pimental et al. 1993).

Technology	Treatments	Soil loss (tons/ha/yr)	Slope (%)	Country
Rotation	corn-wheat-hay-hay-hay-hay; continuous corn	3 44	12 12	USA
Contour planting	potatoes on contour; potatoes up-and-down hill	0.2 32	- -	USA
Rotation plus contour planting	cotton on contour and grass strips; continuous cotton planted up and down hill	8 200	- -	USA
Terraces	peppers on terraces; peppers on slope	1.4 63	35 35	Malaysia
Manure	corn with 36 t/ha of wet manure; corn without manure	11 49	9 9	USA
Mulch	corn planted on land with 6 t/ha of rice straw; continuous corn	0.1 148	5 5	Nigeria
Grass cover	grass; plowed	0.08 13.6	10 10	Tanzania
No-till	corn; conventional corn	0.14 24	15 15	Nigeria
Ridge planting-crop residues left in trenches on land surface	corn; conventional corn	0.2 10	2 2	USA

Although irrigation practices are not the primary source of erosion in western Oregon lowlands, appropriate, prescription irrigation management can help reduce erosion. For example, in the Tualatin Valley Irrigation District, specific irrigation systems are used to minimize erosion (e.g., pressurized irrigation water delivery systems). Additional irrigation monitoring or alternative application schedules may also effectively reduce soil erosion from fields and sediment delivery to streams.

Pasture management is also important in reducing impacts of erosion and sediment input from agricultural practices. Infiltration of precipitation into the soil profile is as important in pastures as it is in cultivated agriculture. Maintaining some vegetation in grazed pastures is key to preventing sedimentation and suspended bacterial pollution of nearby streams. Off-site water facilities for livestock are valuable for preventing direct bacterial inputs to streams and, by implication, a reduction in sediment (Miner et al. 1992, Larsen et al. 1994, Clawson et al. 1994).

Drainage ditches and unpaved roads also require attention. Both have the potential of being sediment sources to streams and a conduit for sediment transport. For example, the Tualatin Hydrologic Unit Area spent considerable time and energy to vegetate ditch banks, road fills, and road cuts, as well as to promote conservation tillage practices. The USDA Natural Resources Conservation Service (1998) reported that the Tualatin Hydrologic Unit Area was successful in its public awareness and landowner education and application of the technologies program. They reported the following accomplishments from 1991 to 1995:

Resource Management Plans written	30,344 acres
Number of Long Term Agreements signed	113 contracts
Number of Acres associated with Long Term Agreements	22,217 acres
Manure managed	77,524 tons

Net Tons of Soil saved	95, 832 tons

Erosion and sediment delivery to streams on forestlands have been reduced by maintaining streamside vegetation, and by modifying road construction, road maintenance, and timber harvest practices (Hicks et al. 1991a). The IMST addresses sediment erosion from forestlands in greater detail in their report on west-side forest practices (IMST 1999).

Findings and Conclusions

Findings

Water Quantity and Flow modifications

Adequate water quantity is necessary at critical periods for salmonids to complete their life histories. Present flow hydrographs in flow-modified streams of western Oregon are no longer similar to historical flow hydrographs.

Dams and Reservoirs

Due to the high number of dams, western Oregon rivers are frequently highly modified ecosystems with altered water quantity and flow hydrographs. These changes directly and indirectly impact salmonid populations in western Oregon.

Water Withdrawals by Diversions

Diversions for irrigation are common in the agricultural lands of western Oregon. Adequate streamflow and sufficient water quantity are especially important for salmonids during summer months and are extremely important to salmonid rearing and migration. Water withdrawals have affected salmonids by reducing streamflow during critical periods. Many streams in western Oregon are fully or over-allocated for a variety of out-of-stream uses.

Wetlands for Water Storage and Flow Mediation

Wetlands play an important role in storing water from winter floods, assuring that water is available to recharge groundwater aquifers, and to provide water to surface streams during summer low flows.

Wetlands that have been drained are no longer functioning effectively as groundwater recharge areas and no longer supply base flow to surface streams during the dry summer months. When surface flows are re-routed, wetlands are effectively removed from the hydrologic system. A large proportion of wetlands in western Oregon have been lost.

Fish passage

Salmonid life histories involve upstream spawning migrations, downstream migrations of juveniles, and movements into off-channel rearing habitats. Fish ladders, small dams, culverts, tide gates, irrigation diversions, and some fish hatcheries still block salmonid passage in many streams in the western Oregon lowlands.

Water Quality

In general, salmonids need cold, oxygenated, clean, clear water. Seventy percent of stream miles in western Oregon have not been evaluated for water quality or compliance with water quality standards.

Water Temperature

Cool temperatures are vital to salmonids, which evolved in cold-water, oxygen-rich systems. Overly warm, oxygen-poor waters are detrimental to salmonids and their ecosystems. Length of exposure, degree of exposure, strain or race of fish species, and presence of cold-water microsites all influence how well an individual fish can cope with elevated river and stream temperatures.

Water generally warms as it travels downstream. Many biological and physical factors such as climate, elevation, groundwater inputs, stream width, riparian vegetation and shade, and anthropogenic factors (water withdrawal and flow augmentation) interact to influence stream temperature. Intact stream ecosystem structures and functions - infiltration of ground water, low stream width-to-depth ratios, streamside shade, and structural complexity that provides cool-water microhabitats - can reduce long-term effects of short-term water temperature increase.

Summertime temperatures in many lowland streams in western Oregon do not meet Oregon's water quality standards for temperature and are outside the temperature range needed for salmonid recovery.

Riparian vegetation is of fundamental importance in helping to regulate stream temperature, maintain cool stream temperature by potentially blocking incoming solar radiation, reduce stream heating, and maintain channel morphology. Stream width to depth ratios, volumes of flow, turbulence, orientation, aspect, elevation, subsurface water inputs, as well as a host of climatic features are all important factors related to shading and/or stream temperature.

Pesticides

Chemical contaminants enter western Oregon lowland rivers and streams from a variety of rural and urban sources: sewage treatment facilities, septic systems, pulp and paper mills, chemical plants, illegal dumping, accidental spills, and runoff from roads and agricultural fields. Typical categories of western Oregon chemical contaminants include pesticides (herbicides, fungicides, insecticides), fertilizer, pulp and paper mill chemicals, road chemicals, household cleansers, wood and other preservatives, light-industrial chemicals, personal care products, and human and veterinary medicinal drugs.

Pesticides entering lowland rivers from agriculture and urban areas can be detrimental to aquatic ecosystems and salmonids. Of major concern to salmonids are chemicals that have the potential to be lethal (cause death) or sub-lethal (cause deformities or behavior alterations). Very few pesticide chemicals commonly found in aquatic systems have been evaluated in depth for their long and short-term impacts on salmonids.

Diazinon, carbofuran and atrazine are three examples of pesticides that have been sufficiently studied in relation to salmonids native to the Pacific Northwest and have been measured at sub-lethal levels in western Oregon.

Because fish live and swim through a mixture of chemical contaminants (that may interact and have synergistic effects) the LC_{50} levels determined for single compounds may not adequately represent pesticide effects in natural systems. Pesticides can also have detrimental effects on invertebrates and algae inhabiting streams that support salmonids.

Inorganic and Organic Nutrients

Inorganic nutrients (mineral nutrients) and organic nutrients (contained in organic matter) support stream productivity. However, an over-abundance of inorganic and organic nutrients entering lowland streams rivers from agriculture and/or urban areas can cause eutrophication and subsequent decrease in dissolved oxygen concentrations, which are detrimental to aquatic ecosystems and salmonids.

Sediment and Turbidity

Some level of erosion and sediment production is valuable to salmonids. However, an over-abundance of sediments entering lowland rivers from agriculture and urban areas can be detrimental to aquatic ecosystems and salmonids by adding too many nutrients to the stream, and by increasing turbidity in the water column.

Problems with turbidity from sediment in water can:

- Decrease light penetration, and therefore decrease photosynthesis
- Settle into and bury spawning gravel
- Have adsorbed pesticides and inorganic nutrients attached
- Cause physical wear and failure of fish gills

Agricultural practices that discourage runoff and encourage the infiltration of rain into soil can ameliorate the effects of cultivation. If plowed every year, cultivation of annual crops is potentially more likely to lose sediment than cultivation of perennial (long-term) vegetation.

Conclusions

Water Quantity and Flow Modifications

We conclude that alterations in flow regimes in western Oregon lowland streams have contributed to alterations in channel and floodplain form and function, often negatively affecting salmonid habitat. Restoration of flows to pre-dam levels is not expected, but it is possible to restore more normative conditions and recover portions of lost capacity.

Dams alter sediment/gravel transport and deposition, but there is little quantitative data on the magnitude or effects of alterations to sediment/gravel transport and deposition that result from dams in streams in the western Oregon lowlands.

Adequate water quantity is important to maintaining good water quality and salmonid habitat. Hydromodification and extraction of water in western Oregon lowlands have caused habitat loss and damage, as well as reduction in streamflow at critical times for salmonids. We need to better understand the effects of water withdrawals on groundwater recharge and surface streamflow. Through hydrologic functions, wetlands link the terrestrial and aquatic environments and should continue to be inventoried and prioritized for protection and restoration.

Fish Passage

Recovery of salmonid populations will be improved by permitting access of spawners and juveniles to previously unavailable and favorable habitat within watersheds. The amount of habitat potentially useful for recovery is large, possibly much larger than indicated by the ODFW and ODOT survey of blockages. The IMST suggests coordination with among watershed councils to improve fish passage.

Fish ladders, culverts, tide gates, and barriers at fish hatcheries should be assessed and modified, when appropriate and possible, to improve fish passage.

The IMST concludes that the State needs to 1) assess the impacts of water withdrawals via pumps, irrigation diversions, pushup dams, etc. on salmonids and stream ecosystems, 2) assess the spatial extent of these impacts, and 3) identify the effectiveness of alternative practices that would have less impact on salmonids.

Water Quality

Since 70% of stream miles in western Oregon have not been assessed for water quality, we conclude that more streams should be assessed to determine the overall condition of water quality in western Oregon streams inhabited or potentially inhabited by salmonids.

Water Temperature

Salmonids require cool water temperatures; therefore, Oregon's temperature standards for salmonids are reasonable given the state of the science. The scientific basis for considering the role of solar inputs in affecting appropriate stream temperatures for fish is well established in the scientific literature. The physical and biological processes that influence stream temperature, are well understood and should be incorporated in salmonid recovery plans (IMST 2000a).

In attempting to deal with land use activities that impact stream temperature, the IMST concludes that:

- Many factors, which vary widely across the landscape and over time, affect stream heating and cooling. Human activities affect four major factors that influence stream temperature – riparian vegetation, channel morphology, water volume, and exchange between surface and subsurface water.
- Riparian vegetation often plays a key role in regulating stream temperature.
- Fish habitat management is closely tied to vegetation management. Management of vegetation in both the riparian area and the uplands, is site-specific yet frequently amenable to management activities.
- The role of site-specific relationships, particularly those of infiltration, soil conditions, local geology, and site capacity for vegetation production influence the nature of streamside vegetation.

Because temperature strongly influences salmonids and aquatic ecosystems, we need a better understanding of the influence of land-use practices on temperature in lowland streams and rivers.

Pesticides

Chemical contamination is potentially a major issue in urban and rural lowland rivers and streams of western Oregon. Minimizing or preventing exposure of salmonids to pesticide and other chemical contaminant levels that have adverse effects, including sub-lethal adverse effects, will enhance salmonid recovery.

We believe current monitoring programs are not sufficiently intensive, inclusive, or extensive to allow appropriate assessment of pesticide presence in waters and risk to salmonids.

Because pesticides strongly influence salmonids and aquatic ecosystems, we need a better understanding of the influence of land-use practices on pesticides in lowland streams and rivers.

Inorganic and Organic Nutrients

Because an overabundance of inorganic nutrients (mineral nutrients) and organic nutrients (contained in organic matter) is harmful to aquatic ecosystems that support salmonids, we need a better understanding of origin and volume from multiple sources, as well as the effects of high nutrient concentrations on salmonids and aquatic ecosystems.

Because nutrients strongly influence salmonids and aquatic ecosystems, we need a better understanding of the influence of land-use practices on nutrients in lowland streams and rivers.

Sediment and Turbidity

Because an overabundance of sediment is harmful to aquatic ecosystems supporting salmonids, we need a better understanding of origin and volume from multiple sources, as well as the effects of high sediment concentrations on salmonids and aquatic ecosystems.

Because sediment and turbidity strongly influence salmonids and aquatic ecosystems, we need a better understanding of the influence of land-use practices on sediment in lowland streams and rivers.

Question 4. What is the scientific evidence for the importance of vegetation within riparian areas in enhancing ecological processes and functions critical to salmonid recovery in western Oregon lowland ecosystems?

In this question, the IMST describes ecological functions and management of vegetation inhabiting lowland riparian areas.

Ecological Functions of Vegetation Inhabiting Riparian Areas

Gregory et al. (1991; p. 540) define riparian areas "as three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems. Boundaries of riparian zones extend outward to the limits of flooding and upward to the canopy of streamside vegetation." Riparian areas are adjacent to bodies of water (streams, rivers, lakes, and estuaries) and include floodplains. The vegetation communities inhabiting riparian areas are composed of facultative-wet and obligate riparian plant species, which reflect the presence of free or unbound water; aquatic plant species, which require submergence in water; and, often, terrestrial upland plant species, which do not require free water.

Because of their disturbance regimes and steep environmental gradients, riparian areas are some of the most dynamic and ecologically rich portions of the landscape. Riparian areas constantly change in terms of vegetation composition, geomorphology, and hydrology due to channel meandering and flooding disturbances, which are typical in unconstrained reaches of lowland streams. Gregory et al. (1991; p. 542) describe the riparian area of unconstrained reaches as "broad and complex, with a diverse array of geomorphic surfaces and plant communities of various ages..." Consequently, the riparian areas of western Oregon lowlands are a dynamic mosaic of exposed substrate, herbs, grasses, sedges, rushes, shrubs, and/or trees.

Since riparian disturbances are periodic and vary in location and magnitude, at any point in time, a landscape will be composed of patches of different ages and types of plant communities, as well as areas not yet vegetated. Vegetation composition of a riparian site (patch) is influenced and directed by environmental factors that affect initial establishment, such as nearby seed sources of exotics and natives, seed bed conditions, soil type, depth to water table, and residual plants. Changes in species dominance (community structure) become evident in those patches that persist for longer periods of time. Dynamics in vegetative communities are influenced and directed by factors such as initial species presence, time as a relatively stable environment, and disturbance events (Hibbs, pers. comm.[23]). Consequently, species composition in western Oregon lowland riparian areas varies greatly among sites.

In this section, we address how vegetation in riparian areas generally enhances salmonid habitat by providing the following important ecological functions for aquatic systems: aquatic community diversity, large wood, channel morphology and streamflow regulation, hydrologic connectivity, temperature mediation, sediment filtration and nutrient uptake.

<u>Riparian Vegetation Contribution to Aquatic Community</u>

Riparian vegetation can have a significant effect on instream biotic community structure since it provides food and habitat for invertebrates, as well as cover and refuge from stream current for fish (Hickin 1984, Gregory et al. 1991, Sedell and Beschta 1991, NRC 1996).

[23] Hibbs, David. Personal Communication, 2002. Department of Forest Science, Oregon State University, Corvallis, Oregon

Riparian vegetation is important in providing leaf and twig litter (allochthonous inputs) to streams, an important nutritional contribution to the aquatic food chain (Wallace et al. 1997). Changes in riparian vegetation due to conversion to agricultural fields or pastureland can limit the amount of organic matter entering a river or stream from the surrounding terrestrial ecosystem (Young et al. 1999). Streams with wooded riparian areas have higher percentages of benthic insectivores and herbivores than streams with open riparian areas, and greater fish species richness and diversity (Stauffer et al. 2000). Stewart et al. (2000) found more diverse fish communities in streams with higher percentages of riparian forest within 30 m of the stream (. These studies support the concept that reestablishment of riparian vegetation in agricultural areas can have positive effects on the integrity of fish communities (Wichert and Rapport 1998).

<u>Large Wood and Habitat Diversity</u>

Trees in western Oregon riparian areas are important as a source of large wood for many streams and rivers (Question 2 discusses large wood in estuaries). Trees provide large wood when tree branches break off, and when trees or snags fall into streams. Not all large wood in streams originates from riparian vegetation; some large wood originates in upland forests and enters streams via landslides, slope failures, debris flows, etc. Large wood in streams and rivers can provide physical habitat for aquatic communities by affecting channel morphology and hydraulics, creating pools, undercut banks, channel complexity, back alcoves, sloughs and side-channels; thereby, enhancing the diversity of stream habitats and aquatic species (Keller and Swanson 1979, Bilby 1984, Hicks 1989, Shirvell 1990, Gregory and Davis 1992, Ralph et al. 1994).

The importance of wood for creating habitat complexity and cover for salmonids in lowland rivers is well documented. Shrivell (1990) found that root wads and large wood were important habitat structures for juvenile coho and chinook salmon and steelhead during both high-flow and low-flow periods. Wood cover in the modified mainstem of Skagit River, Washington, was significantly and positively correlated with the abundance of juvenile coho and chinook salmon (Beamer and Henderson 1998). Peters et al. (2000) found the abundance and distribution of juvenile coho were significantly influenced by the complexity and abundance of large wood in the Clearwater River in western Washington. In spring and summer, both chinook and coho salmon were positively correlated with larger complex wood accumulations, and, in winter, the presence of all species of salmon fry were related to large wood accumulations (Peters et al. 2000).

Pools are preferred habitats for many stream fishes including salmonids (Sedell et al. 1990, Bisson et al. 1992) and large wood is important in the formation and maintenance of these pools (Bilby 1984, Hicks 1989, Trotter 1990, Ralph et al. 1994, Spence et al. 1996, Lassettre 2000). Pools provide essential habitat for salmonids throughout salmonid residence in fresh water (Bjornn and Reiser 1991). Roni and Quinn (2001) found pools formed by large wood contained higher densities of juvenile cutthroat trout and steelhead during winter, and juvenile coho during summer and winter.

During high flows, large wood slows instream flow and provides resting places for fish. Large wood can provide refuge from high flows during all seasons, especially during winter when flows are highest and winter freshets can displace fish downstream (Tschaplinski and Hartman 1983, Bisson et al. 1987, McMahon and Hartman 1989, Sedell and Beschta 1991). Large wood also prevents salmonid carcasses from washing out to sea after spawning, allowing nutrients from the carcasses to be released to the watershed (Cederholm and Peterson 1985). The influence of large wood habitat and channel morphology emphasizes the crucial link between aquatic and terrestrial riparian communities (Triska 1984, NRC 1996).

Channel Morphology, Streamflow, and Hydrologic Connectivity

Both large wood and riparian vegetation are important in regulating channel morphology, streamflow, and hydrologic connectivity.

Effects of Large Wood

Stream reaches with large wood have greater depth, width, and morphological and hydrologic heterogeneity than reaches without large wood (Trotter 1990). Wood from large, mature trees is important for pool formation and for storage of sediment and organic matter (Trotter 1990). Large wood is important in retaining sediment and organic matter (Lassettre 2000). Reaches with large wood stored twice the amount of organic matter as reaches without large wood (Trotter 1990).

In larger low-gradient streams, accumulations of wood can sometimes span the channel thus creating large pools, secondary channels, and backwaters (Bilby and Bisson 1998). Even where large wood does not bridge the river, large wood can deflect streamflow and create eddies, pools, and low-velocity areas used as rearing and refuge areas for juvenile salmonids and other fish and wildlife species (Bisson et al. 1987, Gregory et al. 1991, Murphy and Meehan 1991, USFWS 2000).

During spring runoff, large wood reduces water velocities, lessening the potential energy available for erosion, channel incision and bank scour (Montgomery et al. 1996). Large wood along the channel margin reduces the erosive capacity of streamflow on channel banks and diverts water onto the floodplain; thereby, creating hydrologic connectivity (Sedell and Beschta 1991, Leopold et al. 1992, Abbe and Montgomery 1996, Coulton et al. 1996). This hydrologic connectivity increases groundwater recharge, raising the adjacent water table (DeBano and Heede 1987), and thereby, maintains cool water temperatures and increases water quantity.

Many functions of large wood have more impact on small streams (less than 7 meters wide) than in larger streams (Bilby and Ward 1989). In small streams, large wood is more readily transported, and logjams are transient and more easily breached than in large rivers and streams (Marston 1982). The USDA Forest Service (1994) reported that large wood accumulations and logjams were common in unconstrained, depositional reaches. Logjams also temporarily impede downstream transport of large wood in constrained channels (Schumm 1977).

Effects of Riparian Vegetation

In addition to large wood, rooted riparian vegetation (herbaceous and woody) can also regulate channel morphology by influencing the delivery of both water and sediment to the channel. Sediment delivery and overland water flow may be altered by both natural disturbances and land use practices (Smith 1976, Sedell and Beschta 1991, Beschta et al. 1996), but riparian forests can affect floodplain and channel morphology by influencing erosion and sediment deposition (Decamps et al. 1988). Riparian vegetation moderates rates of streamflow and energy loss, intercepts sediment, and reduces erosion; thereby maintaining long-term channel stability. Vegetation plays an important role in forming and maintaining stream channels through the binding effects of root systems, and by decreasing flow velocities during periods of bank overflows (Darby 1999). Bank vegetation increases resistance to flow, which slows the rate of water flow and provides sites for sediment deposition, which is subsequently important for more vegetation establishment (Baker 1977, Hupp and Simon 1991, Sedell and Beschta 1991, Gordon et al. 1992, McKenney et al. 1995, Knighton 1998). Lack of bank vegetation can lead to channel widening, channel incision, and lowering of the water table (Abt et al. 1994).

Alteration of the riparian area with a decrease in riparian vegetation has also been associated with loss of instream pools (McIntosh et al. 1994, Magilligan and McDowell 1997).

Bank vegetation can contribute to channel and riparian recovery by trapping sediment along the bank, creating depositional sites for regeneration of vegetation (Hupp and Simon 1991, Friedman et al. 1996). Once depositional surfaces form along the bank, plant communities establish more easily, thereby, trapping additional sediment and stabilizing banks from further erosion (Hupp and Simon 1991).

Riparian Vegetation and Water Quality

Vegetation growing in the riparian area performs a number of important ecological functions that affect water quality, including: stream temperature mediation, sediment interception, and nutrient processing.

Temperature Influences

Riparian vegetation provides shade for streams, which may influence stream temperature (IMST 2000a). The extent of shading and the type of riparian vegetation varies among streams, rivers, and reaches. The relative influence of shade on stream warming depends on many factors, such as quality of shade, angle of sun, degree of cloud cover, leaf angle, aspect and orientation of watershed, time of year, stream volume, volume of subsurface flows, width and depth of water column, and height and density of vegetation. Human activity influences four major factors that influence stream temperature – riparian vegetation, channel dimension, water quantity, and exchange between surface and subsurface water (discussed in Question 3).

On a landscape basis, the relationship between stream temperature and riparian vegetation varies along the length of a stream. While a myriad of factors influence stream temperatures in headwater streams, riparian vegetation exerts considerable influence on stream temperature. In preparation of the temperature workshop report (IMST 2000), the IMST examined thirty studies in which vegetation was modified by harvest and other land uses. The IMST found that stream temperature increased by 2 to 19^{o} F in all but two studies. In the two studies where temperature did not increase, hyporheic exchange was proposed to be the factor responsible for moderating stream temperature.

The majority of stream miles in western Oregon lowlands are composed of small streams that, historically, were surrounded by riparian forests of ash, alder, cottonwood, willow, hawthorn, scattered Douglas fir, grand fir, ponderosa pine, and other conifers (SOER Science Panel 2000, Gregory et al. 2002a). In small lowland streams, stream temperature was strongly influenced by adjacent vegetation (DEQ 2000b, DEQ 2000c, DEQ 2001).

As streams become larger downstream, the relative influence of shade on stream temperature is likely to decrease. In large rivers, riparian shade is important primarily for creating lateral habitats and small cold-water refuges along river margins (SOER Science Panel 2000, Gregory et al. 2002a).

Sediment Filtration and Nutrient Uptake

Riparian vegetation and floodplain wetlands are important for water quality because of the ability of wetland vegetation to take up inorganic (mineral) nutrients and chemical pollution, and to attenuate sediment inputs into stream and rivers (Lowrance et al. 1983, 1984, 1985, Johnston et al. 1990a, Reimold 1994, Richards et al. 1996, Woltemade 1999, Brown 2000, SOER Science Panel 2000).

Water quality in wetlands has been negatively affected by human activities and inputs, and poor floodplain water quality in wetlands contributes to poor water quality in streams (SOER Science Panel 2000). Floodplain wetlands can function as filters for agricultural lands, including crops, pastures, and dairy operations, which are common activities in western Oregon lowlands and often affect aquatic systems (Ruprecht and George 1993, Strittholt and Frost 1995, Ewing 2000, Dent and Robben 2000, Strittholt et al. 2000). Where channel incision has lowered streams below the rooting zone, this filtration function is diminished or lost (Pinay et al. 1998).

During flooding events, the roots and submerged leaves of vegetation may filter suspended particles of sediment (such as silts and sands) in the water column. The water deposits these suspended particles when the velocity is so low that it does not have the kinetic energy necessary to keep the particle in suspension. When floodwaters inundate banks, standing vegetation can slow flows and trap sediment on the banks, providing inorganic nutrients (adsorbed on sediment particles) to riparian vegetation.

Riparian vegetation has been shown to be important for uptake and storage of several inorganic nutrients such as nitrate, ammonium, phosphate, potassium, calcium, magnesium, and chloride ions. Herbaceous plants (herbs, grasses, sedges, and rushes) release many inorganic nutrients back into the environment at the end of the growing season when the plants die and are later decomposed. Woody plants, however, do not always release all of their nutrients at leaf fall: because nitrogen is translocated within a tree or shrub before the leaves or needles are dropped, a significant percentage of the nitrogen can be transported from the leaves and stored elsewhere in the tree or shrub (Chapin and Kedrowski 1983).

Riparian vegetation can be particularly important in reducing inputs of nutrients, especially nitrate and phosphate, from runoff and groundwater of upland agricultural applications (Lowrance et al. 1983, 1984, 1985; Peterjohn and Correl 1984; Pinay and Décamps 1988; Pinay et al. 1992, 1998; Spruill and Galeone 2000). Grasses also can be effective in removing nutrients (Osborne and Kovacic 1993) and pesticides (Douglass et al. 1969). Removal of nitrates is particularly important in nitrogen limited streams and occurs both from uptake by vegetation, and from denitrification and immobilization by microbes in wetland and riparian soils adjacent to streams and rivers (Ryden et al. 1979; Lowrance 1992; Pinay et al. 1992, 1993, 1998, 1999; Brown 2000).

Management of Vegetation In Riparian Areas

Natural vegetation in riparian areas provides the following important ecological functions: habitat diversity, allochthonous food supply for benthic invertebrates, large wood input, stream bank stabilization, streamflow moderation, hydrologic connectivity, temperature mediation, sedimentation interception, and nutrient uptake. Because riparian areas facilitate all or some of these ecological functions, managers should be cautious when making decisions based on single ecological functions (NRC 2002).

Management of vegetation in riparian areas may reflect a gradient of management objectives and approaches. In general, these approaches range from protecting a suite of riparian ecological functions in a riparian area (managed to emulate a natural system), to restoring just a few ecological parameters in a riparian area (as in some riparian buffers managed just for shade), to modifying riparian areas for specific management needs (as in some buffer strips managed just for sediment filtration). In addition, some riparian areas are dramatically modified to support agricultural crops that may be capable of providing specific ecological functions to a stream.

In this section, we discuss some human modifications of vegetation in riparian areas of western Oregon lowlands, as well as protection of riparian ecological functions.

Some Human Modifications of Vegetation in Lowland Riparian Areas

Historically, extensive floodplain forests grew along the rivers and estuaries of western Oregon's lowlands (Johannessen et al. 1971, Towle 1982, Boyd 1986, Boag 1992, Coulton et al 1996, Pearl 1999, Benner and Sedell 2000, Knox 2000). These forests of ash, alder, cottonwood, willow, hawthorn, scattered Douglas fir, grand fir, ponderosa pine, and other conifers contributed to the ecological functions and complex habitats supporting salmonid populations (SOER Science Panel 2000, Gregory et al. 2002a). At present, woody vegetation in riparian ecosystems is in serious decline in the western United States (Obedzinski et al. 2001). The loss of riparian vegetation in agricultural lands is widespread and often permanent (Botkin et al. 1995).

Cottonwoods (Poplars)

Black cottonwood trees (*Populus trichocarpa*) are native to the riparian areas of the Willamette Valley and other major inland lowland rivers and streams in western Oregon (Hibbs, pers. com.[24]). Historically, native black cottonwood trees were logged along lowland rivers and streams in Oregon (Dykaar and Wigington, Jr. 2000). Clearing of cottonwoods from agricultural land on floodplains still takes place, and the wood is used for lumber and pulp (Fletcher, pers. comm.[25])

Hybrid poplars, also known as hybrid cottonwoods (*Populus* spp.), have been recently planted as a short rotation crop for pulpwood or as a longer rotation crop for furniture lumber in some agricultural bottomlands. If the hybrid poplars are harvested before they are 12 years old, they are considered an agricultural crop and, therefore, are not subject to the forest practice regulations that apply to all other forestlands in Oregon. Poplar plantations are found across Oregon with several plantations in the Willamette Valley and along the Columbia River. Hybrid poplars are also being planted as shelterbelts between streams and agricultural operations (Fletcher, pers. comm.).

Although hybrid poplars tolerate some flooding and act as a bio-filter for chemicals, some scientists have concerns about their use in riparian areas because of the following attributes of hybrid poplar plantations (Braatne 1999; Fletcher, pers. comm.), including:

1. High herbicide applications the first few years may negatively affect water quality as young hybrid poplars require herbicide applications because they do not compete well with grasses;
2. Poor habitat for wildlife because most plantations are a monoculture of non-native hybrid poplars; few wildlife species have been found in hybrid plantations;
3. Loss of structure for riparian ecosystems: structural loss of native trees; loss of sources of large wood; and, until harvest stands mature, less shade over streams;
4. Potential stream sedimentation during short or long rotations including cultivation, planting and harvest activities. Since hybrid cottonwood plantations are planted on flat ground, not much sedimentation occurs during harvest; however, stump removal and plowing increase the soil's erosion potential.

In his review of hybrid poplar literature, Braatne (1999; p. 14) suggests more scientific studies are necessary to determine how and if "hybrid poplars can be integrated into agricultural floodplains in a manner that promotes the natural functions of riparian corridors." Regeneration of cottonwood is a concern, and many factors that affect reestablishment of cottonwood are poorly understood.

[25] Fletcher, R. Personal Communication, 2002. Department of Forest Resources, Oregon State University, Corvallis, Oregon.

Buffer Strips for Specific Management Purposes
Riparian management zones, *riparian reserves, riparian buffers,* and *buffer strips* are terms that refer to areas along streams and rivers that are delineated for specific management purposes. These delineated areas are not synonymous with natural riparian areas. Any riparian buffer or management zone provides for some riparian functions and excludes others.

In some circumstances, buffer strips are managed specifically to reduce chemical and sediment inputs to streams from agricultural lands. Studies show that these buffers strips have been successful in meeting those objectives (Thornton et al. 1997, Tufford et al. 1998, Gold et al. 2000, Moorman et al. 2000, Spruill and Galeone 2000). Determination of appropriate widths of riparian management zones (buffers) for specific management purposes is a complex and often controversial topic (Johnson and Ryba 1992).

Recommended riparian buffer widths vary according to the ecosystem functions under consideration, as well as the attributes of the ecosystem (Budd et al. 1987, Johnson and Ryba 1992, Osborne and Kovacic 1993, NRC 2002). For example, a relatively narrow strip of vegetation may provide shade or reduce chemical and sediment inputs, but maintaining relative humidity in the riparian area may require a buffer in excess of 328 feet (100 m) (Dong et al. 1998).

<u>Protection of Riparian Ecological Functions</u>
Unlike forested uplands, many riparian areas in lowlands receive little or no protection. Few studies examine what percentage of a landscape must contain intact riparian management zones, and where these riparian management zones should be located to be most beneficial for maintaining quality salmonid habitat (IMST 1999). On a landscape basis, care should be taken to maintain a variety of riparian vegetation types and ages along stream reaches, including small and intermittent streams, larger rivers, and floodplains. These native riparian plant communities contribute to the proper structure and function of river and stream ecosystems.

Riparian vegetation, especially on large, low-gradient streams, often differs from upslope vegetation because of differing environmental conditions, disturbance histories, and successional patterns (Pabst and Spies 1998). Riparian protection strategies need to incorporate understanding of interactions between riparian and adjacent upslope agricultural fields or forests, as well as the historical patterns created by riparian vegetation and its role in maintaining ecosystem heterogeneity.

The IMST believes that protection and restoration of riparian areas in western Oregon lowlands requires ongoing assessment of riparian conditions through remote sensing or any other landscape-level assessment of riparian conditions (discussed in Question 5). Riparian assessment is an important tool for both identifying and protecting healthy riparian areas, and prioritizing, identifying, and restoring riparian areas not yet in a condition necessary to support salmonid recovery.

Riparian Management Zones
Spence et al. (1996; p. 229) write, "Specific recommendations for riparian buffer widths can only be made with a clear definition of riparian management goals. If the goal is to maintain instream processes over a relatively short time frame (years to decades), then fully protected riparian buffers of approximately one site-potential tree (30-45 m in most Pacific Northwest forests) are likely to maintain 90%-100% of most key functions."

In terms of protecting a suite of ecological functions, Johnson and Ryba (1992; p. 10) write, "Buffer widths for stream and wetland habitats may be established using two general methods...a *fixed width* to protect specific functions, or a *variable width* that considers specific site conditions."

In an earlier report on west-side forestry, the IMST (1999; p. 20) stated the following about Oregon Department of Forestry's fixed-width riparian buffer system, "given the distinctive differences between stream functions based on size, we conclude it is scientifically sound to vary riparian widths with stream size." Stream size impacts aquatic structure and function. The following components of stream function correspond to stream size: invertebrate feeding groups (Cummins 1973, 1974), large wood contributions (Bilby and Ward 1989, Bilby and Bisson 1998, Prichard et al. 1998), and solar radiation (Naiman 1992). In addition to basing buffer widths on stream size, one should also take into account adjacent land use and natural or degraded site conditions.

Although both fixed-width buffers and variable-width buffers may be related to stream size, variable-width buffers also consider other attributes of streams: soil type and erosion potential; vegetation (organic inputs, shading, large wood, wildlife habitat); landscape (topography, elevation, slope, stream structure and flow); and land-use characteristics (forestry, agriculture, grazing, urban, etc.) (Budd et al. 1987, Johnson and Ryba 1992). In comparing the two methods of determining widths of riparian management zones, the IMST notes that fixed-width buffers are easy to determine but do not necessarily consider variations in the landscape, while variable-width buffers are more difficult to determine but do consider variations in the landscape and stream function.

An alternative approach to determining widths for riparian management zones is based on the *flood-prone area* of a stream or river, which can be described operationally as the area inundated when a stream is twice bankfull depth (Rosgen 1996). This definition applies to small streams and does not work well in large rivers. Because naturally functioning lowland rivers and streams are generally less constrained than upland stream systems, lowland rivers have wide floodplains which may or may not be feasibly protected.

The roots of vegetation stabilize floodplains; and vegetated floodplains 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. Protection of riparian vegetation on floodplains is needed for the floodplain to perform these functions (IMST 1999).

In lowland stream and river systems, the IMST acknowledges that recommended widths of riparian management zones might vary, not only by stream size and floodplain width, but also according to the riparian ecosystem functions under consideration and according to the attributes of the particular stream system. In addition, the length of a riparian management zone is just as relevant as the width in terms of protecting riparian ecosystem functions.

Site Potential

The influence of riparian vegetation on an aquatic system differs among vegetation types and location (Richards et al. 1996). Therefore, the quality and amount of shade, or other beneficial functions of riparian vegetation, depend upon the vegetation capability of a site.

Because of site differences (precipitation, microclimate, hydrology, aspect, soil type, flooding regimes, etc.), not all riparian areas can support the same vegetation type. Some riparian areas in western Oregon lowlands are capable of supporting hardwood species, while other riparian areas in western Oregon, especially along coastal lowlands, support conifer species. The differing abilities of sites to support vegetation is called *site potential*.

Barrington et al. (2001, p. 1666) describe site potential as "the highest [ecological] functional status attainable on a site..." In application, some sites probably cannot reach true site potential due to physical constraints imposed on the landscape by humans. Barrington et al. (2001) suggest also considering *site capability*, which modifies site potential by human infrastructure constraints, such as power-lines, roads, and ditches. In practical terms, site capability is the highest state attainable for a given stream, given the legal and jurisdictional constraints of the land manager.

Application of the concepts of site potential and/or site capability in development of riparian management protection and restoration strategies is consistent with a landscape approach and our guidance to emulate, to a greater degree than at present, the historical condition and range of conditions of riparian areas. Infrastructure constraints should be seen in the context of loss of salmonid habitat availability and quality, and not as an excuse for lack of riparian vegetation.

Findings and Conclusions

Findings

<u>Ecological Functions of Vegetation Inhabiting Riparian Areas</u>

Because of their disturbance regimes and steep environmental gradients, riparian areas are some of the most dynamic and ecologically rich portions of the landscape. Riparian areas do not exist in a fixed-state for long periods of time; they are in a state of change.

Riparian vegetation provides many important ecological functions to aquatic systems: habitat diversity, organic matter inputs, large wood input, regulation of channel morphology and streamflow, hydrologic connectivity, temperature mediation, sediment interception, and nutrient uptake.

Riparian Vegetation Contribution to Aquatic Community

Riparian vegetation supports a diverse biotic community in rivers and streams by providing:

- Cover for salmonids resting or hiding from predators
- Fallen leaves and detritus, which are food for aquatic invertebrates
- Refuge from floods
- Habitat for invertebrates and salmonid fishes

Large Wood and Habitat Diversity

Riparian vegetation is an important source of large wood. Upland forests contribute large wood to lowland streams. Large wood provides the following ecological functions to stream ecosystems:

- Physical habitat and organic material for aquatic communities
- Heterogeneity of channel morphology (creating pools and refuge from current)
- Habitat complexity and cover for salmonids
- Refuge from high flows

Channel Morphology, Streamflow, and Hydrologic Connectivity

Both large wood and riparian vegetation are important in regulating channel morphology, streamflow and hydrologic connectivity through the following functions:

- Erosion control and sediment storage
- Hydrologic connection of floodplain to stream channel
- Protection of streambanks
- Reduction of channel incision

Riparian Vegetation and Water Quality
Riparian vegetation can improve water quality through:

- Mediation of stream temperature by providing shade and stabilizing stream banks
- Reduction of erosion of sediments into stream
- Filtration of suspended particles of sediment
- Interception of nutrients and chemical pollution

Management of Vegetation In Riparian Areas
At present, woody vegetation is in decline (much lower than historic levels) in western Oregon riparian ecosystems.

Some Human Modification of Vegetation in Lowland Riparian Areas
Black cottonwood trees are native to the riparian areas of the Willamette Valley and other major inland lowland rivers and streams in western Oregon. These tree species provide important riparian structure and function; however, many black cottonwood forests in western Oregon have been cleared for agriculture.

Recently, non-native hybrid poplars have been planted in some Oregon floodplains. Due to a variety of potential impacts on water quality and habitat, more scientific studies are needed to determine how and if hybrid poplar plantations can restore some natural riparian functions while cultivated as an agricultural crop. Regeneration of cottonwood is a concern, and many factors that affect reestablishment of cottonwood are poorly understood.

Protection of Riparian Ecological Functions
Riparian assessment is an important tool for identifying and protecting healthy riparian areas, as well as identifying and restoring riparian areas that are not in conditions needed for salmonid recovery.

Riparian management zones (buffers) are a common site-specific strategy, which can be managed to provide the following natural ecosystem functions:

- Wildlife habitat
- Cover for salmonids resting or hiding from predators
- Fallen leaves and detritus, which are food for aquatic invertebrates
- Habitat for invertebrates and salmonid fishes
- Physical habitat and organic material for aquatic communities
- Heterogeneity of channel morphology (creating pools and refuge from current)
- Habitat complexity and cover for salmonids
- Refuge from high flows
- Erosion control and sediment storage
- Hydrologic connection of floodplain to stream channel
- Protection of streambanks
- Reduction of channel incision
- Mediation of stream temperature by providing shade
- Reduction of erosion of sediments into stream
- Filtration of suspended particles of sediment
- Processing nutrients and chemical pollution

Determining riparian management area widths is a complex and often controversial subject. Widths may vary, not only by stream size or floodplain width, but also according to the riparian and adjacent upland ecosystem functions under consideration. Length of the riparian management zone is just as relevant as width in terms of protecting riparian ecosystem functions.

The influence of vegetation on aquatic systems depends on vegetation type and location, which will vary from one site to another. Site potential responds to precipitation, microclimate, hydrology, aspect, soil type, flooding regimes, etc.

Conclusions

Ecological Functions of Vegetation Inhabiting Riparian Areas

Riparian vegetation is crucial to the protection and restoration of salmonid habitat in western Oregon lowlands. Riparian vegetation provides several ecological functions that contribute to fish habitat.

Because vegetation and large wood within riparian areas contribute important hydrologic and biologic functions to lowland rivers and estuaries, they should receive protection and be restored toward their historic level of function within river networks.

Management of Vegetation Inhabiting Riparian Areas

Reductions in the extent of vegetation inhabiting riparian areas have limited the exchange of nutrients and the recruitment of large wood from riparian forests.

Some Human Modifications of Vegetation in Lowland Riparian Areas

Since questions remain as to the ability of hybrid poplar plantations to replace the ecological functions of native cottonwoods which have been in notable decline, the IMST recommends that native cottonwoods no longer be removed from riparian areas, on-channel or off-channel, and that, where appropriate, native cottonwoods and willows should be restored along streams and rivers, especially as a buffer adjacent to agricultural lands.

More scientific studies are needed to determine how and if hybrid poplar plantations can restore some natural riparian functions while cultivated as an agricultural crop.

One of the simplest and most effective site-specific ways to ameliorate many of the negative anthropogenic effects currently observed on lowland rivers is to protect and/or re-establish riparian vegetation and wetlands to intercept sediment and take up organic materials, pesticides and fertilizers. Riparian vegetation can also stabilize banks, provide large wood to the ecosystem, and provide shade to reduce the rate of instream warming.

Protection of Riparian Ecological Functions

Riparian vegetation is an important ecological component of western Oregon lowlands that should be protected and restored under the Oregon Plan. The IMST concludes that riparian assessment is needed as a framework for protection and restoration of riparian areas.

Protection and restoration of riparian areas can greatly improve salmonid habitat and water quality by contributing the following ecological functions:

- Providing higher infiltration rates of precipitation into the soil profile with the resultant benefits of prolonged subsurface water flows, delivery of cool subsurface waters through interflow and hyporheic flows, attenuation of flood flows, reduction of kinetic energies necessary for erosion, and filtration of nutrients originating in uplands
- Increasing shading, which results in cooler water temperatures
- Reducing the negative impact of chemical, sediment, and excessive nutrient impacts through interception, biological uptake and sequestration by plants. Riparian soils and microbes are also important in nutrient uptake and sequestration

- Protecting against channel incision and accelerated streambank erosion
- Providing for a diversity of habitat for fish rearing, refuge, and escape
- Providing a long-term source of large wood for macroinvertebrate habitat, (including hiding and escape)

The IMST suggests that we seek to establish trends toward the historical range of riparian conditions for future success in restoring stocks of wild salmonids. On a landscape basis, care should be taken to maintain a variety of vegetation life forms and ages on all stream reaches, including small and intermittent streams, and on the floodplain.

The widths of riparian management zones can be based on stream size, watershed function, and /or width of flood-prone area. Because stream size affects aquatic structure and function, it is scientifically logical to vary riparian buffer widths with stream size. Scientifically, riparian buffer widths should be determined in terms of watershed function (e.g., appropriate distances to trap overland flows and precipitate out sediments or pollutants). Therefore, buffer widths vary with climatic, hydrologic, edaphic, topographic, and vegetative regimes.

Since riparian areas differ considerably in the type of vegetation supported, each riparian area must be assessed for its potential to support the establishment and growth of a variety of vegetation life forms (i.e., site potential). Blanket recommendations to establish conifers, deciduous trees, or willows in all riparian areas will not be successful everywhere because these site potentials are not obtainable everywhere. Plant species must be appropriate for the vegetative capability of the site.

Question 5. What general actions are needed in the western Oregon lowlands to facilitate recovery of salmonid populations?

In this question, we describe how both preservation of functioning habitats and restoration of the key habitats are needed for salmonid recovery. We then illustrate how the landscape perspective and scientific information can be employed in planning, assessing, prioritizing, and monitoring salmonid protection and restoration activities. We conclude with examples of how landscape scale processes might be restored through floodplain and estuary restoration. Throughout the discussion, we include examples of protection and restoration efforts that utilize scientific principles that are consistent with strategies we believe to be important to salmonid recovery under the Oregon Plan.

Protection and Restoration

Two general actions that should facilitate recovery of salmonid populations in lowlands are protection and restoration. Protection, or preservation, of an aquatic system involves preventing anthropogenic alterations to the structure and function of the system (NRC 1992). Ideally, this would involve protection of biological processes (e.g., spawning migrations, metapopulation dynamics; Rieman and Dunham 2000) and the physical processes that maintain salmonid habitat (e.g., disturbance regimes, flows of water, sediment, and large wood; Reeves et al. 1995). The mechanisms for protection, including regulation, acquisition, conservation easements, and partnership building, lie in the realm of policy and will not be addressed further in this discussion. However, scientific information can be used to make informed decisions about where protection may be an effective tool.

In contrast, restoration involves improving aquatic functions and related physical, chemical, and biological characteristics of riparian and aquatic systems. Restoration may involve reconstruction of previous physical conditions, adjusting chemical properties of soil and water, or biological re-introductions (NRC 1992). As pointed out in the Oregon Plan (1997), habitat restoration includes more than reintroducing structure to stream channels. Restoration activities include changes in water quality, water quantity, fish passage, and riparian vegetation (Oregon Plan 1999). Different types of restoration activities vary in the amount of human intervention involved and represent a continuum of “passive” to “active” restoration (NRC 1996).

In this report, we use the term restoration broadly to encompass activities that are sometimes classified as “rehabilitation”, “enhancement”, and “mitigation” (NRC 1992). Rehabilitation has been defined as “re-establishment of naturally self-sustaining aquatic-riparian ecosystems the extent possible while acknowledging that irreversible changes – such as dams, permanent channel changes due to urbanization and roads, stream channel incision, floodplain losses, and estuary losses – might permit only partial restoration of ecological functions ” (NRC 1996; p. 207). In Oregon today, reestablishing pre-EuroAmerican settlement aquatic conditions and functions across entire watersheds is not feasible because of societal constraints and/or irreversible landscape changes. However, at individual sites, restoration to pre-EuroAmerican settlement conditions may be possible, and even desirable.

“Enhancement” activities focus on improving selected habitat characteristics, and may involve technological approaches or artificial structures that mimic habitat elements (NRC 1996). “Mitigation” describes a range of activities with the intent to, “avoid, reduce, or compensate for the effects of environmental damage” (NRC 1992; p. 522). Therefore, mitigation may involve habitat creation, enhancement, or rehabilitation.

Under the Oregon Plan, watershed restoration is defined as the “process of restoring systems and processes to the point they can provide the natural materials and ecological functions that create habitat” (Oregon Plan 1997). Restoration activities that have been reported thus far under the Oregon Plan include rehabilitation, enhancement, and mitigation activities (Maleki and Riggers 2000). In this report, we emphasize the restoration and rehabilitation of ecological function. However, we acknowledge that enhancement and mitigation activities may have a role to play in salmonid recovery.

Landscape Approach to Protection and Restoration

Productive salmonid ecosystems require a chain of favorable, interconnected habitats that are maintained by natural physical (geomorphic and hydrologic) and biological processes within a watershed. These habitats are linked in both space and time and allow expression of diverse life histories (Bisson 1995, Reeves et al. 1995).

As we have described throughout this report, favorable habitat is not static either within or among basins. Disturbances, such was wildfires, landslides, and floods produce a mosaic of habitats in different successional stages (Reeves et al. 1995). This dynamic mosaic argues for identification, protection, and restoration of habitat throughout the landscape, including floodplains, wetlands, and surrounding land. Preservation of habitat fragments may not be sufficient to maintain natural diversity in streams or rivers (Harding et al. 1999), and restoration may be effective only if watersheds are protected from land use practices that disrupt fundamental ecological processes in streams (Hynes 1975). An approach to salmonid recovery that considers the varied spatial and temporal distribution of key habitats needed by anadromous salmonids to complete their life histories has been recognized as necessary to the long-term recovery of salmonid stocks (NRC 1992, 1996). We have discussed using a landscape approach in previous IMST reports (IMST 1999, 2001).

In the sections that follow, we demonstrate how the landscape concepts outlined above (and in the report's introduction) could be applied to salmonid recovery, through:

- Considering landscape scale biological processes,
- Landscape scale research, modeling and planning,
- Inventory and assessment,
- Prioritization,
- Monitoring, and
- Selecting projects that maintain and restore landscape scale processes.

Considering landscape scale biological processes - metapopulations

A landscape approach to salmonid recovery is consistent with the concepts of metapopulation dynamics. According to the metapopulation concept, species occur as discrete local populations on networks of idealized habitat patches. Groups of populations that are linked by migration of individuals are considered to be metapopulations. Local or regional events cause extinction of local populations, but long-term persistence of metapopulations is due to asynchrony, local population dynamics, and the ability of individuals to re-colonize habitats (Harrison 1991, Hanski and Gilpin 1991, Hanski 1998).

Metapopulation theory has been applied to many groups of organisms, leading to the development of multiple theories (or models). These metapopulation models differ according to the relative size of populations, relative rates of extinction and recolonization, and relative habitat quality (Hanski 1991, Harrison 1991). These models have been applied to Pacific salmon biology elsewhere (Li et al. 1995, Schlosser and Angermeier 1995, Independent Science Group1996, Rieman and Dunham 2000). Here, we briefly describe three models to illustrate how metapopulation theory can be applied to salmon recovery planning.

In a group of models termed core-satellite models by the IMST (Figure 23) – large (core) populations are less prone to extinction and provide a source of immigrants to smaller (satellite) populations (Li et al. 1995, IMST 2001). The mainland-island group of models described by Hanski and Gilpin (1991) and Harrison (1991) falls under this category. In these models, a larger (mainland) population is generally stable, while smaller (island) populations may fluctuate widely in abundance as a result of demographic processes, genetic processes, and changing environmental conditions (Harrison 1991). For salmon, these environmental changes may be broad-scale variation in climate and ocean conditions, or changes in local conditions. In this situation, persistence of the mainland population is therefore critical to the persistence of the metapopulation.

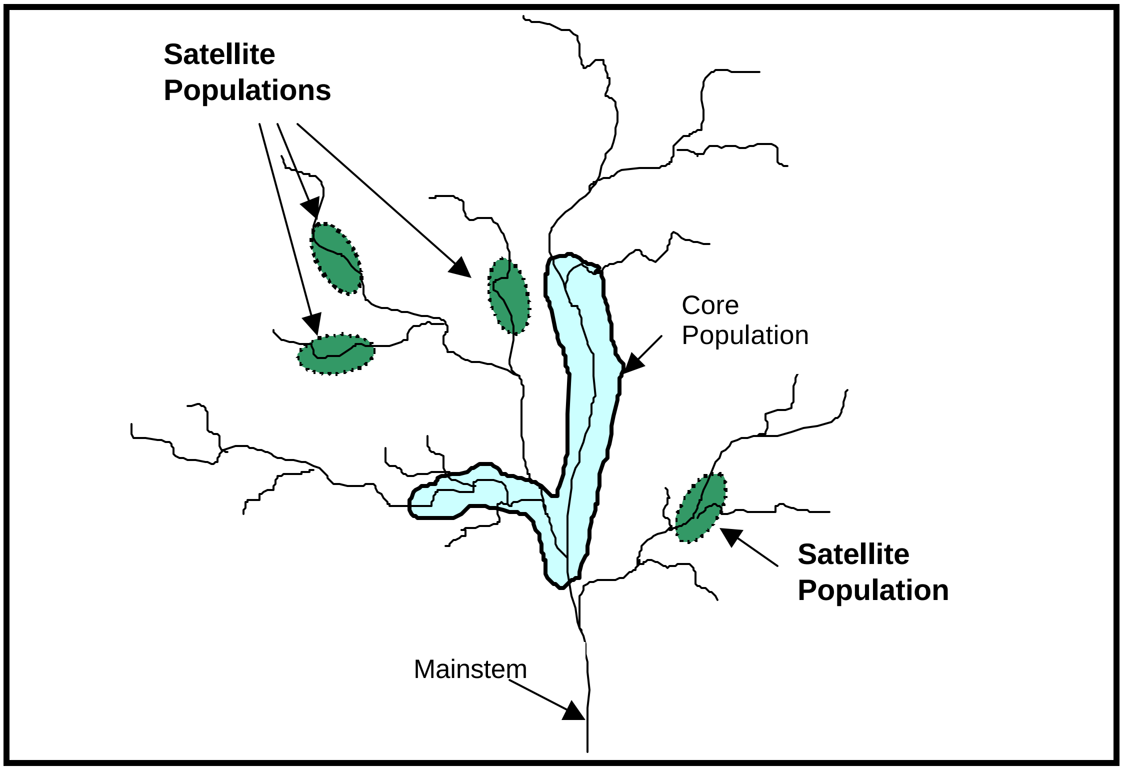

Figure 23. Schematic diagram of a core-satellite model of metapopulation structure. The figure shows a large core population and four satellite populations (IMST 2001).

Frissell (1993) concluded that in western Oregon lowlands, core populations were closely associated with streams that had high levels of ecological function in low gradient stream reaches. If the *core areas* for coho identified in the Oregon Plan supported core (or mainland) populations of a coho metapopulation, then protecting these core area habitats would be critical to recovery. However, as we describe in this report, the dynamic nature of aquatic systems in the Pacific Northwest demonstrates that salmonid habitat quality is highly variable, both spatially and temporally (Reeves et al. 1995). Therefore, we would expect that core populations of salmon would not remain static over time and space, and successful management would need to anticipate and respond to these changes.

A similar model to the mainland-island model, that also could be considered a core-satellite model, is the source-sink model. The source-sink model emphasizes that habitat quality varies enough among areas to cause differences in productivity among populations (Harrison 1991). Variation in habitat quality may be due to natural processes or human disturbance (Pulliam 1988). In the source-sink model, source populations occupy high quality habitat, leading to enhanced survival and reproduction (Pulliam 1988). Salmonids that disperse into lower quality habitat form sink populations. However, because habitat quality is lower, sink populations are less likely to persist if source populations are extirpated (Pulliam 1988). In a source-sink system, protection of source populations is even more critical because smaller populations are not self-sustaining in the absence of the source population. In contrast, in a mainland-island system, island populations might serve as a refuge if a mainland population went extinct.

Another model, the patchy population model, consists of a number of populations that are highly connected by dispersal (Harrison 1991). Salmon exhibit some characteristics of patchy populations (Reeves et al. 1995). Like other species that exhibit this pattern, salmon exist in a dynamic environment with variable patch quality and have strong dispersal capabilities (Harrison 1991). In this case, the presence of multiple habitat patches and the potential for dispersal among patches is important to salmon persistence and recovery (Reeves et al. 1995; Schlosser and Angermeier 1995).

At present, scientists have little data to determine which, if any, of the models is most appropriate to describe demographic processes in Oregon salmonids. Empirical evidence suggests that fall chinook salmon share characteristics of several metapopulation models (Schlosser and Angermeier 1995). Furthermore, population size and dispersal rates vary among species and runs. Regardless of differences among models, metapopulation structure was likely a key strategy by which salmonids survived and adapted to changes in their environment.

Metapopulation theory has only recently been used to formulate salmon management strategies (Gresswell et al. 1994, Li et al. 1995, Mundy et al. 1995, Schlosser and Angemeier 1995, NRC 1996, Independent Science Group 1996), but it can provide important guidance to recovery efforts. Local populations, even an entire metapopulation, are more prone to extinction in fragmented landscapes having little connectivity. Given the dynamic nature of essential salmonid habitats, currently unoccupied habitats may be critical for long-term survival (Hanski 1997). Recovery strategies, to be successful, need to consider metapopulation structure within and among watersheds, the scale thought to be relevant to salmonid metapopulation dynamics (Reeves et al. 1995).

Understanding that salmonid populations interact with one another highlights the importance of identifying core (mainland or source) populations, maintaining connectivity among habitat patches, and designing habitat restoration strategies to support multiple self-sustaining populations. A better understanding of critical parameters of salmonid metapopulations, such as dispersal among basins (stray rates) and productivity (smolt-adult ratios), can help to design more effective recovery strategies. We conclude that metapopulation theory is useful for understanding of salmonid population structure, and should be carefully evaluated.

Landscape scale research, modeling, and planning

Restoration projects are usually applied to only a small portion of a watershed and may not provide measurable increases in smolt or adult production at the larger, watershed level (NRC 1996, Roni et al. 2002). Most restoration efforts to date have been conducted in upland reaches and on the site scale rather than the landscape or watershed scale (Frissell and Ralph 1998). Common restoration activities – including barrier removal and in-channel restoration – are by definition constrained to an individual site. Additionally, while fish may need to be restored to a certain reach of a stream, it may be necessary to apply habitat restoration efforts to some other reach of the river because of the river continuum. One of the greatest challenges of recovery planning is selecting site-specific protection and restoration activities without losing the landscape perspective (Roni et al. 2002). To overcome this challenge, decision-making within a landscape approach needs to be informed by research and planning at the appropriate scales.

Examples of landscape scale research and modeling

Researchers participating in the Pacific Northwest Ecosystem Research Consortium (PNW-ERC) are undertaking landscape-scale modeling at the basin and watershed level to evaluate ecosystem processes and opportunities for restoration in the Pacific Northwest (http://www.orst.edu/Dept/pnw-erc/). These projects provide examples of landscape level analyses that integrate many ecosystem functions and characteristics. The goal of the projects is to understand processes at a variety of spatial and temporal scales and to identify opportunities for restoration and for improving ecological functions.

The Willamette Basin Futures is a project undertaken by members of the PNW-ERC (Hulse et al. 2002). The group has developed datasets and digital maps that have been used to develop models of past, present, and future conditions in the Willamette Valley. Historic conditions are based on General Land Office Surveys from the 1850's. Possible future conditions are based on assumptions about future development trajectories. The Willamette Basin Futures Project also identified restoration opportunities in the Willamette Basin. Sections of the Willamette River were evaluated for their potential to increase river complexity, to increase forest floodplain area, and to increase natural water storage during floods. The same sections were evaluated for socioeconomic constraints to river restoration, such as urban development (high population density), major infrastructure (roads or bridges), and high land values. Based on this framework, the group was able to identify areas with high ecological potential for restoration and lower demographic and economic constraints (Figure 24).

PNW-ERC is undertaking another project to design, implement, and evaluate restoration scenarios at the watershed scale using geographic information system (GIS) modeling (OSU-EPA 2001). Researchers are integrating biophysical factors to evaluate restoration options and strategies within the context of current land uses and stakeholder goals. Currently, the research group is assessing the modeling framework and the use of the GIS-based decision tool in two watersheds in the Willamette Basin: the Long Tom River Watershed and the S. Santiam Basin. While this research and modeling effort has not been completed, the project illustrates a possible method of integrating comprehensive and diverse landscape level conditions and characteristics at the subbasin scale.

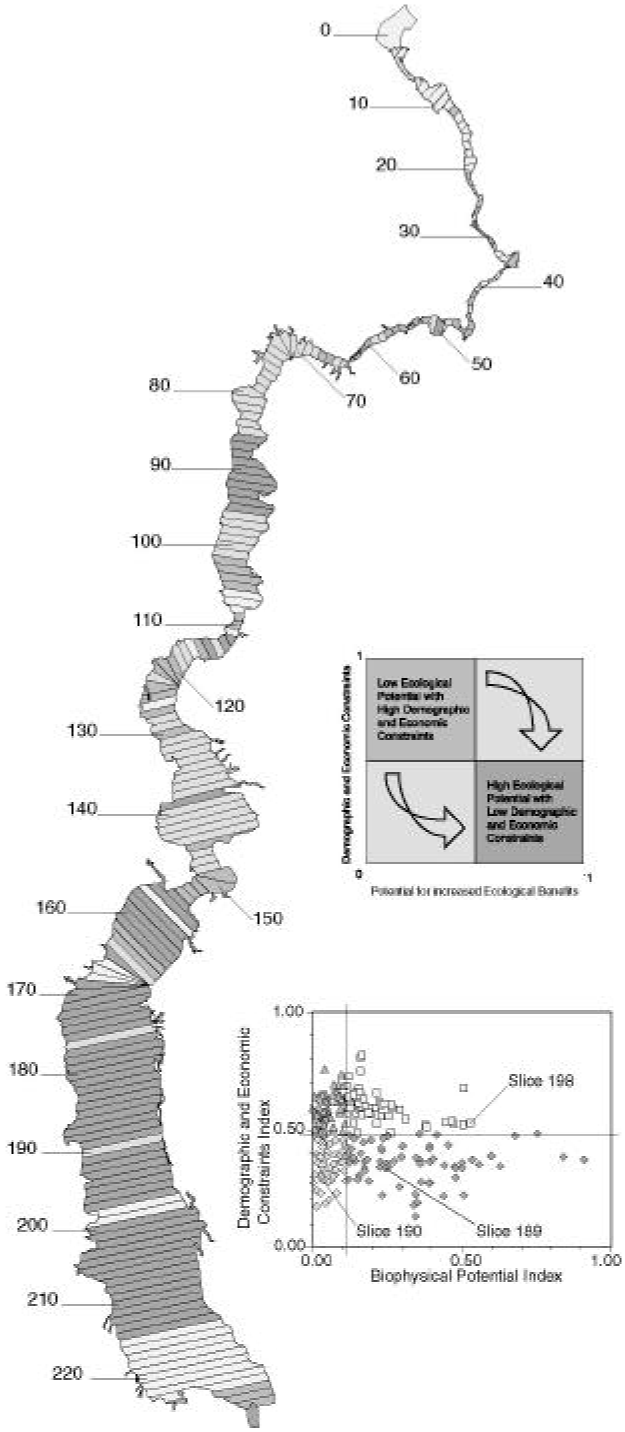

Figure 24. Restoration priorities for the Willamette River determined by the Willamette Futures Project. These priorities are based on the objectives of 1) increasing channel complexity, 2) increasing the area of floodplain forest, and 3) increasing non-structural floodwater storage. Reproduced from Hulse et al. (2002).

Another collaborative research group that works on the landscape scale in Oregon's Coast Range is the Coastal Landscape Analysis and Modeling Study (CLAMS). CLAMS is a multi-disciplinary research effort sponsored cooperatively through Oregon State University, the USFS Pacific Northwest Research Station, and the Oregon Department of Forestry (http://www.fsl.orst.edu/clams/). The effort was formed to analyze the ecological, economic, and social consequences of forest policies of different landowners in the Coast Range. In one project, Burnett (2001) identified watershed level features that were most related to conditions of lowland unconstrained stream reaches in the Elk River (Oregon). CLAMS also plans to project in-channel conditions for lowland streams on forested lands for the next 100 years based on watershed conditions (road density, vegetation age) under different management scenarios (G. Reeves and K. Burnett, pers. comm.[26]).

Landscape scale planning

Watershed scale planning

The need for protection and restoration of entire watersheds has been proposed many times since Livingston Stone's (1892) idea of "salmon parks" (e.g., Frissell et al. 1986, Doppelt et al. 1993, Healey and Prince 1995, Pacific Rivers Council 1997, Lichatowich et al. 1999). Using the basin or watershed as a management unit for natural resource planning was first recognized in Oregon during 1993 with the implementation of the Watershed Health Program (Oregon Plan 1997). If the river basin or watershed is the fundamental freshwater geographic unit for salmon (NRC 1996), it is logical that research and planning be conducted at the watershed scale.

Many watershed councils have conducted watershed assessments and action plans as preliminary steps towards restoration. Some plans (e.g., Williams Creek Watershed Action Plan; Church 2000) attempt to identify and integrate upland and lowland conditions and processes, to designate critical lowland habitats, to increase stream habitat complexity and streamflow, and to improve fish passage. OWEB has provided guidance to watershed councils on how watershed plans, restoration activities, and monitoring could be based on conditions identified in the watershed assessment process (Figure 25; Oregon Plan 1999). In addition, under Oregon Senate Bill 1010, Agricultural Water Quality Management area plans (AgWQM area plans) are being developed to improve water quality in subbasins and basins, largely in agricultural land, although they do not directly address lowland habitat needs for salmonids.

[26] Reeves, G. and K. Burnett. Personal Communication, 2002. USFS PNW Research Lab, Corvallis, OR.

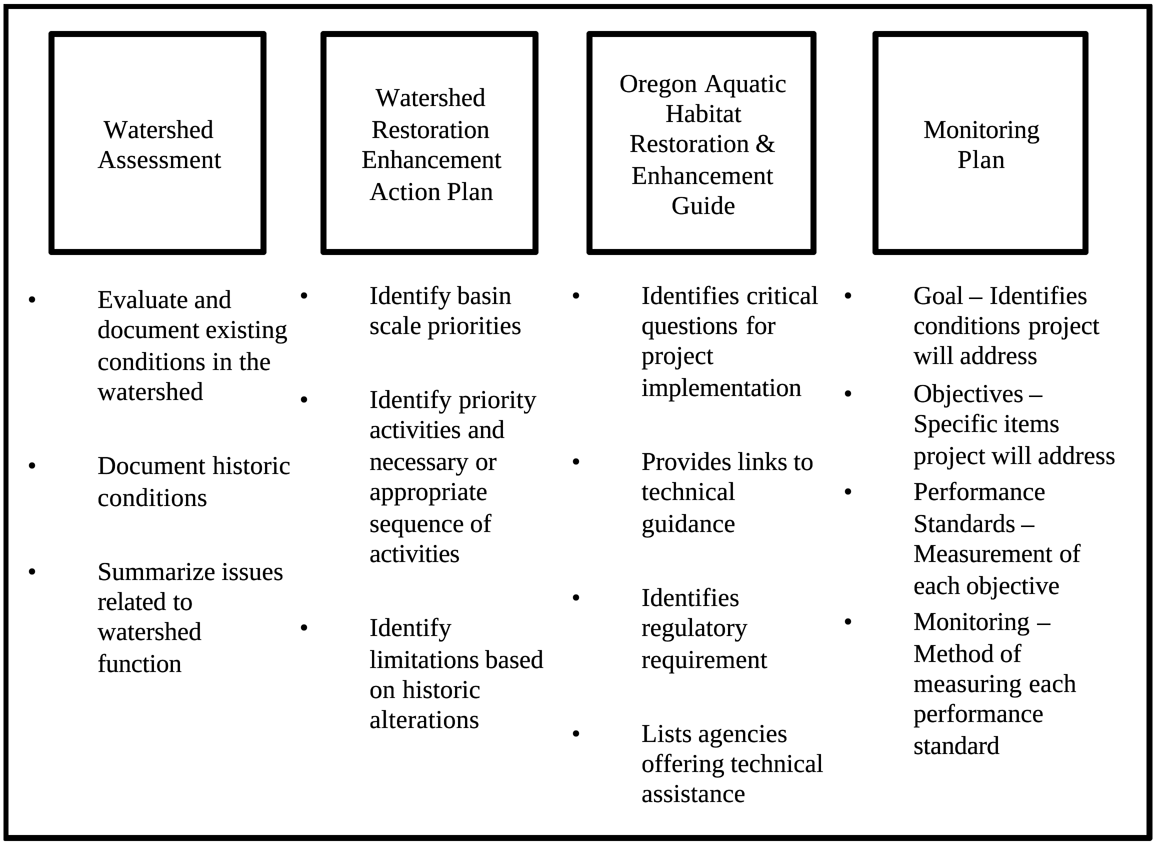

Figure 25. Watershed scale restoration strategy from the Oregon Aquatic Habitat Restoration Guide (Oregon Plan 1999).

Basin scale planning

Planning for units larger than watersheds are important to maintaining and restoring large-scale biological processes such as metapopulation structure. An example of landscape scale planning is the Willamette Restoration Initiative, which was established by an Executive Order of the Governor of Oregon (98-18 and 99-17) (WRI 2001). The Initiative has developed a basin-wide strategy for protection and restoration of fish and wildlife habitat, to increase declining species, to enhance water quality, and to manage floodplains. This strategy was presented to the Governor in February 2001 and has been recommended as the Willamette Basin Supplement to the Oregon Plan for Salmon and Watersheds.

The Willamette Restoration Initiative (Allen et al. 1999, WRI 2001) represents a basin-wide effort to understand and make recommendations for restoration of floodplain function and aquatic habitats. We briefly summarize some of the efforts below because the Initiative recognizes the connections between upland and lowland land uses, the loss of connection between the river and its floodplain, and the function of aquatic habitat.

The Willamette Restoration Strategy proposes 27 critical actions. Many of these actions (which address the scientific basis for restoration and recovery identified by the IMST in this report) are relevant to restoring lowland ecosystem structure and function and can have a positive effect on salmonid recovery. The most relevant actions include:

Clean Water (Water Quality)

- Support the Willamette Basin total maximum daily load (TMDL) process, including coordination and communication.
- Support effective implementation of AgWQMP (Senate Bill 1010) and encourage its use to address species needs.
- Identify agricultural areas that are a high priority for salmonid recovery and focus program efforts on management to meet fish habitat needs related to water quality in those areas.
- Reduce the levels of toxic pollutants in the Willamette Basin.
- Initiate an effluent and "water quality impact" trading pilot project in the Willamette Basin.

Water Quantity

- Support improvements to water quantity management efforts to meet water supply needs for ecologic and economic purposes.
- Support the US Army Corps of Engineers' ongoing assessment of flood control reservoir operation by helping identify and communicate changes needed to address streamflow issues.

Habitat and Hydrology

- Establish science-based riparian area protection guidelines.
- Develop and implement a statewide riparian policy to provide healthy riparian areas in sufficient quantity to achieve statewide water quality standards and protect and restore aquatic habitat for salmonids. Also recommended is the development of a landscape-based riparian management strategy for the Willamette.
- Support basin-wide scientific investigations of how to restore floodplain function.
- Inventory, map, and conserve priority fish and wildlife habitats in the basin.
- Improve both upstream and downstream fish passage at dams, culverts, and water diversions.

Inventory and Assessment

One critical component of natural resource planning is inventory and assessment. The National Research Council (1996) identified four categories of information needed for effective watershed restoration:

- Spatial context of the watershed,
- Temporal and natural disturbance history,
- Riparian vegetation community,
- Nature and magnitude of human impacts.

We concur that these landscape scale features are critical to successful recovery planning, including both protection and restoration efforts. Inventory and assessment form the basis both for protecting existing resources and restoring degraded areas. Without an understanding of a resource's status, whether riparian condition or fish abundance, planning cannot proceed effectively (NRC in press).

As we discussed in Question 4, functioning riparian areas are critically important for salmonid habitat. Several protocols, both qualitative and quantitative, have been developed for riparian assessment (reviewed in NRC in press). Coarse, landscape scale riparian assessments can be conducted using remote sensing technology, either satellite remote sensing or aerial photography, with a corresponding program of field validation. This level of assessment can distinguish the extent of mature forest, shrubby or young forest, and open area along streams. At a state or regional level, coarse assessments provide valuable information about the extent and distribution of riparian vegetation. Comparisons can be made with historic land cover data to assess changes in extent of vegetation and categories of riparian communities. In western Oregon, assessments have been conducted for the Willamette River (Gregory et al. 2002e) and for the Coast Range (CLAMS, http://www.fsl.orst.edu/clams). However, the State of Oregon lacks a systematic, statewide program to assess the status of riparian areas that includes a continuing monitoring component.

Site-specific riparian assessments generally examine the condition and species composition of riparian vegetation as well as stream conditions. Riparian assessments may also examine how watershed conditions and land use affect aquatic-riparian conditions (Prichard et al. 1998). Therefore, site-specific riparian assessments provide a tool to understand how watershed conditions might affect degraded stream reaches, and are valuable in planning individual restoration projects.

With respect to assessments of fish abundance and habitat, ODFW has instituted a systematic inventory of salmonid abundance and instream habitat features in the Oregon Coast Range that has emphasized coho salmon (Flitcroft et al. 2002). Abundance and habitat data for other species and other regions of the state is patchy. Likewise, as we discussed in Question 1, historic data on salmonid distribution and abundance is scarce for western Oregon, limiting analysis of changes in salmonid abundance and distribution.

Prioritization

Technical basis for prioritizing protection and restoration activities

Another critical aspect of planning is prioritization. Prioritization may be based entirely on scientific information, or may integrate social and economic considerations. An example of social and economic considerations for project selection is an "extension" model of watershed restoration. In this model, initial restoration sites are selected based on their potential to educate landowners. This process continues until sufficient support and partnerships are built to prioritize projects at the watershed scale (D. Godwin, pers. comm.[27]) In this section, we restrict the discussion to the technical basis for prioritizing restoration activities. By summarizing available scientific information in a spatial context, decision making for protection and restoration activities can be made more objective.

When weighing salmonid recovery efforts, the relative effectiveness of protection and restoration should be considered. As a general principle, preservation and protection of intact, functional aquatic habitats should be the first priority (NRC 1996). As Roni et al. (2002) conclude, maintaining high quality habitat is much easier than restoring degraded habitat. High quality areas that maintain healthy and diverse salmonid populations should be protected from further human-caused disturbance that degrades habitat or biological conditions (Frissell 1993, Bisson 1995, Nehlsen 1997). Many terms have been applied to areas that provide favorable salmonid habitat including refugia, core areas, anchor habitats, sanctuaries, or reserves (Sedell et al. 1990, others). Relatively intact habitats, including reaches, sub-basin or basins, that sustain populations are a source of individuals to repopulate other areas (Niemi et al. 1990, Sedell et al. 1990; see previous section on metapopulations). As we will discuss later, protected areas can also serve as "reference areas". These areas provide fundamental information on natural processes and habitat structure,

[27] Godwin, D. Personal Communication, 2002. OSU Extension Service, Salem, Oregon.

enable evaluation of temporal and spatial changes, and provide a basis for estimating attainable future conditions for restoration (Hughes et al. 1986, Hughes 1995).

Along with protecting intact aquatic habitat, the second priority should be to restore a system of habitats adjacent to protected watersheds. Salmonids have the capacity to recover productivity, if favorable habitats are provided. Although much salmonid life history diversity has been lost (Nehlsen et al. 1991; Huntington et al. 1996), there is evidence that this diversity can be reestablished as well (Quinn and Unwin 1993; Healey 1994, Healey and Prince 1995). Areas with a high potential and opportunity for restoration should be selected, including floodplain, wetland, and estuarine habitats that historically had high productivity and diversity (Frissell et al. 1993, Nehlsen 1997, Lichatowich et al. 1999). Restoration activities that emphasize reconnection of high quality habitats should be emphasized (Roni et al. 2002). Finally, restoration of all habitat types in entire watersheds is needed, including habitats now used by anadromous salmonids and those not used but having potential for use.

Protection and restoration activities can be prioritized according to their likelihood for longevity of response and probability of success. However, the effectiveness of various restoration techniques to increase salmonid production is not always well known (Kondolf 1995, Roni et al. 2002). Inherent variability in biological data can make it difficult to detect real change; more than 10 years of monitoring data is often needed to evaluate restoration success (Reeves et al. 1997, Roni et al. 2002). Lack of effective monitoring, including an emphasis on physical rather than biological factors, has limited our understanding of salmonid response to restoration (Roni et al. 2002).

Roni et al. (2002) reviewed the effectiveness of salmon restoration activities (Table 16). They found that instream activities provided immediate benefits (1-5 years), but the benefits were not lasting beyond 5 years. In contrast, barrier removal (habitat reconnection) provided more lasting benefits (10-50+ years). Roni et al. (2002) concluded that estuary restoration and carcass placement (nutrient enhancement) are new techniques whose effectiveness are uncertain. However, they speculated that reconnecting estuary habitats is similar to reconnecting off-channel habitats, which has been shown to be successful.

Table 16. Typical response time, duration, variability in success and probability of success of common restoration techniques (Modified from Roni et al. in press).

Restoration type	Specific action	Years to achieve response	Longevity of action (y)	Variability of success among projects	Probability of success
Reconnect habitats	Culverts	1-5	10-50+	Low	High
	Off channel	1-5	10-50+	Low	High
	Estuarine	5-20	10-50+	Moderate	Moderate to high
Road improvement	Removal	5-20	Decades to centuries	Low	High
	Alteration	5-20	Decades to centuries	Moderate	Moderate to high
Riparian vegetation	Fencing	5-20	10-50+	Low	Moderate to high
	Riparian replanting	5-20	10-50+	Low	Moderate to high
	Rest-rotation or grazing strategy	5-20	10-50+	Moderate	Moderate
	Conifer conversion	10-100	Centuries	High	Low to moderate
Instream habitat restoration	Artificial log structures	1-5	5-20	High	Low to high[a]
	Natural LWD placement	1-5	5-20	High	Low to high[a]
	Artificial log jams	1-5	10-50+	Moderate	Low to high[a]
	Boulder placement	1-5	5-20	Moderate	Low to high[a]
	Gabions	1-5	10	Moderate	Low to high[a]
Nutrient enhancement	Carcass placement	1-5	Unknown	Low	Moderate to high
	Stream fertilization	1-5	Unknown	Moderate	Moderate to high
Habitat creation	Off channel	1-5	10-50+	High	Moderate
	Estuarine	5-10	10-50+	High	Low
	Instream	See various instream restoration techniques above			

[a] Depends upon species and project design

Location of protection and restoration activities can also be prioritized according to their probability of being effective. Prioritization can be conducted at multiple spatial scales such as basin, watershed, and sub-watershed scales. Many criteria may be weighed when prioritizing restoration and preservation of key habitats (NRC 1992, 1996, Bradbury 1995, Li et al. 1995, Nehlsen 1997, Oregon Plan 1997, Whidden and Lichatowich 1999). These criteria include historical and current productivity (e.g., Lichatowich and Nicholas 1992), habitat quality (Li et al. 1995 and others), metapopulation structure (connectivity, dispersal rates; Rieman and Dunham 2000), hydrologic function (Reeves et al. 1995, Beechie and Bolton 1999), and life history diversity.

During prioritization of restoration activities within a watershed, landscape position is an important factor to consider. Several authors have advocated that restoration proceed from headwater reaches downstream, largely because human disturbances proceeded from the river mouth into headwater areas (Sedell et al. 1990, Stanford and Ward 1992). As a result, headwater tributaries, often in forested areas and in federal ownership, are the most intact (Frissell et al. 1993, Bradford and Irvine 2000). Furthermore, successful preservation and restoration of any riverine habitat depends on upstream processes and upland land use (Sedell et al. 1990). Minimizing adverse impacts on small streams and restoring their ecological connections are of paramount importance to the improvements downstream (NRC 1996). Often, the effects of disturbances such as major floods are magnified as they progress downstream. Stream restoration without modification of upslope land management activities could be ineffective (Doppelt et al. 1993).

Nevertheless, small headwater streams are not capable of producing large numbers of salmonids compared with lower reaches. In addition, as we described in Question 1, lowland streams provide connectivity important to the completion of salmonid life cycles. Restoring habitats in lowlands, which historically were more productive than uplands, is critical for increasing life history diversity and production (Lichatowich et al. 1999; Nehlsen 1997). We conclude that restoration activities should be prioritized to focus on critical watersheds, streams, or reaches that have the potential to protect and reestablish core populations at strategic locations within mainstem rivers, estuaries, and tributaries. Protection and restoration activities should be spread across the landscape to include all habitats within a watershed that historically supported salmonids (Healey 1994). Choices of upstream or downstream habitat could be made based on the target species (Beechie and Bolton 1999). As an example, if coho were the target species, off-channel habitat in lowlands might be restored first; in contrast, upstream habitat might be restored first if the emphasis were steelhead habitat (Beechie and Bolton 1999).

Prioritizing salmonid habitat in Oregon

The State of Oregon has undertaken several efforts to prioritize geographic areas important to salmonid recovery. One of the first major efforts was constructed by a group of fisheries biologists, convened under former State Senate President (now Secretary of State) Bill Bradbury. This system, termed the Bradbury Protocol (Bradbury et al. 1995, Nehlsen 1997), was used to identify priority geographic areas or river basins occupied by anadromous salmonids in Oregon. Prioritization was based on the number and relative abundance of native salmonid species, aquatic diversity, relative integrity, risk to the resource, and protection and restoration potential.

During the development of the Oregon Plan, another effort was undertaken to prioritize areas important to coho salmon. *Core areas* are stream reaches within Oregon's coastal watersheds, designated by the Oregon Plan to be important areas for spawning and rearing of coho salmon (Oregon Plan 1997). The core area concept is based on the premise that not all regions within a watershed are equal. Some are of critical importance for recovery and long-term persistence of salmonid populations and may support source populations that can re-colonize other habitats within a watershed. The concept is similar to intact "focal" areas of Frissell et al. (1993) and "reserves" that support remaining viable populations (Williams et al. 1997, 1999).

When designating core areas, data for each basin on adult spawner density, juvenile density, and habitat quality were used to identify stream reaches having above average adult spawner and/or juvenile densities. A recognized weakness to this protocol is the lack of information on fish densities or habitat in some basins. In addition, most core areas for coho salmon are located in upland reaches rather than lowland habitats.

Since 1997, ODFW has designated core areas for fall and spring chinook and chum salmon, and winter and summer steelhead (see maps on http://rainbow.dfw.state.or.us/maps-core.html). Core areas listed in the Oregon Plan included 38% of the anadromous salmonid habitat in coastal basins and 15% of total stream miles. Areas selected under the Bradbury Protocol and core areas, as well as habitat integrity, instream flow, and water quality, have been used by ODFW and OWRD to prioritize streams for streamflow restoration (R. Kruger, pers. comm.[28]).

ODFW recognized that protection and restoration are needed at the landscape level, and that core areas were simply "to serve as a tool in helping to prioritize where these watersheds occur" (Oregon Plan 1997). Recently, ODFW has been developing a new prioritization process (A. Talabere, pers. comm.[29]). They are using a landscape approach to prioritize recovery activities at the sub-watershed level; prioritized areas are called *Salmon Habitat and Diversity Watersheds*. While core areas were designated at the scale of stream reaches, Salmon Habitat and Diversity Watersheds include entire 6th field Hydrologic Unit Code (HUC6) units, or sub-watersheds. Prioritized areas are thought to support healthy populations and are small enough to be influenced by land management (average size of about 15,000 acres).

ODFW is designating Salmon Habitat and Diversity Watersheds for coho, chinook, chum, and steelhead in all major coastal basins. The areas are based on surveys of the number of spawning adults, habitat data from basin-wide and randomly selected surveys, and qualitative judgments of district fish biologists based on hatchery influence, species diversity, unique life histories, spatial distribution, and other management issues. For the mid-coast area, coho juvenile distribution data is being used.

The ranking, or importance, of individual sub-watersheds may differ among species and runs. This is because species and runs have distinct life histories and habitat preferences, especially during spawning and juvenile rearing. However, considerable overlap in habitat utilization often occurs when juveniles rear in lowland reaches and estuaries. In designating Salmon Habitat and Diversity Watersheds, ODFW is giving the most weight to sub-watersheds with high production of a single species, overlapping production of multiple species, and high quality habitat (A. Talabere, pers. comm.[15])

To most effectively to help in salmonid recovery, Salmon Habitat and Diversity Watersheds could be used by agencies, private landowners, and watershed councils to prioritize assessments, monitoring, protection, and restoration efforts. However, at this time, no special management protocols have been established for core areas or Salmon Habitat and Diversity Watersheds. It is important to recognize, however, that areas not designated as Salmon Habitat and Diversity Watersheds or core areas should not be neglected or considered unimportant. Lowland rivers and estuaries, as we have shown, are important for the completion of the life histories of many juvenile salmonids and are migration corridors for all anadromous salmonids. Restoration of other, non-priority, watersheds may be required for full recovery. Based on metapopulation concepts and dynamic landscapes, areas not thought to be important now may become habitat for core (or

[28] Kruger, Rick. Personal communication, 2001. Oregon Department of Fish and Wildlife. Portland, Oregon.
[29] Talabere, A. Personal communication, 2002. Oregon Department of Fish and Wildlife. Corvallis, Oregon.

source) populations in the future (Harrison 1991, Reeves et al. 1995, Hanski 1997). As core populations are dynamic in space and time, the long-term challenge is to develop new core areas that will allow populations to persist.

Monitoring

Well-designed, systematic monitoring is required as part of the process to recover salmonids. Appropriate sampling designs, with the power to detect changes, are important for any monitoring where quantitative data will be used in decision-making. For example, ODFW is currently using a rigorous survey design to track status and trends of coastal coho populations. The agency is using a spatially balanced random survey design to examine both number of spawners and habitat variables (Thom et al. 2000, Jacobs et al. 2001).

From a landscape perspective, the spatial and temporal scales of monitoring are particularly important variables to consider when designing monitoring programs. For example, in a seven-year study of salmonid habitat in the Oregon Coast Range, Burnett (2001) found high interannual variation in habitat use, and that conclusions about habitat use changed with multiple years of data. Furthermore, there can be a lag between changes in habitat quality, both positive and negative, and the response of fish populations. The time and extent for habitat restoration is poorly understood, and it will often take longer for the biological function of systems to be restored than would be desired and often planned for. Consequently, project success needs to be assessed over the long-term (decades), as well as over the short term (years).

<u>Biological and habitat monitoring</u>

Monitoring is essential to determine status of populations, and to distinguish population trends from natural variation over time and space. Population variables, or “life history” variables, that can be monitored to provide useful information about salmonid recovery include escapement, number of outmigrating smolts, percentage of spawning fish of hatchery origin, stray rates, ocean harvest, and in-river harvest (McElhany et al. 2000). Monitoring fish productivity and survival in relation to habitat factors (e.g., habitat quantity, habitat quality, water quality, and streamflow) provides a baseline against which changes in population status can be compared.

<u>Reference areas</u>

Favorable habitats that provide population persistence or resilience are also important for reference, to gauge the status and recovery of other areas. Because the vast majority of lowland and estuarine habitats have been significantly altered by human activities over the past 150 years, and because lowland rivers and estuaries are the least studied portions of watersheds (Stanford and Ward 1992), reference areas with no significant anthropogenic disturbances are often difficult to find. Although major changes in the ecology and physical loss of habitat in lowland river systems due to human activities have been documented (see Question 2), it is difficult to quantify the relationship between declines in lowland habitat and in salmonid populations because there are other contributing factors. Nevertheless, lowland reference sites that are relatively intact should be preserved to provide comparisons that would assist future restoration.

Because salmonid habitat is dynamic, reference areas should represent the range of conditions of functioning ecosystems (Reeves et al. 1995). A reference basin might contain watersheds with different histories of natural disturbance, including wildfire and landslides. Reference areas would be expected to change over time, as a result of human actions or natural processes. A management strategy that uses reference areas must therefore be flexible, and not rely solely on protection of single sites in perpetuity (Reeves et al. 1995). However, in the short-term, we believe even isolated segments of high quality salmonid habitat can provide useful comparisons.

Potential reference areas may be located on lands already protected (as identified by the Oregon Natural Heritage Program; National Heritage Advisory Council 1998); however, the program has not specifically identified reference reaches that have high levels of ecological function or provide high quality habitat for salmonids. Finally, reference conditions can be determined by other means than comparison with appropriate regional reference areas. Analyses of historical trends of attributes, experiments, modeling, "best professional judgment," or a combination of these approaches can also be used (Hughes 1995).

Effectiveness monitoring and adaptive management

After projects are implemented, the effectiveness of protection and restoration actions also needs to be monitored in relation to the status of salmonid populations. This type of monitoring is sometimes termed "effectiveness monitoring". Effectiveness monitoring asks the basic question: Was the action (e.g. permit conditions, restoration) effective in attaining or maintaining the desired future conditions and in meeting objectives (Kershner 1997)? Effectiveness monitoring is more complex than compliance/implementation monitoring and requires longer time frames and understanding of the physical, biological, and sometimes social factors that influence aquatic ecosystems (Kershner 1997).

Effectiveness monitoring and evaluation are prerequisites for effective adaptive management. Adaptive management is a learning process that will assist in identifying ineffective strategies and recovery efforts and can be used to posit other, more promising strategies (Baydack et al. 1999, Noble 2000). The Independent Science Panel (2000) outlined the necessary elements for a successful monitoring program in an adaptive management context. These elements were used to help create scientifically credible programs and more information can be found in their report.

- Monitoring should be based on a set of clearly articulated goals, objectives, or questions that need to be addressed,
- The statistical designs are appropriate,
- Indicator and variables are based on needs defined by objectives and the appropriate geographical, temporal, and biological scales,
- Monitoring protocols are standardized to allow comparison among locations, times, or programs,
- Programs are in place for quality assurance and quality control of the data,
- Data are managed to allow easy access and coordination among different collaborators,
- Funding is stable and adequate to allow planning and implementation of sustained long-term efforts, and
- The information is analyzed and integrated into decision-making.

In the context of adaptive management, the IMST supports setting quantitative targets or goals that can be used to measure if progress is being made or not. To integrate effectiveness monitoring analyses into decision-making, programs must:

- Identify actions or strategies that seem to be limiting progress,
- Develop alternative actions or strategies to overcome limitations,
- Select the more promising alternatives, and
- Implement the alternative strategies or actions by integrating them into agency action programs. Action programs could be in the form of new regulations, incentives, or education.

The Oregon Plan Monitoring Program has not evaluated the results of monitoring (findings) or synthesized the meaning of monitoring results in the context of salmonid recovery under the

Oregon Plan. Without this synthesis, progress towards the goals of the Oregon Plan is difficult to measure. OWEB's current development of a strategic monitoring plan includes these critically important aspects. It will establish quantitative goals or benchmarks, will analyze and synthesize data, and will relate findings to the recovery of wild salmonids. However, obtaining adequate monitoring data will also be key to measuring progress toward the goals of the Oregon Plan.

<u>Example of adaptive management – Chesapeake Bay and watershed restoration</u>
An example of adaptive management of aquatic resources by an interagency consortium is the Chesapeake Bay Program. The Chesapeake Bay is the largest estuary in North America and drains a watershed approximately 64,000 square miles. The watershed includes areas of Maryland, Virginia, Pennsylvania, New York, Delaware, West Virginia, and all of Washington, D.C. Water quality degradation and decreases in fisheries, particularly striped bass, became a concern in the 1970's. A congressionally mandated report was completed in 1983 that called for immediate attention to high levels of nitrogen and phosphorus in the Bay, severe declines in submerged aquatic vegetation, and over-harvesting of aquatic resources, most notably striped bass. In 1983, Maryland, Virginia, Pennsylvania, Washington, D.C. and EPA (representing the federal government) entered into their first agreement to restore water quality, fisheries, and aquatic habitat. This is now known as the Chesapeake Bay Program.

An agreement was signed in 1987 that set goals to reduce controllable nitrogen and phosphorous inputs (agriculture, urban, and industrial) by 40% by the year 2000. In 1989, when progress was evaluated, the Program found that decreases in P and N from phosphate detergent bans, improved waste water treatment plants, and improved best management practices on agricultural lands were not occurring fast enough to allow them to meet their goals by the year 2000. Focus was then shifted to the tributaries of the Bay and to the P and N entering the system higher in the watershed with each of the nine main tributaries preparing strategies specific to the type of land uses in those basins. Recent analysis shows that many of the large tributaries are showing a decrease in P and N and but natural increases in streamflow from large storm events during the monitoring period have often counteracted the improvements (Belval and Sprague 1999).

Nutrient enrichment of Bay has been identified as the primary factor leading to decreased abundances of submerged aquatic vegetation (Boynton 2000). The Bay organisms including juvenile fish and blue crabs are dependent on the habitat and enhanced food web-production provided by the submerged aquatic vegetation (Boynton 2000). However recent increase in water quality alone have not increased the distribution of the aquatic vegetation possibly due to the loss of seed sources in many areas (Boynton 2000). The Program originally set a goal of protecting and restoring 114,000 acres of the vegetation. By 2002 that goal is to be revised to reflect historic abundance, measured as acreage and density from the 1930's to the present. At the same time the Program is to implement a strategy to accelerate protection and restoration (http://www.chesapeakebay.net).

Another example is a riparian forest buffer initiative created in 1996, calling for conserving existing forests along streams, rivers, and shorelines. The initiative set a goal of restoring 2,010 miles of forest buffers on streams and shorelines in the watershed by 2010. By fall 2001, approximately 1,298 miles had been planted with trees (http://www.chesapeakebay.net/press.htm). Monitoring programs for planting success and buffer effectiveness are being designed. Several regulations are in place for three states to preserve existing riparian forests and have created shoreline set backs for construction (new construction prohibited within a given distance from the shoreline or cliffs) (Palone and Todd 1998). These riparian policies are unique, as is the degree of the cooperation among states, as well as the interagency cooperation within states.

The Chesapeake Bay Program uses an adaptive management protocol by identifying problems, setting goals, evaluating progress, and modifying their strategies in response to evidence that existing strategies were ineffective. Even with this framework, the effectiveness of restoration strategies is sometimes difficult to assess, particularly with ever changing land uses within the basin and a human population of 15 million people growing by 300 people per day. However, the IMST believes that an adaptive management approach enables a group to respond to improvements in the understanding of complex environmental problems.

Restoring Habitat-forming Processes

Throughout this report, we have emphasized the importance of protecting and restoring the processes that create and maintain salmonid habitat, and have documented many of the disruptions to these processes throughout western Oregon. As Beechie and Bolton (1999) point out, restoration of ecological processes have a greater likelihood of long-term success than improvement of individual habitat characteristics (enhancement). Below, we give examples of two types of restoration, floodplain restoration in the Willamette River and estuary salt marsh restoration, which are consistent with the approach of restoring landscape scale function and disturbance regimes.

Floodplain restoration

As we have noted, the Willamette River is a large, braided, alluvial floodplain river in western Oregon, and has been highly altered since EuroAmerican settlement in the 1800s (Sedell and Froggatt 1984, Gregory et al. 1998). At workshops held in July 1998, many stakeholders (including Federal and state agencies, cities, watershed councils, scientists, the Willamette Basin Task Force, and Willamette Valley Livability Forum) identified floodplain restoration as a key component in the restoration of the Willamette River. The group concluded that floodplain restoration will have positive impacts on absorbing and reducing floodwaters, reducing flood damages, improving habitat for fish, and improving water quality (see http://www.orst.edu/dept/caec/meet.htm). These workshops identified what is needed to evaluate the conditions in the Willamette River. The needs included:

Data and information, including:

- Remote sensing data incorporated into and evaluated with GIS,
- Better topographic surveys and digital elevation model mapping,
- Analysis of historical flow data,
- Statistical sampling designs for long-term monitoring,
- Incorporation of research and monitoring into habitat restoration projects and wetland assessments, and
- Development of guidelines for habitat restoration that are made available to the public.

The IMST agrees that these are important goals that should be addressed, not only in the restoration of the Willamette River, but also in all lowlands of western Oregon.

On regulated rivers, one means to restore floodplains would be to more closely mimic the historic flow regimes (magnitude, frequency, timing, duration, and rate of change; Poff et al. 1997). On other regulated rivers throughout North America, “natural” flow regimes have been mimicked with the goal of improving fish habitat and ecological function (e.g., Collier et al. 1997). While the IMST has not reviewed these projects on a case-by-case basis, we encourage and support restoration of flow patterns and timing to enhance floodplain function and salmonid habitat in western Oregon. Social constraints may limit the extent to which historic flow regimes can be reestablished (Poff et al. 1997).

Another method of restoring floodplains is to reconnect the main river with its historic off-channel habitats. In this way, site-specific projects contribute to restoration of floodplain function. Restoration projects to open former side channels along the Willamette River and its tributaries are being considered or implemented. One example is the South Pasture Restoration project, being conducted by the Friends of Buford Park and Mt. Pisgah (Friends of Buford Park and Mt. Pisgah 2001). The project is being implemented in the lowlands along the Coast Fork of the Willamette just upstream of its confluence with the Willamette River near Eugene, Oregon. The restoration plans call for removal of berms and revetments that plugged the side channels and for excavation of some of the floodplain adjacent to the channels. After these structural changes, high flows will be able to inundate portions of the floodplain to restore ecological processes and connectivity, and winter rearing habitat for salmonids will be opened. In addition to re-opening the side channels, Friends of Buford Park and Mt. Pisgah volunteers are planning native trees and shrubs to restore the former riparian/floodplain forest (Friends of Buford Park and Mt. Pisgah 2001).

Another project designed to restore floodplain function was implemented on an aggregate mining site near Harrisburg, Oregon (Bayley et al. 2000). As we described in Question 2, this portion of the Willamette River historically had multiple channels that frequently shifted location (Sedell and Froggatt 1984). Two goals of this floodplain restoration project were to establish: 1) “off-channel habitats for the recovery of native biota,” and 2) “functioning segments of the original floodplain system” (Bayley et al. 2000). The project involved constructing a channel between an isolated gravel pond and the main channel. Monitoring has demonstrated that the project has increased the hydrologic connectivity of the pond with the mainstem river from 44 days per year to 132 days per year, and demonstrated utilization of the gravel ponds by juvenile chinook salmon. Native riparian trees and shrubs were planted, with 90% survival through July 2001. However, overbank flooding, which would restore nutrients to the floodplain, was not observed during the initial two years of monitoring, due to regional drought.

Tideland and estuary restoration

Restoration of estuarine habitats has the potential to contribute greatly to the conservation and recovery of depressed Pacific salmon populations (Simenstad and Cordell 2000). Some of the most notable restoration successes have involved tidal marshes. Frenkel and Morlan (1991) concluded that dike removal and creek excavation to restore connections to tidal inflows are the most important actions to restore function to tidal marshes in estuaries. Restoration of former diked wetlands is reversing a long-term trend, increasing the availability of habitat for juvenile salmonid, and improving the ecological functions of estuaries (SOER Science Panel 2000). Studies of restored marshes in South Slough of Coos Bay and Salmon River Estuary indicate that diked estuarine wetlands in Oregon have a good potential for restoration.

However, many of the anthropogenic changes in estuaries, such as the lowering of land surface levels (discussed previously in Question 2), channelization of stream reaches, and changes in sediment distribution patterns have significant implications for restoration and the reestablishment of tidal flow regimes. Some researchers have estimated that it would take decades (Frenkel and Morlan 1990, 1991) to hundreds of years (Rumrill and Cornu 1995) for tidal marshes to return to their previous elevation after dikes have been removed. Rumrill and Cornu (1995) estimate that marsh surfaces in South Slough Estuary in Coos Bay, Oregon are 60-80 cm below their pre-modified level, and it would take 250-300 years for natural recovery to their original elevations. These changes in tide marsh surface elevation result in different spatial patterns of water flow and habitat use than before alteration.

In the Salmon River Estuary, Frenkel and Morlan (1991) observed significant channel incision after the restoration of tidal flows. Many channels in the tidal marsh had filled with sediment after dikes were installed because trampling by cattle increased bank erosion and reduced the ability of tidal streams to remove sediment. Once tidal inflows were re-established, these tidal channels were scoured and incised, which facilitates succession to natural conditions. Returning to the original elevation may take a long time and happen incrementally. However, in time, the elevations should approach their historical levels, with attendant return to more historic hydrologic conditions.

Restoration projects in the South Slough Estuary demonstrate an approach to estuary restoration that considers connections between uplands and lowlands (Rumrill and Cornu 1995). In the course of implementing restoration in the South Slough Estuary, vegetation became established in the uplands along abandoned roads, and other roads are being decommissioned or treated to promote vegetation establishment. Efforts have been made to control erosion problems associated with roads and drainage diversions. Restoration activities also included the removal of dense understory vegetation followed by planting locally adapted tree stock to establish stands of native coastal forests in riparian areas. Goals for the Dalton Creek restoration project in South Slough included the reintroduction of large wood, reestablishing scour and meander patterns in channels, elevating the water table, and reestablishing the composition and diversity of vegetation. The Winchester Tidelands Restoration project in South Slough was designed to restore the surface elevation of formerly diked tidal marshes (in Kunz Marsh) and to reestablish hydrologic functions (Rumrill and Cornu 1995). Both the Dalton Creek and Winchester Tidelands projects have been conducted as experiments by incorporating pre- and post-project monitoring and habitat assessment (Rumrill and Cornu 1995).

The results of monitoring in Kunz Marsh show high levels of fish utilization for rearing in both restored tidal marshes and marsh stream channels (Sadro 1999). In the Salmon River Estuary, the potential benefits of restored marshes varied as a function of recovery age, location, and salmon species. Juvenile chinook, the most abundant salmonid species, were most common in the control or youngest restored marsh and least abundant in the oldest restored site (Cornwell et al. 2001). In the Salmon River Estuary, complete removal of dikes resulted in relatively rapid recovery of hydrologic functions and vegetation (Mitchell 1981, Frenkel and Morlan 1990, 1991). Removal or modification of tide gates may also result in increased and rapid utilization of tidal channels by salmonids (P. Heikkila, pers. comm. [30]).

We conclude from these studies that restoration of diked marshes is an incremental process that requires many years for restoration to pre-disturbance hydrologic and vegetative conditions. However, some biological responses are rapid and have important benefits for rearing of juvenile salmonids. Potential benefits of restored marshes will vary as a function of recovery age, accessibility, and location of each marsh in the tidal gradient (Cornwell et al. 2001).

Findings and Conclusions

Findings

Protection of salmonids involves preventing alteration to the structure and function of aquatic systems, including:

- Biological processes:
  - Spawning migrations

[30] Heikkila, P. Personal Communication, 2001. OSU Extension Service, Coos County Office, Coquille, Oregon.

    - Metapopulation dynamics
- Physical processes that create and maintain salmonid habitat:
    - Disturbance regimes
    - Flows of water, sediment, and large wood.

Restoration has been defined under the Oregon Plan as the process of restoring systems and processes to the point they can provide the natural materials and ecological functions that create habitat.

Most restoration efforts to date have been conducted in upland reaches.

Restoration projects are usually applied to only a small portion of the watershed and may not provide measurable increases in smolt or adult production at the larger, watershed level.

Several attempts to identify and prioritize the most productive areas for salmonids in Oregon have been conducted as an initial step in recovery planning.

- A weakness of the ODFW *core areas* approach to identifying and prioritizing important salmonid habitat is that *core areas* are presently mostly in upland areas.
- The importance of connectivity between high quality habitats within a watershed has been recognized in the new ODFW *Salmon Habitat and Diversity* Areas approach, which prioritizes entire coastal sub-watersheds.
- No special management protocols have been established for *core areas* or *Salmon Habitat and Diversity Watersheds*.

Data on fish density and habitat quality are lacking for some basins, limiting the technical foundation for prioritization.

There can be a lag between physical habitat restoration and the response of fish populations. Likewise, there can be a lag in fish response to degraded stream conditions.

Reference areas provide a basis for evaluating for restoration effectiveness, but unaltered reference systems are rarely available.

Initial progress has been made in breaching dikes and restoring tidal marshes in several of Oregon’s estuaries. These projects have demonstrated rapid utilization by juvenile salmonids. However, restoration of pre-disturbance levels and regimes may take many years.

Restoration of tidal wetlands has increased habitat availability for salmonids at individual sites.

Conclusions

Protection of intact, functional aquatic habitats should be the first priority when weighing salmonid recovery efforts. From a technical perspective, maintaining high quality habitat is much easier than restoring degraded habitat. High quality areas that maintain healthy and diverse salmonid populations should be protected from further human-caused disturbance that degrade habitat or biological conditions.

Few management initiatives facilitate protection of the best habitat or the most productive sites.

Much of the ecological function in western Oregon lowlands can be improved. Restoration of structure and function of lowland systems – including the geomorphic, hydrologic, and biological processes that create and maintain salmonid habitat – will have beneficial effects on salmonids and lowland ecosystems in general.

Restoration of western Oregon lowland ecosystems is essential in meeting the restoration objectives of the Oregon Plan. A system of habitats adjacent to functioning watersheds should be restored. Restoration of all habitat types in entire watersheds is needed, including habitats now used by anadromous salmonids and those not used but having potential for use.

Protection and restoration of riparian areas will require ongoing assessments.

Types of protection and restoration activities can be prioritized according to the longevity of response and probability of success.

The effectiveness of various restoration techniques to increase salmonid production is not well known. This is due to the 1) inherent variability in the data making it difficult to detect real change and 2) lack of effective monitoring, including an emphasis on physical rather than biological factors.

ODFW is to be commended on their progress in implementing a landscape approach by identifying entire coastal sub-watersheds important to salmonids. This strategy has the potential to enhance the productivity, life history diversity, and stability of salmonid populations.

Metapopulation theory is useful for understanding of salmonid population structure, and should be carefully evaluated. Understanding that salmonid populations interact with one another highlights the importance of identifying core (mainland or source) populations, maintaining connectivity among habitat patches, and designing habitat restoration strategies to support multiple self-sustaining populations.

Our understanding of population structure and metapopulation dynamics within and among basins, including dispersal patterns of wild fish, is limited. To make effective decisions about where protection and restoration efforts and to design more effective recovery strategies, we need a better understanding of:

- Metapopulation dynamics (dispersal of naturally produced fish) and connectivity among habitats,
- Salmonid productivity of watersheds and sub-watersheds (e.g., smolt-adult ratios),
- Distribution and abundance of spawning adults.

Well-designed, systematic monitoring provides a scientific basis for salmonid recovery planning and adaptive management.

An adaptive management approach to salmonid management is needed. Biological and effectiveness monitoring are integral components of adaptive management.

Monitoring should be conducted at both site-specific and aggregate scales.

Reference areas should be identified and protected because of their value for distinguishing population trends from natural variation, and as models of high quality habitat and functioning systems. Reference areas should represent the range of conditions of a functioning ecosystem.

Restoration of lowland rivers and estuaries will require reconnection of streams with floodplains and tidal marshes to produce more habitat, greater habitat complexity, and connectivity among habitats used at different phases of salmonid life cycles.

Dike removal to restore tidal inflows to marshes may be the most important action to restore tidal marsh habitat for salmonids.

More evaluation is needed to assess the effectiveness (increases in salmonid utilization and productivity) and longevity of protection and restoration actions, both in lowland rivers and estuaries.

RECOMMENDATIONS

The science questions previously answered in this report provide the basis for these recommendations. In general, our approach was to develop and answer each science question and then summarize our findings and conclusions for each question. Our specific recommendations are developed from our findings and conclusions. In some cases a specific recommendation is drawn narrowly from a specific finding and conclusion, but in many cases the recommendations resulted from a synthesis across several findings and conclusions. For this reason the order in which recommendations appear do not correlate with the order in which material was covered in the science questions. The recommendations are grouped into broad subject areas for convenience. The order is not intended to imply priority. We consider each recommendation as important to accomplishing the mission of the Oregon Plan.

IMST recommendations are based on our assessment of the best available science as it pertains to salmonid and watershed recovery and the management of natural resources. Recommendations are directed to one or more agencies or entities that have the ability to implement, or to affect changes in management or regulation that are needed for implementation. It should be noted that the IMST looks beyond an agency's *current* ability to implement the recommendations because current legal, regulatory, or funding situations may need to change. It is the belief of the IMST that if an agency agrees that a recommendation is technically sound and would aid the recovery of salmonid stocks and watersheds, the agency would then determine what impediments might exist to prevent or delay implementation and work toward eliminating those impediments. The Team also assumes that each agency has the knowledge and expertise to determine how best to identify and eliminate impediments to implementation and to determine appropriate time frames and goals needed to meet the intent of the recommendation. In addition, the IMST recognizes that an agency may already have ongoing activities that address a recommendation. Our inclusion of such an "overlapping" recommendation should be seen as reinforcement for needed actions.

Senate Bill 924, which created the IMST, specifies that agencies are to respond to the recommendations of the IMST, stating "(3) If the Independent Multidisciplinary Science Team submits suggestions to an agency responsible for implementing a portion of the Oregon Plan, the agency shall respond to the Team explaining how the agency intends to implement the suggestion or why the agency does not implement the suggestion". Once agency responses are received, the IMST reviews the scientific adequacy of each response and if further action or consideration by the agency is warranted. IMST reviews of responses are forwarded to the Governor and the State Legislature. State agencies are expected to respond to IMST recommendations within six months after a report is issued.

The format of the recommendation section is important to understand. The following will illustrate the format:

#. Each specific recommendation is numbered, shown in bold and is directed to one or more agencies or entities of state government. The agency (or agencies) or entity listed is believed to have lead responsibility, but logically would collaborate with the other agencies or entities listed in developing the response to the recommendation as required by Senate Bill 924.

> Inset under each recommendation is a brief explanation or illustration of the context for the recommendation, or what is meant by it, and sometimes suggestions on what should be incorporated into its implementation. This inset material is related to the recommendation but is not an explicit part of it. This means that the agency or entity

that is taking the lead for responding to the recommendation is not required (Senate Bill 924) to incorporate the material in the inset into their response. Our goal in providing the inset is to improve understanding of our meaning and to suggest direction for implementation.

RECOMMENDATIONS

Protection of existing healthy ecosystems and salmonid strongholds in western Oregon lowlands is the first and most important element of the Oregon Plan in lowlands. Restoration of salmonid habitat in lowland landscapes is also essential to recovery of salmonids in western Oregon. Currently, many lowland land use practices are not consistent with the goals of the Oregon Plan for Salmon and Watersheds. In making a case for continuing such activities, their compatibility with salmonid recovery needs to be demonstrated.

Protection and restoration of many lowland ecosystems can be accomplished by the following recommendations:

Recommendation 1. The Core Team of the Oregon Plan for Salmon and Watersheds should develop and implement a landscape approach to manage salmonid habitat in western Oregon lowlands.

The Independent Multidisciplinary Science Team (IMST) has consistently recommended that the State of Oregon and its agencies take a landscape approach to accomplish the goals of salmonid recovery. Fundamentally, this approach is the application of ecological principles over larger spatial scales and longer periods of time than has traditionally been used to manage natural resources. Following are some elements that should be considered in managing western Oregon lowlands. We expect that the Oregon Department of Fish and Wildlife (ODFW) will take a lead role in implementing the last two bullets.

- Incorporate principles of landscape ecology in salmonid habitat management at both site-specific and landscape levels by:
    - evaluating current and historic watershed hydrologic regimes;
    - assessing protection and restoration effectiveness at site-specific and aggregate scales;
    - prioritizing protection and restoration efforts based on assessment of factors that affect salmonids in a watershed;
    - integrating temporal scales (historical, present, and future) and spatial scales (reach, stream, watershed, landscape) into management decisions;
    - integrating cumulative impacts into management decisions; and
    - improving coordination between state agencies, federal agencies, watershed councils, Soil and Water Conservation Districts, and various plans (e.g., watershed action plans, Total Maximum Daily Loads, Agricultural Water Quality Management (AgWQM) area plans).
- Establish a statewide policy and plan for management of riparian areas and large wood (see recommendations 2 and 3).
- Identify links between fish habitat requirements and landscape patterns and processes in lowland ecosystems by taking into account both historical and current distribution patterns.
- Expand habitat protection and restoration (including ODFW prioritized areas such as *Salmon Habitat and Diversity Watersheds)* for current and future populations of

anadromous salmonids to include lowland streams, rivers and estuaries as well as uplands. This effort requires:

- o protecting and restoring the connectivity, structure, and function of high quality habitats
- o reconstructing probable historical population structures;
- o identifying and characterizing core populations, habitats, and key watersheds within Gene Conservation Areas (GCAs) or Evolutionary Significant Units (ESUs); and
- o evaluating watersheds based on estimates of historical productivity, potential productivity, life history diversity, metapopulation structure, habitat quality, and native fish diversity.

Recommendation 2. The Core Team of the Oregon Plan should develop and implement a statewide riparian policy and plan that provides for proper function and condition of riparian areas in Oregon.

Significant differences exist in how riparian areas are managed across Oregon land uses and ownerships reflecting local, state, and federal jurisdictions. We acknowledge that site potential for riparian vegetation varies across the landscape, but we find no scientific basis for current differences between management activities in riparian areas. We believe that a consistent policy for the State that focuses on proper function and condition consistent with site potential should enhance the opportunities for improving riparian area conditions and salmonid recovery.

The goal of a statewide policy should be to achieve greater consistency in riparian zone management across land uses to:

- Maintain the dynamics of landscape structure and function of wetlands, floodplains, and riparian forest;
- Improve fish and wildlife habitat;
- Protect and improve water quality (including temperature);
- Maintain and improve hydrologic and ecological structure and function;
- Promote connectivity of the river with its floodplain and off-channel habitats;
- Allow for the presence of various stages of native plant community development and species composition to emulate historical conditions and disturbance regimes and stop removal of native vegetation; and
- Recognize site potential.

The implementation of a statewide riparian policy would also include rigorous monitoring to determine overall management effectiveness and provide a framework to link monitoring results and adaptive management. Some elements to consider are:

- Inventory and monitor watershed habitats to assess riparian condition in order to prioritize protection and restoration, and to predict susceptibility to degradation and change over time.
- Devise specific tactics for improving riparian area condition, such as establishment and protection of native vegetation and, where possible, large trees.
- As riparian goals, objectives, and management strategies are developed, investigate the role of site-specific relationships, particularly those of water infiltration, soil variability, local geology, and site capacity for vegetation production to help make the statewide policy be applicable on a site-specific basis. As part of doing this, it will be helpful to:

- Establish and protect reference reaches to investigate vegetation site potential and riparian vegetation effects on water quality.
- Determine effectiveness of riparian buffer widths.
- Inventory fish distribution and diversity relative to riparian conditions, and monitor changes over time.

A statewide riparian policy should also include an education component for landowners and general citizens to increase understanding of riparian area functions and of the need for this type of policy and to demonstrate its effectiveness through monitoring results.

Recommendation 3. The Core Team of the Oregon Plan should develop a statewide policy and plan for the management of large wood in and near streams and estuaries.

Current levels of large wood in western Oregon lowland streams, rivers, and estuaries are lower than historical levels and may limit salmonid recovery. Future recruitment of large wood is also limited in lowland areas because of the loss of riparian forests and aggressive programs (e.g. maintaining navigability, salvage logging, protecting private property) to remove large wood lowland streams, rivers and estuaries. Management, including placing, recruiting, or maintaining large wood, is also inconsistent across land use practices. In some cases, the various policies and management strategies may be working at cross-purposes. The goal of a statewide policy should be to achieve consistent management of large wood in stream, river, and estuary systems to enhance salmonid habitat and ecosystem functions. This type of policy would include elements that do the following:

- Prevent unnecessary removal of large wood from beaches, channels, banks, estuaries, beaches, and floodplains;
- Protect and maintain existing riparian and floodplain forests as sources of large wood in the future;
- Promote the development of large trees in riparian zones as a source of future large wood for streams and estuaries; and
- Develop and incorporate a long-term monitoring program within the Oregon Plan to determine the effectiveness of the large wood policy. Such a monitoring plan should include equivalent efforts in upland and lowland systems.

Recommendation 4. The Oregon Watershed Enhancement Board (OWEB) should develop strategic priorities for protection and restoration activities in western Oregon lowland streams, rivers, and estuaries to enhance salmonid recovery.

OWEB should consult with the Oregon Department of Fish and Wildlife (ODFW) and other agencies to identify protection and restoration efforts within and among watersheds. Activities should include restoring or maintaining structure and function of stream channels, wetlands, floodplains, and riparian areas; restoring hydrologic regimes, off-channel habitat, and large wood; and maintaining water quality. Elements to consider in strategic protection and restoration planning include:

- Giving high priority to protection of salmonid strongholds and healthy resources,
- Evaluating the potential for restoration and protection,
- Prioritizing restoration and protection efforts within and among watersheds taking into consideration the project's potential contribution to effective protection and restoration, and

- Maintaining and developing long-term monitoring programs to evaluate restoration and protection effectiveness. Monitoring approaches used in the Salmon River Estuary and the South Slough could be used as models for monitoring of estuary restoration.

Recommendation 5. The Division of State Lands (DSL) should reconnect main river channels to off-channel areas and floodplains to increase available lowland habitat for salmonids.

Connection of stream channels to floodplains and off-channel areas and protection and restoration of the structure and function of lowland stream, river and estuary systems are important for salmonid recovery. Reestablishing this connectivity will provide salmonids access to historically productive habitat that is no longer available. Structures that have reduced connectivity include dikes, revetments, hydrologic dams, pushup dams, and tide gates.

The aim of this recommendation is to increase the quantity of available habitat and provide increased habitat for life history forms that are currently absent or low in abundance. Ideally, accomplishing this recommendation will restore access to off-channel habitat by reconnecting rivers with wetlands, sloughs, and tidal marshes to allow the river to flow within the active floodplain. Steps involved in this process may include:

- Inventorying potential sites for reconnection,
- Identifying dikes and revetments that can be removed,
- Evaluating potential contribution of restoring each site for salmonid productivity, and
- Prioritizing sites for protection and restoration, taking into consideration site potential and costs (environmental and economic) and benefits of carrying out a reconnection project.

Recommendation 6. The Oregon Department of Fish and Wildlife (ODFW) should determine fish abundance and establish fish-habitat relationships in western Oregon lowland rivers, streams, and estuaries.

Assessments of historical and contemporary habitat availability and quality as well as fish utilization of that habitat are needed to determine fish-habitat relationships in lowland rivers, streams, and estuaries. This information can be improved by increasing fish surveys in lowland streams, rivers and estuaries and by determining the spatial extent of potentially productive habitat in these systems. Surveys of off-channel winter habitats for coho and other salmonids are also needed. This will provide a quantitative basis to assess fish abundance, life history diversity, and habitat utilization when identifying and prioritizing habitat protection and restoration efforts.

Recommendation 7. The Oregon Watershed Enhancement Board (OWEB) should implement a long-term systematic monitoring strategy to evaluate the status and trends of salmonid populations, the capacity of habitat to produce salmonids and support diverse salmonid life histories, and the effectiveness of protection and restoration. The strategy should represent the diversity of land uses and aquatic ecosystems in western Oregon lowlands.

Effective monitoring programs, which include integrative analysis and synthesis of findings, are critical to evaluating the progress that has been made toward protection and restoration of important salmonid habitats. Adaptive management is dependent on monitoring as the basis for adjusting plans and programs to reach stated goals.

Evaluation of changes in physical and biological variables requires careful experimental designs that have the power to detect changes. For example, ODFW is currently using a rigorous and technically sound survey design to track status and trends of coastal coho populations.

Following are some aspects that will strengthen monitoring for the Oregon Plan:

- Increase monitoring, including life history monitoring, in key sub-watersheds and watersheds to evaluate changes in freshwater productivity and the abundance and distribution of life-history types.
- Use ecologically intact, productive sub-watersheds as experimental reference areas to help distinguish natural variation and trends from changes associated with restoration efforts.
- Establish paired sub-watershed studies to evaluate differences in salmonid productivity with and without restoration activities and to assist in identifying critical processes and habitats.
- Systematically assess lowland streams for water quality (including temperature) to determine seasonal and long-term trends.
- Integrate lowland monitoring programs used by state, local, and federal agencies, and programs administered through Soil and Water Conservation Districts, watershed councils, and AgWQMP.
- Develop historical reconstruction of land cover and riparian vegetation in lowland streams, rivers, and estuaries.
- Repeat surveys of estuaries and riparian vegetation to assess temporal changes, including changes from historical conditions.

Recommendation 8. Oregon Department of Agriculture (ODA) and Oregon Department of Environmental Quality (DEQ) should establish the effects that land use activities in western Oregon lowlands have on salmonid populations and habitat quality.

The purpose of this recommendation is to develop a more comprehensive monitoring program to evaluate the impact of land use activities on salmonids. Key elements include:

- Improve baseline data for current conditions. Although DEQ assessments provide baseline information for water quality, additional assessments are needed to establish baseline conditions for riparian areas, aquatic habitat, channel condition, abundance and distribution of large wood, fish passage, water quantity and flow regimes.
- Integrate information on land use practices with water quality, water quantity, flow regimes, aquatic habitat, fish passage and screenings, large wood abundance and distribution, and riparian area conditions.
- ODA, DEQ, and the Oregon Watershed Enhancement Board (OWEB) should refine water quality measurement within the Oregon Plan Monitoring Program to make a more specific connection between land use practices and resulting water quality parameters in western Oregon lowlands.

Recommendation 9. The Oregon Department of Agriculture (ODA) should improve the technical strength of their program under the Oregon Plan and expand its scope to address salmonid habitat requirements.

The Agricultural Water Quality Management Program (AgWQMP) appears to be ODA's key vehicle for implementing the Oregon Plan on agricultural lands. AgWQM area plans should be modified to include a description of how the plan will contribute to salmonid recovery, and to specifically address factors contributing to salmonid population declines. Examples include protecting habitat and improving water quality, water quantity, and fish passage. Habitat indictors currently used under the US Clean Water Act and Oregon Department of Environmental Quality 303(d) listings may not adequately measure physical stream characteristics and biological requirements for salmonids.

Following are some – but not all – elements that should be incorporated into ODA’s program to address salmonid recovery:

- Improve assessments of current conditions in basins. In general, assessments currently done under AgWQMP are not technically strong.
    - Assessments need to specifically focus on water quality, water quantity, habitat quality, and riparian conditions.
    - Assessments should establish baseline conditions and used to determine changes in status.
- Habitat indicators should be modified to include specific requirements of salmonids.
- Plans should be specifically related to the goals of the Oregon Plan and explicitly specify objectives relative to baseline conditions. These objectives should be quantifiable, such as attainment of Total Maximum Daily Loads (TMDLs) and removal from 303(d) listings.
- When selecting among water quality improvement measures, methods that contribute to salmonid recovery and improve riparian function should be prioritized.
- Detailed monitoring is needed to evaluate management practice effectiveness, changes in habitat conditions, and compliance with accepted practices.

Recommendation 10. Water Resources Department (OWRD), in cooperation with other agencies, should reestablish a more natural hydrograph (timing and magnitude) on an experimental basis in river systems where flow modification is occurring as a result of storage operations.

These experiments should be designed to enhance connectivity of rivers with their flood plains and to increase floodplain function. These experiments should be monitored comprehensively to assess effectiveness. This recommendation will require collaboration with the US Army Corps of Engineers, as this federal agency controls the hydrograph, and rule curves are set in federal statute. OWRD needs to analyze historical data to establish historical hydrographs and their variability. Timing and magnitude of flood flows need to be reestablished (including spring and winter freshets) to emulate natural regimes on rivers where flow modification is occurring. By doing so on highly modified river systems, such as the Rogue, Willamette, and Columbia rivers, connectivity of rivers with their floodplains should be enhanced and floodplain function should increase. Reestablishing natural hydrographs should be approached experimentally and include comprehensive monitoring programs to determine effectiveness. Research should be conducted to better understand the contribution of areas to flow, and timing of flood and base flows.

In many cases, a more natural hydrograph cannot be reestablished due to social and economic constraints or environmental concerns. For example, higher than normal flows are sometimes maintained to minimize problems associated with low dissolved oxygen and high contaminant concentrations in western Oregon’s lowland rivers.

Recommendation 11. Water Resources Department (OWRD) should maintain or increase streamflow where water withdrawals and/or impoundments presently limit salmonid distribution, productivity, or migration.

There are several aspects and possible actions related to this recommendation:

- Identify streams where salmonid productivity is limited by streamflow.
- Prioritize streams for flow protection and restoration based on fish and habitat requirements and time of year when flow is most critical.
- Develop strategies to improve water use efficiency and reduce consumptive water use.

- Continue to develop ground water studies and watershed hydrological models to evaluate water use and seasonal water availability, including the role irrigation may have in groundwater recharge.
- Determine relationships between groundwater extraction and adjacent streams flows in regions where instream flows are inadequate.
- Incorporate the role and contribution of wetlands into water availability models. For example, compare the historic, current, and potential contribution of wetlands to water availability.
- Coordinate with other agencies to restore wetlands that will enhance streamflows during low flow conditions (see Recommendation 19).

Recommendation 12. The Water Resources Commission should develop and implement a strategic plan for the long-term management of water in western Oregon.

A strategic plan is needed to mitigate current instream water flow deficiencies and to plan for efficient water use over the near and long term. A strategic plan should incorporate key elements of landscape management, including water management at larger spatial scales and over longer periods of time. In developing a strategic plan, the Water Resources Commission should consider:

- Identifying a lead agency such as Water Resources Department (OWRD) to coordinate with other state, local, and federal agencies;
- Expanding the geographic scope of areas identified for streamflow restoration;
- Incorporating a landscape approach and sub-watersheds prioritized for salmonids into the process for determining these priorities;
- Incorporating elements listed in Recommendations 10 and 11 into the strategic plan;
- Incorporating projected human population growth and demographics and water needs into the plan; and
- Acknowledging the integration of ground and surface water in the plan.

Recommendation 13. The Water Resources Department (OWRD) should coordinate with USGS to establish and maintain hydrologic gaging stations on stream and river systems critical to salmonid recovery where data are not currently available.

Monitoring streamflow through gaging stations is important for:

- Determining seasonal and long-term trends in streamflow,
- Assessing effectiveness of efforts to restore instream flow,
- Assessing effectiveness of transferring and leasing water rights for instream water uses, and
- Watershed analysis based on historical data.

Recommendation 14. The Oregon Department of Agriculture (ODA) should reduce sedimentation from agricultural practices in western Oregon lowlands.

Methods to reduce soil erosion from agricultural fields and access roads should be developed that are specific to climate conditions (including storm frequency and intensity) and cropping systems in western Oregon. Preventative measures should be used to minimize accelerated erosion.

Recommendation 15. The Oregon Department of Agriculture (ODA) and Department of Environmental Quality (DEQ) should prevent adverse pesticide impacts on aquatic systems.

Most of the current pesticides used in agriculture lack federal standards for allowable levels in surface waters. For some of these chemicals, sub-lethal deleterious effects on salmonids are known, and for many others, the effects are not known. While more research is needed in these areas (see Recommendation 17), pesticide effects on salmonids should be taken into account in managing and monitoring pesticide levels in surface waters. Management strategies are needed to reduce pesticide inputs into surface waters and to reduce subsequent exposure to salmonids; these might include promoting the reduction of pesticide use and promoting the use of alternatives to pesticides. We recommend that ODA manage pesticide application, and consult with EPA on pesticide labeling with the aim of minimizing pesticide impacts on aquatic systems. Under the Clean Water Act, DEQ should coordinate with EPA to determine water quality impairment due to pesticide inputs and should monitor changes in water quality as a result of pesticide inputs.

Recommendation 16. The Oregon Department of Agriculture (ODA) and Oregon Department of Environmental Quality (DEQ) should prevent adverse eutrophication impacts of aquatic systems.

Although nutrient inputs are important in maintaining terrestrial and aquatic productivity land use practices such as fertilizer application, organic waste disposal, and livestock wastes can sometimes increase nutrient levels beyond the ability of an ecosystem to use them. This nutrient increase can result in negative effects such as eutrophication of surface waters and have adverse effects on aquatic ecosystems. Conservation practices such as filter strips in riparian buffers, soil nutrient testing, contour plowing, strip cropping, and no-till cultivation may reduce nutrient inputs into streams.

Recommendation 17. The Oregon State University (OSU) Agriculture Experiment Station (AES) and the OSU Cooperative Extension Service (CES), working with other state agencies involved in research, should increase understanding of how rural land use activities in the western Oregon lowland systems interact with and affect salmonid recovery.

Areas of concern include:

- How the timing and magnitude of nutrient inputs (e.g. from fertilizers and animal wastes) into streams affect water quality and composition of aquatic communities;
- The fate of pesticides (ones predominately used in Oregon agriculture) in aquatic ecosystems and lethal and sub-lethal effects of pesticides on salmonids;
- The effect of other agricultural chemicals on salmonids;
- How low concentrations of pesticides and agricultural chemicals impact salmonids, including delayed mortality and reduced fitness;
- The degree to which organic matter inputs from land use activities affects dissolved oxygen in aquatic systems;
- How land use practices directly and indirectly affect stream heating and cooling; and
- Sources of excess sediment inputs into aquatic systems and methods to minimize inputs.

It will be important to take into consideration the many factors that operate across the landscape through time and space and that affect temperature, nutrients, sediment, pesticides and other aspects of water quality. Models can be developed and refined to predict how land use practices and adjacent functioning riparian zones may affect water quality.

ODA, SWCDs and the OSU Extension Service should provide more information on how specific land use practices affect water quality, water quantity, large wood, riparian areas and fish passage. This information should be related to salmonid recovery. Specific information is needed regarding Best Management Practices that are specific to Oregon crops and climate. Effective implementation of this approach will increase the likelihood that performance based plans accomplish the goals intended.

Recommendation 18. The Division of State Lands (DSL), Water Resources Department (OWRD), Oregon Department of Fish and Wildlife (ODFW), and Oregon Department of Transportation (ODOT) should reestablish and maintain natural fish passage for juveniles and adults in lowland stream systems.

Restricting salmonid access to lowland habitat limits recovery potential. Recently, ODOT and ODFW have surveyed, identified, and prioritized impassable culverts on state (and some county) maintained roads and have begun to address problematic culverts. In addition, other barriers to fish passage need to be addressed.

Accomplishing this recommendation will take several cooperative steps between agencies, including:

- ODFW should inventory fish passage impediments including tide gates, road crossing, push up dams, low flows, ineffective fish ladders, and other barriers to passage.
- Develop and maintain an up-to-date, centralized, spatially explicit database of fish passage barriers.
- In areas prioritized for salmonid recovery, barrier free areas that need protecting should be prioritized and tracked.
- Sites that need barrier modification or removal and should continue to be prioritized and tracked.
- DSL, OWRD, ODOT, and ODFW should develop and implement a strategic plan to reach long-term goals of eliminating fish passage barriers and mitigate fish passage impediments that cannot be addressed.
- Monitor the effectiveness of efforts to reestablish fish passage.
- OWEB should include effectiveness monitoring of fish passage remediation efforts in the Oregon Plan Monitoring Program’s strategic plan.
- OWEB should encourage culvert assessment on private lands.
- Tide gates should be replaced, modified, or removed to allow fish passage and to emulate historical hydrologic functions in estuaries.

Recommendation 19. Division of State Lands (DSL) and Oregon Department of Fish and Wildlife (ODFW) should protect and restore hydrologic function and salmonid habitat in freshwater and tidal wetlands.

Providing salmonid habitat in floodplain wetlands adjacent to stream channels and in tidal wetlands is one goal of this recommendation. A second goal is to maintain and restore the processes that create salmonid habitat. Therefore, addressing the water storage functions of floodplains away from the main channel is an important component of this recommendation. In the Willamette Valley and elsewhere, wetlands on the prairie terrace would fall in this category. Steps to achieve this recommendation could include:

- Survey wetlands to assess changes from historical conditions.
- Assess and prioritize wetland protection and restoration with respect to contribution to salmonid habitat and hydrologic function in the basin (i.e. maintaining base flows, water filtering).
- Develop explicit plans for freshwater wetland and estuarine habitat protection and restoration in cooperation with state agencies, local governments, and watershed councils.
- Protect wetlands from further alteration that disrupts hydrologic function.
- Implement habitat restoration activities including tide gate removal (see Recommendation 18).

- Monitor effectiveness of protection and restoration programs.

Recommendation 20. Department of Land Conservation and Development (DLCD), in conjunction with Oregon Department of Fish and Wildlife (ODFW), should improve and protect salmonid habitat in Oregon's estuaries.

The goal of this recommendation is to protect and restore the structure and function of important estuary habitats used by salmonids during rearing and migration. Steps to achieve this recommendation might include:

- Surveying estuaries to assess changes from historical conditions,
- Devising goals and guidelines based on current understanding of aquatic habitats and salmonid habitat needs, and
- Develop explicit plans for estuarine habitat protection and restoration in cooperation with state agencies, local governments, and watershed councils.

Recommendation 21. Oregon Department of Fish and Wildlife (ODFW) should prevent loss of salmonids because of water diversion.

Entrainment and entrapment is a source of salmonid mortality in western Oregon lowlands. The following steps may prevent loss of salmonids at points of water diversion:

- Implement techniques for preventing entrainment and entrapment of smolts and fry in diversions.
- Accelerate screening schedules on existing diversions. The overall goal is to effectively screen all diversions in areas where salmonids are present.
- Require screening on all new diversions.

IMPLICATIONS FOR POLICY

Addressing salmonid recovery in western Oregon lowlands presents tremendous challenges for a number of reasons, such as population density, land ownership, and environmental conditions. The predominance of land in private ownership coupled with the diversity of land uses makes land use planning and land management complex. Human population density is high compared with other areas of the state, and can be expected to continue to increase in the near future. Furthermore, many lowland aquatic systems are in poor condition (SOER Science Panel 2000). The basic processes by which water and sediment move from uplands via streams to the ocean have been highly altered.

The poor condition of lowland systems demonstrates that land use practices and management have been ineffective in maintaining healthy streams and anadromous fish populations. An example may be the use of complaint-driven processes by state natural resource agencies. The IMST believes that the Oregon Plan for Salmon and Watersheds is a positive step toward a better understanding of scientific processes, which will in turn lead to better management. Creative thinking is needed to move forward in the face of enormous challenges. In particular, we need solutions that will work across boundaries of land ownership, agencies, and ecosystems.

Based on our scientific review, recovery of wild salmonids requires habitat that is functional across the landscape. For example, management of upland riparian zones in conjunction with those on adjacent lowlands is needed to maintain the dynamics of riparian structure and function across the landscape. Other areas that need to be addressed both within and beyond the boundaries of the western Oregon lowlands include roads and sediment, large wood, fish passage, anthropogenic chemicals, and inorganic nutrient inputs to streams. We conclude that management practices must be considered on a large spatial scale, among agencies, and across different land uses.

A consistent policy framework, which incorporates landscape perspectives and makes regulation, management, and voluntary actions possible at the landscape scale, may help to overcome institutional barriers to salmonid recovery. Plans and/or policies may need to be developed that are not under the purview of one specific agency, but become the responsibility of several agencies. The IMST strongly endorses the current development of a statewide riparian policy by the Core Team. A statewide riparian policy is consistent with a landscape approach, which aims to link productive, healthy regions within watersheds and basins and emphasizes preservation and restoration of the structure and function of lowland systems. Statewide policies on issues such as riparian and large wood management could contribute greatly to salmonid recovery by providing consistent direction to the diverse agencies working on salmonid recovery in western Oregon lowlands.

The IMST recognizes that state agencies may face institutional barriers to implementing a landscape approach to salmonid recovery planning. In Oregon, natural resource agencies have regulatory authority to oversee specific activities or resources, and/or to manage a specific land use type (e.g., the Department of Environmental Quality (DEQ) has regulatory authority for water quality; Oregon Department of Agriculture (ODA) has regulatory authority for water quality on agricultural land). Therefore, measures to address salmonid recovery under the Oregon Plan are often either site-specific or address only one component of salmonid recovery. For example, state rules provide for riparian protection on a site-by-site basis only on forest land, rather than at the landscape or watershed level. ODA's Agricultural Water Quality Management Program

(AgWQMP) is another example. Although the plans developed under this program cover a large geographic region, they address only one component of the aquatic system (water quality). AgWQM area plans do not currently address salmonid habitat requirements, or give high priority to methods to improve water quality that benefit salmonid habitat. Limited regulatory authority may restrict an agency's ability to implement actions that may be needed for salmonid recovery. Limited regulatory authority may also impede attempts to monitor the effectiveness of agency actions. Agencies with responsibility for land condition, such as ODA, should have the authority to assess land condition. Without this authority, monitoring the effectiveness of agency actions will be difficult.

As many of the factors that affect salmonids cross the boundary of a single agency's responsibility or authority, collaboration among state agencies on lowland resource management will be necessary to achieve the objectives of the Oregon Plan. An example of interagency coordination is Water Resources Department (OWRD) and Oregon Department of Fish and Wildlife (ODFW) efforts to identify and prioritize basins for improving streamflow, which appears to be effective. However, there are many other activities where more coordination is needed. For example, an interagency agreement might be in order between ODFW, ODA, DSL, and ODOT on how best to preserve riparian vegetation for a variety of functions (including water quality, nutrient inputs, effects on channel form and complexity, floodplain function and habitat development). However, interagency agreements are only effective if implemented; a state and federal interagency agreement to cooperate on riparian management, signed in The Dalles, Oregon in 1978, was never implemented.

Cooperation of state agencies with federal agencies, non-governmental agencies, and private citizen groups will also be important to achieving the goals of the Oregon Plan. Watershed councils and the watershed planning process provide an opportunity for interagency coordination (both federal and state), while addressing salmonid recovery at the landscape scale. Watershed assessments and watershed action plans could provide an empirical framework for developing landscape-scale management plans (Church 2000). A challenge will be to integrate watershed level planning with planning at other scales, including AgWQMP, the TMDL process, Northwest Power Planning Council subbasin plans, and the Willamette Restoration Initiative.

A large percentage of lowlands are in private ownership, and the cooperation and contribution of individual private landowners will be integral to the success of the Oregon Plan. Landowners need to be encouraged to protect intact salmonid habitat, rather than focusing mainly on restoration of already degraded habitat. This might be accomplished through incentives, education, and/or regulations. Conservation easements are one type of incentive. For example, the National Resources Conservation Service Cascade Pacific Resource Conservation and Development Office (Corvallis, OR 757-4807) acquires development rights, which offer benefits for both the landowner and the environment. Other incentives are partnerships, rewards, awards, positive press releases, and recognition of "jobs well done" for landowners documented that have managed well and have protected riparian zones.

As we conclude in this report, maintaining high quality habitat is much easier than restoring degraded habitat. In addition to incentives to private landowners for proper management of salmonid habitat, state acquisition of key habitats may be appropriate. Land acquired by the state can be managed specifically for watershed structure and function within lowland systems. Floodplains in lowland regions may be acquired and/or leased for restoration of salmonid habitats. A program could be developed that is designed to preserve and acquire already intact and well-functioning riparian zones.

REFERENCES

Abbe, T.B. and Montgomery, D.R. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research and Management 12: 201-221.

Abt, S.R., Clary, W.P., and Thornton, C.I. 1994. Sediment deposition and entrapment in vegetated streambeds. Journal of Irrigation and Drainage Engineering 120: 1098-1113.

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.

Allan, J.D., Erickson, D.L., and Fay, J. 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37: 149-161.

Allen, J., Salamack, A., and Schoonmaker, P. 1999. Restoring the Willamette Basin: Strategic issues and challenges. Prepared by the Institute for the Northwest and the US Army Corps of Engineers, Portland, Oregon.

Allen, T.F.H. and Hoekstra, T.W. 1992. Toward a unified ecology. Columbia University Press , New York.

Allendorf, F.W. and Waples, R.S. 1996. Conservation and genetics of salmonid fishes. *In* Conservation genetics: Case histories from nature. *Edited by* J.C. Avise and J.L. Hamrick. New York, New York. pp. 238-280.

Alsea Valley Alliance v. Evans. 2001. Alsea Valley Alliance, and Mark Sehl, v. Donald L. Evans, Secretary of the United States Department of Commerce; National Marine Fisheries Service; Penelope Dalton, NMFS Director; and William Stelle, NMFS Regional Director for the Northwest Region. Case No. 99-6265-HO.

Altman, B., Henson, C.M., and Waite, I.R. 1997. Summary of information on aquatic biota and their habitats in the Willamette Basin, Oregon, through 1995. Water-Resources Investigations Report 97-4023. US Geological Survey, Portland, Oregon.

Amoros, C., Rostan, J.C., Pautou, G., and Bravard, J.P. 1987. The reversible process concept applied to the environmental management of large river systems. Environmental Management 11(5): 607-617.

Anderson, C.W., Wood, T.M., and Morace, J.L. 1997. Distribution of dissolved pesticides and other water quality constituents in small streams, and their relation to land use, in the Willamette River Basin, Oregon, 1996. Water-Resources Investigations Report 97-4268. US Department of the Interior, US Geological Survey, Portland, Oregon.

Anisfeld, S.C. and Benoit, G. 1997. Impacts of flow restrictions on salt marshes: An instance of acidification. Environmental Science and Technology 31: 1650-1657.

Azuma, D.L., Birch, K.R., DelZotto, P., Herstrom, A.A., and Lettman, G.J. 1999. Forests, farms and people: Land use change on non-federal land in western Oregon, 1973-1994. USDA Forest Service, Pacific Northwest Research Station and the Oregon Departments of Forestry, Land Conservation and Development, and Agriculture, Salem, Oregon.

Baker, P.F., Speed, T.P., and Ligon, F.K. 1995. Estimating the influence of temperature on the survival of chinook salmon smolts (*Oncorhynchus tshawytscha*) migrating through the Sacramento-San Joaquin River delta of California. Canadian Journal of Fisheries and Aquatic Sciences 52(4): 855-863.

Baker, V.R. 1977. Stream-channel response to floods, with examples from central Texas. Geological Society of America Bulletin 88: 1057-1071.

Banks, M.A., Rashbrook, V.K., Calavetta, M.J., Dean, C.A., and Hedgecock, D. 2000. Analysis of microsatellite DNA resolves genetic structure and diversity of chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley. Canadian Journal of Fisheries and Aquatic Sciences 57: 915-927.

Barrington, M., Wolf, D., and Diebel, K. 2001. Analyzing riparian site capability and management options. Journal of the American Water Resources Association 37(6): 1665-1679.

Bauer, S.B. and Ralph, S.C. 2001. Strengthening the use of aquatic habitat indicators in Clean Water Act programs. Fisheries 26(6): 14-24.

Baydack, R.K., Campa, H.I., and Haufler, J.B. 1999. Practical approaches to the conservation of biological diversity. Island Press, Washington, D.C.

Bayley, P.B. 1995. Understanding large river-floodplain ecosystems. Bioscience 45(3): 153-158.

Bayley, P.B. and Baker, C.F. 2000. Floodplain restoration in off-channel habitats used for gravel mining in the Willamette River Basin: Fish population observations in Endicott and Truax ponds. 1998/00 Report to Willamette Gravel Group, Oregon. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon. 29 pp.

Beacham, T.D. and Murray, C.B. 1990. Temperature, egg size, and development of embryos and alevins of five species of Pacific salmon: A comparative analysis. Transactions of the American Fisheries Society 119(6): 927-945.

Beamer, E.M. and Henderson, R.A. 1998. Juvenile salmonid use of natural and hydromodified stream bank habitat in the mainstem Skagit River, Northwest Washington. Report Prepared for the United States Army Corps of Engineer, Seattle District, Environmental Resources Section, Seattle , Washington.

Beckman, B.R., Larsen, D.A., Sharpe, C., Lee-Pawlak, B., Shreck, C.B., Dickhoff, and W.W. 2000. Physiological status of naturally reared juvenile spring chinook in the Yakima River: seasonal dynamics and changes associated with smolting. Transactions of the American Fisheries Society 129: 727-753.

Beechie, T., Beamer, E., and Wasserman, L. 1994. Estimating coho salmon rearing habitat and smolt production losses in a large river basin, and implications for habitat restoration. North American Journal of Fisheries Management 14: 797-811.

Beechie, T. and Bolton, S. 1999. An approach to restoring salmonid habitat-forming processes in Pacific Northwest watersheds. Fisheries 24(4): 6-15.

Beiningen, K.T. 1976. Fish runs. *In* Section E in Investigative Reports of Columbia River Fisheries Project. Pacific Northwest Regional Commission, Vancouver, Washington.

Belval, D.L. and Sprague, L.A. 1999. Monitoring nutrients in the major rivers draining to Chesapeake Bay. Water-Resources Investigations Report 99-4238. Baltimore, MD, USDI US Geological Survey.

Benda, L. 1994. Stochastic geomorphology in a humid mountain landscape. Ph.D. thesis. University of Washington, Seattle, Washington.

Benda, L., Beechie, T.J., Wissmar, R.C., and Johnson, A. 1992. Morphology and evolution of salmonid habitats in a recently deglaciated river basin, Washington State, USA. Canadian Journal of Fisheries and Aquatic Sciences 49: 1246-1256.

Benda, L.E., Miller, D.J., Dunne, T., Reeves, G.H., and Agee, J.K. 1998. Dynamic landscape systems. *In* River ecology and management: Lessons from the Pacific coastal ecoregion. *Edited by* R.J. Naiman and R.E. Bilby. Springer, New York. pp. 261-288.

Benner, P.A. and Sedell, J.R. 1997. Upper Willamette River landscape: A historic perspective. *In* River quality, dynamics and restoration. *Edited by* A. Laenen and D.A. Dunnette. Lewis Publishers, Boca Raton. pp. 23-47.

Benner, P.A. and Sedell, J.R. 2000. Historical abundance of large wood in Oregon, USA tidal rivers and estuaries. *In* Abstracts, International Conference on Wood in World Rivers. October 23-27, 2000, Oregon State University, Corvallis, Oregon. p. 37.

Bernert, J.A., Eilers, J.M., Eilers, B.J., Blok, E., Daggett, S.G., and Bierly, K.F. 1999. Recent wetland trends (1981/2-1994) in the Willamette Valley Oregon, USA. Wetlands 19: 545-559.

Beschta, R.L. 1985. River channel responses to accelerated mass erosion. *In* Symposium on effects of forest land use on erosion and slope stability. East-West Center, Environment and Policy Institute, Honolulu, Hawaii. pp. 155-163.

Beschta, R.L. 1991. Stream habitat management for fish in the northwestern United States: The role of riparian vegetation. American Fisheries Society Symposium 10: 53-58.

Beschta, R.L. 1997. Riparian shade and stream temperature: An alternative perspective. Rangelands 19(2): 25-28.

Beschta , R.L., Bilby, R.E., Brown, G.W., Holtby, L.B., and Hofstra, T.D. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. *In* Streamside management: Forestry and fishery interactions. *Edited by* E.O. Salo and T.W. Cundy. Institute of Forest Resources, University of Washington, Seattle, Washington. pp. 191-230.

Beschta, R. L. and Kauffman, J. B. 2000. Restoration of riparian systems - taking a broader view. *In* P.J.Jr. Wigington and R.L. Beschta (Editors). International conference on riparian ecology and management in multi-land use watersheds. Portland, Oregon, American Water Resources Association, Middleburg, Virginia. pp.323-328.

Beschta, R.L. and Platts, W.S. 1986. Morphological features of small streams: Significance and function. Water Resources Research 22: 369-379.

Beschta, R. L., Platts, W. S., Kauffman, J. B., and Hill, M. T. 1996. Artificial stream restoration, money well spent or an expensive failure. 10th International Stream Habitat Improvement, Salmonid: Operational Solutions to Problems in Forested Streams. Corvallis, Oregon, Oregon State University, the American Fisheries Society, the Oregon Forest Resources Institute, La Sells Center, Corvallis, Oregon.

Bilby, R.E. 1984. Removal of woody debris may affect stream channel stability. Journal of Forestry 82(10): 609-613.

Bilby, R.E. and Bisson, P.A. 1998. Function and distribution of large woody debris. *In* River ecology and management: Lessons from the Pacific coastal ecoregion. *Edited by* R.J. Naiman and R.E. Bilby. Springer, New York. pp. 324-346.

Bilby, R.E., Fransen, B.R., and Bisson, P.A. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: Evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences 53(1): 164-173.

Bilby, R.E. and Ward, J.W. 1989. Changes in characteristics and functions of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society 118: 368-378.

Bisson, P.A. 1995. Ecosystem and habitat conservation: More than just a problem of geography. American Fisheries Society Symposium 17: 329-333.

Bisson, P.A., Quinn, T.P., Reeves, G.H., and Gregory, S.V. 1992. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. *In* Watershed management: Balancing sustainability and environmental change. *Edited by* R.J. Naiman. Springer-Verlag, New York. pp. 189-232.

Bisson, P.A., Reeves, G.H., Bilby, R.E., and Naiman, R.J. 1997. Watershed management and Pacific salmon: Desired future conditions. *In* Pacific salmon and their ecosystems: Status and future options. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, New York. pp. 447-474.

Bjornn, T.C. and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.

Boag, P.G. 1992. Environment and experience: Settlement culture in nineteenth century Oregon. University of California Press, Berkeley, California.

Botkin, D., Cummins, K., Dunne, T., Reiger, H., Sobel, M., and Talbot, L. 1995. Status and future of salmon of western Oregon and northern California: Findings and options. The Center for the Study of the Environment, Santa Barbara, California.

Bottom, D.L., Howell, P.J., and Rodgers, J.D. 1985. The effects of stream alterations on salmon and trout habitat in Oregon. Oregon Department of Fish and Wildlife, Portland, Oregon.

Bottom, D.L., Simenstad, C.A., Baptista, A.M., Jay, D.A., Burke, J.L., Jones, K.K., Casillas, E., and Schiewe, M.H. 2001. Salmon at the river's end: The role of the estuary in the decline and recovery of Columbia River salmon. Unpublished report. National Marine Fisheries Service, Seattle, Washington.

Boule, M.E. and Bierly, K.F. 1987. History of estuarine wetland development and alteration: What have we wrought? Northwest Environmental Journal 3(1): 43-61.

Bowman, M.L., Gerritsen, J., Gibson, G.R., and Snyder, B.D. 2000. Estuarine and coastal marine waters: Bioassessment and biocriteria technical guidance. US Environmental Protection Agency, Washington, D.C.

Boyd, R. 1986. Strategies of Indian burning in the Willamette valley. Canadian Journal of Anthropology 5(1): 65-86.

Boynton, W.R. 2000. Impact of nutrient inflows of Chesapeake Bay. *In* Agriculture and phosphorous management: The Chesapeake Bay. *Edited by* A.N. Sharpley. Lewis Publishers, Boca Raton, FL. pp. 23-40.

Braatne, J.H. 1999. Biological aspects of hybrid poplar cultivation on floodplains in western North America: A review. EPA 910-R-99-002. Environmental Protection Agency, Seattle, Washington.

Bradbury, B., Nehlsen, W., Nickelson, T.E., Moore, K.M.S., Hughes, R.M., Heller, D., Nicholas, J., Bottom, D.L., Weaver, W.E., and Beschta, R.L. 1995. Handbook for prioritizing watershed protection and restoration to aid recovery of native salmon. Pacific Rivers Council, Portland, Oregon.

Bradford, C.S., Schreck, C.B., David, L.E., Slater, C.H., Beck, M.T., and Ewing, S.K. 1990. Migratory characteristics of spring chinook salmon in the Willamette River. *In* Annual Report to Bonneville Power Administration. Bonneville Power Administration, Portland, Oregon. 48 pp.

Bradford, M.J. 1997. An experimental study of stranding of juvenile salmonids on gravel bars and in sidechannels during rapid flow decreases. Regulated Rivers: Research and Management 13(5): 395-401.

Bradford, M.J. and Irvine, J.R. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, coho salmon. Canadian Journal of Fisheries and Aquatic Sciences 57: 13-16.

Bradford, M.J., Myers, R.A., and Irvine, J.R. 2000. Reference points for coho salmon (*Oncorhynchus kisutch*) harvest rates and escapement goals based on freshwater production. Canadian Journal of Fisheries and Aquatic Sciences 57(4): 677-686.

Brady, N.C. 1984. The nature and properties of soils. Macmillan Publishing Company, New York.

Brett, J.R. 1952. Temperature tolerance in young pacific salmon, genus *Oncorhynchus*. Journal of the Fisheries Research Board of Canada 9(6): 265-323.

Brierley, G.J. and Hickin, E.J. 1991. Channel planform as a non-controlling factor in fluvial sedimentology: The case of the Squamish River floodplain, British Columbia. Sedimentary Geology 75: 67-83.

Brookes, A. 1988. Channelized rivers: Perspectives for environmental management. John Wiley and Sons, New York.

Brown, A.G. 1997. Biogeomorphology and diversity in multiple-channel river systems. Global Ecology and Biogeography Letters 6: 179-185.

Brown, D.E. 2000. Denitrification and vegetative uptake in a pasture, poplar and native oak riparian buffer area. M.S. thesis. Oregon State University, Corvallis, Oregon.

Brown, T.G. and Hartman, G.F. 1988. Contribution of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Transactions of the American Fisheries Society 117: 546-551.

Buckhouse, J.C. 2000. Chapter 14, Domestic grazing, Part IV: Effects of grazing animals, birds, and fish on water quality. *In* Drinking water from forests and grasslands: A synthesis of the scientific literature. *Edited by* G.E. Dissmeyer. General Technical Report SRS-39. US Dept. of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina. 153-157.

Buckhouse, J.C., Stringham, T.K., and Krueger, W.C. 1997. Stream temperature amelioration through subsurface (interflow) delivery of water. *In* Watershed management guide for the interior northwest. Extension Publication EM 8436. *Edited by* T.E. Bedell and M.M. Borman. Oregon State University, Corvallis, Oregon. pp. 35-36.

Budd, W.W., Cohen, P.L., Saunders, P.R., and Steiner, F.R. 1987. Stream corridor management in the Pacific Northwest: I. determination of stream-corridor widths. Environmental Management 11(5): 587-597.

Burmgarner, J., Mendel, B., Milks, D., Ross, L., Varney M., and Dedloff, J. 1997. Tucannon River spring chinook hatchery evaluation. H97-07. Washington Department of Fish and Wildlife, Olympia, Washington.

Burnett, K.M. 2001. Relationships among juvenile anadromous salmonids, their freshwater habitat, and landscape characteristics over multiple years and spatial scales in the Elk River, Oregon. Ph.D. thesis. Oregon State University, Corvallis, Oregon.

Busby, P.J., Wainwright, T.C., Bryant, G.J., Lierheimer, L.J., Waples, R.S., Waknitz, F.W., and Lagomarsino, I.V. 1996. Status review of West Coast steelhead from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-27. US Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, Seattle, Washington.

Campbell, H.J. 1954. The effect of siltation from gold dredging on the survival of rainbow trout and eyed eggs in Powder River, Oregon. Oregon State Game Commission, Portland, Oregon. 3 pp.

Carl, L.M. and Healey, M.C. 1984. Differences in enzyme frequency and body morphology among three life history types of chinook salmon (*Oncohychus tshawytscha*) in the Nanaimo River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 41: 1070-1077.

Cederholm, C.J. and Peterson, N.P. 1985. The retention of coho salmon (*Oncorhynchus kisutch*) carcasses by organic debris in small streams. Canadian Journal of Fisheries and Aquatic Sciences 42: 1222-1225.

Cederholm, C.J. and Scarlett, W.J. The beaded channel: a low-cost technique for enhancing winter habitat of coho salmon. American Fisheries Society Symposium 10: 104-108.

Cederholm, C.J. and Scarlett, W.J. 1988. Low-cost enhancement technique for winter habitat of juvenile salmon. North American Journal of Fisheries Management 8: 438-441.

Chapin, F.S.I. and Kedrowski, R.A. 1983. Seasonal changes in nitrogen and phosphorous fractions and autumn retranslocation in evergreen and deciduous taiga trees. Ecology 64: 376-391.

Chapman, D.W. 1958. Studies on the life history of Alsea River steelhead. Journal of Wildlife Management 22(2): 123-134.

Chapman, D.W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. Journal of the Fisheries Research Board of Canada 19(6): 1047-1080.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117(1): 1-21.

Chen, Y.H. and Simons, D.B. 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River System. Hydrobiologia 136: 5-20.

Chesapeake Bay Program. 1999. The state of the Chesapeake Bay: A report to the citizens of the Bay region. Report No. EPA 903-R99-013 and CBP/TRS 222/108. Environmental Protection Agency and Chesapeake Bay Program, Annapolis, Maryland.

Church, C. 2000. Williams Creek watershed action plan. Williams Creek Watershed Council, Williams, Oregon.

Church, M. 1996. Channel morphology and typology. *In* River flows and channel forms: Selected extracts from the rivers handbook. *Edited by* G. Petts and P. Calow. Blackwell Science, Cambridge, Massachusettes. pp. 126-143.

Clawson, J., Buckhouse, J., Miner, J., and Moore, J. 1994. An evaluation of off-site water development and fencing configurations designed to ameliorate water quality impacts by livestock. *In* Proceedings of the Oregon Academy of Science, Corvallis, Oregon, February 28, 1994. Oregon State College Press, Corvallis, Oregon. p. 8.

Coats, R., Collins, L., Florsheim, J., and Kaufman, D. 1985. Channel change, sediment transport, and fish habitat in a coastal stream: Effects of an extreme event. Environmental Management 9(1): 35-48.

Collier, M.P., Webb, R.H., and Andrews, D.D. 1997. Experimental flooding in Grand Canyon. Scientific American 276(1): 82-89.

Collins, B.D., Montgomery, D.R., and Has, A.D. 2000. Historic changes in the distribution and functions of large woody debris in Puget lowland rivers. *In* Abstracts, International Conference on Wood in World Rivers, October 23-27, 2000. Oregon State University, Corvallis, Oregon. p. 77.

Cornwell, T.J., Bottom, D.L., and Jones, K.K. 2001. Rearing of juvenile salmon in recovering wetlands of the Salmon River Estuary. Information Reports 2001-05. Oregon Department of Fish and Wildlife, Portland, Oregon.

Corrarino, C. 2001. Personal Communication. Fish Passage Program Coordinator. Oregon Department of Fish and Wildlife, Portland, Oregon.

Correll, D.L., Jordan, T.E., and Weller, D.E. 1992. Nutrient flux in a landscape: Effects of coastal land use and terrestrial community mosaic on nutrient transport to coastal waters. Estuaries 15(4): 431-442.

Cortright, R., Weber, J., and Bailey, R. 1987. The Oregon Estuary Plan Book. State of Oregon, Department of Land Conservation and Development (DLCD), Salem, Oregon.

Coulton, K.G., Goodwin, P., Perala, C., and Scott, M.G. 1996a. An evaluation of flood management benefits through floodplain restoration on the Willamette River, Oregon, USA. Report prepared by Philip Williams and Associates for the River Network. River Network, Portland, Oregon.

Coulton, K.G., Williams, P.B., and Benner, P.A. 1996b. An environmental history of the Tillamook Bay estuary and watershed. Tillamook Bay National Estuary Project Technical Report 09-96. Tillamook Bay National Estuary Project, Garibaldi, Oregon.

Cummins, K.W. 1973. Trophic relations of aquatic insects. Annual Review of Entomology 18: 183-206.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience 24: 631-641.

D'Angelo, D.J., Gregory, S.V., Ashkenas, L.R., and Meyer, J.L. 1997. Physical and biological linkages within a stream geomorphic hierarchy. Journal of the North American Benthological Society 16: 480-502.

D'Angelo, D.J., Howard, L.M., Meyer, J.M., Gregory, S.V., and Ashkenas, L.R. 1995. Ecological uses for genetic algorithms: predicting fish distributions in complex physical habitats. Canadian Journal of Fisheries and Aquatic Sciences 52: 1893-1908.

D'Itri, F.M.A. 1985. A systems approach to conservation tillage. Lewis Publishers, Chelsea, Michigan.

Daggett, S.G., Boule, M.E., Bernert, J.A., Eilers, J.M., Blok, E., Peters, D., and Morland, J.C. 1998. Wetland and land use change in the Willamette Valley, Oregon: 1982 to 1994. Shapiro and Associates, Inc. Report to the Division of State Lands, Wetlands Program, Salem, Oregon.

Dahl, T.E. 1990. Wetlands losses in the United States 1780's to 1980's. US Department of the Interior, Fish and Wildlife Service, Washington, D.C.

Dambacher, J. M., Li, H. W., and Rossignol, P. A. 1999. Historical reconstruction, through qualitative modelling, of the effects of exotic fish introductions in Tenmile Lakes, Oregon. *In* Oregon Department of Fish and Wildlife and National Marine Fisheries Service. Management implications of co-occurring native and introduced fishes: Proceedings of the workshop. Portland, Oregon. National Marine Fisheries Service, Portland, Oregon.

Darby, S.E. 1999. Effect of riparian vegetation on flow resistance and flood potential. Journal of Hydraulic Engineering May: 433-454.

Dawley, E.M., Ledgerwood, R.D., and Jensen, A.L. 1985. Beach and purse seine sampling of juvenile salmonids in the Columbia River estuary and ocean plume, 1977-1983. Vol. I-II U.S. NOAA Tech. Memo. NMFS, F/NWC-74. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Coastal Zone and Estuarine Studies Division, Seattle, Washington. 260 pp.

DeBano, L.F. and Heede, B.H. 1987. Enhancement of riparian ecosystems with channel structures. Water Resources Bulletin 23: 463-470.

Decamps, H. 1993. River margins and environmental change. Ecological Applications 3(3): 441-445.

Decamps, H., Fortune, M., Gazelle, F., and Pautou, G. 1988. Historical influence of man on the riparian dynamics of a fluvial landscape. Landscape Ecology 1(3): 163-173.

Delong, M.D. and Brusven, M.A. 1994. Allochthonous input of organic-matter from different riparian habitats of an agriculturally impacted stream. Environmental Management 18(1): 59-71.

Dent, L. and Robben, J. 2000. Oregon Department of Forestry: Aerial pesticide application monitoring final report. Forest practices monitoring program technical report 7. Oregon Department of Forestry, Philomath, Oregon.

Department of Environmental Quality (DEQ). 1994. Willamette River Toxics Study. Oregon Department of Environmental Quality, Portland, Oregon.

Department of Environmental Quality (DEQ). 1995. 1992 - 1994 water quality standards review: Final issue paper. State of Oregon, Department of Environmental Quality, Portland, Oregon.

Department of Environmental Quality (DEQ). 1999. Willamette River Basin, briefing packet. Oregon Department of Environmental Quality, Salem, Oregon.

Department of Environmental Quality (DEQ). 2000a. Oregon's 2000 water quality status assessment report. Section 305(b) report. State of Oregon, Department of Environmental Quality, Salem, Oregon.

Department of Environmental Quality (DEQ). 2000b. Draft South Fork Coquille Total Maximum Daily Load (TMDL) and Water Quality Management Plan. Oregon Department of Environmental Quality, Water Quality Division, Salem, Oregon. 420 pp.

Department of Environmental Quality (DEQ). 2000c. Draft Tillamook Subbasin total Maximum Daily Load (TMDL). Oregon Department of Environmental Quality, Salem, Oregon.

Department of Environmental Quality (DEQ). 2000d. Memorandum of Agreement between the United States Environmental Protection Agency and the State of Oregon Department of Environmental Quality regarding the Implementation of Section 303(d) of the Federal Clean Water Act. Oregon Department of Environmental Quality and US Environmental Protection Agency, Salem, Oregon.

Department of Environmental Quality (DEQ). 2001. Tualatin Subbasin Total Maximum Daily Load (TMDL). Oregon Department of Environmental Quality, Water Quality Division, Salem, Oregon. 420 pp.

Department of Environmental Quality (DEQ) with the Umatilla Basin Watershed Council and The Confederated Tribes of the Umatilla Indian Reservation. 2001. Umatilla River Basin Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP). Oregon Department of Environmental Quality, Salem, Oregon. 420 pp.

Desmond, J.S., Zedler, J.B., and Williams, G.D. 2000. Fish use of tidal creek habitats in two southern California salt marshes. Ecological Engineering 14(3): 233-252.

DeVries, P.E. 2000. Scour in low gradient gravel bed streams: Patterns, processes, and implications for the survival of salmonid embryos. Ph.D. thesis. University of Washington, Seattle, Washington.

Dickhoff, W.W., Beckman, B.R., Larsen, D.A., Mahnken, C.V.W., Shreck, C.B., Sharpe, C., and Zaugg, W.S. 1995. Quality assessment of hatchery-reared spring chinook salmon smolts in the Columbia River Basin. American Fisheries Society Symposium 15: 292-302.

Dimick, R.E. and and Merryfield, F. 1945. The fishes of the Willamette River system in relation to pollution. Bulletin 20. Oregon State College, Engineering Experiment Station, Corvallis, Oregon.

Domagalski, J. 1996. Pesticides and pesticide degradation products in stormwater runoff: Sacramento River basin, California. Water Resources Bulletin 32(5): 953-964.

Dong, J., Chen, J., Brosofske, K.D., and Naiman, R.J. 1998. Modelling air temperature gradients across managed small streams in western Washington. Journal of Environmental Management 38: 309-321.

Doppelt, B., Scurlock, M.C., Frissell, C.A., and Karr, J.R. 1993. Entering the watershed: A new approach to save America's river ecosystems. Island Press, Washington, D.C.

Douglass, J.E., Cochrane, D.R., Bailey, G.W., Teasley, J.I., and Hill, D.W. 1969. Low herbicide concentration found in stream flow after a grass cover is killed. Research Note SE-108. USDA Forest Service, Southeastern Forest Experiment Station (now the Southern Research Station), Asheville, North Carolina.

Dunne, T. and Leopold, L.B. 1978. Water in environmental planning. W.H. Freeman and Company, New York.

Dykaar, B.B. and Wigington, P.J.Jr. 2000. Floodplain formation and cottonwood colonization patterns on the Willamette River, Oregon, USA. Environmental Management 25(1): 87-104.

Edwards, C.L., Shannon, R.D., and Jarrett, A.R. 1999. Sedimentation basin retention efficiencies for sediment, nitrogen, and phosphorus from simulated agricultural runoff. Transactions of the ASAE. 42(2): 403-409.

Eisler, R. 1986. Diazinon hazards to fish, wildlife, and invertebrates: A synoptic review. US Fish and Wildlife Service Biological report 85(1.9). 37 pp.

Everest, F.H. 1973. Ecology and management of summer steelhead in the Rogue River. Fishery Research Report 7. Federal Aid to Fish Restoration Project AFS 31. Oregon State Game Commission, Corvallis, Oregon.

Ewing, R.D. 2000. Herbicide concentrations in stream runoff after rain events in the Alsea River basin. Final Report to the Alsea Citizen's Monitoring Committee. Biotech Research and Consulting, Inc., Corvallis, Oregon.

Federal Interagency Stream Corridor Restoration Working Group (FISRWG). 1998. Stream corridor restoration: Principles, processes, and practices. GPO Item No. 0120-A. Federal Interagency Stream Corridor Restoration Working Group (FISRWG) (15 Federal agencies of the US gov't), Washington, D.C.

Fisher, S.G. and Likens, G.E. 1973. Energy flow in Bear Brook, New Hampshire: An integrative approach to stream ecosystem metabolism. Ecological Monographs 43: 421-439.

Flitcroft, R.L., Jones, K.K., Reis, K.E.M., and Thom, B.A. 2002. 2000 stream habitat conditions in western Oregon. Monitoring Program Report Number OPSW-ODFW-2001-05. Oregon Department of Fish and Wildlife.

Forman, R.T.T. and Gordon, M. 1986. Landscape Ecology. John Wiley and Sons, New York.

Frenkel, R.E. and Morlan, J.C. 1990. Restoration of the Salmon river salt marshes: Retrospect and prospect. Final Report to the U.S. Environmental Protection Agency. US Environmental Protection Agency, Seattle, Washington.

Frenkel, R.E. and Morlan, J.C. 1991. Can we restore our salt marshes? Lessons from the Salmon River, Oregon. Northwest Environmental Journal 7: 119-135.

Frenkel, R.E., Wickramaratne, S.N., and Heinitz, E.F. 1984. Vegetation and land cover change in the Willamette River Greenway in Benton and Linn Counties, Oregon: 1972-1981. Yearbook of the Association of Pacific Coast Geographers 46: 63-77.

Friedman, J.M., Osterkamp, W.R., and Lewis, W.M.Jr. 1996. Channel narrowing and vegetation development following a Great Plains flood. Ecology 77(7): 2167-2181.

Friends of Buford Park and Mt Pisgah (FBP). 2001. HBRA master plan meeting, Buford Park, Inundation Enhancement Opportunity at the 2-year flood interval discharge. Friends of Buford Park and Mt. Pisgah, Eugene, Oregon.

Frissell, C.A. 1993. Topology of extinction and endangerment of native fishes in the Pacific Northwest and California, USA. Conservation Biology 7: 342-354.

Frissell, C. A., Liss, W. J., and Bayles, D. 1993. An integrated, biophysical strategy for ecological restoration of large watersheds. Water resources education--a lifetime of learning: Changing roles in water resources management and policy: Symposia proceedings. American Water Resources Association (AWRA), Bethesda, Maryland.

Frissell, C.A., Liss, W.J., Warren, C.E., and Hurley, M.D. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management 10(2): 199-214.

Frissell, C.A. and Ralph, S.C. 1998. Stream and watershed restoration. *In* River ecology and management: Lessons from the Pacific coastal ecoregion. *Edited by* R.J. Naiman and R.E. Bilby. Springer, New York. pp. 599-624.

Gammon, J.R. 1970. The effect of inorganic sediment on stream biota. Grant #18050DWC. Water Quality Office of the Environmental Protection Agency, US Government Printing Office, Washington, D.C.

Giannico, G.R. and Healey, M.C. 1998. Effects of flow and food on winter movements of juvenile coho salmon. Transactions of the American Fisheries Society 127: 645-651.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Oregon State Game Commission, Fishery Research Report Number 6. 64 pp.

Gold, A. J., Groffman, P. M., Addy, K., Kellogg, D. Q., and Rosenblatt, A. E. 2000. The role of landscape setting in riparian groundwater nitrate removal. *In* P.J.Jr. Wigington and R.L. Beschta (Editors). International conference on riparian ecology and management in multi-land use watersheds. Portland, Oregon, American Water Resources Association, Middleburg, Virginia. pp.113-117.

Gonor, J.J., Sedell, J.R., and Benner, P.A. 1988. What we know about large trees in estuaries, in the sea, and on coastal beaches. *In* From the forest to the sea: A story of fallen trees. *Edited by* C. Master, R.F. Tarant, J.M. Trappe, and J.F. Franklin. General Technical Report PNW-GTR-229. USDA, Forest Service, Pacific Northwest Research Station, Portland, Oregon. pp. 83-112.

Gordon, N.D., McMahon, T.A., and Finlayson, B.L. 1992. Stream hydrology: An introduction for ecologists. John Wiley and Sons, Inc. , New York, New York.

Grant, G.E., Swanson, F.J., and Wolman, M.G. 1990. Pattern and origin of stepped-bed morphology in high-gradient streams, Western Cascades, Oregon. Geological Society of America Bulletin 102: 340-352.

Gregory, K.J. and Davis, R.J. 1992. Coarse woody debris in stream channels in relation to river channel management in woodland areas. Regulated Rivers: Research and Management 7: 117-136.

Gregory, R.S. and Levings, C.D. 1996. The effects of turbidity and vegetation on the risk of juvenile salmonids, *Oncorhynchus* spp., to predation by adult cutthroat trout, *O. clarki*. Environmental Biology of Fishes 47(3): 279-288.

Gregory, S., Ashkenas, L., Haggerty, P., Oetter, D., Wildman, K., Hulse, D., Branscomb, A., and Van Sickle, J. 2002a. Riparian vegetation in the Willamette Basin. *In* Willamette River Basin: Trajectories of environmental and ecological change, a planning atlas. *Edited by* D. Hulse, S. Gregory, and J. Baker. Oregon State University Press, Corvallis, Oregon. pp. 40-42.

Gregory, S., Ashkenas, L., Jett, S., and Wildman, R. 2002b. Flood inundations/FEMA floodplains. *In* Willamette River Basin: Trajectories of environmental and ecological change, a planning atlas. *Edited by* D. Hulse, S. Gregory, and J. Baker. Oregon State University Press, Corvallis, Oregon. pp. 28-29.

Gregory, S., Ashkenas, L., Oetter, D., Minear, P., and Wildman, K. 2002c. Historical Willamette River channel change. *In* Willamette River Basin: Trajectories of environmental and ecological change, a planning atlas. *Edited by* D. Hulse, S. Gregory, and J. Baker. Oregon State University Press, Corvallis, Oregon. pp. 18-25.

Gregory, S., Ashkenas, L., Oetter, D., Minear, P., Wildman, K.C.J., Kolar, S., and Alverson, E. 2002d. Presettlement vegetation ca. 1851. *In* Willamette River Basin: Trajectories of environmental and ecological change, a planning atlas. *Edited by* D. Hulse, S. Gregory, and J. Baker. Oregon State University Press, Corvallis, Oregon. pp. 38-39.

Gregory, S., Ashkenas, L., Oetter, D., Wildman, R., Minear, P., Jett, S., and Wildman, K. 2002e. Revetments. *In* Willamette River Basin: Trajectories of environmental and ecological change, a planning atlas. *Edited by* D. Hulse, S. Gregory, and J. Baker. Oregon State University Press, Corvallis, Oregon. pp. 32-33.

Gregory, S.V. 1996. Management of wood is critical to rivers and salmon. *In* The Northwest salmon crisis: A documentary history. *Edited by* J. Cone and S. Ridlington. Oregon State University Press, Corvallis, Oregon. pp. 148-160.

Gregory, S.V. and Bisson, P.A. 1997. Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. *In* Pacific salmon and their ecosystems: Status and future options. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, New York. pp. 277-314.

Gregory, S.V., Hulse, D.W., Landers, D.H., and Whitelaw, E. 1998. Integration of biophysical and socioeconomic patterns in riparian restoration of large rivers. *In* Hydrology in a changing environment. *Edited by* H. Wheater and C. Kirby. John Wiley and Sons, New York. pp. 231-247.

Gregory, S.V., Swanson, F.J., McKee, W.A., and Cummins, K.W. 1991. An ecosystem perspective of riparian zones: Focus on links between land and water. Bioscience 41(8): 540-551.

Gresh, R., Lichatowich, J., and Schoonmaker, P. 2000. Salmon decline creates nutrient deficit in Northwest streams. Tidepool-internet website.

Gresswell, R.E., Liss, W.J., and Larson, G.L. 1994. Life-history organization of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) in Yellowstone Lake. Canadian Journal of Fisheries and Aquatic Sciences 51(1): 298-309.

Griffin, L.E. 1938. Experiments on the tolerance of young trout and salmon for suspended sediment in water. Bulletin of Oregon Department of Geology 10: appendix B: 28-32.

Groot, C. and Margolis, L. 1991. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Gutowsky S. and Jones, J. A. 2000. Riparian cover changes along the upper Willamette River, 1939-1996. *In* P.J.Jr. Wigington and R.L. Beschta. International conference on riparian ecology and management in multi-land use watersheds. Portland, Oregon, American Water Resources Association, Middleburg, Virginia. pp.233-238.

Gutowsky, S.L. 2000. Riparian cover changes associated with flow regulation and bank stabilization along the upper Willamette River in Oregon between 1939 and 1996. M.S. thesis. Oregon State University, Corvallis, Oregon.

Hanski, I. 1991. Single species metapopulation dynamics: Concepts, models and observations. *In* Metapopulation dynamics. *Edited by* M.E. Gilpin and I. Hanski. Academic Press, London. pp. 17-38.

Hanski, I. 1997. Metapopulation dynamics: From concepts and observations to predictive models. *In* Metapopulation biology: Ecology, genetics, and evolution. *Edited by* I. Hanski and M.E. Gilpin. Academic Press, San Diego, California. pp. 69-92.

Hanski, I. 1998. Metapopulation dynamics. Nature 396: 41-49.

Hanski, I. and Gilpin, M.E. 1991. Metapopulation dynamics: Brief history and conceptual domain. *In* Metapopulation dynamics: Empirical and theoretical investigations. *Edited by* M.E. Gilpin and I. Hanski. Published for the Linnean Society of London [by] Academic Press, London. pp. 3-16.

Harding, J.S., Benfield, E.F., Bolstad, P.V., Helfman, G.S., and Jones, E.B.D.I. 1998. Stream biodiversity: The ghost of land use past. Proceedings of the National Academy of Sciences of the USA 95: 14843-14847.

Harding, J.S., Young, R.G., Hayes, J.W., Shearer, K.A., and Stark, J.D. 1999. Changes in agricultural intensity and river health along a river continuum. Freshwater Biology 42: 345-357.

Harrison, S. 1991. Local extinction in a metapopulation context: An empirical evaluation. Biological Journal of the Linnean Society 42: 73-88.

Harrison, S. 1994. Metapopulations and conservation. *In* Large-scale ecology and conservation biology. *Edited by* P.J. Edwards, R.M. May, and N.R. Webb. Blackwell Scientific Publications, Oxford, England.

Hartman, G.F. and Brown, T.G. 1987. Use of small, temporary, floodplain tributaries by juvenile salmonids in a west coast rain-forest drainage basin, Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 44(2): 262-270.

Hawkins, C.P., Murphy, M.L., and Anderson, N.H. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in the Cascade range streams of Oregon. Ecology 63(6): 1840-1856.

Healey, M.C. 1980. Utilization of the Nanaimo River estuary by juvenile chinook salmon, *Oncorhynchus tshawytscha*. Fishery Bulletin 78(3): 653-668.

Healey, M.C. 1982. Juvenile Pacific Salmon in estuaries: The life support system. *In* Estuarine Comparisons. *Edited by* V.S. Kennedy. Academic Press, New York. pp. 315-341.

Healey, M.C. 1994. Variation in the life history characteristics of chinook salmon and its relevance to conservation of the Sacramento winter run of chinook salmon. Conservation Biology 8(3): 876-877.

Healey, M.C. and Prince, A. 1995. Scales of variation in life history tactics of Pacific salmon and the conservation of phenotype and genotype. American Fisheries Society Symposium 17: 176-184.

Healey, M.C. and Richardson, J.S. 1996. Changes in the productivity base and fish populations of the Lower Fraser River (Canada) associated with historical changes in human occupation. Archiv fur Hydrobiologie Suppl.(113 (Large Rivers 10)): 279-290.

Heede, G.H. 1981. Dynamics of selected mountain streams in the western United States of America. Zeitschrift fur Geomorphologie 25: 17-32.

Herbert, D.W.M., Alabaster, J.S., Dart, M.C., and Lloyd, R. 1961. The effect of china-clay wastes on trout streams. International Journal of Air and Water Pollution 5(1): 56-74.

Hetrick, N.J., Brusven, M.A., Meehan, W.R., and Bjornn, T.C. 1998. Changes in solar input, water temperature, periphyton accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in southeast Alaska. Transactions of the American Fisheries Society 127: 859-875.

Hickin, E.J. 1984. Vegetation and river channel dynamics. Canadian Geographer 28: 111-126.

Hicks, B.J. 1989. The influence of geology and timber harvest on channel morphology and salmonid populations in Oregon coast range streams. Ph.D. thesis. Oregon State University , Corvallis, Oregon.

Hicks, B.J., Beschta, R.L., and Harr, R.D. 1991a. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resources Bulletin 27(2): 217-226.

Hicks, B.J., Hall, J.D., Bisson, P.A., and Sedell, J.R. 1991b. Responses of salmonids to habitat changes. *In* Influences of forest and rangeland management on salmonid fishes and their habitats. *Edited by* W.R. Meehan. American Fisheries Society Special Publication 19, Bethesda, Maryland. pp. 483-518.

Hill, M.T., Platts, W.S., and Beschta, R.L. 1991. Ecological and geomorphological concepts for instream and out-of-channel flow requirements. Rivers 2(3): 198-210.

Hjort, R.C., Hulett, P.L., LaBolle, L.D., and Li, H.W. 1983. Fish and invertebrates of revetments and other habitats in the Willamette River, Oregon. US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Hoagland, K.D., Drenner, R.W., Smith, J.D., and Cross, D.R. 1993. Freshwater community responses to mixtures of agricultural pesticides: Effects of atrazine and bifenthrin. Environmental Toxicology and Chemistry 12: 627-637.

Hoffnagle, J. and Olson, R. 1974. The salt marshes of the Coos Bay estuaries. Port of Coos Bay Commission and Oregon Institute of Marine Biology, University of Oregon, Charleston, Oregon.

Hokanson, K.E.F., Kleiner, C.F., and Thorslund, T.W. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yeild of juvenile rainbow trout, *Salmo gairdner*. Journal of the Fisheries Research Board of Canada 34: 639-648.

Hughes, R.M. 1995. Defining acceptable biological status by comparing with reference conditions. *In* Biological assessment and criteria: Tools for water resouce planning and decision making. *Edited by* W.S. Davis and T.P. Simon. Lewis Publishers, Boca Raton. pp. 31-47.

Hughes, R.M. and Gammon, J.R. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Transactions of the American Fisheries Society 116: 196-209.

Hughes, R.M., Larsen, D.P., and Omernik, J.M. 1986. Regional reference sites: A method for assessing stream potentials. Environmental Management 10(5): 629-635.

Hulse, D., Gregory, S., and Baker, J. 2002. Willamette River Basin: Trajectories of environmental and ecological change, a planning atlas. Oregon State University Press, Corvallis, Oregon.

Huntington, C., Nehlsen, W., and Bowers, J. 1996. A survey of healthy native stocks of anadromous salmonids in the Pacific Northwest and California. Fisheries 21(3): 6-14.

Hupp, C.R. and Simon, A. 1991. Bank accretion and the development of vegetated depositional surfaces along modified alluvial channels. Geomorphology 4: 111-124.

Hynes, H.B.N. 1975. The stream and its valley. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 19: 1-15.

Independent Multidisciplinary Science Team (IMST). 1998. Pinniped and seabird predation: Implications for recovery of threatened stocks of salmonids in Oregon under the Oregon Plan for Salmon and Watersheds. Technical Report 1998-2 to the Oregon Plan for Salmon and Watersheds. Governor's Natural Resources Office, Salem, Oregon.

Independent Multidisciplinary Science Team (IMST). 1999. 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 to the Oregon Plan for Salmon and Watersheds. Governor's Natural Resources Office, Salem, Oregon.

Independent Multidisciplinary Science Team (IMST). 2000a. Influences of human activity on stream temperatures and existence of cold-water fish in streams with elevated temperature: Report of a workshop. Technical Report 2000-2 to the Oregon Plan for Salmon and Watersheds. Oregon Watershed Enhancement Board, Salem, Oregon.

Independent Multidisciplinary Science Team (IMST). 2000b. Salmon abundances and effects of harvest: Implications for rebuilding stocks of wild coho salmon in Oregon. Technical Report 2000-3 to the Oregon Plan for Salmon and Watersheds. Oregon Watershed Enhancement Board, Salem, Oregon.

Independent Multidisciplinary Science Team (IMST). 2001. The scientific basis for artificial propagation in the recovery of wild anadromous salmonids in Oregon. Technical Report 2001-1 to the Oregon Plan for Salmon and Watersheds. Oregon Watershed Enhancement Board Office, Salem, Oregon.

Independent Science Panel. 2000. Recommendations for monitoring salmonid recovery in Washington State. Report 2000-2. Independent Science Panel, Olympia, Washington. 48 pp.

Independent Scientific Group (ISG). 1996. Return to the river: Restoration of salmonid fishes in the Columbia River. Northwest Power Planning Council, Portland, Oregon.

Iwata, M. and Komatsu, S. 1984. Importance of estuarine residence for adaptation of chum salmon (*Oncorhynchus keta*) fry to seawater. Canadian Journal of Fisheries and Aquatic Sciences 41(5): 744-749.

Jackson, P.L. 1991. Managing Oregon's estuarine resource lands. Journal of Soil and Water Conservation 46: 23-26.

Jacobs, S., Firman, J., and Susac, G. 2001. Status of Oregon coastal stocks of anadromous salmonids, 1999-2000. Monitoring Program Report Number OPSW-ODFW 2001-3. Oregon Department of Fish and Wildlife, Portland, Oregon.

Jefferson, C.A. 1974. Plant communities and succession in Oregon coastal salt marshes. Ph.D thesis. Oregon State University, Corvallis, Oregon.

Johannessen, C.L., Davenport W.A., Millet, A., and McWilliams, S. 1971. The vegetation of the Willamette Valley. Annals of the Association of American Geographers 61(2): 286-302.

Johnson, A.W. and Ryba, D.M. 1992. A literature review of recommended buffer widths to maintain various functions of stream riparian areas. King County Department of Natural Resources, Water and Land Resources Division, Seattle, Washington.

Johnson, O.W., Grant, W.S., Kope, R.G., Neely, K., Waknitz, F.W., and Waples, R.S. 1997. Status review of chum salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-32. US Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division , Seattle, Washington.

Johnson, O.W., Ruckelshaus, M.H., Grant, W.S., Waknitz, F.W., Garrett, A.M., Bryant, G.J., Neely, K., and Hard, J.J. 1999. Status Review of Coastal Cutthroat Trout from Washington, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-37. National Marine Fisheries Service, Seattle, Washington.

Johnston, C.A. 1994. Ecological engineering of wetlands by beavers. *In* Global wetlands: Old world and new. *Edited by* W.J. Mitsch. Elsevier, New York. pp. 379-398.

Johnston, C.A., Detenbeck, N.E., and Niemi, G.J. 1990a. The cumulative effect of wetlands on stream water quality and quantity: A landscape approach. Biogeochemistry 10: 105-141.

Johnston, N.T., Perrin, C.J., Slaney, P.A., and Ward, B.R. 1990b. Increased juvenile salmonid growth by whole-river fertilization. Canadian Journal of Fisheries and Aquatic Sciences 47: 862-872.

Jordan, E. 2000. Cooperative Extension Compilation Report for the Dairy-McKay Hydrologic Unit Area, from 1991-2000. Oregon State University Cooperative Extension Department of Rangeland Resources, Corvallis, Oregon. 44 pages plus appendices.

Junk, W. J., Bayley, P. B., and Sparks, R. E. 1989. The flood pulse concept in river-floodplain systems. *In* D.P. Dodge (Editor). Proceedings of the international large river symposium. Honey Harbour, Ontario, Canada, Dept. of Fisheries and Oceans, Ottawa, Ontario, Canada. pp.110-127.

Kahler, T.H., Roni, P., and Quinn, T.P. 2001. Summer movement and growth of juvenile anadromous salmonids in small western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58: 1947-1956.

Karr, J.R. and Schlosser, I.J. 1977. Impact of nearstream vegetation and stream morphology on water quality and stream biota. US Environmental Protection Program, Athens, Georgia.

Karr, J.R. and Schlosser, I.J. 1978. Water resources and the land-water interface. Science 201: 229-234.

Keeler, E.L. 1985. Willamette valley river towns and steamboats. M.A. thesis. University of Oregon, Eugene, Oregon.

Keller, E.A. and Swanson, F.J. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes and Landforms 4: 361-380.

Kentula, M.E. 1986. Wetland creation and rehabilitation in the Pacific Northwest. *In* Wetland functions, rehabilitation, and creation in the Pacific Northwest: The state of our understanding; proceedings of a conference held April 30 - May 2, 1986, Fort Worden State Park, Port Townsend, Washington. *Edited by* R. Strickland. Washington State Department of Ecology, Olympia, Washington. pp. 119-126.

Kershner, J.L. 1997. Monitoring and adaptive management. *In* Watershed restoration: Principles and practices. *Edited by* J.E. Williams, C.A. Wood, and M.P. Dombeck. American Fisheries Society, Bethesda, Maryland. pp. 116-131.

Kiker, C. F. 1974. Public and private rights related to water use. *In* M.C. Blount (Editor). Water Resources: Utilization and conservation in the environment. Proceedings: Southeast Region Water Resources Symposium. Fort Valley State College, Fort Valley, Georgia.

Kjelson, M.A., Raquel, P.F., and Fisher, F.W. 1982. Life history of fall-run juvenile chinook salmon, *Oncorhynchus tshawytscha*, in the Sacramento - San Joaquin Estuary, California. *In* Estuarine comparisons. *Edited by* V.S. Kennedy. Academic Press, New York, New York. pp. 393-411.

Klingeman, P.C. 1973. Indications of streambed degradation in the Willamette Valley. WRRI-21. Oregon State University, Water Resources Research Institute, Corvallis, Oregon.

Knighton, D. 1998. Fluvial forms and processes: A new perspective. Edward Arnold, London, England.

Knox, M.A. 2000. Ecological change in the Willamette Valley at the time of Euro-American contact ca. 1800-1850. M.A. thesis. University of Oregon, Eugene, Oregon.

Koluvek, P.K., Tanji, K.K., and Trout, T.J. 1993. Overview of soil erosion from irrigation. Journal of Irrigation and Drainage Engineering 119(6): 929-946.

Kondolf, G.M. 1995. Managing bedload sediment in regulated rivers: Examples from California, U.S.A. *In* Natural and anthropogenic influences in fluvial geomorphology. Geophysical Monograph 89. *Edited by* J.E. Costa, A.J. Miller, K.W. Potter, and P.R. Wilcock. American Geophysical Union, Washington D.C. pp. 165-176.

Konecki, J.T., Woody, C.A., and Quinn, T.P. 1995. Temperature preference in two populations of juvenile coho salmon, *Oncorhynchus kisutch*. Environmental Biology of Fishes 44: 417-421.

Lake, R.G. and Hinch, S.G. 1999. Acute effects of suspended sediment angularity on juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 56(862-86): 862-867.

Large, A.R.G., Petts, G.E., Wilby, R.L., and Greenwood, M.T. 1993. Restoration of floodplains: A UK perspective. European Water Pollution Control 3(5): 44-53.

Larsen, R.E., Miner, J.R., Buckhouse, J.C., and Moore, J.A. 1994. Water-quality benefits of having cattle manure deposited away from streams. Bioresource Technology 48: 113-118.

Larsson, P.O. 1985. Predation on migrating smolt as a regulating factor in Baltic salmon, *Salmo salar* L., populations. Journal of Fish Biology 26: 391-397.

Lassettre, N. S. 2000. The geomorphic and ecological influence of large woody debris in streams and rivers. International Conference on Wood in World Rivers. Oregon State University, Oregon State University, Corvallis, Oregon.

Lawson, P.W. 1993. Cycles in ocean productivity, trends in habitat quality, and the restoration of salmon runs in Oregon. Fisheries 18(8): 6-10.

Lenat, D.R. 1988. Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of the North American Benthological Society 7(3): 222-233.

Leopold, K., Wolman, M., and Miller, J. 1992. Fluvial processes in geomorphology. Dover Publishers, Inc, New York, New York.

Levin, P.S. and Schiewe, M.H. 2001. Preserving salmon biodiversity. American Scientist 89: 220-227.

Levings, C.D., McAllister, C.D., and Chang, B.D. 1986. Differential use of the Campbell River estuary, British Columbia, by wild and hatchery-reared juvenile chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences 43: 1386-1397.

Levings, C.D., McAllister, C.D., Macdonald, J.S. , Brown, T.J., Kotyk, M.S., and Kask, B.A. 1989. Chinook salmon (*Oncorhynchus tshawytscha*) and estuarine habitat: A transfer experiment can help evaluate estuarine dependency. *In* Canadian Special Publications of Fisheries and Aquatic Sciences 105. *Edited by* C.D. Levings, L.B. Holtby, and M.A. Henderson. pp. 116-122.

Levins, R. 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bulletin for the Entomological Society of America 15: 237-240.

Levy, D.A. and Northcote, T.G. 1982. Juvenile salmon residency in a marsh area of the Fraser River Estuary. Canadian Journal of Fisheries and Aquatic Sciences 39: 270-276.

Levy, D. A., Northcote, T. G., Hall, K. J., and Yeanki, I. 1989. Juvenile salmonid responses to log storage in littoral habitats of the Fraser River Estuary and Babine Lake. Proceedings of the national workshop on effects of habitat alteration on salmonid stocks. Ottawa, Ottawa Department of Fisheries and Oceans, Ottawa.

Lewin, J. 1978. Floodplain geomorphology. Progress in Physical Geography 2: 408-437.

Li, H.W., Currens, K., Bottom, D., Clarke, S., Dambacher, J., Firssell, C., Harris, P., Hughes, R.M., McCullough, D., McGie, A., Moore, K., Nawa, R., and Thiele, S. 1995. Safe havens: Refuges and evolutionarily significant units. American Fisheries Society Symposium 17: 371-380.

Lichatowich, J. 1999a. Recovering salmon and healthy watersheds in the Willamette basin: Review of the Willamette River initiative. Prepared through the Oregon Business Council, Portland, Oregon.

Lichatowich, J. 1999b. Salmon without rivers: A history of the Pacific salmon crisis. Island Press, Covelo, California.

Lichatowich, J., Mobrand, L., and Lestelle, L. 1999. Depletion and extinction of Pacific salmon (*Oncorhynchus spp*.): A different perspective. ICES Journal of Marine Science 56: 467-472.

Lichatowich, J. A. 1989. Habitat alterations and changes in abundance of coho (*Oncorhynchus kisutch*) and chinook (*O. tshawytscha*) salmon in Oregon's coastal streams. *In* C.D. Levings, L.B. Holtby, and M.A. Henderson (Editors). Proceedings of the national workshop on effects of habitat alteration on salmonoid stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105.

Lichatowich, J.A., Mobrand, L., Lestelle, L., and Vogel, T. 1996. Chinook salmon in the Columbia River: The components of decline. *In* Ecosystem diagnosis and treatment, applied ecosystem analysis-background. DOE/BP-33243-1, Report #5. Prepared by Mobrand Biometrics Inc. for Bonneville Power Administration, Portland, Oregon.

Lichatowich, J. A. and Nicholas, J. W. 1992. Oregon's first century of hatchery intervention in salmon production: Evolution of the hatchery program, legacy of a utilitarian philosophy and management recommendations. Proceedings of the international symposium on biological interactions of enhanced and wild salmonids. Nanaimo, British Columbia, Canada.

Ligon, F.K., Dietrich, W.E., and Trush, W.J. 1995. Downstream ecological effects of dams, a geomorphic perspective. Bioscience 45(3): 183-192.

Lindsay, R.B. 1974. Distribution and survival of coho salmon fry after emigration from natal streams. M.S. thesis. Oregon State University, Corvallis, Oregon.

Lindsay, R.B., Kenaston, K.R., and Schroeder, R.K. 1991. Steelhead production factors. Annual Progress Report. Oregon Department of Fish and Wildlife, Portland, Oregon.

Little, C. 2000. The biology of soft shores and estuaries. Oxford University Press, Oxford.

Lowrance, R. 1992. Groundwater nitrate and denitrification in a coastal plain riparian forest. Journal of Environmental Quality 21: 401-405.

Lowrance, R., Leonard, R., and Sheridan, J. 1985. Managing riparian ecosystems to control nonpoint pollution. Journal of Soil and Water Conservation 40(1): 87-91.

Lowrance, R., Todd, R., Fail, J.Jr., Hendrickson, O.Jr., Leonard, R., and Asmussen, L. 1984. Riparian forests as nutrient filters in agricultural watersheds. Bioscience 34(6): 374-377.

Lowrance, R.R., Todd, R.L., and Asmussen, L.E. 1983. Waterborne nutrient budgets for the riparian zone of an agricultural watershed. Agriculture, Ecosystems and Environment 10: 371-384.

Macdonald, J.S., Levings, C.D., McAllister, C.D. , Fagerlund, U.H.M., and McBride, J.R. 1988. A field experiment to test the importance of estuaries for chinook salmon (*Oncorhynchus tshawytscha*) survival: Short-term results. Canadian Journal of Fisheries and Aquatic Sciences 45(8): 1366-1377.

Magette, W.L. and Dillaha, T.A. 1987. Vegetated filter strips for agricultural runoff treatment. CBP/TRS 2/87. Chesapeake Bay Program, US Environmental Protection Agency. 125 pp.

Magilligan, F.J. and McDowell, P.F. 1997. Stream channel adjustments following elimination of cattle grazing. Journal of the American Water Resources Association 33(4): 867-878.

Maleki, S.M. and B.L.K. Riggers 2000. Watershed restoration inventory. Monitoring Program report to the Oregon Plan for Salmon and Watersheds. Governor's Natural Resource Office, Salem, Oregon.

Maleki, S.M. and Riggers, B.L.K. 1999. Oregon plan for salmon and watersheds: Watershed restoration inventory. Annual Report, 1999. Monitoring Program Report No. 1999-2. Governor's Natural Resources Office , Salem, Oregon.

Mallin, M.A. 2000. Impacts of industrial animal production on rivers and estuaries. American Scientist 88(January-February): 26-38.

Marston, R.N. 1982. The geomorphic significance of log steps in forest streams. Annals of the Association of American Geographers 72: 99-108.

Maser, C. and Sedell, J.R. 1994. From the forest to the sea: The ecology of wood in streams, rivers, estuaries, and oceans. St. Lucie Press, Delray Beach, Florida.

Matson, R.B. and Coupland, G. 1995. The prehistory of the northwest coast. Academic Press, New York.

Matthews, K.R. and Berg, N.H. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. Journal of Fish Biology 50: 50-67.

McCabe, G.T.Jr., Muir, W.D., Emmett, R.L., and Durkin, J.T. 1983. Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary NOAA. Fishery Bulletin 81(4): 815-826.

McCullough, D., Spalding, S., Sturdevant, D., and Hicks, M. 2001. Issue paper 5: Summary of technical literature examining the physiological effects of temperature (draft). Region 10 Temperature Water Quality Criteria Guidance Development Project.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to chinook salmon. EPA 910-R-99-010. US Environmental Protection Agency, Region 10 , Seattle, Washington. 279 pp.

McElhany, P., Ruckelshaus, M.H., Ford, M.J., Wainwright, T.C., and Bjorkstedt, E.P. 2000. Viable salmonid populations and the recovery of evolutionary significant units. NOAA Technical Memorandum NMFS-NWFSC-42. National Marine Fisheries Service, Seattle, Washington.

McIntosh, B.A., Sedell, J.R., Smith, J.E., Wissmar, R.C., Clarke, S.E., Reeves, G.H., and Brown, L.A. 1994. Historical changes in fish habitat for select river basins of eastern Oregon and Washington. Northwest Science 68: 36-53.

McIntosh, B.A., Sedell, J.R., Thurow, R.F., Clarke, S.E., and Chandler, G.L. 2000. Historical changes in pool habitats in the Columbia River Basin. Ecological Applications 10(5): 1478-1496.

McKenny, R., Jackson, R.B., and Wertheimer, R.C. 1995. Woody vegetation and channel morphogenesis in low-gradient, gravel-bed streams in the Ozark Plateau, Missouri and Arkansas. Geomorphology 13: 175-198.

McMahon, T.E. and Hartman, G.F. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46: 1551-1557.

McMahon, T.E. and Holtby, L.B. 1992. Behaviour, habitat use, and movements of coho salmon (*Oncorhynchus kisutch*) smolts during seaward migration. Canadian Journal of Fisheries and Aquatic Sciences 49: 1478-1485.

McManus, J., Komar, P.D., Bostrom, G., and Colbert, D. 1998. Sediment sources and the history of accumulation in Tillamook Bay, Oregon. Final Report: The Tillamook Bay National Estuary Project sedimentation study. College of Oceanic and Atmospheric Sciences, Oregon State University , Corvallis, Oregon.

McNamara, M. L., Klingeman, P. C., Bakke, P. D., and Sullivan, R. J. 2000. Channel maintenance flows in the upper Klamath Basin, Oregon. *In* P.J.Jr. Wigington and R.L. Beschta (Editors). International conference on riparian ecology and management in multi-land use watersheds. Portland, Oregon, American Water Resources Association, Middleburg, Virginia. pp.53-58.

Mead, A., Williams, P.B., and Haltiner, J.P. 2000. Equilibrium channel geometry in a tidally influenced river reach. *In* International conference on riparian ecology and management in multi-land use watersheds. *Edited by* P.J.Jr. Wigington and R.L. Beschta. American Water Resources Association, Middleburg, Virginia. p. 616.

Milhous, R.T. 1998. Modelling of instream flow needs: The link between sediment and aquatic habitat. Regulated Rivers: Research and Management 14(1): 79-94.

Miller, B.A. and Sadro, S. 2000. Residence time, habitat utilization and growth of juvenile coho salmon (*Oncorhynchus kisutch*) in South Slough, Coos Bay, Oregon. Preliminary report of findings. Oregon Department of Fish and Wildlife, Portland, Oregon.

Milston, R.H. 2001. Effects of *o,p'*-DDE on the immune system of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). M.S. thesis. Oregon State University, Corvallis, Oregon.

Miner, J.R., Buckhouse, J.C., and Moore, J.A. 1992. Will a water trough reduce the amount of time hay-fed livestock spend in the stream (and therefore improve water quality)? Rangelands 14(1): 35-37.

Mirati, A.H.Jr. 1999. Assessment of road culverts for fish passage problems on state - and county-owned roads. Statewide Summary Report. Oregon Department of Fish and Wildlife, Portland, Oregon.

Mitchell, D.L. 1981. Salt marsh reestablishment following dike breaching in the Salmon River Estuary, Oregon. Ph.D. thesis. Oregon State University, Corvallis, Oregon.

Mitsch, W.J. and Gosselink, J.G. 2000. Wetlands. John Wiley, New York.

Montgomery, D.R. 1997. What's best on the banks? Nature 388: 328-329.

Montgomery, D.R. and Buffington, J.M. 1998. Channel processes, classification, and response. *In* River ecology and management: Lessons from the Pacific coastal ecoregion. *Edited by* R.J. Naiman and R.E. Bilby. Springer, New York. pp. 13-42.

Montgomery, D.R., Buffington, J.M., Peterson, N.P., Schuett-Hames, D., and Quinn, T.P. 1996. Stream-bed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival. Canadian Journal of Fisheries and Aquatic Sciences 53: 1061-1070.

Moore, A. and Waring, C.P. (*Editors*). 1996. Sublethal effects of the pesticide diazinon on olfactory function in mature male Atlantic salmon parr. Journal of Fish Biology 48.

Moore, A. and Waring, C.P. 1998. Mechanistic effects of a triazine pesticide on reproductive endocrine function in mature male Atlantic salmon (*Salmo salar* L.) parr. Pesticide Biochemistry and Physiology 62: 41-50.

Moorman, T. B., Reungsang, A., and Kanwar, R. 2000. Transport and fate of atrazine in midwestern riparian buffer strips. *In* P.J.Jr. Wigington and R.L. Beschta (Editors). International conference on riparian ecology and management in multi-land use watersheds. Portland, Oregon, American Water Resources Association, Middleburg, Virginia. pp.131-136.

Moring, J.R., Youker, R.L., and Hooton, R.M. 1986. Movements of potamodromous coastal cutthroat trout, *Salmo clarki clarki*, inferred from tagging and scale analysis. Fisheries Research 4: 343-354.

Morlan, J.C. 1991. Ecological status and dynamics of a salt marsh restoration in the Salmon River estuary, Oregon. Oregon State University, Corvallis, Oregon.

Mrakovcich, K.L. 1998. Anthropogenic activities associated with the status of salmon stocks in Pacific Northwest watersheds. Ph.D. thesis. Oregon State University, Corvallis, Oregon.

Mundy, P.R., Backman, T.W.H., and Berkson, J.M. 1995. Selection of conservation units for Pacific salmon: Lessons from the Columbia River. American Fisheries Society Symposium 17: 28-38.

Murphy, M.L. and Meehan, W.R. 1991. Stream ecosystems. American Fisheries Society Special Publication 19: 139-179.

Myers, J.M., Kope, R.G., Bryant, G.J., Teel, D., Lierheimer, J.J., Wainwright, T.C., Grant, W.S., Waknitz, F.W., Neely, K., Lindley, S.T., and Waples, R.S. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-35. US Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division , Seattle, Washington.

Myers, K.W.W. 1980. An investigation of the utilization of four study areas in Yaquina Bay, Oregon, by hatchery and wild juvenile salmonids. M.S. thesis. Oregon State University, Corvallis, Oregon.

Myers, T.J. and Swanson, S. 1996. Long-term aquatic habitat restoration: Mahogany Creek, Nevada, as a case study. Water Resources Bulletin 33(2): 241-252.

Nabb, E.J. and Shankman, D. 1997. Hydrogeomorphic response of a coastal plain stream to tributary channelization. Geographical Bulletin 39(2): 81-89.

Naiman, R.J. 1992. Watershed management: Balancing sustainability and environmental change. Springer-Verlag, New York.

Naiman, R.J., Bilby, R.E., and Bisson, P.A. 2000. Riparian ecology and management in the Pacific coastal rain forest. Bioscience 50(11): 996-1011.

Naiman, R.J. and Decamps, H. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecological Systems 28: 621-658.

Naiman, R.J., Johnston, C.A., and Kelley, J.C. 1988. Alteration of North American streams by beaver. Bioscience 38(11): 753-762.

Naiman, R.J. and Sedell, J.R. 1979. Characterization of particulate organic matter transported by some Cascade Mountain streams. Journal of the Fisheries Research Board of Canada 36(1): 17-31.

Nanson, G.C. 1980. Point bar and floodplain formation of the meandering Beatton River, northeastern British Columbia, Canada. Sedimentology 27: 3-29.

National Academy of Sciences (NAS). 1982. Water Quality Criteria. Environmental Protection Agency, Washington, D.C.

National Marine Fisheries Service (NMFS). 1999. Endangered Species Act- Section 7 consultation. Biological opinion and conference report. Columbia River federal navigation channel deepening. US Army Corps of Engineers, Portland District and National Marine Fisheries Service, Northwest Region, Portland, Oregon.

National Research Council In press. Riparian areas: Functions and strategies for management. National Academy Press, Washington, D.C.

National Research Council (NRC). 1992. Restoration of aquatic ecosystems: Science, technology, and public policy. National Academy Press, Washington, D.C.

National Research Council (NRC). 1996. Upstream: Salmon and society in the Pacific Northwest. Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, National Academy of Science , Washington, D.C.

Natural Heritage Advisory Council (NHAC). 1998. 1998 Oregon natural heritage plan. State Land Board, Salem, Oregon.

Nehlsen, W. 1997. Prioritizing watersheds in Oregon for salmon restoration. Restoration Ecology 5(45): 25-33.

Nehlsen, W., Williams, J.E., and Lichatowich, J.A. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2): 4-21.

Newcombe, C.P. and MacDonald, D.D. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11(1): 72-82.

Nicholas, J., O'Mealy, M., Moore, K., and King, B. 1999. Oregon Plan for Salmon and Watershed Annual Report 1999. Oregon Watershed Enhancement Board, Salem, Oregon.

Nicholas, J.W. 1978. A review of literature and unpublished information on cutthroat trout *Salmo clarki clarki* of the Willamette watershed. Information Report No. 78-1. Oregon Department of Fish and Wildlife, Portland, Oregon.

Nicholas, J.W. and Hankin, D.G. 1988. Chinook salmon populations in Oregon coastal river basins: Description of life histories and assessment of recent trends in run strengths. Oregon Department of Fish and Wildlife, Portland, Oregon.

Nichols, D. 1990. An inventory of water diversions in Oregon needing fish screen (volume I - summary results). Oregon Department of Fish and Wildlife, Habitat Conservation Division, Portland, Oregon.

Nickelson, T., Rodgers, J., and Moore, K. 2001. The importance of low gradient, unconstrained stream reaches for anadromous salmonids. *In* Oregon Salmon: Essays on the state of the fish at the turn of the millennium. Oregon Trout, Portland, Oregon. pp. 155-160.

Nickelson, T.E., Rodgers, J.D., Johnson. S.L., and Solazzi, M.F. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49: 783-789.

Niemi, G.J. and seven coauthors. 1990. Overview of case studies on recovery of aquatic systems from disturbance. Environmental Management 14: 571-587.

Noble, B.F. 2000. Strengthening EIA through adaptive management: A systems perspective. Environmental Impact Assessment Review 20(1): 97-111.

Noggle, C.C. 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. M.S. thesis. College of Fisheries, University of Washington, Seattle, Washington.

Norris, L.A., Lorz, H.W., and Gregory, S.V. 1991. Forest chemicals. *In* Influences of forest and rangeland management on salmonid fishes and their habitat. *Edited by* W.R. Meehan. American Fisheries Society, Bethesda, Maryland. pp. 207-296.

North Coast Basin Local Advisory Committee (NCBLAC). 2000. North Coast Basin agricultural water quality management area plan. North Coast Basin Local Advisory Committee and Oregon Department of Agriculture.

Obedzinski, R.A. 2001. Declining woody vegetation in riparian ecosystems of the western United States. Western Journal Applied Forestry 16(4): 169-181.

Omernik, J.M. 1995. Ecoregions: A spatial framework for environmental management. *In* Biological assessment and criteria: Tools for water resource planning and decision making. *Edited by* W.S. Davis and T.P. Simon. Lewis Publishers, Boca Raton, Florida.

Oregon Department of Agriculture (ODA). 2000. Water quality and agriculture in Oregon: Implementation of Senate Bill 1010. Draft Report. Oregon Department of Agriculture, Salem, Oregon.

Oregon Department of Fish and Wildlife (ODFW). 2000. Fish passage report. Oregon Department of Fish and Wildlife, Portland, Oregon.

Oregon Department of Fish and Wildlife (ODFW). 2000a. Effects of Lost Creek dam on spring chinook salmon in the Rogue River. Phase II completion report. Fish Research Project DAWC 57-77-C-0033. Oregon Department of Fish and Wildlife, Portland, Oregon.

Oregon Department of Forestry and the Department of Environmental Quality (ODF/DEQ). 2000. ODF/DEQ sufficiency analysis: Stream temperature evaluation of the adequacy of the Oregon Department of Forestry forest practices act in the achievement and maintenance of water quality standards (Draft). Oregon Department of Forestry and the Department of Environmental Quality, Salem, Oregon. 142 pp.

Oregon Plan. 1997. Oregon Plan for Salmon and Watersheds (consisting of the Oregon Coastal Salmon Restoration Initiative, March 10, 1997 and as amended with the Steelhead Supplement, December 1997). Governor's Natural Resources Office, State of Oregon, Salem, Oregon.

Oregon Plan. 1999. Oregon aquatic habitat: Restoration and enhancement guide. Oregon Plan for Salmon and Watersheds, Salem, Oregon.

Oregon State University and US Environmental Protection Agency (OSU/EPA). 2001. Developing methods and tools for watershed restoration: Design, implementation, and assessment in the Willamette Basin, Oregon. http://biosys.bre.orst.edu/restore/default.cfm. (Retrieved 5/10-01). Oregon State University, Corvallis, Oregon.

Orr, E.L., Orr, W.N., and Baldwin, E.M. 1992. Geology of Oregon, 4th edition. Kendall/Hunt Publishing Co., Dubuque, Iowa.

Osborne, L.L. and Kovacic, D.A. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biology 29: 243-258.

Pabst, R.J. and Spies, T.A. 1998. Distribution of herbs and shrubs in relation to landform and canopy cover in riparian forests of coastal Oregon. Canadian Journal of Botany 76: 298-315.

Pacific Fishery Management Council (PFMC). 1998. Review of 1997 Ocean Salmon Fisheries. Pacific Fishery Management Council, Portland, Oregon.

Pacific Rivers Council. 1997. Restoration: A blueprint for saving wild fish and watersheds in the Northwest. Pacific River Council, Eugene, Oregon.

Palone, R.S. and Todd, A.H. 1998. Chesapeake Bay riparian handbook: A guide for establishing and maintaining riparian forest buffers. Chesapeake Bay Program, Annapolis, Maryland.

Parsons, J.E., Daniels, R.D., Gilliam, J.W., and Dillaha, T.A. 1990. Water quality impacts of vegetative filter strips and riparian areas. American Society of Agricultural Engineering Paper 90-2501.

Parsons, J. E., Daniels, R. D., Gilliam, J. W., and Dillaha, T. A. 1994. The effects of vegetative filter strips on sediment and nutrient removal from agricultural runoff. *In* K.L. Campbell, W.D. Graham, and A.B. Bottcher. Environmentally sound agriculture: Proceedings of the 2nd conference. Orlando, Florida, American Society of Agricultural Engineers, St. Joseph, Michigan. pp.147-154.

Pearcy, W.G. 1997. Salmon production in changing ocean domains. *In* Pacific salmon and their ecosystems: Status and future options. *Edited by* D.J. Stouder, P.A. Bisson, and R.J. Naiman. Chapman and Hall, New York. pp. 331-352.

Pearcy, W.G., Wilson, C.D., Chung, A.W., and Chapman, J.W. 1989. Residence times, distribution, and production of juvenile chum salmon, *Oncorhynchus keta*, in Netarts Bay, Oregon. Fishery Bulletin 87(3): 553-568.

Pearl, C.A. 1999. Holocene environmental history of the Willamette Valley, Oregon: Insights from an 11,000-year record from Beaver Lake. M.S. thesis. University of Oregon, Eugene, Oregon.

Percy, K.L., Bella, D.A., Sutterlin, C., and Klingeman, P.C. 1974. Descriptions and information sources for Oregon estuaries. Sea Grant College Program, Oregon State University, Corvallis, Oregon.

Pess, G.R., Collins, B.D., Pollock, M., Beechie, T.J., Haas, A., and Grigsby, S. 1999. Historic and current factors that limit coho salmon (*Oncorhynchus kisutch*) production in the Stillaguamish River Basin, Washington State: Implications for salmonid habitat protection and restoration. Final Report, September, 1999. A report prepared for Snohomish County Department of Public Works and the Stillaguamish Tribe of Indians, Everett, Washington.

Pess, G.R., Montgomery, D.R., Bilby, R.E., Steel, E.A., Feist, B.E., and Greenberg, H.M. 2001. Influence of landscape characteristics and land use on coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Washington State, USA. National Marine Fisheries Service, Seattle, Washington.

Peterjohn, W.T. and Correll, D.L. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65(5): 1466-1475.

Peters, R., Knudsen, E., Tabor, R., and Cederholm, J. 2000. Influence of woody debris on the abundance of juvenile salmonids in large western Washington rivers. International Conference on Wood in World Rivers. Oregon State University, Oregon State University, Corvallis, Oregon.

Peterson, N.P. 1982. Immigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Canadian

Journal of Fisheries and Aquatic Sciences 39(9): 1308-1310.

Peterson, N. P. and Reid, L. M. 1984. Wall-base channels: Their evolution, distribution and use by juvenile coho salmon in the Clearwater River, Washington. *In* J.M. Walton and D.B. Houston (Editors). Proceedings of the Olympic Wild Fish Conference. Peninsula College, Port Angeles, Washington. pp.215-225.

Petts, G., Maddock, I., Bickerton, M., and Ferguson, A.J.D. 1995. Linking hydrology and ecology: The scientific basis for river management. *In* The Ecological Basis for River Management. *Edited by* D.M. Harper and A.J.D. Ferguson. John Wiley and Sons , Chichester. pp. 1-16.

Pierce, F.J. and Frye, W.W. 1998. Advances in soil and water conservation. Ann Arbor Press , Chelsea, Michigan.

Pimental, D., Allen, J., Beers, A., Guinand, L., Hawkins, A., Linder, R., McLaughlin, P., Meer, B., Musonda, D., Perdue, D., Poisson, S., Salazar, R., Siebert, S., and Stoner, K. 1993. Soil erosion and agricultural productivity. *In* World soil erosion and conservation. *Edited by* D. Pimental. Cambridge University Press, New York. pp. 277-292.

Pimental, D., Beers, A., Guinand, L., Linder, R., McLaughlin, P., Meer, B., Musonda, D., Perdue, D., Poisson, S., Siebert, S., Stoner, K., Salazar, R., and Hawkins, A. 1986. World food economy and the soil erosion crisis. Environmental Biology Report 86-2. Cornell University, Ithaca, New York.

Pinay, G. and Decamps, H. 1988. The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: A conceptual model. Regulated Rivers: Research and Management 2: 507-516.

Pinay, G., Decamps, H., and Naiman, R.J. 1999. The spiralling concept and nitrogen cycling in large river floodplain. Archiv fur Hydrobiologie 3(Suppl. 1): 281-291.

Pinay, G., Fabre, A., Vervier, Ph., and Gazelle, F. 1992. Control of C, N, P distribution in soils of riparian forests. Landscape Ecology 6(3): 121-132.

Pinay, G., Roques, L., and Fabre, A. 1993. Spatial and temporal patterns of denitrification in a riparian forest. Journal of Applied Ecology 30: 581-591.

Pinay, G., Ruffinoni, C., Wondzell, S., and Gazelle, F. 1998. Change in groundwater nitrate concentration in a large river floodplain: Denitrification, uptake, or mixing? Journal of the North American Benthological Society 17(2): 179-189.

Pinit, P.T. 1999. A survey of Oregon coastal wetland restoration and case study on fish monitoring. M.S. thesis. University of Oregon, Eugene, Oregon.

Poff, N.L., Allan, J.D., Bain, M.B.K.J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., and Stromberg, J.C. 1997. The natural flow regime: A paradigm for river conservation and restoration. Bioscience 47(11): 769-784.

Poff, N.L. and Ward, J.V. 1990. Physical habitat template of lotic systems: Recovery in the context of historical pattern of spatiotemporal heterogeneity. Environmental Management 4: 629-645.

Power, M.E., Dietrich, W.E., and Finlay, J.C. 1996. Dams and downstream aquatic biodiversity: Potential food web consequences of hydrologic and geomorphic change. Environmental Management 20: 887-895.

Power, M.E., Sun, A., Parker, G., Dietrich, W.E., and Wootton, J.T. 1995. Hydraulic food-chain models. Bioscience 45(3): 159-167.

Prichard, D., Anderson, J., Correll, C., Fogg, J., Gebhardt, K., Krapf, R., Leonard, S., Mitchell, B., and Saats, J. 1998. Riparian area management: A user guide to assessing proper functioning condition and the supporting science for lotic areas. TR-1737-15. US Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center, Denver, Colorado.

Pulliam, R. 1988. Sources, sinks, and population regulation. American Naturalist 132: 652-661.

Quinn, T.P. and Unwin, M.J. 1993. Variation in life history patterns among New Zealand chinook salmon (*Oncorhynchus tshawytscha*) populations. Canadian Journal of Fisheries and Aquatic Sciences 50: 1414-1421.

Ralph, S.C., Poole, G.C., Conquest, L.L., and Naiman, R.J. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Canadian Journal of Fisheries and Aquatic Sciences 51: 37-51.

Redding, J.M., Schreck, C.B., and Everest, F.H. 1987. Physiological effects on coho salmon and steelhead of exposure to suspended solids. Transactions of the American Fisheries Society 116: 737-744.

Reed, D.J., Thomas, S., Murray, A.L., French, J.R., and Lynn, L. 1999. Marsh surface sediment deposition and the role of tidal creeks: Implications for created and managed coastal marshes. Journal of Coastal Conservation 5: 81-90.

Reeves, G.H., Benda, L.E., Burnett, K.M., Bisson, P.A., and Sedell, J.R. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. American Fisheries Society Symposium 17: 334-349.

Reeves, G.H., Bisson, P.A., and Dambacher, J.M. 1998. Fish communities. *In* River ecology and management: Lessons from the Pacific coastal ecoregion. *Edited by* R.J. Naiman and R.E. Bilby. Springer-Verlag, New York. pp. 200-234.

Reeves, G.H., Hall, J.D., Roelofs, T.D., Hickman, T.L., and Baker, C.O. 1991. Rehabilitating and modifying stream habitats. *In* Influences of forest and rangeland management on salmonid fisheries and their habitats. *Edited by* W.R. Meehan. American Fisheries Society, Special Publication 19, Bethesda, Maryland. pp. 519-557.

Reimers, P.E. 1973. The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Oregon Fisheries Commission Research Report 4(2): 1-43.

Reimold, R.J. 1994. Wetlands functions and values. *In* Applied Wetlands Science and Technology. *Edited by* D.M. Kent. Lewis Publishers, Boca Raton. pp. 54-78.

Rich, W.H. 1920. Early history and seaward migration of chinook salmon in the Columbia and Sacramento Rivers. US Bureau of Fish Bulletin 37: 2-73.

Richards, C., Johnson, L.B., and Host, G.E. 1996. Landscape-scale influences on stream habitats and biota. Canadian Journal of Fisheries and Aquatic Sciences 53(suppl. 1): 295-311.

Rieman, B.E. and Dunham, J.B. 2000. Metapopulations and salmonids: A synthesis of life history patterns and empirical observations. Ecology of Freshwater Fish 9(1-2): 51-64.

Roby, D.D., Craig, D.P., Collis, K., and Adamany, S.L. 1998. Avian predation on juvenile salmonoids in the lower Columbia River. Annual Report to Bonneville Power Administration and US Army Corps of Engineers.

Rodgers, J.D. 1986. The winter distribution, movement, and smolt transformation of juvenile coho salmon in an Oregon coastal stream. M.S. thesis. Oregon State University, Corvallis, Oregon.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, F.E., Pollack, M.M., and Pess, G.R. 2002. A review of stream restoration and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. North American Journal of Fisheries Management 22: 1-20.

Roni, P., Beechie, T.J., and Pess, G.R. 2002. Using results of assessements to prioritize specific restoration actions. *In* Ecosystem recovery planning for listed salmon: An integrated assessment approach for salmon habitat (preview draft). *Edited by* T.J. Beechie, P. Roni, and E.A. Steel. National Marine Fisheries Service, Seattle, Washington.

Roni, P., Liermann, M., and Steele, A. In Press. Monitoring and evaluating responses of salmonids and other fishes to instream restoration. *In* Restoration of Puget Sound Rivers. *Edited by* D.R. Montgomery, S. Bolton, and D.B. Booth. University of Washington Press, Seattle, Washington.

Roni, P. and Quinn, T.P. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58 (2): 282-292.

Roper, B.B. and Scarnecchia, D.L. 1999. Emigration of age-0 chinook salmon (*Oncorhynchus tshawytscha*) smolts from the upper South Umpqua River basin, Oregon, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 56: 939-946.

Rosenfeld, J.S., MacDonald, S., Foster, D., Amrhein, S., Bales, B., Williams, T., Race, F., and and Livingstone, T. Importance of small streams as rearing habitat for coastal cutthroat trout. North American Journal of Fisheries Management 22: 177-187.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Rumrill, S.S. and Cornu, C.E. 1995. South Slough coastal watershed restoration: A case study in integrated ecosystem restoration. Restoration and Management Notes 13(1): 53-57.

Ruprecht, J.K. and George, P.R. 1993. Hydrology of the Peel-Harvey estuary catchment. Fertilizer Research 36: 127-133.

Ryden, J.C., Lund, L.J., and Focht, D.D. 1979. Direct measurement of denitrification loss from soils: II. Development and application of field methods. Soil Science Society of America Journal 43: 110-118.

Sadro, S. 1999. Winchester tidelands monitoring report. South Slough National Estuarine Research Reserve, Charleston, Oregon.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). *In* Pacific salmon life histories. *Edited by* C. Groot and L. Margolis. UBC Press, Vancouver, British Columbia. pp. 233-309.

Sandercock, F.K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). *In* Pacific salmon life histories. *Edited by* C. Groot and L. Margolis. University of British Columbia Press, Vancouver, British Columbia. pp. 395-446.

Schalk, R.F. 1986. Estimating salmon and steelhead usage in the Columbia Basin before 1850: The anthropological perspective. Northwest Environmental Journal 2(2): 1-29.

Schlosser, I.J. and Angermeier, P.L. 1995. Spatial variation in demographic processes of lotic fishes: Conceptual models, empirical evidence and implications for conservation. American Fisheries Society Symposium 17: 392-401.

Scholz, N.L., Truelove, N.K., French, B.L., Berejikian, B.A., Quinn, T.P., Casillas, E., and Collier, T.K. 2000. Diazinon disrupts antipredator and homing behaviors in chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 57: 1911-1918.

Schumm, S.A. 1971. Fluvial geomorphology: Channel adjustment and river metamorphosis. *In* River Mechanics. *Edited by* H.W. Shen. Ft. Collins, Colorado. pp. 5-1 to 5-22.

Schumm, S.A. 1977. The fluvial system. Wiley and Sons, New York.

Scott, M.L., Auble, G.T., and Friedman, J.M. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7(2): 677-690.

Scott, M.L., Shafroth, P.B., and Auble, G.T. 1998. Responses of riparian cottonwoods to alluvial water table declines. Environmental Management 23(3): 347-358.

Sedell, J.R. and Beschta, R.L. 1991. Bringing the "bio" back in bioengineering. American Fisheries Society Symposium 10: 160-175.

Sedell, J.R., Bisson, P.A., Swanson, F.J., and Gregory, S.V. 1988. What we know about large trees that fall into streams and rivers. *In* From the forest to the sea: A story of fallen trees. *Edited by* C. Maser, R.F. Tarrant, J.M. Trappe, and J.F. Franklin. General Technical Report PNW-GTR-229. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. pp. 47-82 pp.

Sedell, J.R. and Froggatt, J.L. 1984. Importance of streamside forests to large rivers: The isolation of the Willamette River, Oregon, U.S.A. from its floodplain by snagging and streamside forest removal. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 22: 1828-1834.

Sedell, J.R., Reeves, G.H., Hauer, F.R., Stanford, J.A., and Hawkins, C.P. 1990. Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems. Environmental Management 14(5): 711-724.

Sedell, J.R., Yuska, J.E., and Speaker, R.W. 1983. Study of westside fisheries in Olympic National Park, Washington. CX-9000-0-E 081. Clearwater Bio Studies, Inc. USDA National Park Service and Oregon State University, Department of Fisheries and Wildlife, Corvallis, Oregon.

Sedell, J. R., Yuska, J. E., and Speaker, R. W. 1984. Habitats and salmonid distribution in pristine sediment-rich river valley systems: S. Fork Hoh and Queets river, Olympic National Park. *In* W.R. Meehan, T.R. Merrell Jr., and T.A. Hanley (Editors). Fish and wildlife relationships in old-growth forests: Proceedings of a symposium. Juneau, Alaska, American Institute of Fishery Research Biologists, Morehead, North Carolina. pp.33-46.

Servizi, J.A. and Martens, D.W. 1992. Sublethal responses of coho salmon (*Oncorhynchus kisutch*) to suspended sediments. Canadian Journal of Fisheries and Aquatic Sciences 49: 1389-1395.

Sharma, R. and Hilborn, R. 2001. Empirical relationships between watershed characteristics and coho salmon (*Oncorhynchus kisutch*) smolt abundance in 14 western Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58(7): 1453-1463.

Sherwood, C.R., Jay, D.A., Harvey, R.B., Hamilton, P., and Simenstad, C.A. 1990. Historical changes in the Columbia River estuary. Progress in Oceanography 25: 299-352.

Shirvell, C.S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows. Canadian Journal of Fisheries and Aquatic Sciences 47: 852-861.

Shreffler, D.K., Simenstad, C.A., and Thom, R.M. 1990. Temporary residence by juvenile salmon in a restored estuarine wetland. Canadian Journal of Fisheries and Aquatic Sciences 47(11): 2079-2084.

Sibert, J.T., Brown, T.J., Healey, M.C., Kask, B.A., and Naiman, R.J. 1977. Detritus-based food webs: Exploitation by juvenile chum salmon (*Oncorhynchus keta*). Science 196: 649-650.

Simenstad, C.A. and Cordell, J.R. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15: 283-302.

Simenstad, C.A., Jay, D.A., and Sherwood, C.R. 1992. Impacts of watershed management on land-margin ecosystems: The Columbia River estuary. *In* Watershed Mangement: Balancing Sustainability and Environmental Change. *Edited by* R.J. Naiman. Springer-Verlag, New York. pp. 266-306.

Simenstad, C.A., Thom, R.M., Levy, D.A., and Bottom, D.L. 2000. Landscape structure and scale constraints on restoring estuarine wetlands for Pacific coast juvenile fishes. *In* Concepts and controversies in tidal marsh ecology. *Edited by* M.P. Weinstein and D.A. Kreeger. Kluver Academic Publishers, Dordrecht. pp. 597-630.

Simmons, M. and Gregory, S. V. 2000. Composition and distribution of riparian tree communities in three geomorphic reach types along the Willamette River, Oregon. International Conference on Wood in World Rivers. Oregon State University, Oregon State University, Corvallis, Oregon.

Skeesick, D.G. 1970. The fall immigration of juvenile coho salmon into a small tributary. Research Report 2. Fish Commission of Oregon.

Smith, D.G. 1976. Effect of vegetation on lateral migration of anatomosed channels of a glacial meltwater river. Geological Society of America Bulletin 87: 857-860.

SOER Science Panel. 2000. Oregon State of the Environment Report. Prepared for the Oregon Progress Board, Salem, Oregon.

Soil Conservation Service. 1977. Willamette Valley drainage guide. Soil Conservation Service, Portland, Oregon.

Solazzi, M.F., Johnson, S.L., and Nickelson, T.E. 1983. The effectiveness of stocking hatchery coho presmolts to increase the rearing density of juvenile coho salmon in Oregon coastal streams. ODFW Information Report 83-1. Oregon Department of Fish and Wildlife , Portland, Oregon.

Solazzi, M.F., Nickelson, T.E., Johnson, S.L., and Rodgers, J.D. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences 57: 906-914.

Sommer, T.R., Nobriga, M.L., Harrell, W.C., Batham, W., and Kimmerer, W.J. 2001. Floodplain rearing of juvenile chinook salmon: Evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58: 325-333.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. Bioscience 45(3): 168-182.

Spence, B.C., Lomnicky, G.A., Hughes, R.M., and Novitzki, R.P. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, Oregon.

Spruill, T. B. and Galeone, D. R. 2000. Effectiveness of riparian buffers in reducing nitrate-nitrogen concentrations in ground water. *In* P.J.Jr. Wigington and R.L. Beschta. International conference on riparian ecology and management in multi-land use watersheds. Portland, Oregon, American Water Resources Association, Middleburg, Virginia. pp.119-124.

Stanford, J.A. and Ward, J.V. 1988. The hyporheic habitat of river ecosystems. Nature 335(6185): 64-66.

Stanford, J.A. and Ward, J.V. 1992. Management of aquatic resources in large catchments: Recognizing interactions between ecosystem connectivity and environmental disturbance. *In* Watershed Mangement: Balancing Sustainability and Environmental Change. *Edited by* R.J. Naiman. Springer-Verlag, New York. pp. 91-119.

Stauffer, J.C., Goldstein, R.M., and Newman, R.M. 2000. Relationship of wooded riparian zones and runoff potential to fish community composition in agricultural streams. Canadian Journal of Fisheries and Aquatic Sciences 57(2): 307-316.

Sterner, R. 2001. Color Landform Atlas of the United States. http://fermi.jhuapl.edu/states/ retrieved 10/30/01.

Stewart, J. S., Downes, D. M., Wang, L., Wierl, J. A., and Bannerman, R. 2000. Influences of riparian corridors on aquatic biota in agricultural watersheds. *In* P.J.Jr. Wigington and R.L. Beschta (Editors). International conference on riparian ecology and management in multi-land use watersheds. Portland, Oregon, American Water Resources Association, Middleburg, Virginia. pp.209-214.

Stone, L. 1892. A national salmon park. Transactions of the twenty-first annual meeting of the American Fisheries Society 21: 49-162.

Stouder, D.J., Bisson, P.A., and Naiman, R.J. 1997. Pacific salmon and their ecosystems: Status and future options. Chapman and Hall, New York.

Stringham, T.K., Buckhouse, J.C., and Krueger, W.C. 1998. Stream temperatures as related to subsurface waterflows originating from irrigation. Journal of Range Management 51: 88-90.

Strittholt, J.R. and Frost, P.A. 1995. Landscape change in Tillamook Bay watershed. Tillamook Bay National Estuary Project Technical Report #07-95. Tillamook Bay National Estuary Project, Garibaldi, Oregon.

Strittholt, J.R., Garono, R.J., and Frost, P.A. 2000. Spatial patterns in land use and water quality in the Tillamook Bay Watershed: A GIS mapping project. Earth Design Consultants, Inc., Corvallis, Oregon.

Swales, S., Caron, F., Irvine, J.R., and Levings, C.D. 1988. Overwintering habitats of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Keogh River system, British Columbia. Canadian Journal of Zoology 66: 254-261.

Swales, S. and Levings, C.D. 1989. Role of off-channel ponds in the life cycle of coho salmon (*Oncorhynchus kisutch*) and other juvenile salmonids in the Coldwater River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46: 232-242.

Swanson, F.J., Kratz, T.K., Caine, N., and Woodmansee, R.G. 1988. Landform effects on ecosystem patterns and processess: Geomorphic features of the Earth's surface regulate the distribution of organisms and processes. Bioscience 38(2): 92-98.

Thom, B.A., Jones, K.K., and Flitcroft, R.L. 1999. Stream habitat conditions in Western Oregon. Oregon plan for salmon and watersheds, Monitoring program report 1999-1. Governor's Natural Resources Office, Salem, Oregon.

Thom, B.A., Jones, K.K., Kavanagh, P.S., and Reis, K.E.M. 2000. 1999 stream habitat conditions in western Oregon. Monitoring Program Report Number OPSW-ODFW-2000-5. Oregon Department of Fish and Wildlife, Portland, Oregon.

Thompson, K.E. and Fortune, J.D.Jr. 1968. The fish and wildlife resources of the North Coast Basin, Oregon and their water requirements. Oregon State Game Commission Basin Investigations Section, Portland, Oregon. 102 pp.

Thornton, C.I., Abt, S.R., and Clary, W.P. 1997. Vegetation influence on small stream siltation. Journal of the American Water Resources Association 33(6): 1279-1288.

Thorpe, J.E., Mangel, M., Metcalfe, N.B., and Huntington, F.A. 1998. Modelling the proximate basis of salmonid life history variation, with application to Atlantic salmon, *Salmo salar* L. Evolutionary Ecology 12: 581-599.

Titus, J.H., Christy, J.A., VanderSchaaf, D., Kagan, J.S., and Alverson, E.R. 1996. Native wetland and riparian plant communities in the Willamette Valley, Oregon. Retrieved 4-21-01. Oregon Natural Heritage Program and The Nature Conservancy, Portland, Oregon.

Towle, J.C. 1982. Changing geography of Willamette valley woodlands. Oregon Historical Quarterly 83(1): 66-87.

Triska, F.J. 1984. Role of wood debris in modifying channel geomorphology and riparian areas of a large lowland river under pristine conditions: A historical case study. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 22: 1876-1892.

Trotter, E.H. 1990. Woody debris, forest-stream succession and catchment geomorphology. Journal of the North American Benthological Society 9(2): 141-156.

Tschaplinski, P. J. 1988. The use of estuaries as rearing habitats by juvenile coho salmon. *In* T.W. Chamberlin (Editor). Proceedings of the workshop: Applying 15 years of Carnation Creek results. Carnation Creek Steering Committee, Pacific Biological Station, Nanaimo, British Columbia. pp.123-143.

Tschaplinski, P.J. and Hartman, G.F. 1983. Winter distribution of junvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Canadian Journal of Fisheries and Aquatic Sciences 40: 452-461.

Tufford, D.L., McKellar, H.N., and Hussey, J.R. 1998. In-stream nonpoint source nutrient prediction with land-use proximity and seasonality. Journal of Environmental Quality 27(1): 100-111.

Turner, R.E. and Lewis, R.R.I. 1997. Hydrologic restoration of coastal wetlands. Wetlands Ecology and Management 4(2): 65-72.

United States Fish and Wildlife Service (USFWS), Sacramento. 2000. Impacts of riprapping to ecosystem functioning, lower Sacramento River, California. Prepared for the US Army Corps of Engineers, Sacramento District, by the US Fish and Wildlife Service, Sacramento, California. 40 pp.

United States Geological Survey (USGS). 2000. Willamette basin ground-water study (Available at http://oregon.usgs.gov/projs_dir/willgw/overview.html). US Geological Survey, Portland, Oregon.

US Army Corps of Engineers (USACE). 1980. Final environmental impact statement: Operations and maintenance of the Willamette Reservoir System. US Army Corps of Engineers, Portland District, Portland, Oregon.

US Army Corps of Engineers (USACE). 2000. Biological assessment of the effects of the Willamette River Basin Flood Control Project on listed species under the Endangered Species Act. USACE, Portland District Office, Portland, Oregon.

USDA Forest Service. 1994. Section 7 Fish Habitat Monitoring Protocol for the Upper Columbia River Basin. USDA Forest Service, Pacific Northwest Region, Intermountain Region, Northern Region, Portland, Oregon. 94 pp.

USDA Natural Resources Conservation Service. 1998. Dairy-McKay Creek Hydrologic Unit Area Summary/Close Out Report. Tualatin River Basin USGS H.U. Codes 17090010-010. 50. USDA Natural Resources Conservation Service, Washington County, Oregon.

Waldichuck, M. 1993. Fish habitat and the impact of human activity with particular reference to Pacific salmon. *In* Perspectives on Canadian marine fisheries management. Canadian Bulletin of Fisheries and Aquatic Sciences 226. *Edited by* L.S. Parsons and W.H. Lear. Department of Fisheries and Oceans, Ottawa, Canada. pp. 295-337.

Wallace, J.B., Eggert, S.L., Meyer, J.L., and Webster, J.R. 1997. Multiple trophic levels of a forest stream linked to terrestrial litter inputs. Science 277: 102-104.

Wallace, M. and Collins, B.W. 1997. Variation in use of the Klamath River estuary by juvenile chinook salmon. California Fish and Game 83(4): 132-143.

Wang, L.Z., Lyons, J., Kanehl, P., and Gatti, R. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22(6): 6-12.

Waples, R.S., Gustafson, R.G., Weitkamp, L.A., Myers, J.M., Johnson, O.W., Busby, P.J., Hard, J.J., Bryant, G.J., Waknitz, F.W., Neely, K., Teel, D., Grant, W.S., Winans, G.A., Phelps, S., Marshall, A., and Baker, B.M. 2001. Characterizing diversity in salmon from the Pacific Northwest. Journal of Fisheries Biology 59(Suppl. A): 1-41.

Ward, J.V. and Stanford, J.A. 1995. The serial discontinuity concept: Extending the model to floodplain rivers. Regulated Rivers: Research and Management 10: 159-168.

Waring, C.P. and Moore, A. 1997. Sublethal effects of a carbamate pesticide on pheromonal mediated endocrine function in mature male Atlantic salmon (*Salmo salar* L.) parr. Fish Physiology and Biochemistry 17(1-6): 203-211.

Weitkamp, L.A., Wainwright, T.C., Bryant, G.J., Milner, G.B., Teel, D.J., Kope, R.G., and Waples, R.S. 1995. Status review of coho salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-24. US Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division, Seattle, Washington. 258 pp.

Welcomme, R.L. 1995. Relationships between fisheries and the integrity of river systems. Regulated Rivers: Research and Management 11: 121-136.

Wentz, D.A., Bonn, B.A., Carpenter, K.D., Hinkle, S.R., Janet, M.L., Rinella, F.A., Uhrich, M.A., Waite, I.R., Laenen, A., and Bencala, K.E. 1998. Water quality in the Willamette basin, Oregon, 1991-1995. USGS Circular 1161. US Department of the Interior, US Geological Survey, Water Resources Division, Portland, Oregon.

Whidden, S.M. and Lichatowich, J. 1999. Pacific salmon sanctuaries: The hope and challenge of a new millennium. Research Publication PO99-6. Lewis and Clark Law School, Northwest Water Law and Policy Project, Portland, Oregon.

Wichert, G.A. and Rapport, D.J. 1998. Fish community structure as a measure of degradation and rehabilitation of riparian systems in an agricultural drainage basin. Environmental Management 22(3): 425-443.

Wildman, R. C., Gregory, S. V., and Simmons, M. M. 2001. Species composition and occurrence of anomalies in fish communities of the Willamette River, Oregon. Fish and wildlife... the next generation: Landscape and land use in a booming society. Joint Annual Meeting of Oregon Chapters of American Fisheries Society and the Wildlife Society. Portland, Oregon, American Fisheries Society, Portland, Oregon.

Willamette Restoration Initiative Board of Directors (WRI). 2001. Restoring a river of life, the Willamette restoration strategy, recommendations for the Willamette basin supplement to the Oregon Plan for Salmon and Watershed. (Also available at http://www.oregonwri.org/basin_strat.html). Willamette Restoration Initiative Board of Directors, Salem, Oregon. 240 pp.

Williams, G.P. and Wolman, M.G. 1984. Downstream effects of dams on alluvial rivers. U.S. Geological Survey Professional Paper 1286. US Government Printing Office, Washington, D.C.

Williams, I.A. 1914. The drainage of farm lands in the Willamette and tributary valleys of Oregon. Oregon Bureau of Mines 1(4): 3081.

Williams, J.E., Wood, C.A., and Dombeck, M.P. 1997. Watershed restoration: Principles and practices. American Fisheries Society, Bethesda, Maryland.

Williams, R.N., Bisson, P.A., Bottom, D.L., Calvin, L.D., Coutant, C.C., Erho, M.W.Jr., Frissell, C.A., Lichatowich, J.A., Liss, W.J., McConnaha, W.E., Mundy, P.R., Stanford, J.A., and Whitney, R.R. 1999. Scientific issues in the restoration of salmonid fishes in the Columbia River. Fisheries 24(3): 10-19.

Wimberly, M.C., Spies, T.A., Long, C.J., and Whitlock, C. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. Conservation Biology 14(1): 167-181.

Wolf, D.W. 1992. Land use and nonpoint phosphorus pollution in the Tualatin Basin, Oregon: Tualatin River Basin Special Reports. Oregon State University and Extention Service, Corvallis, Oregon.

Wolman, M.G. and Leopold, L.B. 1957. River flood plains: Some observation on their formation. US Geological Survey Professional Paper 282-C. US Government Printing Office, Washington D.C. pp. 87-107.

Woltemade, C. J. 1999. Ability of restored wetlands to improve habitat and water quality in agricultural regions. *In* R. Sakrison and P. Sturtevant (Editors). Proceedings: AWRA's 1999 annual water resources conference:

Watershed management to protect declining species. Seattle, Washington, American Water Resources Association, Middleburg, Virginia.

Wood, P.J. and Armitage, P.D. 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21(2): 203-217.

Woodward, D.G., Gannett, M.W., and Vaccaro, J.J. 1998. Hydrogeologic framework of the Willamette lowland aquifer system, Oregon and Washington. US Geological Survey Professional Paper 1424-B. US Government Printing Office, Washington, D.C.

Young, R.G., Huryn, A.D., and Huryn, A.D. 1999. Effects of land use on stream metabolism and organic matter turnover. Ecological Applications 9(4): 1359-1378

APPENDIX A

303(d) WATER QUALITY STANDARD LISTING CRITERIA[31]

Parameter	Criteria
Aquatic Weeds or Algae	Macrophytes
Aquatic Weeds or Algae	Periphyton (attached Algae)
Aquatic Weeds or Algae	Phytoplankton (floating algae)
Bacteria	Water Contact Recreation (fecal coliform-96 Std)
Bacteria	Water Contact Recreation (E. coli) Freshwater
Bacteria	Marine and shellfish growing area (fecal coliform)
Biological Criteria	Impaired Conditions
Biological Criteria	Fish species decline due to water quality
Biological Criteria	Fish Skeletal Deformities
Chlorophyll a	Natural lakes which do not thermally stratify
Chlorophyll a	Natural lakes which thermally stratify
Dissolved Oxygen (DO)	Estuarine waters: DO < 6.5 mg/l
Dissolved Oxygen (DO)	Marine Waters: reduction in DO concentrations
Dissolved Oxygen (DO)	Salmonid spawning: water DO < 11mg/l
Dissolved Oxygen (DO)	Salmonid spawning: intergravel DO>8mg/l,water<9mg/l
Dissolved Oxygen (DO)	Salmonid spawning: natural conditions < 95% sat.
Dissolved Oxygen (DO)	Salmonid spawning: intergravel DO < 6 mg/l
Dissolved Oxygen (DO)	Cold-water aquatic life: DO < 8 mg/l or 90% sat.
Dissolved Oxygen (DO)	Warm-water aquatic life: DO < 5.5 mg/l
Dissolved Oxygen (DO)	Cool-water aquatic resources: DO < 6.5 mg/l
Flow Modification	Beneficial uses are impaired
Flow Modification	Does not meet Instream Water Right
Habitat Modification	Beneficial uses are impaired
Habitat Modification	Habitat conditions limit fish or other aquatic life
Nutrients	General concerns
Nutrients	Total Phosphorus as P
Nutrients	Nitrate
pH	Violates specific basin standards
pH	Violates specific water body standards
Sedimentation	Beneficial uses are impaired
Temperature	Oregon Bull Trout 50 F (10 C)
Temperature	Warm Water Fishery
Temperature	Columbia River 68 F (20 C)
Temperature	Salmon Spawning 55 F (12.8 C)
Temperature	Rearing 64 F (17.8 C)
Temperature	Willamette River 68 F (20 C)
Total Dissolved Gas	Above 110 percent of saturation
Total Dissolved Gas	Identified beneficial use impairment
Total Dissolved Gas	Violates Columbia River Standard
Toxics	Tissue - Mercury
Toxics	Tissue - Tributyltin
Toxics	Water - Pesticides (Dieldrin)
Toxics	Water – Lead
Toxics	Tissue - 2,3,7,8 TCDD
Toxics	Tissue - PCB's
Toxics	Tissue - Pesticides (DDE, DDT)
Turbidity	

[31] Source: DEQ 1994/96 303(d) Database

APPENDIX B.

Stream Miles in Western Oregon meeting 303 (d) Water Quality Standards. [32]

Watershed	Total Stream Miles	Total Stream Miles Assessed	Aquatic Weeds			Bacteria		
			303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards
Lower Columbia-Youngs Watershed (NC)	456.31	107.08	0.00	0.00	52.22	28.16	0.00	52.22
Necanicum (NC)	126.51	27.09	0.00	0.00	20.68	20.68	4.02	20.68
Lower Columbia-Clatskanie (NC)	443.63	160.13	0.00	0.00	0.00	58.33	3.54	2.57
Nehalem (NC)	930.24	317.83	0.00	0.00	16.53	17.08	7.08	104.89
Wilson-Trask-Nestucca (NC)	1057.59	414.17	0.00	0.00	61.79	73.90	20.56	158.59
Tualatin (Wil)	873.98	356.33	52.92	0.00	101.26	235.65	8.07	73.35
Lower Willamette (Wil)	420.56	165.85	20.20	0.00	47.95	75.19	0.00	28.89
Yamhill (Wil)	966.38	289.21	43.61	0.00	146.90	190.52	57.35	124.02
Middle Willamette (Wil)	915.35	237.5	0.00	0.00	93.37	124.79	40.81	93.37
Lower Columbia-Sandy	819.99	323.48	0.00	0.00	33.84	0.00	12.36	138.64
Molalla-Pudding (Wil)	1049.63	221.95	0.00	0.00	104.01	83.20	45.87	33.53
Clackamas (Wil)	1104.33	361.76	0.00	0.00	27.47	0.00	3.99	27.47
Siletz-Yaquina (Mid C)	1074.39	284.27	0.00	0.00	77.50	19.15	6.78	139.08
Upper Willamette (Wil)	2170.76	498.72	0.00	0.00	180.27	195.47	42.57	212.62
North Santiam (Wil)	868.16	194.56	0.00	0.00	43.76	0.00	32.54	56.77
South Santiam (Wil)	1134.05	244.59	0.00	0.00	30.76	29.54	0.00	41.69
Alsea (Mid C)	783.47	254.82	0.00	0.00	26.48	0.00	5.58	26.48
McKenzie (Wil)	1239.45	300.26	0.00	0.00	37.44	0.00	0.00	37.44
Siuslaw (Mid C)	908.16	343.88	0.00	0.00	100.32	0.00	0.00	100.32
Middle Fork Willamette (Wil)	1343.45	290.62	0.00	0.00	19.56	0.00	0.00	19.56
Siltcoos (Mid C)	114.7	27.42	0.00	0.00	0.00	0.00	0.00	0.00
Umpqua (Umpqua)	1674.44	596.44	0.00	0.00	128.39	157.40	0.00	99.40
Coast Fork Willamette (Wil)	686.5	134.25	0.00	0.00	7.32	29.11	0.00	7.32
Coos (SC)	837.11	313.43	0.00	0.00	0.00	38.40	4.25	164.00
North Umpqua (Umpqua)	1333.75	373.98	0.00	0.00	53.13	0.00	0.00	53.13
South Umpqua (Umpqua)	1914.89	586.45	57.44	0.00	93.27	67.01	0.00	42.03
Coquille (SC)	1212.07	468.38	30.86	0.00	55.48	111.51	0.00	95.57
Sixes (SC)	474.25	185.36	0.00	0.00	30.31	0.00	0.00	60.15
Lower Rogue (Rogue)	908.03	318.89	0.00	33.03	54.89	27.50	0.00	68.72
Middle Rogue (Rogue)	846.29	333.26	0.00	0.00	29.84	125.40	23.18	45.16
Upper Rogue (Rogue)	1613.03	469.27	0.00	0.00	42.24	16.69	0.00	25.55
Chetco (SC)	617.62	174.61	0.00	0.00	70.06	0.00	0.00	70.06
Illinois (Rogue)	970.42	382.21	0.00	0.00	23.94	0.00	0.00	23.94
Applegate (Rogue)	740.73	226.17	0.00	0.00	49.65	0.00	9.22	49.65
	32630.22	9984.22	205.03	33.03	1860.63	1724.68	327.77	2296.86

[32] **Source: DEQ 1994/96 303(d) Database**

Watershed	BioCriteria			D.O.			Flow Modification		
	303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards
Lower Columbia-Youngs Watershed (NC)	0.00	NE	NE	37.46	0.00	19.54	0.00	16.83	NE
Necanicum (NC)	0.00	NE	NE	0.00	4.02	20.68	0.00	0.00	NE
Lower Columbia-Clatskanie (NC)	0.00	NE	NE	58.33	0.00	2.57	0.00	6.56	NE
Nehalem (NC)	0.00	NE	NE	0.00	0.00	94.32	0.00	57.52	NE
Wilson-Trask-Nestucca (NC)	0.00	NE	NE	0.00	0.00	104.64	28.80	61.44	NE
Tualatin (Wil)	64.17	55.55	NE	137.84	30.51	180.47	0.00	0.00	NE
Lower Willamette (Wil)	24.18	NE	NE	20.20	0.00	47.95	0.00	0.00	NE
Yamhill (Wil)	0.00	NE	NE	33.05	38.57	157.47	45.81	34.12	NE
Middle Willamette (Wil)	93.24	NE	NE	0.00	21.18	98.17	24.82	37.81	NE
Lower Columbia-Sandy	0.00	NE	NE	0.00	0.00	95.18	0.00	53.15	NE
Molalla-Pudding (Wil)	0.00	NE	NE	8.25	19.09	33.53	33.40	56.53	NE
Clackamas (Wil)	0.00	NE	NE	0.00	29.63	27.47	0.00	19.33	NE
Siletz-Yaquina (Mid C)	0.00	NE	NE	0.00	0.00	82.89	0.00	47.59	NE
Upper Willamette (Wil)	11.70	0.00	NE	32.38	28.93	248.90	13.83	70.06	NE
North Santiam (Wil)	0.00	NE	NE	0.00	0.00	56.77	0.00	59.83	NE
South Santiam (Wil)	0.00	NE	NE	0.00	0.00	30.76	0.00	76.55	NE
Alsea (Mid C)	0.00	NE	NE	0.00	18.33	26.48	0.00	0.00	NE
McKenzie (Wil)	0.00	NE	NE	0.00	0.00	37.44	0.00	19.44	NE
Siuslaw (Mid C)	0.00	NE	NE	0.00	115.15	100.32	0.00	68.63	NE
Middle Fork Willamette (Wil)	0.00	NE	NE	0.00	0.00	19.56	0.00	34.76	NE
Siltcoos (Mid C)	0.00	NE	NE	0.00	0.00	0.00	0.00	3.02	NE
Umpqua (Umpqua)	0.00	NE	NE	44.53	0.00	128.39	128.31	95.54	NE
Coast Fork Willamette (Wil)	0.00	NE	NE	0.00	0.00	7.32	0.00	0.00	NE
Coos (SC)	0.00	NE	NE	9.76	5.61	0.00	0.00	0.00	NE
North Umpqua (Umpqua)	0.00	NE	NE	0.00	6.11	53.13	53.11	20.57	NE
South Umpqua (Umpqua)	85.32	NE	NE	67.01	0.00	137.73	29.14	139.64	NE
Coquille (SC)	0.00	NE	NE	87.57	3.80	109.44	0.00	13.62	NE
Sixes (SC)	0.00	NE	NE	0.00	0.00	60.15	0.00	25.50	NE
Lower Rogue (Rogue)	0.00	NE	NE	0.00	0.00	96.35	0.00	33.45	NE
Middle Rogue (Rogue)	0.00	NE	NE	0.00	0.00	84.35	26.27	60.95	NE
Upper Rogue (Rogue)	0.00	NE	NE	0.00	0.00	42.24	16.27	42.16	NE
Chetco (SC)	0.00	NE	NE	0.00	0.00	70.06	0.00	25.65	NE
Illinois (Rogue)	0.00	NE	NE	0.00	17.80	23.94	72.97	25.79	NE
Applegate (Rogue)	8.74	NE	NE	0.00	25.84	49.65	64.33	42.95	NE
	287.35	55.55	NE	536.38	364.57	2347.86	537.06	1248.99	NE

Watershed	Habitat Modification			Nutrients			pH		
	303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards
Lower Columbia-Youngs Watershed (NC)	0.00	0.00	NE	0.00	0.00	NE	0.00	0.00	52.22
Necanicum (NC)	0.00	0.00	NE	0.00	6.41	NE	0.00	4.20	20.68
Lower Columbia-Clatskanie (NC)	0.00	0.00	NE	0.00	3.54	NE	55.83	0.00	2.57
Nehalem (NC)	0.00	12.80	NE	0.00	7.08	NE	0.00	0.00	94.32
Wilson-Trask-Nestucca (NC)	10.70	161.79	NE	0.00	97.99	NE	0.00	0.00	86.10
Tualatin (Wil)	0.00	115.48	NE	0.00	15.72	NE	30.31	0.00	285.79
Lower Willamette (Wil)	0.00	3.40	NE	24.91	28.46	NE	20.20	0.00	68.70
Yamhill (Wil)	0.00	22.25	NE	0.00	50.72	NE	0.00	0.00	190.52
Middle Willamette (Wil)	0.00	93.44	NE	0.00	36.36	NE	0.00	0.00	124.95
Lower Columbia-Sandy	0.00	170.10	NE	0.00	12.36	NE	58.55	0.00	77.30
Molalla-Pudding (Wil)	0.00	37.77	NE	0.00	61.51	NE	0.00	0.00	110.09
Clackamas (Wil)	13.21	97.12	NE	0.00	7.92	NE	0.00	0.00	27.47
Siletz-Yaquina (Mid C)	29.53	23.20	NE	0.00	6.78	NE	0.00	0.00	100.62
Upper Willamette (Wil)	0.00	53.38	NE	0.00	53.79	NE	0.00	0.00	248.90
North Santiam (Wil)	0.00	33.13	NE	0.00	33.13	NE	0.00	0.00	56.77
South Santiam (Wil)	0.00	100.52	NE	0.00	16.40	NE	0.00	0.00	30.76
Alsea (Mid C)	0.00	73.27	NE	0.00	0.00	NE	0.00	0.00	26.48
McKenzie (Wil)	0.00	36.30	NE	0.00	0.00	NE	0.00	0.00	37.44
Siuslaw (Mid C)	63.15	258.67	NE	0.00	0.00	NE	0.00	0.00	100.32
Middle Fork Willamette (Wil)	0.00	25.53	NE	0.00	0.00	NE	0.00	0.00	19.56
Siltcoos (Mid C)	0.00	24.40	NE	0.00	0.00	NE	0.00	0.00	0.00
Umpqua (Umpqua)	0.00	344.03	NE	0.00	0.00	NE	18.64	0.00	128.39
Coast Fork Willamette (Wil)	0.00	44.09	NE	0.00	0.00	NE	0.00	0.00	36.46
Coos (SC)	0.00	161.00	NE	0.00	0.00	NE	0.00	0.00	0.00
North Umpqua (Umpqua)	67.28	54.68	NE	0.00	0.00	NE	42.63	0.00	53.13
South Umpqua (Umpqua)	60.19	171.67	NE	15.83	0.00	41.65	158.14	0.00	93.27
Coquille (SC)	5.01	266.32	NE	0.00	3.80	NE	0.00	0.00	129.68
Sixes (SC)	19.53	1.34	NE	0.00	0.00	NE	0.00	0.00	60.15
Lower Rogue (Rogue)	0.00	84.92	NE	0.00	0.00	NE	54.69	0.00	41.46
Middle Rogue (Rogue)	26.27	53.73	NE	0.00	27.59	NE	0.00	0.00	84.35
Upper Rogue (Rogue)	37.24	16.70	NE	0.00	0.00	NE	0.00	0.00	42.24
Chetco (SC)	0.00	0.00	NE	0.00	0.00	NE	0.00	0.00	70.06
Illinois (Rogue)	25.08	40.67	NE	0.00	0.00	NE	0.00	0.00	23.94
Applegate (Rogue)	14.44	60.48	NE	0.00	9.22	NE	0.00	0.00	49.65
	371.63	2642.18	NE	40.74	478.78	41.65	438.99	4.20	2574.34

Watershed	Sediment			Temperature			Total Dissolved Gas		
	303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards
Lower Columbia-Youngs Watershed (NC)	0.00	69.62	NE	28.16	17.99	0.00	28.16	0.00	NE
Necanicum (NC)	0.00	0.00	NE	0.00	20.68	0.00	0.00	0.00	NE
Lower Columbia-Clatskanie (NC)	0.00	95.25	NE	55.83	2.57	0.00	55.83	0.00	NE
Nehalem (NC)	0.00	118.35	NE	91.93	13.07	0.00	0.00	0.00	NE
Wilson-Trask-Nestucca (NC)	35.59	145.48	NE	59.03	42.22	104.61	0.00	0.00	NE
Tualatin (Wil)	0.00	44.60	NE	163.88	92.08	64.86	0.00	0.00	NE
Lower Willamette (Wil)	0.00	83.26	NE	73.21	8.49	0.00	0.00	0.00	NE
Yamhill (Wil)	0.00	65.19	NE	150.51	61.29	0.00	0.00	0.00	NE
Middle Willamette (Wil)	0.00	53.46	NE	118.06	43.08	0.00	0.00	0.00	NE
Lower Columbia-Sandy	0.00	136.06	NE	91.98	17.24	119.36	58.55	0.00	NE
Molalla-Pudding (Wil)	0.00	82.88	NE	83.20	74.04	5.49	0.00	0.00	NE
Clackamas (Wil)	0.00	81.92	NE	55.80	24.96	175.10	0.00	0.00	NE
Siletz-Yaquina (Mid C)	29.53	158.11	NE	70.14	59.82	3.29	0.00	0.00	NE
Upper Willamette (Wil)	0.00	220.10	NE	176.05	92.70	0.00	0.00	0.00	NE
North Santiam (Wil)	0.00	104.97	NE	58.78	32.38	97.71	0.00	0.00	NE
South Santiam (Wil)	0.00	191.01	NE	29.54	161.01	10.93	0.00	0.00	NE
Alsea (Mid C)	0.00	115.98	NE	118.91	6.82	7.23	0.00	0.00	NE
McKenzie (Wil)	0.00	125.93	NE	153.83	53.58	20.50	0.00	0.00	NE
Siuslaw (Mid C)	44.02	114.55	NE	132.82	91.65	14.65	0.00	0.00	NE
Middle Fork Willamette (Wil)	0.00	209.22	NE	49.31	141.48	20.52	0.00	0.00	NE
Siltcoos (Mid C)	0.00	24.40	NE	0.00	24.40	0.00	0.00	0.00	NE
Umpqua (Umpqua)	0.00	152.17	NE	268.73	154.04	19.36	0.00	0.00	NE
Coast Fork Willamette (Wil)	0.00	78.98	NE	55.27	61.08	0.00	0.00	0.00	NE
Coos (SC)	0.00	142.83	NE	3.94	70.16	3.85	0.00	0.00	NE
North Umpqua (Umpqua)	50.89	35.46	NE	210.68	17.12	96.17	0.00	19.00	NE
South Umpqua (Umpqua)	71.48	108.72	NE	299.67	124.65	12.94	0.00	0.00	NE
Coquille (SC)	0.00	96.76	NE	277.94	58.37	44.93	0.00	0.00	NE
Sixes (SC)	0.00	31.41	NE	113.20	34.54	28.00	0.00	0.00	NE
Lower Rogue (Rogue)	0.00	57.04	NE	214.11	45.35	49.55	0.00	0.00	NE
Middle Rogue (Rogue)	0.00	62.07	NE	224.92	49.24	16.66	0.00	0.00	NE
Upper Rogue (Rogue)	57.81	69.22	NE	181.44	67.94	207.34	0.00	0.00	NE
Chetco (SC)	0.00	52.07	NE	97.49	37.26	17.59	0.00	0.00	NE
Illinois (Rogue)	0.00	49.79	NE	199.41	56.18	117.27	0.00	0.00	NE
Applegate (Rogue)	8.74	37.90	NE	93.00	23.86	92.04	0.00	0.00	NE
	298.06	3214.76	NE	4000.77	1881.34	1349.95	142.54	19.00	NE

Watershed	Toxics			Total Miles		
	303d listed	Needs Data	Meets Standards	303d listed	Needs Data	Meets Standards
Lower Columbia-Youngs Watershed (NC)	28.16	54.21	NE	37.46	107.12	0.00
Necanicum (NC)	0.00	0.00	NE	20.68	27.09	0.00
Lower Columbia-Clatskanie (NC)	55.83	75.98	NE	55.83	180.35	0.00
Nehalem (NC)	109.01	297.18	NE	109.01	297.18	0.00
Wilson-Trask-Nestucca (NC)	0.00	2.13	NE	160.01	273.33	70.69
Tualatin (Wil)	0.00	143.89	NE	282.95	315.51	12.04
Lower Willamette (Wil)	20.20	66.36	NE	80.25	151.96	0.00
Yamhill (Wil)	0.00	95.96	NE	190.52	268.39	0.00
Middle Willamette (Wil)	6.25	114.54	NE	155.86	237.66	0.00
Lower Columbia-Sandy	58.55	75.11	NE	91.98	292.59	47.85
Molalla-Pudding (Wil)	35.46	0.00	NE	83.20	208.33	5.49
Clackamas (Wil)	0.00	0.00	NE	55.80	219.98	113.45
Siletz-Yaquina (Mid C)	0.00	0.00	NE	89.29	175.92	21.11
Upper Willamette (Wil)	0.00	129.04	NE	240.72	462.45	0.00
North Santiam (Wil)	0.00	0.00	NE	58.78	148.73	30.80
South Santiam (Wil)	0.00	0.00	NE	29.54	204.12	10.93
Alsea (Mid C)	0.00	0.00	NE	118.91	204.66	0.00
McKenzie (Wil)	0.00	95.85	NE	153.83	288.86	20.50
Siuslaw (Mid C)	0.00	0.00	NE	177.59	265.06	1.55
Middle Fork Willamette (Wil)	0.00	0.00	NE	49.31	280.33	5.33
Siltcoos (Mid C)	0.00	0.00	NE	0.00	27.42	0.00
Umpqua (Umpqua)	0.00	0.00	NE	282.70	546.55	28.77
Coast Fork Willamette (Wil)	0.00	0.00	NE	55.27	134.31	0.00
Coos (SC)	8.41	12.55	NE	48.16	256.34	32.60
North Umpqua (Umpqua)	0.00	0.00	NE	220.35	198.91	55.37
South Umpqua (Umpqua)	0.00	0.00	NE	314.51	466.00	12.94
Coquille (SC)	0.00	0.00	NE	303.10	363.01	45.67
Sixes (SC)	0.00	0.00	NE	115.57	78.94	28.00
Lower Rogue (Rogue)	27.50	0.00	NE	214.11	192.32	44.40
Middle Rogue (Rogue)	0.00	30.46	NE	241.52	259.4	10.77
Upper Rogue (Rogue)	0.00	0.00	NE	206.28	169.86	174.39
Chetco (SC)	0.00	0.00	NE	97.49	158.92	17.59
Illinois (Rogue)	0.00	0.00	NE	206.68	220.06	91.95
Applegate (Rogue)	0.00	49.65	NE	107.44	131.29	69.34
	349.37	1242.91	NE	4654.70	7812.95	951.53