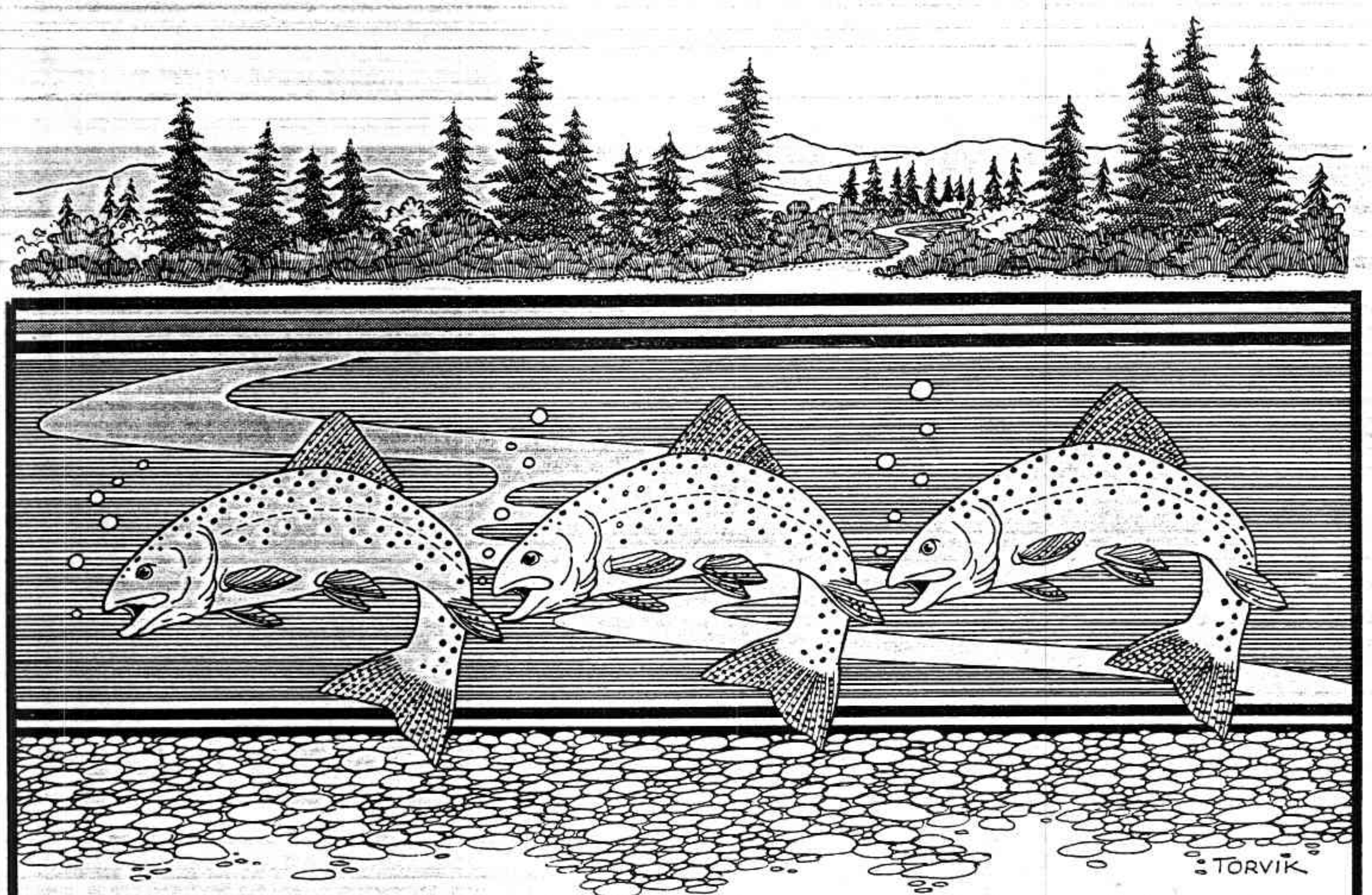
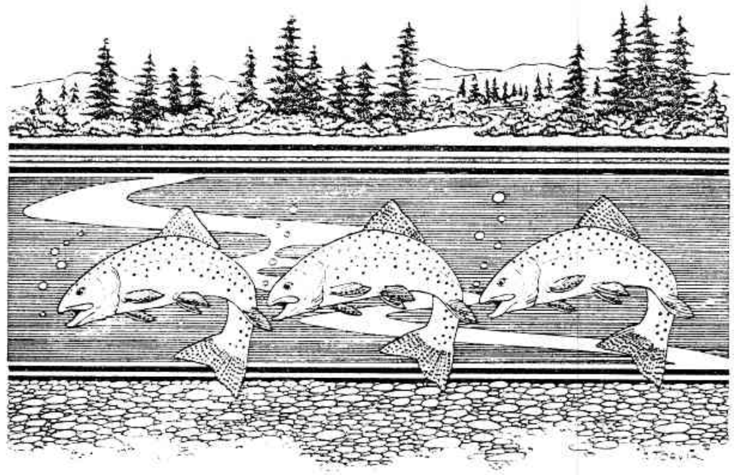
The Effects of Stream Alterations on Salmon and Trout Habitat in Oregon



Oregon Department of Fish & Wildlife



The Effects of Stream Alterations on Salmon and Trout Habitat in Oregon

Prepared by D. L. Bottom
P. J. Howell
J. D. Rodgers

Oregon Department of Fish and Wildlife
506 S.W. Mill Street
P.O. Box 3503
Portland, Oregon 97208

1985

Although the research or investigation described herein has been funded wholly or in part by the U.S. Environmental Protection Agency through grant 000-217 to the Oregon Department of Environmental Quality and passed through to the Oregon Department of Fish and Wildlife, it has not been subject to the Agency's peer and adminstrative review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

CONTENTS

Page

SUMMARY AND RECOMMENDATIONS 1
Fish Habitat Problems 1
Habitat Management 3
Research 4
Planning 5

INTRODUCTION 7

STREAMFLOW 10
Characteristics and Salmonid Requirements 10
Altered Flows 13
Streamflow and Temperature Problem Areas in Oregon 15
Oregon coast 15
Interior valleys 16
Eastern Oregon 18
Protection of Minimum Streamflows 21
Flow Enhancement 23

RIPARIAN HABITAT 25
Characteristics and Salmonid Requirements 25
Erosion control 25
Flow 27
Temperature control 27
Cover 29
Structure 29
Food supply 29
Effects of Riparian Losses 29
Riparian Habitat Losses in Oregon 33
Oregon coast 33
Interior valleys 33
Eastern Oregon 34
Protection of Riparian Habitat 35
Range land 35
Cultivated land 35
Forest land 35
Buffer width 36
Riparian protection programs 37

INSTREAM HABITAT 37
Characteristics and Salmonid Requirements 37
Substrate 37
Food production 39
Gradient 39
Structure 39
Cover 40
Losses of Instream Habitat 40
Sedimentation and debris torrents 40
Stream channelization 43
Other instream impacts 46

CONTENTS (continued)

	Page
Instream Habitat Problem Areas	47
Western Oregon	47
Eastern Oregon	54
Protection of Instream Habitat	56
Agricultural erosion and streambank stabilization	56
Forest land	58
REFERENCES	59

List of Tables

Number | Page

1. Water depth and velocity preferences for upstream migration and spawning of selected adult salmonid species.............. 12

2. Water uses in the lower Willamette basin in 1976 and projected for 1985.. 17

3. Mean September flows and temperatures for selected tributaries in the Deschutes River basin..................... 19

4. Winter flows below reservoirs on the Malheur and Owyhee rivers and McKay Creek, 1979-80............................. 21

5. Cover, shade, and water temperatures associated with good and poor riparian zones on selected streams in eastern Oregon.. 31

6. Salmonid standing crops associated with good and poor riparian zones on selected streams in eastern Oregon.................. 33

7. Riparian habitat losses for mainstem and tributary reaches in the Deschutes, Grande Ronde, Umatilla and John Day river basins... 34

8. Spawning gravel requirements for salmonids.................. 38

9. Gradient in relation to stream order for selected coastal and Cascade watersheds.. 39

10. Landslides and erosion rates for forested, clearcut, and roaded areas in western Oregon.............................. 43

11. Miles of stream habitat available to salmon in Oregon coastal basins... 47

12. Erosion and sedimentation rates in the Tillamook Bay drainage.. 50

13. Erosion and sedimentation intensity by sub-basin on forest lands in the Tillamook Bay drainage......................... 50

14. Inventory of landslides in Smith River and lower Umpqua watersheds, February 1982.................................. 53

15. Inventory of mass failures in Mapleton Ranger District (Siuslaw National Forest) following storms November 29-December 1, 1975................................. 54

16. Sources of riparian and associated instream habitat problems for the Deschutes, John Day, Umatilla, and Grande Ronde drainages... 56

List of Figures

Number		Page
1.	Interactions of major factors controlling salmonid production in fresh water	9
2.	Temperature preferences and danger zones for rearing and incubating anadromous salmonids	11
3.	Relationship of flow to summer water temperature and dissolved oxygen	11
4.	Less habitat is available to salmonids and other stream organisms as flows decrease	14
5.	Percentage change in depth, surface area, and water velocity with reduction in streamflow	15
6.	Minimum and maximum daily temperatures on the mainstem John Day River at McDonald Ferry, Oregon, November 1979-February 1980 and June-September 1980	19
7.	Usable width technique for determining required spawning flow	22
8.	Estimated increases in spawning adult steelhead from streamflow increases due to riparian restoration	25
9.	The riparian zone is defined by vegetation that requires moister soil conditions than occur in surrounding upland areas	26
10.	Trout production in relation to streambank stability	27
11.	Trout production in relation to surface shading of small streams	28
12.	Changes in cross-sectional channel profile due to riparian degradation	30
13.	Effects of logging on large woody debris in streams	32
14.	Trout production in relation to substrate covered by fine sediment	38
15.	Comparison of off-channel storage and return of flood water before and after channelization	45
16.	Effect of channelization on stream length	46
17.	Splash dams on western Oregon rivers, 1880-1910	48

List of Figures (continued)

Number		Page
18.	Sites of land failures and massive erosion in the South Fork Trask watershed	51
19.	Outlines of the Willamette River between the mouth of the McKenzie River and Harrisburg, Oregon, in 1854 and 1967	55

Appendix Figures

Number		Page
1.	Oregon geographic areas	69
2.	Oregon drainage basins	70

SUMMARY AND RECOMMENDATONS

Fish Habitat Problems

Much of the effort to curb pollution adversely affecting fisheries has been directed at controlling point sources (e.g., domestic sewage, industrial waste). However, many of the widespread problems limiting freshwater salmonid production in Oregon today are due to nonpoint source pollution--principally reduced streamflows and extreme water temperatures, loss of streamside vegetation, and degradation of instream habitat.

The statewide assessment of nonpoint source water pollution problems (ODEQ 1978) does not distinguish between natural sources of pollution and impacts of human activity. While such a distinction may in many cases be difficult to determine, an understanding of the impact of natural events versus the impacts of development is needed to evaluate the effects of nonpoint pollution on fish.

Many of the so-called pollution problems are to some extent the products of natural processes. Erosion and mass soil movements have always occurred and will continue. Flooding in winter and spring and low flows-warm water during the summer are normal cycles for many streams, especially considering the seasonal precipitation patterns in Oregon. Fish are adapted to the environment in which they have evolved; consequently, they have survived despite these periodic perturbations and changes in their habitats. In fact, many of the natural "pollutants" and the processes that generate them are beneficial to fish production, although they may have negative short-term impacts. Run-off from the land contains nutrients that increase stream productivity. Bank cutting and landslides release spawning gravel and add structural elements to streams. As Leopold (1941) suggested, it is the dynamic exchange between land and water that drives the stream ecosystem: "Soil and water are not two organic systems, but one. Both are organs of a single landscape; a derangement in either affects the health of both."

The principal habitat problems affecting fisheries occur largely when land use practices greatly accelerate these processes, increasing the frequency and magnitude of natural events, and when artificial elements (e.g., toxic chemicals, channelization) alter the stream. Although salmonids are adaptable to natural changes in stream conditions, they are not able to tolerate many of the large scale changes in streams brought about by land use practices.

In general, land use practices have reduced salmonid production in streams by decreasing habitat diversity and complexity. These changes reduce bank and channel structure and stability, the quality and quantity of spawning gravel, riparian vegetation, flow, and water quality (temperature, turbidity, dissolved oxygen, toxicity).

Much of the land in Oregon is used for timber and agricultural production. The most serious impacts of logging on salmonid production are increased water temperature and sedimentation, reductions in cover and structural diversity, and alterations of instream habitat due to debris torrents. Logging roads are a major cause of sedimentation in forested areas.

Protection of the riparian zone on both Class I and smaller Class II streams is of prime importance in providing cool water and a steady recruitment of large woody structure and organic material, filtering out fine sediments from upland areas, reducing bank erosion, and maintaining the overall stability and productivity of salmonid streams.

Debris torrents primarily related to logging roads and clearcuts have scoured channels and deposited large amounts of sediment and debris in many coastal streams. More specific inventory data are needed to determine the extent of salmonid habitat losses from this source. Available techniques for road and landing location, design, construction, and maintenance (Soils Task Force 1982) should be utilized to minimize road and landing related slides. Greater attention should be focused on preventing debris avalanches originating in clear cuts, which account for a large proportion of slides. As the Soils Task Force (1982) points out, "Little is known about methods to minimize debris avalanches in harvested areas." Protective measures such as vegetated "leave" areas in headwalls or reduced timber harvest in unstable areas with high potential for landslides may be needed. As recommended by the Task Force, guidelines and techniques should be developed for restoring fish habitat in streams damaged by debris torrents.

Recent inventories indicate that debris torrents cause the most serious habitat losses in a broad region of the Oregon coast between Yachats and Bandon and in Tillamook Bay drainages. Efforts to prevent landsides and to restore stream habitat impacted by debris torrents should be directed to these regions of the coast.

Implementation of the Forest Practices Act (FPA) has slowed but not stopped habitat destruction from logging. Many of the regulations (e.g., buffer strips) are not specified in terms of requirements. Damage to streams continues in areas that were roaded and logged prior to implementation of the FPA.

The two major agricultural impacts on salmonid production are due to water withdrawals and grazing in the riparian zone. These problems are most acute in central and eastern Oregon. Of more than 3,000 miles of stream inventoried in eastern Oregon, 52% of the riparian habitat was degraded (USFWS and USNMFS 1981a, 1981b, 1981c, 1982).

New legislation establishes priority for minimum flows based on the date of application rather than on approval by the Water Resources Board. This will help to insure adequate flows on streams that are not already overappropriated and need new or revised minimum flow standards to protect fish life. However, minimum flow requirements do not protect fisheries in streams where water rights have been fully allocated. Efforts to protect streamflows should be focused on streams where fisheries resources are threatened by increasing demands for water and where streamflows are adequate to support viable fish populations. In response to recent legislation (SB 225), the Oregon Department of Fish and Wildlife (ODFW) and the Oregon Department of Environmental Quality (ODEQ) have prepared minimum streamflow recommendations for 75 priority stream reaches in the state.

Headwater storage reservoirs may be feasible to increase summer flows on some streams. However, the concept of water storage for fisheries enhancement has not been widely tested. Downstream enhancement benefits must be weighed against upstream habitat losses and potential passage problems. Riparian restoration should be considered as an alternative that provides greater overall habitat improvement in addition to increased summer flows. The fishery values of enhanced flows may be negated if the additional water is withdrawn for irrigation or other out-of-stream uses or if other factors are limiting production.

Habitat Management

ODFW policy states that "The protection and enhancement of wild stocks will be given first and highest considerations" (ODFW 1980). Productive habitat is essential to meet that goal and to insure the survival of hatchery fish released in freshwater. The principal objectives of habitat management are (1) protection of existing high quality habitat and prevention of future degradation, and (2) restoration of degraded habitat and enhancement of habitat with naturally low productivity. Much of the present emphasis in habitat management is on restoration and enhancement. For example, the Northwest Power Planning Council's Columbia River Basin Fish and Wildlife Program is funding a number of habitat improvement projects. This trend is encouraging because it draws attention to habitat problems and promotes wild production. Restoration and enhancement are also attractive politically because regulations and restrictions on land and water uses are not usually directly involved.

Habitat restoration is not without problems, however. It may appear that habitat destruction is not really that bad because it can later be fixed. Many severely degraded streams may never be able to be restored to their former level of productivity. Development of restoration techniques depends on a thorough understanding of natural systems and factors limiting production. Our knowledge of these is still very limited. Present restoration techniques have largely been derived through trial and error. As pointed out by Hall and Baker (1982), there has been little documentation or evaluation of the effects of most restoration projects. Stream restoration can also be very expensive.

Habitat protection is generally cheaper, simpler, and more effective. For example, the costs to replace the structure provided by a large conifer in a stream with a gabion or log weir greatly exceeds the value of that tree as a merchantable log (Sedell et al. undated). The effectiveness of restoration is also limited by time and manpower.

There are few streams that still retain relatively pristine characteristics. These unaltered streams are invaluable not only for their own fisheries, but they are irreplaceable models of natural systems needed to further understand the principles of stream ecology and to develop protection, restoration and enhancement techniques for managing the rest of the streams in the state. "Wild" streams are also yardsticks with which habitat changes in other streams can be measured.

Prevention of further habitat degradation is also essential if restoration and enhancement projects are to provide lasting benefits. Habitat protection should receive the highest priority in habitat management.

Research

Habitat management must be supported by adequate research and planning. A solid base of information on the relationship between salmonids and their habitats is fundamental to species management and habitat management. That information helps determine what we manage for, how much, and the means to achieve our management goals. The following areas should be investigated to develop sound habitat protection and restoration strategies:

1. Historical assessment of habitat conditions

   The abundance of many salmonid species has drastically declined from historical levels. Information on the habitat characteristics of streams during their early periods of high productivity may provide clues to the decline and ways to correct it. Previous work has indicated the importance of large woody debris, beavers, and off-channel areas to historical productivity.

2. Stream classification system

   Streams are neither all alike nor totally unique. A hierarchical stream classification is needed to assemble comparative physical and biological characteristics of Oregon streams, to identify important habitat features, and to help determine production potentials. Several classification methods have been proposed for streams in the Northwest (Platts 1974; Warren 1979; Armantrout 1981). These may be useful in developing a classification system for Oregon. Coastal streams should be classified initially due to their importance to anadromous salmonids. This information would facilitate development of basin plans, habitat management plans, and stream enhancement projects.

3. Limiting factors

   The habitat requirements of salmonids are complex and temporally shifting. A variety of factors limit their growth, survival, and reproductive success. For habitat restoration work to be successful, it must focus on the problems that limit production.

   Most of the research to date on freshwater limiting factors has concentrated on the spawning and summer rearing phase of the salmonid life cycle. There is a large gap of information on juvenile ecology during the winter rearing period. There is evidence that winter habitat may be critical in determining smolt output in some streams (e.g., Mason 1976).

Salmonid requirements for instream structure and cover are not well defined partially because they are not easily quantified. Ongoing research on salmonid production factors could help fill this void by more fully exploring these requirements.

Limitations to production outside of the freshwater environment must also be considered. After anadromous juveniles migrate from freshwater, bottlenecks in estuaries and the ocean may reduce adult production. Overfishing may further depress adult spawning escapement so that freshwater habitat is underseeded. These constraints and the continued loss of freshwater habitat can greatly overshadow restoration and enhancement efforts.

4. Habitat index

Although ODFW has established index streams to evaluate trends in escapement of salmon, there are little data with which changing trends in habitat conditions of Oregon streams can be monitored. A quantitative index of habitat quality should be developed. Initially the index streams used to monitor spawning escapement could be used to index habitat quality.

5. Evaluation

Since much habitat restoration work is in its pioneering stage, thorough documentation of the methods and results of habitat projects is needed to evaluate benefits, to determine which techniques are most effective and economical, and to provide a basis for further refinement in the function and design of techniques.

Currently several habitat projects in the John Day basin are being evaluated. These evaluations are aimed primarily at determining direct fishery benefits. Although this should be an integral part of habitat project evaluations, changes in the physical habitat features (e.g., channel morphology, substrate) and closely related biological characteristics (e.g., riparian vegetation, invertebrate production) need to be monitored as well.

In most cases existing data on fishery benefits is in terms of increases in spawners or juvenile standing crops in the immediate vicinity of the habitat project. Often there are little or no data from control areas to determine if perceived increases in fish populations are due to the habitat improvements, natural variability, changes in distribution, or other causes. Localized increases in spawners and/or rearing juveniles during the summer may not necessarily result in net increases in freshwater production (smolts). Smolt output should be monitored before and after some representative habitat projects to provide a more definitive measure of success.

Planning

Habitat projects in Oregon have largely been a response to isolated habitat problems. Habitat restoration and protection activities should be guided by habitat management plans developed for the state, regions, and river basins. Basin plans are just beginning to be formulated by ODFW. Habitat considerations should be an important part of those plans.

Within the basins and sub-basins, the watershed is the logical planning unit. A given reach of stream is inextricably tied to the rest of the stream and watershed. Thus, it is not possible to manage a portion of the stream without considering upstream influences and downstream effects. To be successful, stream habitat management must address land use management in upland areas of the watershed as well as in the immediate stream corridor.

Habitat management plans should be developed concurrently with timber and range management plans. In that way areas that are fragile, problem-prone (e.g., highly erosive or unstable), or highly productive could be identified for more stringent protection. Habitat management could then be an integral part of land management rather than an after-the-fact response to habitat degradation.

This type of planning would also provide improved coordination of the many habitat management programs in the state. ODFW alone has nine different programs related to stream habitat management. Numerous federal agencies (Forest Service, Bureau of Land Management, Bureau of Reclamation, Soil Conservation Service, Bonneville Power Administration) are involved in stream habitat work as well. A mechanism for improved habitat planning among public land use agencies now exists (Oregon Task Group for Coordinated Resource Management 1978).

Land management is a joint venture that involves a variety of disciplines and objectives. In developing stream habitat management plans, the fisheries biologist should utilize the expertise of agricultural and forestry specialists, hydrologists, engineers, and geologists to provide the broad scope of perspectives required for ecosystem management.

Habitat protection and restoration programs depend on cooperation and incentives. Legally, streams are public domain. However, they are largely controlled by state and federal agencies and private landowners, whose primary interests are generally not fish production. To date many of the habitat projects have taken place on federal lands. Because federal land management agencies are charged with managing their lands under a multiple-use policy, which involves consideration of fish and wildlife, federal lands will probably continue to play a major role in stream habitat management as long as there is support from agency officials and the public.

The main incentive for management of private lands is economic. In most cases fish and wildlife offer little direct economic incentive to the landowner. However, programs tied to fish and wildlife habitat that provide land owners with financial assistance or subsidies can be effective. Great strides in wildlife habitat enhancement were made during the 1950s with the Soil Bank program. There are current set-aside or agricultural land retirement programs, but they do not contain provisions for fish and wildlife habitat.

The Riparian Tax Incentive Program is a promising step in promoting riparian and instream habitat improvement on private land. The actual monetary savings for the landowner from the property tax reductions and income tax credits will be small since the agricultural and forest lands involved are already taxed at a low rate. But the Riparian program offers some financial inducement nonetheless. The ODFW Salmon Trout Enhancment Program is also designed to involve the public in stream habitat improvement.

Sound land use management is beneficial for fish and wildlife as well as economically justified for the landowner or land management agency. Erosion costs the farmer and the fishery. Landslides reduce forest productivity and damage stream habitat. A deterioration of the environment is detrimental to fish and wildlife and to human inhabitants. Admittedly, this line of logic has been difficult to sell, mainly because short-term gain usually overrides long-term prosperity. However, efforts to promote stream habitat management should continue to stress benefits to the landowner.

Where voluntary programs to improve fish habitat fall short, additional regulations and legislation will be needed. Congress has been hesitant to pass legislation making nonpoint pollution control manadatory. The three most pressing needs for regulations to improve stream habitat are (1) further protection of streamflows, (2) forestry practices that minimize debris torrents, and (3) additional protection of the riparian zone, particularly larger trees, and off-channel habitat in the flood plain.

In the long run the most effective incentive for habitat protection and enhancement is derived from a social-ethical sense of responsibility--resource stewardship. Additional education and information on resource values, habitat problems, and management programs are essential to gain public support for habitat improvement programs and necessary regulations.

INTRODUCTION

In 1972 Congress passed amendments to the Water Pollution Control Act (PL 92-500) that established a national goal to halt all discharge of water pollutants by 1985. Section 208 of the Act provided incentives for states to develop and implement water quality management plans to achieve the goal of "fishable and swimmable" water quality by 1983. The 208 program emphasizes control of land uses and "nonpoint" sources of pollution that affect water quality. The ODEQ (1978) has defined nonpoint source pollution as:

1. Pollutants from land runoff into streams, lakes, reservoirs, or estuaries.
2. Physical alterations of a stream corridor or the banks and adjacent areas of any water body.
3. Reduced streamflows due to water withdrawals that interfere with other "beneficial uses".

Pollution resulting from land use practices can significantly reduce the growth, reproduction, and survival of salmon and trout in Oregon streams. An understanding of the habitat requirements of salmonids is necessary to minimize the effects of logging, residential and municipal development, agricultural practices, and other land and water uses on sport and commercial fisheries. Research has shown that a wide variety of factors control salmonid populations in fresh water: water velocity (MacKinnon and Hoar 1953), depth (Thompson 1972), pool volume (Nickelson et al. 1979), substrate (Phillips et al. 1975), insect production (Griffith 1974), large woody material (Sedell and Triska 1977), temperature (Dwyer and Kramer 1975), streamside vegetation (Meehan et al. 1977), dissolved oxygen (Doudoroff and Warren 1965), etc. Several recent reviews discuss salmonid habitat requirements in detail (Reiser and Bjornn 1979; Everest et al. 1982; Hickman and Raleigh 1982). Many of these requirements are closely interrelated (Fig. 1), which complicates attempts to predict environmental impacts or to establish simple rules to adequately protect or restore stream habitat for fish.

The most obvious environmental problems for fish are barriers that block passage or direct sources of mortality. In Oregon, regulations have been established to protect stream access for migrating fish and to maintain water quality within tolerance levels for salmonids. Enforcement of water quality standards, for example, has improved dissolved oxygen conditions for fishery resources in the Willamette River and in Isthmus Slough (Coos Bay). Oregon's Forest Practices Act requires clean-up of logging debris to maintain water quality and to allow passage of migrating adults. Efforts continue on the Columbia and other rivers to minimize and mitigate fishery losses resulting from dams that block access to spawning and rearing habitats or cause mortalities of juveniles migrating downstream.

Some of the most serious problems facing Oregon salmonids, however, are not so apparent. The sources of many pollutants cannot be traced to any specific origin. Runoff from land adjacent to a stream can result in chemical contamination, turbidity, and sedimentation. A host of different land uses may contribute to low flows, high temperatures, or channel alterations in a single stream. Most of these pollutants produce gradual, long-term effects rather than obvious or immediate fish mortalities. Sublethal doses of chemicals, stressful water temperatures, altered streamflows, or gradual changes in physical habitat cause subtle shifts in population abundance, species composition, and age structures of stream communities. Reduced growth rates, poor reproductive success, and increased stress reduce the "fitness" of a fish population or its ability to withstand subsequent changes--natural or man-caused--in the stream environment. These subtle impacts and the long-term cumulative effects of a variety of land uses along a stream are the most widespread problems influencing the freshwater production of salmonids in Oregon.

It is much more difficult to maintain optimal conditions for growth and reproduction of salmonids than it is to apply standards of water quality or stream access. A complete set of stream conditions, not a single variable, is necessary to maintain productive fisheries. In Oregon we manage for a variety of salmonid species that overlap in their freshwater distribution. Each

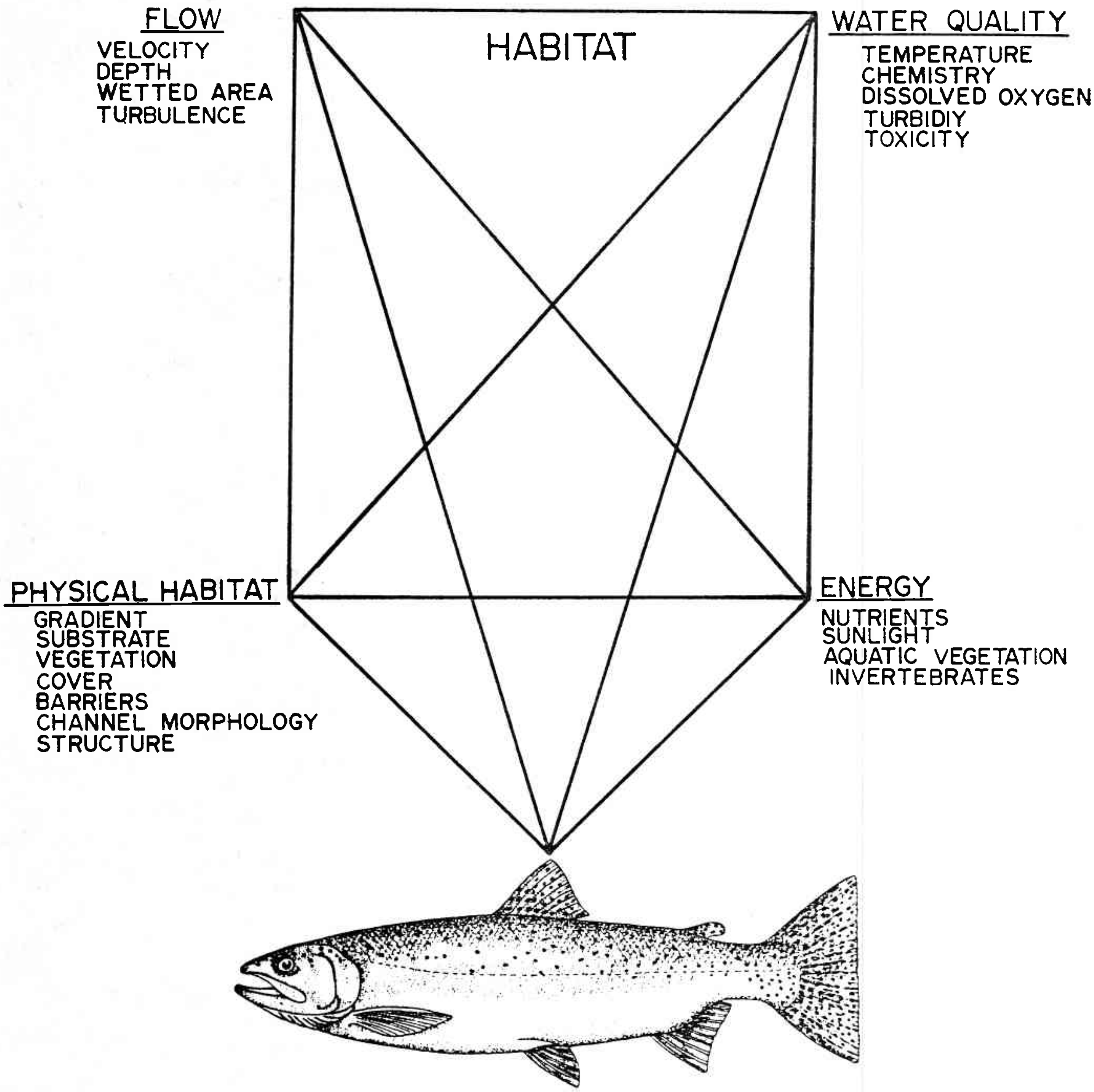


Fig. 1. Interactions of major factors controlling salmonid production in fresh water.

species exhibits a slightly different array of habitat requirements that varies throughout its life cycle. Within species, separate stocks have adapted to the habitat conditions in a particular river system or geographic region. To satisfy the full range of environmental requirements for different species, stocks, and life history stages of Oregon salmonids, we must manage our streams and rivers to provide a diverse mixture of the appropriate stream habitat conditions. Most development in or near Oregon rivers and streams limits fish productivity by decreasing habitat diversity and altering that proper mixture of habitat characteristics.

This report reviews the habitat requirements of salmonids, the impacts of land use practices in Oregon on salmonid habitat and production, and techniques to reduce these impacts. The report is intended as a general guide for developing stream restoration projects and habitat management plans for the river basins in Oregon. Appendix Figures 1 and 2 show the major geographic regions and stream locations referred to in the report.

STREAMFLOW

Characteristics and Salmonid Requirements

To a great extent, streamflow regulates the quantity and quality of habitat available to fish. The width and depth of a stream fluctuate in response to changes in flow. This in turn exposes or inundates riffles where salmonids spawn and many of the aquatic insects consumed by salmonids are produced. Water depth is a measure of pool quality. Water velocity, a component of flow, affects the composition and distribution of insect species, predation on small fish, and spawning site selection. High flows distribute spawning gravel, flush fine sediment from spawning areas, and scour pools.

During the summer, stream temperatures rise with increased solar radiation. In some streams, temperatures may reach or exceed the upper limits preferred by salmonids (Fig. 2). Adequate flows are critical to maintain a cool, well oxygenated supply of water (Fig. 3). A sufficient volume of water is also necessary to dilute pollutants that may enter a stream (Stalnaker and Arnette 1976).

Salmonids, particularly anadromous species, have adapted their life cycles to seasonal changes in flow. Flow requirements for each salmonid species differ with life-history stage, size, and behavior. Increased streamflows in the fall and winter stimulate upstream migrations of anadromous adults. However, water velocities that exceed the swimming abilities of adult salmonids can prevent migrations to spawning areas. Table 1 summarizes approximate velocity and depth requirements for migration and spawning of some salmonids.

Habitat preferences and, hence, flow requirements of juvenile salmonids also vary. In spring and summer, young-of-the-year steelhead, for example, are found in shallow riffles, while rearing coho frequently occur in deep pools (Hartman 1965). Small juveniles tend to use the shallow margins of streams where water velocity is slow. Large juveniles, on the other hand, maintain positions in faster currents farther out in the channel, where feeding opportunities are greater. In general, the greatest number of aquatic insects occur in riffles with velocities of 1-3 ft/sec (Giger 1973).

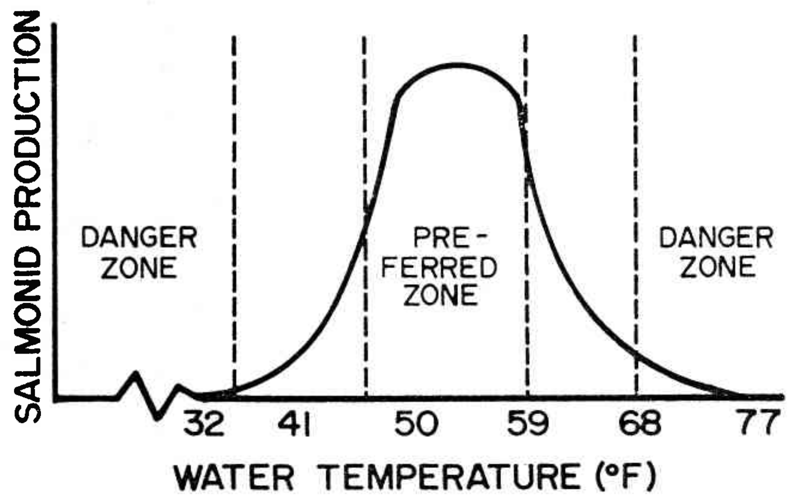


Fig. 2. Temperature preferences and danger zones for rearing and incubating anadromous salmonids [adapted from Brett (1952) and Everest et al. (1982)].

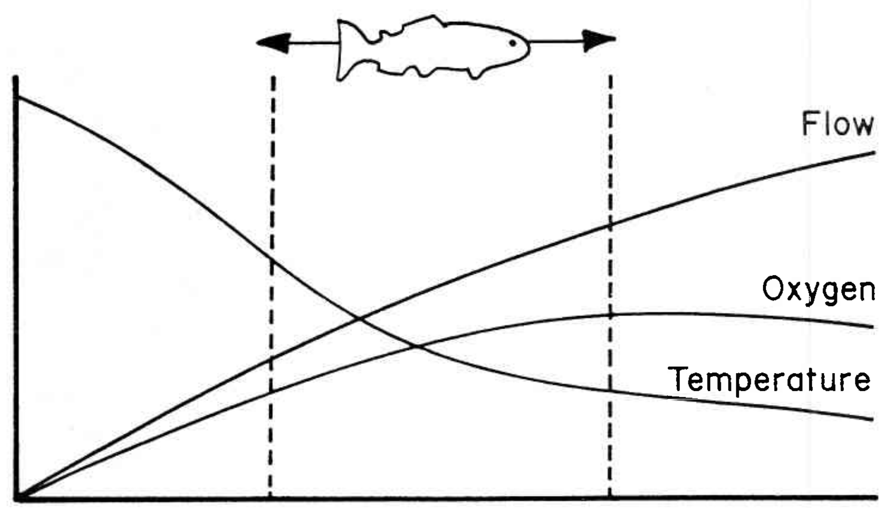


Fig. 3. Relationship of flow to summer water temperature and dissolved oxygen. (The range for optimum salmonid production is indicated by dashed lines.)

Table 1. Water depth and velocity preferences for upstream migration and spawning of selected adult salmonid species. [a]

Fish species	Migration [b]		Spawning		References
	Minimum depth (ft)	Maximum velocity (ft/sec)	Depth (ft)	Velocity (ft/sec)	
Fall chinook salmon	0.8	8.0	$\geq$0.8	1.0-3.0	Thompson (1972)
Spring chinook salmon	0.8	8.0	$\geq$0.8	1.0-3.0	Thompson (1972)
Summer chinook salmon	0.8	8.0	$\geq$1.0	1.0-3.6	[c]
Chum salmon	0.6	8.0	$\geq$0.6	1.5-3.3	Smith (1973)
Coho salmon	0.6	8.0	$\geq$0.6	1.0-3.0	Thompson (1972)
Sockeye salmon	0.6	7.0	$\geq$0.5	0.7-3.3	[d]
Steelhead trout	0.6	8.0	$\geq$0.8	1.3-3.0	Smith (1973)
Large resident trout	0.6	8.0	--	--	
Rainbow trout	--	--	$\geq$0.6	1.6-3.0	Smith (1973)
Cutthroat	--	--	$\geq$0.2	0.4-2.4	Hunter (1973)
Brown trout	--	--	$\geq$0.8	0.7-2.1	Thompson (1972)

[a] *Data summarized from Reiser and Bjornn (1979) and converted to English units. Original sources also cited.*
[b] *Migration data from Thompson (1972).*
[c] *Unpublished data of D.W. Reiser, Idaho Cooperative Fisheries Research Unit, Moscow, Idaho 1978.*
[d] *Estimated.*

Altered Flows

Changes in drainage patterns and the water retention of soils in developed areas alter streamflows and fish populations. Removal of vegetation also reduces infiltration of precipitation, and compacted soils from road-building and other disturbances increase runoff. Runoff is greater from heavily grazed watersheds than lightly grazed areas (Rauzi and Hanson 1966). Clearcutting on forest lands can increase annual flow, summer flow, and peak flows (Harr 1976; Toews and Brownlee 1981). Increased peak flows can accelerate bank erosion and sedimentation, alter the riffle-pool patterns in a stream, and reduce survival of salmonid eggs in the gravel and juveniles rearing in the stream.

Dams constructed for irrigation, flood control, and power generation change the natural flow patterns to which anadromous species have adapted. Alternate stranding, desiccation, and scour can occur below dams depending on the volume of water released. Water fluctuations below power facilities have caused mortality of eggs incubating in the gravel (Bauersfeld 1978) and reduced the production of food organisms for fish. Inadequate flushing below dams can increase sedimentation (Giger 1973).

Increasing costs of electricity and decreasing supplies of fossil fuel have stimulated interest in the development of small hydro [1] projects for power generation on streams in the Northwest. A study of potential sites for small hydro-power identified 1,443 reaches covering 7,626 miles of stream in Oregon (Klingeman 1979). A preliminary feasibility analysis narrowed that list to 56 sites or 374 miles of stream due to possible land use or environmental conflicts. However, the results of detailed evaluations of specific sites may change the status of many of the sites previously considered unfeasible (Kelly 1980).

Although the effects of an individual small hydro project may seem insignificant compared with large hydro-electric facilities, the cumulative impact of numerous small hydro-projects in Oregon streams is potentially great. Upstream passage of adult anadromous salmonids and downstream migration of juveniles are among the primary fishery concerns. Other potential environmental impacts downstream from projects include increased temperature, reduced flow, decreased insect drift, and decreased recruitment of spawning gravel, nutrients, and other material from upstream reaches (Kelly 1980). Impoundments above the generating facilities may inundate spawning areas.

In many portions of Oregon, summer flows are naturally low due to rapid spring runoff or minimal snowpack in upper watersheds and low summer rainfall. During the same time the demand for water for irrigation and other uses is maximum. As a result, many streams experience excessively low flows and high temperatures. Some of the river basins with inadequate streamflows from water withdrawals and high water temperatures were identified by ODEQ (1978).

---

1 "Small hydro" or "low-head hydro" have been defined as projects with capacity to produce a minimum power of 200 kw at least 50% of the time and with a drop or head 20 m (65.6 ft) or less (Kelly 1980).

Salmonid production in freshwater has been directly related to summer-early fall flows (Giger 1973). Low flows reduce the availability and quality of instream habitat for fish (Fig. 4). Depth, surface area, velocity, and oxygen decline as flows drop (Fig. 5) (Curtis 1959; Kraft 1972; unpublished data from Tom Nickelson, ODFW, Corvallis, OR). Since riffles are relatively shallow and consequently are subject to greater reduction from low flows, fish may be concentrated in pools, where competition and predation increases (Kraft 1972; USFWS and USNMFS 1981a). As flows subside, water temperatures may increase to stressful or lethal levels for salmonids. Growth declines at high temperatures, and the incidence and virulence of many salmonid diseases increases. High temperatures also favor competing and predatory nongame fish (USFWS and USNMFS 1981a). Fish may become stranded in isolated pools that eventually dry up.

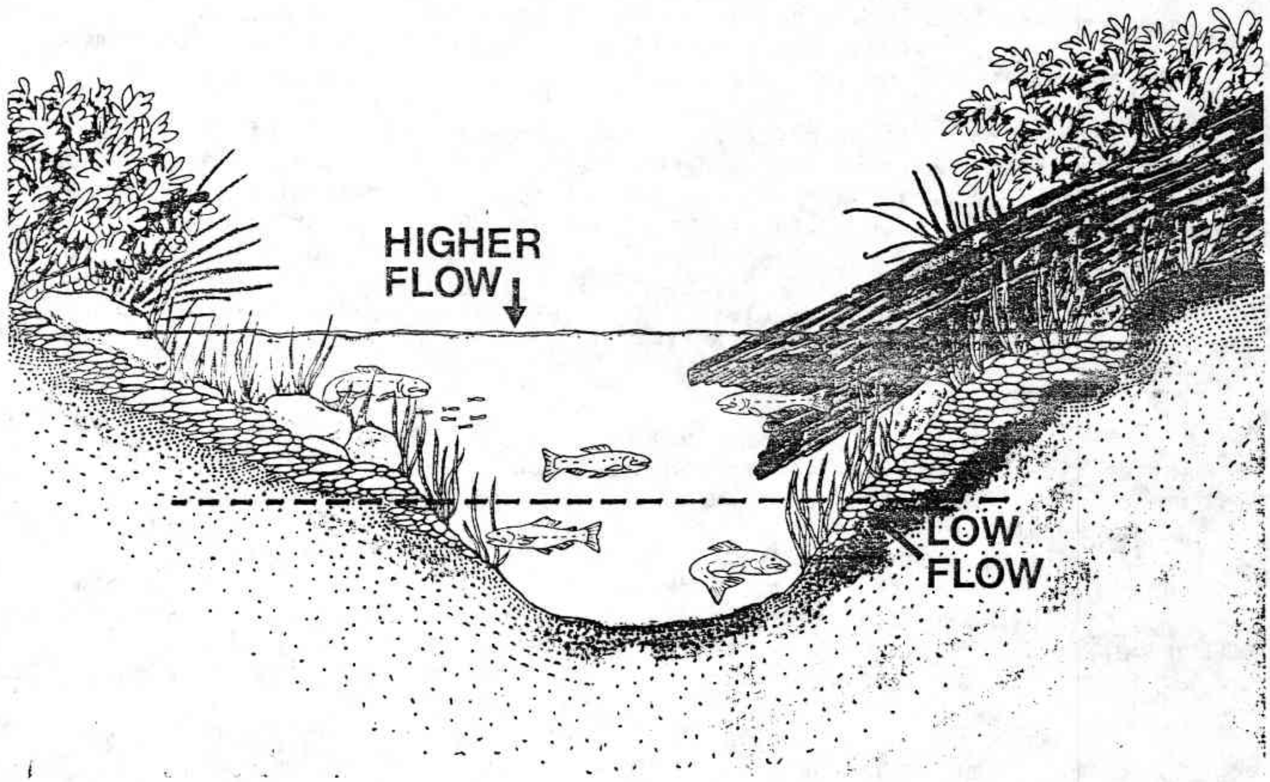


Fig. 4. Less habitat is available to salmonids and other stream organisms as flows decrease.

Low flows can also limit adult migration, spawning, and incubation of eggs. However, most of the salmonids inhabiting smaller streams during the summer low-flow period are juvenile steelhead and coho and resident trout. Juvenile rearing has been considered the most limiting stage of the life cycle for salmonids in many areas of Oregon (Pitney 1969). Low summer flows and high temperatures are among the most widespread fishery habitat problems statewide.

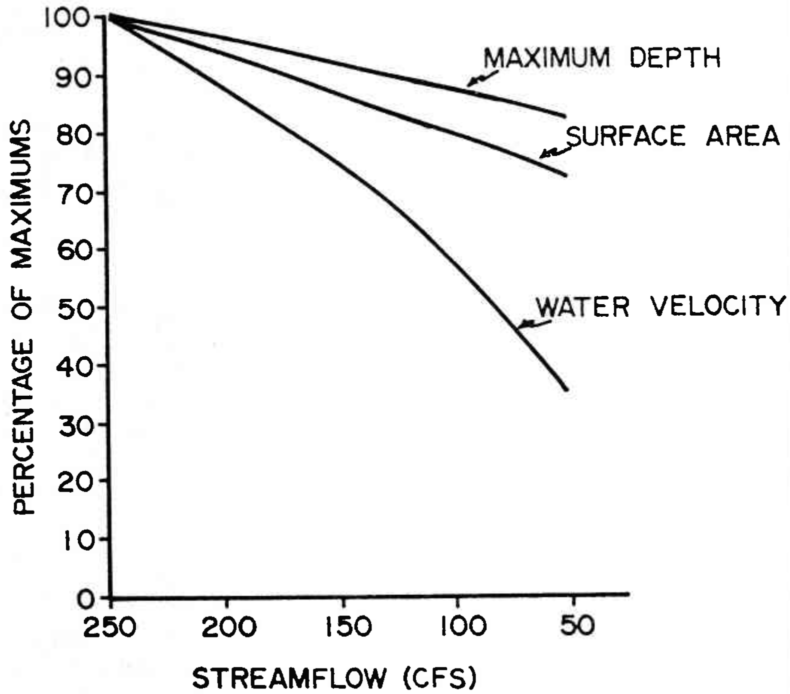


Fig. 5. Percentage change in depth, surface area, and water velocity with reduction in streamflow (from Curtis 1959).

Streamflow and Temperature Problem Areas in Oregon

Oregon coast

Although the Oregon coast typically receives 67 to 118 inches of precipitation annually, 75% to 85% of the rain falls between October 1 and March 31 (Franklin and Dyrness 1973). Low summer rainfall, short drainage systems, and small accumulations of snow in the coastal mountains cause naturally low streamflows and contribute to high water temperatures for many coastal streams from June through September. In some areas, water withdrawals for irrigation, municipal, and industrial uses further reduce naturally low water supplies to critical levels for fish life during the dry summer season.

Because of seasonal variations in precipitation, coastal streamflows fluctuate from very low in late summer to very high in winter. Seasonal ranges in flow for coastal drainages are illustrated by the Siuslaw River, where average flows in January 1980 were 50 times the values for the previous September (USGS 1980a, 1980b). Flows as low as 33 cfs and as high as 35,000 cfs have been recorded on the Wilson River in the Tillamook Bay drainage system (interview on 2/23/81 with David Heckeroth, ODFW, Tillamook, OR). Resident trout and anadromous species that rear in freshwater throughout the year must tolerate a wide range of streamflow conditions in coastal streams.

Low flows and high temperatures reach stressful or lethal levels during the summer in Tillamook Bay drainages, in the mainstem of the Alsea, Siletz, and Siuslaw rivers, and in south coast streams. On the mainstem Siuslaw, temperatures reach 87°F and prevent salmonids from rearing throughout the summer. Only a remnant run of adult spring chinook is able to survive temperatures in the Siuslaw River in a few deep holding pools (interview on 4/21/82 with Jerry McLeod, ODFW, Newport, OR). High temperatures and low flows may limit production of coho, cutthroat, and steelhead in the South Fork and mainstem Coos and in the Middle and South Fork of the Coquille, where temperatures typically reach >75°F (interview on 4/11/82 with William Mullarkey, ODFW, Coos Bay, OR).

In the Tillamook sub-basin, irrigation and municipal withdrawals are concentrated in the narrow coastal fringe. The heaviest irrigation in the North Coast Basin (Appendix Fig. 2) occurs along the lower Nestucca, Tillamook, Trask, and Wilson rivers. Other streams affected by irrigation withdrawals are the little Nestucca, Kilchis, and Miami rivers, and tributaries to Sand Lake. When updated minimum streamflows were approved for the North Coast Basin in 1972, the Water Policy Review Board noted that existing streamflows were not adequate to meet recommended minimum flows for fish life during the low flow season in Neskowin Creek and the Little Nestucca, Trask, Wilson, Kilchis, and Miami rivers (Oregon Water Policy Review Board 1978).

Summer flows are also less than the minimum recommended for fish life for many midcoast streams. Poor ground water retention (Smith and Lauman 1972) and industrial and irrigation withdrawals contribute to seasonal flow problems in the Midcoast Basin. Muncipal water demand is increasing. Revised minimum flow standards to protect fish life in the Midcoast Basin were adopted in 1975.

Interior valleys

East of the Coast Range and west of the Cascades, the Willamette Valley and interior valleys of southwestern Oregon experience a drier climate and greater temperature extremes than the Oregon coast. Amounts of rainfall decrease from north to south in the shadow of the coastal mountains (Franklin and Dyrness 1973). There is little rain during the summer months. In the lower Willamette Basin, only about 7% of the annual water yield occurs from June to October (Oregon Water Policy Review Board 1978). Consequently, low summer streamflows and high water temperatures are common in interior valley streams, particularly in the hot, dry regions to the south. Poor flow and temperature conditions are also characteristic of low gradient Willamette Valley streams fed from the east slope of the coastal mountains. Temperatures and streamflows in the Willamette and Umpqua river valleys reach critical levels for salmonids where there are significant withdrawals for irrigation and municipal and industrial uses and where land use practices have removed large stretches of streamside vegetation. District fishery biologists consider salmonid production to be limited by seasonally low flows and high temperatures in the Tualatin, lower Molalla, Yamhill, Long Tom, Coast Fork Willamette, and the South Fork Umpqua rivers.

Low flows occur in streams on the west side of the upper Willamette Valley and summer temperatures approach critical levels near the valley floor. Productivity of snow-fed streams draining the west slope of the Cascades may be limited by low temperatures and nutrient levels. Releases of very cold water from dams may reduce salmonid growth below some dams in the upper Willamette basin (interview on 6/10/82 with Jim Hutchison, ODFW, Springfield, OR).

Dams in the Willamette basin have improved summer flows and water quality below the facilities and in the lower Willamette River. However, some habitat problems have also resulted. Many miles of anadromous fish habitat were destroyed when the dams were built. Large fluctuations in streamflow below the dams can create additional problems for salmonids. Flow in the Long Tom River below Fern Ridge Reservoir is reduced to about 30 cfs in the summer, and high water temperatures are more suited to warm water species than to salmonids (interview on 6/10/82 with Jim Hutchison, ODFW, Springfield, OR). Draw-down of the reservoirs for flood control does not begin until September. High flows from fall releases can scour reaches below the reservoirs. Other impacts of reservoir operations in the Willamette system are flooding and desiccation of spawning areas, water temperature extremes, changes in smolt and adult migration timing and success, and mortality of downstream migrants passing through generator turbines (Buchanan and Wade 1982, 1983).

The Oregon Water Policy Review Board established revised minimum flows for the Lower Willamette Basin in 1976. The Board noted that natural flows were inadequate to meet actual demands or to satisfy existing legal rights for water from July 31 to September 15. Projected water demands for the lower Willamette are listed in Table 2.

Table 2. Water uses in the Lower Willamette Basin in 1976 and projected for 1985 (Oregon Water Policy Review Board 1978).

Water use	Consumption in 1976 (acre-feet)	Estimated consumption in 1985 (acre-feet)
Industry	120,000	240,000
Municipalities	90,400	226,000
Irrigation	90,000	200,000

Streamflows are naturally low in the Umpqua basin; however, water withdrawals further deplete instream water. Irrigation is the major consumptive water use in the Umpqua basin. Loss of riparian vegetation and sprawling rural development along Umpqua tributaries may further contribute to high temperatures in the basin.

Although minimum flows were adopted for streams in the Umpqua basin in 1974, flows are not adequate in the South Umpqua River to meet demands for all uses or to meet requirements for minimum perennial streamflows for fish life in most years (Oregon Water Policy Review Board 1978). In 1980, for example, average flows during August and September were less than recommended minimum flows. Temperatures reach 90°F at the mouth of the North and South Umpqua and are generally high throughout the South Umpqua. Summer flows in the main river frequently decrease to 90 cfs and occasionally reach 60 cfs. In the South Umpqua the spring chinook salmon run has declined to low levels and summer steelhead do not occur as a result of poor temperature and flow conditions. Minor fish kills from high temperatures during the summer have been reported on the mainstem Umpqua (interview on 3/9/82 with Dave Anderson, ODFW, Roseburg, OR).

Low water temperatures are critical for summer runs of steelhead and chinook in the North Umpqua. Flows in the North Umpqua are generally adequate to satisfy recommended minimum flows and temperature requirements for salmonids. However, temperatures are relatively high near Roseburg. Loss of riparian vegetation from logging and other land uses may be responsible for excessive summer temperatures in Rock Creek, a tributary of the North Fork Umpqua. Most of the wild summer steelhead in the North Umpqua spawn and rear in the Steamboat Creek system, where temperatures are approaching critical levels (interview on 3/9/82 with David Anderson, ODFW, Roseburg, OR).

Eastern Oregon

East of the Oregon Cascades average annual precipitation is only 10-20 inches. The climate is more extreme than in western Oregon: winters are colder, summers are hotter, and daily temperatures typically fluctuate 18°-30°F (Franklin and Dyrness 1973).

High summer-low winter temperatures and low streamflows are the primary limiting factors for salmonid production in many streams east of the Cascades. Streamflows below recommended levels occur in late summer and early fall in the Grande Ronde, Umatilla, and John Day rivers. An example of extreme annual water temperature variation is shown in Fig. 6 for the lower John Day River. In 1980 temperatures in the John Day dropped to freezing in January and February and peaked above 86°F in midsummer. Daily temperature fluctuations of 11° to 14°F were recorded in August and September.

Effects of water withdrawals

Because of the low precipitation and hot summers, water for irrigation is in high demand in eastern Oregon. Water withdrawals seriously reduce streamflows where supplies are naturally low. Water rights often in excess of streamflows and lack of satisfactory minimum flow requirements result in inadequate protection for fish in many rivers and streams east of the Cascades. In the Malheur and Owyhee river basins, for example, there is practically no unappropriated water. To satisfy all legal water rights on the Malheur River, the average annual water yield would need to double. Legal rights are 125% of the annual yield of the Owyhee River (Malheur County Planning Office 1981).

Water withdrawals and overgrazing seriously reduce summer flows in Deep, Bakeoven, Buckhollow, and Trout creeks, the principal summer steelhead spawning and rearing tributaries of the Deschutes River (Table 3). A habitat restoration project is planned for Trout Creek to improve cover, streamflows, and channel stability.

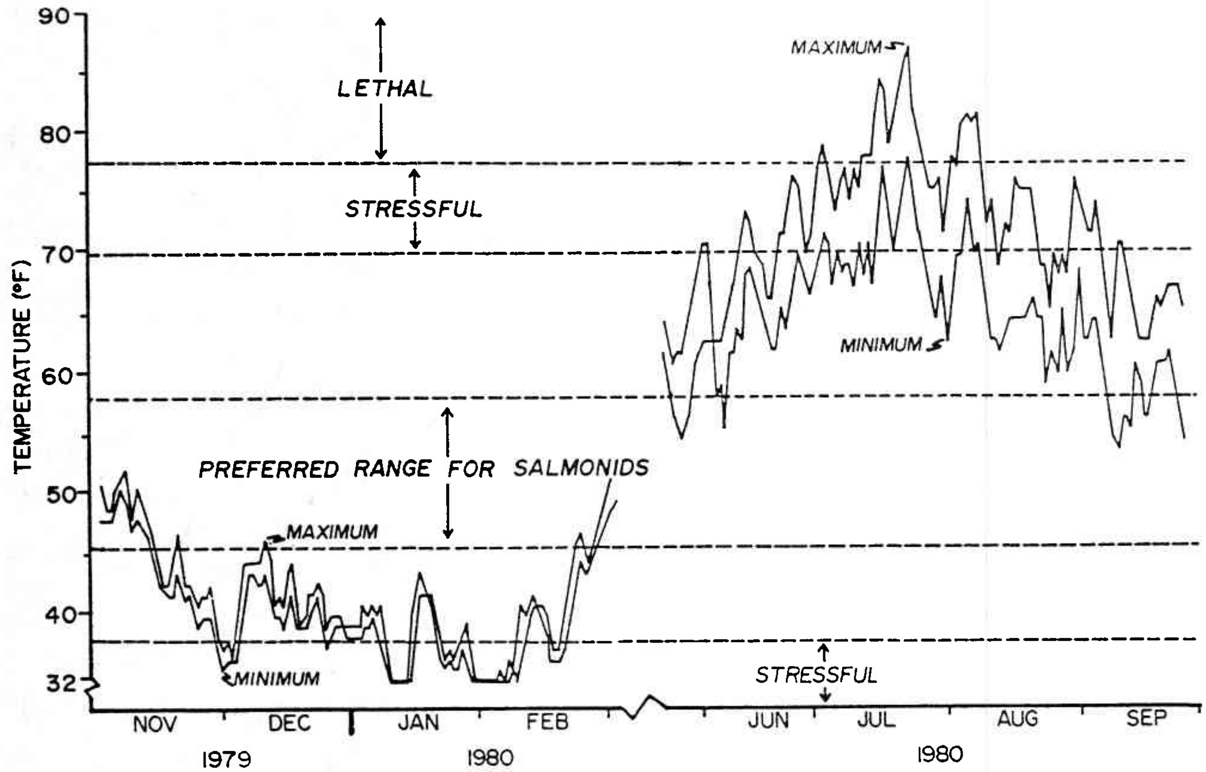


Fig. 6. Minimum and maximum daily temperatures on the mainstem John Day River at McDonald Ferry, Oregon, November 1979-February 1980 and June-September 1980 [data from USGS (1980a)].

Table 3. Mean September flows and temperatures for selected tributaries in the Deschutes River basin (USFWS and USNMFS 1981a).

Stream section (river mile)	Mean flow (cfs)	Mean temperature (°F)
Deep Creek:		
12.6 to 9.7	0.0	65
Bakeoven Creek:		
9.7 to 5.2	0.0	65
5.2 to 0.0	0.1	63
Buckhollow Creek:		
26.5 to 19.2	0.0	66
19.2 to 14.7	0.0	66
14.7 to 5.8	0.1	66
5.8 to 0.0	0.1	66
Trout Creek:		
41.9 to 36.1	0.0	64
36.1 to 25.8	0.1	64
25.8 to 12.5	0.1	64
12.5 to 0.0	0.3	71

In the Umatilla River summer flows often drop to 35 cfs between McKay Creek and Pendleton due to withdrawals. Below Pendleton summer temperatures reach stressful levels for salmonids, and nongame fish are abundant. There is little or no late summer flow in the lower Umatilla River below Coal Springs diversion or in the Walla Walla River below the town of Milton-Freewater. Low flows, subterranean flows, and lack of pools limit rearing habitat for salmonids in the lower 15 miles of Meacham Creek. Approximately 30%-40% of the steelhead in the Umatilla basin spawn in Meacham Creek (interview on 9/23/82 with James Phelps, ODFW, Pendleton, OR).

In the Grande Ronde River basin, flows in the late fall, winter, and early spring are frequently less than recommended for fish life (Smith 1975). Irrigation withdrawals and low flows are severe on the mainstem Grande Ronde between La Grande and the Wallowa River and on the Powder and Wallowa rivers (interview on 9/21/82 with Duane West, ODFW, La Grande, OR). Smith (1975) noted that water in the Lostine River, Bear Creek, and Hurricane Creek is greatly overappropriated, and many smaller streams in Joseph and Cottonwood creek drainages have inadequate summer flows.

All Owyhee basin streams suffer from low flows. Thompson and Fortune (1969) identified critical problems on the Middle Fork Owyhee and Little Owyhee rivers; and on Jordan, Cow, Antelope, Pole, Bogus, Rattlesnake, and Dry creeks. Water temperatures in the mid-80s (°F) are common throughout the basin. The first 10 miles below Owyhee Reservoir support an excellent trout fishery due to cool water released during the irrigation season, but low winter flows are a limiting factor. Below this reach, flows are diverted, summer temperatures are high, and trout are replaced by warmwater species (interview on 6/12/82 with Steve Pribyl, ODFW, Ontario, OR).

Return water from irrigation diversions increases stream temperatures in parts of the Klamath, Umatilla, Owyhee, and Malheur basins. Nongame fish species are favored and outcompete salmonids where return water is warm, extremely turbid, and contaminated with agricultural chemicals. Irrigation diversions, low summer flows, and high temperatures create poor stream conditions for salmonids in the upper Middle Fork Malheur (above Warm Springs) and the South Fork Malheur. The lower Malheur from Namorf Dam to the Snake River is a maze of irrigation and waste water return systems and will not support salmonids.

Effects of reservoirs

Storage reservoirs and hydroelectric dams have altered natural streamflows and blocked passage for anadromous salmonids in much of eastern Oregon. Runs of chinook salmon into the mid- and upper Klamath basin (in Oregon) have been blocked by dams since 1917. Fortune et al. (1966) listed seven impassable dams and 10 unscreened irrigation diversions on the South Fork Sprague River in the Klamath basin. In the Umatilla basin, numerous dams and diversions block anadromous fish passage and prevent intrastream movement by fish. Problem areas include dams on Willow Creek and McKay Creek. Dams on the Snake River have blocked upstream migration of anadromous salmonids to the Powder River, Owyhee River, and Malheur River basins since the 1950s. The last reported capture of a juvenile chinook salmon in the Owyhee River was in 1954, 4 years prior to construction of Brownlee Dam on the Snake River (interview on 6/16/82 with Steve Pribyl, ODFW, Ontario, OR).

Storage reservoirs in central and eastern Oregon create low flow problems for fish during periods when water is stored for the irrigation season. Little or no winter flow below reservoirs limits fish production on the Lost River (Klamath basin), McKay Creek (Umatilla basin), and numerous reservoirs in the Malheur and Owyhee basins including Beulah (North Fork Malheur), Warm Springs (Middle Fork Malheur), and Owyhee (upper Owyhee River) reservoirs. Low winter flows contribute to icing in streams below these reservoirs. Examples of extreme low winter flows on McKay Creek, Owyhee River, and Malheur River are shown in Table 4.

Table 4. Winter flows below reservoirs on the Malheur and Owyhee rivers and McKay Creek, 1979-80 (USGS 1980a).

	Gauge		Flow (cfs)					
Stream	Location	Number	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
McKay Cr.	Near Pendleton	14023500	1	0	0	0	0	0
Owyhee R.	Below Owyhee Dam	1318300	90	5	4	4	7	153
Malheur R.	Below Warm Springs Dam	13215000	103	<0.1	<0.1	<0.1	0.1	0.1

Ironically, high flows are also a problem for fish below dams on the Malheur and Owyhee rivers in years when reservoirs fill to capacity and release excess water prior to the irrigation season. Large fluctuations in flow are also a problem for fish in the mainstem Klamath River, where flows can vary from 400 to 3,000 cfs in a single day due to operation of hydroelectric facilities (interview on 6/9/82 with John Fortune, ODFW, Klamath Falls, OR). Moderation of discharge schedules is a prerequisite to restoration or enhancement of salmonid production in rivers below many dams.

Protection of Minimum Streamflows

Maintaining adequate streamflows for fish is often in direct conflict with other water needs, particularly consumptive uses. In 1955 the Oregon Legislature enacted a water code that created the Water Policy Review Board. The law identified 10 beneficial uses for Oregon streams that included recreation and fish and wildlife. Priority was given for domestic and livestock consumption over other beneficial uses. Oregon law (ORS 536.310) directed the Water Resources Board to consider "the maintenance of minimum perennial streamflows sufficient to support aquatic life." By 1978 approximately 400 minimum flows had been established under this statute (USFWS 1978).

The methodology to determine recommended flows for fish has gradually evolved over the years. Early flow recommendations were established for an entire year based on an average of the three consecutive lowest flows on record (Pitney 1969). New methods have been developed that provide more adequate protection to fish throughout the year. Currently, ODFW recommends monthly minimum flows for salmonids based on field measurements at many sites within a stream system to estimate adequate water supplies for migration, spawning, incubation, and rearing. Stream depth and velocity are the principal criteria used to determine flows needed during each phase of the salmonid life cycle. For example, recommended minimum flows for passage of adults are based on adequate depth for passage over 25% of the total stream width. Recommended spawning flows are based on the percentage of total spawning gravel available over a range of stream flows (Pitney 1969) (Fig. 7). Although recommended flows are based on volumes "sufficient to support aquatic life," these are generally less than flows needed for optimum fishery production.

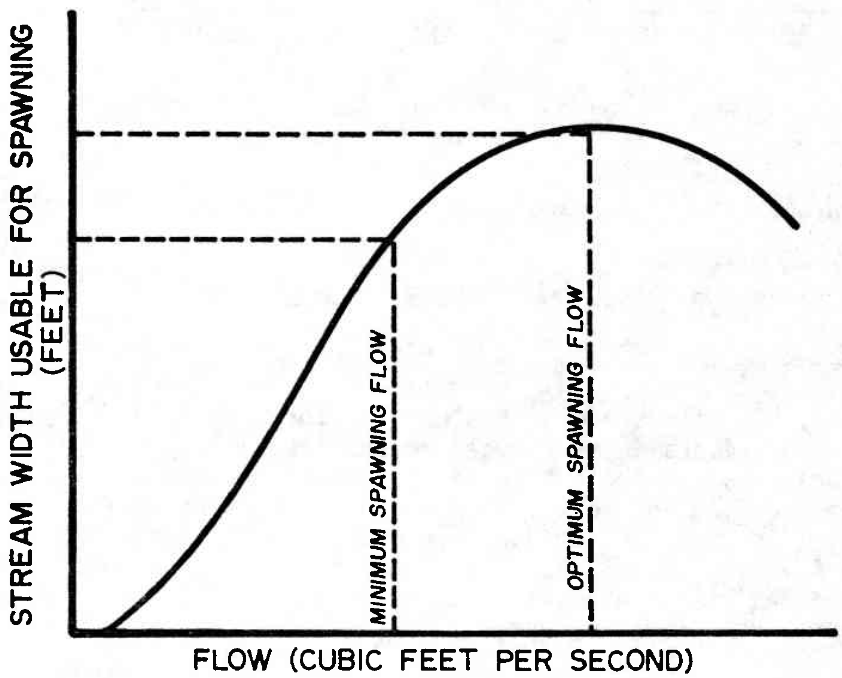


Fig. 7. Usable width technique for determining required spawning flow. Recommended flows are approximately 80% of optimum flows (Thompson 1972).

The Cooperative Instream Flow Service Group (IFG) of the U.S. Fish and Wildlife Service has developed the most sophisticated approach to date for determining minimum flow requirements. The IFG method is similar to the ODFW method but uses computer simulation to integrate hydraulic, water quality, and biological factors. The IFG method also offers analysis of flow requirements for warmwater fish. The IFG method is being tested in Oregon to plan specific water development projects. Preliminary indications are that the Oregon and IFG methods produce comparable results (interview on 12/9/83 with Lou Fredd, ODFW, Portland, OR).

Streamflow protection for fish remains inadequate in many areas of Oregon. The process of establishing instream flow requirements for fish throughout all river basins in the state is a long and difficult task. The update of minimum flow requirements based on ODFW recommendations has proceeded very slowly. Decisions regarding water allocations and flow recommendations must balance conflicting needs and desires of many agencies and users. ODFW minimum flows are recommendations to the Water Policy Review Board, and their implementation is not guaranteed.

ODFW has recommended minimum flows for fish and wildlife in a series of basin reports to the state Water Policy Review Board (e.g., Lauman et al. 1972). Senate Bill 225, which was passed in August 1983, required ODFW and ODEQ to submit a list of priority streams for application for minimum streamflow standards. The list submitted includes 75 locations for consideration by the Water Policy Review Board. The Board is required to act on these applications by January 1, 1986.

The objective of a minimum flow requirement is to protect rather than restore or augment flows. In many locations in Oregon, water rights have been granted in excess of the water available in a stream. Instream flow standards offer no protection in areas where water has been overappropriated. New instream flow rights are subordinate to existing appropriations. Continued water appropriation may cause additional problems in low water years if junior water appropriators petition for suspension of minimum streamflow requirements.

In 1983 the Oregon Legislature passed SB 523 to develop water management plans for 18 river basins. The plans will be prepared jointly by nine separate state agencies to integrate management of the quality and quantity of surface and groundwater. A pilot mangement plan will be developed for the John Day basin.

Despite the inherent legal and biological problems associated with water appropriation and instream flow policies, the minimum flow standard remains a primary tool for protection of water for fish in many Oregon streams. New minimum flow recommendations are especially needed to protect fisheries where flows have not been overallocated.

Another method used to protect streamflows for fish resources is the designation of "beneficial use." For example, the Water Policy Review Board has classified numerous streams in the North Coast Basin to protect fish and wildlife from downstream diversions for irrigation, municipal, and industrial purposes.

Flow Enhancement

Where water demands are high, minimum flow requirements often exceed available streamflow during critical periods of water use. In some river basins water storage projects may augment low streamflows. Permits for water releases from reservoirs have been issued to ODFW to increase streamflows. In a few rivers where minimum flow standards have been established, stored water has been purchased for release from reservoirs during low flow periods (USFWS 1978).

Dams, diversions, and other water projects constructed specifically for fisheries habitat restoration have not been widely tested. Designation of fishery benefits as partial justification for the Lost Creek and Applegate dams on the Rogue River was a relatively new concept when the projects were authorized by Congress in 1961. Enhancement was anticipated through improved temperature and flow conditions for wild salmon and steelhead below the dams. However, upstream spawning and rearing habitat was lost. Spring chinook losses due to Lost Creek Dam, for example, were estimated to be 33% of the average escapement. Cole Rivers Hatchery was built to mitigate for those losses.

The long-term benefits and negative impacts of controlled flows from storage projects are largely unknown. An intensive study began in 1974 to evaluate the effects of the Rogue dams and to establish operating criteria necessary to achieve fishery benefits.

Other storage projects are now under consideration to improve instream flows for Oregon fisheries. In the Umatilla basin, a large number of project alternatives have been identified to enhance anadromous fish runs and to meet other water needs in the basin (United States Bureau of Reclamation 1983). One plan involves pumping water from the Columbia River in exchange for water storage in McKay Reservoir. Reservoir storage would be available to increase flows in the lower Umatilla from September through November.

Water storage is also considered as an alternative to ease flow problems in the South Umpqua River. Releases from Galesville Reservoir under construction on Cow Creek will improve summer water temperatures and flows downstream where temperatures reach 80°F and flows now decrease to 12 cfs (interview on 3/9/82 with David Anderson, ODFW, Roseburg, OR). Douglas County has identified a number of potential dam sites in the South Umpqua system.

Potential fishery benefits from water storage projects in Oregon are based on the premise that appropriate seasonal instream flows can be reserved for fish. Long term benefits from new water projects must also be evaluated against net fishery losses resulting from the impoundment. Intensive research is required before and after project construction to evaluate project impacts and to determine whether anticipated benefits are fully realized. Water storage as a potential fishery enhancement tool is limited to those sites where the benefits of increased flow outweigh other environmental consequences. Unfortunately, these other environmental consequences frequently may not be evident until after a reservoir project has been completed.

In the past, water storage projects for power, irrigation, and flood control have severely damaged anadromous fish runs in Oregon, particularly in the Columbia and Willamette river systems. We are still trying to correct fishery problems and mitigate losses that have resulted from the construction of dams throughout the state.

Restoration of riparian habitat also may help remedy low flow problems for salmonids, particularly in eastern Oregon. Although the estimated increases in flow from riparian restoration may be small in comparison to impoundments, resulting increases in salmonid production could be substantial (Fig. 8), especially when the other benefits of a healthy riparian zone are included.

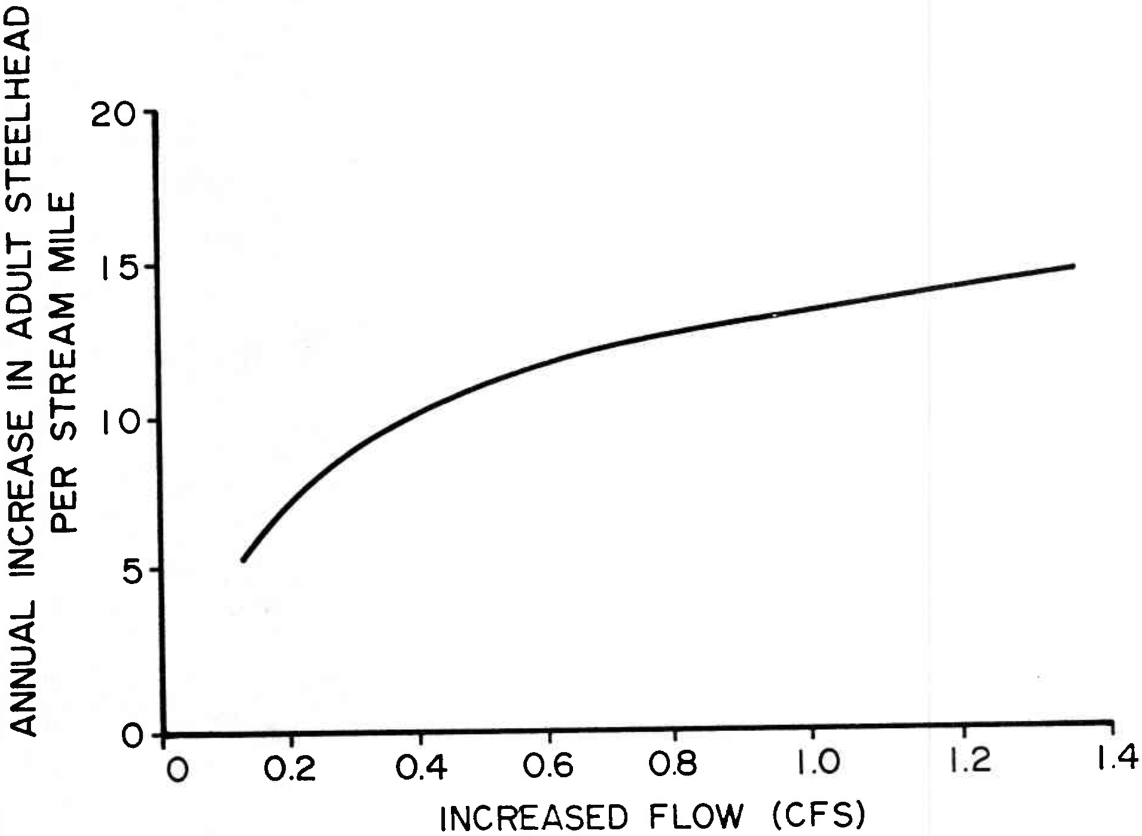


Fig. 8. Estimated increases in spawning adult steelhead from streamflow increases due to riparian restoration (adapted from USFWS and USNMFS 1981a).

RIPARIAN HABITAT

Characteristics and Salmonid Requirements

The riparian zone consists of the area adjacent to and influenced by the stream (Fig. 9). The vegetation associated with the riparian zone has profound effects on the physical make-up of the stream habitat as well as the biological communities of which salmonids are a part.

Erosion control

Root masses along streambanks prevent erosion and stabilize the channel. During high flows, flood crests are dispersed, and water velocity and erosive power are reduced. Riparian vegetation filters fine sediment, debris, and other pollutants such as pesticides and herbicides in runoff from upland sources (Karr and Schlosser 1977).

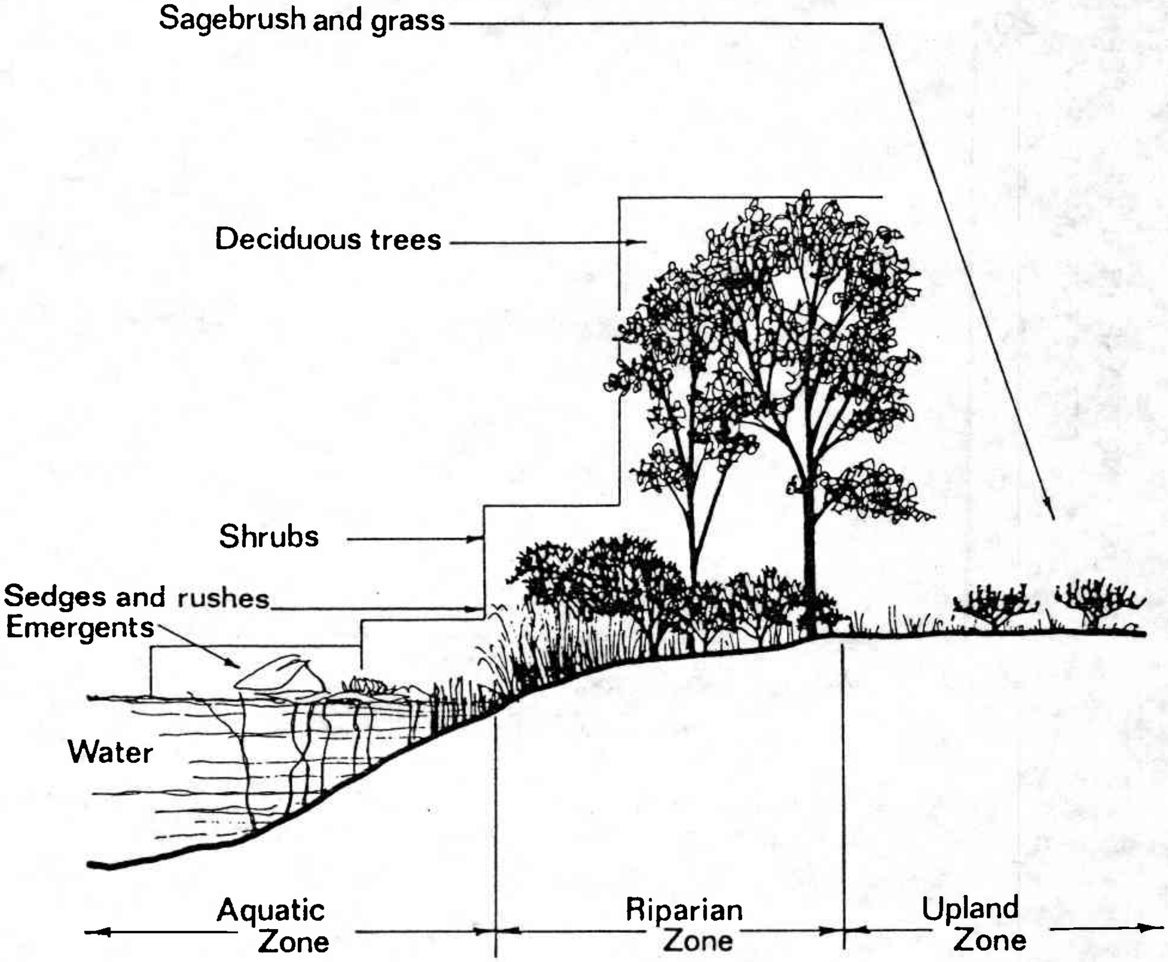


Fig. 9. The riparian zone is defined by vegetation that requires moister soil conditions than occur in surrounding upland areas (Thomas et al. 1980).

The Riparian Habitat Committee (1979) recommends that at least 80% of the length of streambanks be in a stable condition to maximize salmonid production (Fig. 10). Bank stability can be rated on the following criteria: mass wasting, upper bank vegetation, rock content of lower bank, and lower bank cutting. Procedures for evaluating these criteria are discussed by Cooper (1978).

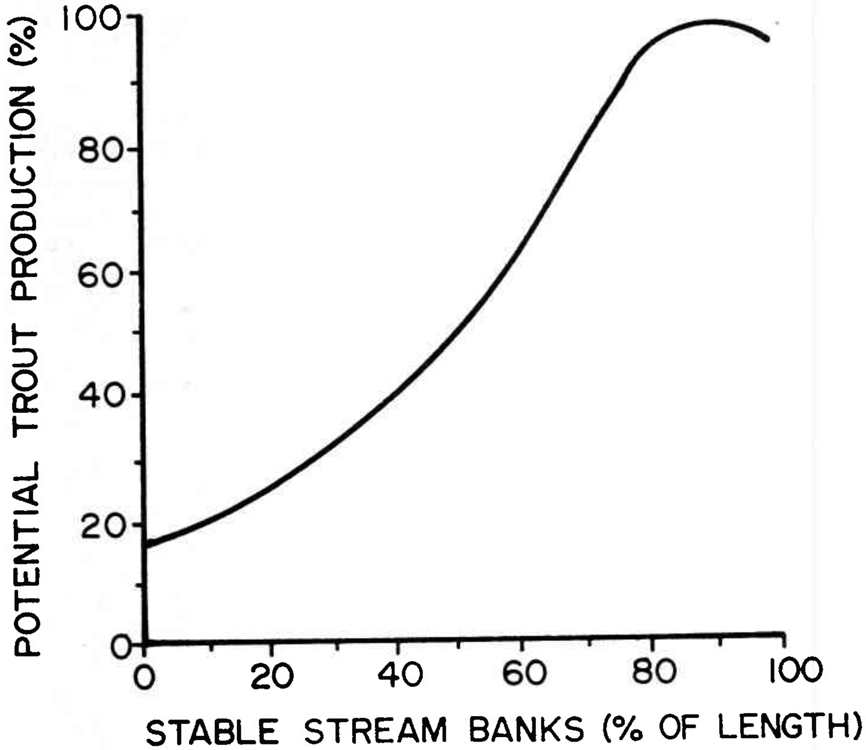


Fig. 10. Trout production in relation to streambank stability (Riparian Habitat Committee 1979).

Flow

The riparian zone acts as a reservoir, storing surplus runoff and dampening discharge fluctuations. This "sponge effect" increases the capacity of a stream's aquifer to retain water during periods of precipitation for gradual release during the summer and early fall. Investigations of several streams in Crook County suggest that the riparian zone helps maintain perennial flows during dry periods (USFWS and USNMFS 1981a).

Temperature control

In addition to enhancing the temperature regime by augmenting streamflow, a vegetated riparian zone creates a canopy that shields the stream from solar radiation. This prevents water temperatures from reaching stressful or lethal levels for salmonids during the summer. In winter the insulating properties of riparian vegetation may keep streams from freezing and thereby increase the overwinter survival of fish and other aquatic organisms.

The influence of shading on salmonid production is shown in Fig. 11. In eastern Oregon it is recommended that 60%-80% of the stream surface should be shaded from 1000 to 1600 during June through September (Riparian Habitat Committee 1979). This standard applies mainly to streams less than 50 feet wide. The vegetation along large streams and rivers (greater than fifth order [1]) with wide channels may not be tall enough to provide that degree of shading even under natural conditions. However, greater depths and flows in larger streams help to keep water temperatures within salmonid requirements (Everest et al. 1982).

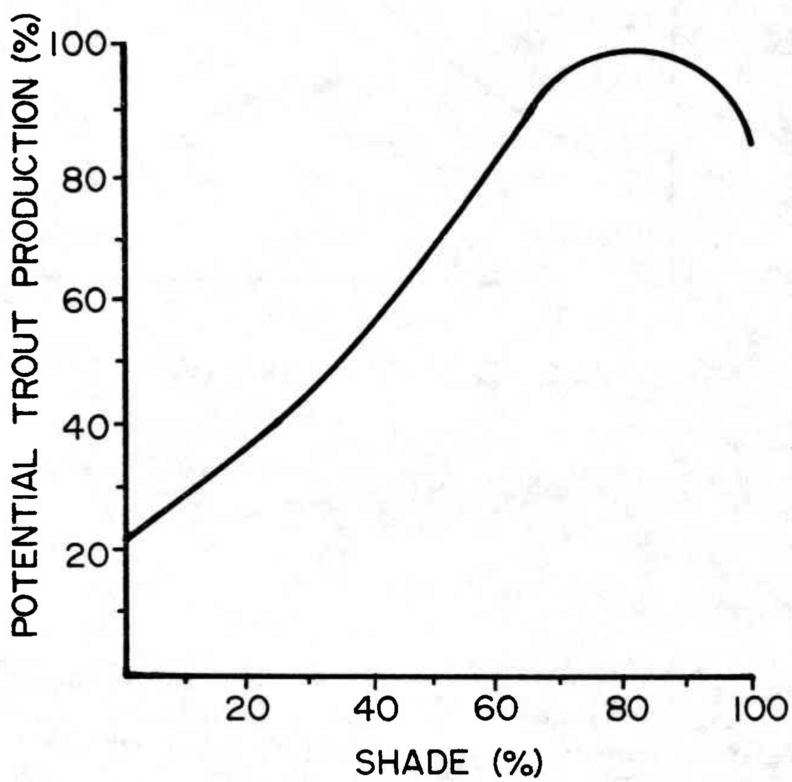


Fig. 11. Trout production in relation to surface shading of small streams (Riparian Habitat Committee 1979).

---

[1] *As defined by Strahler (1957), first order streams are unbranched tributaries. Streams below the junction of two or more first order streams are second order; third order streams are below the junction of two or more second order streams; etc.*

Cover

Vegetation along the stream perimeter also provides fish with cover to escape predation and disturbance, and refuge from high velocity water in the channel. Riparian vegetation allows controlled undercutting along sections of the streambank. Undercut banks, overhanging vegetation, and other forms of overhead cover are the preferred habitat of many juvenile salmonids (Hartman 1965; Chapman 1966; Allen 1969; Everest 1969; Mundie 1969; Everest and Chapman 1972). Numerous studies have documented declines in salmonid abundance after removal of cover and increases in abundance after reestablishment of cover (Reiser and Bjornn 1979).

Structure

A large proportion of the structure in streams in forested areas is derived from trees in the riparian zone. Large woody debris creates much of the habitat diversity necessary for salmonid production in the stream channel and off-channel areas (Sedell et al. undated). Logs and root wads in the stream trap sediment and nutrients, form pools, and provide cover. In essence, they create the variety of depths, velocities, and substrates utilized throughout the freshwater residence of salmonids (Everest et al. 1982).

Food supply

Terrestrial insects that fall from riparian vegetation are a major source of food for salmonids (Reiser and Bjornn 1979). In fact, most of the energy that fuels small streams (orders 1-3) is derived from terrestrial sources (Cummins 1974). Leaves and other organic material from riparian vegetation are the principal food source for aquatic invertebrates that also dominate a salmonid's diet (Minshall 1967; Meehan et al. 1977).

Effects of Riparian Losses

Land use practices have reduced the amount and quality of riparian habitat. The primary sources are livestock grazing, mining, water development, irrigation, road construction, farming, urbanization, and timber harvest (American Fisheries Society 1980). Overgrazing, in particular, has been recognized as one of the most important factors limiting the fish and wildlife production in Oregon and other western states (Saltzman 1976; Platts 1981).

The destruction of riparian habitat can significantly alter all of the major components of the stream ecosystem (Fig. 1), resulting in decreased salmonid production. Soil compaction and reduced infiltration increase runoff and alter flow patterns (Platts 1981). High flows following snow melt and storms can entrench the channel and lower the water table. Riparian plant communities may be replaced by drier habitat species, such as sagebrush (USFWS-USNMFS 1981a). Winegar (1977) suggests that some perennial streams have become intermittent during the summer due to the loss of riparian vegetation.

When vegetation is removed from the streambanks, erosion accelerates, the channel becomes unstable, and the deposition of fine sediment in spawning, rearing, and aquatic insect production areas increases. The stream profile flattens as the channel becomes wider and shallower, exposing more surface area to solar heating (Fig. 12). As the abundance and diversity of plant species declines, the loss of cover and shade further increase water temperatures (Platts 1981) (Table 5).

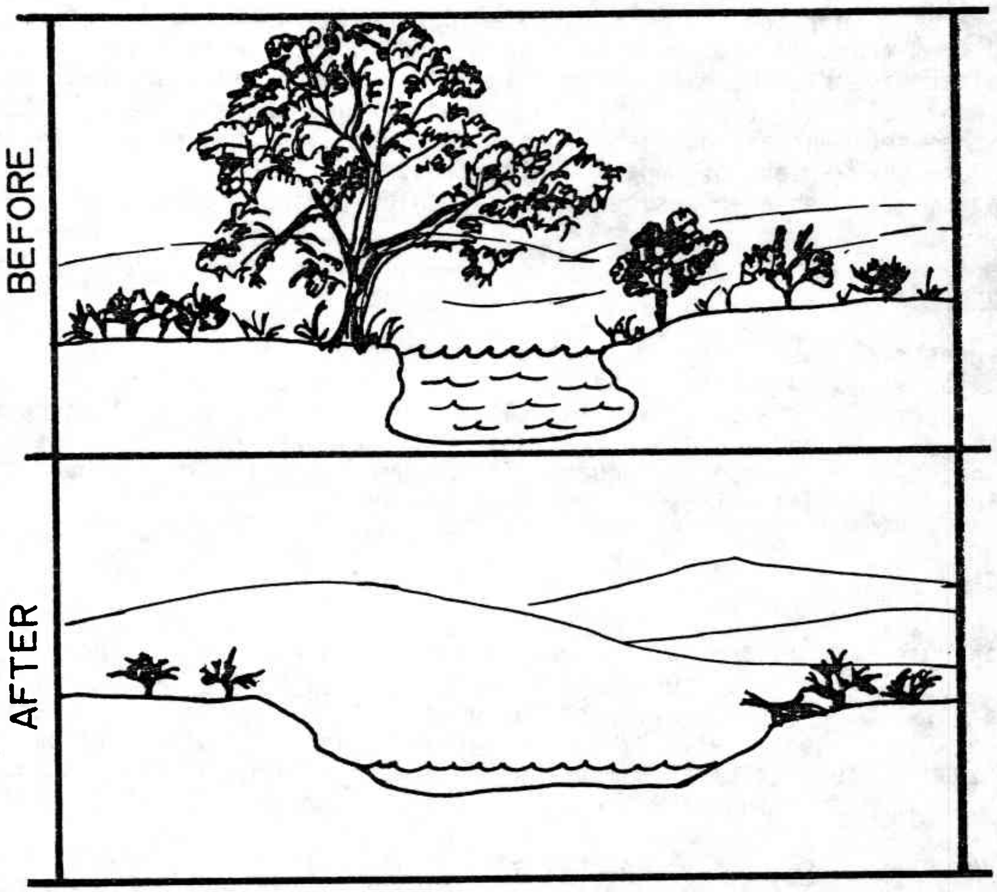


Fig. 12. Changes in cross-sectional channel profile due to riparian degradation.

Table 5. Cover, shade, and water temperatures associated with good and poor riparian zones on selected streams in eastern Oregon (USFWS and USNMFS 1982).

River system, stream	Condition of riparian zone: Shade (%) Good	Shade (%) Poor	Overhead cover (%) [a] Good	Overhead cover (%) [a] Poor	Average max. August temp. (°F) Good	Average max. August temp. (°F) Poor	Max. temp. difference (°F)
Deschutes River:							
Trout Creek	63	26	33	6	68	72	4
John Day River:							
South Fork	50	4	29	8	61	66	5
Camp Creek	68	23	55	14	61	66	5
Silvies River	20	22	18	9	64	64	0
Grande Ronde River:							
Peavine Creek	89	15	66	12	64	67	3
Elk Creek	61	10	41	13	66	66	0
Devils Run	81	7	39	15	63	70	7
Mean	61.7	15.3	40.1	11.0	63.9	67.3	3.4

[a] Undercut bank, root masses, and vegetation.

The effects of increased solar radiation on salmonid production depend on stream order, location, flow, and initial water temperature. In small streams originating on the west slope of the Cascades, for example, removal of the canopy from streamside clearcuts stimulates algal and periphyton production, which enhances salmonid production further up the food chain (Gregory 1980; Murphy and Hall 1980). In studies in the Clearwater drainage in Washington (Martin et al. 1981), water temperature increases associated with logging were within tolerable limits for salmonids. However, in the Coast Range and semi-arid areas east of the Cascades in Oregon, temperature increases due to the loss of riparian shading can be excessive, especially when combined with reductions in flow from irrigation withdrawals (Hall and Lantz 1969; USFWS and USNMFS 1981a). Although water temperatures rarely reach levels lethal to trout, increases to stressful, sublethal levels can ultimately reduce survival, and the cumulative effects of high temperatures in upstream tributaries can limit production in downstream reaches (Everest et al. 1982).

The daily maximum water temperatures in seven study streams in eastern Oregon averaged 3.4°F higher in sections with little riparian vegetation (Table 5). Those differences would probably have been greater had the good riparian areas not been affected by temperature increases from water passing through upstream sections with poor riparian cover. Other streams in Oregon with more extensive riparian cover have average temperatures 12°F lower than sections lacking riparian vegetation (Clair and Storch 1977). Stream segments referred to in Table 5 with natural riparian communities also had four times as much shade and overhead cover (USFWS and USNMFS 1982).

A major impact of the removal of riparian vegetation along forested streams is a reduction in instream and off-channel structure due to the harvest of large trees (Osborn 1980) (Fig. 13) . Other detrimental changes include reductions in litterfall and terrestrial insect drop (Everest et al. 1982).

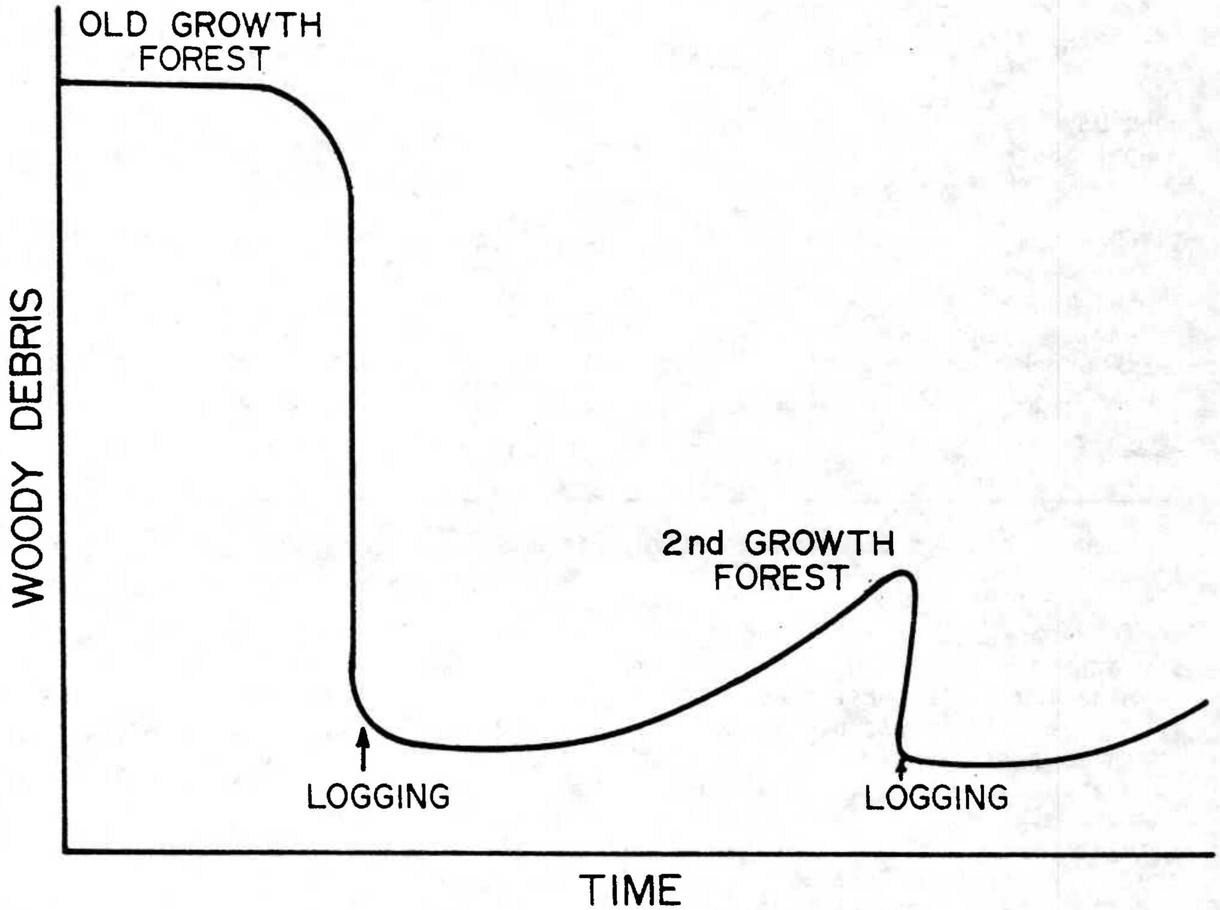


Fig. 13. Effects of logging on large woody debris in streams.

The relationship between the riparian zone and salmonid production can perhaps be best illustrated by a comparison of salmonid standing crops in stream sections with abundant versus little riparian vegetation (Table 6). In the seven streams in eastern Oregon sampled, the average salmonid biomass in sections with well vegetated riparian zones was almost five times greater than in sparsely vegetated sections (USFWS and USNMFS 1981a).

Table 6. Salmonid standing crops associated with good and poor riparian zones on selected streams in eastern Oregon (USFWS and USNMFS 1981a).

River system, stream	Good riparian		Poor riparian	
	Fish/1,000 ft	Lb/acre	Fish/1,000 ft	Lb/acre
Deschutes River:				
Trout Creek	1,750 [a]	35.3	280	8.5
Bakeoven Creek	2,227 [a]	207.9	237	7.9
John Day River:				
Middle Fork	353	47.6	134	16.1
Pine Creek	20	25.4	13	6.2
Silvies River	138	48.9	112	16.3
Grande Ronde River:				
Peavine Creek	342	130.5	259	44.9
Elk Creek	145	26.0	162	5.7

[a] *Includes 0+ age steelhead.*

Riparian Habitat Losses in Oregon

Oregon coast

Small farms are located in coastal valleys and floodplains and along low gradient streams to take advantage of a limited supply of pasture. In many areas small tributary streams used by anadromous salmonids have been channelized and rerouted to the edge of the pastures. Growth of riparian vegetation is frequently limited by grazing and continual scouring of the steep banks in channelized sections. Streams in these areas resemble straight, narrow ditches with little habitat structure and no streamside cover. Tributaries of Siltcoos Lake (south of Florence) and small streams in the Coos Bay drainage exemplify this type of riparian loss.

The riparian habitat along many streams throughout the Coast Range, particularly small tributaries where buffer strips are not required by the Forest Practices Act, has been impacted by logging. More than 50% of the watersheds (including riparian zones) inventoried in the Coast and Cascade ranges in the Salem District of the Bureau of Land Management have been logged, resulting in a large reduction in instream woody structure (Boehne and House 1983). Logging activities along headwater streams may aggravate temperature, turbidity, and sedimentation problems for salmonids in the Siletz, Siuslaw, and Umpqua drainages.

Interior valleys

In the interior valleys of Oregon, riparian losses most frequently result from agricultural practices and rural and urban streamside development. Farming to the edge of the streams has increased erosion and field loss in many areas of the Willamette and Umpqua valleys. Lack of riparian vegetation may contribute to high sediment loads, bank erosion, and shifting channels along the lower Molalla River (interview on 12/28/81 with John Haxton, ODFW, McMinnville, OR). Bank erosion is severe on the North and South Yamhill and has resulted in extensive bank stabilization projects. In the Tualatin River, severe erosion occurred as a result of floods in 1964 and continued removal (or lack of regrowth) of riparian vegetation on agricultural land (interview on 12/30/81 with Jay Massey, ODFW, Clackamas, OR). Vertical banks up to 17 ft high occur in the stretch of river between Gaston and Cherry Grove. Extensive revetments to stabilize channels and prevent loss of land along the Willamette River and lower portions of its tributaries have reduced riparian habitat in the valley. Rural residential development has caused scattered losses of riparian habitat along much of the McKenzie River. Similar problems on tributaries to the South Umpqua River may contribute to temperature and flow problems in the drainage.

Eastern Oregon

The most devastating losses of streamside vegetation in Oregon occur east of the Cascades, where stream cover and shade are most needed to moderate the effects of extreme seasonal temperature fluctuations and low water supplies. Most of these losses are caused by overgrazing; however, in localized areas, agricultural practices, timber harvest, road building, and stream channelization have also caused significant losses. Table 7 illustrates the extent of riparian problems in central and eastern Oregon. Detailed summaries by stream segment are provided in a series of habitat planning reports (USFWS and USNMFS 1981a, 1981b, 1981c, 1982).

Table 7. Riparian habitat losses for mainstem and tributary reaches in the Deschutes, Grande Ronde, Umatilla and John Day river basins. [a]

		Area requiring riparian restoration		
Drainage system	Stream miles inventoried	Miles		Percentage of inventoried reach
Deschutes	178	150		84
Umatilla	422	294		70
Lower Grande Ronde	352	206		59
Upper Grande Ronde	409	154		38
Upper mainstem John Day	320	128		40
North Fork John Day	817	447		55
Middle Fork John Day	432	159		37
South Fork John Day	132	56		42
Total	3,062	1,594	Average	52

a Data from estimates by ODFW district biologists reported in USFWS and USNMFS 1981a, 1981b, 1981c, 1982.

In the Grande Ronde drainage, overgrazing in riparian zones is most pronounced on private land. Prime steelhead and salmon spawning areas have been degraded along Sheep Creek, Fly Creek, and the mainstem Grande Ronde. Similar problems are prevalent on McKay, Lower Meadow, and Rock creeks (interview on 9/21/82 with Duane West, ODFW, La Grande, OR). Infestation of mountain pine beetle in the upper Grande Ronde has destroyed large areas of lodgepole pine, the primary riparian species along some streams.

In the Umatilla basin, farming to the edge of streambanks is a major source of riparian habitat losses on tributaries such as Butter, Willow, Birch, and McKay creeks. Overgrazing has also reduced streamside vegetation on tributaries of the Umatilla River (e.g., Buckaroo, Squaw, Meacham, and Lick creeks), the Walla Walla River (e.g., North Fork and Dry, Pine, Springbrook, and Birch creeks), the Malheur River (e.g., North Fork and middle sections of the Middle Fork), and the Klamath River basin (e.g., Sprague River valley, North Fork Sprague, lower Sycan, and Wood rivers).

Protection of Riparian Habitat

Providing buffer strips or "greenbelts" along streams is the principal means of protecting the riparian zone in agricultural areas, commercial forests, roadways, and urban-suburban areas.

Range land

On grazing lands, fenced exclosures that restrict livestock access to streams except at specific watering sites prevent damage to riparian areas. Grazing systems (e.g., rest-rotation, deferred) that more evenly distribute grazing pressure have also been used to limit livestock use of streamside areas. Another grazing management principal that will reduce overgrazing in the riparian zone and encourage better grazing distribution is to keep facilities and activities that concentrate livestock out of the riparian area. These include salt blocks, supplementary feeding and watering sites, stock driveways, corrals, and bedding areas (Riparian Habitat Committee 1982).

Cultivated land

The best method to protect riparian habitat in cultivated areas is to leave vegetated buffers between the field and stream. Native vegetation consisting of a mixture of grasses, shrubs, and trees is preferable to planted grasses alone since it provides more diverse habitat for fish and wildlife. Streamside fencing may be necesary to protect buffers on cropland that is periodically grazed. Temporary electric fence may be adequate; however, in many cases cultivated fields are permanently fenced to exclude livestock during the growing season.

Forest land

The Oregon Forest Practices Act (FPA) contains provisions for maintaining or restoring vegetative cover along portions of streams that are logged. However, these provisions are not requirements, and they have been applied principally to Classs I streams [1] designated for fish production. Class II streams [2] in most cases are smaller, low order streams. The productivity and natural processes of first- through third-order streams are much more dependent on the riparian zone than larger streams. The cumulative effects of logging along these streams can significantly decrease salmonid production in downstream reaches through changes in water quality, nutrient input, and transport of large woody debris (Everest et al. 1982).

FPA buffer regulations emphasize shade and sediment control rather than protection of large trees in the riparian zone that contribute essential structure and cover to the stream. Although regrowth of riparian vegetation may reestablish litter input and shade within a few years, recruitment of large woody debris from second growth timber is very slow to recover and may never recover if mature conifers in buffers are continually cropped (Swanson et al. 1976). Buffers should contain a mixed stand of hardwoods and conifers, grasses, shrubs, and smaller understory trees as well as larger overstory trees. Large conifers (>18 inches dbh), particularly cedar, should be left as a future source of stable structural material.

Timber adjacent to buffers should be harvested away from the buffer and stream. Aerial yarding systems can help protect riparian buffers; however, the yarding set-up should be designed to avoid transporting logs through the buffer and damaging the vegetation (Everest et al. 1982).

Buffer width

The width of the riparian zone varies from stream to stream and along the course of an individual stream. Consequently, there is no predetermined distance or simple formula that can be used to calculate desirable buffer widths. The dimensions of the riparian management area on each stream should be determined on the basis of the flow characteristics, the vegetation type, and the profile and stability of the channel and sideslope. A change in vegetation may delineate the riparian zone, although the boundary of riparian vegetation may expand as the area recovers and the height of the water table increases.

---

[1] *Class I streams as defined by Oregon Forest Practice rules are "waters that are valuable for domestic use, angling or other recreation, and/or used by signifiant numbers of fish for spawning, rearing, or migration. Flows may be perennial or intermittent for part of the year."*

[2] *Class II streams are defined as "minor drainages or headwaters that have limited or no direct value for angling or other recreation. They are used by only a few, if any, fish for spawning or rearing. Flows may be perennial or intermittent."*

In most cases, buffers that are too wide are seldom a problem, whereas buffers that are too narrow may not provide all of the necessary characteristics of high quality riparian habitat. Streams with narrow buffers (<100 ft) have shown little recovery in macroinvertebrate diversity and continued elevated levels of sediment 6-10 years after logging (Erman and Mahoney 1983). The buffer strip should include the area inundated at peak flows. This would encompass off-channel habitat used by salmonids in winter and spring. Although buffers in some areas are subject to blow-down, large trees that fall into the stream can benefit streams that lack structural diversity.

There are also more practical concerns regarding buffer width. If the stream corridor is fenced, the fence line must be far enough back so that ice and debris transported by high flows do not damage the fence. The size of the exclosure may also have to be adjusted to avoid an excessive number of bends and corners in the fence. If limited grazing will be allowed inside the exclosure after recovery, the fenced area should be large enough to permit the area to be managed as a discrete grazing unit. Grazing within a narrow exclosure may further concentrate livestock in the riparian zone compounding problems of overutilization of riparian vegetation and bank damage.

Riparian protection programs

The Oregon Riparian Tax Incentive Program (Senate Bill 397) administered by ODFW exempts from property taxes up to 100 feet of protected riparian buffer on private land in farm and forest land use zones. The exemption is restricted to 100 miles of streambank per year in each county with an approved land use plan. The program also provides a 25% state income tax credit for costs of streamside fencing and instream fish habitat enhancement.

ODFW has also undertaken riparian protection projects in conjunction with its general fish habitat and non-game wildlife programs, including the Salmon and Trout Enhancement Program (STEP). ODFW has cooperated with other state and federal agencies, such as the Forest Service, Bureau of Land Management, and Soil Conservation Service in riparian protection efforts.

INSTREAM HABITAT

Characteristics and Salmonid Requirements

Substrate

The bottom material of salmonid streams ranges from bedrock and large boulders to fine silt. The type and sizes of these materials is a function of geology, instream structure, and water velocity. Boulders and rubble are usually associated with the faster riffles, while smaller particles of silt and sand tend to settle out in the slower moving pools.

Boulders are an important structural element (see Structure), particularly in streams where there is little input of large trees. Cobbles and rubble are used for cover by juveniles (Reiser and Bjornn 1979). Suitable gravel size, quality, and availability are essential for successful adult spawning, egg incubation, and fry emergence. Salmon spawn in 0.5 to 5-inch gravel, while resident trout require smaller spawning gravel (Table 8). Redd area varies among species as well (Table 8). Salmon reproductive success generally declines with increasing amounts of fines in the gravel (Fig. 14). Fine sediment (<0.25 inch) should not exceed 25% of the bottom composition during spawning, incubation, and emergence (Reiser and Bjornn 1979).

Table 8. Spawning gravel requirements for salmonids [modified from Reiser and Bjornn (1979) and Everest et al. (1982)].

Species	Substrate size (inch)	Average area of redd (yd^2)
Spring chinook	0.5-4.0	3.9
Fall chinook	0.5-4.0	6.1
Summer chinook	0.5-4.0	6.1
Coho	0.6-5.0	3.3
Chum	0.5-4.0	2.8
Sockeye	0.5-4.0	2.2
Steelhead	0.2-4.0	6.5
Steelhead	- -	5.3
Rainbow	0.2-2.0	0.2
Cutthroat	0.2-4.0	0.9-1.1
Brown	0.2-3.0	0.6

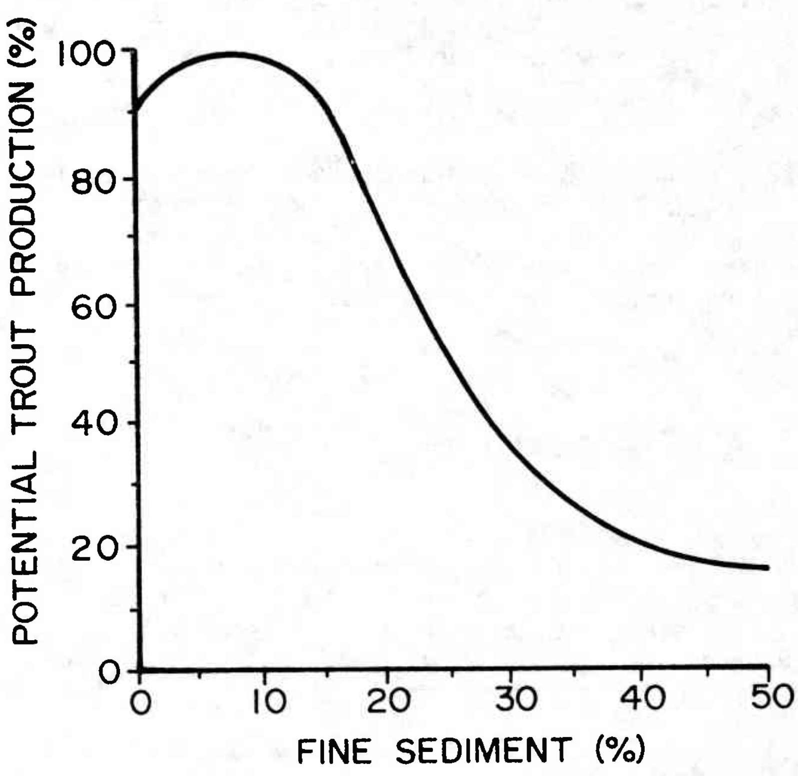


Fig. 14. Trout production in relation to substrate covered by fine sediment (Riparian Habitat Committee 1979).

Food production

The growth of juvenile anadromous salmonids to the smolt stage and of resident trout is largely dependent on food supply (Chapman 1966). The primary food sources are terrestrial and aquatic insects. Aquatic insects are produced on the substrate and on woody debris in the stream channel. The most productive areas for benthic invertebrates contain large gravel and rubble, which usually is found in riffles (Sprules 1947).

Gradient

Stream gradient generally decreases with increasing stream order (Table 9). In streams where anadromous salmonids spawn, high gradient reaches are primarily utilized by cutthroat and steelhead; coho occur in sections with moderate gradient; and chinook and chum are usually found in lower gradient sections. Although species diversity and population density are inversely related to gradient, this probably reflects overall differences in the habitat capacity (e.g., stream depth and width) rather than gradient alone (Platts 1974). The role of gradient as a determinant of habitat can also be greatly altered by instream structure.

Table 9. Gradient in relation to stream order for selected coastal and Cascade watersheds (Boehne and House 1983).

	Gradient (%)	
Stream order	Coastal watersheds	Cascade watersheds
2	18	11
3	6	9
4	4	6
5	3	3

Structure

In western Oregon much of the instream structure consists of large trees which topple into or are transported in the stream (Swanson and Lienkaemper 1978; Froehlich et al. 1972). Large trees are also probably an important structural element in the forested streams of eastern Oregon, while boulders provide much of the instream structure in unforested areas. Beaver dams serve a similar function.

Instream structure is largely responsible for physically transforming running water into diverse, productive habitat. Without structure, a stream basically resembles a shallow canal. The force of flowing water and the resistance to that force from structural components in the channel produce many of the physical characteristics of streams that are important to salmonid production. In obstructing streamflow, instream structure ponds water upstream and funnels it into chutes that scour pools below, thereby increasing water depths and the amount of available habitat. Pool area and volume are closely correlated with production of coho (Nickelson and Hafele 1978) and chinook (Bjornn et al. 1977). Structure decreases water velocities so that spawning gravels transported during higher flows are deposited. Downstream structures trap and stabilize the gravel as well as organic material, which is processed by invertebrates and cycled through the food chain.

Cover

Instream cover can take many forms: overhead cover (undercut banks, water turbulence, floating debris) and submerged cover (logs, boulders and coarse substrate, vegetation, root wads). Both cover types are used extensively by most salmonids. Instream cover provides refuge from predators, slack water areas, shade, and territorial isolation. It is difficult to determine exact cover requirements for salmonids since needs vary diurnally and seasonally and according to species and size. Submerged cover consisting of rock and rubble substrate provides refuge for newly emerged and overwintering juveniles, partiuclarly 0-age steelhead (Reiser and Bjornn 1979). Coho juveniles and age 1+ steelhead are most frequently associated with logs and root wads and, to a lesser extent, undercut banks (Bustard and Narver 1975). Although cover is most important during juvenile rearing, spawning areas with adjacent cover may be preferred by adults (Reiser and Bjornn 1979).

Losses of Instream Habitat

Changes in channel shape and depth, gravel size and composition, streambank stability, amount of woody debris, or riffle:pool ratios directly influence stream habitat for salmonids. The following are the most significant instream habitat problems in Oregon.

Sedimentation and debris torrents

Heavy silt loads in streams are detrimental to production of salmonids. High turbidity can stop or delay adult migration and interfere with sight feeding fishes including salmonids. Prolonged exposure to abrasive suspended sediment can injure the gill surfaces. Excessive fines can cement the gravel together so that it is difficult for adults to construct redds. Fines reduce the permeability of the gravel, decreasing the flow of oxygenated water to and the removal of metabolic wastes from incubating eggs and hatched alevins (Wickett 1958; McNeil and Ahnell 1964). Fry emergence is poor in gravel imbedded with fines (Koski 1966; Moring 1975). Food production from aquatic insects declines. Siltation also decreases pool size, reducing rearing and holding area.

Sediment enters Oregon streams from surface runoff, gulley erosion, and mass wasting. Soil disturbance and removal of vegetative cover related to road building and construction, farming, logging, and grazing increase erosion and the delivery of sediment to streams. ODEQ (1978) has identified general regions in Oregon where erosion potential and sediment delivery rates are high, and where sedimentation and streamside erosion create significant nonpoint pollution problems in Oregon streams and rivers. Erosion rates in the Umatilla

Plateau, for example, are among the highest in Oregon and are estimated at 1,000-2,000 tons per square mile per year. The fallow system of dryland wheat farming in this and other areas exposes bare soil for extended periods and accelerates soil loss. In some areas of intense row crop production, turbidity and sedimentation are chronic problems due to the return of warm, turbid irrigation water directly into streams. Such areas are frequently unsuited for salmonid production.

Most studies of the effects of sedimentation on fish production in the Northwest have focused on forest lands. In steep mountainous terrain of the region, landslides or debris avalanches are the dominant erosive process (Brown 1973; Swanson and Dyrness 1975) and can significantly affect instream habitat. Episodes of debris avalanches are most commonly associated with periods of heavy rainfall or rain-on-snow events (Ketcheson and Froehlich 1978). In the Cascades, storms of a 7-year occurrence or greater cause debris avalanches in forested areas (Swanston and Swanson 1976). In the Coast Range a large number of small mass movements are produced by large infrequent storms as well as by more frequent storms that occur every 5 to 10 years (Ketcheson and Froehlich 1978). A large number of landslides related to land management activities occurred in the Mapleton Ranger District (Siuslaw National Forest) following winter storms in 1973-74 and after a major storm in November 1975 (Gresswell et al. 1979).

The frequency of landslides and rate of erosion in Oregon forestlands vary greatly with location, slope, and soil type. Increased probability of debris avalanches has been associated with certain "high risk" land types. On the Central Oregon coast, for example, the following areas frequently experience debris avalanches:

1. Headwalls and channel depressions on slopes 60% or greater.
2. Slopes 80% or greater.
3. Sandstone outcroppings.
4. Steep, deeply cut drainage channels with bedrock bottoms (Ketcheson and Froehlich 1978).

Debris avalanches can cause debris torrents in streams. Debris torrents result from the rapid movement of water-charged soil, rock, and vegetation along stream channels. Some torrents are started by debris avalanches less than 100 yd^3 but collect up to 10,000 yd^3 of debris along the torrent's path. Torrents often remove most of the structure, gravel, and vegetation in their track and scour the stream channel to bedrock (Swanston and Swanson 1976). As a debris torrent loses velocity in lower gradient reaches of a stream, large quantities of rock, soil, and wood are deposited. Large debris and sediment jams can block the upstream passage of adult salmonids. The channelized character of the stream above the jam and reduced recruitment of stable structural material from adjoining logged areas can limit production in that section for many years.

Debris avalanches usually begin in upper drainage areas triggering torrents in steep, intermittent first- and second-order channels. Where these small tributaries enter larger streams at a sharp angle, debris torrents may not have the energy to turn the corner and continue downstream (Ketcheson and Froehlich 1978). Small debris torrents that entered Knowles Creek in the

Siuslaw River drainage did not scour the main channel and improved fish habitat by delivering gravel and debris to a stream that lacked habitat structure (interview on 5/15/82 with Fred Everest, Oregon State University Forestry Sciences Laboratory, Corvallis, OR).

However, not all torrents are contained within upper watersheds. In the Coast Range many torrents have traveled from upper tributaries through 3rd and 4th order streams. Miles of fish habitat are destroyed when torrents scour channels used for spawning and rearing. Direct losses of fish life can result if streams are impacted during fish migration or after eggs have been deposited in the gravel. The likelihood of direct fish losses is high because the frequency of torrents is greatest during the rainy season, when many salmonids are in coastal streams to spawn.

Stream channels in the Northwest have evolved with heavy loads of debris that are periodically flushed by torrents triggered by debris avalanches (Ketcheson and Froehlich 1978). However, timber harvest activities increase the incidence of debris avalanches and torrents, the amount of material transported, and the length of stream scoured by torrents. In the Oregon Cascades clearcutting increased debris torrents 4.5 times in the H.J. Andrews experimental forest and 8.8 times in the Alder Creek area; roads increased the frequency of torrents 42.5 and 133 times that of undisturbed forests. Debris torrents traveled 2.1 times farther in clearcut drainages than in uncut forests in the Oregon Coast Range (Ketcheson and Froehlich 1978). The size, distribution, and stability of woody debris entering drainages from logged areas, and consequently salmonid habitat, may differ considerably from forested areas where recruitment of debris from occasional torrents proceeds at a slower rate.

Debris avalanches and torrents could significantly impact salmonid production in Oregon, because much of the remaining old and second growth cutting will occur on steep, dissected slopes, where the potential for landslides is high (Ketcheson and Froehlich 1978). Studies in the western Cascades and the Oregon Coast Range show that clearcutting accelerates erosion by landslides 2 to 4 times the rate for forested lands (Table 10). A major factor in slope stability is the binding effect of plant roots. Clearcutting reduces root strength and increases the risk of landslides on steep, shallow soils. Gresswell et al. (1979) indicated reduced root strength within 3 years of clearcutting resulted in 60% of the landslides on clearcut sites in the Mapleton Ranger Distrct (central Coast Range). In this area logging-related landslides following a 1975 storm were 10 times the number of naturally occurring landslides.

Road-related debris avalanches in the Oregon Cascades increased erosion from 50 to 340 times the rate in forested areas (Table 10). Although roads accelerate erosion from landslides at a higher rate than clearcutting, roads cover much less area than clearcuts. Weighted by area, clearcutting and roads in the western Cascades and the central Coast Range contribute equally to total erosion from managed forests (Swanson and Dyrness 1975; Greswell et al. 1979).

Table 10. Landslides and erosion rates for forested, clearcut, and roaded areas in western Oregon.

Site	Period of record (yr)	Area (%)	(mi^2)	Number of failures	Erosion rate ($yd^3/ac/yr$)	Erosion rate related to forested areas
Alder Creek, western Cascade Range, (Morrison 1975)						
Forest	25	70.5	4.7	7	0.24	1.0
Clearcut	15	26.0	1.7	18	0.62	2.6
Road	15	3.5	0.23	75	82.46	343.6
H.J. Andrews Experimental Forest, western Cascade Range, (Swanson and Dyrness 1975)						
Forest	25	77.5	19.2	31	0.19	1.0
Clearcut	25	19.3	4.8	30	0.70	3.7
Road	25	3.2	0.77	69	9.39	49.4
Mapleton Ranger District, central Coast Range (Swanson and Swanson 1977)						
Forest	15		2.0	42	0.17	1.0
Clearcut	10		22.0	317	0.33	1.9
Mapleton Ranger District, central Coast Range (Ketcheson and Froehlich 1978)						
Forest	15		1.8	38	0.10	1.0
Clearcut	6		1.1	34	0.37	3.7

Stream channelization

Many miles of Oregon streams have been realigned and channelized for a variety of purposes:

1. Flood control: Water courses are deepened, widened, and straightened to increase the efficiency of water flow and to decrease the risk of flooding and property loss.

2. Erosion control: River channels are straightened, riparian vegetation is removed, and banks are armored with rip-rap to deflect river flow and prevent bank erosion.

3. Navigation: Channels are deepened and debris is removed to improve the navigability of larger rivers.

4. Agricultural production: Streams are straightened and relocated to the edge of pastures or croplands to increase the acreage available for agricultural production.

5. Road construction: Streams are straightened when highways, railroads, and logging roads are constructed along a stream.

Channelization and realignment reduce the productivity of Oregon rivers and streams for salmonids. Channelization creates a uniform depth and width profile and reduces water storage capacity (Fig. 15). Base flows are lower and peak flows are higher (Simpson et al. 1982). Where water supplies are naturally low during summer, flow may become intermittent. High flows are funneled downstream, which aggravates flooding in lower reaches (Wydoski 1978) and alters stream substrates and flood plain soils (Simpson et al. 1982).

Because of the increased hydraulic efficiency and gradient of a channelized stream, water velocities and erosive power are increased. In some areas, stream channels are annually bulldozed in a futile attempt to control bank erosion after streamside vegetation has been removed. The result is a straight, unstable channel, increased water velocities, and accelerated erosion as the stream attempts to return to its natural meandering pattern. Meanders are the most efficient means of dissipating stream energy. Meanders also provide more potential fish habitat than a straight channelized stretch (Fig. 16). Reduced stream length also decreases the capacity of a river to assimilate wastes. Organic loads increase downstream, because less detritus is processed in the altered reach (Simpson et al. 1982).

Channelization destroys the diversity of physical habitat necessary for optimum salmonid production. Gravel substrate in spawning areas and aquatic insect habitat may be replaced by bedrock (Simpson et al. 1982). Riparian habitat is often destroyed and may not readily recover due to increased scouring by channelized flows or placement of rip-rap for erosion control. Undercut banks used by trout and juvenile salmon are lost when the bank is sloped and straightened. Riffle-pool sequences important for spawning, rearing, and insect production are altered or destroyed after channelization (Elser 1968).

Construction of revetments and channelization of large rivers influence the composition and diversity of fish communities. Research on the upper Willamette has shown higher densities of smaller fishes along streambanks stabilized by revetments; however, species diversity was greater along unaltered banks of the main channel (Hjort et al. 1983). This was probably due to more diverse habitat characteristics, including water velocities and substrates. Shallow, nonrevetted secondary channels that run parallel to the main river provided the most varied habitat conditions for fish. These areas contained abundant cover from submerged logs and vegetation and a wide range of velocities. Secondary channels were used by rainbow and cutthroat trout and chinook salmon.

Numerous studies of small streams have shown significant decreases in trout production following stream channelization. Whitney and Baily (1959) found a 94% decrease in number and biomass of trout (>6 inches) after alteration of a small stream for highway construction. Channelization of Little Prickly Pear Creek (Montana) reduced the number and biomass of trout by 12% and 19%, respectively (Elser 1968). Natural reaches of 13 Montana streams had 3.5 times the number and 9 times the biomass of trout compared with reaches with altered channels (Peters and Alvord 1964). In Idaho over 1/3 the length of 45 stream channels surveyed (1,138 miles) were altered; fish production was estimated at 80%-90% below original levels (Gebhards 1970).

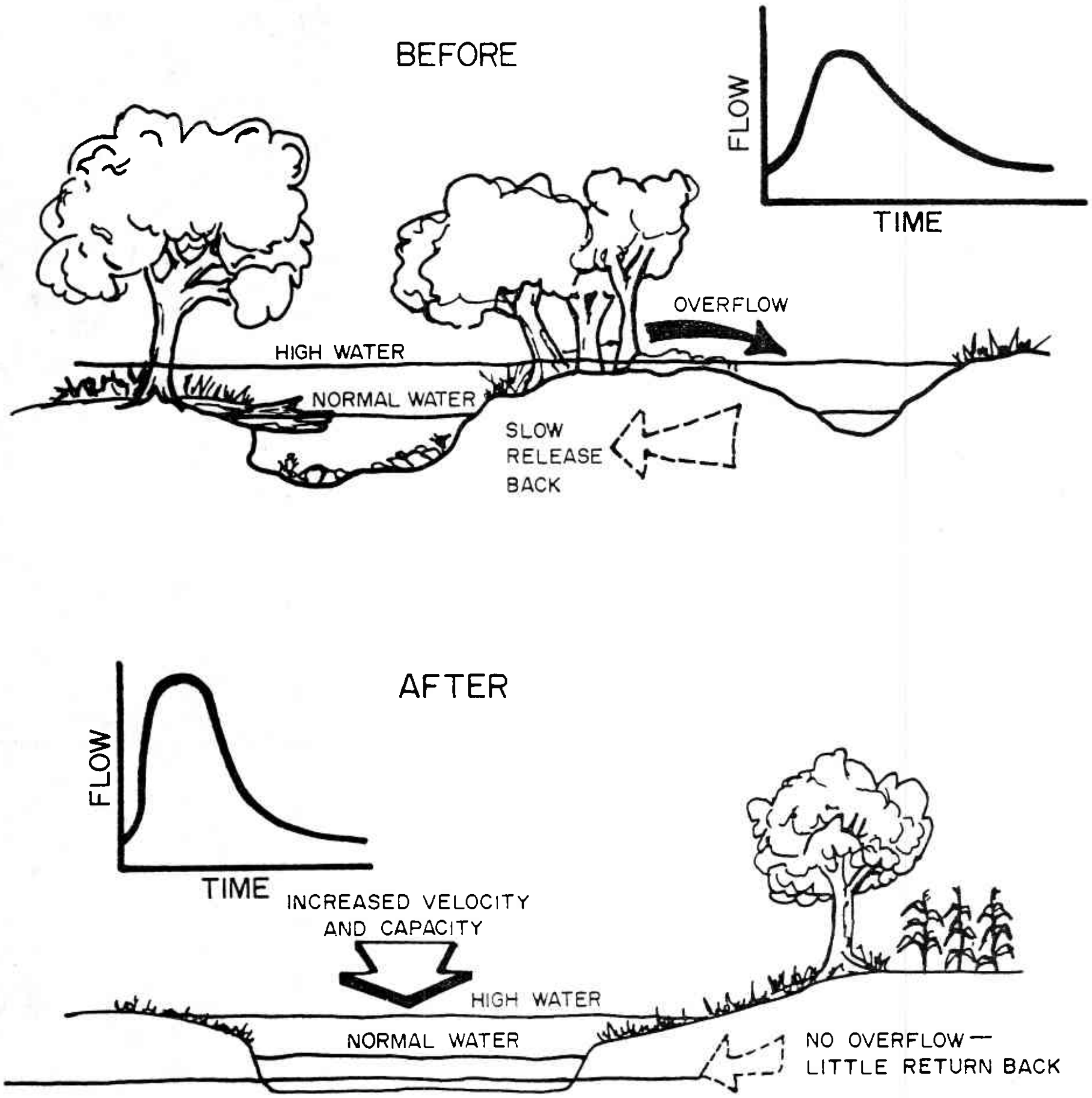


Fig. 15. Comparison of off-channel storage and return of flood water before and after channelization (Simpson et al. 1982).

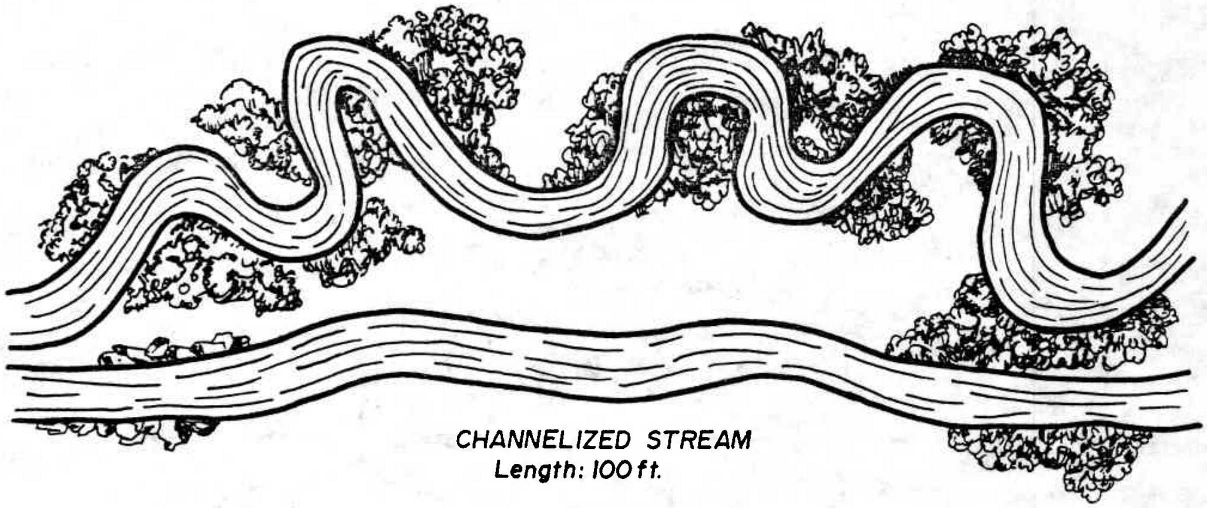


Fig. 16. Effect of channelization on stream length.

Other instream impacts

In western Oregon, many streams remain scoured to bedrock and barren of structure where splash dams were constructed to drive logs downstream. The physical effects of splash dams and debris torrents are similar. Removal of snags, large trees, and debris jams to reduce channel cutting and bank erosion, improve navigation, clear the way for log drives, and improve passage of anadromous fish have also reduced instream structure and available rearing habitat for juvenile and resident salmonids in Oregon (Sedell and Luchessa 1981).

During the 1930s and 1940s gold dredges channelized miles of streambed in eastern Oregon that remain in essentially the same condition today. Restoration of these streams for fish production, if possible, will be very costly. Interest in recreational mining is increasing and could cause future habitat losses if gravel composition and channel structure are significantly altered. Excessive grazing along stream channels not only removes riparian vegetation but also alters the configuration of stream channels and the quality of instream habitat available to fish (see Effects of Riparian Losses).

Instream Habitat Problem Areas

Western Oregon

Splash dams and debris removal

In the past 100 years the structure of Oregon coastal streams has been modified by logging, splash dams, and the widespread removal of beaver dams, log jams, and snags from stream channels. More than 160 splash dams on coastal and Columbia River tributaries (Fig. 17) blocked migrations of anadromous fish, scoured stream channels, and caused long-term damage to fish habitat in western Oregon (Sedell and Luchessa 1981). Although most of these operated between 1880 and 1910, splash dams were in use on the South Coos River as late as 1957 (Thompson et al. 1972). In the late 1940s and early 1950s, large debris jams originating from clearcuts of entire watersheds blocked passage of anadromous salmonids in many coastal rivers. Log jams blocked 12% of the tributaries in the Coquille River system. Approximately 20% of the Tillamook Bay tributaries were inaccessible to fish due to salvage logging activities following the 1933 fires (Sedell and Luchessa 1981).

Cleanup efforts, fish ladders, and improved logging practices have enhanced passage for fish in western Oregon streams and rivers. There are probably more miles of stream accessible to anadromous fish in western Oregon today than 100 years ago. Over half of the estimated 11,700 miles of Oregon coastal streams are presently accessible to salmon (Table 11). Most of the remaining areas are steep headwaters unsuited for spawning and rearing of anadromous salmonids (Anadromous Salmonid Environmental Task Force 1979).

Table 11. Miles of stream habitat available to salmon in Oregon coastal basins (Anadromous Salmonid Environmental Task Force 1979).

		Number of stream miles used by--			
Basin	Stream miles in basin	Spring chinook	Fall chinook	Coho	Chum
North coast	1,500	200	400	1,200	220
Central coast	2,500	200	700	1,900	65
South coast [a]	7,700	600	1,400	3,000	25
Total	11,700	1,000	2,500	6,100	310

[a] *Includes Umpqua and Rogue basins.*

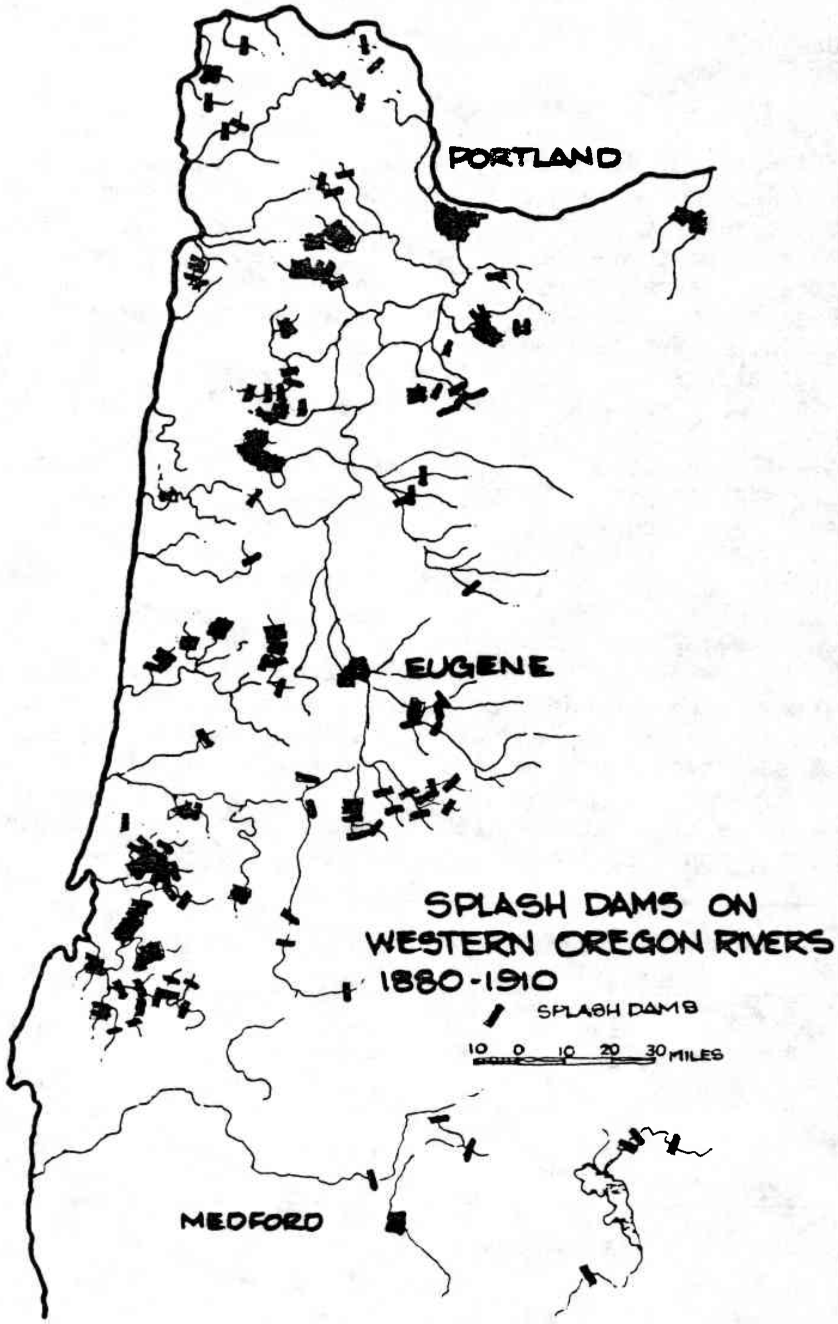


Fig. 17. Splash dams on western Oregon rivers, 1880-1910 (Sedell and Luchessa 1981).

Despite the benefits of improved access, there are indications that widespread cleanup of woody debris in western Oregon has created other habitat problems for salmonids. Fish in Oregon evolved in streams naturally obstructed by trees and beaver dams that blocked channels for 100 to 1,500 yards as late as the mid-1800s. In spite of these apparent passage problems, coastal rivers were highly productive during that period. The estimated coho run in the Siuslaw River alone during the 1890s was 218,750 fish (Sedell and Luchessa 1981). The current goal for coho escapements to all coastal streams combined is 200,000-250,000 fish (ODFW 1982). Sedell and Luchessa (1981) estimate that 80%-95% of the stream miles available to salmonids in western Oregon today lack adequate structure and habitat complexity due to loss of large woody debris.

Removal of debris and scouring by log drives and debris torrents may also reduce the supply of spawning gravel stored in some coastal streams. However, it is difficult to determine whether the lack of spawning gravel is due to natural geological characteristics or the loss of instream structure. The following list indicates some coastal areas having low supplies of gravel for spawning adult salmon (Smith and Lauman 1972; Thompson et al. 1972; interview on 3/11/82 with William Mullarkey, ODFW, Coos Bay, OR):

Mainstem Siuslaw and tributaries,
Yaquina River and Elk Creek,
Lower Alsea River and lower Five Rivers,
Smith River and tributaries,
Coos River system (West Fork Millicoma, South Fork Coos, Tioga Creek),
East and Middle Fork Coquille.

Sedimentation and debris torrents

Although road-building methods and logging practices in Oregon have vastly improved since the 1940s and 1950s, sedimentation, landslides, and debris torrents from managed forests continue to create stream habitat problems in steep, unstable regions of western Oregon. The most detailed information about sedimentation and landslide activity are from surveys in the Tillamook Bay drainage system and the coastal region between Heceta Head and Coos Bay.

Serious erosion problems began in the Tillamook drainage with wildfires and salvage logging operations between 1939 and 1945. Erosion rates have declined to approximately 12% of the maximum since 1949. However, erosion continues at a rate 20 times greater than in 1875 (TBTF 1978) and rates are among the highest of any forested area in Oregon. Roads and trails, landslides, clearcuts, and burned forestland account for 52% of the sediment load in the Tillamook basin (Table 12). Erosion of stream channels and banks also account for a high percentage (44%) of the annual instream sediment load. Instream erosion may be intensified by the abrasive action of heavy sediment loads from other sources (TBTF 1978).

Table 12. Erosion and sedimentation rates in the Tillamook Bay drainage [data from TBTF (1978)].

Sediment source	Acres	Land area (%)	Annual erosion (T/yr)	Erosion (%)	Annual sediment (T/yr)	Sediment (%)
Forest cover	230,324	71.0	25,568	9.1	2,306	3.9
Roads and trails	32,941	10.2	54,341	19.3	6,271	10.6
Landslides	5,112	1.6	25,621	9.1	6,650	11.2
Streams	310	0.1	49,141	17.4	26,073	44.0
Clearcuts	12,124	3.7	51,216	18.2	4,517	7.6
Burns	39,330	12.1	75,716	26.9	13,379	22.6
Other	4,088	1.3	--	--	--	--
Total	324,230	100	281,603	100	59,196	100

Sedimentation rates are highest on the mainstem and East Fork Trask River and the Tillamook, lower Wilson, and lower and South Fork Kilchis sub-basins (Table 13). The South Fork Trask sub-basin had an average of nearly 23 landslides/mi^2 (TBTF 1978). Analysis of 1978 aerial photos has shown that the land area covered by failures and massive erosion equals 6% of the surface area of the entire South Fork Trask watershed (Fig. 18) (Dale McCullough, Oregon State University, Department of Fisheries and Wildlife, unpublished data).

Table 13. Erosion and sedimentation intensity by sub-basin on forest lands in the Tillamook Bay drainage [data from TBTF (1978)].

Subbasin	Area (mi^2)	Landslides/ mi^2	Gross erosion T/mi^2/yr	Gross sediment T/mi^2/yr
Tillamook	52.45	2.59	793.68	135.30
Miami	37.95	16.07	539.97	53.70
Upper Kilchis	33.44	15.40	360.05	32.00
Lower Kilchis	23.45	8.96	578.45	98.54
South Fork Kilchis	10.80	12.13	967.23	92.60
Lower Wilson	74.56	9.24	557.07	114.20
Upper Wilson	89.00	13.21	323.97	46.80
North Fork Wilson	25.67	3.54	276.72	16.21
Main Trask	109.25	4.15	718.57	150.90
East Fork Trask	29.42	6.66	985.57	246.45
South Fork Trask	20.61	22.95	240.45	52.90
Total	506.60			

Fig. 18. Sites of land failures and massive erosion in the South Fork Trask watershed (interpreted from 1977 color aerial photos, 1:12000 scale) (Dale McCullough, Oregon State University, Department of Fish and Wildlife, unpublished data).

A 1978 inventory identified 4,680 landslides in the Tillamook Bay drainage (TBTF 1978). Of this total, 4,440 were considered man-caused and 240 were identified as "natural". Many landslides in the area are associated with roads. Roads and trails comprise more than 100 times the area of streams and floodplains and account for more than 10% of the total area of Tillamook basin forestlands. Land failures and debris torrents continued to cause habitat losses in the Tillamook drainage after heavy winter rains in 1981-82.

Debris torrents also impacted many other coastal areas in 1981-82. An aerial survey of state and private forest land in the Coast Range by the Oregon Department of Forestry found that 95% of the inventoried landslides occurred between Mapleton and Bandon. An estimated 49% of these slides occurred in clearcuts and 40% were caused by roads or landings (Soils Task Force 1982). Debris torrents were common in short, steep ocean tributaries between Heceta Head and Yachats. For example, 8 landslides entered Gwynn Creek and caused a debris torrent.

Table 14 summarizes an ODFW inventory of landslides in the Smith River and lower Umpqua region during the winter of 1981-82. Of the 740 landslides counted, 56% occurred within clearcuts ("in-unit"). About 38% of the landslides were road-related. Natural landslides, unrelated to timber harvest or roads, composed a minor percentage of the total (5.5%). Railroad Creek (Smith River), Butler Creek (lower Umpqua), and Scholfield Creek (lower Umpqua) were among the most seriously impacted in 1981. Twenty-six landslides entered Scholfield Creek or its tributaries. Ten log jams were identified in 2 miles of the stream, and gravel bars were buried in silt. Useable spawning gravel in the creek estimated at 24,000 yd^2 in 1960 was only 1,100 yd^2 following the 1982 torrents (interview on 3/10/83 with John Johnson, ODFW, Reedsport, OR).

South of the Umpqua basin, tributaries of the Tenmile Lakes and Coos River systems also experienced extensive damage from debris torrents during the winter of 1981-82.

River system	Tributary
Coos Bay	Larson Creek Palouse Creek
Millicoma	Deton Creek Marlow Creek
South Fork Coos	Williams River Fall Creek Bottom Creek

There was probably little survival from eggs of early spawning coho in south coast streams damaged by debris torrents. Late spawners were blocked by log jams from debris torrents in some Tenmile and Coos tributaries. Survival of overwintering coho, steelhead, and cutthroat juveniles was also probably decreased by flooding and debris torrents (Reese Bender, ODFW, memo to Bob Thompson, April 7, 1982).

Table 14. Inventory of landslides in Smith River and lower Umpqua watersheds, February 1982 (Anderson et al., ODFW, memo to Bob Thompson, March 12, 1982).

Stream system, area	Number of in-unit slides	Number of road-related slides	Number of natural slides
Railroad Creek	14	6	0
Section 36 Area	16	29	0
Spencer Creek	34	34	1
Doe-Fawn creeks	13	15	0
Johnson Creek	4	0	0
Edmunds-Georgia creeks	25	27	0
Wassen Creek	13	15	1
Vincent Creek	7	4	0
West Fork Smith	36	32	0
Smith Corridor (Twin Sister to Big Creek)	0	1	1
Big Creek	0	0	3
Scholfield Creek	74	21	3
Hakki Creek	14	4	0
Dean Creek	49	14	6
Indian Creek	4	0	0
Charlotte Creek	0	1	0
Luder Creek	0	2	1
Umpqua Corridor (Scottsburg to Reedsport)	17	2	20
Butler Creek	19	16	1
Sawyer Creek	10	8	0
Elk Creek	18	6	2
Heddin Creek	6	10	2
Mehl Creek	13	19	0
Waggoner Creek	20	9	0
Wolf Creek	12	6	0
Total	418 (56.5%)	281 (37.9%)	41 (5.5%)

Heavy winter rains are common on the coast. The events of December 1981, although severe, were not unique. Following a November 1975 storm, United States Forest Service personnel completed a landslide inventory that covered approximately 70% of the Mapleton Ranger District (Gresswell et al. 1979). A total of 245 failures were counted (Table 15). These produced debris torrents that scoured 17.26 miles of stream channel. In this area 3/4 of the landslides and 2/3 of the total volume of debris were from in-unit failures unrelated to roads (Gresswell et al. 1979).

Table 15. Inventory of mass failures in Mapleton Ranger District (Siuslaw National Forest) following storms November 29-December 1, 1975 [data from Gresswell et al. (1979)].

	Natural failures	Road-related failures	In-unit slides
Number	22 (9%)	34 (14%)	187 (77%)
Frequency (1 slide / number of acres)	1/6,129	1/85 [a]	1/261
Stream scoured (miles)	3.35 (19%)	4.95 (29%)	8.98 (52%)
Volume of debris to streams (yd^3)	2,750 (3%)	29,460 (34%)	55,100 (63%)
Average volume per failure (yd^3)	125	860	290

[a] *1 per 4 miles of road.*

Stream channelization

Alteration of stream channels has also caused losses of fish habitat throughout western Oregon; however, there are no inventories to show the number of stream miles affected. On the Oregon coast, many small, low gradient streams have been rerouted to provide additional pasture where available grazing land is in limited supply. Streams have been more extensively channelized in the interior valleys. Tributaries of the Willamette River in agricultural areas have been altered for flood control and to provide additional acreage for farm production. Long sections of the Molalla, Yamhill, and mainstem Willamette have been revetted to prevent meandering channel changes that cause loss of land or threaten roads, buildings, and utilities. A comparison of the upper Willamette River (McKenzie River to Harrisburg) in 1854 with the same reach in 1967 shows a considerable loss of channel complexity from revetments, channelization, and development of the flood plain (Fig. 19). Secondary channels where species and habitat diversity are greatest have been lost due to these restrictions of the river (Hjort et al. 1983).

Eastern Oregon

In many cases instream habitat problems and riparian habitat degradation are closely related. Loss of riparian vegetation results in increased bank erosion and changes in channel morphology. Streams may then be continually channelized in an attempt to remedy recurring bank instability. This further compounds riparian and instream habitat problems for salmonids. Studies of the Deschutes, John Day, Umatilla, and Grande Ronde drainages have summarized factors that have led to the present riparian-instream conditions of those river systems (Table 16). As indicated in Table 7, the riparian-instream habitat of 1,594 miles of streams inventoried in those drainages needs restoration.

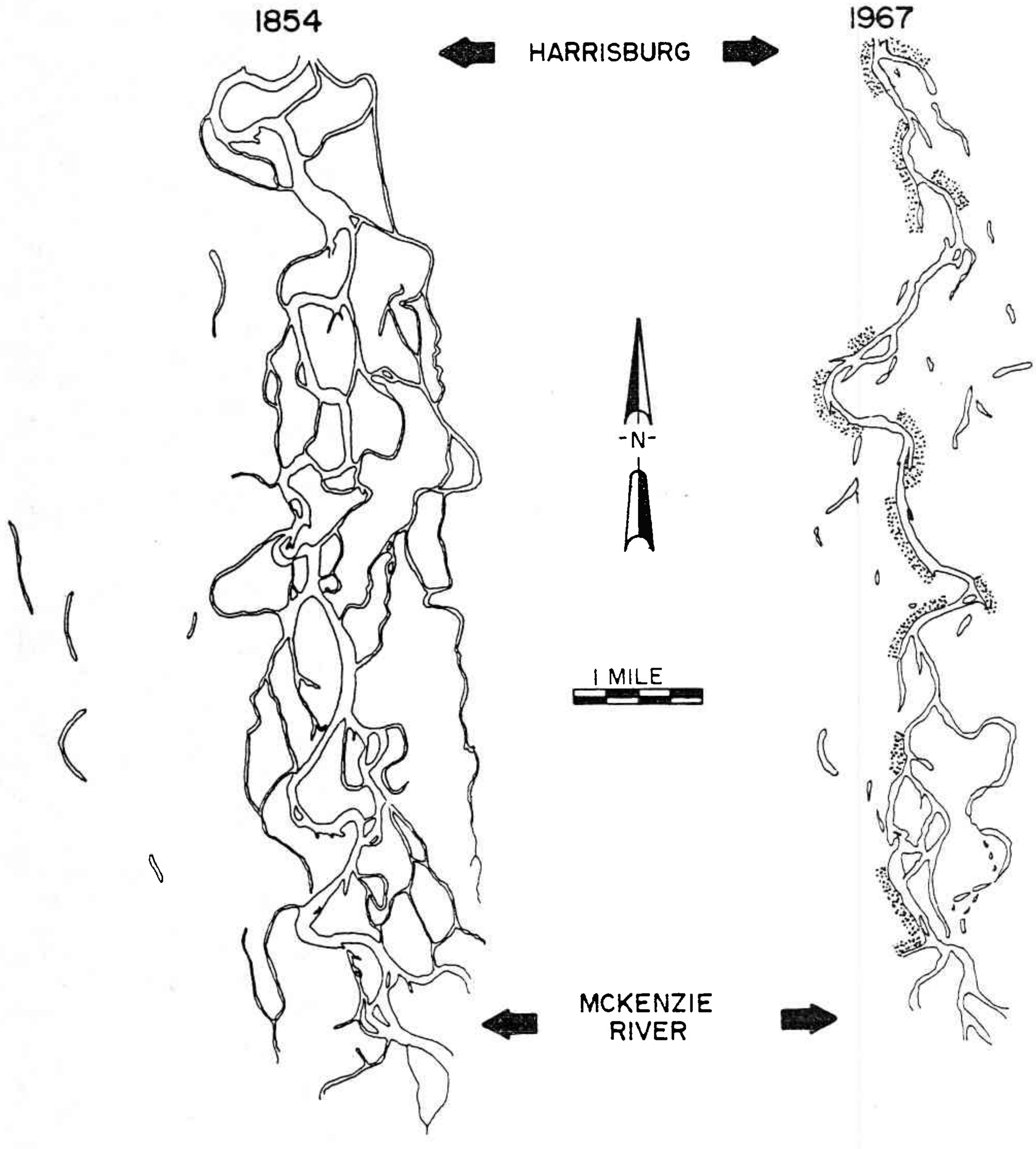


Fig. 19. Outlines of the Willamette River between the mouth of the McKenzie River and Harrisburg, Oregon, in 1854 and 1967. (The shaded sections on the 1967 map are revetments.) [Adapted from Sedell and Froggatt (in press), and Hjort et al. (1983).]

Table 16. Sources of riparian and associated instream habitat problems for the Deschutes, John Day, Umatilla, and Grande Ronde drainages (information from USFWS and USNMFS 1981a, 1981b, 1981c, 1982). (xx = primary source; x = secondary source).

Drainage system	Over-grazing	Farming	Timber removal	Road building	Channeli-zation	Mining	Recreational development
	Pollution source						
Deschutes	xx	xx	xx	x	x	x	x
John Day	xx	xx	xx	x	x	x	x
Umatilla	xx	x	xx	xx	xx	x	x
Grande Ronde	xx	x	xx	xx	xx	x	x

Mining has destroyed instream habitat in a number of areas in eastern Oregon. Gold dredging was extensive on Granite and Clear creeks and other sections of the North Fork of the John Day River and in the Powder River basin. Although dredging ceased in the 1950s, the streams still retain a channelized profile, and much of the spawning gravel lies heaped along the streams in piles of dredge tailings. Sub-surface mines along Clear Creek leach effluent containing copper and zinc, which adversely affect the ability of migrating juvenile salmonids to survive saltwater entry (Lorz and McPherson 1976). In southeastern Oregon, mercury pollution from mining activities has been discovered in Jordan and Succor creeks (Malheur County). Willow Creek, a tributary of the Malheur River, has been placer mined and dredged for gold and silver (Malheur County Planning Office 1981).

Sedimentation has been classified as severe in the Crooked River above Prineville Reservoir, the southeastern portion of the John Day basin, the Hood basin, and the Malheur River basin (ODEQ 1978). The Umatilla Plateau and the Wallowa Mountains are considered to have a high potential for erosion. The regional hotspots for streambank erosion generally correspond to the areas with severe sedimentation and erosion potential: Crooked River (Deschutes basin), Malheur River, Umatilla basin, northern part of the John Day basin, and the Hood River basin. The accelerated bank erosion and resulting stream sedimentation probably result from land use practices, particularly along the stream corridor (ODEQ 1978).

Protection of Instream Habitat

Agricultural erosion and streambank stabilization

Numerous local, state, and federal programs have been developed in Oregon to inventory erosion problems and to identify methods for reduced soil loss. A sediment reduction project was instigated by the Oregon State Soil and Water Conservation Commission (OSSWCC) (1978) to control soil loss from croplands in Wasco, Sherman, Morrow, and Umatilla counties. A demonstration project is underway in north central Oregon to test reduced tillage and other methods to minimize erosion on steep dry cropland (George 1982). ODEQ (1978) and the

OSSWCC (1982) have prepared inventories of streambank erosion problems for the state. The OSSWCC study identifies "best management practices" to prevent or reduce streambank erosion and outlines plans to control erosion on the Lostine, South Fork John Day, and Coquille rivers. Best management practices have been identified to prevent nonpoint pollution (including sedimentation) from federal range and grazing lands (ODEQ mimeo, October 6, 1982).

There are many other state and local programs to control upland erosion that also benefit fish by reducing sedimentation. Improved methods are needed to reduce sediment in irrigation return water from agricultural lands. Sprinkler irrigation systems, vegetative filter strips, and settling basins may help decrease turbidity and sedimentation in areas of intensive row crop production. Activities within or near the stream corridor are especially important to fisheries management due to their direct impact on fish habitat. Protection of riparian vegetation on agricultural land is necessary to reduce the flow of upland sediments into streams and to minimize bank erosion. Cattle exclosures and/or controlled grazing systems are usually required to protect streamside vegetation and reduce erosion on grazing lands.

Although severe bank erosion can degrade water quality and instream habitat for fish, the methods used to control streambank erosion often pose an equal or greater threat to salmonid habitat. Riprap eliminates cover and streamside vegetation. Where riprap is the best solution to a serious erosion problem, the length of stream that is altered should be minimized and riparian vegetation reestablished. Deflectors and bankline revetments are more suited to planting or regrowth of vegetation structure than full bank riprap. In parts of eastern Oregon, juniper riprap offers a low cost alternative to rock revetments and provides improved habitat conditions for fish (Sheeter and Claire 1981).

Where stream channels are altered, fishery impacts can be lessened if new channels meander, maintain an equal channel area, and have desirable riffle-pool sequence. Check dams or other instream structures may be needed to restore structure in an altered channel (Barton and Cron 1979). Backwater areas, sloughs, overflow channels, and marshes should be protected as rearing habitat for salmonids and other fishes.

In a few locations it may be possible to reroute altered channels to former locations. A small channel restoration project on a portion of Murderer's Creek (South Fork John Day River) has revived approximately 800 feet of meandering channel.

The Oregon Division of State Lands administers the state fill and removal law (ORS 541.605 to 541.695) governing stream channel changes and removal or addition of material from streambeds and streambanks. Through the permit process, other state agencies including ODFW may be consulted to establish appropriate conditions for a fill and removal permit. To minimize impacts where projects require in-water work, ODFW has developed specific guidelines for each major river in the state to identify time periods when in-water projects will result in the least damage to fish and wildlife resources.

Forest land

The Oregon Forest Practices Act contains provisions to minimize impacts of forest management activities on instream habitat. Guidelines in the Act discuss riparian protection, yarding techniques, soil protection, and road design, construction, and maintenance. The Oregon State Game Commission developed recommendations for stream protection during timber harvest activities (Lantz 1971). Recommendations were also prepared as a result of a 15-year research program on the effects of logging on stream habitat in the Alsea River watershed (Moring 1975).

Buffer strips are one of the most effective methods to protect streams from upland erosion related to logging activities. In clearcut areas, Moring and Lantz (1974) found fine sediments increased in only 1 of 4 Oregon streams with buffers while the fine sediment increased in 3 of 4 streams without buffers.

Buffer strips are most frequently left on Class I streams. However, protection of Class II streams helps to insure that instream habitat for fish is maintained downstream. As logging activity shifts to more unstable terrain, the importance of adequate forest practices in upper drainages to protect water quality and fish habitat will also increase. Most mass wasting events that carry sediment into streams begin in upper watersheds (Ketcheson and Froehlich 1978).

In the wake of widespread debris torrents on the Oregon Coast, the State Forester appointed a Soils Task Force to study the cause of the landslides and recommend methods to minimize future debris avalanches. The Task Force concluded that surface water drainage control and improper placement of excavated material were the two most important causes of landslides associated with roads and landings. Recommendations were developed to minimize the risk of avalanches due to failures from roads and landings (Soils Task Force 1982).

A large percentage of the landslides that occur in the coastal forests are the result of clearcutting and are not related to roads and landings. Additional protective measures are needed in Oregon to minimize the risk of landslides from clearcuts on steep, unstable areas. Unharvested "leave" areas on high risk headwalls and slopes adjacent to streams are the most common protective methods currently used by the United States Forest Service to prevent in-unit landslides in the Mapleton Ranger District (Gresswell et al. 1979).

The Forest Practices Act requires the removal of logging debris and slash that fall into streams during harvest. Biologists have also emphasized removal of debris jams in streams to insure passage of anadromous salmonids. There is growing evidence, however, that many of our streams lack habitat structure due to long-term efforts to remove woody debris. Habitat structure in western Oregon streams is dependent upon the steady recruitment of logs adjacent to the stream. Small debris from timber harvesting should be kept out of streams to protect water quality. However, large stable debris and jams that do not prevent fish passage should be left in the stream.

REFERENCES

Allen, K.R. 1969. Limitations in production in salmonid populations in streams. Pages 3-20 *in* T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver, Canada.

American Fisheries Society. 1980. Management and protection of western riparian stream ecosystems. American Fisheries Society, Western Division, Kalispell, Montana, USA.

Anadromous Salmonid Environmental Task Force. 1979. Freshwater habitat, salmon produced, and escapements for natural spawning along the Pacific coast of the United States. Pacific Fishery Management Council, Portland, Oregon, USA.

Armantrout, N.B., editor. 1981. Proceedings of symposium on acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland, USA.

Barton, J.R., and F.W. Cron. 1979. Restoration of fish habitat in relocated streams. United States Department of Transportation, Federal Highway Administration, Washington, District of Columbia, USA.

Bauersfeld, K. 1978. The effect of daily flow fluctuations on spawning fall chinook in the Columbia River. Washington Department of Fisheries, Technical Report 38, Olympia, Washington, USA.

Bjornn, T.C., M.A. Brusven, M.P. Molnau, J.H. Milligan, R.A. Klamt, E. Chacho, and C. Schaye. 1977. Transport of granitic sediment in streams and its effects on insects and fish. Forestry Wildlife and Range Experiment Station, Completion Report Water Resources Research Institute Project B-036-IDA. University of Idaho, Moscow, USA.

Boehne, P.L., and R.A. House. 1983. Stream ordering: a tool for land managers to classify western Oregon streams. United States Bureau of Land Management, Technical Note OR-3, Portland, Oregon, USA.

Brett, J.R. 1952. Temperature tolerance in young Pacific Salmon, genus *Oncorhynchus*. Journal of the Fisheries Research Board of Canada 9:265-309.

Brown, G.W. 1973. The impact of timber harvest on soil and water resources. Oregon State University Extension Bulletin 827, Corvallis, Oregon, USA.

Buchanan, D.V., and M.G. Wade. 1982. Restoration of the native winter steelhead run on the South Santiam River above Foster Dam. Oregon Department of Fish and Wildlife, Fisheries Reseach Project DACW57-79-C-0059-P0001, Annual Progress Report, Portland, Oregon, USA.

Buchanan, D.V., and M.G. Wade. 1983. Restoration of the native winter steelhead run on the South Santiam River above Foster Dam. Oregon Department of Fish and Wildlife, Fisheries Research Project DACW57-79-C-0059-P0001, Annual Progress Report, Portland, Oregon, USA.

Bustard, D.R., and D.W. Narver. 1975. Aspects of the winter ecology of juvenile salmon *(Oncorhynchus kisutch)* and steelhead trout *(Salmo gairdneri)*. Journal of the Fisheries Research Board of Canada 32:667-680.

Chapman, D.W. 1966. Food and space as regulators of salmonid populations in streams. American Naturalist 100:345-357.

Claire, E., and R. Storch. 1977. Streamside management and livestock grazing: An objective look at the situation. *In* Symposium on livestock interactions with wildlife, fisheries and their environments, May 3-5, 1977, Sparks, Nevada. United States Department of Agriculture Forest Service, Sparks, Nevada, USA.

Cooper, J.L. 1978. A technique for evaluating and predicting the impact of grazing on stream channels. *In* Transactions of the Bonneville Chapter of American Fisheries Society, Salt Lake City, Utah, USA.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience 24:631-641.

Curtis, B. 1959. Changes in river physical characteristics under substantial reduction in flow due to hydroelectric diversions. California Fish and Game 45:181-188.

Doudoroff, P., and C.E. Warren. 1965. Environmental requirements of fishes and wildlife--dissolved oxygen requirements of fishes. Oregon State University Agricultural Experiment Station, Special Report Number 141, Corvallis, Oregon, USA.

Dwyer, W.P., and R.H. Kramer. 1975. Influence of temperature on scope of activity in cutthroat trout, *Salmo clarki*. Transactions of the American Fisheries Society 58:71-77.

Elser, A.A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Transactions of the American Fisheries Society 97:389-397.

Erman, D.C., and D. Mahoney. 1983. Recovery after logging in streams with and without bufferstrips in northern California. University of California, California Water Resources Center, Davis, California, USA.

Everest, F.H. 1969. Habitat selection and spatial interaction of juvenile chinook salmon and steelhead trout in two Idaho streams. Doctoral dissertation. University of Idaho, Moscow, Idaho, USA.

Everest, F.H., N.B. Armantrout, S.M. Keller, W.D. Parante, J.R. Sedell, T.E. Nickelson, J.M. Johnston, and G.N. Haugen. 1982. Salmonids. Chapter 10 *In* Westside forest-wildlife habitat relationship handbook. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, Final Draft Report, Portland, Oregon, USA.

Everest, F.H., and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 19:91:100.

Fortune, J.D., A.R. Gerlach, and C.J. Hanel. 1966. A study to determine the feasibility of establishing salmon and steelhead in the upper Klamath Basin. Oregon State Game Commission, Klamath Falls, Oregon, USA. (Unpublished report.)

Franklin, J.F., and C.T. Dyrness. 1973. Natural vegetation of Oregon and Washington. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-8, Portland, Oregon, USA.

Froehlich, H.A., D. McGreer, and J.R. Sedell. 1972. Natural debris within the stream environment. US/IBP Coniferous Forest Biome, Internal Report 96. College of Forest Resources, University of Washington, Seattle, Washington, USA.

Gebhards, S. 1970. The vanishing stream. Idaho Wildlife Review, March/April:3-8.

George, G.O. 1982. Best management practices and water quality demonstration and evaluation project. Five-county north central Oregon area, October 1977 to April 1981. Oregon State University Agricultural Experiment Station, Special report 646, Corvallis, Oregon, USA.

Giger, R.D. 1973. Streamflow requirements of salmonids. Oregon Wildlife Commission, Project AFS-62-1, Job Final Report, Portland, Oregon, USA.

Gregory, S.V. 1980. Effects of light, nutrients, and grazing on periphyton communities in streams. Doctoral dissertation. Oregon State University, Corvallis, Oregon, USA.

Gresswell, S., D. Heller, and D.N. Swanston. 1979. Mass movement response to forest management in the central Oregon coast ranges. United States Forest Service, Pacific Northwest Range and Experiment Station, Resource Bulletin PNW-84, Portland, Oregon, USA.

Griffith, J.S. 1974. Utilization of invertebrate drift by brook trout *(Salvelinus fontinalis)* and cutthroat trout *(Salmo clarki)* in small streams in northern Idaho. Journal of the Fisheries Research Board of Canada 29:265-273.

Hall, J.D., and C.O. Baker. 1982. Stream rehabilitation and enhancement: 1. Review and evaluation. *In* W.R. Meehan, technical editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report Series, Portland, Oregon, USA.

Hall, J.D., and R.L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. Pages 355-357 *in* T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver, Canada.

Hanson, D.L. 1977. Habitat selection and spatial intraction in allopatric and sympatric populations of cutthroat and steelhead trout. Doctoral dissertation. University of Idaho, Moscow, Idaho, USA.

Harr, R.D. 1976. Forest practices and streamflow in western Oregon. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-49, Portland, Oregon, USA.

Hartman, G.F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon *(Oncorhynchus kisutch)* and steelhead trout *(Salmo gairdneri)*. Journal of the Fisheries Research Board of Canada 22:1036-1081.

Hickman, T.J., and R.F. Raleigh. 1982. Habitat suitability index models: Cutthroat trout. United States Fish and Wildlife Service, Western Energy and Land Use Team, FWS/OBs-82/10.5, Fort Collins, Colorado, USA.

Hjort, R.C., P.L. Hulett, L.D. LaBolle, and H.W. Li. 1983. Fish and invertebrates of revetments and other habitats in the Willamette River, Oregon. Oregon State University, Oregon Cooperative Fishery Research Unit, Corvallis, Oregon, USA. (Draft report.)

Hunter, J.W. 1973. A discussion of game fish in the State of Washington as related to water requirements. Washington State Department of Game, Olympia, Washington, USA.

Karr, J.R., and I.J. Schlosser. 1977. Impact of nearstream vegetation and stream morphology on water quality and stream biota. United States Environmental Protection Agency, Report EPA-600/3-77-097, Athens, Georgia, USA.

Kelly, J.A. 1980. Potential environmental effects of small-scale hydroelectric development in Oregon. Oregon State University, Water Resources Research Institute, Corvallis, Oregon, USA.

Ketcheson, G., and H. Froehlich. 1978. Hydrologic factors and environmental impacts of mass soil movements in the Oregon Coast Range. Oregon State University, Water Resources Research Institute, WRRI 56, Corvallis, Oregon, USA.

Klingeman, P.C. 1979. Synopsis report: A resource survey of river energy and low-head hydroelectric power potential in Oregon. Oregon State University, Water Resources Research Institute, Corvallis, Oregon, USA.

Koski, K.V. 1966. The survival of coho salmon *(Oncorhynchus kisutch)* from egg deposition to emergence in three Oregon coastal streams. Master's thesis. Oregon State University, Corvallis, Oregon, USA.

Kraft, M.E. 1972. Effects of controlled flow reduction in a trout stream. Journal of the Fisheries Research Board of Canada 29:1405-1411.

Lantz, R.L. 1971. Guidelines for stream protection in logging operations. Oregon State Game Commission, Portland, Oregon, USA.

Lauman, J., A.K. Smith, and K.E. Thompson. 1972. Supplement to the fish and wildlife resources of the North Coast Basin, Oregon, and their water requirements, April 1968. Oregon State Game Commission, Federal Aid to Fish Restoration Project 69494, Job 14, Completion Report, Portland, Oregon, USA.

Leopold, A. 1941. Lakes in relation to terrestrial life pattern. Pages 17-22 *in* University of Wisconsin symposium on hydrology, University of Wisconsin, Madison, Wisconsin, USA.

Lorz, H.W., and B.P. McPherson. 1976. Effects of copper or zinc in fresh water on the adaptation to sea water and ATPase activity, and the effects of copper on migratory disposition of coho salmon *(Oncorhynchus kisutch)*. Journal of the Fisheries Research Board of Canada, 33(9):2023-2030.

MacKinnon, D., and W.S. Hoar. 1953. The responses of coho and chum fry to current. Journal of the Fisheries Research Board of Canada 10:523-538.

Malheur County Planning Office. 1981. Two-year sampling program, Malheur County water quality management plan. Malheur County Nonpoint Source Water Quality Management Planning Program, Final Report, Vale, Oregon, USA.

Martin, D.J., E.O. Salo, S.T. White, J.A. June, W.J. Foris, and G.L. Lucchetti. 1981. The impact of managed streamside timber removal on cutthroat trout and the stream ecosystem. University of Washington Fisheries Research Institute, FRI-UW-8107, Seattle, Washington, USA.

Mason, J.C. 1976. Response of underyearling coho to supplemental feeding in a natural stream. Journal of Wildlife Management 40:775-788.

McNeil, W.J., and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning materials. United States Fish and Wildlife Service, Special Scientific Report--Fisheries 469, Washington, District of Columbia, USA.

Meehan, W.R., F.J. Swanson, and J.R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular references to salmonid fishes and their food supply. Pages 137-145 *in* R.R. Johnson and D.A. Jones, technical coordinators. Importance, preservation and management of riparian habitat: A symposium. United States Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-43, Fort Collins, Colorado, USA.

Minshall, G.W. 1967. Role of allochthonous detritus in the trophic structure of a woodland spring brook community. Ecology 48:139-149.

Moring, J.R. 1975. The Alsea Watershed Study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part II--Changes in environmental conditions. Oregon Department of Fish and Wildlife, Fishery Research Report 9, Portland, Oregon, USA.

Moring, J.R., and R.L. Lantz. 1974. Immediate effects of logging on the freshwater environment of salmonids. Oregon Wildlife Commission, Fish Research Project AFS-58, Final Report, Portland, Oregon, USA.

Morrison, P.H. 1975. Ecological and geomorphological consequences of mass movements in the Alder Creek watershed and implications for forest land management. Master's thesis. University of Oregon, Eugene, Oregon, USA.

Mundie, J.H. 1969. Ecological implications of the diet of juvenile coho in streams. Pages 135-152 *in* T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver, Canada.

Murphy, M.L., and J.D. Hall. 1980. Effects of clearcutting on predators and their habitat in small streams of the Cascade Mountains, Oregon. Canadian Journal of Fisheries and Aquatic Sciences 38:137-145.

Nickelson, T.E., W.M. Beidler, and J.W. Willis. 1979. Streamflow requirements of salmonids. Oregon Department of Fish and Wildlife, Fish Research Project AFS-623-8, Job Completion Report, Portland, Oregon, USA.

Nickelson, T.E., and R.E. Hafele. 1978. Streamflow requirements of salmonids. Oregon Department of Fish and Wildlife, Fish Research Project 14-16-0001-88-538, Annual Progress Report, Portland, Oregon, USA.

Nickelson, T.E., and R.R. Reisenbichler. 1977. Streamflow requirements of salmonids. Oregon Department of Fish and Wildlife, Fish Research Project 14-16-0001-4247, Annual Progress Report, Portland, Oregon, USA.

ODEQ (Oregon Department of Environmental Quality). 1978. Oregon's statewide assessment of nonpoint source problems. Oregon Department of Environmental Quality, Portland, Oregon, USA.

ODFW (Oregon Department of Fish and Wildlife). 1980. Policies and procedures manual. Oregon Department of Fish and Wildlife, Portland, Oregon, USA.

ODFW (Oregon Department of Fish and Wildlife). 1982. Comprehensive plan for production and management of Oregon's anadromous salmon and trout, Part II. Coho Salmon Plan. Portland, Oregon, USA.

OSSWCC (Oregon State Soil and Water Conservation Commission). 1978. Sediment reduction project; 208 nonpoint source pollution control program. Salem, Oregon, USA.

OSSWCC (Oregon State Soil and Water Conservation Commission). 1982. Stream corridor management: a report for the Department of Environmental Quality. Salem, Oregon, USA.

Oregon Task Group for Coordinated Resource Management. 1978. Coordinated resource management planning handbook. Salem, Oregon, USA.

Oregon Water Policy Review Board. 1978. Oregon drainage basins and beneficial use programs as required by ORS 536.300. Salem, Oregon, USA. (Unbound collection of water quality decisions by the State Water Resources Board of Oregon through April 1978.)

Osborn, J.G. 1980. Effects of logging on resident and sea-run populations of cutthroat trout in small tributaries of the Clearwater River, Jefferson County, Washington. University of Washington Fisheries Research Institute, FRI-UW-8018, Seattle, Washington, USA.

Peters, J.C., and W. Alvord. 1964. Man-made channel alterations in thirteen Montana streams and rivers. Transactions of the North American Wildlife and Natural Resources Conference 29:93-102.

Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104:461-466.

Pitney, W.E. 1969. Determination of stream flows for fish life. Oregon Department of Fish and Wildlife, Portland, Oregon, USA. (Mimeographed report.)

Platts, W.S. 1974. Geomorphic and aquatic conditions influencing salmonids and stream classification. United States Forest Service, Surface Environment and Mining Program, Boise, Idaho, USA.

Platts, W.S. 1981. Effects of livestock grazing. Series 7 *in* W.R. Meehan, technical editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-124, Portland, Oregon, USA.

Rauzi, F., and C.L. Hanson. 1966. Water intake and runoff as affected by intensity of grazing. Journal of Range Management 19:351-356.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Volume 1 *in* W.R. Meehan, technical editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-96, Portland, Oregon, USA.

Riparian Habitat Committee. 1979. Management and riparian ecosystems (zones) for fish and wildlife in eastern Oregon and eastern Washington. Oregon/ Washington Interagency Wildlife Committee.

Riparian Habitat Committee. 1982. Best management practices for the management and protection of western riparian stream ecosystems. American Fisheries Society, Bethesda, Maryland, USA.

Saltzman, W.O. 1976. Impact of streamside use on fisheries. Pages 160-163 *in* Columbia River salmon and steelhead. American Fisheries Society, Special Publication 10, Washington, District of Columbia, USA.

Sedell, J.R., F.H. Everest, and F.J. Swanson. Undated. Fish habitat and streamside management: Past and present. United States Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon, USA.

Sedell, J.R., and Frogatt, J.L. In press. Verhandlungen der Internationalen Vereinigung fur theorefische und augewante Limologie 22.

Sedell, J.R., and K.J. Luchessa. 1981. Using the historical record as an aid to salmonid habitat enhancement. United States Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon, USA.

Sedell, J.R., and F.J. Triska. 1977. Biological consequences of large organic debris in Northeast streams. *in* Logging debris in streams Workshop II. Oregon State University, Corvallis, Oregon, USA.

Sheeter, G.R., and E.W. Claire. 1981. Use of juniper trees to stabilize eroding streambanks on the South Fork John Day River. USDI Bureau of Land Management, Technical Note OR-1, Portland, Oregon, USA.

Simpson, P.W., J.R. Newman, M.A. Keirn, R.M. Matter, and P.A. Guthrie. 1982. Manual of stream channelization impacts on fish and wildlife. United States Fish and Wildlife Service, Office of Biological Services, FWS/OBS-82/24, Washington, District of Columbia, USA.

Smith, A.K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Transactions of the American Fisheries Society 10:312-316.

Smith, A.K. 1975. Fish and wildlife resources of the Grande Ronde Basin, Oregon, and their water requirements. Oregon Department of Fish and Wildlife, Federal Aid to Fish Restoration Project F-69-R-10, Job 5, Completion Report, Portland, Oregon, USA.

Smith, A.K., and J.E. Lauman. 1972. Fish and wildlife resources of the Middle Coast Basin, Oregon, and their water requirements (revised). Oregon State Game Commission, Federal Aid to Fish Restoration Project F-69-R-8, Job 15, Completion Report, Portland, Oregon, USA.

Soils Task Force. 1982. Minimizing debris avalanches on forest land. Oregon Department of Forestry, Salem, Oregon, USA.

Sprules, W.M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. University of Toronto Studies, Biology 56, Ontario Fisheries Research Laboratory 69:1-81.

Stalnaker, C.B., and J.L. Arnette, editors. 1976. Methodology for the determination of stream resource flow requirements: An assessment. United States Fish and Wildlife Service, Office of Biological Services, Washington, District of Columbia, USA.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. American Geophysical Union Transactions (EOS.) 38:913-920.

Swanson, F.J., and C.T. Dyrness. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon. Geology 3:393-396.

Swanson, F.J., and G.W. Lienkaemper. 1975. The history and physical effects of large organic debris in western Oregon streams. in Proceedings, logging debris in streams workshop. Oregon State University, Corvallis, Oregon, USA.

Swanson, F.J., and M.M. Swanson. 1977. Inventory of mass erosion in the Mapleton Ranger District, Siuslaw National Forest. United States Forest Service, Forest Sciences Laboratory, Corvallis, Oregon, USA.

Swanson, F.J., D.N. Swanston, and F.M. McCorison. 1976. Mass erosion processes in forested western Oregon watersheds. 72nd Annual Meeting of the Geological Society of America 8(3):414.

Swanston, D.N., and F.J. Swanson. 1976. Timber harvesting, mass erosion and steepland forest geomorphology in the Pacific Northwest. Pages 199-219 *in* D.R. Coates, editor. Geology and Engineering. Dowden, Hutchison and Ross, Inc., Stroudsburg, Pennsylvania, USA.

TBTF (Tillamook Bay Task Force). 1978. Tillamook Bay drainage basin erosion and sediment study. Tillamook Bay Task Force; Oregon State Water Resources Department; United States Soil Conservation Service; and United States Forest Service Economics, Statistics and Cooperative Services, Portland, Oregon, USA.

Thomas, J.W., C. Mash, and J.E. Rodick. 1980. Riparian zones. *in* J.W. Thomas and C. Maser, technical editors. Wildlife habitats in managed rangelands--The Great Basin of southeastern Oregon. United States Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-80, Portland, Oregon, USA.

Thompson, K.E. 1972. Determining stream flows for fish life. Pages 31-50 in Proceedings of the instream flow workshop. Pacific Northwest River Basin Commission, Vancouver, Washington, USA.

Thompson, K.E., and J.D. Fortune. 1969. The fish and wildlife resources of the Owyhee Basin, Oregon, and their water requirements. Oregon State Game Commission, Federal Aid to Fish Restoration Project F-69-R-4, Job 2, Completion Report, Portland, Oregon, USA.

Thompson, K.E., A.K. Smith, and J.E. Lauman. 1972. Fish and wildlife resources of the South Coast Basin, Oregon, and their water requirements (revised). Oregon State Game Commission, Federal Aid to Fish Restoration Project F-60-R-7, Job 11, Completion Report, Portland, Oregon, USA.

Toews, D.A., and M.J. Brownlee. 1981. A handbook for fish habitat protection on forest lands in British Columbia. Canada Department of Fisheries and Oceans, Vancouver, Canada.

United States Bureau of Reclamation. 1983. Umatilla Basin project, Oregon Planning Aid Report. United States Bureau of Reclamation, Pacific Northwest Region, Boise, Idaho, USA.

USFWS (United States Fish and Wildlife Service). 1978. Instream flow strategies for Oregon. United States Fish and Wildlife Service, Office of Biological Service, FWS/OBS-78/42, Washington, District of Columbia, USA.

USFWS and USNMFS (United States Fish and Wildlife Service and United States National Marine Fisheries Service). 1981a. Deschutes River Basin planning aid report. Portland, Oregon, USA.

USFWS and USNMFS (United States Fish and Wildlife Service and United States National Marine Fisheries Service). 1981b. Grande Ronde River Basin planning aid report. Portland, Oregon, USA.

USFWS and USNMFS (United States Fish and Wildlife Service and United States National Marine Fisheries Service). 1981c. John Day River Basin planning aid report. Portland, Oregon, USA.

USFWS and USNMFS (United States Fish and Wildlife Service and United States National Marine Fisheries Service). 1982. Umatilla River Basin planning aid report. Portland, Oregon, USA.

USGS (United States Geological Survey). 1980a. Water resources data for Oregon. Volume 1. Eastern Oregon. U.S. Geolgical Survey Water-Data Report OR-80-1. Portland, Oregon, USA.

USGS (United States Geological Survey). 1980b. Water resources data for Oregon. Volume 2. Western Oregon. U.S. Geological Survey Water-Data report OR-80-2. Portland, Oregon, USA.

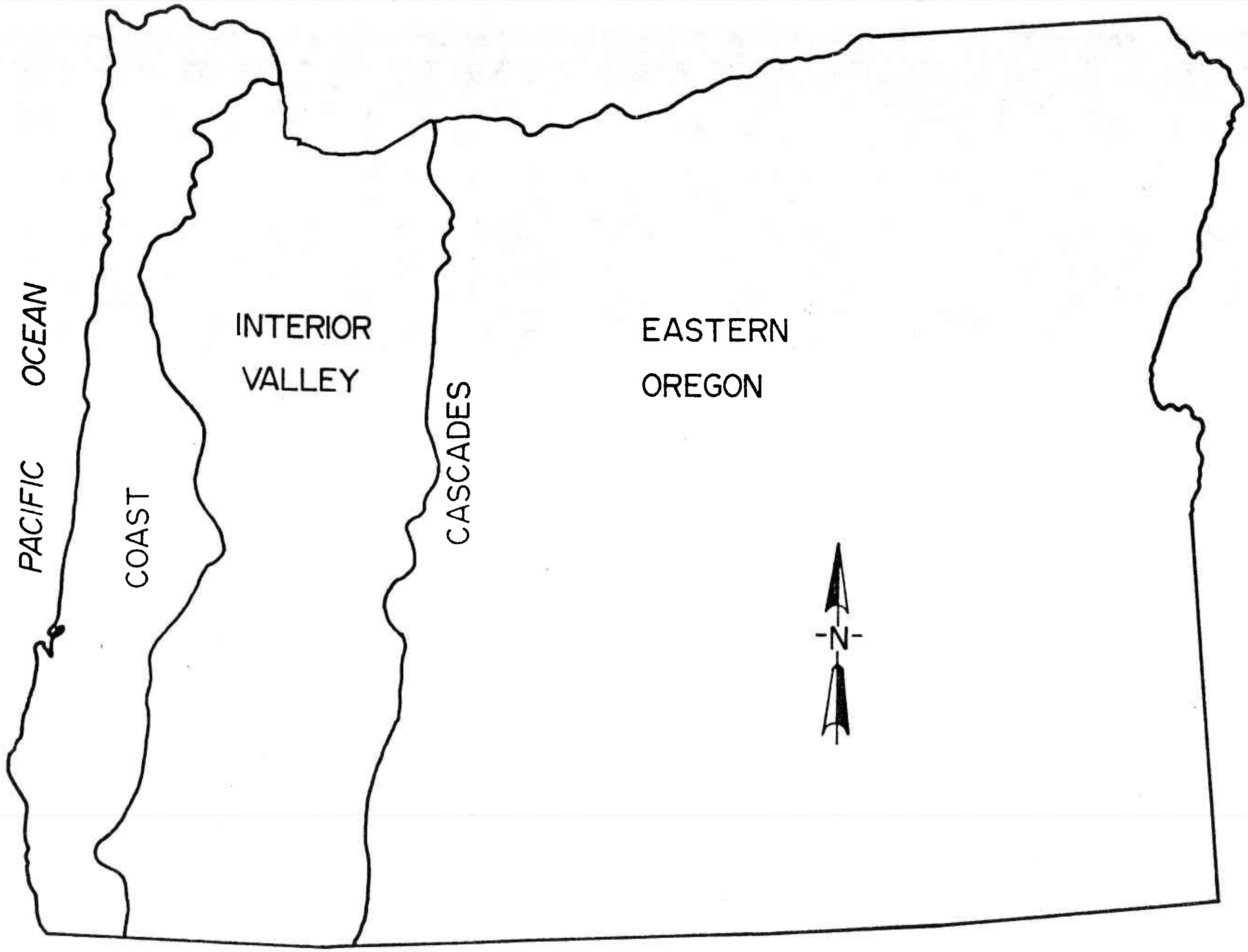
Warren, C.E. 1979. Toward classification and rationale for watershed management and stream protection. United States Environmental Protection Agency, EPA-600/3-79-059, Corvallis, Oregon, USA.

Whitney, A.N., and J.E. Bailey. 1959. Detrimental effects of highway construction on a Montana stream. Transactions of the American Fisheries Society 88:72-73.

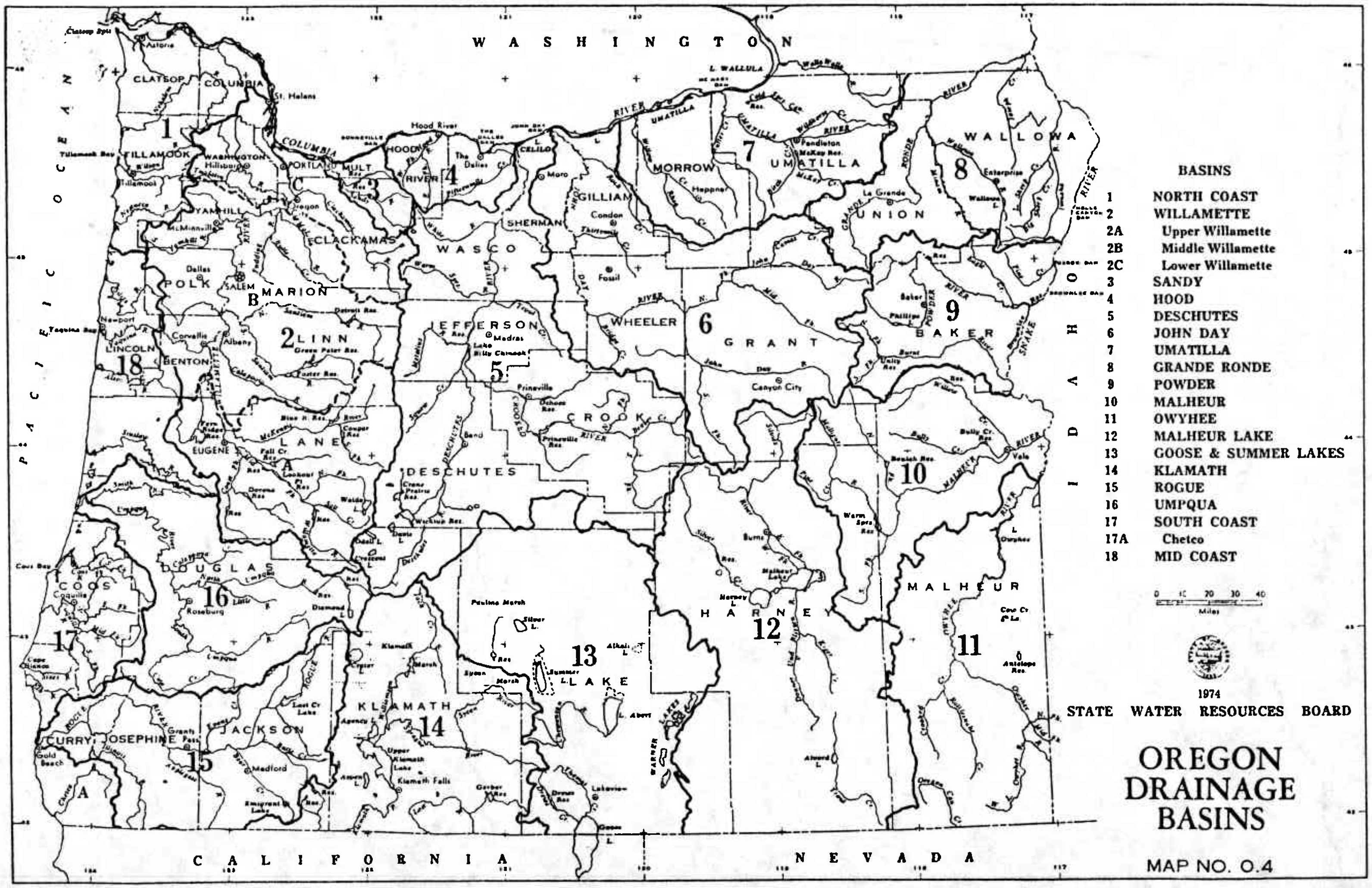
Wickett, W.P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. Journal of the Fisheries Research Board of Canada 15:1103-1126.

Winegar, H.H. 1977. Camp Creek channel fencing--plant, wildlife, soil, and water response. Rangeman's Journal 4(1):10-12.

Wydoski, R.S. 1978. Responses of trout populations to alterations in aquatic environments: A review. Pages 57-92 *in* J.R. Moring, editor. Proceedings of the wild trout-catchable trout symposium. Oregon Department of Fish and Wildlife, Portland, Oregon, USA.



Appendix figure 1. Oregon geographic areas.



Appendix fig. 2. Oregon drainage basins (Oregon Water Resources Board 1974).