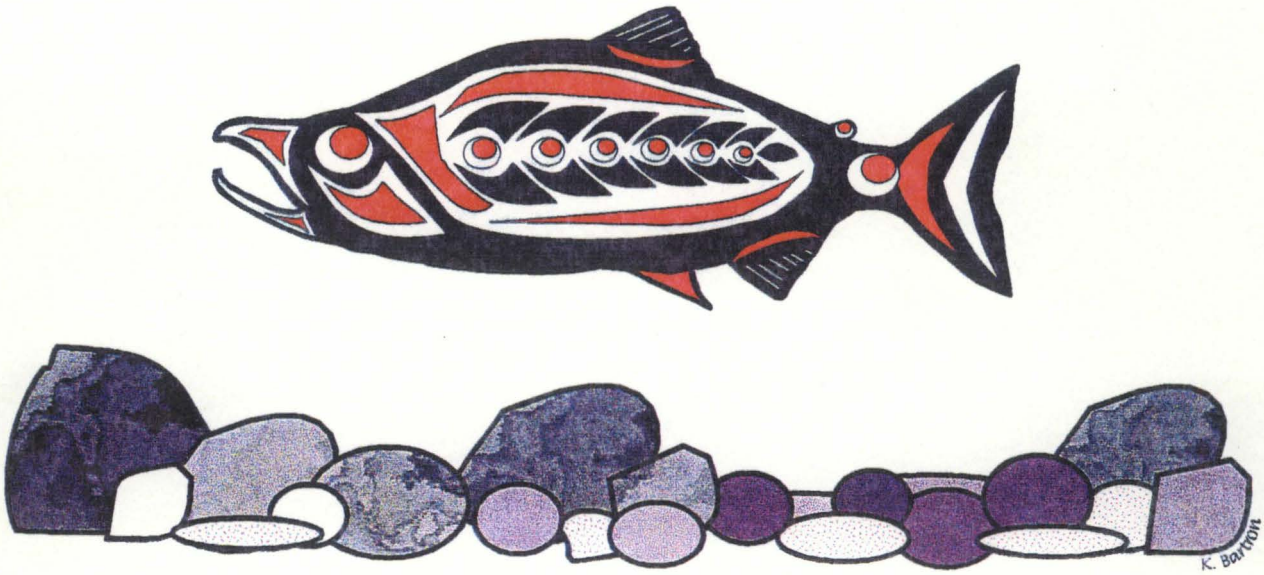
Gravel Disturbance Impacts on Salmon Habitat and Stream Health

VOLUME II: TECHNICAL BACKGROUND REPORT

A report for the
Oregon Division of State Lands



Prepared by the
Oregon Water Resources Research Institute
April 1995

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Oregon State University

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INTRODUCTION

Legislative Action and Interagency Agreement

The Oregon Legislature registered its concern over declining salmonid populations by enacting Senate Bill 81 in 1993. An interagency agreement was signed between the Oregon Division of State Lands (ODSL) and Oregon State University's Oregon Water Resources Research Institute as a result of requirements in Senate Bill 81. The objectives of this study were to:

1. Examine the relationship between removal of material from streams and stream health in support of "essential indigenous anadromous salmonid habitat."
2. Enhance ODSL's knowledge of stream processes and impacts on salmon habitat to assist in permit review.
3. Examine potential benefits and problems of gravel removal in streams.
4. Answer questions about gravel removal impacts on salmon habitat.

Gravel removal and fill/alteration projects in Oregon's streams and rivers represent a significant management dilemma for natural resources agencies. Bank protection activities, urban and recreational encroachments, and sand and gravel extraction are three typical activities where this management dilemma arises. For example, the aggregate industry provides valuable and necessary resources of sand and gravel to Oregon's growing economy. Additional restrictions upon this industry must be carefully evaluated as to the cost and benefits of increased environmental protection. However, gravel removal and fill/alteration project can potentially destroy or damage salmonid habitat and stream health; such losses of habitat have been identified as a key cause of the decrease of salmonid populations in the Pacific Northwest.

Response to Study Charge

Like all significant man-made alterations of natural streams, gravel removal and fill/alteration projects need to be managed using the best scientific knowledge of watershed interactions. An increased level of innovation and creativity will be needed to facilitate new and better approaches for using our riverine gravel resources to the benefit of Oregon's citizens, present and future.

The findings of the Oregon State University study are presented in two reports. The first titled "**Volume I: Summary Report**," gives a synthesis of study findings and makes recommendations. The second, titled "**Volume II: Technical Background Report**," gives the extensive technical background information that underlies the synthesis and recommendations.

Nature of the Problem

The largest gravel removal volumes in the State of Oregon are concentrated at sites in the Willamette and Umpqua Basins. However, the distribution of environmental impacts is unknown since there are many small gravel removal operations that also have the potential for significant localized environmental impacts. The ODSL has issued over 4000 permits for gravel removal since 1967 for a total permitted volume of over 800 million cubic yards. No organized parallel program for the monitoring and assessment of resulting environmental impacts exists.

Oregon's streams and rivers have been impacted over the last 150 years by a variety of human activities including agriculture, forestry, livestock grazing, urban and industrial development, and gravel removal. Coupled to these activities, mankind has dammed, stabilized, and channelized streams with accompanying drainage of wetlands, channel dredging, and removal of side channels. All have contributed to dramatic losses of habitat and productivity, and to a shift of these riverine systems

away from their natural states. Management of gravel removal, like all other human impacts upon Oregon's streams and rivers, needs to be focused towards stopping any further degradation of streams and, if possible, moving stream systems back to a more natural state.

The many human impacts and activities, including gravel removal, result in a variety of on-site and cumulative impacts. Cumulative impacts are characterized by being dispersed over a large distance for the impact activity, tend to be long term, and result from multiple causes. It is clear that cumulative impacts are becoming increasingly related to declining productivity of Oregon's watersheds. Cumulative impacts are the most difficult to manage because they cross jurisdictional and geographic delineations. Appropriate management of gravel removal needs to involve approaches that give adequate weight to cumulative effects. It is suggested that a watershed approach would be a first step in developing such management methods.

The ODSL Permit Process

The permit process used for fill-removal/ alteration projects by the Division of State Lands appears to be adequate to manage on-site impacts. The successful management of gravel removal to date has largely resulted from the quality and dedication of the ODSL's resource coordinators and similarly denoted personnel in other agencies that review permits. These persons provide assistance to permit applicants, on-site evaluation of potential impacts, and a risk assessment based upon experience and natural resource knowledge.

More efforts need to be directed by the ODSL, however, in collecting and analyzing data related to gravel mining and the natural processes related to this industry such as gravel recruitment within specific watersheds. Specifically, the ODSL needs to incorporate all aspects of gravel removal (permits, permitted volumes, removed volumes, recruitment rates, known gravel bars, etc.) on the State's Geographical Information System (GIS) system so that such information can be used by other natural resources agencies in reviewing permits. Future management needs to be directed towards watershed analysis that includes both short-term, localized impacts and long-term, dispersed cumulative impacts. Cumulative impacts cannot be adequately addressed by any permit-by-permit management system, including the one presently used by the ODSL.

Hydrology, Hydraulic, and Geomorphology Linkages

The hydrologic, hydraulic, and geomorphic characteristics of a watershed strongly determines both the kind and extent of salmonid habitat. The presence of extensive gravel beds is essential for salmonid habitat both as spawning areas and areas for growth of food invertebrates. Gravel removal can affect a variety of hydrologic, hydraulic, and geomorphic characteristics of a stream. On-site and cumulative impacts can occur and need to be considered. Specific data needs and potential impacts related to hydrologic, hydraulic, and geomorphic considerations have been identified and summarized into lists to be used in impact analysis and permit review.

Fish and Aquatic Habitat Linkages

Salmonid and other important fish species are under a serious decline in the State of Oregon. Management of Oregon's natural resources to reverse this trend has become of critical importance. Such management needs to be conservative and overly-protective until such negative trends in fish populations have been reversed. To this end, it is concluded that essential indigenous anadromous salmonid habitat should be defined as the entire watershed from the headwaters through the estuary, as these are ecologically linked and each component is critical to ecosystem function and salmon survival.

After a thorough review of salmon status and habitat requirements relative to riverine gravel operations and their potential effects, it is concluded that no ecological basis exists for the suggestion that only 20% of Oregon waterways needs to be protected to provide adequate habitat for remaining salmonids. Under the present circumstances, it is our opinion that no areas exist in Oregon's rivers and streams where gravel removal and fill/alteration projects can occur without constraints. Maps of

critical locations and tables of critical time periods for specific salmonid populations have been included to assist in determining the degree of constraint that must be addressed by responsible management.

Management Innovations: The Burden of Proof

Salmon have thrived in the Pacific Northwest for hundreds of thousands of years. For many millennia they have been able to survive natural changes and disasters. But with the arrival of modern technological society, they have been decimated and driven to the brink of extinction within a mere century, a brief moment of ecological time. Salmon have historically been valued and even treasured. Indeed they have become a symbol for the people of the Pacific Northwest. The salmon crisis is an identity crisis. It is about who Americans are and how they live. The decimation and salmon indicate something is being done wrong.

It has become apparent that more information about salmon will not be sufficient to resolve the current crisis. The historical fact that salmon have been both valued and destroyed, forces Americans to question their own ways of thinking and acting. The authors of this technical study were repeatedly confronted with facts that challenged long established practices, even within their own disciplines. More of the same would not suffice. This report presents conventional scientific assessments which are necessary but are insufficient. This report also explores opportunities beyond the established practices of current disciplines. The facts demand such an exploration.

NATURE AND EXTENT OF FILL AND REMOVAL ACTIVITIES

Methods of Gravel Removal

There are three types of mining commonly associated with in-stream, alluvial gravels. They are **dry pit, wet pit,** and **bar skimming**. Kondolf (1994) described these as follows. **Dry pit mining** is characterized by pits excavated by bulldozers, scrapers and loaders on the ephemeral stream beds. In **wet pit mining,** draglines or hydraulic excavators remove the material from either below the water table or directly from a perennial stream channel. **Bar skimming** involves removing the tops of gravel bars without excavating below the summer water level. Other mining methods include **safe yield mining,** where extraction is limited to the removal of the annual resupply; and **floodplain** and **terrace pit mining** (Sandecki, 1989).

Currently, floodplain and river terrace mining are widely practiced. This consists of excavating gravel from pits in the floodplain or terrace adjacent to the active channel. As active channels naturally move, the channel may migrate into the excavated area. The chance of this occurring is increased in the event of a flood. Such was the case in 1971, when gravel pits on Washington's Yakima River became integrated into the active channel (Dunne & Leopold, 1978), and in 1975, when this partially occurred on the Rogue River at the Touvelle gravel pits (Klingeman, personal communication, unpublished data). Because of this, "floodplain pits should be considered as being potentially in-stream when viewed on a time scale of decades" (Kondolf, 1994). This is particularly true for unregulated rivers.

Oregon's gravel removal is dominated by floodplain, wet pit, and bar skimming operations. Wet pit operations are limited to the Columbia River, the Willamette River below Newburg, and the lower reaches of the Umpqua River.

Gravel Removal in Oregon

The removal of river gravel for commercial purposes has occurred for several decades in Oregon. In general, river gravel is more economical to mine since it is cleaner than upland sources and is readily available. In addition, the gravel extracted from rivers is stronger than other aggregates since sediment transport processes select more resistant materials. Where gravel removal activities occur within the "waters of the State" (ORS 196.800), a permit through the Division of State Lands (ODSL) is required. Since 1967, ODSL has issued over 4,300 permits for removal of material from streams, rivers, and wetlands throughout Oregon. These permits include removal of material for dredging, flood control, commercial gravel mining, boat ramps, and roads and bridges (Table 1). The permit numbers alone do not indicate the volume of material under each category. The volume of material removed (by permit type) under removal permits from 1967 to 1994 is shown in Figure 1. As indicated, the greatest volume of material is removed for dredging; the next greatest amount of material is removed for "unknown" purposes. The third highest amount is removed for commercial gravel removal. Though all these fill and removal activities have the potential of causing on-site and cumulative effects to the streams and rivers of Oregon, only commercial gravel removal will be examined in detail in this report.

Commercial gravel removal does not occur uniformly throughout the State, but is dependent on supply and demand. In areas of large population growth where gravel is abundant, there tends to be greater utilization of gravel from streams and rivers. The relative volume of gravel removal for major basins in the State is shown in Figure 2. As is evident from this figure, the Willamette Valley has the greatest amount of permitted gravel removal. The combination of the growing population of the Portland Metropolitan area and

Table 1. Number of DSL Removal and Removal-Fill Permits by Permit Type From 1967 to 1994

Type Code	Description	No. of permits since 1967
0	Unknown	934
1	Erosion/flood control	11
2	Roads/bridges	941
3	Pipeline/cable/utility	429
4	Maintenance dredging	1,185
5	Moorage	145
6	Channel relocation	12
7	Misc. fill	207
8	Resource enhancement	178
9	Prospecting	5
10	Dam	69
11	Boat ramps	85
12	GA/Fish habitat enhancement	4
13	GA/Erosion control	0
14	GA/Road construction	0
15	GA/Wetland enhancement	0
16	Maintenance/repair exemption	0
17	**Commercial gravel removal**	**126**
18	Ponds	12
19	Misc. removal	54
	TOTAL	**4,397**

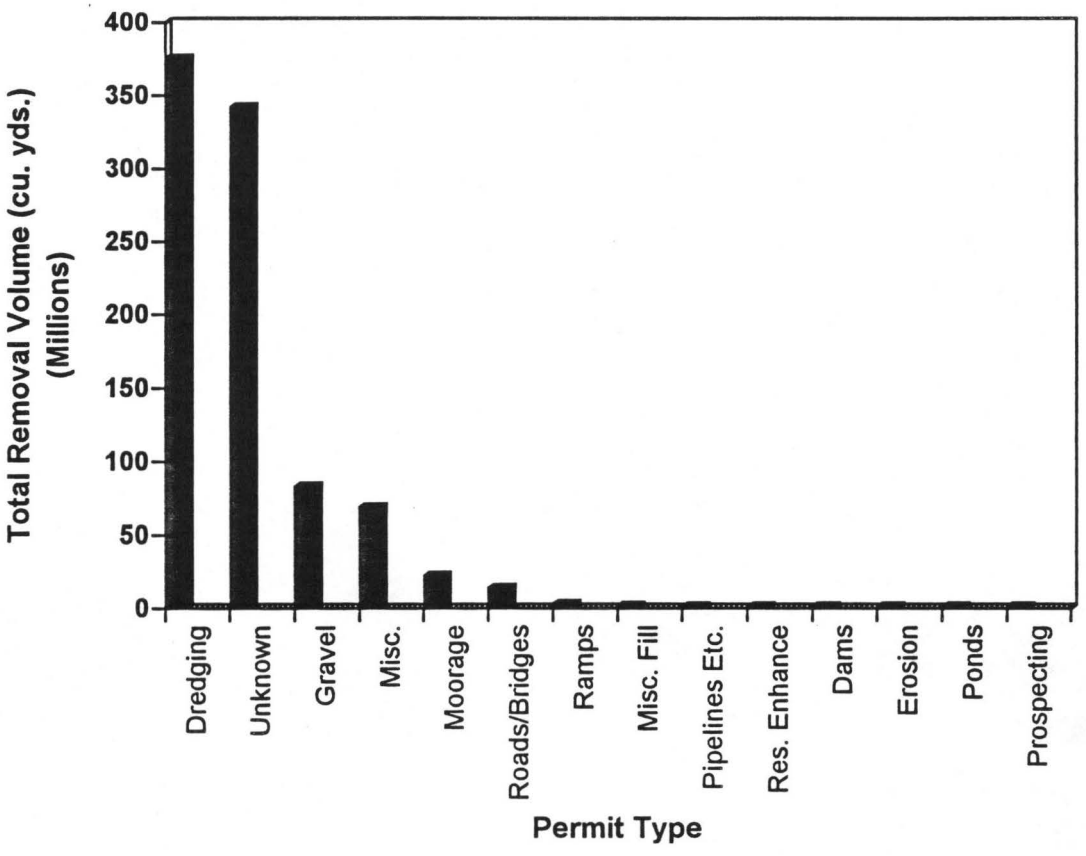

Figure 1. Total Permitted Removal Volumes For All Removal Permits from 1967 to 1994.

the abundance of gravel along the Willamette River creates high gravel usage. Other areas of high supply and demand are in the Umpqua Basin. The eastern portion of the State contains little to no commercial gravel removal except for small amounts in the Northeast portion of the State. In general, the number of actual basins with current or past permitted gravel removal is relatively small (31 total) (see Figure 3).

Gravel usage changes with shifting trends in population and construction of major projects such as dams and freeways. For Oregon, a period of dam construction caused a significant increase in sand and gravel production for the State. The total annual volume of permitted gravel removal for the State from 1967 to 1990 is shown in Figure 4. As illustrated, permitted gravel removal has steadily increased since 1967. Post-1990 data were not utilized since several permits were temporarily suspended due to land use issues in both the Chetco River and the Tillamook Basin.

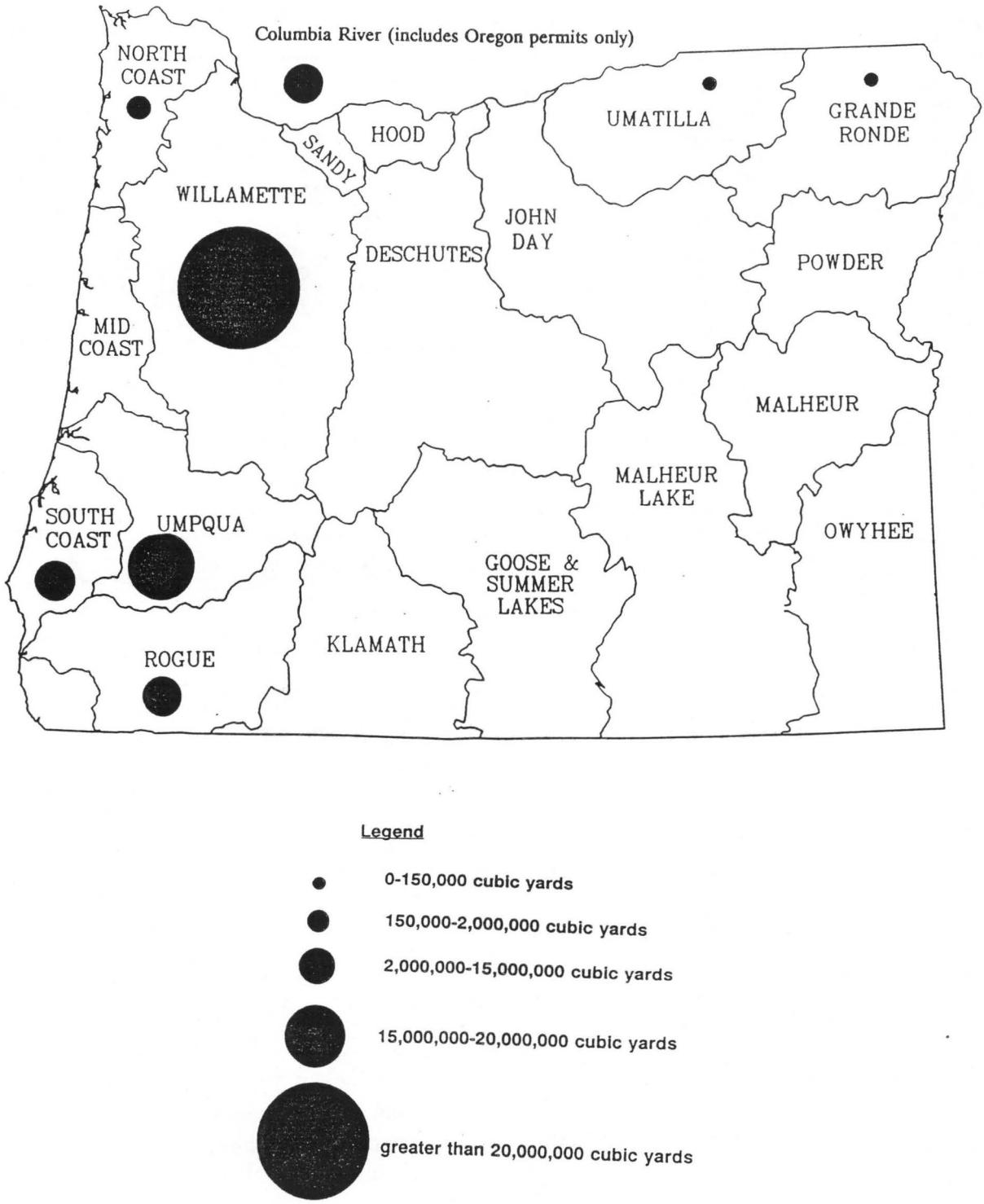

Figure 2. Geographical Distribution of Permitted Gravel Removal Volumes in Oregon by Drainage Basin from 1967 to 1994.

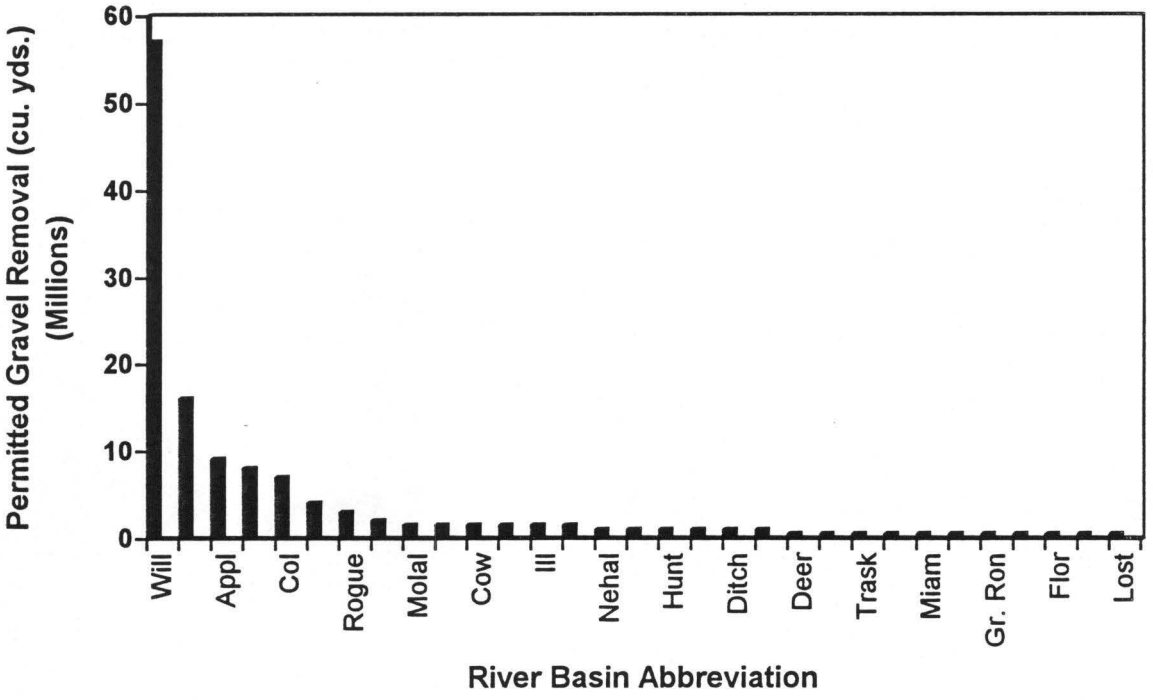

Figure 3. Total Permitted Gravel Removal in Oregon by Watershed for 1967 to 1994.

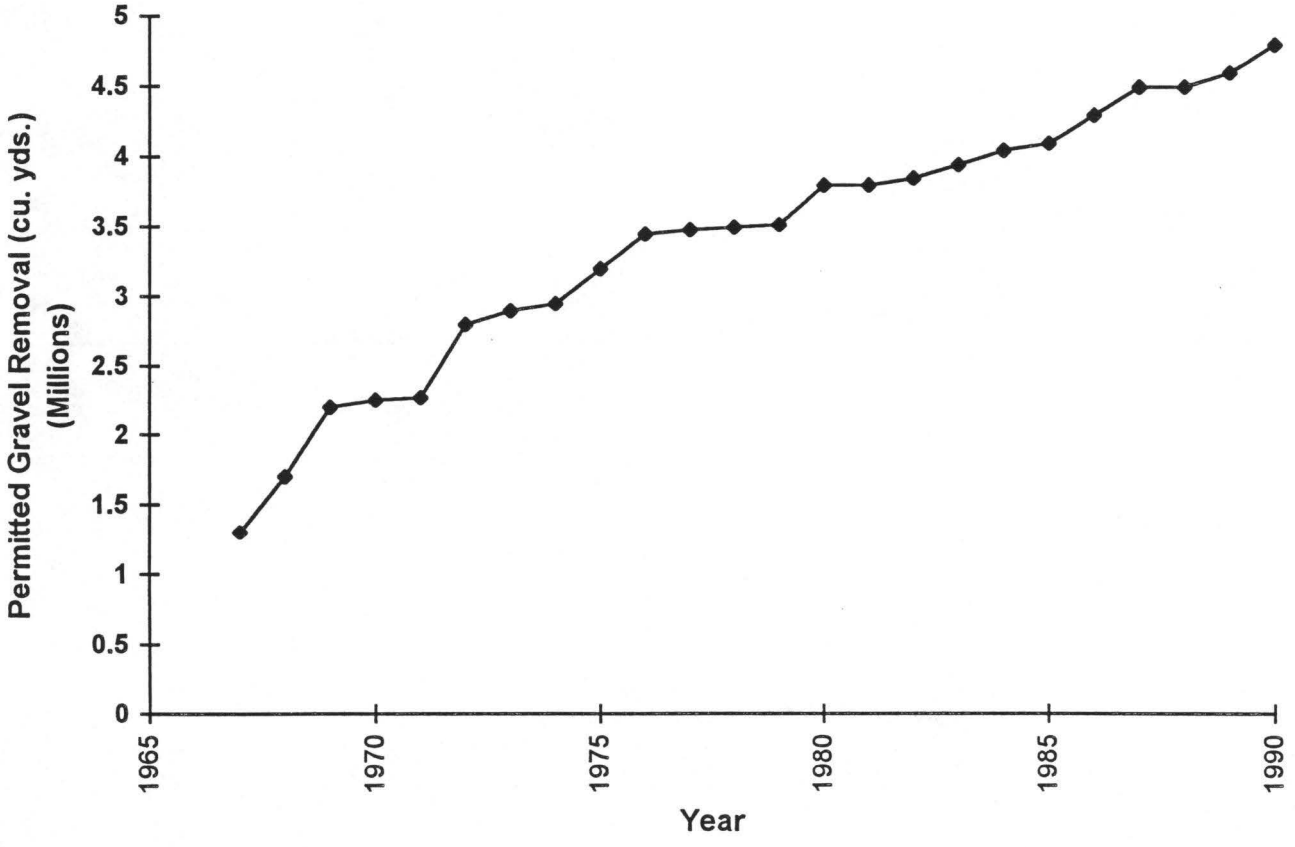

Figure 4. Total Permitted Commercial Gravel Removal Volumes in Oregon from 1967 to 1994.

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CONCEPTUAL FRAMEWORK

Historical Context -- Water Resources Development Projects and Land Use Practices in Oregon

The streams, rivers, estuaries, coastline, and lakes of Oregon have been major factors in the economic development of the State. Since the mid-1800s, when the State began to be settled by western Europeans, waterways provided transportation, water supplies, and food. As the population of the State grew, the water resources were increasingly altered to allow for greater resource utilization.

Projects such as dam construction, irrigation projects, bank stabilization projects, and channelization projects directly manipulated the waterways of the State for economic and flood protection goals. Other in-channel practices such as sand and gravel production, directly impacted stream resources. Land use practices such as agriculture, urbanization, and forestry have also had impacts on the water resources of the State. The major land cover categories delineated for the State of Oregon indicate that forest land accounts for approximately 46.2%, agriculture and rangeland comprises 46.5%, deserts 6%, water bodies 1.2%, and urban areas 0.075% of the State (Evergreen Foundation & Oregon Forest Resources Institute, 1994). Since forest, agricultural, and range lands comprise the majority of the State, the effects of their practices will be most extensive and may have significant impacts on streams.

The streams and rivers of Oregon, while providing physical resources, also have significant biological resources. With the salmon fisheries in Oregon is in serious decline, the many uses of Oregon's streams and rivers are coming into question.

The following sections provide a context for understanding the effects of gravel removal amidst the numerous other water resource developments that have altered waterways throughout Oregon.

Dam Construction

Dam construction in the Pacific Northwest began during the late 1800s when hydroelectric facilities were built on some of the larger Columbia River tributaries such as the Willamette and Spokane Rivers. During the early 1900s, dam construction proceeded at a relatively slow pace with the focus on hydropower generation. The authorization of the Grand Coulee and Bonneville projects by Congress during the early 1930s signaled the start of an intensive period of water resource development in the Pacific Northwest. The emphasis during this time was on multipurpose projects which, in addition to providing hydropower generation, would also afford benefits such as navigation, flood control, and irrigation (Grizzel, 1993).

Along with these major water development projects, a large number of smaller projects are located throughout the region, providing water for municipal, industrial, irrigation, stock and rural users. The Oregon Water Resources Department estimates that there are 10,000 to 12,000 smaller dams not included in the State inventory (Grizzel, 1993).

Trends in dam construction in Oregon are illustrated in Figure 5 (number of dams through time in Oregon). Prior to the turn of the century, the hydrology of the free-flowing rivers and streams of the region remained relatively unaltered. During the period 1910-40, dam construction grew at a rapid rate largely as a result of increased demands for electricity and irrigation. This period of water resource development was followed by an even greater growth period following World War II. During the early 1940s and continuing through the 1960s, both the number of dams and the volume of water impounded behind the dams increased at their highest rates. Although the rate at which volumes of water impounded by dams has decreased dramatically since the mid-1970s, the number of dams being constructed is still expanding. This suggests that new construction is focusing on smaller dams that have lower storage capacities.

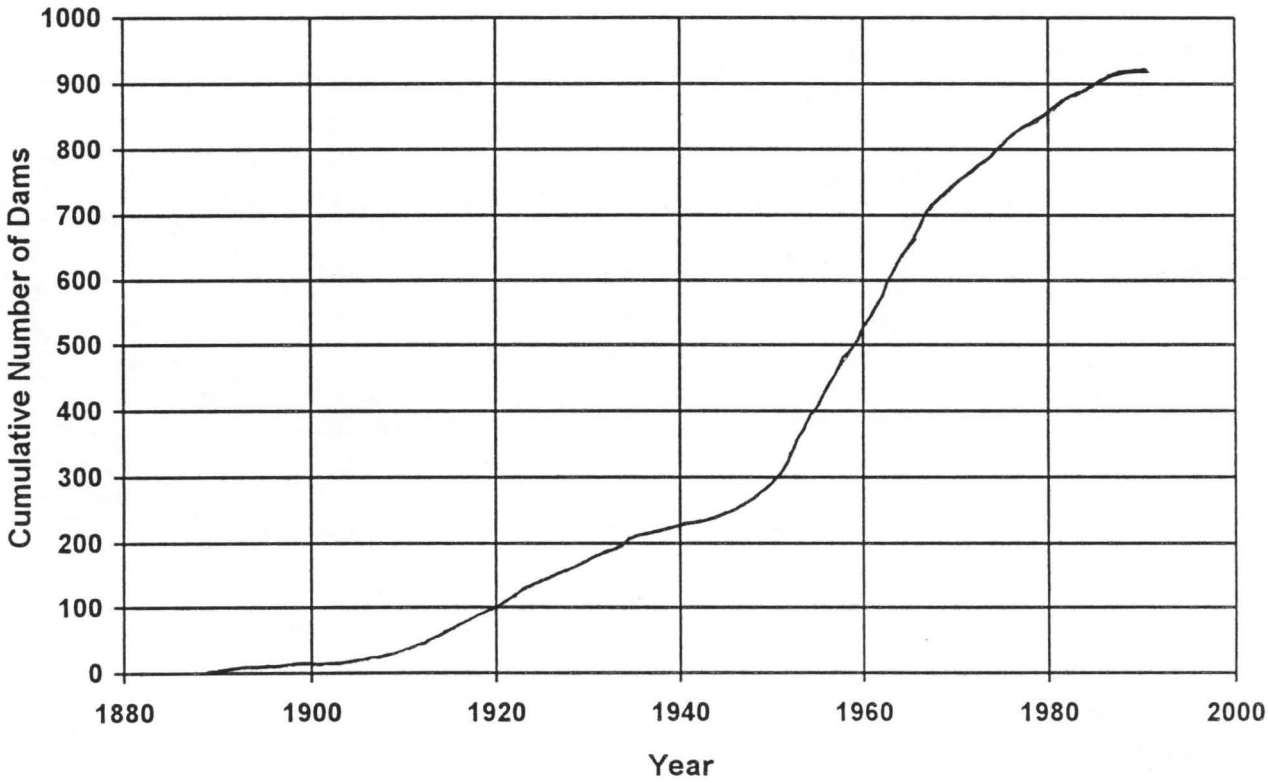

Figure 5. Dam Construction in Oregon Between 1800 to 1990.

The construction of dams throughout the State of Oregon used significant amounts of aggregate (see Figure 6). Since the dams were constructed on riverways, the most efficient source of aggregate material was the sand and gravel of the river. The 1960-1970 period saw the greatest use of sand and gravel usage throughout the State. Thus, dams have not only affected rivers through the impoundment of water, but also through extensive removal of in-channel and near-channel sand and gravel resources for their construction.

Irrigation

In the Pacific Northwest, irrigation, municipal, and industrial interests comprise the majority of off-stream uses of water. Irrigation accounts for the largest portion of water withdrawn from the lakes, streams, and rivers of the Pacific Northwest. For example, in the Upper Snake River Sub-Basin, irrigation withdrawals are approximately five times greater than the combined withdrawals of municipal and industrial interests in the entire Pacific Northwest (Kimerling & Jackson, 1985).

The history of irrigation in the Pacific Northwest dates back to the early days of settlement. In 1840, missions near Walla Walla, Washington and Lewiston, Idaho were the first sites to utilize irrigation to aid in crop production. The first irrigation project began in 1859 in the Walla Walla River Valley. Soon thereafter, water projects developed in the John Day, Umatilla, and Hood River Valleys of Oregon. An increasing demand for agricultural products combined with the expansion of railroads throughout the region attracted commercial-scale farmers to the Northwest during the 1890s and early 1900s (Northwest Power Planning Council, 1986). Federal legislation which encouraged the establishment of irrigation on newly acquired lands included the 1877 Desert Land Act and the Carey Act of 1894 (Johansen & Gates, 1967).

The United States Geological Survey (USGS) estimated that in 1990 alone, total surface water withdrawals for irrigation purposes in the Pacific Northwest amounted to 26.8 million acre-feet (Solley et al., 1990). As a comparison, the average annual water yield of the Columbia River at its mouth is approximately 180.0 million acre-feet (Pacific Northwest River Basins Council, 1979). While a portion of the water diverted or withdrawn eventually returns to the stream, the Pacific Northwest River Basins Commission estimated that in 1966, 47% of the water used for irrigation in the region was lost either through consumptive use or conveyance loss (Pacific Northwest River Basins Commission, 1971). However, Solley, Pierce, and Perlman (1993), estimated consumptive use and conveyance losses amounted to 67% of withdrawals for the Pacific Northwest region during 1990 (Grizzel, 1993).

Sand and Gravel Removal

The use of sand and gravel (generally derived from alluvial and lacustrine deposits) and crushed stone (quarried from pits) in Oregon has mainly been for construction, with roads historically consuming approximately 50% of the State's total production of sand and gravel, and 75% of the State's total crushed stone production (Friedman et al., 1979). The other major consumers of sand, gravel, and crushed stone are building construction and landfills. Since sand, gravel, and crushed rock generally have low value relative to their weight, transportation costs are a significant proportion of their total cost (35 to 50%), thus production tends to occur near the area of consumption.

Figure 6 shows the sand, gravel, and crushed stone production for the State of Oregon from 1940 to 1976. The period from 1960 to 1966 is high compared to the overall trend as a result of the construction of several dams in the State including Green Peter, Foster, and the John Day Dam. Figure 6 does not include the sand, gravel, and crushed rock production for national forest lands in the State since they are reported differently. Most sand, gravel, and crushed rock production are reported on a county-by-county basis, however, national forests report their usage on a statewide basis. The rock usage for national forests is mainly crushed stone, with a smaller percentage of alluvially derived sand and gravel. On a statewide basis, the alluvially derived sand and gravel used on national forests constitutes approximately 5% for the 1970 to 1976 period while crushed stone constituted 21% (Friedman et al., 1979).

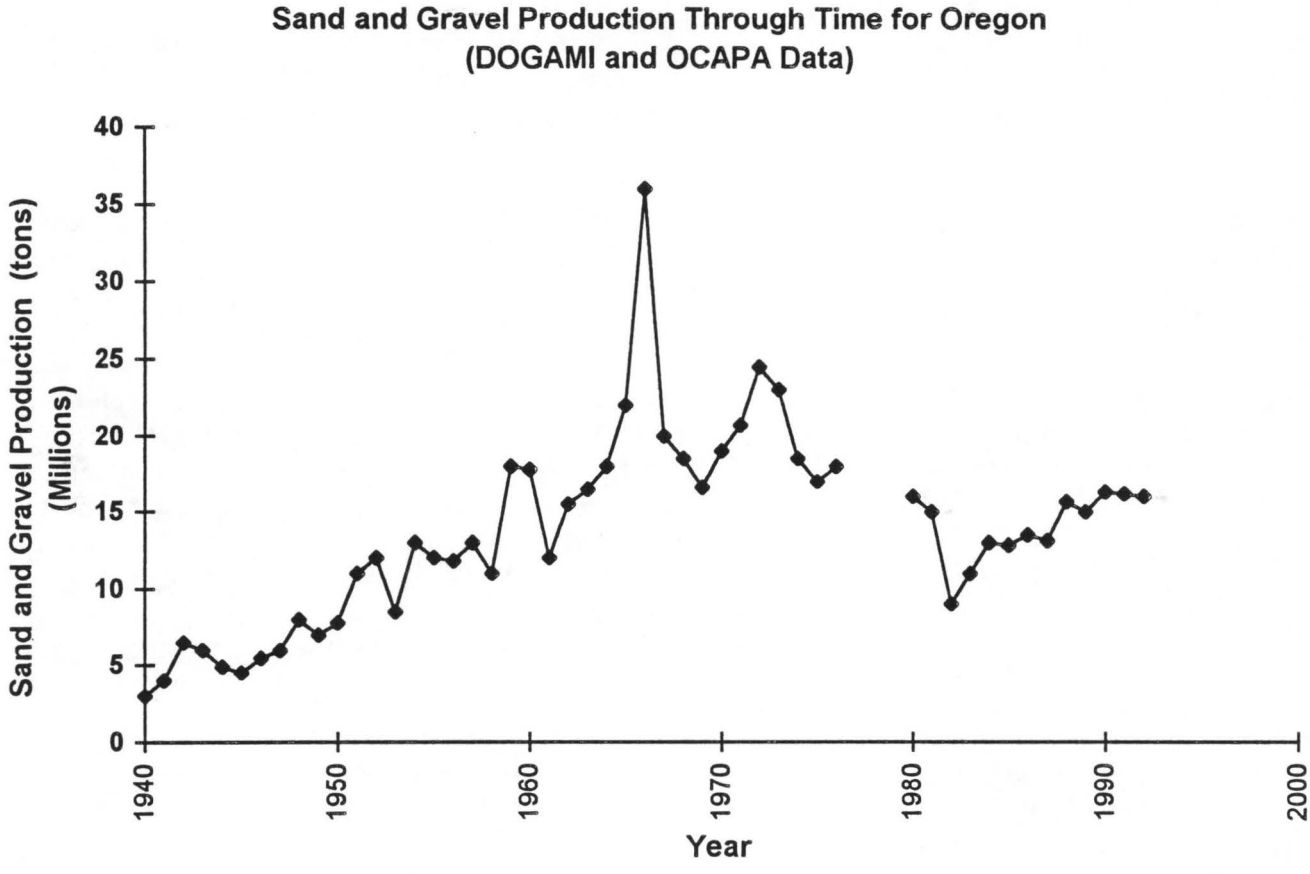

Figure 6. Sand and Gravel Production in Oregon From 1940 to 1990.

The trend of sand and gravel and crushed stone production from 1940 to 1976 fluctuates depending on economic conditions, but shows an overall increasing trend through time. In general, the production of sand and gravel has exceeded that of crushed stone in the period between 1940 and 1976. The Willamette Valley, which contains the majority of the State's population and economic activity, is also the major producer and consumer of rock resources in the State. For example, from 1970 to 1976 the Willamette Valley has accounted for 70.7% of the State's sand and gravel production and 43.2% of the State's crushed stone production (Friedman et al., 1979).

The available historical numbers for sand and gravel removal referenced here include all alluvially derived sources, without specific reference to in-channel or near-channel removal. Permitted in-channel or near-channel removal numbers are available since 1967. As discussed in the Introduction, the permitted volume for all categories of removal has decreased significantly since the 1970s and has been fairly constant since that time.

Agricultural Practices

The agricultural practices of the State have effected water resources in numerous direct and indirect ways. The sediment and nutrients and other sources of non-point pollution that leave agricultural lands have an impact on the water quality of streams and rivers. The other practices, such as ditching and draining of fields associated with historical and current agricultural practices, also serve to impact waterways in Oregon.

The amount of sediment leaving an agricultural field is determined mainly by the intensity and duration of a rainfall event, soil erodibility, field topography, vegetative cover, and tillage practices. In addition to these factors influencing the amount of sediment delivered to a stream, they can also influence the amount of nutrients and other chemicals that are delivered as well. However, the delivery of nutrients and chemicals to waterbodies also depends on the soil type, fertilizer type and amount, farm management practices, cropping patterns, presence of animals and manure storage practices, and weather (Clark et al., 1985).

In the Willamette Valley above Salem, Oregon a study on sediment production indicated that 22% of the annual sediment budget is from agricultural lands, 24% is from forested lands, and 54% is from actively eroding banks (Anderson, 1954). The percentage distributions of the annual sediment budget for the Willamette were in agreement with a later study by Young (1980).

A practice associated with the development of farmland is the draining of wetlands and wet areas. Since colonial times, wetlands in the United States have been regarded as a hindrance to productive land use. Swamps, bogs, marshes, and other wet areas were considered wastelands to be drained, filled, or manipulated to produce crops or commodities. Recently other values associated with wetlands, such as providing fish and wildlife habitat, maintaining groundwater supplies, improving water quality, protecting shorelines from erosion, storing floodwaters, and trapping sediments, have been recognized.

In the United States, agricultural conversion of wetlands has historically been the main cause of wetland loss -- 87% during the 1950s to mid-1970s (Dahl & Johnson, 1991). More recent trends in wetland losses (mid-1970s to mid-1980s) indicate that agricultural conversion accounted for 54% of losses while conversions to "other" land uses accounted for 41% of losses (Dahl & Johnson, 1991). In Oregon, wetland areas have gone from 2.26 million acres in 1780 to 1.39 million acres in 1980, a 38% loss (Dahl, 1990).

Urban and Industrial Development

Urban and industrial development, while accounting for a small percentage of the total land use of the State, has significant impacts to the water resources of the State. Figure 7 shows the population of the State through time. With continued growth expected to lead to a doubling of the population in Oregon in the next 25 years, the effects of urbanization and industrialization are bound to increase. The effects of urbanization and industrialization on waterways include intensive channelization through engineered structures and through increased scour associated with the increased velocities of runoff from paved areas and degradation of water quality from pollutants in storm runoff.

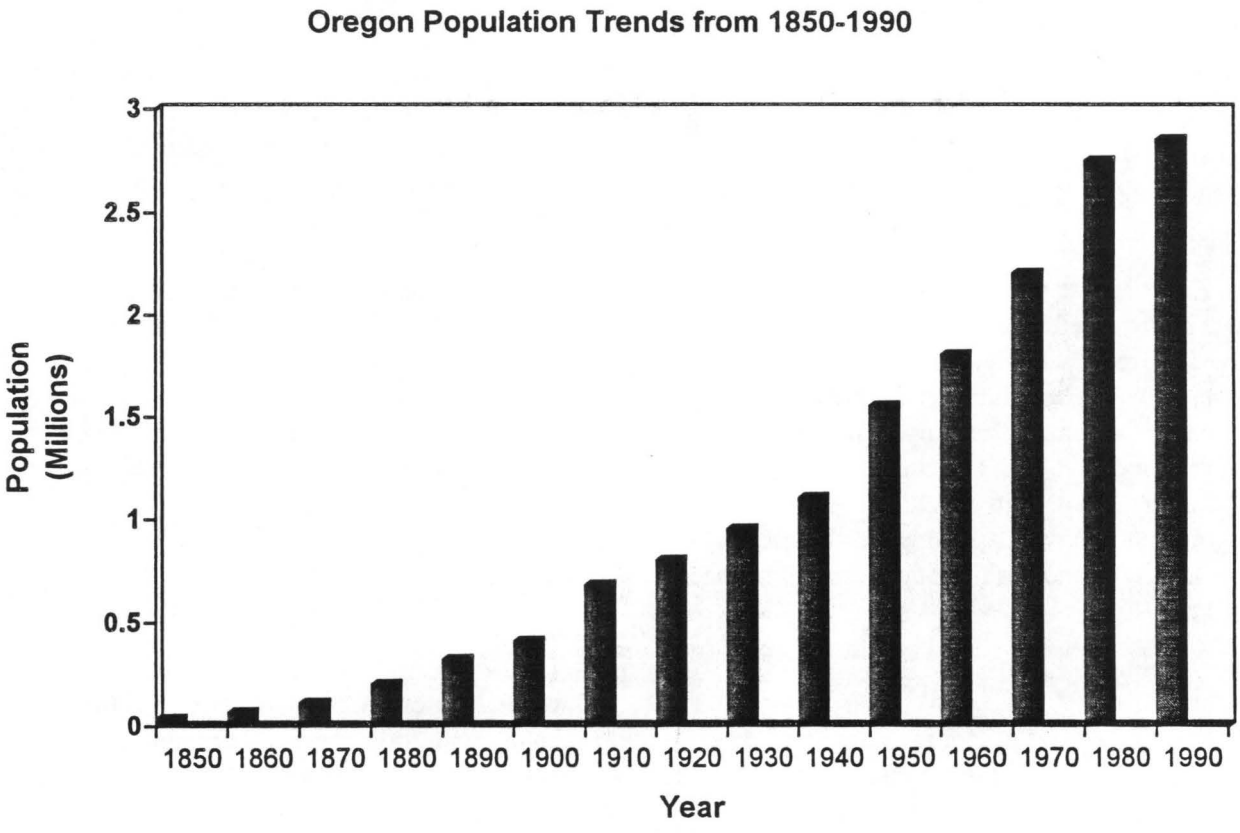

Figure 7. Population Growth in Oregon.

Urban and industrial development also lead to wetland loss in both freshwater and saltwater areas and are the primary cause of estuarine wetland losses (Grizzel, 1993). Coastal salt marshes close to sea ports and population centers are especially vulnerable to conversion, with losses commonly between 50 and 90% in individual estuaries (Frenkel & Morlan, 1991). Frenkel and Morlan estimated that prior to 1978, 75% of the Salmon River estuary in Oregon had been isolated from the rest of the estuary by dikes. Thomas (1983) reported that 24% of the Columbia River estuary had been converted from wetland habitat types between 1870 and 1983. Tidal swamps and marshes together lost approximately 65% of their former area where diking and filling were the principal activities causing the losses (Thomas, 1983).

Forest Practices

The first sawmill in the Pacific Northwest was constructed near Vancouver, Washington in 1827. Since that time, forestry has become one of the leading industries in the region. Log production in the region peaked during the early 1970s and has declined significantly in recent years. Long known for its vast timber resources, the Northwest has experienced drastic changes in the way forest management is practiced on both public and private forest lands. While most of the earlier changes in forest management resulted from technological advances, more recent changes have occurred due to concern for the protection of water quality and fish and wildlife habitat.

The earliest logging operations in the region were located along the banks of larger rivers and streams where logs could easily be floated downstream for milling. When the timber supply within easy access of a navigable stream was exhausted, logging operations would simply move to another location. It was not until the 1970s, over a century later, that scientists began to recognize the importance of riparian vegetation in maintaining healthy aquatic systems. In addition to providing shade, these forests also serve as a source of large woody debris which is a critical component of fish habitat (Bustard & Narver, 1975; Bisson et al., 1987; Lisle, 1986). Logging of riparian forests continued into the 1970s until the enactment of forest practice rules in Oregon and Washington limited the number of trees that could be harvested from streamside areas (Grizzel, 1993).

In addition to the harvesting of riparian timber, the direct removal of large wood from stream channels was a common practice until only recently. Streams and rivers used for navigation purposes were routinely "cleaned" of all large wood and boulders to provide an unobstructed route for the transport of log rafts. Salvage logging of timber in streams and rivers, especially western red cedar, heavily impacted small streams throughout western portions of Washington and Oregon. Beginning in the late 1940s and early 1950s and continuing into the 1970s, the removal of debris jams to benefit fish migration was widely instituted. Fishery biologists viewed large accumulations of wood as barriers to fish migration or material that might scour channels during a major storm event (Sedell & Luchessa, 1982). Current management ideologies view large woody debris as a critical component in restoring fish habitat and the overall functioning of stream and river systems.

While the removal of wood from in and around stream channels was in itself a major impact to fish habitat in the Pacific Northwest, the use of splash dams to transport logs downstream degraded many miles of important spawning and rearing habitat for salmon and steelhead. While splash damming is no longer used as a means to transport logs, the effects of this practice are still evident in many small streams throughout the region.

With the advent of modern logging technology, areas that had been formerly inaccessible due to terrain limitations became part of the commercial forest land base. Extensive networks of forest roads were constructed to access stands of timber.

Sediment generated from road surfaces, skid trails, and harvested hillslopes often entered stream channels where it filled pools or clogged spawning gravels (Grizzel, 1993).

Livestock Grazing

In 1934, Congress passed the Taylor Grazing Act (TGA) in order to "stop injury to the public grazing lands by preventing overgrazing and soil deterioration" (Preamble to the Act, 1934). Until passage of the TGA, the practice of livestock

grazing on public rangelands in the western states was unregulated. The TGA established the Grazing Service within the Department of Interior (later to become the Bureau of Land Management) to regulate grazing on public lands. The high levels of grazing which occurred during the late 1800s and early 1900s led to widespread degradation of many rangeland resources by the 1930s. A report entitled "The Western Range" written by the Secretary of Agriculture in 1936 (United States Department of the Interior, undated) noted the poor condition of western rangelands, pointing to such problems as erosion, reduced productivity, impaired watershed service, and siltation of waterways.

In 1941, the Grazing Service authorized approximately 22 million Animal Unit Months (AUMs) of grazing on 258 million acres of public rangelands, which was the highest level of use ever authorized (United States Department of the Interior, undated). Since then, the amount of livestock grazing on public lands has declined steadily. The Bureau of Land Management (BLM) cites a shrinking land base and reductions in use as reasons for the decline in total livestock grazing. The effects of reduced livestock grazing on public rangelands have not been quantified with specific regard to riparian and/or aquatic resources.

Riparian areas, as noted previously, are important in maintaining healthy, functioning stream ecosystems. The concentration of livestock grazing in riparian areas over the last 130 years has resulted in the degradation of fish habitat in many arid land stream systems. Elmore and Beschta (1987) report that due to their poor condition, many riparian areas in eastern Oregon "no longer dampen flood peaks or assist in recharging subsurface aquifers" and streams "that once handled spring runoff and summer freshets easily are now unstable and eroding." According to the Northwest Power Planning Council (1986), Platts reported that overgrazing within the Columbia River Basin has negatively affected salmon and steelhead populations primarily through sedimentation of spawning beds.

Historical Perspective of Oregon's Streams and Rivers

The prehistoric condition of Oregon's vegetation, streams, and rivers prior to European settlement in the 1800s represent an important ecological benchmark for Pacific Northwest salmonids. It was under these conditions salmonids evolved and adapted. Admittedly, these conditions will never return, but the contrast with current conditions helps to frame an understanding of the current plight of salmonids. Often humans do not notice gradual changes in their environment. This short-term thinking may be a product of human evolution for which modern humans must consciously compensate before their actions irreparably damage natural ecosystems (Ornstein & Ehrlich, 1989). One way to visualize the magnitude and direction of change over time is to create before and after "snapshots" of conditions over longer time scales than individual daily perceptions allow.

The 1800s brought many changes to Oregon as waves of settlers arrived and sought ways to exploit the region's vast resources to earn their livelihood. The order in which forests were cut depended primarily upon the availability of markets. By the early 1880s, the best, most accessible timber along the larger rivers was already cut. Any stream large enough to float logs provided the means by which the next timber would be accessed and brought to market (Figure 8). By the end of the 1880s most of the timber along the coast and the lower Columbia had been cut and rafted, towed or driven to nearby ports. Trees were cut first from riparian areas and nearby uplands, with dire implications for channel stability and stream conditions (Sedell & Duval, 1985).

As the forests were cut, the rivers and streams were converted from complex aquatic habitat into systems generally devoid of any structure that might slow the log drives. Snag boats operated from the 1890s to as late as the 1970s, pulling logs out of channels as an aid to transportation. Removal of in-channel logs released pulses of sediment, which had been stored behind the logs, and filled coastal estuaries. Off-channel habitat was blocked to keep logs and water in the main channel. Boulders, trees, and other structural elements in the channel were blasted so that logs would not be held up during log drives. Pools above rapids were lowered by blasting.

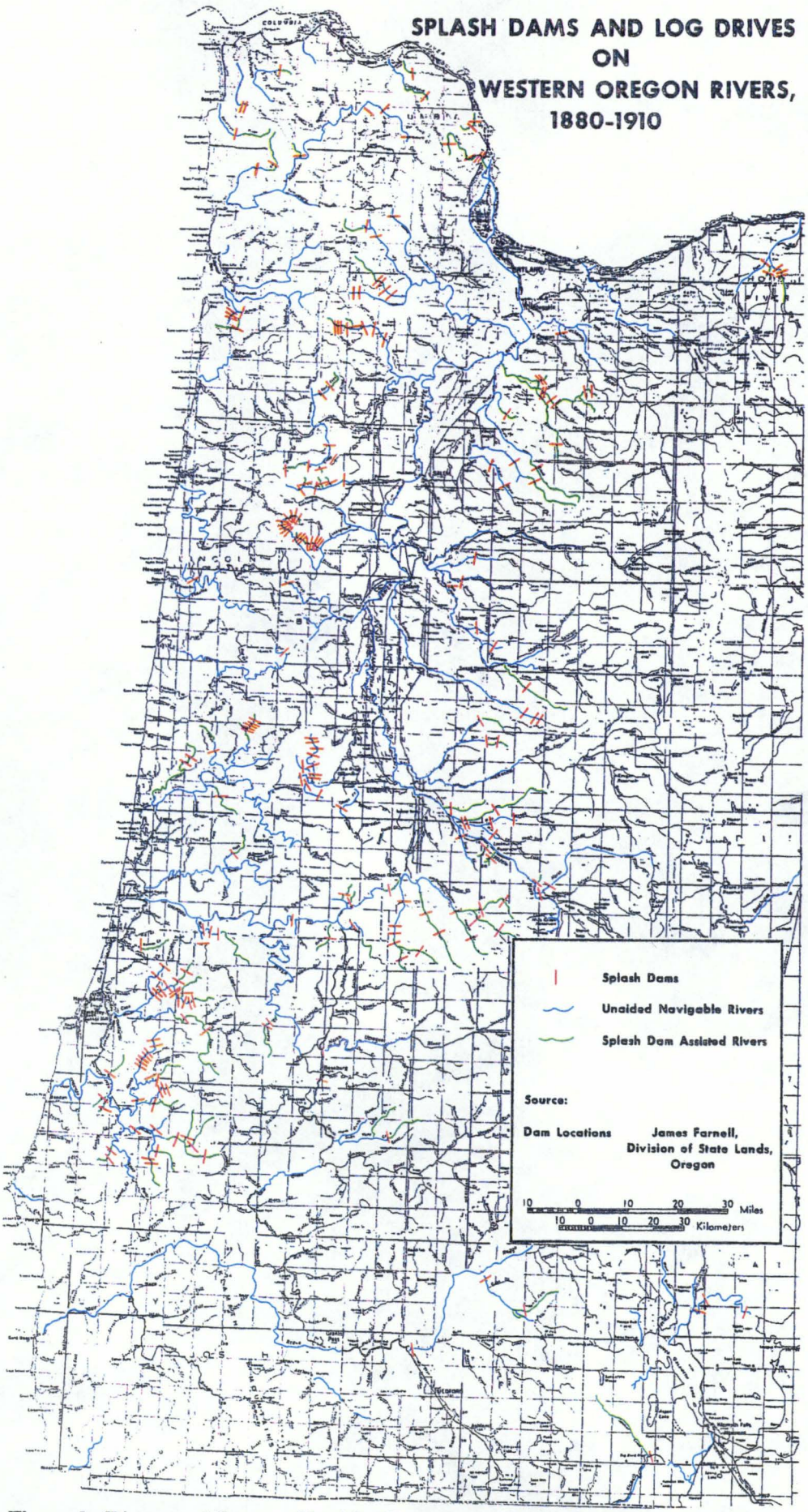

Figure 8. Rivers and Streams Used for Transport of Logs (Sedell & Duval, 1987).

Remaining large stands of timber were more distant and not located on navigable rivers that could float logs to mills. The solution was to store logs behind "splash" dams until winter storms increased stream flow, then blow the dam, and flush the logs downstream. The dams were barriers to salmon migration, and observers noted that salmon runs declined within three to four years after splash dam construction in a basin. Log jams often developed, which had to be released by manipulating logs or exploding dynamite, which killed countless salmon and other fish. Logs being flushed downstream battered riparian vegetation and devastated channels. By 1900 Oregon had more than 160 splash dams in coastal basins and the Columbia Basin. Extreme damage to channels had occurred from scouring, widening, and unloading logs, and main channel gravels had been greatly disturbed. Even smaller streams were cleared to cut and transport cedar bolts for shingles. The number of logs floated and rafted in Oregon diminished within the last few decades (Figure 9).

Historic reconstruction of the Willamette River channel and streamside forest provides a graphic example of extensive habitat simplification brought about by large-scale channelization, which entailed snagging logs, removing riparian vegetation, and closing off side channels (Figure 10). This Willamette River channel simplification resulted in an incredible loss of secondary side channels, backwaters and oxbows -- important habitats for rearing of juvenile salmonids and the endangered Oregon chub (*Hybopsis crameri*). Streams such as the mainstem of the John Day have also been straightened and channelized. Revetments reduce the establishment of riparian vegetation, especially tall trees, and redirect hydraulic energy from lateral scour to downcutting.

After this initial assault on river and stream riparian ecosystems in Oregon during the late 1800s, construction of dams, channelization and bank revetments, logging, livestock grazing, draining of wetlands and dewatering of streams, irrigation, mining, dredging, and filling of wetlands have further changed the ways rivers function in the Pacific Northwest. Dams, perhaps, have been the most visible change on the riverscape. Over 100 high dams exist in the Columbia River Basin and 900 dams have been built in Oregon since the first recorded construction in 1850. Dams can cause some of or all of the following changes to river systems: (1) intercept the downstream movement of bedload materials, (2) alter the timing and shape of the hydrograph, (3) interfere with upstream and downstream migrations of anadromous fishes, (4) disconnect floodplains from rivers, (5) increase loading of dissolved nitrogen leading to problems of gas bubble disease in fishes, (6) increase predation on salmonid juveniles by native and exotic predators, and (7) alter trophic relationships.

The combination of dams, pollution and commercial fishing and other factors has changed the flow and concentration of nutrients in watersheds. Upstream migration of adult anadromous fish can add significant amounts of nutrients to the relative sterile headwaters of streams. Carcasses of dead salmon and lampreys contributed over 7,000,000 kilograms of nitrogen annually to the Columbia River before European settlement. These nutrients were rapidly sequestered by the periphyton community and through the food chain to juvenile salmonids.

In many ways, livestock grazing and logging have had similar impacts on riparian systems. Separately or in combination these activities can (1) open the riparian canopy leading to greater temperature loading which mitigates against good salmonid habitat, (2) decrease the input of large woody debris necessary for cover and formation of fish habitat, (3) increase stream sedimentation from runoff, (4) increase soil impaction and decrease water percolation through the soil, (5) increase bank slumping and mass soil movement into streams, (6) alter trophic networks of healthy salmon and trout streams, and (7) decrease stability and complexity of fish habitat.

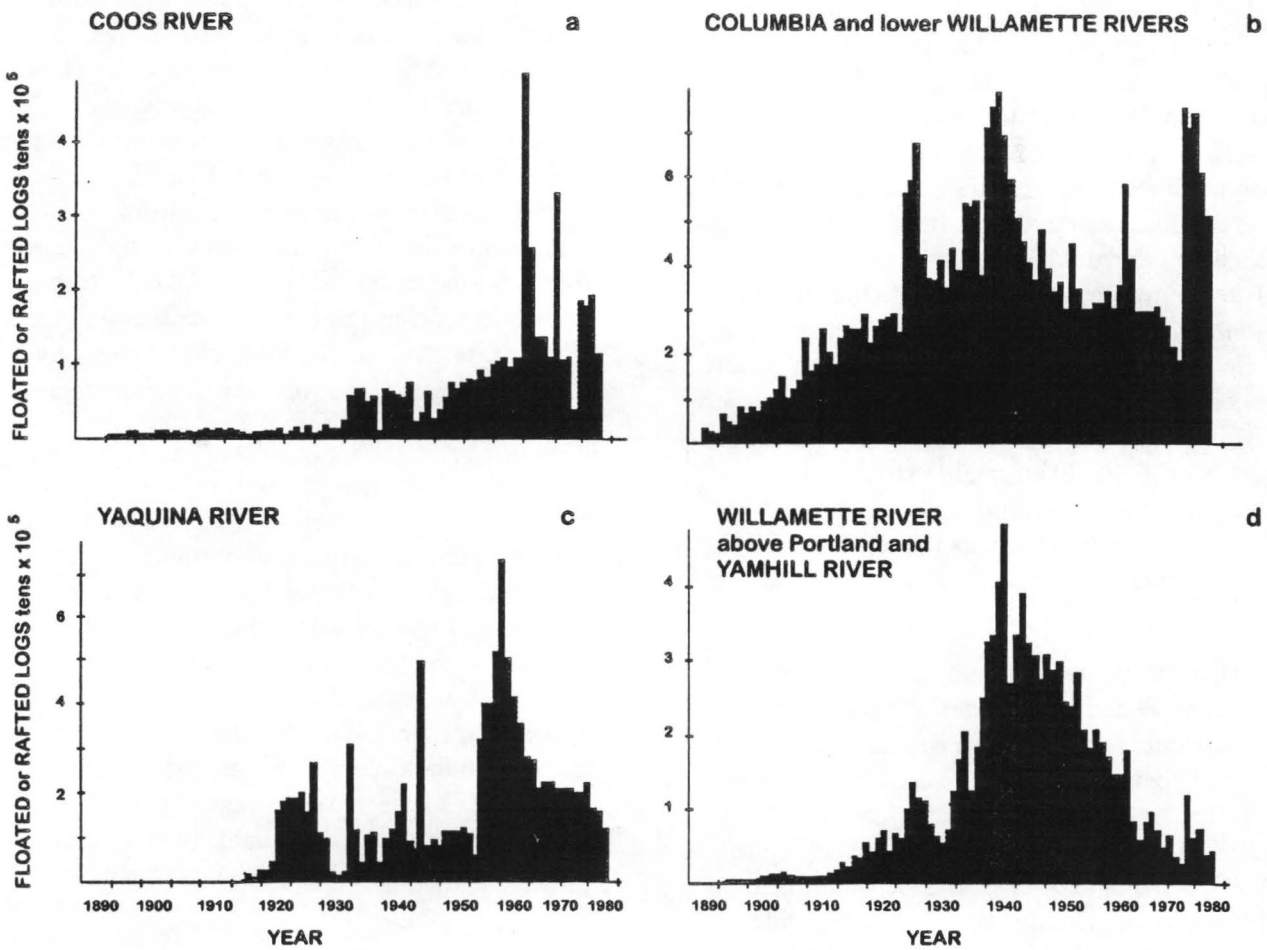

Figure 9. Amount of Logs Floated or Rafted on Selected Oregon Rivers:
a. Coos River from 1895-1978;
b. Yaquina River from 1918-1978;
c. Columbia and lower Willamette Rivers from 1893-1978;
d. Willamette River above Portland and Yamhill River from 1896-1978
(Sedell & Duval, 1985).

Draining wetlands decouples linkages between the flood plain, the hyporheos, and the stream channel. This directly affects (1) seasonal water storage and the hydrograph, (2) Permanent streams can become intermittent, (3) spawning habitat and rearing habitat diminish, (4) aquatic invertebrate production decreases, and (5) critical habitats for terrestrial vertebrates associated with aquatic and riparian habitats are lost. Dewatering streams for agriculture can lead to (1) stranded migrating fishes on irrigated lands, (2) increased water temperatures, and (3) increased deposition of silt that embeds stream substrates with sand, silt, and mud, which in turn, impairs spawning gravels and aquatic insect production.

A review of long-term trends in fish abundance and diversity in the Pacific Northwest noted a relationship between simplification of stream channels and a decrease in habitat

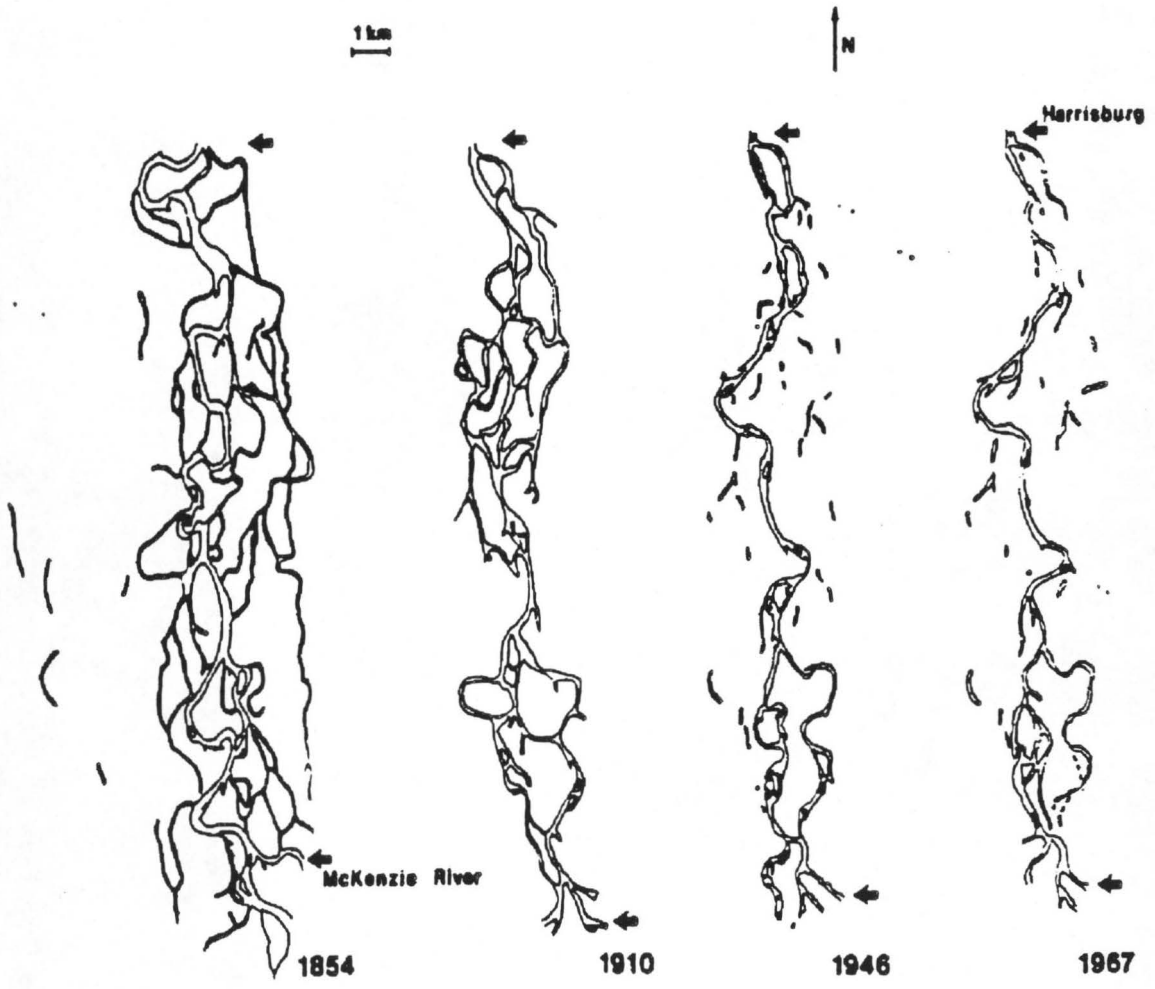

Figure 10. Channelization of the Willamette River since the 1800s Reduced Channel Complexity, Riparian Trees, and Off-Channel Habitat (Sedell & Froggatt, 1984).

complexity due to human alteration of watersheds (Bisson et al., 1992). Removal of beaver and their dams has also influenced channel complexity. Simplification of stream channels (e.g., removal of large wood, channelization) decreases habitat complexity needed by salmonids (Bisson & Sedell, 1984; Hicks et al., 1991). Construction of dams and revetments creates barriers to migrating fish, restricts the occurrence of overbank flows onto the floodplain and concurrent nutrient exchange, disrupts continuity of flow and temperature down the channel, and may decrease biodiversity downstream (Stanford & Ward, 1992). Elimination of edge habitat by forestry and other land-uses, such as road-building, has decreased the available habitat for resting, feeding and protection of young fish (Moore & Gregory, 1989).

Summary

The management of gravel removal from Oregon's streams and rivers needs to be considered in the context of the historical stream alterations by a variety of human impacts and activities. Because of the numerous and widespread effects of human activities, it is difficult, if not impossible, to isolate the effect of any particular activity. However, these impacts and activities have generally resulted in a continual alteration and destruction of the natural characteristics of the streams and rivers. It is this loss of natural ecosystem function that must be curtailed and reversed if high-quality aquatic habitats are to again occur throughout Oregon's waterways. All forms of human activities that impact Oregon's streams need to be managed with this goal in mind.

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MANAGING FOR ON-SITE AND CUMULATIVE EFFECTS

Effective management of gravel operations on rivers and streams should be based on understanding how any given activity is likely to influence and be influenced by other activities. Accomplishing this requires a broad perspective that recognizes the historical, geomorphical, and ecological context of a particular activity, and its likely consequences on a wide range of physical and biological processes. This section outlines a framework and some basic principles that assist the practitioner to evaluate how human activities are linked to the underlying geomorphic and ecologic structures and processes as well as to each other.

Assessing the context of a specific activity is not easy. Several properties of river systems come into play: **connectivity**, **typology**, and **memory**. First, rivers are **connected**. That is, they are networks where water, sediment, woody debris, and nutrients move downstream under the influence of gravity, while fish and other mobile organisms can move upstream. In some cases, physical disturbances, such as migrating knickpoints (sharp breaks in bed elevation), can also move upstream. What happens in one part of a river network can propagate both upstream and downstream affecting other parts of the network. This underscores the importance of understanding the spatial context of any particular activity.

The spatial context of channels as further defined by their **typology** is the second property to consider. Channels adopt a wide variety of forms in response to increasing size, decreasing slope, and changes in the amount and size of sediment delivered to the channel (Figure 11). Headwater and step-pool channels typically have high gradients and stream power, bed material composed of bedrock, boulders and cobbles that moves infrequently, store little gravel, and are strongly influenced by adjacent forest and hillslope processes. In lower gradient pool-riffle and meandering systems, channels typically have less energy but move their finer bedloads of gravel and sand more frequently. They may move or scroll laterally, and are often less tightly coupled to their surrounding hillslopes (Montgomery & Buffington, 1993). While these channel types are generally arrayed more or less sequentially along a longitudinal profile, mountain rivers may have reaches with low-gradient characteristics and vice versa.

This typology of channels is particularly important in assessing the effects of human impacts on anadromous fish such as salmon and steelhead. Different species utilize different parts of channel network at various stages of their life cycles. Significant impacts to a fish population may occur because of localized impacts on only one of these life stages (e.g., changes in the suitability of gravels for spawning or suitability of pools for rearing).

A third property of river systems is that they retain a **memory** of their own history. The history of a river system can be characterized in terms of a **disturbance regime**, defined by the type, magnitude, frequency, and spatial distribution of processes causing change to physical or biological systems. This disturbance regime is reflected in a legacy of floodplain stratigraphy, channel morphology, pattern and age distribution of riparian vegetation, and population structure of fish and other aquatic organisms, among other factors. System memory extends back into geological times but becomes stronger with decreasing time from the present. Rivers are most obviously affected by their most recent disturbance history, which may include the last major flood events, other recent natural disturbance events such as fires and windstorms, and, in the Pacific Northwest, the last one and a half centuries of human impacts. The latter may include direct impacts to streams, such as logging of riparian corridors, removal or replacement of woody debris in streams, dams, diversions, channel revetments and other modifications, gravel extraction, hydraulic or placer mining, or grazing of riparian zones. These impacts also tend to array themselves longitudinally (Figure 12). Streams may also be affected indirectly by watershed-scale disturbances such as upslope logging, agriculture, urbanization, or other land use activities which influence the movement of water and materials through streams.

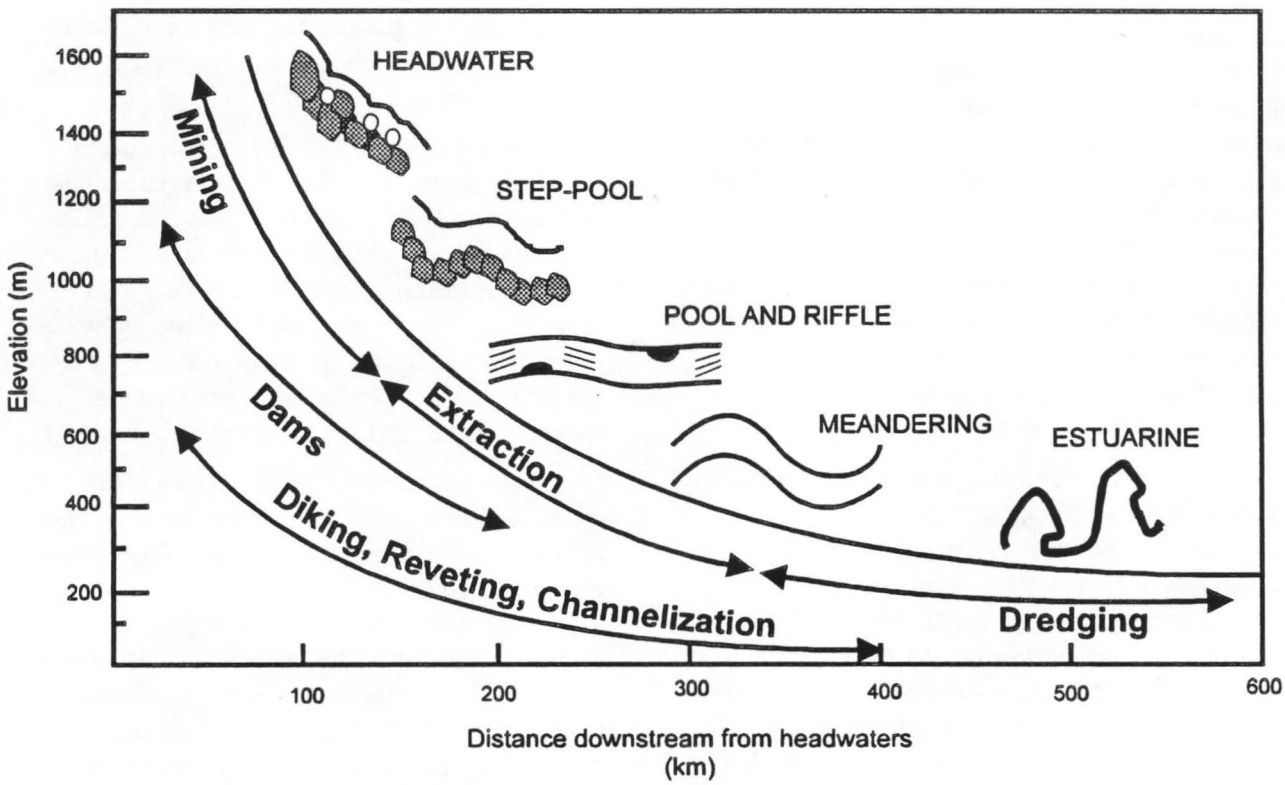

Figure 11. Schematic Representation of Riverine Morphology and Human Activities.

A key aspect of river systems having memory is that there may be time lags before changes in system behavior emerge. A related concept is that certain kinds of channel responses -- bed degradation or aggradation, for example -- may only happen after some threshold level of upstream disturbance (e.g., number of gravel operations) has occurred. At the same time, system memory means that there may be long periods required for channels to 'recover' or return to some pre-existing state following disturbance, or they may never recover.

Interpreting Cumulative Effects

Placing current activities such as gravel extraction within these spatial and temporal contexts is essential to intelligent stewardship of natural resources. For example, declining salmon stocks are responding to the **cumulative effects** of these various impacts combined with the natural variability of streams through space and time. The effects of any given gravel operation must be placed against this broader backdrop of riverine systems that have already experienced a wide range of recent disturbances and aquatic ecosystems that, in some cases, are declining rapidly and regionally.

Cumulative effects arise in those situations where: (1) the incremental effects of separate activities are too small to be measured or accounted for individually but interact additively or synergistically to produce observable changes in system behavior (e.g., degradation of water quality due to non-point source pollution); or (2) numerous measurable changes in system properties or behavior interact to cause large-scale changes, but it is not possible to assign a unique cause to a given effect (e.g., decline of salmon stocks due to the combined effects of dams, ocean harvest practices, degraded habitat, and hatchery programs). Both types of cumulative effects pose problems for management and regulatory agencies, in that the normal process of accounting for the effects of any particular activity frequently fail to take into account the possibilities of insidious, synergistic, or pervasive cumulative effects.

It is often possible, however, to simplify the problem of cumulative effects by breaking down the issues of declining stream health and salmon stocks into more tractable cause-and-effect linkages (Figure 13). This cascading series of links, where each link is both an effect of preceding causes and a cause of subsequent effects, can be thought of as a model of management-induced disturbances. It provides a useful way of identifying particular mechanisms giving rise to cumulative effects, and may help guide management decisions. It is a general model that can be used for any type of watershed impacts, and has been applied to cumulative effects associated with forestry operations (Grant, 1988).

When this management-induced disturbance model is applied to gravel operations it is initiated by the specific activities associated with gravel removal, dredging, or fill, including bar scalping (Figure 12). These impacts can cause on-site effects: changes in the structure of the channel and surrounding areas or physical or biological processes occurring at a site (e.g., channel structure, turbidity, gravel mobility or sorting, fish mortality etc.). Because such changes often involve mobile components (water, sediment, fish), they can move to other parts of the drainage basin, causing physical changes in channel morphology, substrate composition, water quality, etc., which may in turn cause changes to the quality or quantity of fish habitat or directly impact aquatic organisms. Such off-site effects may occur immediately following the activities, or be delayed until a sufficient number of activities occur, or a threshold-exceeding event such as a storm occurs. It is important to recognize that cumulative effects can be positive, negative, or neutral, although we typically associate the term with deleterious changes.

Institutional Considerations

The consequence of these changes has societal and institutional implications, particularly for those organizations required by law to regulate the initial activities. From the standpoint of a regulatory agency, the relationship between on-site and cumulative effects can be viewed simply in terms of three dimensions: (1) the location of effects relative to an activity (near vs. far); (2) the timing of an effect relative to an activity (now vs. later); and (3) the number of activities (few vs. many) (Figure 13). Most regulation of activities focuses on effects that occur locally, immediately, and in response to a few activities (shaded box in Figure 13). As one

moves away from this box in any of the three directions, a variety of institutional issues begin to emerge that typically limit the effectiveness of regulatory measures. For example, as the potential effects become more removed spatially, institutional jurisdiction issues ("whose problem is it?") become important. As effects become more removed in time, institutional memory issues (i.e., data records on what was done, where, and when) begin to surface. Finally, as the number of activities begins to increase, questions about allocation (how many activities should be allowed) with corresponding issues about equity arise. Developing a strategy to effectively regulate gravel mining operations on state waterways will require grappling with these issues of on-site and cumulative effects.

Summary

The effective management of impacts related to human activities on streams requires consideration of important riverine properties. Three such properties are connectivity, typology, and memory. These give a spatial and temporal context to the effects of human activities which can be understood under the framework of on-site and cumulative impacts. Effective management requires strategies for addressing both cumulative and on-site impacts.

Negative cumulative effects can be reduced when watershed-based management is employed. Under such an approach, the important questions are related to how much of any activity can be allowed in a watershed and still maintain desirable watershed health. Continued survival and restoration of salmon runs is clearly one desirable characteristic. Such a watershed approach could involve analytical predictions as to activity levels, or could involve trial-and-error adjustments by adaptive management. Adaptive management of gravel removal would rest on granting of permits after an impact analysis by a wide range of natural resource experts. Projects would need to be followed by extensive monitoring and interpretation of monitoring results to improve the management process.

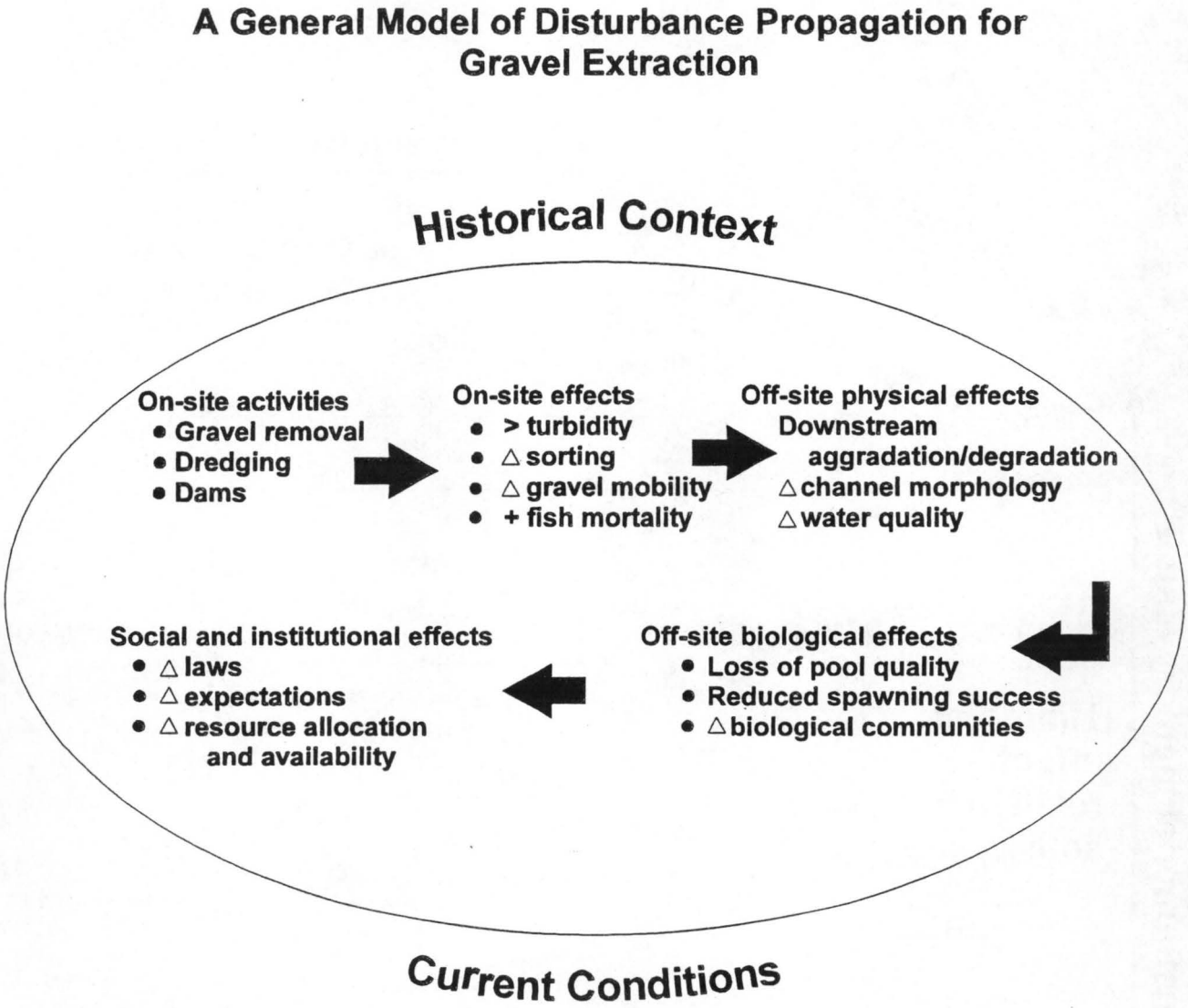

Figure 12. A General Model of Disturbance Propagation for Gravel Extraction.

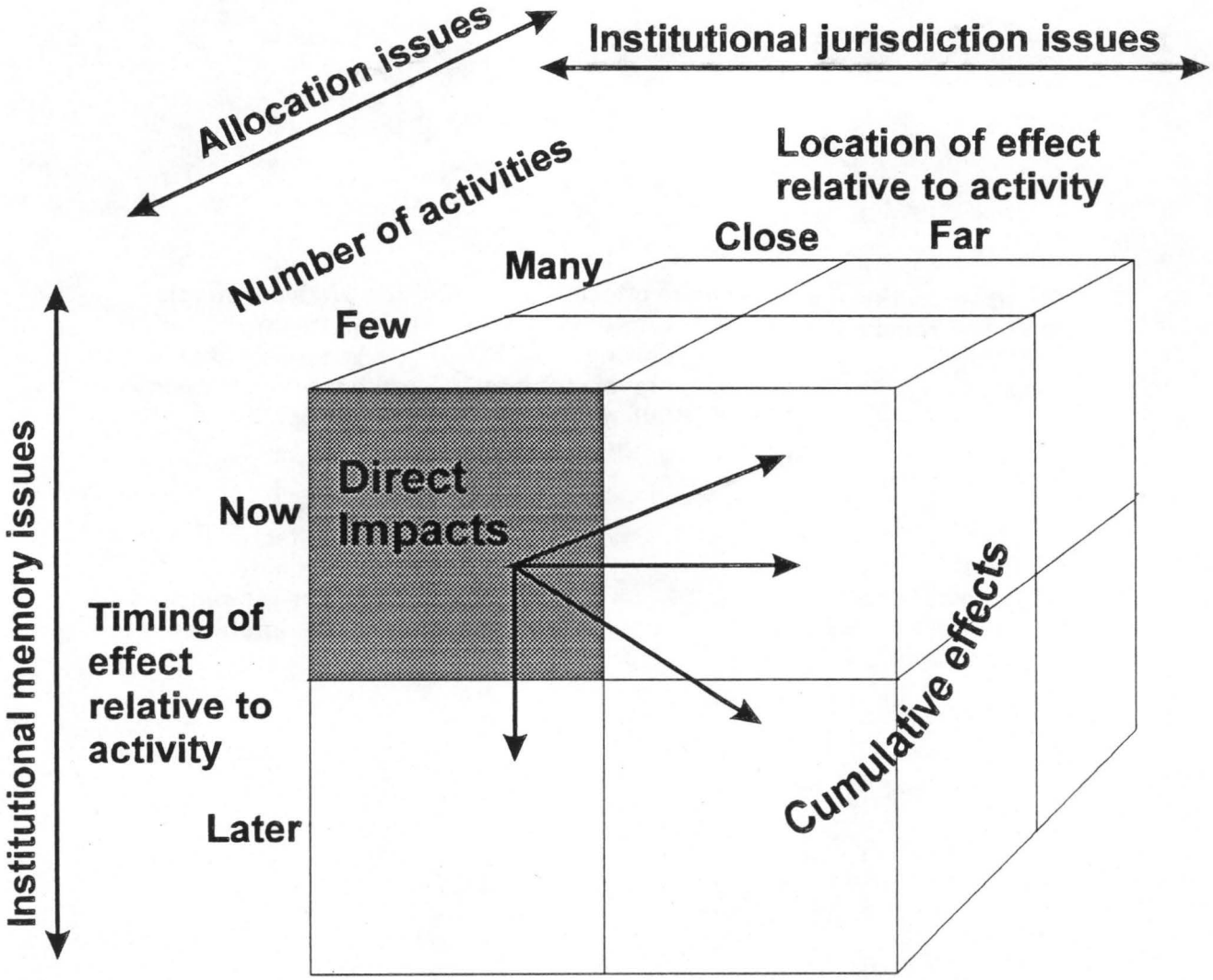

Figure 13. Relation of On-Site and Cumulative Impacts.

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PHYSICAL STREAM PROCESSES

Sediment Production and Delivery Processes

In the Pacific Northwest, the rate of sediment produced from basins is highly variable due to differences in storm patterns (e.g., frequency of occurrence, magnitude, and spatial distribution), steepness of topography, varying geology (Swanson et al., 1987) and land use patterns. For example, in southwest Oregon and northern California, high rainfall and a sheared bedrock geology combine to produce an estimated 5,000 to 8,000 tons/mi^2/yr of sediment. In contrast, the western Cascades, which have less intense precipitation and more stable geology, produce only 80 to 200 tons/mi^2/yr of sediment (Sullivan et al., 1987). Coast Range watersheds have projected annual sediment yields of generally 200-400 tons/mi^2/yr (Beach & Rickert, 1976).

Geologic parent materials are an important determinant affecting not only total sediment production but also the size and durability of sediment particles from watersheds. For example, basins underlain by basalt in southwest Washington have a relatively high percentage of their sediment load in sand, while basins mainly underlain by sedimentary formations have higher percentages of clay, silt, and fine to medium sand-sized particles (Duncan & Ward, 1985). Topography can also have an important role in affecting sediment yields. In general, watershed studies in mountainous terrain have generally shown that areas with slopes of greater than 35% are most likely to show an increase in sediment production due land use practices (Swanson et al., 1987).

A crucial factor in considering sediment budgets for larger river systems is the spatial and temporal variability in sediment movement as well as sediment production. Sediment budgets have generally been derived for smaller basins where there may be greater geomorphic homogeneity. In larger river systems such as the Willamette, sediment budgets at a downstream point do not necessarily represent an immediate integration of upstream or headwater basin sediment budgets due to both spatial and temporal lags from production to a delivery point. The lag in time from production to delivery can range from years to thousands of years depending on channel morphology, distance from headwater sources, timing of large storm events and other factors. As the spatial scale of the of river systems increase, so does the complexity (Campbell, 1992). Moving from headwater streams to lowland rivers involves changes in dimensions, routing processes, input processes, and more. These morphologic and process level changes lead to changes in erosion, sediment transport, sediment storage, and sediment yield (Campbell, 1992). Thus, caution must be used in assuming that sediment produced from tributary basins will equate to sediment availability at some point downstream in the near future.

Sediment Production Mechanisms

Sediment input to streams usually results from several mechanisms which produce varying sizes and amounts of sediment. The terms mass soil movement, mass wasting, mass failure, and landslide are used to describe the relatively rapid movement of a large volume of soil, rock, and other assorted debris downslope under the influence of gravity. Landslides occur when the forces promoting movement (e.g., gravity and pore water pressure) are greater than the forces resisting movement (e.g., soil cohesion, friction, and root strength). Sediment generally comes from two sources: hillslope and channel or near channel sources.

In mountainous terrain, debris avalanches/ flows (landslides) and slump-earthflows represent important types of mass wasting. Although soil creep and rockfall generally make up a smaller portion of mass wasting material or have less dramatic effects on hillslopes and channels, these processes may contribute a significant portion to the overall sediment budget. The in-channel or near-channel sources of sediment are associated with debris torrents, dambreak floods, and bank sloughing. The mechanisms of production and

delivery for the different source areas are described below.

Debris avalanches/flows (landslides) are rapid, shallow failures that typically occur in non-cohesive soils on steep slopes which are underlain by less permeable bedrock. These are the most common type of landslide on forested regions in the Pacific Northwest (Ice, 1985) and generally result from precipitation events where pore water pressures become high and slopes are steep. Debris avalanches and debris flows are differentiated by the soil moisture content with debris avalanches having lower moisture contents than debris flows (Megahan & King, 1985; Swanston, 1978).

Slump-earthflow slope failures are complex mass soil movements that have an upslope component (slump) and a translational deformation at the lower slope (earthflow; Ice, 1985). This form of mass wasting can be deep-seated. Slump-earthflows can occur on moderate slopes and be a persistent source of sediment to streams due to their sometimes slow deformation process (Sidle et al., 1985). The delivery of hillslope sources of sediment depends on several factors including geomorphic features and processes.

Debris torrents and dambreak floods are rapid, water driven failures that travel down drainage channels causing in-channel or near-channel sediment production. Debris torrents and dambreak floods can be initiated by debris avalanches or slump-earthflows that enter a steep drainage (Ice, 1985). These types of mass soil movements can also result from the breakup or removal of in-channel debris jams. The delivery of sediment and organic debris to lower-ordered channels is determined by the properties of the torrent and the drainage pattern of the basin. In basins with high junction angles of the tributaries, these catastrophic failures are less likely to reach lower portions of the watershed.

Bank sloughing can represent a major source of sediment in larger river systems. In unconstrained reaches comprised of previously deposited alluvial sediments, lateral migration of the channel can result in significant bank erosion and can account for a high percentage of the entrained material. In smaller tributaries of a basin, the contribution of sediment from bank erosion is often presumed to be small in comparison to that delivered from hillslope processes.

Factors Affecting the Production of Sediment

Numerous factors affect the form, severity, magnitude, and duration of mass movements and general soil erosion. The relative importance of these factors, and their interaction with other landscape features and processes, can also change depending upon natural disturbance patterns, land use practices, and basin characteristics.

Topography

The characteristics of landform or topography that influence mass soil movement include: slope gradient, position, shape, drainage area, and geomorphic processes. Studies in the mountainous portions of the Oregon Coast Range found that the amount of sediment reaching the stream from upslope areas was dependent on certain topographic characteristics. In steeply sloping areas with streams immediately below the hillslope, the amount of sediment delivered to the stream was 70% of the original failure volume (Swanson et al., 1987). Slope position can also influence sediment production and delivery. In Idaho, Megahan et al. (1978) found that 18% of the hillslope failures occurred on upper slopes, while 31% and 38% occurred on middle and lower slopes, respectfully. In addition, slope failures which occur on lower areas of the hillside have greater potential of reaching a stream channel.

Geology

Geologic factors which influence landslide potential include composition of bedrock or parent material, fracturing, jointing or faulting, orientation of bedding planes, and degree of weathering. Geology is also a major determinant in gravel production since only that material which is resistant to physical and chemical weathering is suitable for commercial gravel use. Thus, areas of the State such as the North and South Coast and the Willamette Valley contain resistant material. In the Central Coast Region the geology is mainly composed of sandstone, which is not suitable for gravel.

Soil Properties

Geologic as well as other conditions and processes influence soil properties. Soil properties that are important in soil mass movement processes include: texture, clay mineralogy, cohesion, structure, porosity, moisture capacity, drainage, chemical properties, and soil depth (Swanston & Swanson, 1980).

Vegetation

Vegetation has the potential of influencing the occurrence of slope failures through its regulation of soil moisture and root network providing strength. Vegetation along stream channels also increases bank stability, which in turn reduces bank sloughing. Thus, vegetation plays an active role in reducing the delivery of both fine and coarse sediments in streams. The role of vegetation on bank stability discussed further in the aquatic portion of this report.

Natural Disturbances

Natural disturbance regimes provide the opportunity for soil mass movements and other forms of erosion to occur. For example, large storm events, fires, windstorms, or disease outbreaks can all influence the magnitude and frequency of mass movements on natural watersheds. In western Oregon, the 100-year flood in 1964 dramatically altered not only the streams and rivers of the State, but also the hillsides. The fires in the Tillamook area during the 1930s-1950s denuded a large portion of the landscape which led to sedimentation in Tillamook Bay in the 1950s. Thus, in considering sediment production from a given basin, it is essential to include the effects of natural disturbance regimes on sediment production and delivery.

Land Use practices

Where human influences have altered the landscape via a wide range of land use practices, the erosional effects of natural disturbance patterns may be amplified (e.g., increased landslides in steep terrain from forest harvesting and roading, accelerated surface erosion from agricultural activities, increased bank erosion from the removal of riparian vegetation). In the Pacific Northwest, the effects of sediment production and delivery to stream channels are dependent on such factors as the sequence of storm events, storm/land use interactions, hillslope sediment delivery mechanisms, stream competence, and bank stability (Hodgins-Carlson, 1993). Thus, land use practices are an important concern since they can greatly affect the magnitude and timing of sediment production from a basin.

The effects of forest practices on sediment production depends on the area where the practice is occurring as well the particular practice. For example, forest roads may have a different effect on sediment production than timber harvest. The following discussion separates out the effects attributable to individual practices and then discusses the effects of combined forest practices.

The construction and use of roads in many mountainous areas of the Pacific Northwest can represent a major source of sediment to streams (Swanson et al., 1987; Ice, 1985; MacDonald et al., 1991). Where such increases occur, they may be associated with both mass failures and surface erosion.

A study of the Oregon Coast Range found that road failures were a principle factor contributing to episodic debris avalanche inputs to streams (Beschta, 1978). These mass failures altered the channel network by scouring the steeper tributaries to bedrock and depositing the material in lower gradient reaches causing localized aggradation. Following these road-related failures, increased sediment loads returned to background levels within one to two years (Beschta, 1978). In another Coast Range study, a large landslide was apparently initiated following the stockpiling of end-haul material on a hillslope. Although field observations indicated in-channel sediment deposition along the bed and banks for approximately 1.5 miles downstream of the slide input, significant changes in channel width or depths were not found (Dent, 1993).

In the west central Cascades, roadfill failures were also found to represent the most frequent cause of debris flow initiation (Swanson & Fredricksen, 1982). Furthermore, the amount of the sediment reaching stream channels and the length of channel impacted by debris flows was associated with characteristics of the drainage network (Grant & Wolff, 1991). Road failures which occurred at the

top of long, straight tributary channels typically became debris flows that were capable of reaching larger channels. In other instances, road failures were often unable to sustain their downstream momentum as they encountered tributary junctions. Thus, debris accumulations of sediment and large wood often occurred in the vicinity of tributary junctions.

In addition to being a major factor affecting episodic sediment inputs to streams in steep terrain, roads can also be an important source of chronic production of small-size sediment. This occurs both from their surface and due to erosion at the outlet of cross-drain culverts. The problems resulting from small sediment depositing in gravel are discussed further in the aquatic portion of this report.

Roads usually produce greater amounts of sediment immediately after construction, and then decline over time as cut and fill slopes stabilize with vegetation and road surfaces develop an "erosion pavement." In the East Cascades of Washington, initial sediment increases due to road construction decreased to approximately background levels within two years (Fowler et al., 1988). A similarly rapid decline in suspended sediment was noted following road construction in the Oregon Coast Range (Beschta, 1978). However, continued hauling on unsurfaced roads can sometimes generate a sustained increase in sediment yields to stream systems (Reid & Dunne, 1984). While increased levels of fine sediments to streams and rivers may have little direct effect on gravel availability to a system, indirect effects (e.g., degrading the quality of existing gravel supplies, altering the quality of spawning gravels, augmenting channel instability because of high transport levels) may be important in some river systems.

The harvesting of forest trees can sometimes increase sediment production by exposing mineral soil during yarding operations. In steep terrain, timber harvest can also increase sediment production by increasing the frequency of mass failure. Studies in Oregon and Washington generally indicate that the harvesting of trees in steep terrain increases the rate of mass failures by two to four times over that experienced on uncut areas (Ice, 1985).

Although increased sediment production can result from forestry practices, there are many studies where little or no increases occur. For example, no increase in sediment concentrations were found for a patch-clearcut watershed in the Oregon Coast Range even though several minor mass failures occurred within the patch-cut units. The harvest units were yarded using a high-lead system and lightly burned (Brown & Krygier, 1970; Beschta, 1978). Similarly, only slight suspended sediment increases (excluding landslides) were found for two years following clearcut harvest in a western Oregon Cascades watershed (Fredricksen, 1970). In southwestern Oregon, erosion and landslides from managed forests were initially identified as the cause of damage to a water supply system. However, after conducting a sediment budget for the area, it was concluded that clearcut timber harvest only accounted for 3% of the total soil erosion over the period from 1955-1976 while surface erosion from older road surfaces accounted for the majority of the sediment (Smith & Hicks, 1982).

Differences in watershed characteristics can influence both the amount and timing of sediment production from watersheds. A study that examined long-term patterns of sediment transport after timber harvest in the western Oregon Cascades found that even when watersheds are in close proximity to each other they can have differing response mechanisms (Grant & Wolff, 1991). Following clearcutting, Watershed 1 (WS-1) of the H.J. Andrews Experimental Forest (HJA) had average annual sediment production levels during the post-harvest period that were 12 times the pre-treatment level. Sediment production remained high for 10 years after harvest and is currently approximately four times greater than pre-treatment levels. Sediment production levels for WS-1 are projected to return to pre-treatment levels some 30 years after harvest. In addition to the increase in sediment yields, the dominant transport mechanism changed following harvest. Prior to harvest, suspended sediment yields exceeded bedload yields in all years; following harvest, bedload yields exceeded suspended load yields in 5 out of 16 years. Suspended load has been recovering toward pre-harvest levels more rapidly than bedload (Grant & Wolff, 1991). In the nearby Watershed 3 (WS-3), a different response to roading and harvesting occurred. Post-harvest sediment yields were 27 times that of pre-harvest levels with 88% of the increased sediment production from debris slides and debris flows

occurring in a single event, a major storm in the winter of 1964. Most of the additional sediment originated from roadfills (90%) with the remainder coming from in-channel storage. Virtually all the sediment yield during the 1958-88 study period occurred during the 1964 storm. Each year since 1965, the amount of suspended load has exceeded bedload.

A wide range of studies has shown that forest harvesting and roading in steep terrain has the potential to alter the amount and rate of sediment delivery to streams. Where such increases are large or occur over short time spans, the capacity of the stream to move the sediment may be overwhelmed and channel aggradation may occur. In other instances, changes in channel morphology may not result, although qualitative changes to the composition of spawning gravels and riffles may result. Analysis of gravel bed composition for small streams in the Oregon Coast Range indicated that the proportion of fine sediments in stream gravels are not only affected by watershed characteristics such as slope, area, and relief, but may be increased by the combined effects of roads and logging operations (Adams & Beschta, 1980).

The combined effect of forest practices on the landscape may lead to changes in sediment production from the hillslope. The change in sediment delivery to a stream channel may in turn alter the morphology of the channel. For example, a study in southwest Oregon found that downstream channel effects were related to the location and intensity of upslope timber harvest activity (Ryan & Grant, 1991). Downstream effects on channels in the Elk River basin included openings in the riparian corridor brought about by disturbances such as: landslides, debris flows, large floods, and excessive sedimentation. Debris flow disturbances did not travel far from the site of initiation and apparently traveled shorter distances than those that occur in Oregon's Western Cascades or Coast Range. Open channel reaches (a measure of channel response to disturbance) occurred in higher-ordered channels, but did not appear to be influenced by upslope activities. However, in lower-order channels, a casual link between open channel reaches and upslope forestry activity was indicated (i.e., nearly a thirty-fold increase). Channel openings extended downstream from roads and clearcuts and the timing and pattern of the open reaches varied in direct relation to the intensity of upslope forest practices. Thus, forest practices conducted on hillslopes were found to have the potential of causing effects to riparian vegetation and channel morphology by creating areas which had a higher susceptibility to slope failure, especially when coupled with large storm events.

Land use practices alone may not alter hillslope sediment production or channel morphology, but when they are combined with natural disturbance events, the effects of land use practices may be exacerbated. In the Middle Fork of the Willamette River (MFW), increased levels of sediment input from steep terrain following the occurrence of forest practices, in conjunction with the high flow events, represented a primary factor responsible for changes in channel morphology (Lyons & Beschta, 1983; Beschta, 1984). The downstream movement of sediment in the MFW during the large storm of 1964 caused channel widening and aggradation, with aggradation greatest at tributary junctions (Lyons & Beschta, 1983). The source of this sediment was predominantly from local landslides and upstream areas. During the 1964 flood, landslides from clearcuts were 23 times more frequent than from forested areas. Although some changes in planform geometry and channel morphology of the MFW would have likely occurred naturally during the large 1964 storm, accelerated sediment inputs from forest practices appear to have greatly increased the magnitude of channel responses. In addition, the continued selection logging of riparian trees and the in-stream removal of coarse woody debris during the years following the 1964 event appear to have contributed to sustaining these widened channels (Lyons & Beschta, 1983).

In a study of the Redwood Creek drainage in northern California, changes in stream channel dimensions due to accelerated channel erosion were evaluated (Hagans et al., 1986). As a result of accelerated sedimentation from harvesting and roading practices, 19% (on average) of the total natural stream channel length was enlarged or gullied. Forest practices during the study period accounted for 40% of the total basin-wide sediment production and significantly contributed to channel changes. Long-term changes in channel geometry for larger streams were not as widespread as those in the smaller basins. Changes to larger channels

include temporary storage of sediment on channel beds, filling of pools (a decrease in pool depths and overall number of pools), and enlargement of gravel bars. Along portions of the main channel, the effects of these sediment increases is expected to persist for 25 to 100 years or more.

The effects of agricultural practices on sediment production in a basin can also be significant. It is generally assumed that the particle size of agriculturally derived sediments is small and does not contribute to sand and gravel resources. However, sediment production by agricultural lands can effect the quality of sand and gravel resources through the deposition of fine sediments. The amount of sediment leaving an agricultural field is determined mainly by the intensity and duration of a rainfall event, soil erodibility, field topography, vegetative cover, and tillage practices (Clark et al., 1985).

In agricultural areas where finer-textured soils are underlain by gravel, agricultural practices may influence sediment delivery to the channel. For example, in the Willamette Valley of Oregon, alluvial gravels are underneath much of the agricultural land near the Willamette River. Lateral movement of the channel essential "mines" the gravel. In this situation, where agricultural practices cause increased erosion along the banks of the river, there is an increase in the larger sized material available to the channel. Thus, in low lying portions of watersheds with sizable floodplains, the production of sediment may be more controlled by lateral and vertical channel movement than from headwater sources.

The channelization of rivers throughout the United States has been a common practice to control floods in meandering rivers (Brookes, 1988). The cutting off of meanders combined with the widening and deepening of the channel serve to route floodwaters more efficiently and rapidly (Shankman & Samson, 1991). This practice, while beneficial to those who inhabit floodplains, can cause incision of the channel and bank erosion and an increased sediment load. In Oregon, the Willamette River has been channelized through the truncation of side-channels since the mid-1800s (see Figure 10). Subsequent to the channelization of the Willamette has been a deepening of the channel with an approximate drop of one foot per ten years (Klingeman, 1993).

Sediment Transport Mechanisms

As indicated in the previous sections, sediment is delivered to stream channels in variety of ways that vary both spatially and temporally in a given basin. Factors which effect the delivery and subsequent downstream routing of sediment include: basin morphology, disturbance pattern, and the legacy of historical land use practices. Once the sediment reaches the stream, sediment can be transported by mainly suspended load and bedload depending on the characteristics of the sediment, the channel, and flow regime.

Sediment Delivery to Channels

The delivery of sediments to channels and the downstream routing of sediment through larger river systems is still a poorly understood process. The sediment delivery ratio describes the ratio of sediment yield or production and the total amount of material delivered from the slopes and channel above a given gauging station (Petts & Foster, 1985). Calculations of sediment delivery ratios have yielded considerable scatter of data points, though in most cases the drainage area is a significant variable (Petts & Foster, 1985). Thus, there is still a need to further understand the link between sediment production on a basin with delivery processes and downstream routing.

In northern California's Redwood Creek, most sediment in transport along the main channel apparently occurs from channel scour and bank erosion associated with low to moderate peakflows (Nolan & Janda, 1981). However, during large storm events, aggradation was common at tributary junctions along the main channel as a result of excess material being exported from tributaries where sediment had previously been in storage. Although the tributaries, being relatively steep in comparison to the main river, could efficiently route previously stored sediment downvalley (usually within a decade) under moderate flows, sediment deposited along inactive channels and fill terraces of the main river may have a residence time of many centuries.

As previously indicated, sediment that is produced from harvest unit failures may not immediately reach downstream channels but may be stored on sideslopes or in tributaries until moved by subsequent runoff events. In northern California, sediment attributed to upslope harvest activities was stored in tributaries during years with moderate storm events (Janda, 1978). During years with high storm events, sediment from the tributaries was transported farther downstream causing aggradation of the mainstem of Redwood Creek. In another Northern California study, a sediment budget was constructed for the North Fork of Caspar Creek in northern California. The sediment budget indicates that Caspar Creek is still adjusting to logging caused sedimentation that occurred in the late 19th and early 20th centuries (Ziemer et al., 1991a, b).

Land use practices have also altered sediment delivery paths and processes in streams and rivers in Oregon. In the last 20 years the role of coarse woody debris in stream channels has been investigated and found to retain sediment within a watershed and reduce stream velocities (Sullivan et al, 1987). However, over many previous decades large wood associated with channels and floodplains was systematically removed throughout the Pacific Northwest. This wood was removed to allow increased navigation of rivers and streams and also allow for log drives to occur.

In northern California, woody debris from redwood forests was found to have a storage capacity representing approximately 80% of the annual sediment production; Douglas fir forests had a storage capacity of 40% (Kelsey et al., 1981). In the Coast Range of Washington, Bilby (1984) found that the removal of coarse woody debris resulted in significant channel scour of previously stored sediment during the first high-flow event following debris removal. In addition, 60% of the remaining debris was repositioned by the high flows. The resultant effect on channel morphology was an overall reduction in the number, area, and volume of pools. Similarly, removal of a debris jam in the Oregon Coast Range initiated channel downcutting and the release of thousands of cubic yards of sediment the following winter during a period of relatively normal winter flows (Beschta, 1979).

Sediment Transport in Stream Channels

Suspended Load

Suspended sediment concentration indicates the amount of inorganic sediments transported in suspension due to the turbulent flow of a stream and is often represented by clay, silt, or fine-sand particle sizes, i.e., those particles generally less than one millimeter in diameter (Everest et al., 1987). The transport of suspended sediment can occur over a wide range of flow conditions, however, the majority is transported during high flow events (Beschta, 1987). Although the amount of sediment carried by a stream depends to some extent on the streams ability to move the sediment, for suspended sediment its "availability" to the stream is crucial because stream energy is usually not a limiting factor during high flows. Thus, if the availability of suspended sediment to the stream can be minimized, the amount of suspended sediment in transport will remain relatively low regardless of flow magnitude. While suspended sediment concentrations and stream discharge are often correlated, changes in the availability of suspended sediments represent an important concern for a wide variety of land uses (e.g., mining, agriculture, grazing, forestry, urbanization).

During the periods of high flow, in-stream turbidities can be an important indicator of suspended sediment concentrations (Beschta, 1980). However, because turbidity is a measure of the general optical properties of materials in water, turbidity values are susceptible to the amount of colloidal material (both organic and inorganic) in suspension.

Bedload

Bedload refers to relatively large sediment particles, usually coarse sands and larger, which roll, slide, or saltate downstream; they are generally greater than one millimeter. Whereas, increased turbidities and suspended sediment concentrations can occur over a wide range of flows, the movement of relatively large particles as bedload generally occurs only during high discharge events. The downstream movement of bedload is controlled by interactions between bedload particle size, channel morphology, and flow conditions (Everest et al., 1987). Bedload occurs only during storm runoff

events. Stream channels and banks represent long-term sinks and sources of bedload sediments.

Aquatic Habitats in Gravel-Bed Rivers

Physical factors dominate the development of particular types of aquatic habitat in gravel-bed rivers. The interplay of hydraulic and morphologic conditions is important. The hydraulic regime of a channel is regulated by the basin's hydrologic regime, which gives pattern to the streamflows. Basin geology and climate exert physical influences on channel morphology. Severe shifts in the annual hydrologic balance can lead to noticeable morphometric and ecologic changes. Climate also influences channel morphology through effects on riparian vegetation and stream canopy.

Land uses and a wide variety of human activities influence aquatic habitat through direct physical changes, streamflow changes, and alterations of riparian vegetation and water quality. Rivers have a long "memory;" they constantly try to adjust to past physical and ecological changes and to establish an equilibrium balance of physical and ecological forces.

Aquatic habitats are often classified and evaluated by stream reach based on physical features of the channel. Stream reach definition is usually based on channel patterns (straight, meandering and braided reaches), gradient changes, geologic controls, or tributary locations. Recent trends involve use of total-watershed analyses (Hall, 1984), hierarchical evaluation frameworks (Adams et al., 1990), and systems approaches (Orsborn & Anderson, 1986) for better evaluation of many habitat characteristics, ecological influences, and manipulative actions.

Aquatic habitat types reflect particular sets of physical features in a reach. Gravel-river habitat classification is based on major bedforms. Pools and riffles are the most common habitat components. For smaller streams, these tend to be mainly longitudinal features. In wider streams, they also take on lateral variability, with many shallow side bars and point bars. Runs and glides differ from riffles due mainly to greater lengths and flatter local channel slopes. Rapids are longer, with scattered large boulders, and have swifter flows than riffles. Cascades and step pools are indicative of steep, broken channel slopes.

Microhabitats are small components of habitats (e.g., pool, riffle, or side-channel microhabitats). On the microhabitat scale, additional physical features are important in ecological evaluations. These features include actual particle sizes of bed and bank sediments, details of embeddedness and imbrication of coarse surface particles, bed permeability, presence of large "roughness elements" (e.g., boulders in a gravel channel), and presence of woody debris. Zones of local bed and bank scour and deposition of sediment, with variations of water depth and velocity over short distances, are also quite important in the definition and description of microhabitats.

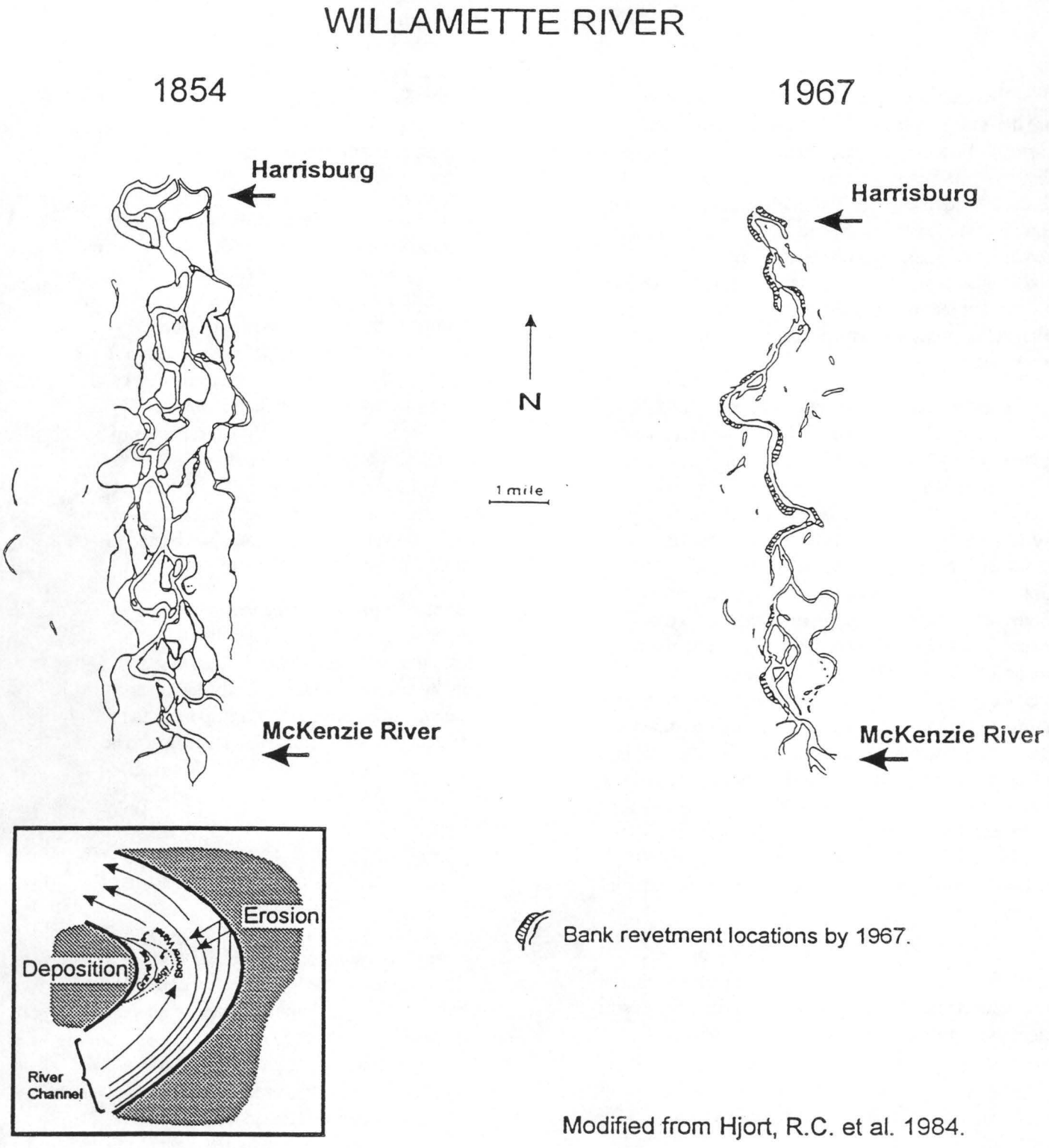

Figure 14. Influence of Revetment Stabilization on Willamette River Strategy

Sediment Transport Processes that Affect Aquatic Habitats

Transport Processes

Bedload and suspended sediment load transport are dynamic processes. Natural adjustments of channel slope, shape and roughness occur in alluvial rivers as they use the varying available discharge to transport the furnished sediment. Channel configuration and rate of equilibrium adjustment depend on the material in the bed and banks, the antecedent flow, sediment inflow and channel morphologic conditions, and the hydraulic regime that the river is presently experiencing. Not all such adjustments are detrimental to aquatic habitat resources.

Important distinctions exist between gravel-bed (and coarser) channels and sand-bed channels. The greater heterogeneity and larger sizes of bed material in gravel-bed channels lead to vertical differences and lateral morphometric and, hence, habitat variability. Surface layers tend to be coarser than subsurface zones, even though large particles are found in both. Gravel-bed channels tend to be more stable during larger flows and for longer periods than sand channels, given similar streamflow regimes when large particles are present in the bed and the surface layer is armored. Incipient motion in gravel-bed channels may be more abrupt than in sand-bed streams, due to breakup of armor layers and quick mobilization of subsurface bed material. The heterogeneity and coarseness of surface layers may allow siltation of subsurface material through surface voids. If there is a large supply of small sediment, but little scouring action from flows, bed surfaces may become embedded with fine material and even buried.

Sediment with a wide range of sizes may be transported through a river reach. Deposits in coarse-bed channels have much more lateral variability in size range and representative size than for sand-bed channels. This is most notable when large boulders and woody debris are present, causing significant local variations in velocity and shear stress over short distances.

Temporal variability is also of great importance. Flow alignments, depths and velocities are likely to be appreciably altered as water discharge changes, particularly when large boulders and debris are present. Hence, detailed analysis of sediment transport entails detailed consideration of the channel to include spatial aspects and changes due to temporal events.

Short-term transient runoff events exert important influences over gravel-bed channels. Flushing of fines and sedimentation of voids occur on rising and falling limbs of runoff hydrographs, respectively. Debris is picked up or deposited as water levels change. Organic matter present in benthic zones changes as bed material is moved and re-deposited.

Flood flows are highly significant in terms of sediment transport and habitat impact. The formation and presence of large protrusions (boulders and boulder bars) from the general bed surface depend strongly on modes of transportation and deposition. Such protrusions can result from single high-discharge flood flows. Bedform (hence, effective bed roughness) and bed material sizes increase with increasing flood magnitude. Large floods cause large discharges of bed materials and may activate the bed to great depths. The channel of a coarse-bed stream may become particularly stable after a large, infrequent flood event, with the post-flood bed surface features adjusted to those conditions.

The actual transporting processes are thus dependent not only on the prevailing hydraulic conditions, but also on present bed conditions and antecedent hydraulic conditions. Bed conditions control the type of material being transported and the roughness conditions that cause stream energy to be dissipated by friction and turbulence. These high-energy regimes support high rates of oxygenation, nutrient mixing, and waste removal.

Habitat Interrelations with Sediment Transport

Sediment transport and bed mobilization in gravel-bed rivers determine the character and quality of aquatic habitat. They also impose changes on the habitats present and the factors influencing them. In spite of such dynamics, aquatic habitats in gravel-bed rivers tend to exhibit a high degree of stability. This is particularly the case when the load of large woody debris or ice is moderate and discharges are not too large or flashy. The main features of channel morphology may be "fixed" by local controls on stream width and channel slope, and by erosion-resistant banks. The beds may be coarse enough to be "armored" against movement during much of the year,

other than during large discharges. Thus, there may be long periods of bed stability and only short periods of bed mobility when physical channel adjustments can occur that might modify habitats.

In addition to local conditions, aquatic habitat is affected by upstream and downstream conditions. The stream continuum concept (Vannote et al., 1980) and other similar approaches help describe fluxes of water, sediment, debris, food, biomass, energy, and nutrients through river systems. The ease of movement affects the quality, availability and usability of particular habitats along the channel.

Spatial variability of bed surface characteristics in coarse-bed channels provides much diversity and variability in aquatic habitat. Morphological features such as large, abrupt changes in bed slope and in width and depth of flow (and resulting abrupt changes in velocity) are a direct result of bed material composition and of processes by which bed material motion is initiated, continued and terminated. The morphological features and local channel hydraulics interact as part of basic channel adjustment processes. In turn, these features affect the processes involved in the movement of channel bed materials. Large and sudden changes in coarse alluvial materials occur where unusually large particles (boulders) are present and accumulate. Hence, the heterogeneous bed materials cause bed relief features, textural associations, differing structural arrangements, and diverse changes in local turbulence and transport capacity and, therefore, influence local aquatic habitat characterizations and associations.

Adjustment of Aquatic Organisms to Sediment Transport

A variety of organisms occupy aquatic habitats. Diversity is an important attribute for healthy, thriving aquatic ecosystems. The types and range of species in aquatic habitats in gravel-bed streams depend on many ecological constraints. Physical factors are only one category of constraint; many other factors influence the type and condition of aquatic habitat (Adams et al., 1990). Water quality is a major factor.

Species adaptation and ability to colonize are important considerations. The species present at any location are those that have adapted to the local habitat or microhabitat characteristics. If the habitat experiences dynamic changes (either periodic or irregular), different organisms may be present (more adapted for variable conditions) than in a comparable stable habitat. Some aquatic habitats may need periodic flood pulses to thrive. If a habitat is briefly altered by dynamic changes (e.g., a flood), organisms may seek shelter, move to a more stable micro-environment, or be swept downstream with the water, bedload, and detritus. Such a habitat could become depleted of organisms for a brief period. Re-colonization and re-establishment of the aquatic community to something like its former condition can occur within only a few weeks. If sediment transport alters the habitat or microhabitat, there may be shifts in the types and numbers of organisms present.

Evaluating and Predicting Habitat Condition and Changes

Aquatic habitats are analyzed and numerically modeled for many purposes. This is often done assuming a fixed channel morphology (Milhous et al., 1984). Evaluation of in-stream flow effects on availability and suitability of habitat is a typical example. Other attributes of aquatic habitats are also evaluated based on physical parameters, assuming that channel morphology does not change.

Habitat condition can be evaluated by a variety of techniques. Platts et al. (1983, 1987) have standardized the measurement and quantification of many physical and biological attributes of habitat for evaluation and comparison purposes. Their methods provide crucial information for evaluating changes. Detailed techniques are given and data requirements are identified. Hydraulic characterization and simulation techniques have been developed in conjunction with habitat use by fish species (e.g., Bovee, 1982; Milhous et al., 1984). These techniques were developed largely for gravel-bed rivers.

Sediment transport and bed-material movement can have significant impacts on the formation and alteration of aquatic habitat. Lateral variability in channel conditions contribute importantly to habitat diversity. The influence of antecedent events is significant, as channels try to adjust to a dynamic equilibrium whenever bed-material movement occurs. Major floods are particularly critical in moving very large roughness elements and in establishing major features which characterize habitats. Smaller floods contribute to lesser modifications in habitat appearance and quality, but may provide a flushing mechanism to remove accumulated fine sediment and detritus.

Impact Analysis Related to Hydrology, Hydraulics, and Geomorphology

Hydrology

Basin hydrology is affected by a great many natural variables. Some of the most important are precipitation characteristics, basin vegetative cover, other types of basin cover, basin soil types, basin topography, and basin geology. Human impacts on basin hydrology are generally related to the conversion of basin vegetative cover from one type to another (such as clearing forests for agriculture), the compaction of the land surface and reduction of water infiltration (such as in areas with roads or areas of human development), and the obstruction of the channel (such as with road building or the construction of dams for water storage and diversion).

There are several relevant questions about basin hydrology that pertain to the analysis of fish habitat. Some of these include:

1. Is the basin hydrology such that adequate runoff is provided to the river to allow fish passage without blockage at times of fish movement?
2. Is the basin hydrology such that adequate runoff is provided to the river to allow egg development, alevin emergence, and fry rearing?
3. Is the basin hydrology such that extreme events and periods can significantly damage fish runs, either in natural state or in conjunction with human-related impacts that add stress to fish?

Example Methodology for Salmon Habitat Investigation

The following is a proposed list of items that might be included in the hydrologic investigation of salmon habitat.

- Precipitation distribution: Where was it sufficient?
- Runoff distribution: Where was it sufficient?
- Streamflow Gauging Stations:
  - *locations*
  - *lengths of records*
  - *concurrence of records*
- Data Available:
  - *instantaneous water levels*
  - *instantaneous discharges*
    - mean values of discharge for DAY, MONTH, YEAR
    - extreme values
- Analysis of Gauging Station Records:
  - *seasonal/monthly patterns & variability*
  - *average, maximum, and minimum conditions*
  - *flow-duration curves, based on daily values*
  - *low-flow characteristics (stages, discharges, dates)*
  - *flood-flow characteristics (stages, discharges, dates)*
  - *long-term trends:*
    - at gagging stations
    - correlations with longer records
- Streamflow Synthesis for Reaches in Basin:
  - *develop streamflow characteristics for ungauged sites*

Hydraulics

The hydraulics of water flow in a river or stream, as affecting salmon habitat investigations, encompass the velocities of water that are produced by water flowing in the channel, the depths of this flow at various places in the channel, and the widths over which the flow occurs at various places along the channel.

The hydraulics of channel flow are influenced by a few governing variables. These are:

- hydrologic conditions;
- the channel slope in the downstream direction;
- the typical cross-sectional shape of the channel;
- the actual cross-sectional shape along the channel length;
- the channel boundary roughness; and
- channel morphology.

Some of the relevant questions about channel hydraulics include:

1. Does the river have adequate water velocities, depths, and longitudinal connectivity for adult salmonid upriver migration to occur?
2. Does the river have adequate water depths and velocities for spawning, egg incubation and alevin emergence to occur?
3. Does the river have adequate water velocities, depths, and connectivity for fry dispersal, and rearing?
4. Does the river have adequate water velocities, depths, and longitudinal connectivity for juvenile outmigration to occur?
5. Are the channel velocities, depths, and widths highly variable over the years, such that conditions may change from year to year and impact the available/usable habitat?
6. Are channel hydraulic conditions of velocity and depth sensitive to natural events or human-related impacts that could affect the channel?

Example Methodology for Salmon Habitat Investigation

The following is a proposed list of items that might be included in the hydraulic investigation of salmon habitat.

- Gauging Station Rating Curve (relation between river stage-water surface elevation and water discharge):
  - *sensitivity of change in depth to change in discharge*
  - *type of site and type of control over rating curve*
- Transects (Cross Sections) -- Regarding Hydraulics:
  - *at various locations*
  - *use to show conditions and variation with flow available*
  - *develop typical depth-discharge relations for POOLS >> GLIDES >> RIFFLES >> CHUTES*
- Velocity Distributions in the Channel:
  - *lateral variation*
  - *vertical variation*
  - *secondary currents*
  - *eddies, backwash areas, and stagnant zones*
  - *flow interaction with in-channel and bank obstructions*
- Develop Connections between Basin Hydraulic Conditions and River Hydraulics:
  - *seasonality of water availability*
  - *short-term variability in water availability due to snowmelt/rain*
  - *flow recession during the dry season*

Channel Morphology

The morphology of the channel, as affecting salmon habitat investigations, encompasses the shape and form of the channel boundary. This includes channel widths, irregularities in bank shape, bank slope, bank overhang or undercut, the presence of bars, riffles, rapids and pools within the channel, and the corresponding depths of flow at different locations in the channel. These factors are also important to flow hydraulics in the channel.

In addition, channel morphology encompasses any tendencies of the channel to shift location through processes of erosion and deposition, whether gradual or abrupt (avulsive).

In-stream, or in-channel mining affects channel morphology when gravel extraction exceeds gravel replenishment. When this is the case, a river bed incises or degrades at the mining site and several kilometers, both upstream and downstream, from the mining site. This degradation occurs both on-site and off-site, causing a change in channel morphology which often results in severe environmental and physical damage.

Effects of gravel extraction on river morphology and sediment transport include the following (Collins & Dunne, 1990):

1. Bed degradation can result in undermining bridge supports and in exposing pipelines or other structures buried within the river bed.
2. There is an adverse effect upon aquatic habitat and salmonid spawning sites.
3. Gravel depth is depleted, revealing other geologic substrates.
4. Groundwater levels can be lowered if a floodplain aquifer discharges into the stream. This, in turn, reduces aquifer storage capacity, increases depth to the groundwater, and drains wetlands.
5. Riparian vegetation is destroyed, resulting in bank destabilization and erosion.
6. Rivers migrate across the floodplain by eroding the outside bank of a bend and depositing material on a point bar on the inside bank. With time the gravel bar on the inside of the bend is covered with fine sediments and organic materials from overbank flooding, eventually making the soil suitable for vegetation. However, if the accretion occurs while the riverbed is rapidly lowering, the accreted land will be stranded above the active floodplain as a terrace. Newly arrested or existing floodplains may no longer be supplied during floods with water and fine, organic-rich sediments, which are important for some agricultural land uses.
7. When a bed is rapidly degraded, there is a corresponding rapid increase in the bank height. This results in lateral bank erosion.
8. Lowering a point bar by mining may destabilize the opposite bank; increasing erosion on the outside bank of the next bend downstream.
9. Channel stability is affected by reducing gravel supply which affects the armoring that stabilizes the gravel bars (Lagasse et al., 1980).

Some of the relevant questions about channel morphology include:

1. Are the morphologic features of the channel such that upriver migration, spawning, rearing, and outmigration can occur?
2. If morphologic features provide water conditions adequate for migration, spawning, and rearing habitat, is this adequacy provided every year or is it jeopardized in some years and seasons?
3. If morphologic features are adequate for fish habitat, do they provide connectivity or are there features that cause blockages or that could cause

blockages if much variability in flow conditions occurs?

4. Are the channel morphological features highly variable over the years, such that conditions may change from year to year and impact the available/usable habitat?

5. Are channel morphological conditions sensitive to natural events or human-related impacts that could affect the channel?

Example Methodology for Salmon Habitat Investigation

The following is a proposed list of items that might be included in the geomorphological investigation of salmon habitat.

- Channel Plan View:
  - *type (classification) of channel*
    - straight
    - meandering
    - braided
  - *types of bed forms likely*
  - *types of changes likely*
- Channel, Riparian Zone, and Floodplain Relations:
  - *space available for changes, including avulsions*
  - *evidence of past channel locations*
- Longitudinal Profile -- Overall:
  - *major slope breaks that denote upstream vs. downstream differences*
- Longitudinal Profile -- Local:
  - *local slope breaks and possible blockages*
  - *indicators of locations of pools and riffles*
  - *frequency and lengths of riffles*
- Transects (Cross Sections) -- Regarding Morphology:
  - *overall shapes*
  - *depth-width relations at low flows*
  - *details regarding pools, glides, riffles, and chutes*
  - *indications of ease of movement between possible constrictions*
- Stabilization Efforts and their Effects.
- Develop Connections with River Hydrology and Hydraulics:
  - *morphological relation to seasonal water availability*
  - *morphological changes due to short-term large runoff*
  - *morphological relation to dry-season flow recession*

Sediment Transport

Sediment transport in a river, as affecting salmon habitat investigations, encompasses the occurrence, timing, and amount of inorganic matter being dislodged and moved by flowing water and deposited wherever flows are unable to sustain motion. The material may be transported as bedload (sliding, dragging, rolling, and bouncing along the river bed) or as suspended load (carried in suspension by flowing water). The material may originate from surface erosion on the watershed land surface during runoff events, from streambank erosion along all alluvial channels, from more massive failures of hill slopes and river banks, from scour of the channel bed upstream, or from local scour. If large or dense enough to be transported as bedload, the material may move relatively short distances (i.e., measured in feet or hundreds of feet). If small or light enough to be transported in suspension, the material may be carried for long distances (i.e., measured in miles).

The characteristics of sediment transport that may be of greatest importance to salmonids are the overall stability of the larger bed material that provides spawning substrate, the maintenance of intra-gravel water movement and oxygen transfer, the infusion and flushing of finer-sized sediment to/from the void spaces in this coarser matrix, and the incipient motion of this larger material due to runoff events or to abrupt changes in channel morphology. Sediment transport

can be influenced by natural events and human-induced changes in channel conditions.

One important tool for the analysis of sediment transport is the comparison of sediment availability with flow capability at any particular time and place. Another tool is the identification of source areas, through-put transport zones, and deposition areas, based on watershed conditions and channel characteristics.

Some of the relevant questions about sediment transport include:

1. Is the substrate gravel composition suitable for spawning and is this adequacy maintained every year?
2. Are the watershed and bank conditions such that gravel substrate can remain relatively clean, or is there risk of siltation of the gravel due to excessive supply of finer-sized sediment?
3. Are the channel morphology and flow hydraulics such that the voids in the substrate gravel are well flushed and receive oxygen-rich water at low-to-intermediate flows?
4. Do periodic high-water flows in the channel help to flush fines from the voids in spawning gravel, either while the bed itself remains stable or through bed-material transport?
5. Are sediment transport conditions sensitive to natural events or human-related impacts that could affect the channel?
6. Is the bed condition jeopardized in some years due to large flows that result from natural or human-aggravated events?
7. Are the sediment transport features highly variable over the years, such that conditions may change from year to year and impact the available/usable habitat?
8. Do changes in bed morphology, either natural or artificially induced, adversely affect sediment transport, or interact with sediment transport to alter spawning and rearing habitat?
9. Is the replenishment (recruitment) of gravel from upriver and bank sources in balance with the rate of downstream transport or local removal of such material from the active channel system?

Example Methodology for Salmon Habitat Investigation

The following is a proposed list of items that might be included in the sediment transport investigation of salmon habitat.

- Bed Material Characteristics:
  - *sampling and supporting observations to extend spatial information*
  - *representative sizes*
  - *range of sizes*
- Bed Material Variability:
  - *lateral, longitudinal, and vertical variations*
- Bed Material Quality:
  - *imbeddedness*
  - *permeability*
- Source Areas:
  - *land and bank*
  - *upstream*
  - *local bed*
- Zones that are Mainly Through-put Transport Zones:
  - *extent and causative factors*
- Deposition Zones:
  - *due to transect features and lateral variations*
  - *due to planform and channel alignment features*

- Develop Connections with River Hydrology, Hydraulics, and Morphology:
  - *relations to seasonal water availability*
  - *changes due to short-term large runoff*
  - *relations to dry-season flow recession*
  - *siltation and flushing likelihood*

Impacts on Meander Zone

The meander zone is the region spanning and adjacent to a river that is altered or influenced by the meanders of the river over time. The size of this zone will, of course, increase as the defining time period increases. For example, the thousand year meander zone will be greater than the ten year meander zone. The flood plain is defined in a similar manner, except that the influence of floods is likely to be more extensive than that of meanders. Vestiges of the meander zone of the Willamette River over the past few hundred years can still be identified from aerial photographs and topographic maps. Photographic coverage of the river by the U.S. Army Corps of Engineers dates back to the 1930s. The older photographs are better for identification purposes because of less agricultural and urban encroachment into the meander zone. Changes in the Willamette Valley provide ample evidence that the meander zone (for all time periods) has been reduced significantly as a result of human development.

Bank stabilization has been a major factor in the reduction of the meander zone. The main results have been to "harden" banks, limit meandering, and block secondary channels. One consequence is that channel morphology has become less complex over time, thus impacting the associated ecosystems.

Two important consequences of meander zone reduction deserve special attention. First, a supply of gravel to the river has been cut off. Second, meander and other off-channel habitats have been isolated from the river, degraded, and eliminated. Both consequences have negative impacts on salmon.

As the meander zone has decreased, gravel extraction has shifted from active channels to pit mining. This is partly due to aquatic habitat concerns, but also from reduced renewability of the channel gravel. Where formerly the bank erosion at meanders had released stored gravel, that material is retained behind revetments. Thus, mining operations mainly occur at off-channel pits which may also, in the long run, contribute to environmental impacts.

An alternative management strategy might involve the expansion of the meander zone by removing bank protection in some regions. The river would be allowed to meander within regions, thus expanding the supply of gravel to the river and creating meander habitats. Instead of removing the gravel from within the former meander zone through pit mining, this strategy would allow the river to behave in a more natural way which might eventually allow greater gravel removal to again occur from the downstream river. At the same time, meander zone habitats would be restored.

To compare this approach to current practice, consider two future conditions. In the first, a series of abandoned and isolated pit mines are found adjacent to a relatively straight river. In the second, a meandering river is found with diverse habitats, more similar to the underdeveloped state of the river. In both cases, the amount of gravel that had been extracted from the region is the same. The latter scenario would be preferable because of the residual habitat benefits.

The cost of meander zone expansion need not be high in many regions because flood plain restrictions have already limited development. That is, expanded meander zones would be located within the most flood-prone portions of the flood plain. Other than farming, development has not occurred in many of these regions. The public, which often must bear the costs of flood damage, has good reason to prevent development in these regions. For the salmon and for ecological values more generally, this region is extremely important. Thus, expanding the meander zone may be a strategy that can realize significant environmental benefits without cost to development. Of course, such meander zone expansion would not be promoted in those regions where high levels of development has occurred. For developed regions, bank protection would remain. This, however, would seek to identify less developed regions where meander zone expansion was feasible and development is already discouraged due to the risks of flood damage.

With respect to gravel removal, an expanded meander zone could allow increased gravel removability and future downstream in-channel gravel removal as an alternative to pit mining within the same region. Expanded meander zone regions could also provide aesthetic and recreational benefits beyond current practice. Such benefits might offset the small loss of farmland that occurred within the meander zone. Indeed, the State might auction off extraction permits for a sustainable portion of the gravel added to the river from a meander zone and use the receipts to offset the costs of establishing the meander zone.

Summary

The hydraulics, hydrology, and geomorphology of a stream combine to create and maintain aquatic habitats for salmonids. Sediment transport is an important component as it maintains gravel beds; this transport can be strongly affected by a variety of natural processes and human activities. While a variety of practices have impacted the sediment recruitment and transport in streams, the channelization of streams to remove natural meandering characteristics is considered to be one of the dominant impacts upon gravel. The lack of these meandering areas has resulted in significant loss of habitats and reduction of high-water erosion with the subsequent reduction in recruitment of gravels.

Gravel removal results in both local and cumulative impacts related to hydrology, hydraulics, and stream geomorphology. An impact analysis procedure for gravel removal and fill/alteration permits is outlined. The procedure includes specific questions that need to be addressed, and important information required for adequate analysis.

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AQUATIC ECOSYSTEM PROCESSES

Fish and Aquatic Habitats

This section will describe the essential habitat of salmon in the context of their ecosystem and processes governing watershed conditions. Habitat characteristics needed by salmonids at each stage of their life cycle will be described. Overriding concepts in stream ecology that are necessary for a full understanding of salmon habitat and related stream processes are presented. The following topics are clarified:

1. Principles that govern stream and estuarine ecology.
2. The role of disturbance and the difference in natural versus human-induced disturbance.
3. Severity of the problem of sensitive, threatened and endangered species:
   - *extinct salmon stocks*
   - *salmonid stocks presently at risk*
   - *other sensitive, threatened and endangered fish species*
   - *other aquatic-dependent vertebrates at risk*
4. Salmon habitat requirements at stages in their life cycle (general and species-specific).
5. Interdependence of salmonids with other fish species.
6. Effects of gravel extraction on salmonids and their habitat.
7. Effects of estuarine dredging and fill.
8. Cumulative effects in the estuary.

Stream Ecology

Stream as a Continuum

As a stream extends from the headwaters to mid-order, riverine reach changes in shading, abundance of large woody debris, substrate characteristics, stream flow, and depth naturally affect the kinds of algae, invertebrates, and fish that inhabit each reach. The distribution of stream organisms depends on food availability and physical conditions that are predictable in undisturbed streams according to location along the longitudinal stream continuum (Cummins, 1974; Vannote et al., 1979) (Figure 15).

Headwater streams are very narrow and easily shaded by trees and sometimes by herbaceous plants. Light levels are reduced, and the main food supply comes from outside the stream as leaves and plant material drop into the water from surrounding vegetation. Macroinvertebrates that feed on litterfall ("shredders") dominate the invertebrate assemblage. In the Pacific Northwest, cool temperatures and low water volume in headwater streams restrict vertebrate assemblages to young fish (particularly cutthroat trout) and amphibians.

As streams flow from headwaters, join with other tributaries, and form larger streams, the riparian canopy opens up, algal growth increases, and herbivorous invertebrates (scrapers, raspers, collector gatherers) dominate. In western Oregon, increased fish diversity occurs with warmer temperatures and greater habitat diversity in mid-order streams. Fish assemblages include salmonids, sculpins, minnows, lampreys, sturgeons, and suckers.

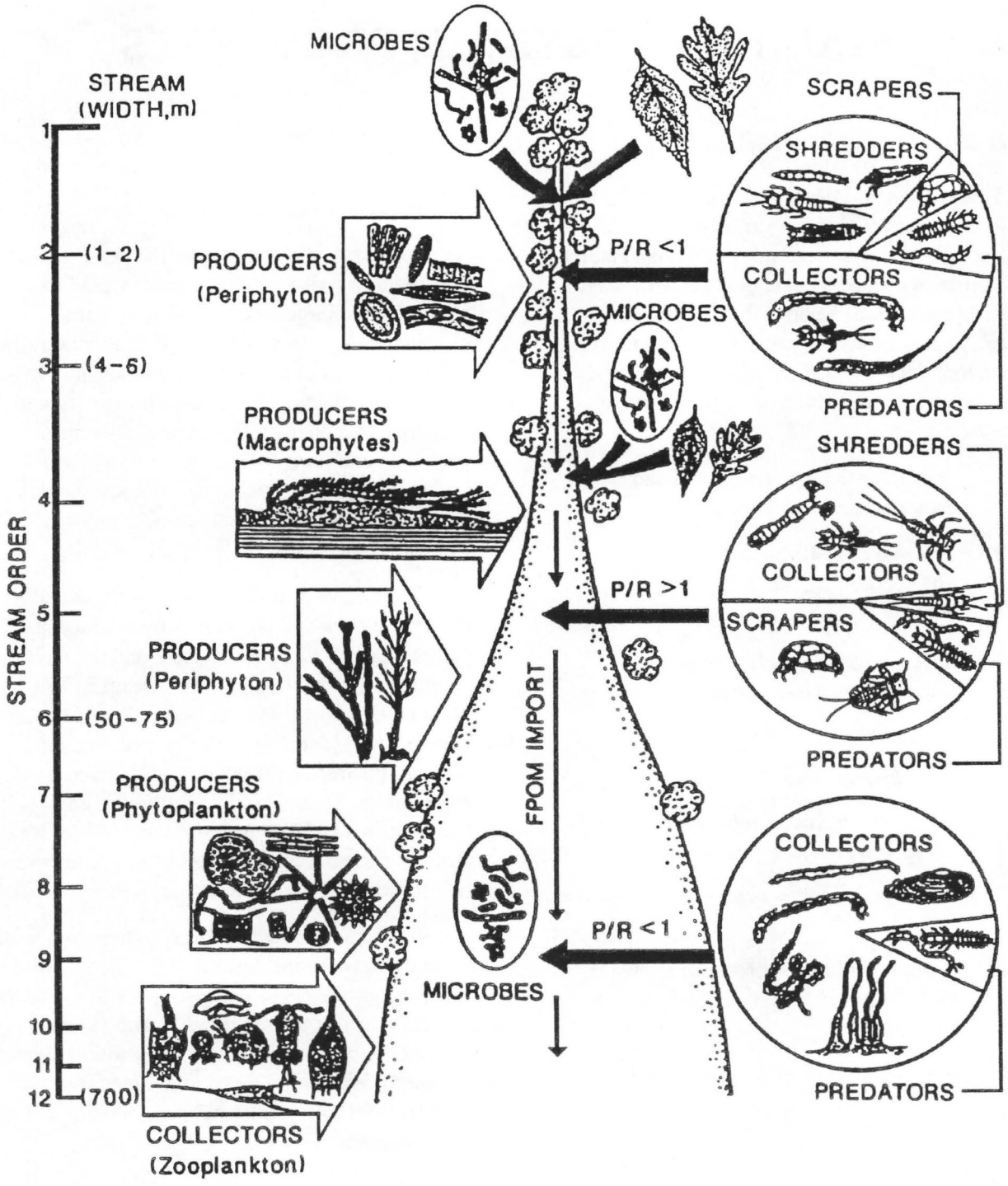


Figure 15. Trends in Physical Habitat, Photosynthesis/Respiration, Food Production, and Macroinvertebrates from the Headwaters (at top of illustration) to Large River Reaches (Vannote et al., 1980). FPOM is fine particulate organic matter. P/R indicates ratio of photosynthesis to respiration.

In riverine reaches larger water volumes restrict bottom-dwelling invertebrate communities of filterers such as clams and burrowers. Zooplankton dominate the water column. Larger fish, many of them predators, thrive in these waters. These include many species of salmon during migration, whitefish, sturgeon, lamprey, and introduced centrarchid fish such as bass and bluegills.

In floodplain areas where the valley floor is wide compared to the width of the stream, the stream channel is unconstrained by hillslopes (Figure 16). During floods the stream will flow onto the valley floor, sometimes changing channel location, establishing wetlands and secondary channels. Large floods construct floodplain surfaces (Leopold et al., 1964), maintain channel units and habitat complexity, and influence patterns of biotic succession (Poff & Ward, 1989). Connectivity with the floodplain during high flow events allows the interaction of the river with the land, permitting lateral exchange of materials, nutrient recycling and increased production within the floodplain (Junk et al., 1989). The aquatic food web is extended onto the land and interwoven with the terrestrial food web.

As streams and rivers approach the sea, saltwater carried upstream by high tides creates a transition area between freshwater and open sea. These estuaries (semi-enclosed coastal bodies of brackish water) and nearshore systems are among the most productive ecosystems on earth. Nearly 70% of the U.S. fisheries catch is derived from species that are either truly estuarine or estuarine-dependent species (McHugh, 1976). During juvenile life stages, many commercially important estuarine-dependent species utilize Oregon estuaries for feeding, growth, refuge from predators, or breeding (e.g., chinook salmon, chum salmon, English sole, starry flounder, dungeness crab).

Estuaries are comprised of marine, bay, riverine, and slough subsystems, all of which provide critical habitat for salmonids and numerous other species of invertebrates, vertebrates, and plants that are essential components of food webs utilized by salmonids and other commercially important species. The marine subsystem usually accounts for the highest fish diversity in the estuary. Major clam and shrimp beds occur in intertidal flats in estuarine bays. At high tide many juvenile fish migrate to these flats to feed on invertebrates. Low tide sand flats are also used as short-term refuge by salmonids (Levings, 1982). Sloughs include marsh, mudflat, and eelgrass communities, and serve as important rearing, feeding, and resting sites for juvenile fishes, invertebrates, and waterfowl. The riverine subsystem of the estuary may be connected to saltmarshes, grading into freshwater marshes or wetlands, and provides rearing and holding areas for juvenile anadromous and freshwater fishes and corridors for adult salmonids during spawning migrations.

Riparian Functions

Although riparian areas can be defined in a number of ways, they are often assumed to comprise the relatively moist zones that border

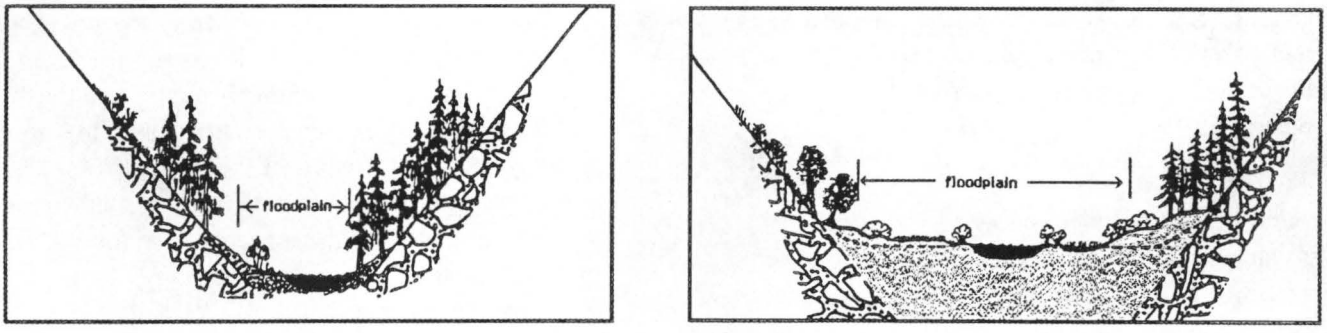


Figure 16. Constrained channel (left) and unconstrained channel (right) have different responses to floods and vary in amount of interaction with floodplain (after Jensen, 1983).

streams, rivers, or other bodies of water (Elmore & Beschta, 1987; USDI Bureau of Land Management, 1987). Mitsch and Gosselink (1986) offer three characteristics of riparian areas which separates them from upslope areas:

1. Riparian ecosystems have a linear form because of their proximity to streams and rivers.
2. Energy and material from the surrounding landscape converge and pass through the riparian ecosystem.
3. Riparian ecosystems are connected to upstream and downstream ecosystems.

Riparian ecosystems, since they provide a transition between terrestrial and aquatic ecosystems, have an important influence on the functions, processes, and structural components of both streams and the near-channel environment. These functions include nutrient and temperature modification, detention storage of water, trapping of sediments and floatable organic debris, influencing channel equilibrium and morphology, recruitment of coarse woody debris, food-web support, and others.

Changes in streamside vegetation, because of its fundamental importance for food-web support through nutrient cycling and organic matter production, also affect the composition and abundance of aquatic and wildlife species associated with the aquatic and riparian ecosystems. For example, differing species compositions of riparian vegetation (e.g., conifers versus deciduous trees) provide differing inputs of organic matter (timing, volume, nutrient quality) to streams. Similarly, changes in the composition of the riparian forest can influence stream chemistry due to differences in nutrient production, mineralization, or other factors.

Riparian vegetation can also contribute to channel stability by providing root systems for streambank reinforcement and large wood to the stream. Coarse woody debris serves to augment and sustain fish habitat complexity by maintaining pools and gravel deposits (Andrus et al., 1988). Gravel removal operations have the potential of altering streamside vegetation by direct and indirect impact. Direct impact would include alteration by machinery while indirect impact would include gradual changes in vegetation caused by changes in channel morphology, bank stability, and groundwater flow alterations. The following section highlights the functions of riparian areas and potential effects of gravel removal on those areas.

Microclimate

Vegetation provides a strong moderating influence on microclimate characteristics of riparian areas, including light, temperature, and humidity. In general, due to their low-lying position on the landscape, riparian areas tend to be cooler than the surrounding hillslopes, especially during the night. Though air temperatures in mountainous landscapes tend to become cooler with increasing elevation, air temperatures associated with riparian systems can exhibit deviations from this general scenario.

Since riparian areas are adjacent to water bodies, they also have higher relative humidities under the canopy than similar upslope areas. This increase in humidity, combined with shading effects, causes intact forested riparian areas to have a moderating effect on microclimate. In the summer, the shading effects of riparian vegetation in combination with relatively high humidities serves to keep air temperatures relatively cool. At night, due to the greater heat capacity of the moisture in the air and reduced rates of longwave energy loss, temperatures associated with riparian systems tend to remain relatively warm in comparison to surrounding landscapes.

Nutrient Dynamics

Leaves, twigs, and branches from stream-adjacent vegetation supplies biomass to the stream, which in turn influence stream chemistry and the availability of food for aquatic organisms. In forested headwater streams of the Pacific Northwest, external food inputs from riparian areas can compromise 99% of the energy base for aquatic organisms; only 1% of the energy base results from primary productivity (Sedell et al., 1974). However, increases in primary production are typically stimulated by canopy removal due to the increases in nutrients, light, and stream temperatures that often accompany the harvest of

riparian trees (Beschta et al., 1987; Gregory et al., 1987). Although streams where riparian vegetation has been removed may exhibit a short-term increase in primary productivity, the abundance and distribution of aquatic organisms may fluctuate more than for streams in mature forests (Gregory et al., 1987).

Changes in species composition of riparian vegetation can also influence stream chemistry and biological responses due to different nutrient cycling characteristics associated with the composition and timing of inputs. For example, leaves from coniferous forests decompose relatively rapidly and provide a longer term food base for aquatic invertebrates than do leaves from deciduous forests. Where riparian areas are dominated by nitrogen-fixing red alder, increased nitrogen levels may occur in streams. Following the removal of riparian forests from along stream systems, temporal patterns of vegetation succession (forbs, deciduous shrubs, deciduous trees, conifers) and their associated terrestrial inputs of organic matter indicate complex productivity and stability responses of aquatic communities (Gregory et al., 1987).

During rainfall and snowmelt events, nutrients from upslope areas may be rapidly transported through riparian areas to the stream channel (Green & Kauffman, 1989). However, during lowflow periods riparian vegetation may contribute nutrients which can alter in-stream productivity. These nutrients, while increasing biological productivity can degrade quality of water used for municipal purposes. For example, red alder leaf fall during the fall lowflow period in an Oregon Coast Range caused color, taste, and odor problems for a local municipal watershed. However, the resulting study (Taylor and Adams, 1986) indicated that water quality impairment due to alder leaves was not a chronic problem for the coastal watershed.

As streams flow down-valley, their dimensional attributes (e.g., total flow, width, depth) systematically increase due to flow additions and changes in stream gradients. Similarly, stream and riparian ecosystems regularly change in a downstream direction resulting in a recognizable ecosystem gradient or stream continuum. The "river continuum concept" (Vannote et al., 1980) provides a conceptual basis for addressing progressive shifts in function and structure that are typically encountered along a downstream gradient. This concept further indicates that processes and organisms associated with the loading, transport, and utilization of organic matter are likely to change in a downstream direction. For example, decomposition processes that occur in low-order streams condition organic matter for subsequent processing at downstream sites. Thus, downstream biotic communities not only receive local inputs of organic matter from stream-adjacent riparian areas but also altered forms of organic matter from upstream reaches. As a consequence of this connectivity within the stream system, the removal or alteration of stream-adjacent vegetation by various land use practices not only has the potential of impacting local aquatic communities, but also those farther downstream.

Bank Stability

The stability of streambanks is largely determined by the size and cohesiveness of bank material, vegetation cover, and the amount of bedload carried by the channel (Sullivan et al., 1987). Banks formed of non-cohesive alluvium that are sparsely vegetated tend to collapse, forming wide, shallow channels. Banks that are composed of more cohesive material tend to form deep, narrow channels (Sullivan et al., 1987).

Riparian vegetation of various types and growth forms play an important role in stabilizing streambanks during the erosive forces of high-flows. The below-ground portion of vegetation (i.e., root systems) serves to bind stream adjacent sediments, which in turn influences bank characteristics and the lateral stability of the channel. Lateral river migration through unvegetated floodplains can be much more rapid than through vegetated floodplains. During overbank flooding, above-ground components of riparian vegetation also provide flow roughness and can exert considerable resistance to flow. This resistance not only reduces the erosive power of the water but typically causes the deposition of sediments (Hickin, 1984).

The roots of vegetation along streambanks can increase erosion resistance of the downstream slope by increasing the bank cohesive strength (Shields & Gray, 1992). In a study of 26 cases where levees where overtopped by flood flows, those levees with

a cover of sod had increased resistance to erosion as compared with unvegetated levees (Gilbert & Miller, 1991, as cited in Shields & Gray, 1992). In the Sacramento River in California, Shield and Gray (1992) found that roots have a significant effect on the stability of sandy levees and that even low root concentration sufficed to make the slope more secure.

The type and age of the roots along streams and rivers has an effect on the cohesive strength they depart to the banks. A study from the Midwest United States (Davidson et al., as cited in Shields & Gray) found that the type and age of the root has a direct effect on bank stability due to varying tensile strengths of the roots. The tensile strength of woody species roots were 1.5 to 8.5 times greater than the tensile strength of herbaceous species. In addition, these authors found that later successional species had greater root strength than earlier successional species (Davidson et al., as cited in Shields & Gray).

In small streams where the channel and its banks are highly interactive, varying vegetation patterns can produce large differences in channel roughness. This in turn influences local stream velocities and energy dissipation over a wide range of flows (Sedell & Beschta, 1991). These riparian plant communities are also sometimes effective in reducing the transport of sediment to streams from nearby forest operations or natural sources (Meehan et al., 1977).

During at least part of the growing season, soil along many forested streams may be anaerobic due to high water levels. Anaerobic soils can limit the extent of downward root growth and windfirm root systems may not develop. Though the direct and indirect effects of tree root systems upon the morphology of channels have been little studied for forested systems, they are nevertheless thought to be an important factor in influencing channel morphology (Sullivan et al., 1987; Sedell & Beschta, 1991). For example, undercut banks associated with forest streams are often indicative of long-term channel stability and provide cover for fish. Although a wide range of factors can affect the occurrence of these channel features, a study in the Oregon Coast Range indicated that the occurrence and general characteristics of undercut banks were strongly correlated with streamside tree densities (Salminen, 1990).

In the south Coast Region of Oregon, bank stability was found to be correlated with the percentage of the basin impacted by forest practices (Frissell, 1992). Streambank erosion rates increased four to six times over that of areas subjected to little or no logging. In basins where harvest occurred on less than 30% of the area, streams with banks in an actively eroded state were less than 15% of the stream length. In basins where harvest was extensive, the percentage of streambanks in an actively eroding state increased to 40%.

Large Wood

Over the last two decades, the role of woody debris as a critical factor affecting aquatic habitat for fish and other aquatic organisms has become increasingly apparent from a wide range of research studies. Coarse woody debris affects the occurrence and morphology of pools and gravel deposits, sediment storage and routing, bank stability, overall in-stream complexity (Sullivan et al., 1987; Andrus et al., 1988; Sedell et al., 1988). The quality and quantity of wood reaching the stream will in turn influence the morphological and biological functioning within the stream, including: (1) creating and maintaining pools, (2) causing local reductions in stream velocities that serve as foraging sites for fish feeding on drifting food items, (3) forming eddies where food organisms are concentrated, (4) supplying protection against predators, (5) providing shelter during high-flows and (6) trapping and storing organic inputs from the streamside forests enabling them to be biologically processed (Beschta, 1989).

Due to their proximity to streams, riparian trees are perhaps the most important sources of coarse woody debris inputs to a channel. As a result, land use practices within the riparian corridor significantly alter large wood recruitment and dynamics. Because of historical logging practices along streams, riparian areas associated with non-federal forest lands are often deficient of large woody debris loadings in comparison to pre-management conditions. For example, a study in the Oregon Coast Range found large woody debris levels to be at relatively low levels due to historical harvesting practices (Veldhuisen, 1990). Just as importantly, the conversion of many riparian forests to other land uses such as agricultural

production, livestock grazing, and urban development have had extensive impacts to these important ecosystems and associated aquatic environments.

Gravel removal operations which remove large wood from bars and banks of river systems, reduce the source of wood for in-channel processes and overbank flooding conditions. Large wood jams at the head of gravel bars serve to anchor the bar and in most cases, cause increased gravel recruitment behind the jam. In addition, large wood on floodplains and gravel bars can also have an important effect on the plant community dynamics of these areas. For example, conifer regeneration in the Coast Range was found to be significantly higher on downed wood than on any other substrate (T. Spies, 1993, personal communication). In lower gradient streams of Oregon where large wood was historically removed and is still removed due to concerns over safety and navigation of rivers, large wood represents an important ecological component.

Floodplain Functions

Riparian floodplains in forested areas serve a variety of functions including the detention storage of overbank flows, deposition of sediments, trapping of floatable organic matter, and moisture recharge of soils and subsurface environments. These are also dynamic areas where various sources of water including hillslope drainage, precipitation, groundwater, subsurface flow, and streamflow interact (Reiter, 1990). Where linkages occur between in-channel and subsurface flows, the stream-adjacent subsurface environments (i.e., hyporheic zone) can also serve as habitat for aquatic invertebrates.

The subsurface hydraulics of floodplain systems may be critical for the functioning of specialized aquatic organisms. Research on former glacial outwash plains along the Flathead River in Montana (Stanford & Ward, 1988) has demonstrated that subsurface flows and water levels are hydraulically connected to the in-channel flows. Although it had been originally assumed that the hyporheic zone (i.e., the interstitial habitat penetrated by riverine animals) was only a few inches to a few feet wide, results of the Montana study indicated the existence of riverine invertebrates over a mile from the channel, thus indicating a much broader hydrological/ecological connection between rivers and floodplains.

During periods of overbank flooding, understory vegetation and the boles of forest trees provide important roughness elements that increase flow resistance (Hickin, 1984). The hydraulic roughness associated with this vegetation serves not only to reduce the velocity of overbank flows but also to trap organic matter and sediment. This organic material serves as a food source for both aquatic organisms and terrestrial organisms (Sedell & Beschta, 1991); the inorganic material contributes to floodplain development.

While in-stream roughness elements such as large woody debris and stream-adjacent vegetation are increasingly recognized as critical factors affecting the hydraulic roughness of fluvial systems (Sedell & Beschta, 1991), little research has been conducted for evaluating the hydrologic and ecologic importance of near-stream areas of forested floodplains. Because of the potential for channel changes to occur at high flows, maintaining some level of riparian protection for these near-channel areas is an important consideration in the channel morphology of many streams and rivers.

It is generally difficult to uniquely separate the effects of a particular land use practice on larger floodplain systems because these systems usually occur relatively low in a drainage basin and typically have been impacted by a variety of land uses (agriculture, highways, urbanization, etc.). In addition, any floodplain response to management activities, similar to other hydrologic components, depends on regional and local conditions. For example, floodplains within competent bedrock and colluvial segments of the South Coast Region appeared to be generally insensitive to land use impacts as compared to floodplains formed in alluvium (Frissell, 1992). The cumulative effects of human activities on these alluviated floodplain reaches included loss of pool area and increased riffle area caused by increased sedimentation from upstream sources. This increased sedimentation caused gravel bars to expand and reduced the effectiveness of obstructions to create scour pools.

The combination of increased sediment load from upstream areas and the reduction of stream-adjacent vegetation both serve to exacerbate the

effects of floods on downstream areas. Floods that occurred in western Washington State during the winter of 1991 were believed to be aggravated by increased sedimentation from upstream land use activities (primarily forestry) which caused stream channel aggradation (Harr & Cundy, 1992). Furthermore, loss of streamside vegetation serves to increase floodflow velocities, which can increase the power of the flood and continue to transport sediment and debris further downstream. Loss of streamside vegetation can also cause a weakening of the streambanks along floodplains which increases the instability of channels and may cause increased rates of lateral migration. Similar effects were found for the Upper Middle Fork of the Willamette River where long-term changes in channels and floodplain functions occurred during the 1964-65 floods as a result of increased sedimentation and loss of riparian vegetation (Lyons & Beschta, 1983).

Factors Affecting Type and Extent of Riparian Vegetation

The characteristics of riparian plant communities are affected by a wide range of site conditions, natural disturbance regimes, and land use practices. Of utmost importance to the sustaining riparian vegetation is the maintenance of those factors that continue to allow the establishment, growth, and succession of riparian dependent plant species.

Site Conditions

Landform has an important influence on the type and extent of riparian vegetation. Unconstrained stream reaches (floodplains and low terraces) tend to be dominated by deciduous tree species while constrained reaches (v-shaped or narrow streams) tend to be dominated by coniferous species. Elevation also plays an important role as the prevalence of various plant species can markedly shift along elevational gradients.

Disturbance Patterns

The frequency and magnitude of flows has a major influence on the type and extent of riparian vegetation since by their nature riparian plants are adapted for wet conditions. The frequency of overbank flooding, the duration of saturated soil conditions, the changing nutrient flux associated with overbank flows, etc., all contribute to create dynamic and diverse plant assemblages. Within a given riparian area there can be numerous hydrologic gradients that further influence the pattern of vegetation.

The instantaneous maximum discharge associated with an individual storm or snowmelt hydrograph represents, by definition, a peakflow or peak discharge. Although the amount and timing of rainfall or snowmelt arriving at a soil surface are of fundamental importance in determining the magnitude of peakflows from a particular watershed, these high-flows are also influenced by topography, antecedent soil moisture levels, soil characteristics, watershed size, and others. Peak discharges are ecologically important to most stream systems as they represent a significant natural disturbance mechanism affecting sediment transport dynamics, channel morphology, riparian functions, and aquatic organisms. Furthermore, in areas of steep mountainous terrain, periods of high streamflow are also often associated with the occurrence of hillslope erosion and landslide processes.

The magnitude of the annual peakflow for a given watershed is highly variable from year-to-year. Because of this variability and the probabilistic nature of these extreme events, the most common method of characterizing them is through the use of frequency analysis. Frequency analysis establishes a relationship between peakflow magnitude and its associated "return period." Thus, such analyses provide a basis for identifying which peakflows represent two year events, which ones represent 10-year events, etc. Frequency analyses of peakflow data are not only useful for establishing design storms for road ditches, culverts, and bridges. In addition, frequency analysis of stream stage data also provides an approach for evaluating in-channel effects of dams, water diversions, gravel mining, changes in channel morphology, etc., upon the local hydrology of a river system.

Although periods of low flow or drought may also influence riparian vegetation, such effects have been little studied or quantified. "Lowflow" is a term that generally is not well defined. Other terms for lowflow include baseflow, groundwater flow,

and dry-weather flow, depending on the area and the specific need placed on the water (Widner, 1991). Periods of low or relatively low stream discharge naturally occur during late summer or early fall months throughout most of Oregon. For mountain watersheds in eastern Oregon where snowpack accumulation is common, late summer flows can continue to slowly decrease through the late summer, fall, and winter months until the advent of snowmelt the following spring.

The Role of Natural Disturbance

When substrate availability, hydraulics, and water quality are changed by activities such as gravel operations, the abundance and health of not only particular species will be affected, but also the connectivity within assemblages and fundamental biological processes can change. These effects occur on several spatial and temporal scales, from microhabitat to watershed and regional patterns, and on day-long to decade-long intervals. The consequences range from momentary effects to those which change life history patterns and regional distribution.

Stream organisms are adapted to natural daily and seasonal disturbances such as normal fluctuations in daily temperature, winter flooding, and summer warming. Behavioral, morphological, and physiological responses have evolved in all organisms to cope with natural disturbance. When disturbances occur outside expected boundaries the response of organisms depends upon the extent of perturbation, as can be measured in the following ways (Pickett & White, 1985):

1. **frequency** -- number of occurrences over time; disturbances may recur during given intervals with a specified degree of probability.

2. **duration** -- the length of time that the perturbation is acting.

3. **magnitude** -- the areal extent of the perturbation on the landscape (e.g., km^2).

4. **intensity** -- force exerted by the perturbation on landscape (e.g., 5.0 on the Richter Scale).

5. **severity** -- biological response of the biota to the frequency, duration, magnitude and intensity of the perturbation.

After episodes of disturbance, ecosystems undergo a period of adjustment during which different species re-colonize disturbed areas, gradually change the microhabitat, and yield to other species. This process is referred to as ecological succession.

Responses of organisms to disturbance vary dramatically because of differences in developmental times, behavioral movements, and responses to environmental factors. For example, lifespans for algae cells can be within a day, for mayflies within weeks, and fish in years. Some invertebrates, such as mayflies and midges, have lifespans occurring over months, whereas riverine zooplankton may live for only a few days. These short-lived organisms produce several generations per year, tend to readily colonize disturbed habitats, and are able to adapt to continued disturbance more easily than longer-lived species. Exotic or introduced species, tend to be representatives of this group of early successional species and can profoundly disturb native ecosystem relationships. Other invertebrates are much longer-lived; snails live for several years, and mussels live for decades. Therefore these animals require habitat stability, and cannot recover quickly from large disturbances. Responses to disturbance may include location of refuge, recolonization, migration, or dormancy.

The timing and longevity of disturbances affect the ability of aquatic biota to recover. For example, mass movement of sediments during winter storms, when many organisms are burrowed or attached to substrates, may be an event to which life history patterns are historically cued. However removal of gravels in summer may severely impact assemblages of algae, and populations of benthic invertebrates and young fish that are exposed on rock surfaces or stream edges at that season. Chronic disturbance to a system will likely result in communities of mobile, short-lived colonizers that could vary greatly in composition from less disturbed situations, a situation with profound effects on habitat and the aquatic food web (Haefner & Wallace, 1981; Gurtz & Wallace, 1984; Molles, 1982; Cushing & Gaines, 1985).

For fish, food availability may also change dramatically in composition and available biomass under conditions of continual disturbance.

Widespread disturbances of sufficient magnitude, severity, and duration may influence the distribution and abundance of species in an entire region. Consequences of global climate change are potentially monumental, causing widespread shifts and extinction of species. Climate change would affect hydrographic and geographic distributions of fishes in lakes and streams, especially through changes in maximum summer temperatures and minimum winter temperatures (Regier & Meisner, 1990). Changes in storm frequencies, amplitudes, and geographic distribution of rainfall would alter regional disturbance regimes and hydrographs. Global climate change may cause intrusion of marine waters into estuaries, further reduction of estuarine habitat, and reductions and relocation of spawning and nursery habitat (Kennedy, 1990; Gucinski et al., 1990).

Cumulative Effects of an Altered Disturbance Regime

Growth in human population increases demands on natural resources and subjects ecosystems to more intense human manipulation. Dam-building, channelization, clearcutting, road building, salvage of large woody debris from channels, and conversion of riparian vegetation within a watershed can affect geomorphic processes, channel form, landscape patterns, ecological function, and biotic interactions. Human-induced changes can alter ecologic thresholds in watersheds, sometimes causing a change in geomorphic processes from which the system may not recover to its previous state. These human disturbances may uncouple the important ecological processes that link ecosystem components within the watershed (Stanford & Ward, 1992).

Changes can result in both localized on-site impacts and cumulative impacts. Chamberlin et al. (1991) identified five main categories of physical changes in streams that result in cumulative effects:

1. Changes in timing or magnitude of small or large runoff events.
2. Changes in stream bank stability.
3. Changes in sediment supply to channels.
4. Changes in retention, especially involving large woody debris.
5. Changes in energy relationships involving temperature, snowmelt, and freezing.

These cumulative effects are alterations of large scale processes and constitute long-term disturbances. Biological responses occur on analogous scales, including:

1. Changes in abundance and diversity of assemblages along the stream continuum.
2. Changes in dominant life history patterns associated with altered timing of physical processes.
3. Changes in trophic processes and food webs resulting from changes in energy resources.

Indicators of stress in aquatic systems in the Pacific Northwest include: diminution of dominant species (e.g., salmonids), lowered diversity of organisms, increase in exotic species, decreased habitat diversity and complexity, and homogeneity of stream states. Ecosystem integrity depends upon the maintenance of natural processes; ability to defend against invasion by exotic species, pests, or diseases; capability to survive and recover from perturbation; and often is further defined in terms of attractiveness of the ecosystem to humans and ability to produce desired goods and services.

How does this concept relate to the human activity of removal or fill of materials in stream channels? The degree to which gravel removal and dredge fill are severe events depends upon the extent to which they deviate from natural patterns of stream aggradation, stream degradation, bedload recruitment, and bedload movement. Over the last six million years salmonids have evolved within the natural disturbance regime. Novel disturbances can shift the ecological rules governing community structure making the recovery of the original biota impossible (Resh et al., 1988; Poff & Ward, 1989; Bayley & Li, 1992). When substrate availability, hydraulics, and water quality are changed, the

abundance and health of not only particular species can be affected, but also the connectivity within assemblages and fundamental biological processes can change. These effects occur on several spatial and temporal scales, from microhabitat to watershed and regional patterns, and on daily to decade-long intervals. The consequences range from momentary effects to those which change life history patterns and regional distribution patterns.

Aquatic-Dependent Species: An Alarming Situation

Historical Distribution and Abundance of Salmonids

The oldest evidence of salmon is a 45 million-year old fossil from the Eocene (McPhail, 1994). About 20 million years ago the Atlantic and North Pacific lineages diverged. The North Pacific lineage gave rise to Mexican golden trout, cutthroat trout, rainbow and steelhead trout, and Pacific salmon. Divergence of the original salmon populations into distinct and different species was driven by natural selection as salmon adapted to unique local conditions in their natal streams and during their migrations.

Spawning populations of chinook, coho, chum, and sockeye are distributed across the entire Pacific rim. This huge range is occupied by thousands of "stocks" which express a diverse array of life history characteristics. Most salmon populations in the Pacific Northwest have invaded post-glacial sites within the last 10,000 years. Varying rates of stock extinction and recolonization are associated, in part, with the geomorphic dynamics within basins as well as oceanic conditions. The stream ecosystems within a basin are in a constant flux with respect to habitat conditions required for salmon production. Historically, stock depletion or extinction may have resulted from "natural" events such as debris flows in lower order streams or El Niño weather anomalies.

Prior to European settlement, juvenile and adult salmonids migrated through the Columbia River system every month of the year (Li et al., 1987). Historically, adult chinook salmon could be found in every month in all but the smallest coastal streams. The summer runs were soon fished to extinction, and the remnant peaks are now considered separate, seasonal "runs." Over one-third of the original Columbia River salmon stocks are now extinct (Nehlsen et al., 1991), and both commercial and recreational fisheries have steadily declined (Figure 17).

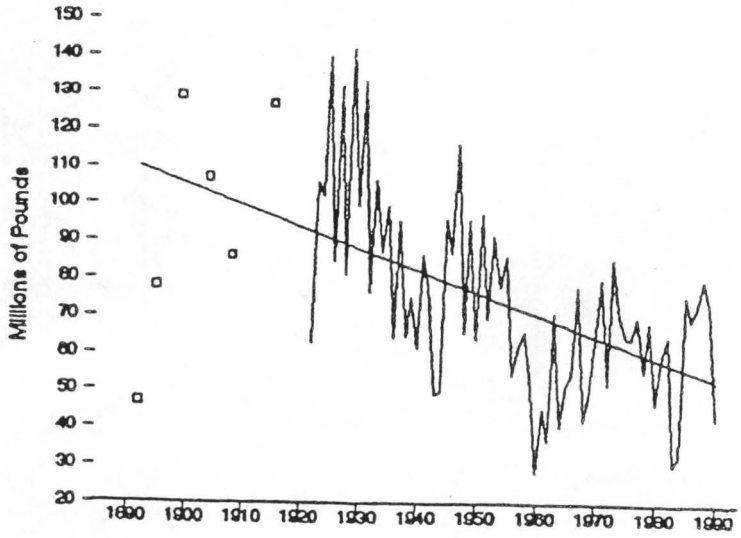


Figure 17. Millions of Pounds of Salmon Landed in Oregon, Washington, and California (1890-1990) (Alkire, 1993).

The extent of cumulative impacts on salmon populations is dramatic. Major impacts include: habitat loss or alterations; hatchery influences; commercial fishing on the salmon, their predators and their prey; introduction of exotic species; and alteration of the trophic relationships in both the ocean and freshwater. The relative contribution of each individual impact to the decline of salmon is impossible to determine, as many impacts have occurred simultaneously and cumulatively, in a non-linear manner. Some impacts compound the effects of others in a synergistic manner (i.e., two impacts having more effect than the two of them added together). The extent industrial society has had on entire species complexes is unknown.

Quantitative information on pre-European (before 1850) abundance of salmon in Oregon is rare. Several estimates of abundance have been conducted for total salmon in the Columbia River Basin. Predevelopment estimates of total run size of all Columbia Basin chinook, coho, sockeye, chum and steelhead populations are between 10 and 16 million fish (NWPPC, 1987). Current estimates of total salmon in the Columbia Basin are around 2 million (Alkire, 1993) with artificially produced (hatchery) fish outnumbering wild fish (Kaczynski & Palmisano, 1992). The number of pounds of salmon caught in the Northwest has dropped precipitously since 1899 (Figure 18).

Although information on historic abundance of salmonids is not well documented, information on historic distributions of salmonids is easier to obtain. Many populations (as defined by run time and/or geographic location) are known to be extinct (ODFW, 1994) (Table 2). Reliable lists of pre-development salmonid populations are not available making it difficult to construct a complete list of extinctions. However, information on reduction of historic distributions is available. The construction of dams has resulted in range reductions of spawning and rearing throughout Oregon. The historical range of chinook salmon included the entire Columbia Basin and all but the smallest coastal streams. The first main channel dam in the Columbia was constructed in 1933, followed by numerous other dams on the Columbia, its tributaries, and coastal rivers. Many of these dams made no accommodation for fish passage. Chinook salmon are now extinct above the Hells Canyon Dam complex on the Snake River, Pelton/Round

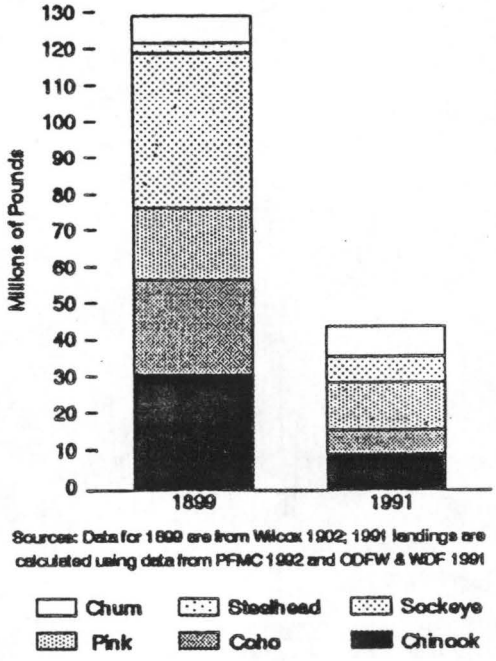


Figure 18. Millions of Pounds of Salmon Landed on the Pacific Coast, Columbia River and Puget Sound (Alkire, 1993).

Butte dam complex on the Deschutes River, above upper basin dams in the Willamette, Umpqua, Rogue, Umatilla, and Walla Walla Rivers. Numerous other populations have been lost from other basins such as the fall chinook in the John Day Basin and the spring chinook in the Hood River Basin.

Table 2. Salmon stocks of the genus *Oncorhynchus* known to be extinct in Oregon (Nehlsen et al., 1991).

Species	Common Name	Extinct Stock
O. keta	Chum Salmon	Umatilla River
O. keta	Chum Salmon	Walla Walla River
O. kisutch	Coho Salmon	Euchre Creek
O. kisutch	Coho Salmon	Grande Ronde River
O. kisutch	Coho Salmon	small tributaries above Bonneville Dam
O. kisutch	Coho Salmon	Snake River
O. kisutch	Coho Salmon	Umatilla River
O. kisutch	Coho Salmon	Walla Walla River
O. kisutch	Coho Salmon	Wallowa River
O. mykiss	Steelhead Trout	Burnt River
O. mykiss	Steelhead Trout	Malheur River
O. mykiss	Steelhead Trout	Owyhee River
O. mykiss	Steelhead Trout	Powder River
O. mykiss	Steelhead Trout	Sandy River
O. mykiss	Steelhead Trout	South Umpqua River
O. nerka	Sockeye Salmon	Metolius River
O. nerka	Sockeye Salmon	Wallowa River
O. tshawytscha	Chinook Salmon	Klamath River Fall Run
O. tshawytscha	Chinook Salmon	Klamath River Spring Run
O. tshawytscha	Chinook Salmon	Malheur River Spring Run
O. tshawytscha	Chinook Salmon	Metolius River Spring Run
O. tshawytscha	Chinook Salmon	Owyhee River Spring Run
O. tshawytscha	Chinook Salmon	Priest Rapids Dam Spring Run
O. tshawytscha	Chinook Salmon	Snake River Fall Run
O. tshawytscha	Chinook Salmon	Sprague River Fall Run
O. tshawytscha	Chinook Salmon	Sprague River Spring Run
O. tshawytscha	Chinook Salmon	Umatilla River Fall Run
O. tshawytscha	Chinook Salmon	Umatilla River Spring Run
O. tshawytscha	Chinook Salmon	Walla Walla River Fall Run
O. tshawytscha	Chinook Salmon	Walla Walla River Spring Run
O. tshawytscha	Chinook Salmon	Willamette River Fall Run
O. tshawytscha	Chinook Salmon	Williamson River Fall Run
O. tshawytscha	Chinook Salmon	Williamson River Spring Run
O. tshawytscha	Chinook Salmon	Wood River Fall Run
O. tshawytscha	Chinook Salmon	Wood River Spring Run

Sensitive, Threatened, and Endangered Salmonid Species of Oregon

The federal Endangered Species Act (ESA)of 1973 was enacted to identify and protect species on the verge of extinction. A species is listed as **threatened** if it is likely to become endangered in the near future, and is listed as **endangered** if it is in danger of extinction throughout all or a significant part of its range (NMFS, 1991). The ESA gave the U.S. Secretary of the Interior (acting through the U.S. Fish and Wildlife Service) the responsibility to identify species in need of listing under the ESA criteria. However, ESA listing of all marine fish species, which includes anadromous salmonids, is the responsibility of the U.S. Secretary of Commerce, acting through the National Marine Fisheries Service (NMFS), an agency in the National Oceanic and Atmospheric Administration. (*For a discussion of criteria that NMFS uses to evaluate Pacific salmon ESA petitions, please see Waples 1991, Definition of "Species" Under the Endangered Species Act: Application to Pacific Salmon.*)

The Oregon Department of Fish and Wildlife (ODFW) biologists have been directed to identify sensitive species and develop a GIS-based map showing specific in-stream habitat used during spawning and rearing. This report section is based extensively on ODFW reports of salmon stocks and their status. The State of Oregon's categories of threatened and endangered (T and E) are for the most part equivalent to federal categories, due in part to a cooperative agreement between ODFW and U.S. Fish and Wildlife Service for the purpose of carrying out research and conservation programs under the auspices of the federal ESA (Oregon Natural Heritage Program, 1993) (Table 3). Both federal and state listings have categories for candidates as potential, threatened, or endangered species. One such category is *Category 2*, which signifies that additional information is needed to propose a candidate species as threatened or endangered under the ESA. A *Category 1* candidate has sufficient information to support a proposal to list as a T and E species under ESA.

The State of Oregon through ODFW maintains a state sensitive species list in order to "help prevent species from qualifying for federal listing as threatened or endangered" (Marshall et al., 1992). Sensitive species are defined as "those naturally-reproducing native animals which are likely to become threatened or endangered throughout all or any significant portion of their range." Categories used in this listing are critical, vulnerable, peripheral (naturally rare), and undetermined. A species is listed as **critical** if its listing as a T and E species is pending and if immediate conservation actions are not taken. A **vulnerable** species is one in which listing as a T and E species is not imminent and can be avoided with proper management. **Peripheral** (naturally rare) species have had historically low population numbers in Oregon. Finally, species with insufficient information on population status are tentatively listed as **undetermined** until additional information is available (Marshall et al., 1992). Most entries on the Table 3 correspond to the set of populations defined by ODFW (Table 4). For example, all 55 chum salmon populations in Oregon are treated as one entity with respect to its listing as critical on Oregon's sensitive species list.

In addition to the sensitive species listed in Table 3, petitions to list additional salmonids are currently under review by NMFS for listing under ESA. Three petitions are currently under review by NMFS: mid-Columbia summer chinook, coastal and Columbia River coho, and all coho populations from California to Washington. NMFS decisions on these petitions are to be announced by the end of 1994. A petition to list Illinois River winter steelhead populations was denied by NMFS in 1993 on the grounds that the taxa did not constitute a "species" as defined by ESA. NMFS is currently investigating whether winter steelhead populations of southern Oregon and northern California constitute a "species" which would merit protection under ESA (Busby et al., 1993).

Distribution and status of ten species and major races of Pacific salmon were summarized from Nehlsen et al. (1991), Frissell (1993), Moyle et al. (1989), Moyle (1976), and Lee et al. (1980 et seq.) and subsequently mapped using GIS (Bolle Center, 1993). These maps are included with this report (Figure 19 through Figure 27) to illustrate status and trends in salmon populations in a geographic context (through). Collapsing ranges and geographic isolation of formerly productive stocks may indicate widespread ecological

Table 3. Other species of endangered, threatened and sensitive fishes of Oregon (after ODFW, 1994). C1 species have enough information to petition for listing as endangered or threatened. C2 species have incomplete information at this time, as determined by USFWS.

Common Name	Status	
	Federal	Oregon
Bull trout		critical
Pacific lamprey		vulnerable
Goose Lake lamprey	C2	critical
Alvord chub	C2	vulnerable
Borax Lake chub	**endangered**	endangered
Catlow tui chub	C2	vulnerable
Hutton Springs tui chub	**threatened**	threatened
Goose Lake tui chub		critical
Oregon Lakes tui chub	C2	vulnerable
Sheldon tui chub	C2	critical
Summer Basin tui chub	C1	critical
Warner Basin tui chub		critical
California (Pit) Roach	C2	peripheral
Oregon chub	**endangered**	critical
Umpqua chub	C2	vulnerable
Lahontan redside shiner		peripheral
Millicoma dace		naturally rare
Foskett speckled dace	**threatened**	threatened
Goose Lake sucker	C2	critical
Jenny Creek sucker	C2	naturally rare
Klamath largescale sucker	C2	none
Tahoe sucker		peripheral
Warner sucker	**threatened**	threatened
Shortnose sucker	**endangered**	endangered
Lost River sucker	**endangered**	endangered
Malheur Mottled sculpin	C2	critical
Margined sculpin	C2	vulnerable
Pit sculpin		peripheral
Slender sculpin	C2	

problems. Further refinement of this type of GIS presentation is underway by ODFW as a requirement of this project and will further pinpoint essential habitat of remaining stocks.

Other Sensitive, Threatened, Endangered Fishes in Oregon

Forty-four percent of Oregon's native fishes are either endangered, threatened or of special concern (Williams et al., 1989; Warren & Burr, 1994) (Table 4). A major reason for this decline is that watershed catchments have deteriorated in quality because of poor landuse practices (FEMAT, 1993; McIntosh et al., 1994; Li et al., 1994; Karr & Chu, 1994; Wissmar et al., in press). Perceptive management will be required to avert the listing of these Oregon fish species under the Endangered Species Act or to constrain human activities as required by federal legislation should their populations be imperiled.

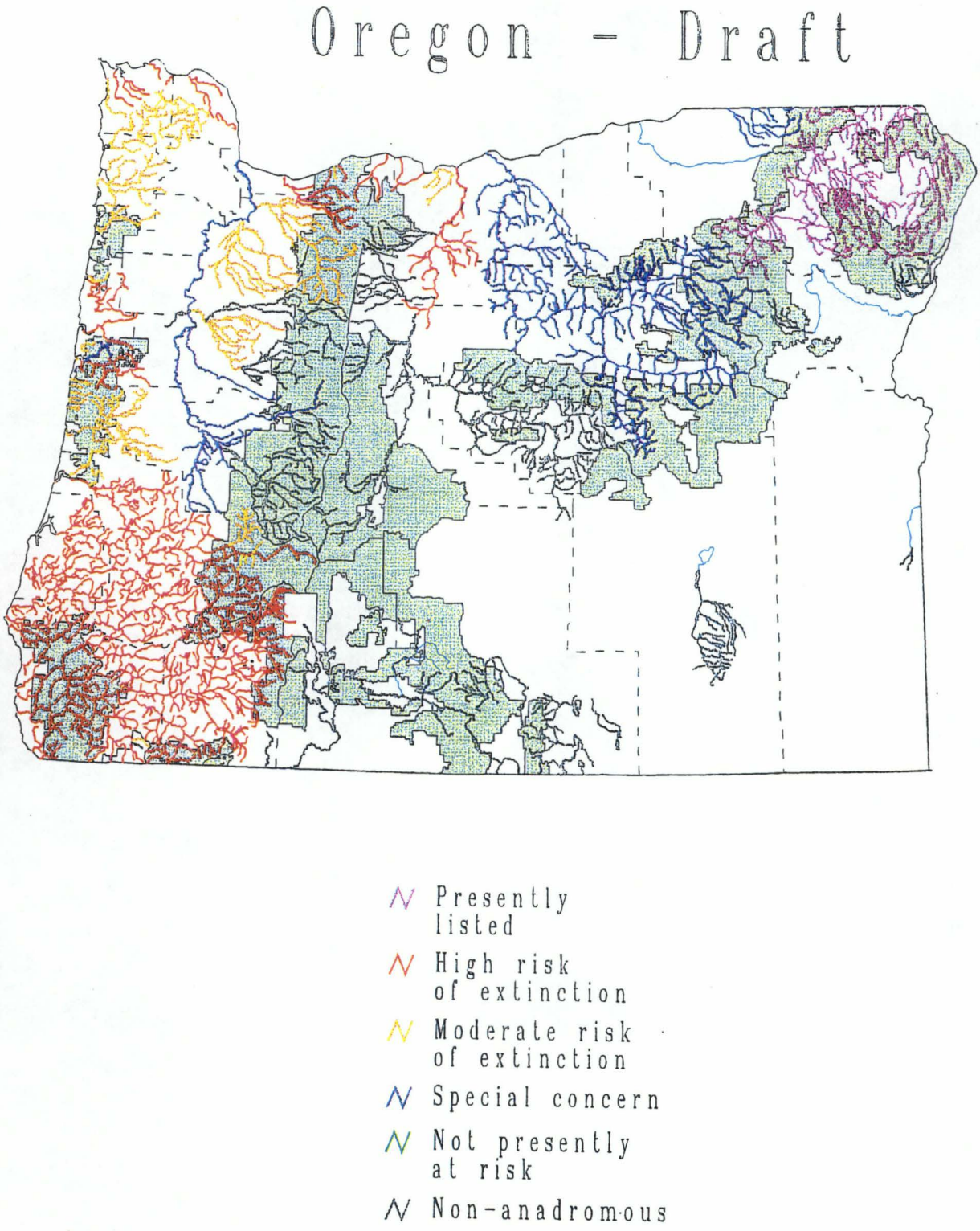


Figure 19. Distribution and status of ten species and major races of Pacific salmon in

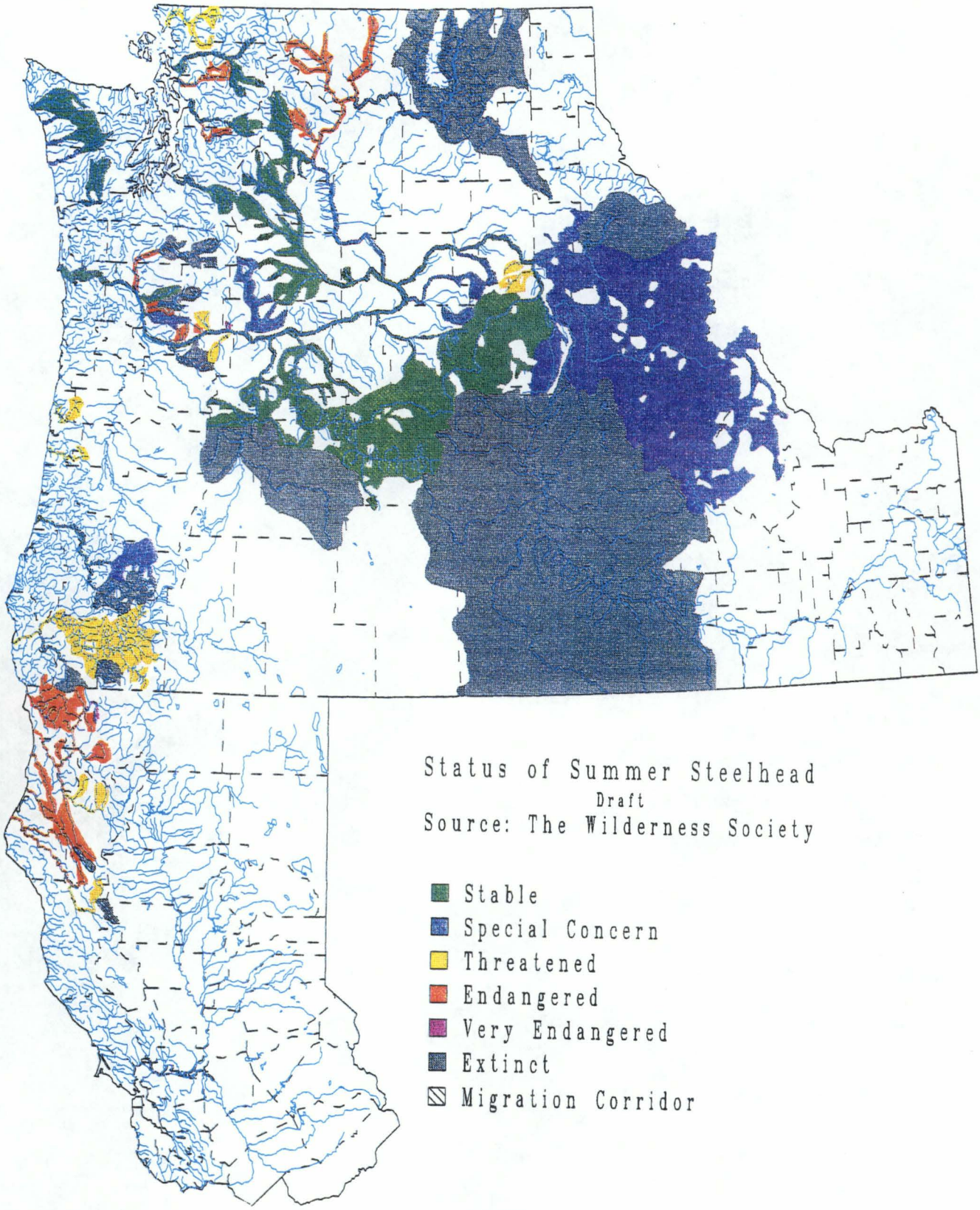


Figure 20. Status of Summer Steelhead

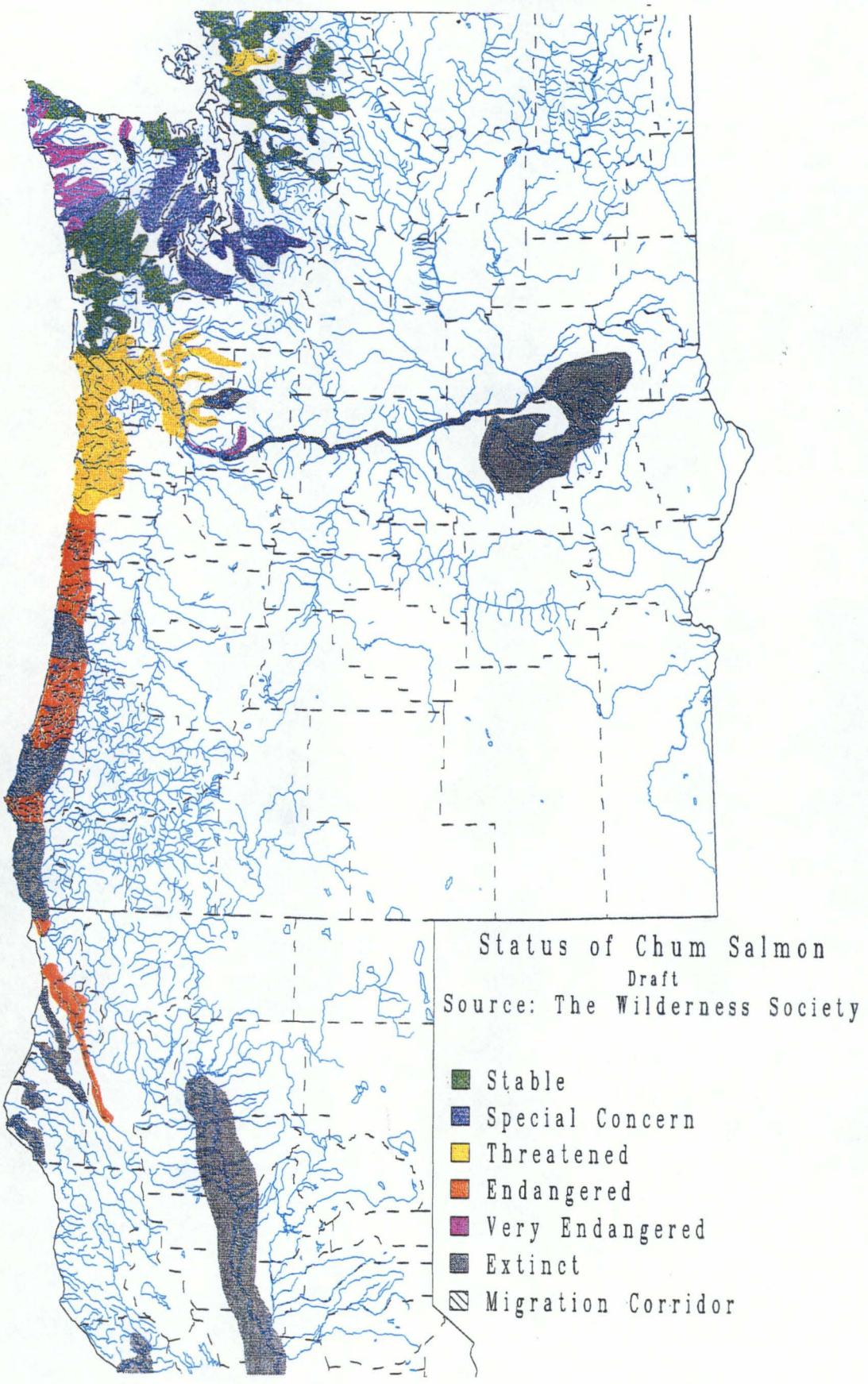


Figure 21. Status of Chum Salmon

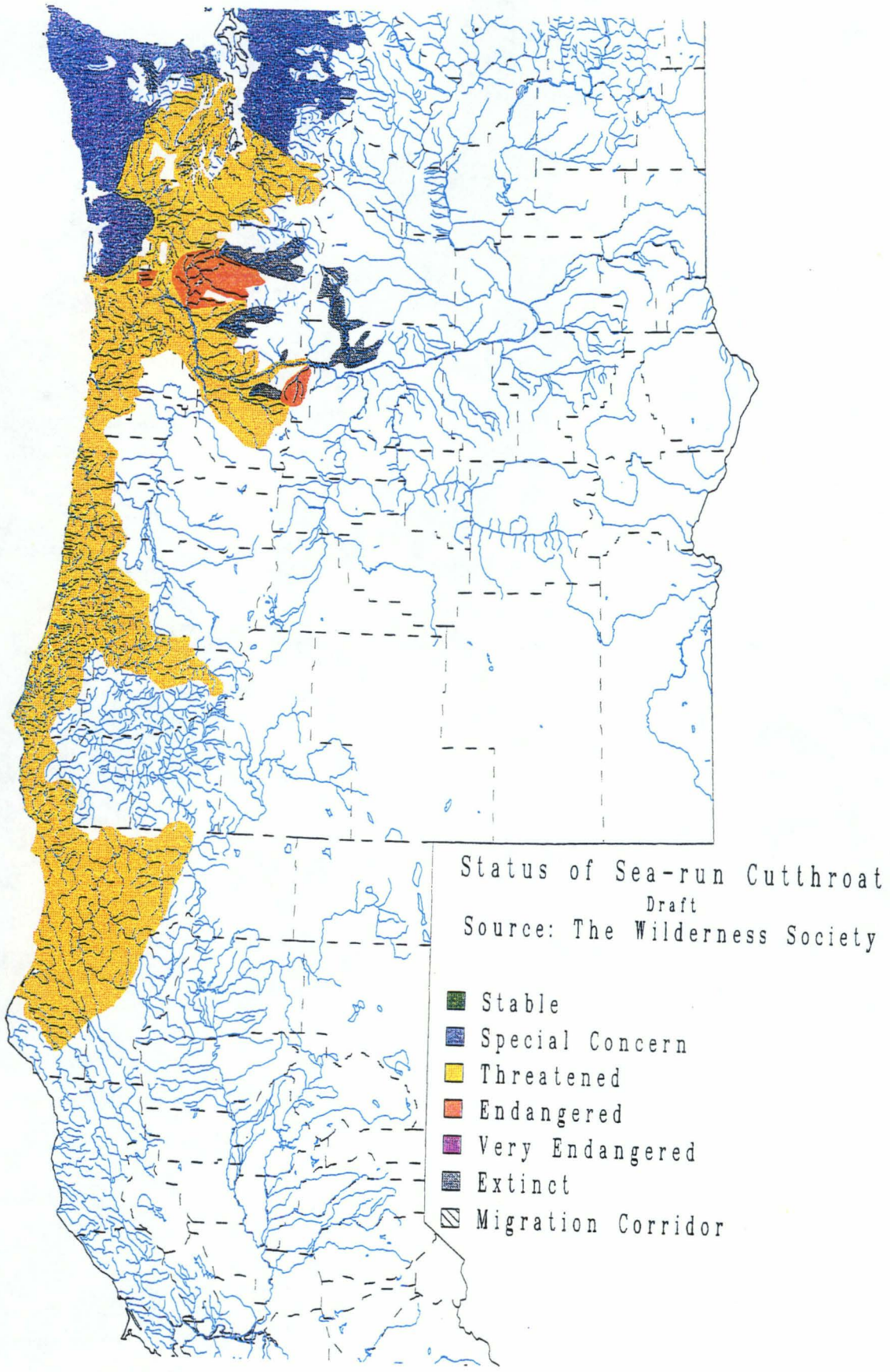


Figure 22. Status of Sea-run Cutthroat

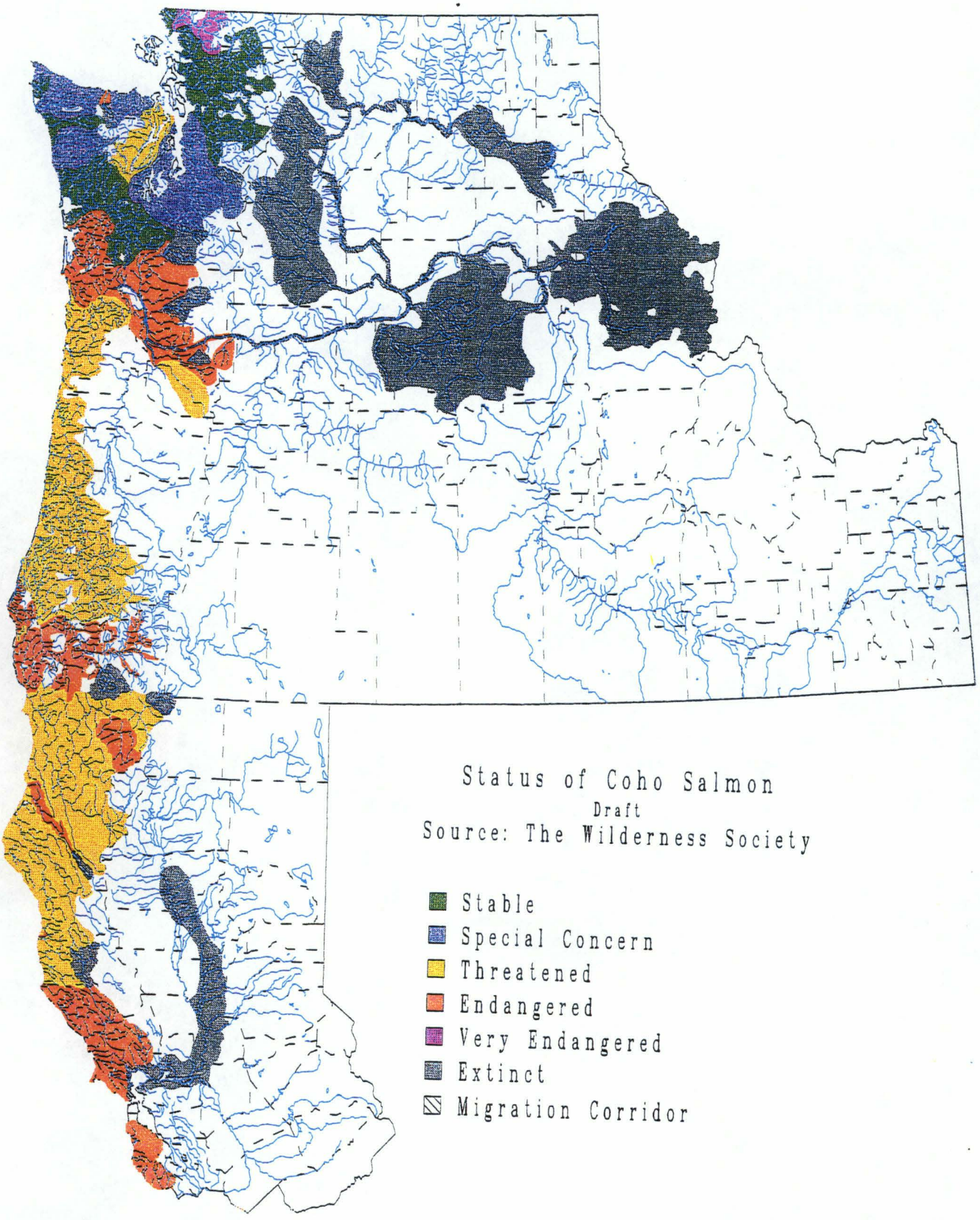


Figure 23. Status of Coho Salmon

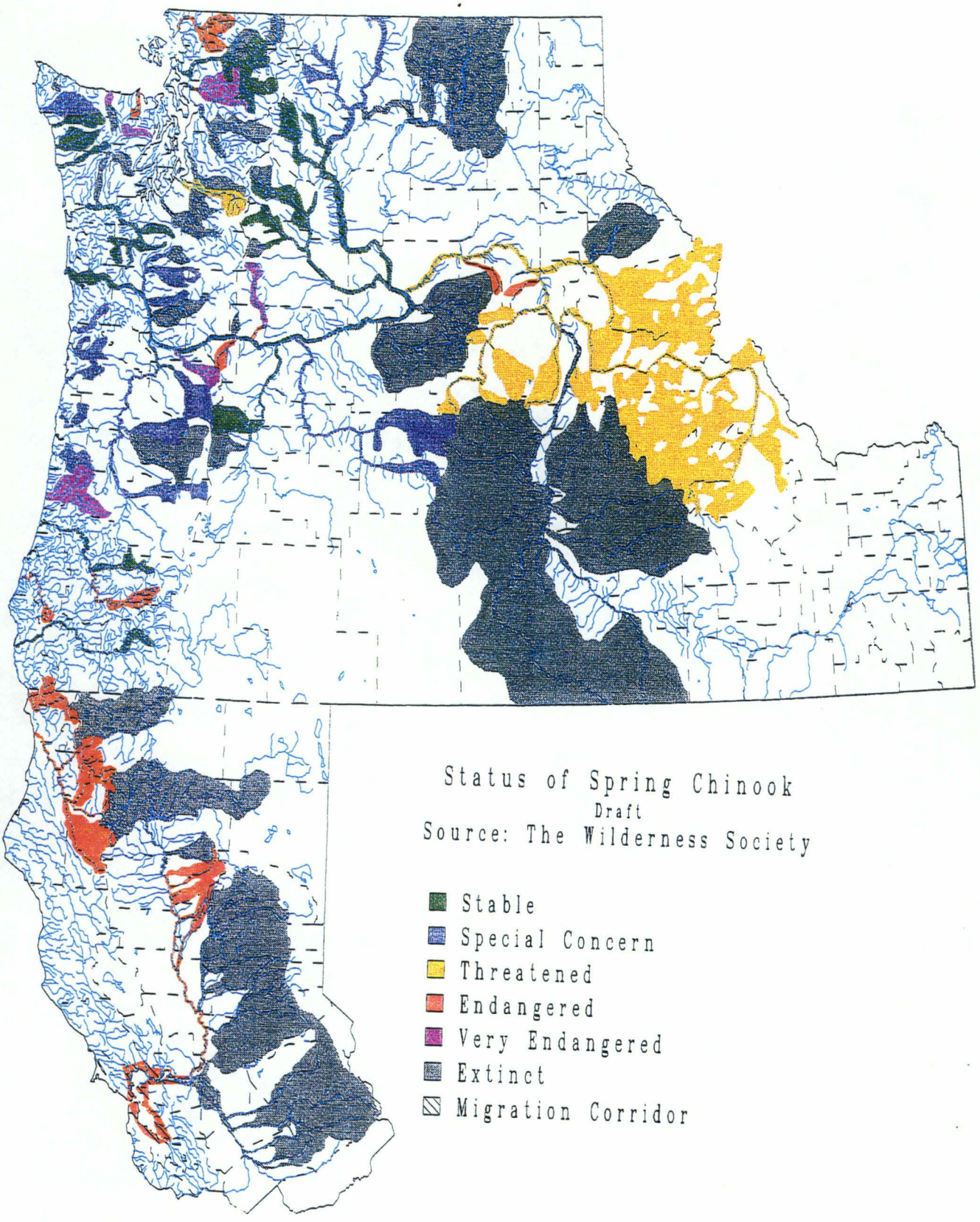


Figure 24. Status of Spring Chinook

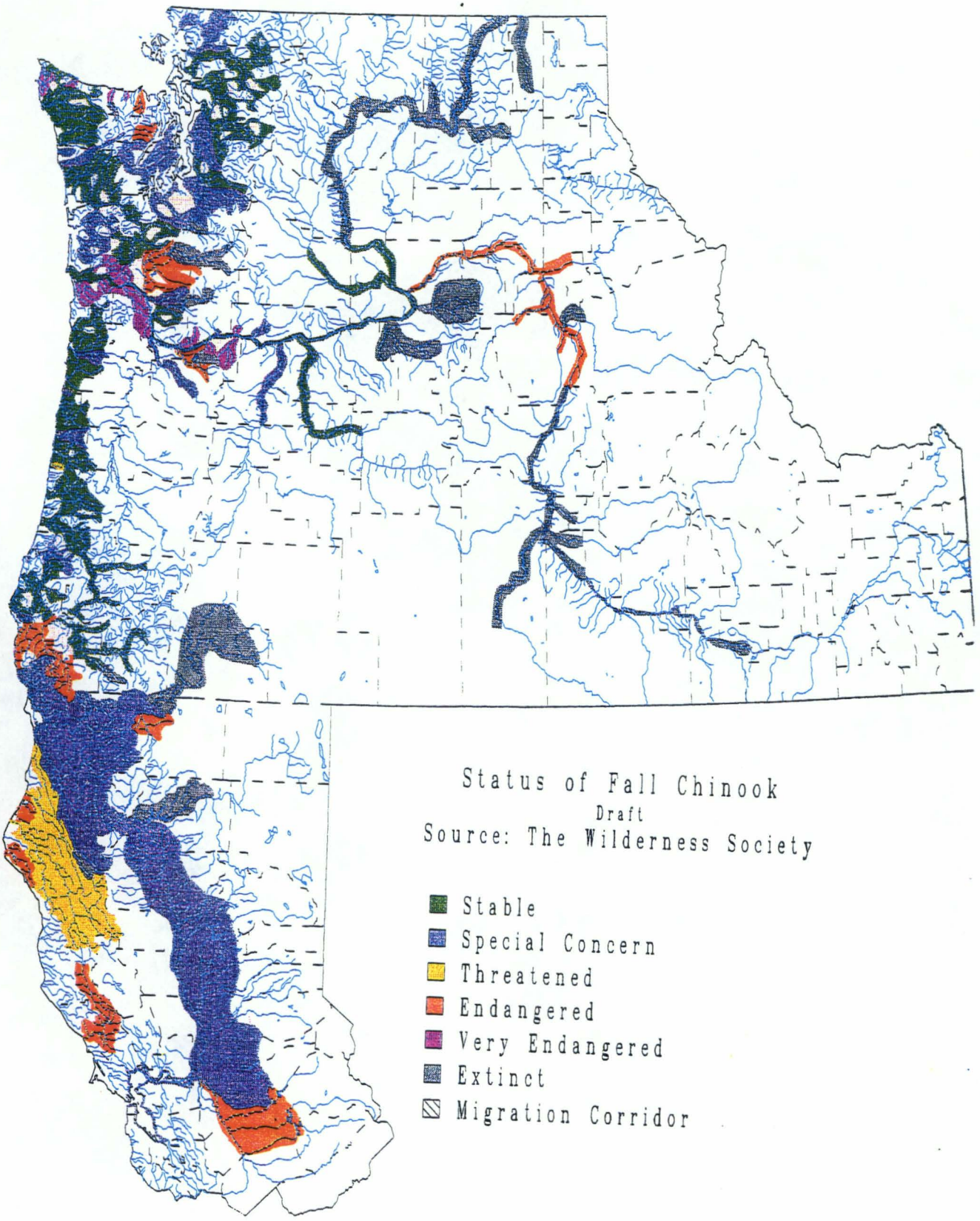


Figure 25. Status of Fall Chinook

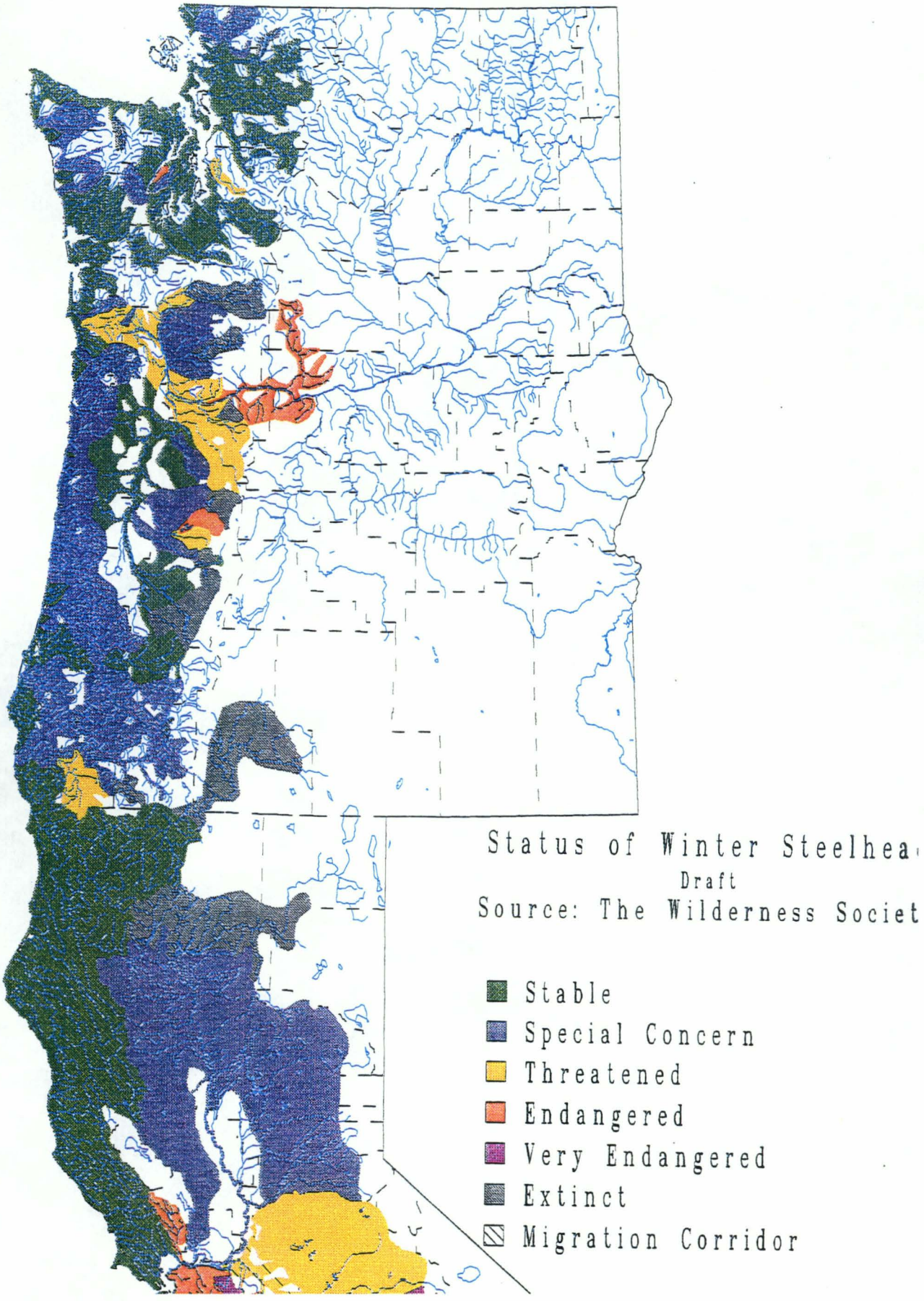


Figure 26. Status of Winter Steelhead

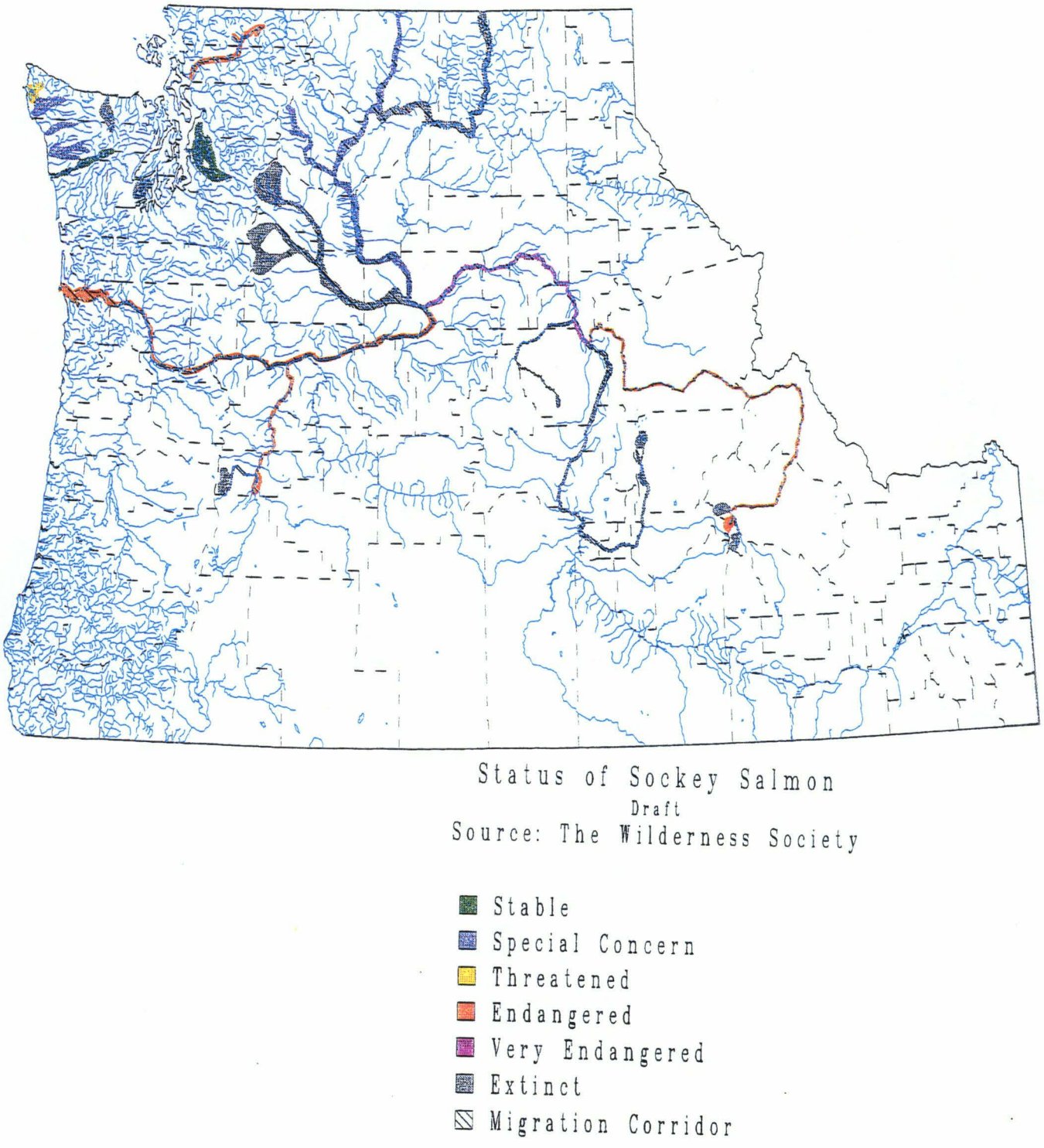


Figure 27. Status of Sockeye Salmon

Additional information on bull trout and Pacific lamprey is included with this report as these species share habitat requirements with the salmonid species discussed in this report and would be similarly impacted by watershed disturbances. Both bull trout and Pacific lamprey are on the State sensitive species list. Listing of these species as threatened or endangered at the federal level would require further adjustment of policies by state and federal land management agencies.

Bull Trout

Large bull trout are fish eaters (piscivores) and inhabit areas of dense cover (e.g., undercut banks, under large rootwads). They are usually found in slow moving pocket water associated with large undercut banks and/or large amounts of large woody debris. Juveniles inhabit spaces between large cobble and gravel. When these spaces are filled in due to silt, populations decline. Bull trout spawn in the fall in sites with substantial interstitial flow such as springs in large streams, but can also spawn in pockets of gravel in high gradient streams.

This species has proven to be very sensitive to changes in aquatic conditions brought about by land uses, especially sedimentation, altered flows, and increased temperature. They are easily overfished and are also threatened by hybridization with brook trout, an introduced species. Bull trout need cold, clear, water of the highest quality. Information suggests that bull trout may find temperatures above 14 °C as barriers to movement. Consequently, they are now restricted in many areas to headwater streams. Bull trout prefer deep pools in cold rivers but many remnant populations have been reduced to small cold headwater streams due to warming and dewatering caused by deforestation and grazing. Table 4 summarizes the current status of bull trout populations in Oregon. Bull trout populations were placed in status categories based on relative abundance, severity of factors suppressing the population, and potential to recover to a healthy condition. Populations were assumed to be extinct if none had been reported since 1980. Presence of brook trout increases the possibility of extinction. A high risk of extinction indicates very low abundance, poor habitat, high numbers of brook trout, and poor recovery potential.

Table 4. Status of Bull Trout in Oregon, from the Gearhart Bull Trout Workshop (After Ratliff and Howell, 1992). ***Criteria for placement in categories is explained in text.***

Drainage	**Tributary**	**Status** (Risk of Extinction)
Willamette	M.F. Willamette R.	High Risk
	McKenzie R.	
	S.F. McKenzie R.	Moderate Risk
	Anderson Cr.	Moderate Risk
	Trailbridge Res.	High Risk
	Carmen Res.	Probably Extinct
	Santiam R.	
	North Santiam R.	Probably Extinct
	South Santiam R.	Probably Extinct
	Clackamas R.	Probably Extinct
Hood	Middle Fork Hood R.	High Risk
	West Fork Hood R.	Probably Extinct
Klamath	Sprague R.	
	Boulder & Dixon C.	High Risk
	Deming Cr.	Moderate Risk
	Brownsworth Cr.	Moderate Risk
	Leonard Cr.	Moderate Risk
	Sycan R.	
	Long Cr.	Moderate Risk
	Coyote Cr.	High Risk
	Upper Sycan R.	Probably Extinct
	Seven Mile Cr.	Probably Extinct
	Upper Klamath Lake	
	Cherry Cr.	High Risk
	Sun Cr.	High Risk
Deschutes	Odell Lake	High Risk
	Upper Deschutes R.	Probably Extinct
	Crescent Lake	Probably Extinct
	Metolius R.	Low Risk
	Shitike Cr.	Low Risk
	Warm Springs R.	Moderate Risk
John Day	Upper John Day R.	Moderate Risk
	Middle Fork	
	Upper Middle Fork	Probably Extinct
	Granite Boulder C.	High Risk
	Big Cr.	High Risk
	North Fork	Special Concern
Umatilla	North Fork Umatilla R.	Low Risk
	South Fork Umatilla R.	Special Concern
Walla Walla	North Fork Walla Walla	Special Concern
	South Fork Walla Walla	Low Risk
	Mill Cr.	Low Risk
Malheur	North Fork Malheur R.	Special Concern
	Middle Fork Malheur R.	High Risk
Burnt River		Probably Extinct

Table 4 continued...

Drainage	**Tributary**	**Status** (Risk of Extinction)
Powder River	Upper Powder R.	
	Silver Cr.	Moderate Risk
	Little Cracker Cr.	Moderate Risk
	Lake Cr.	Moderate Risk
	North Powder R.	
	Indian & Anthony C.	Moderate
	Eagle Cr.	High Risk
Pine Creek	North Pine Cr.	
	Elk Cr.	Moderate Risk
	East Pine Cr.	Special Concern
	Meadow Cr.	Moderate Risk
	Middle Fork Pine Cr.	Special Concern
Grande Ronde	Upper Grande Ronde R.	
	Clear Cr.	Moderate Risk
	Limberjim Cr.	Moderate Risk
	Indiana Cr.	Moderate Risk
	Catherine Cr.	Special Concern
	Indian Cr.	Moderate Risk
	Lookingglass Cr.	Special Concern
	Minam R.	Low Risk
	Little Minam R.	Low Risk
Wallowa	Lostine R.	Moderate Risk
	Bear Cr.	Special Concern
	Hurricane Cr.	Special Concern
	Wallowa Lake	Probably Extinct
Wenaha		Low Risk
Imnaha	Imnaha R.	Low Risk
	Big Sheep Cr.	Special Concern
	Little Sheep Cr.	Special Concern
	McCully Cr.	Special Concern

Pacific Lamprey

The severity of the decline of Pacific lamprey (*Lampetra tridentata*) has not received much publicity. Its decline may be coastwide in nature, but appears to be particularly severe in systems with dams. Lamprey counts declined by two orders of magnitude in eight years at Rocky Reach Dam on the mid-Columbia River, and similar findings were observed at Rock Island Dam (Mullen et al., 1986). Hammond (1979) noted that lampreys appeared to be declining based upon observations noted by several observers and listed a number of possible factors that either impede or kill lampreys as they negotiate passage through dams either as upriver, migrating adults or downriver, migrating juveniles. Porter (1993) used population reconstruction and anecdotal information to conclude that the Lewiston Dam was responsible for lamprey declines in the Clearwater Basin. These were the "June Hogs" of Pacific lampreys and were substantially larger than Pacific lampreys of the lower Columbia River (Carl Bond, Oregon State University, personal communication). Lamprey counts over Winchester Dam on the Umpqua River have declined severely since 1965 (Figure 28).

Fortunately, the Willamette River still has a sizable spawning run of Pacific lamprey; however, even the health of this run is uncertain. Wydowski and Whitney (1979) reported that between 1943 and 1949, Pacific lamprey were harvested from the Willamette for rendering into fertilizer and animal meal at an annual rate of 233,179 pounds, which these authors estimated to be 10 to 20% of the total run. Assuming a weight of one pound per lamprey, the historic run in the Willamette during this period would have been between 1.1 and 2.3 million lampreys. It is unclear if the current Willamette run achieves these historic numbers.

Although the ecology of the Pacific lamprey is incompletely understood, it may be an important part of the food web of north Pacific ecosystems. The adults are a major prey item for sea lions and seals (Bruce Mate, personal communication, 1994) and the carcasses and juvenile stages are important prey for white sturgeon in the Snake River (Ken Witty, personal communication; Wydowski & Whitney, 1979). Lamprey are valuable cultural food resources for Native Americans of the Pacific Northwest and commercial resources with growth potential as biomedical and food export commodities.

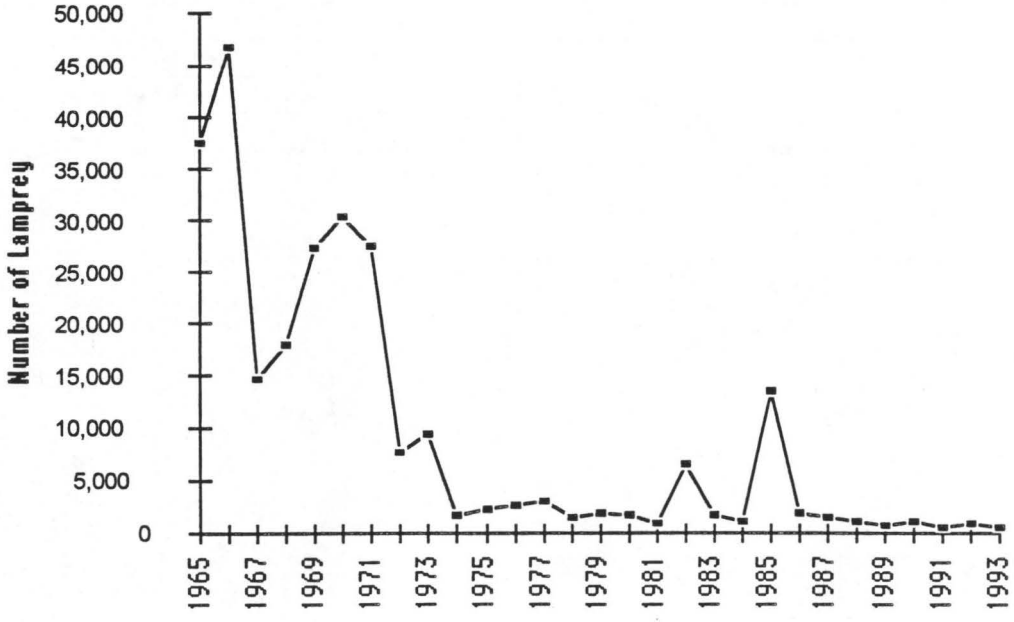


Figure 28. Pacific Lamprey Counts at Winchester Dam on the North Umpqua River, 1965 to 1993 (after PacifiCorp, 1994).

Other Sensitive Vertebrates, Dependent Upon Aquatic Habitat

Many other vertebrates besides fish depend upon bodies of water for their survival. Some must lay their eggs in water, others catch fish or other aquatic organisms for sustenance, and some depend upon edge habitat near streams, rivers, or lakes. Populations of several of these species have declined precipitously in recent years with the result that these aquatic-dependent species have been identified as sensitive species by ODFW (Table 5).

Table 5. List of sensitive vertebrate species (non-fishes) related to watersheds in Oregon (Marshall et al., 1992). Status categories are explained in text.

Sensitive Herptile Species	Status	Reason for sensitive status
Cascade frog *Rana cascadae*	critical	Decline in frogs of this genus world-wide; strong evidence this species is also declining for unknown reasons.
Cope's Giant Salamander *Dicamptodon copei*	critical	Restricted distribution, potential for habitat destruction from logging that would change water temperatures.
Foothill Yellow Legged Frog *Rana boylii*	sensitive	Impoundment of rivers has destroyed some habitat, but the unexplained decline of frogs world-wide, including Oregon, constitutes the reason for sensitive status.
Northern Leopard Frog *Rana pipiens*	vulnerable	Rarity and local distribution if present at all. This species may be suffering the same decline as other frogs on a world-wide basis.
Olympic Salamander *Rhyacotriton olympicus*	vulnerable	Sedimentation from logging upstream may have impacted species. Habitats are not currently protected.
Painted Turtle *Chrysemys picta*	critical	Habitat destruction through drainage, water diversions, grazing, introduction of exotic fishes, and other factors that have caused a decline in quality and quantity of wetlands.
Red-legged Frog *Rana aurora*	sensitive	Possible displacement by the introduced bullfrog and pesticide and herbicide runoff.
Spotted Frog *Rana pretiosa*	critical	Extirpation from much of former range; coincides with introduction of bullfrogs.
Tailed Frog *Ascaphus truei*	vulnerable	Logged or disturbed areas. Presumably because logging causes a drop in humidity and raises temperatures in and near streams. Susceptibility to environmental changes including siltation.
Western Pond Turtle *Clemmys marmorata*	critical	Habitat alteration; plowing to edges of ponds leading to destruction of nests.
American White Pelican *Pelecanus erythrorhynchos*	vulnerable	Shortage of suitable, stable breeding areas in terms of nesting space availability and security.
Bank Swallow *Riparia riparia*	sensitive	Susceptibility to sand mining and construction operations.
Barrow's Goldeneye *Bucephala islandica*	peripheral or naturally rare	Low population numbers combined with reliance on cavities for nesting.
Bufflehead *Bucephala albeola*	peripheral or naturally rare	Low population numbers and shortage of natural cavities caused by forestry practices.

Table 5 continued...

Sensitive Bird Species	Status	Reason for Sensitive Status
Dusky Canada Goose *Branta canadensis occidentalis*	vulnerable	Low population numbers, poor recruitment, and higher than desirable hunting mortality.
Greater Sandhill Crane *Grus canadensis tabida*	vulnerable	Sensitive to human disturbances and land use practices; lowering of water levels to allow mowing of hay.
Harlequin Duck *Histrionicus histrionicus*	peripheral or naturally rare	Low population numbers.
Horned Grebe *Podiceps auritus*	peripheral or naturally rare	Extremely limited population and unstable habitat at Downey Lake including uncertain water supply.
Least Bittern *Ixobrychus exili*	peripheral or naturally rare	Low population numbers in limited habitat in only two areas.
Purple Martin *Progne subis*	critical	Limited population numbers combined with scarcity of nesting sights; habitat eliminated by fire control and salvage logging.
Red Necked Grebe *Podiceps grisegena*	critical	Extremely limited population numbers. Especially susceptible to low reproduction from pesticides, particularly PCBs.
Snowy Egret *Egretta thula*	vulnerable	Low and fluctuating population numbers, related in part to the periodic absence of water in some nesting areas.
Tricolored Blackbird *Agelaius tricolor*	peripheral or naturally rare	Small population numbers combined with inconsistent distribution pattern makes habitat protection difficult.
Sensitive Mammals	**Status**	**Reason for Sensitive Status**
White-Footed Vole *Phenacomys albipes*	peripheral or naturally rare	General rarity.

Habitat Requirements of Salmonids

Energy Pathways in Streams:
The Stream Food Web

The stream food web upon which salmonids depend derives energy almost exclusively from two sources:

1. Plants (algae and rooted aquatic plants) that convert solar radiation into organic biomass.

2. Leafy and woody litter that fall into the stream and provide the energy base for microbial fungi and bacteria.

Herbivorous invertebrates and fish utilize algae, and detritivorous invertebrates (shredders) consume decomposing leaves and litter. The invertebrates are the food base for many fish, particularly young salmonids and adult trout, that feed on drifting organisms. Many adult salmonids prey upon other fish. Because of these interconnections, alterations in the physical environment or on any of the biota profoundly affect upper levels of the chain such as salmonids.

The amount of food available in the food web helps to set the carrying capacity (i.e., the number of organisms that can be sustained in a habitat at a given time). Human activities that affect production, including either algal or macroinvertebrate production, will alter the production of fish. Salmon are primarily drift feeders. The dominant salmon will assume the favored position at the head of the pool to access the most efficient feeding location (Figure 29). Smaller, less aggressive fish will assume less desirable positions in other parts of the pool, under logs, behind boulders, or around the edges. Riffles are the aquatic equivalent of kitchens for salmonids, with favorable conditions of highly dissolved oxygen, ability to trap organic debris, high algal productivity, and invertebrate morsels which will drift to the waiting salmon. To maximize these functions, riffles must be low in silt. Pools are the equivalent of dining rooms, where the fish can dine on food coming to them from the upstream riffle. Both habitats are important to healthy fish populations.

Food webs often reflect amazingly complex interrelationships (Figure 30). A full understanding of these relationships requires intensive study. When one component of a complex food web is disrupted, impacts may be felt at points near and far from the origin of disturbance.

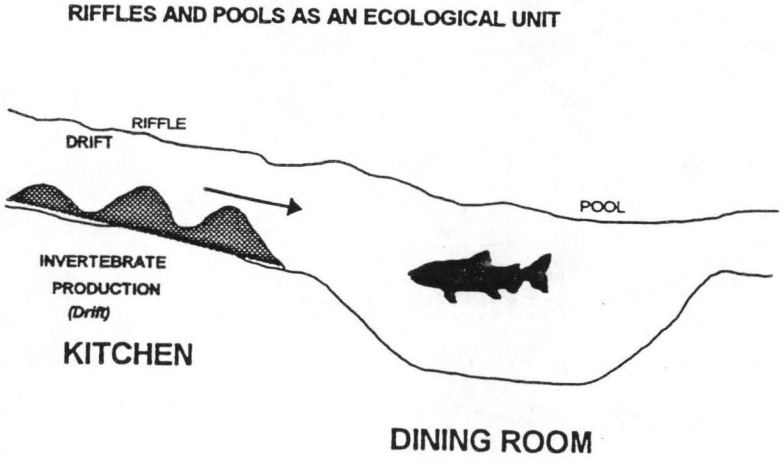


Figure 29. Riffles and pools function as the kitchen and dining room for salmonids.

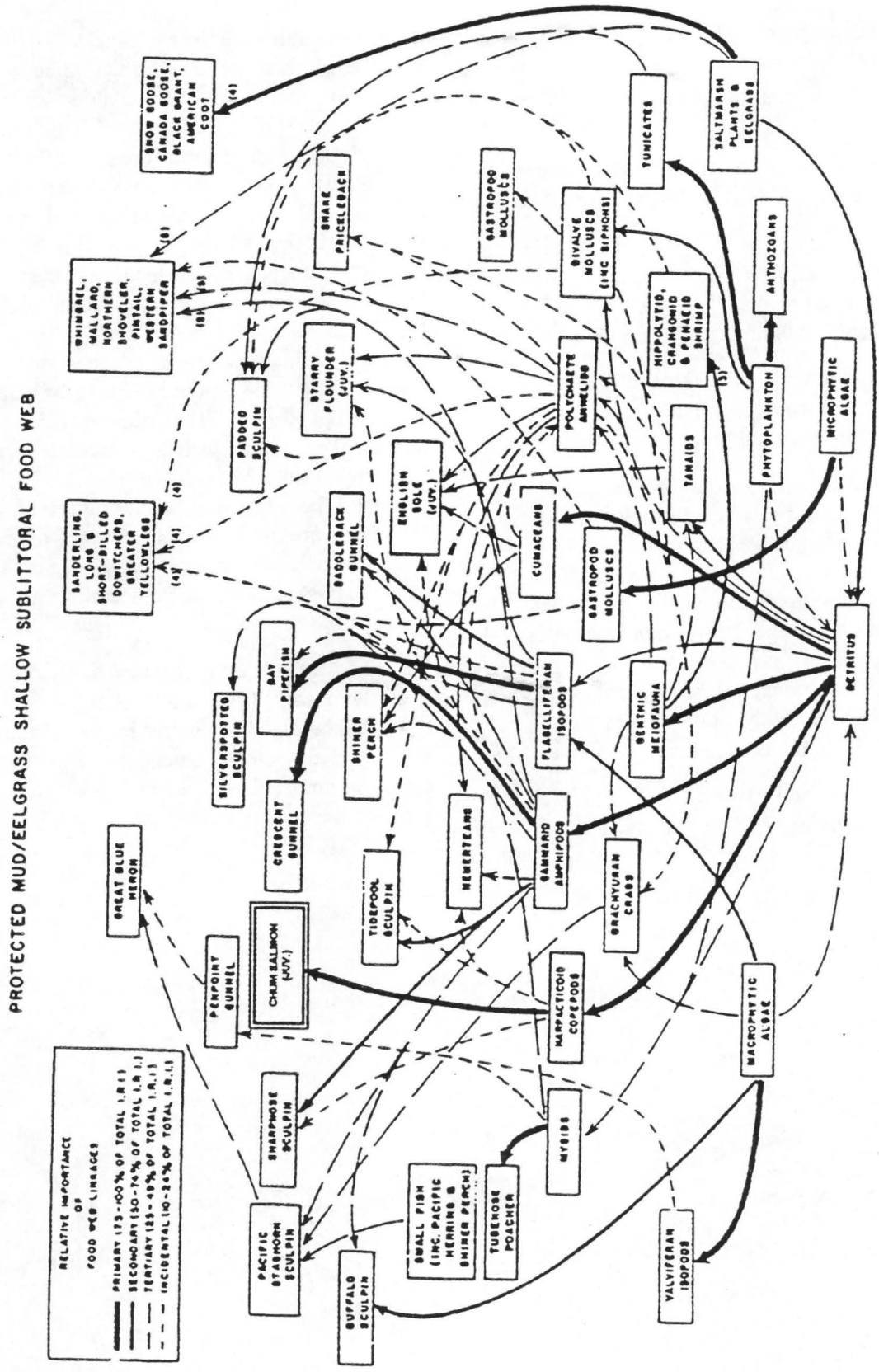


Figure 30. An example of a specific estuarine food web showing the complexity of interactions and the relative place of chum salmon, shown in the upper left quadrant of web (after Simenstad et al., 1979 as edited by Phillips, 1984).

Information in this section is summarized from a highly recommended reference:

Bjornn, T. C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams, p. 83-138. *In* W.R. Meehan [ed.] Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society Special Publication 19. Bethesda, Maryland.

Generalized Salmonid Life Cycle

Adult salmon return to their natal stream to spawn and, for most species, rear. They are able to locate their natal stream using homing mechanisms. The female makes a nest ("redd") in the stream gravel and deposits eggs which are simultaneously fertilized by the male and then covered over with gravel by the female. The fertile eggs develop in the nest until they hatch to form alevins, immature fish that remain in the gravel and complete development (Figure 31). Fry emerge from the gravel and rear in fresh water from days to years, depending on the species. The fry then undergo a physiological conversion ("smoltification"), which allows them to live in salt water. Smolts migrate to the ocean to feed and grow. Adults return to their natal stream to spawn, and the cycle is complete (Figure 32). Many variations of this general plan exist due to the immense environmental variability acting over many thousands of years on salmon populations (Figure 33). Some members of the Salmoninae subfamily have adapted nonanadromous life cycles and spend their entire life cycle in freshwater.

Upstream Migration of Adults

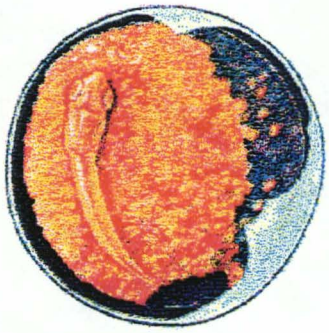
The survival of salmon and trout depends upon arrival of adults at spawning areas at the proper time and with the capacity to spawn. Salmonids have evolved over millions of years to natural variations that faced them as they made the journey from sea to natal stream. Stream conditions known to influence upstream migration include: water depth and velocity, turbidity, dissolved oxygen, and temperature (Everest et al., 1985).

If water temperatures are too warm or too cold salmon will tend to delay or stop migration. Human actions have altered natural stream temperatures by removal of streambank vegetation, withdrawal and return of agricultural water, deepwater release of cold water from reservoirs, and use of water to cool nuclear power plants. Besides altering the timing of migration, these changes in water temperature may increase the incidence of diseases and either accelerate or delay maturation.

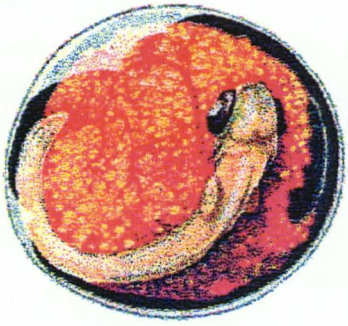
As water temperature increases, it will hold less dissolved oxygen. A decrease in the amount of oxygen dissolved in the water will decrease the sustained swimming speed of the migrating salmon, may cause an avoidance of the area, or halt migration. Other factors that decrease dissolved oxygen include high rates of decomposition, stagnant water, or high levels of organic material in the water.

Turbidity may cause salmon to avoid the turbid water or cease migration. Moderate amounts of turbidity (within the range of natural conditions) may actually enhance migration by providing cover.

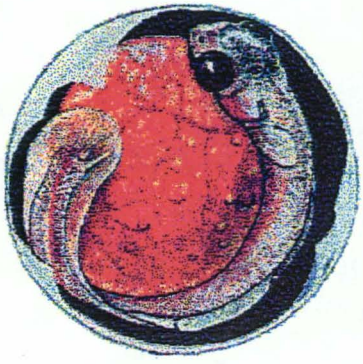
Physical barriers in the stream or river can halt salmon migration. Salmon have well-documented leaping abilities and larger species can clear barriers two to three meters in height. Sufficient streamflow is necessary to allow passage. Spring chinook and winter steelhead were able to pass Willamette Falls at high water using their strong swimming abilities. Successful passage also depends on the size of rocks and the length of stream reach being negotiated.



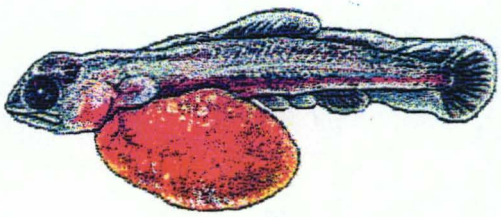
6 days



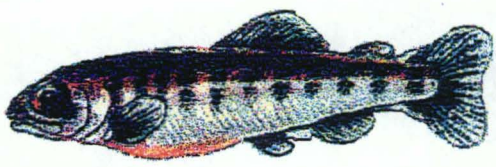
14 days



22 days (a day before hatching)



23 days (newly hatched)



39 days (yolk sac almost absorbed)

Figure 31. Trout as an example of egg incubation and development (Stolz & Schnell, 1991). Eggs and sperm are deposited in the prepared egg pockets of the redd and then covered with gravel by the female. Within hours after fertilization is complete, the cell begins to divide. Spaces in the gravel allows water to flow through, replenishing needed oxygen and carrying away waste. Eyes become pigmented. The yolk sac provides nourishment during incubation, for several weeks after hatching. About half way through incubation the embryo breaks through the membrane and becomes a larval fish, an alevin. The alevin has limited mobility and remains in the gravel to complete development, living off the food stored in the diminishing yolk sac until it emerges from the gravel.

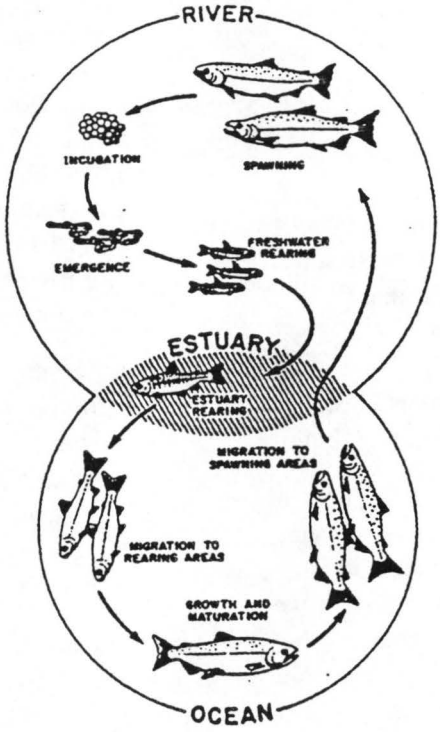


Figure 32. Generalized salmonid life cycle, showing ocean and freshwater components (Nicholas & Hankin, 1988).

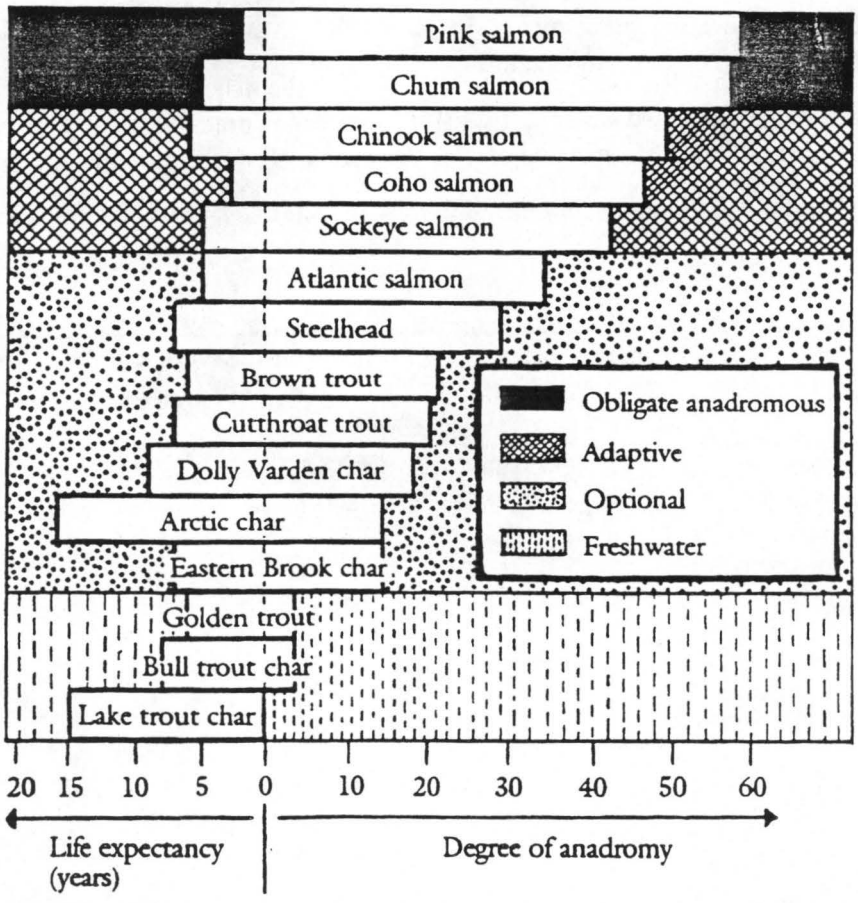


Figure 33. Life expectancy and degree of anadromy of various salmonids(G.B. Pauley in Stolz & Schnell, 1991).

Spawning

Once migrating adults have reached their destination, successful spawning depends upon another series of factors: the number of spawners using a given area, substrate composition (spawning gravels), cover, and water quality and quantity. Streamflows need to be deep enough to cover the gravel without being so deep that the velocity gets too high to maintain the redd structure. In general, water depth must be sufficient to cover the fish during spawning and the velocity of water should be 20–100 cm/s (Table 6).

Different species of salmon spawn in different areas of the watershed, some higher in the system, and some lower in the system. Pink and chum salmon tend to spawn lowest in the basin and have been known to spawn in the intertidal zone. Chinook spawn in larger streams and rivers, while coho prefer coastal rivers and tributaries. Cutthroat and bull trout are found highest in the system, closer to the headwaters. Distribution of salmonid species in the basin tends to coincide with the degree of anadromy seen in the previous figure. Salmon species usually die after spawning, and trout have been known to survive and spawn again.

Each stock has a unique time and water temperature for spawning to maximize survival of the offspring. The basic survival strategy for fall spawners is to spawn early enough that the embryos have time to reach a critical stage before the water temperatures get too cold. The fry will complete development and emerge in the spring. The survival strategy for spring spawners is to spawn early enough for fry to emerge and grow before winter, but not so late that water temperatures are too high.

The size and condition of the spawning substrate (gravel) is critical to successful spawning and maintenance of redd function during incubation. The size of substrate needed varies by fish size with larger fish using larger gravel size. Substrate size ranges from 1.3-10.2 centimeters in diameter for salmon and trout (Table 6).

Cover over the spawning area protects spawners from disturbance and predation and provides shade. This protection is especially important because spawners may hold for a period of time before spawning. Cover is provided by undercut banks, vegetation, wood, rocks, deep water and turbulence.

The space needed by each spawner depends upon the fish size and behavior and the quality of spawning area. Generally, large fish make large redds. The size of redds varies from about 0.6.m^2

Table 6. Physical habitat requirements for spawning salmonids (after Bjornn & Reiser, 1991; Heard, 1991; & Pratt, 1992).

Species	Depth (cm)	Velocity (cm/s)	Substrate size (cm)	Average redd area (m^2)	Area needed per spawning pair (m^2)
Fall chinook salmon	>24	30-91	1.3-10.2	5.1	20.1
Spring chinook	>24	30-91	1.3-10.2	3.3	13.4
Summer chinook	>30	32-109	1.3-10.2	5.1-9.4	20.1
Chum salmon	>18	46-101	1.3-10.2	2.3	9.2
Coho salmon	>18	30-91	1.3-10.2	2.8	11.7
Pink salmon	20-25, <150	30-100	gravel to cobble	1.1	1.5-2.0
Sockeye salmon	>15	21-101	1.3-10.2	1.8	6.7
Steelhead	>24	40-91	0.6-10.2	4.4-5.4	
Rainbow trout	>18	48-91	0.6- 5.2	0.2	
Cutthroat trout	>6	11.0-72	0.6-10.2	0.09-0.9	
Bull trout	20-80	20-60	gravel to cobble		

to 10 m^2. The depth at which eggs are deposited depends upon the size of fish and the size of the streambed material. For example, chinook have been known to lay eggs 43 cm below the stream surface, though the average for chinook is 20-30 cm. Many species of salmon prefer to construct redds at the pool-riffle interface where flow accelerates, gravel is looser and relatively free of fine particles, and currents carry water down through the gravel (Figure 34).

When spawning habitat is limited, a female will dislodge previously laid eggs from another female in order to dig a redd for her own eggs. A limited supply of suitable gravel restricts the area available for spawning and leads to more competition for existing space, limited numbers of successfully constructed redds, and reduction in salmon production.

Incubation

The spawning site (redd) is the incubation area for the developing salmon eggs. Maintenance of flow and gravel conditions is critical for successful incubation of the eggs. Under natural conditions undisturbed redds will produce egg hatching rates up to 97% for chinook (Vronskiy, 1972). Temperatures within the gravel at the level of the eggs fluctuate less than stream temperature and protect the developing eggs from the full range of daily temperature fluctuation (Crisp, 1990). The water that flows through the redd carries oxygen to the developing embryos and carries wastes away.

Stream conditions may develop that interfere with the proper functioning of the redd. Fine sediment tends to settle in the gravel of the redd, even in fast-moving streams, because the water velocities are lower within gravels. If too much

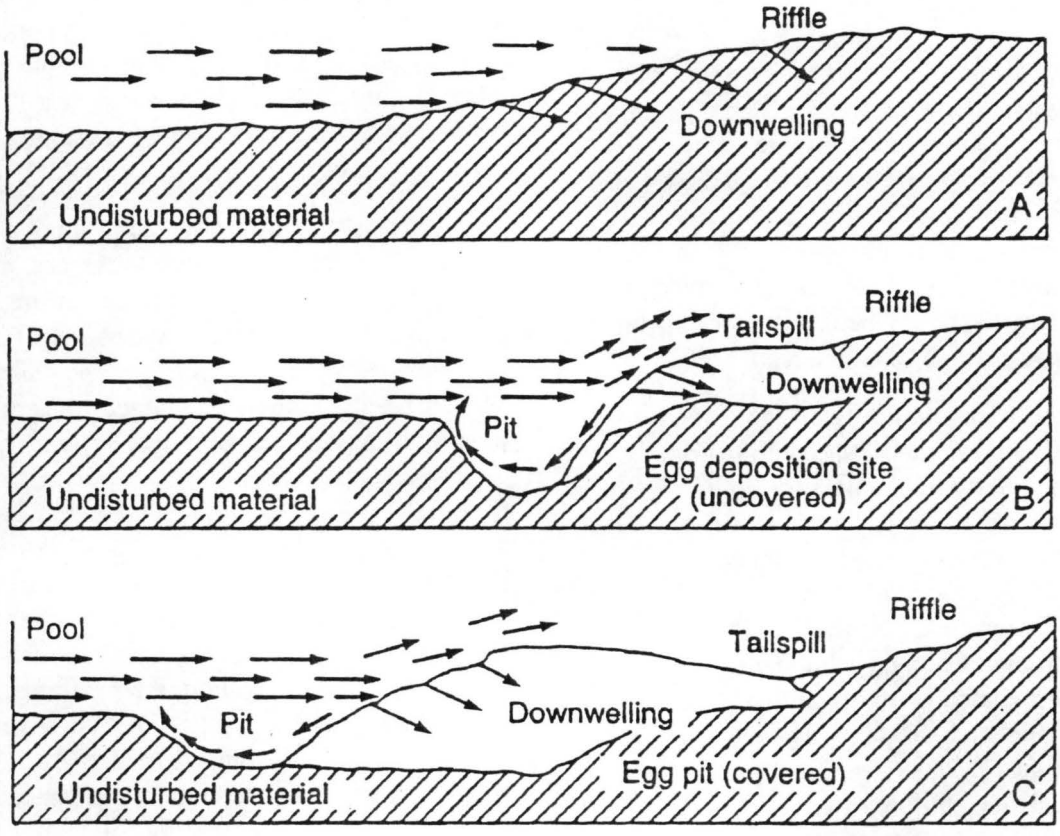


Figure 34. Construction of redd. A: Selection of site at pool-riffle interface allows for percolation of water through gravel. B: Nest is excavated, increasing flow rate through gravel and creating back eddy in pit. C: Eggs are covered with gravel, creating a second pit and enhancing water flow to eggs. (Reiser & Wesche, 1977).

fine sediment is deposited over the redd, crucial spaces between substrate particles will be plugged and survival of eggs can be dramatically reduced (Figure 34). Too many fines in the gravel (30 to 40% by volume) can slow water flow through the redd, reducing dissolved oxygen concentrations and interfering with removal of metabolic wastes from the eggs. Even if sedimentation is not enough to cause a direct increase in egg mortality, the embryonic development can be severely affected, resulting in high mortality.

Lower dissolved oxygen levels may cause smaller size, weaker or defective fry and may alter the time of hatching. In addition to increased sedimentation, dissolved oxygen levels may be lowered by increases in water temperature, decreases in water flow through the redd, and increases in organic matter within the redd. The decay of this organic matter increases the biological oxygen demand, such that less oxygen in available to developing embryos.

Redds can also be disturbed by later spawning fish, floods, and mechanical disruption or compaction from gravel mining, bridge construction, etc. If gravels are unstable, peak flows will cause the gravel to shift, killing the embryos within the redd or flushing them downstream. Streamflow should allow the redds to be covered during the entire incubation period with adequate flow velocity through the redd.

Higher water temperatures during incubation (within the range of tolerance) speed up the rate of development and decrease the time for both incubation and emergence (Alderdice & Velsen, 1978). The specific effect of higher temperatures varies by species and location. If temperatures are too cold after fertilization (less than 2-3 °C) mortalities increase. Chinook salmon were found to have a 50% prehatch mortality at these low temperatures. Prehatch mortality was also 50% at high temperatures (16 °C). Length of time for 50% hatching at these temperature extremes was 159 days (low °C) and 32 days (high °C), respectively.

Emergence from the Gravel

In the alevin stage, young salmonids remain in the gravel and obtain nutrition by absorbing their attached egg sac. After hatching the alevins move downward through the gravel. Dill (1969) reported a downward migration by coho as much as 20 cm from point of hatching. When the egg sac is almost completely absorbed, the alevins make their way to the surface of the gravel and emerge into the water column. Alevins can be trapped in the gravel by fine sediment that has accumulated in intergravel spaces.

Rearing in Fresh Water

After fry emerge from the redd, they must survive in their new environment and compete with other fish for food and hiding places. The social hierarchy (i.e., fish equivalent of pecking order) among salmonids affects where the fish choose to live within the stream, with coho being the most aggressive, then steelhead trout, cutthroat trout, and chinook salmon (Li et al., 1987). Salmon spawn in limited areas but juveniles are not restricted to these areas and will disperse to suitable, accessible areas to rear. For a given level of spawners in a stream, the resulting population of fish depends upon availability of suitable habitat, water quality, cover, stream productivity, macroinvertebrate food base, temperature, seasonal variability, predation, and competition.

Temperature influences the metabolic rate of fish, their behavior, resistance to disease, mortality rate, and interactions with other organisms. High water temperatures decrease the ability of oxygen to dissolve in water. Growth rate and ability to convert food efficiently are limited when dissolved oxygen decreases (below 5 mg/L). Swimming performance is hindered below air-saturation levels (8-9 mg/L at 20 °C). Optimal temperatures for most salmonids are between 8–15 °C. Most salmonids are placed at risk in temperatures above 23-25 °C and will try to avoid warm water by using different areas of the stream during different parts of the year. The lower limit of temperature tolerance is near freezing (0 °C). When water temperatures are low (approximately 4-6 °C; winter conditions) small fish tend to hide in spaces among rocks, and large fish may school and move to more suitable winter habitat, in essence migrating within the stream system on an annual basis. Preferred winter habitats are areas of low flow and plentiful cover (i.e., undercut banks, root wads, debris piles of large wood, cobbles, boulders). Human actions (decreased riparian vegetation, water diversions, dams, power plants) have altered temperature

patterns and reduced overwintering habitat with many possible adverse repercussions for fish populations.

Substrate conditions are important to rearing fish because of the use of substrate by aquatic invertebrates and the cover provided by larger substrate. The ability of an area to support fish declines when the spaces within the substrate are filled with fine materials. Pool depth and number may be reduced by sedimentation or channel changes, resulting in less space for fish, and lower survival rates for overwintering juveniles. Sedimentation often decreases available substrate for producing aquatic insect populations or changes their community composition.

Newly emerged fry are more susceptible to moderate turbidity than older juveniles are. Rearing fish can tolerate occasional episodes of turbid water (e.g., following storms or snowmelt). Short-term exposure to turbid water may affect feeding and territorial behavior. Fish avoid highly turbid water, as found in areas with severe erosion. A review of the effects of fine sediment on fish by Everest et al. (1987) found complex effects that varied, depending upon species of fish, time in freshwater, spawning escapement, competition, available spawning and rearing habitat, channel gradient and morphology, sequence of flow events, basin lithology, and history of land use.

The quality of habitat used by rearing salmon is a factor of water depth, quality, and velocity, plus available cover. Increased habitat complexity usually results in higher carrying capacity. Edge habitat is used extensively by juveniles for protection from high flow velocity and predators. Juveniles also use side channels for rearing and these side channels can be especially important refuge areas during high flow events. The space needed by an individual fish depends upon food abundance, competitors and predators, and increases with the age and size of the fish.

Riparian vegetation provides shade and cover for rearing fish and food for bacteria, fungi and macroinvertebrates. Rooted streamside vegetation stabilizes the channel and decreases the impact of over-bank flows by dissipating the energy. Large riparian conifers provide important stream structural elements when they fall into the active channel.

A decrease in streamflow will decrease the space available for fish. Coastal Oregon streams tend to have high streamflow in winter due to winter storms, while inland streams have some high flow from winter storms, plus high flow in spring due to snowmelt. During high flows, much of the available habitat is not suitable for fish because the velocities are high and substrate and debris are mobilized and may scour the channel. Flows are usually lowest in late summer, fall, and early winter. Dams change this flow pattern and may, in turn, change the carrying capacity of the system during different seasons of the year. Water velocity requirements for rearing fish vary by species, size, and season. Fry tend to prefer water velocities less than 10 cm/s and larger fish (4-18 centimeters long) are found in water velocities up to 40 cm/s. Fish in faster water will be rewarded by better feeding conditions as more invertebrates will drift to them in higher water velocity. Depth of water is probably less important than suitable water velocity, food, and security from predators.

Cover is correlated with fish abundance and is provided by water depth, turbulence, large substrates, overhanging or undercut banks, riparian vegetation, wood, brush, and aquatic vegetation. Use of cover by a particular fish depends upon competitive interactions with other fish.

Seaward Smolt Migration

Seaward migration commonly occurs in spring when high discharge provides adequate flow and water quality, although timing and age at migration vary with species (Figure 35). Smolts depend upon down-river currents to find their way to their destination. Dams have changed conditions, making it harder for migrating fish to find their way within the necessary time period. Smolts may not develop completely from parr to smolt if the temperature is higher and the flow slower than natural conditions, both conditions encountered in reservoirs behind dams. Supersaturation of gases passing over the dams can cause physiological problems and smolt mortality, in addition to direct injuries and mortalities inflicted upon smolts from dam turbines. During this transition from freshwater to saltwater, estuaries provide important habitat for migrating salmon.

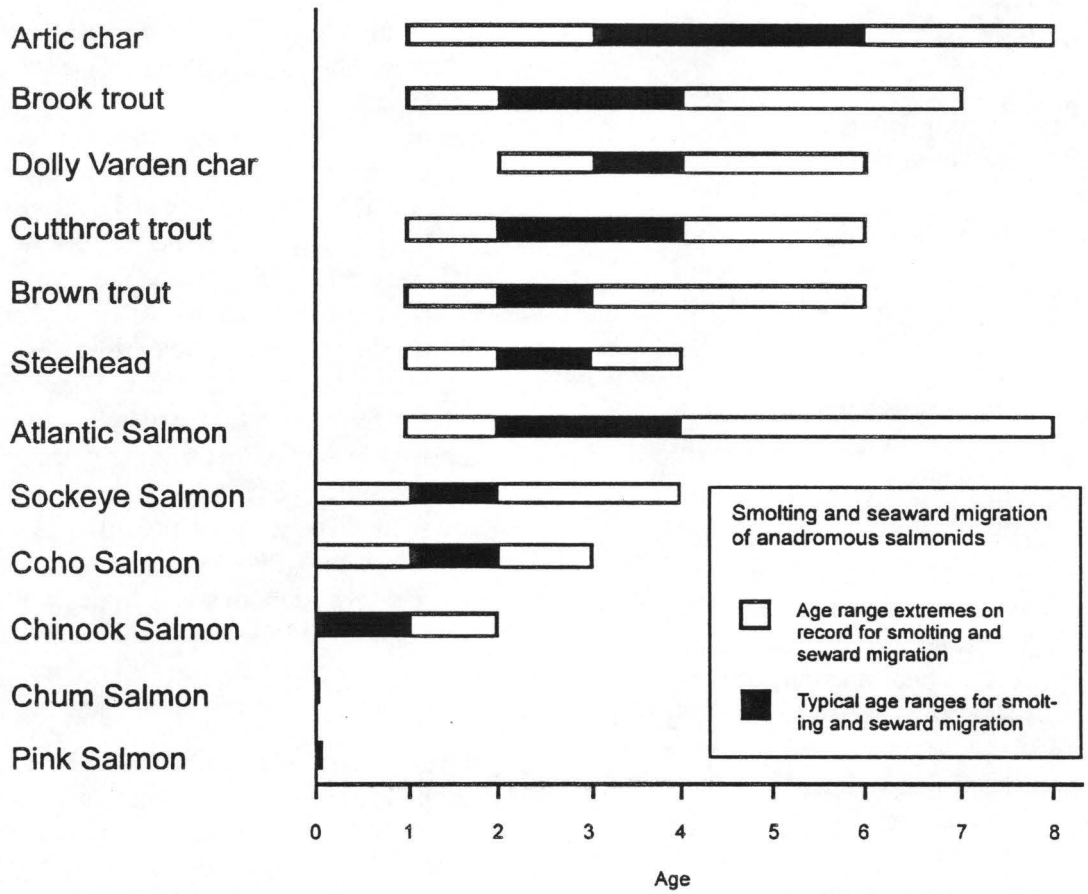


Figure 35. Variations in time of smolting and migration (G.B. Pauley in Stolz & Schnell, 1991).

Life History Variations of Pacific Salmon

At any given month of the year in Oregon, several different species of native salmonids may be using freshwater habitat for more than one stage of their life cycle (Table 7).

Coho salmon are found in tributaries of the Columbia and Willamette Rivers, in tributaries of large coastal streams, and in small coastal streams with relatively low gradient. Spawning runs occur from September through November, and eggs require 301-454 Thermal Units (TUs) (1 TU = 1 day * 1 °C) to emergence, about 35-50 days. Coho spend about 16 months in freshwater as juveniles and prefer large pool habitat as they grow.

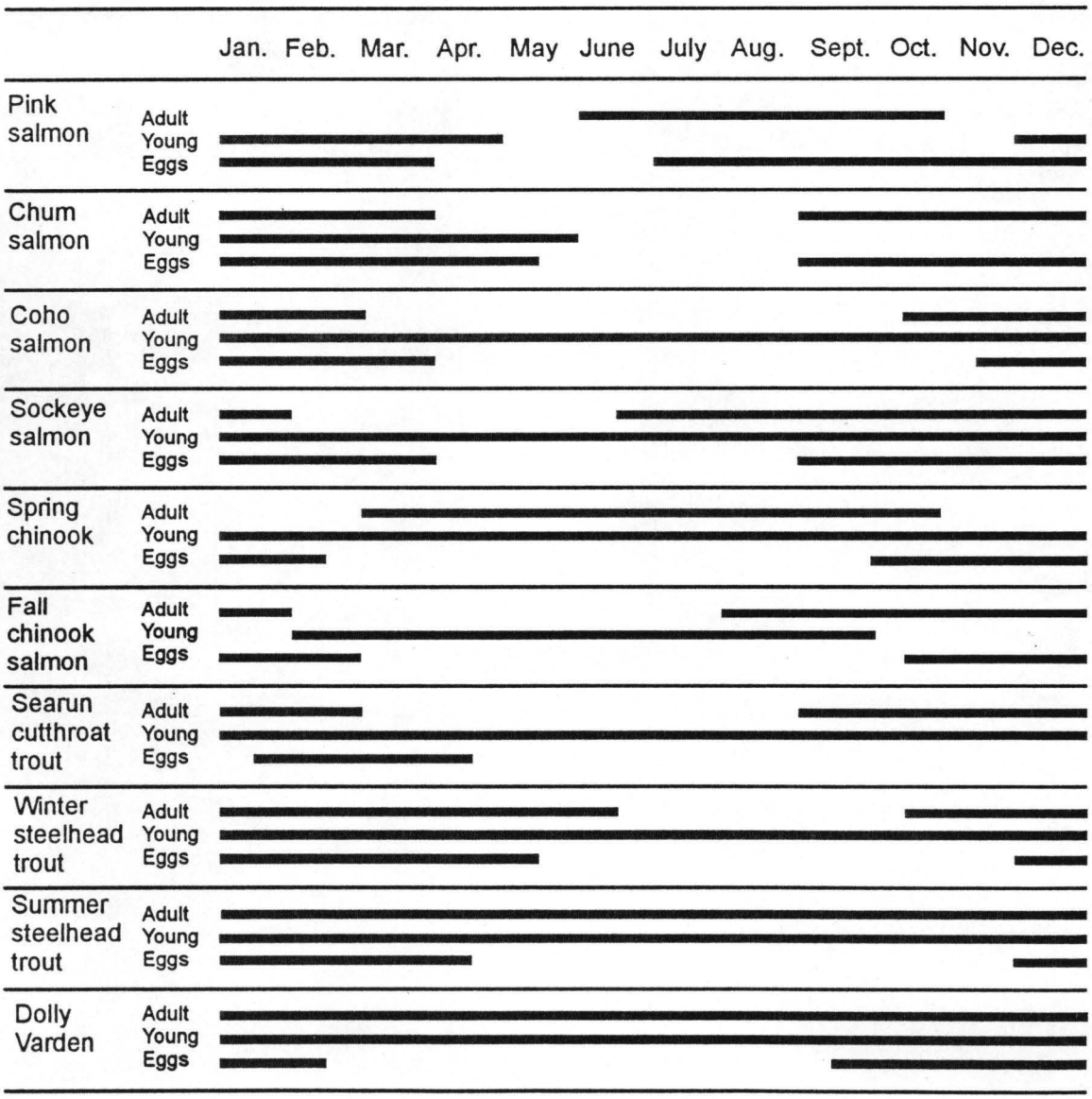
Chinook salmon are found in larger rivers and have three different run times in Oregon. The spring run occurs in April with spawning in late August. Summer-run chinook come up the rivers in July and spawn in late September. Fall-run chinook arrive in late August and spawn in late September. Time to achieve egg hatching is based on 477-512 TUs. At the end of their freshwater rearing, as subyearlings and yearlings, they become smolts on the way to the ocean. Smolts use estuary habitats for two months prior to moving to the open ocean.

Chum salmon inhabit the lower 300 km of the Columbia River and coastal streams. Strong swimmers but not great leapers, they are usually found below the first significant barrier. Principal spawning runs are in October and November. After spawning, 90-182 days are required to hatch (equivalent of 400-600 TUs). Alevins emerge and promptly begin migrating downstream to the estuary, a journey which takes up to 30 days.

Another species of salmon, pink salmon (*Oncorhynchus gorbuscha*), is found irregularly in small runs in coastal streams in Oregon down through northern California. They are not adept at negotiating high velocity barriers or waterfalls and spawn closer to the estuary than other salmonids. The pink salmon run takes place in late August, and they spawn in late September. Eggs require 62-512 TU's to hatch. After emergence, pink salmon migrate quickly to rear in estuaries (up to two months) before heading to sea.

Cutthroat trout are found in many different stream types and reaches in western Oregon. It is the only native fish found in the steepest headwaters of streams with gradients of 15%.

Table 7. Seasonal occurrence of adult, young and eggs of anadromous salmonids in freshwaters of western Oregon and Washington (Everest, 1987).



Resident fishes can spawn in the smallest tributaries, the first and second order streams. Sea-run cutthroat trout inhabit estuaries and do not make long migrations upstream to spawn.

Rainbow trout and steelhead trout are different life history types of the same species. Steelhead are a migratory form of rainbow trout. Rainbow trout are very adaptable, generally found in lakes and streams with gradients up to 15%. They are most often found in water temperatures less than 20 °C, although their upper incipient lethal temperature is relatively high at 26.5 °C. Rainbow trout spawn in streams and require 532-640 TUs to hatch.

Interdependence of Species

Trout will prey on the eggs, juveniles and adults of other species such as lamprey ammocoete larvae, speckled dace and juvenile suckers. The distribution patterns of fish species within the stream, river, or estuary reflect physiological requirements, availability of suitable habitats, and characteristic life history stages established over many thousands of years of co-evolution.

Because of this interdependence of salmonids with other fish, survival of salmonids cannot be achieved without ensuring the long-term viability of these other fish species, many of which seem to have no direct economic importance to humans despite their importance to the aquatic ecosystem. Some other fish species have direct economic value for humans for food or sport, such as starry flounders, English sole, petrale sole, speckled sand dabs, green sturgeon, and white sturgeon. Habitat requirements, regional distribution, spawning needs, and status of all Oregon fish species will need to be carefully monitored for survival of viable populations (Table 8).

Table 8. Habitat requirement of fish species in Oregon (after Li et al., 1987; Matarese et al., 1989; McPhail & Lindsey, 1986; Minckley et al, 1986; Wang, 1986; Misitano, 1977; Balon, 1975; Matthews & Heins, 1987; Pearcy & Myers, 1974). Federal status is indicated as T for threatened, E for endangered, and S for sensitive. State status categories are SC for sensitive critical, SE for sensitive endangered. For each region, species native to Oregon are indicated with N and introduced species are shown as I.

		Status		Region						Habitat Type									Other Habitat Requirements		
Common Name	Scientific Name	federal	state	coastal	Klamath R.	lakes	lower Col.	middle Col.		estuarine	lowland	upland	montane	river	stream	creek	lake	springs	Temperature Guilds	Tolerance to Salinity	Preferred Spawning Surface
SALMONIDS (subfamily Salmoninae)																					
golden trout	Oncorhynchus aguabonita	(see text--						I					x			x	x		cold	narrow	(unknown)
cutthrout trout	Oncorhynchus clarki	listing		N	N	N	N	N		x	x	x	x	x	x	x	x		(unknown)	broad	rocks, gravel
rainbow trout	Oncorhynchus mykiss	varies		N	N		N	N		x	x	x	x	x	x	x	x		cold	broad	rocks, gravel
pink salmon	Oncorhynchus gorbuscha	by run)		N			N			x	x	x		x	x				cold	broad	rocks, gravel
chum salmon	Oncorhynchus keta			N			N			x	x	x		x	x				cold	broad	rocks, gravel
coho salmon	Oncorhynchus kisutch			N			N	N		x	x	x		x	x				cold	broad	rocks, gravel
sockeye salmon	Oncorhynchus nerka			N			N	N		x	x	x	x	x	x	x	x		cold	broad	rocks, gravel
chinook salmon	Oncorhynchus tshawytscha			N			N	N		x	x	x		x	x				cold	broad	rocks, gravel
Atlantic salmon	Salmo salar							I				x	x				x		cold	broad	rocks, gravel
redband trout	Salmo sp.				N	N						x	x		x	x			cold	broad	rocks, gravel
brown trout	Salmo trutta			I			I	I		x	x	x	x	x	x	x	x		cold	(unknown)	rocks, gravel
bull trout	Salvelinus confluentus				N			N				x	x	x	x				cold	narrow	rocks, gravel
brook trout	Salvelinus fontinalis			I			I	I				x	x	x	x	x	x		cold	(unknown)	rocks, gravel
Dolly Varden	Salvelinus malma						N			x	x	x	x	x	x	x	x		cold	broad	rocks, gravel
lake trout	Salvelinus namaycush							I				x	x				x		cold	narrow	rocks, gravel
FRESHWATER FISHES																					
smallmouth bass	Micropterus dolomieui			I			I	I			x			x	x	x			cool	narrow	rocks, gravel
largemouth bass	Micropterus salmoides			I			I	I			x			x			x		warm	narrow	plants
bluegill	Lepomis macrochirus						I				x			x			x		warm	narrow	rocks, gravel
black bullhead	Ameiuris melas			I			I	I			x			x	x		x		warm	narrow	rocks, gravel
yellow bullhead	Ameiuris natalis			I			I	I			x			x	x		x		warm	narrow	rocks, gravel
brown bullhead	Ameiuris nebulosus			I			I	I			x			x	x		x		warm	narrow	rocks, gravel
burbot	Lota lota							N			x	x		x			x		cold	narrow	rocks, gravel
white catfish	Ameiuris catus			I			I	I			x			x	x		x		warm	narrow	(unknown)
channel catfish	Ictalurus punctatus			I			I	I			x			x	x		x		warm	narrow	rocks, gravel
flathead catfish	Pylodictus olivaris							I			x			x			x		warm	narrow	rocks, gravel
chiselmouth	Acrocheilus alutaceus					N	N	N			x	x		x	x		x		warm	narrow	rocks, gravel
Alvord chub	Gila alvordensis		SC			N						x			x	x			warm	(unknown)	(unknown)
tui chub	Gila bicolor	E,T	SC		N	N	N	N			x	x		x	x	x	x	x	warm	narrow	plants, logs, gravel, rocks
Borax Lake chub	Gila boraxobius	T				N						x			x	x	x		warm	broad	(unknown)

Common Name	Scientific Name	Status		Region					Habitat Type								Other Habitat Requirements		
		federal	state	coastal	Klamath R.	lakes	lower Col.	middle Col	estuarine	lowland	upland	montane	river	stream	creek	lake	springs	Temperature Guilds	Tolerance to Salinity	Preferred Spawning Surface
blue chub	Gila coerulea				N			I			x		x	x		x		warm	narrow	rock, gravel
Umpqua chub	Oregonichthyes kalawatseti	T		N						x			x	x	x	x		warm	narrow	rocks, gravel
Oregon chub	Oregonichthys crameri	T		N			N			x	x			x				warm	narrow	aquatic veg.
white crappie	Pomoxis annularis						I	I		x			x			x		warm	narrow	plants
black crappie	Pomoxis nigromaculatus									x			x			x		warm	narrow	plants
longnose dace	Rhinichthys cataractae			N		N	N	N		x	x	x		x	x			cool	narrow	rocks, gravel
Umpqua dace	Rhinichthys evermanni			N						x	x			x	x			warm	narrow	rocks, gravel
leopard dace	Rhinichthys falcatus							N		x			x					warm	narrow	rocks, gravel
speckled dace	Rhinichthys osculus	T		N	N	N	N	N			x	x	x	x	x	x	x	warm	narrow	rocks, gravel
goldfish	Carasius auratus			I	I	I	I	I			x			x	x	x	x	warm	narrow	plants, logs, gravel, rocks
Pit-Klamath Brook	Lampetra lethophaga				N						x			x	x			cool	narrow	rocks, gravel
Western Brook lampre	Lampetra richardsoni			N			N	N		x	x			x	x			cold	broad	rocks, gravel
common carp	Cyprinus carpio			I			I	I		x			x	x		x		warm	narrow	plants, logs, gravel, rocks
yellow perch	Perca flavescens			I			I	I		x			x			x		cool	broad	plants, logs, gravel, rocks
pumpkinseed	Lepomis gibbosus						I			x				x		x		warm	narrow	gravel, sand, sod
California roach	Hesperoleucus symmetricus		SE			I				x	x			x	x			warm	narrow	rock, gravel
sand roller	Percopsis transmontana						N	N		x			x	x	x			cool	narrow	(unknown)
coast range sculpin	Cottus aleuticus			N									x	x				cool	(unknown)	rocks, gravel
mottled sculpin	Cottus bairdi		SC, SE			N	N	N			x	x		x	x	x		cold	narrow	rocks, gravel
Paiute sculpin	Cottus beldingi						N	N			x			x	x	x		cold	(unknown)	rocks, gravel
slimy sculpin	Cottus cognatus							N							x	x		cold	broad	rocks, gravel
shorthead sculpin	Cottus confusus							N					x	x	x			cold	(unknown)	rocks, gravel
marbled sculpin	Cottus klamathensis				N						x			x	x	x		cool	(unknown)	rocks, gravel
margined sculpin	Cottus marginatus		SE					N			x	x			x	x		cold	narrow	rocks, gravel
Klamath Lake sculpin	Cottus princeps				N						x					x		cold	(unknown)	rocks, gravel
torrent sculpin	Cottus rotheus			N			N	N			x	x		x	x			cold	narrow	rocks, gravel
slender sculpin	Cottus tenuis		SC		N						x			x	x			cold	(unknown)	rocks, gravel
redside shiner	Richardsonius balteatus			N		N	N	N			x	x		x	x	x		warm	narrow	plants, logs, gravel, rocks
Northern squawfish	Ptychocheilus oregonensis			N			N	N		x			x	x	x	x		warm	narrow	rocks, gravel

Common Name	Scientific Name	Status		Region						Habitat Type									Other Habitat Requirements		
		federal	state	coastal	Klamath R.	lakes	lower Col.	middle Col		estuarine	lowland	upland	montane	river	stream	creek	lake	springs	Temperature Guilds	Tolerance to Salinity	Preferred Spawning Surface
Umpqua squawfish	Ptychocheilus umpquae			N							x	x		x	x				warm	narrow	rocks, gravel
bridgelip sucker	Catostomus columbianus					N		N				x	x		x	x			cool	narrow	rocks, gravel
largescale sucker	Catostomus macrocheilus			N		N	N	N			x	x		x	x		x		warm	narrow	sand
mountain sucker	Catostomus platyrhynchus							N					x		x	x			cool	narrow	rocks, gravel
Klamath smallscale	Catostomus rimiculus		SC	N								x	x	x	x				warm	narrow	(unknown)
Klamath largescale	Catostomus snyderi				N						x	x		x	x				warm	narrow	rocks, gravel
Warner sucker	Catostomus warnerensis	E				N					x	x			x	x	x		warm	narrow	rocks, gravel
shortnose sucker	Chasmistes brevirostris				N						x			x			x		warm	narrow	rocks, gravel
Lost River sucker	Deltistes luxatus	E			N						x	x		x			x		warm	narrow	rocks, gravel
green sunfish	Lepomis cyanellus						I				x				x		x		warm	narrow	rocks, gravel
walleye	Stizostedion vitreum vitreum						I	I						x			x		cool	(unknown)	rocks, gravel
mountain whitefish	Prosopium williamsoni					N	N	N				x	x	x	x		x		cool	narrow	rocks, gravel
EURYHALINE FISHES (able to tolerate broad range of salinities from freshwater to saline)																					
white bass	Morone chrysops					I				x	x		x	x			x		cool	broad	plants, logs, gravel, rocks
striped bass	Morone saxatilis			I	I					x	x			x			x		cool	broad	rocks, gravel, sand, silt
eulachon	Thaleichthys pacificus			N			N			x	x			x					cold	broad	sand
rainwater killifish	Lucania parva			I			I			x	x		x						(unknown)	broad	plants, logs, gravel, rocks
river lamprey	Lampetra ayresi			N			N			x	x	x	x	x	x	x			cold	broad	rocks, gravel
Pacific lamprey	Lampetra tridentata		SE, S	N	N		N	N		x	x	x	x	x	x	x	x		cool	broad	rocks, gravel
western mosquitofish	Gambusia affinis			I	I	I	I	I		x	x			x	x	x	x		warm	broad	internal
prickly sculpin	Cottus asper			N			N	N		x	x	x			x	x			cool	broad	rocks, gravel
riffle sculpin	Cottus gulosis			N			N			x	x	x			x	x			cold	broad	rocks, gravel
reticulate sculpin	Cottus perplexus			N			N			x	x	x			x	x			cool	broad	rocks, gravel
American shad	Alosa sapidissima			I			I			x	x			x					cool	broad	open water
longfin smelt	Spirinchus thaleichthys			N			N			x	x			x					cold	broad	rocks, gravel
threespine stickleback	Gasterosteus aculeatus			N?	N?		N?			x	x	x		x	x	x	x		warm	broad	mud, sand
green sturgeon	Acipenser medirostris	T,E,S		N			N			x	x			x					cool	broad	rocks, gravel
white sturgeon	Acipenser transmontanus			N			N	N		x	x			x					cool	broad	rocks, gravel
warmouth	Lepomis gulosus						I			x	x			x	x		x		warm	narrow	rocks, gravel

Common Name	Scientific Name	Status		Region				Habitat Type								Other Habitat Requirements		
		federal	state	coastal	Klamath R.	lakes	lower Col.	estuarine	lowland	upland	montane	river	stream	creek	lake	springs	Temperature Guilds	Tolerance to Salinity	Preferred Spawning Surface
ESTUARINE FISHES																			
northern anchovy	Engraulis mordax			N		N		x									cold	broad	open water
cabezon	Scorpaenichthys marmoratus			N		N		x									cold	broad	rocks, algae
northern clingfish	Gobiesox maeandricus			N		N		x									cold	broad	rocks
high cockscomb	Anoplarchus purpurescens			N		N		x									cold	broad	pebble, gravel, sand, shell
Pacific tomcod	Microgadus proximus			N		N		x									cold	broad	open water
lingcod	Ophiodon elongatus			N		N		x									cold	broad	rocks
spiny dogfish	Squalus acanthias			N		N		x									cold	broad	(unknown)
starry flounder	Platichthys stellatus			N		N		x									cold	broad	many
arrow goby	Clevelandia ios			N		N		x									cold	broad	mud, sand, gravel
bay goby	Lepidogobius lepidus			N		N		x									cold	broad	mud
kelp greenling	Hexagrammos decagrammus			N		N		x									cold	broad	rocks
penpoint gunnel	Apodichthys flavidus			N		N		x									cold	broad	rocks, algae
saddleback gunnel	Pholis ornata			N		N		x									cold	broad	(unknown)
Pacific hake	Merluccius productus			N		N		x									cold	broad	open water
Pacific herring	Clupea pallasi			N		N		x									cold	broad	plants, shell, rock, sand
Pacific sand lance	Ammodytes hexapterus			N		N		x									cold	broad	sand
red Irish lord	Hemilepidotus hemilepidotus			N		N		x									cold	broad	rocks, pilings
brown Irish lord	Hemilepidotus spinosus			N		N		x									cold	broad	aquatic veg.
peamouth	Mylocheilus caurinus					N	N	x									cool	broad	rocks, gravel
redtail surfperch	Amphistichus rhodoterus			N		N		x									cold	broad	N/A
shiner perch	Cymatogaster aggregata			N		N		x									cold	broad	N/A
pile perch	Damalichthys vacca			N		N		x									cold	broad	N/A
striped seaperch	Embiotoca lateralis			N		N		x									cold	broad	N/A
spotfin surfperch	Hyperprosopon anale			N		N		x									cold	broad	N/A
walleye surfperch	Hyperprosopon argenteum			N		N		x									cold	broad	N/A
silver seaperch	Hyperprosopon ellipticum			N		N		x									cold	broad	N/A
white seaperch	Phanerodron furcatus			N		N		x									cold	broad	(unknown)
bay pipefish	Syngnathus Leptorhynchus			N		N		x									cold	broad	N/A
white seaperch	Phanerodron furcatus			N		N		x									cold	broad	(unknown)

		Status		Region				Habitat Type									Other Habitat Requirements		
Common Name	Scientific Name	federal	state	coastal	Klamath R.	lakes	lower Col.	middle Col.	estuarine	lowland	upland	montane	river	stream	creek	lake	springs	Temperature Guilds	Tolerance to Salinity	Preferred Spawning Surface
bay pipefish	Syngnathus Leptorhynchus			N			N		x									cold	broad	N/A
pricklebreast poacher	Stellerina xyosterna			N			N		x									cold	broad	(unknown)
blacktip poacher	Xemeretmus latifrons			N			N		x									cold	broad	(unknown)
warty poacher	Occella verrucosa			N			N		x									cold	broad	(unknown)
tubenose poacher	Pallasina barbata			N			N		x									cold	broad	(unknown)
snake prickleback	Lumpenus sagitta			N			N		x									cold	broad	(unknown)
copper rockfish	Sebastes caurinus			N			N		x									cold	broad	N/A
blackmouth rockfish	Sebastes crameri			N			N		x									cold	broad	N/A
black rockfish	Sebastes melanops			N			N		x									cold	broad	N/A
Pacific sandfish	Trichodon trichodon			N			N		x									cold	broad	rocks
speckled sandab	Citharichthys stigmaeus			N			N		x									cold	broad	(unknown)
padded sculpin	Artedius fenestralis			N			N		x									cold	broad	rocks
scalyhead sculpin	Artedius harringtoni			N			N		x									cold	broad	(unknown)
sharpnose sculpin	Clinocottus acuticeps			N			N		x									cold	broad	rocks, algae
buffalo sculpin	Enophrys bison			N			N		x									cold	broad	rocks, pilings
Pacific staghorn sculpi	Leptocottus armatus			N			N		x									cold	broad	mud, rocks
tidepool sculpin	Oligocottus maculosus			N			N		x									cold	broad	rocks, mussels, barnacles
big skate	Raja binoculata			N			N		x									cold	broad	(unknown)
longnose skate	Raja rhina			N			N		x									cold	broad	(unknown)
whitebait smelt	Allosmerus elongatus			N			N		x									cold	broad	(unknown)
topsmelt	Atherinops affinis			N			N		x									cold	broad	plants
jacksmelt	Atherinops californiensis			N			N		x									cold	broad	plants
surf smelt	Hypomesus pretiosus			N			N		x									cold	broad	sand
Arctic smelt	Osmerus dentex			N			N		x									cold	broad	(unknown)
showy snailfish	Liparis pulchellus			N			N		x									cold	broad	(unknown)
ringtail snailfish	Liparis rutteri			N			N		x									cold	broad	(unknown)
butter sole	Isopsetta isolepis			N			N		x									cold	broad	(unknown)
English sole	Pleuronectes vetulus			N			N		x									cold	broad	mud
sand sole	Psettichthys melanostictus			N			N		x									cold	broad	(unknown)
California tonguefish	Symphurus atricauda			N			N		x									cold	broad	(unknown)

Salmonid Populations in Oregon

The information in this section was obtained primarily from three Oregon Department of Fish and Wildlife (ODFW) reports, unless noted otherwise:

- Biennial Report on the Status of Wild Fish in Oregon, 1994
- Wild Fish Management Policy Biennial Progress Report, 1992
- Status of Anadromous Salmonids in Oregon Coastal Basins, 1992

Current Distribution

In 1992, the ODFW recognized 1,869 wild fish populations in Oregon, of which 1,784 were salmonids (salmon, trout, and whitefish) (ODFW, 1992). A revised list of recognized salmonid stocks with the addition of newly recognized stocks will be presented in the next Wildfish Management Report from ODFW, to be released before the end of 1994 (Kathryn Kostow, personal communication). Salmonid populations are defined primarily on the basis of geographical location and, in some cases, run-time.

The five common salmon species of Oregon are all in the genus *Oncorhynchus* and include: coho *(O. kisutch)*, chinook (*O. tshawytscha*), chum (*O. keta*), steelhead (*O. mykiss*) and sea-run cutthroat *(O. clarki)*. Each species has a unique distribution in Oregon (Table 9). Of these five species the most widely distributed in Oregon is *Oncorhynchus clarki* (cutthroat trout), and the species with the smallest range *O. keta* (chum salmon).

A sixth salmon species, sockeye (*O. nerka*) was historically abundant in eastern Oregon's subbasins of the Columbia River system, but is now nearly extinct in this state. Only two major Columbia stocks remain and both are located in lake complexes in Washington: Lake Wenatchee and Osoyoos Lake (CRITFC, 1989). Four spawning populations of landlocked sockeye or kokanee are recognized in Oregon. They are found in Suttle Lake, Deschutes River Basin and Wallowa Lake in the Grande Ronde Basin.

All salmon populations have anadromous life cycles. The most recent summary of the number of salmonid stocks in Oregon was presented in the 1994 Biennial Report on the Status of Wild Fish in Oregon and the Implementation of Fish Conservation Policies. In this report, ODFW identified 100 populations of chinook salmon throughout the State, of which 32 are spring/summer run and 68 are fall run. Fifty-two of these populations are found in the coastal basins and the remainder in the Columbia river system. For coho, 128 naturally breeding populations are recognized, 98 in coastal basins and the remainder in the Columbia system. ODFW recognizes 55 populations of chum salmon, 32 populations in coastal streams and the remainder in tributaries of the lower Columbia.

Both trout species considered here have resident and anadromous populations. Current taxonomic classification of both species recognizes three subspecies for each. Steelhead/rainbow/ redband trout are all of the species *O. mykiss.* Coastal steelhead, *O. mykiss irideus,* is found primarily in Oregon basins west of the Cascades. For this subspecies, ODFW recognizes 119 steelhead populations (113 winter-run and 6 summer-run) and 176 rainbow populations. The second subspecies of steelhead is *O. mykiss gairdneri* or inland Columbia Basin steelhead, and is found primarily in all Oregon subbasins of the Columbia east of the Cascades. ODFW recognizes eighteen populations of steelhead (4 winter and 14 summer runs) and 156 redband trout of this subspecies. The third subspecies is the Oregon basin redband or *O. mykiss newberrii* and is distributed primarily in seven landlocked basins in south central Oregon. One of these basins, the upper Klamath, was historically closed to other bodies of water and formed Lake Modoc, which was secondarily opened to the Pacific Ocean. All 71 populations of this subspecies recognized by ODFW are resident trout.

Three subspecies of cutthroat trout, *O. clarki,* are found in Oregon. Coastal cutthroat, *O. clarki clarki,* is found predominantly in all tributaries of the lower Columbia and in all coastal basins. ODFW recognizes 127 entirely or partially anadromous populations (95 coastal populations and 32 Columbia) and 694 entirely or partially resident populations (378 coastal, 136 Columbia stocks below Willamette Falls, and 180 above Willamette Falls).

Table 9. Occurrence of anadromous salmonids in major Oregon basins (after ODFW, 1992). "H" indicates population comprised of hatchery fish only. "X" indicates presence of wild salmonid populations.

Basin	Coho	Spring Chinook	Fall Chinook	Chum	Summer Steelhead	Winter Steelhead	Searun Cutthroat
Necanicum R.	X		H	X		X	X
Elk Cr.	X					X	X
Nehalem R.	X	X	X	X		X	X
Tillamook Bay							
Miami R.	X		X	X		X	X
Kilchis R.	X	X	X	X	H	X	X
Wilson R.	X	X	X	X	H	X	X
Trask R.	X	X	X	X		X	X
Tillamook R.	X		X	X		X	X
Nestucca R.	X	X	X	X	H	X	X
Neskowin R.	X		X	X		X	X
Salmon R.	X		X	X		X	X
Siletz R.	X	X	X	X	X	X	X
Yaquina R.	X		X	X		X	X
Beaver Cr.	X		X			X	X
Alsea R.	X	X	X	X		X	X
Yachats R.	X		X	X		X	X
Siuslaw R.	X	X	X			X	X
Siltcoos R.	X					X	X
Tahkenitch Cr.	X					X	X
Umpqua R.	X	X	X	X	X	X	X
Smith R.	X			X		X	X
Tenmile Cr.	X					X	X
Coos R.	X		X	X		X	X
Coquille R.	X	X	X	X		X	X
New River	X		X			X	X
Sixes R.	X		X			X	X
Elk R.	X		X			X	X
Euchre Cr.	X		X			X	X
Rogue R.	X	X	X		X	X	X
Hunter Cr.	X		X			X	X
Pistol R.	X		X			X	X
Chetco R.	X		X			X	X
Winchuck R.	X		X			X	X
Lower Columbia R.	X	X	X	X		X	X
Mid Columbia R.	X	X	X		X	X	X
Snake R.		X	X		X		
Upper Willamette R.[1]	H	X	H		H	X	
Lower Willamette R.	H	H	X			X	

[1] above Willamette Falls

The second subspecies of cutthroat is known as the westslope cutthroat or *O. clarki lewisi* and is located in several tributaries of the John Day river basin. ODFW lists 23 breeding populations. The third subspecies of cutthroat found in Oregon is the Lahontan cutthroat or *O. clarki henshawi* and is found in three isolated basins in southeast Oregon. Eight entirely resident populations are recognized by ODFW.

Recognized Salmonid Stocks and their Present Condition

The most recent list of anadromous salmonid populations recognized by ODFW (1992) is presented in Table 10. An updated list will be released by ODFW in 1994 (Kathryn Kostow, personal communication). Status categories in this table are those defined by ODFW (1992) and include: healthy, special concern, depressed, and unknown. A healthy stock is one that has fully seeded its available spawning habitat and abundance has remained relatively stable in the last 20 years. A stock is considered to be of special concern if the population is 300 spawners or less and/or interbreeding is most likely above Wild Fish Management Policy standards. (*Interbreeding specifically refers to adult spawners of hatchery origin: 50% of spawners may be of hatchery origin if stock was selected from genetically similar population, 10% if genetically dissimilar hatchery stock was used.)* A stock is classified as depressed if one of the following conditions has occurred: the spawning habitat has not been fully seeded, abundance has declined over the last 20 years, or abundance in recent years has been below the 20-year average. For the majority of stocks, insufficient information exists to assign one of the three categories mentioned above and status is designated as unknown. Note the large number of stocks about which there is insufficient information.

Except when dam counts have been possible (as on the Columbia, Umpqua, and Rogue rivers), very few of these stocks have quantitative information on abundance over any duration of time, ODFW has conducted salmon spawning surveys in many coastal streams. These surveys produce an index of abundance that is useful in determining long-term trends. Many entries in the table are expert judgments from ODFW field biologists. Given the vast number of stocks and the difficulties in obtaining population estimates, expert judgment is essential in monitoring stock status.

Table 10. Wild populations of selected salmonid species of Oregon, as recognized by ODFW, 1992a. Stocks are named after their natal stream and are presented as they are geographically distributed from north to south. Status categories are explained in text. Table notations are as follows:

[1] 1992a, ODFW Wild Fish Management Policy
[2] 1992b, ODFW Status of Anadromous Salmonids in Oregon Coastal Basins
[3] winter chinook

Basin -*River*	Chum	Fall Chinook	Spring Chinook	Coho	Winter Steelhead	Summer Steelhead	Sea-run Cutthroat
NORTH COAST (Columbia River to Cascade Head)							
Necanicum R.	unknown[2]			depressed[2]	sp. concern[2]		unknown[1]
Indian Cr.				unknown[1]	unknown[1]		unknown[1]
Canyon Cr.				unknown[1]	unknown[1]		unknown[1]
Elk Cr.				depressed[2]	unknown[1]		unknown[1]
Asbury Cr.				unknown[1]	unknown[1]		unknown[1]
Arch Cape Cr.				unknown[1]	unknown[1]		unknown[1]
Short Sands Cr.				unknown[1]	unknown[1]		unknown[1]
Nehalem R.	-	healthy[2]	healthy[2]	-	unknown		-
-Basin below Hwy 26	healthy[2]	healthy[2]		depressed[2]	unknown		unknown[1]
-N. Fork Nehalem R.	healthy[2]	healthy[2]		sp. concern[2]	unknown		unknown[1]
-Salmonberry R.		unknown[2]		unknown[2]	unknown		unknown[1]
-Basin above Hwy 26				depressed[2]	unknown		unknown[1]
Spring Cr.				unknown[1]	unknown		unknown[1]
Watseco Cr.				unknown[1]	unknown[1]		unknown[1]
Whitney Brook							unknown[1]
Tillamook Bay	-	-	-	-	-		-
-Hobson Cr.				unknown[1]			
-Lagler Cr.				unknown[1]	unknown[1]		unknown[1]
-Miami R.	healthy[2]	healthy[2]		depressed[2]	depressed[2]		unknown[1]
-Electric Cr.				unknown[1]	unknown[1]		unknown[1]
-Larson Cr.				unknown[1]	unknown[1]		
-Patterson Cr.	unknown[1]			unknown[1]	unknown[1]		unknown[1]
-Jacoby Cr.				unknown[1]	unknown[1]		unknown[1]
-Doty Cr.	unknown[1]			unknown[1]	unknown[1]		
-Vaughn Cr.	unknown[1]			unknown[1]	unknown[1]		unknown[1]
-Kilchis R.	healthy[2]	healthy[2]	sp. concern[2]	depressed[2]	depressed[2]		unknown[1]
-Wilson R.	healthy[2]	healthy[2]	sp. concern[2]	depressed[2]	depressed[2]		unknown[1]
-Trask R.	healthy[2]	healthy[2]	sp. concern[2]	depressed[2]	depressed[2]		unknown[1]
-Tillamook R.	healthy[2]	healthy[2]	sp. concern[2]	depressed[2]	unknown		unknown[1]
Netarts Bay	healthy[2]			-	-		-
-Jackson Cr.	unknown[1]			depressed[2]			unknown[1]
-Whiskey Cr.	unknown[1]			depressed[2]	unknown[1]		unknown[1]
Royer Cr.				depressed[2]			
Sand Cr.	sp. concern[2]			depressed[2]	unknown[1]		unknown[1]
Nestucca Bay	-	-	-	-	-		-
-Nestucca R.	healthy[2]	healthy[2]		depressed[2]	depressed[2]		unknown[1]
-Little Nestucca R.	sp. concern[2]	healthy[2]		depressed[2]	unknown		unknown[1]
Daley (Bee) Lake Cr.				unknown[1]			unknown[1]
Neskowin Cr.	sp. concern[2]	unknown[2]		unknown[1]	unknown[1]		unknown[1]

Table 10, cont'd.

Basin *-River*	Chum	Fall Chinook	Spring Chinook	Coho	Winter Steelhead	Summer Steelhead	Sea-run Cutthroat
NORTH MID COAST (Cascade Head to Heceta Head)							
Salmon R.	sp. concern[2]	sp. concern[2]	sp. concern[2]	depressed[2]	depressed[2]		unknown[1]
Rock Cr. (Devil's Lake)				unknown	unknown[1]		unknown[1]
Siletz Bay	-	-	-	-	-	-	-
-Siletz R.	sp. concern[2]	healthy[2]	healthy[2]	depressed[2]	depressed[2]	depressed[2]	unknown[1]
-Drift Cr.	sp. concern[2]	unknown[2]		unknown[2]	unknown		unknown[1]
-Schooner Cr.		unknown[2]		unknown[2]	unknown		unknown[1]
Fogarty Cr.				depressed[2]			unknown[1]
Depoe Cr.				depressed[2]			unknown[1]
Spencer Cr.				depressed[2]			unknown[1]
Big Cr.				depressed[2]			unknown[1]
Yaquina R.	healthy[2]	healthy[2]		depressed[2]	unknown		unknown[1]
Thiel Cr.				unknown[1]	unknown[1]		unknown[1]
Beaver Cr.		unknown[2]		depressed[2]	unknown[1]		unknown
Alsea Bay	-	-	-	-	-		-
-Alsea R.	sp. concern[2]	healthy[2]	healthy[2]	healthy[2]	depressed[2]		unknown
-Drift Cr.		healthy[2]		healthy[2]	unknown		unknown
Yachats R.	sp. concern[2]	unknown[2]		depressed[2]	depressed[2]		unknown[1]
Cape Cr.				depressed[2]			unknown[1]
Big Cr.		unknown[2]		depressed[2]	unknown		unknown[1]
Cummins Cr.				depressed[2]	unknown[1]		unknown[1]
Bob Cr.				depressed[2]	unknown[1]		unknown[1]
Tenmile Cr.				depressed[2]	depressed[2]		unknown[1]
Rock Cr.				depressed[2]	unknown[1]		unknown[1]
Big Cr.				depressed[2]	unknown		unknown[1]
China Cr.				depressed[2]			unknown[1]
Cape Cr.				depressed[2]	unknown		unknown[1]
SOUTH MID COAST (Heceta Head to Cape Blanco)							
Sutton Cr.				unknown[1]	unknown[1]		unknown[1]
Siuslaw Bay		-	-	-	-		-
-N. Fork Siuslaw R.		healthy[2]		depressed[2]	unknown		unknown
-Siuslaw R.		healthy[2]	unknown[2]	depressed[2]	depressed[2]		unknown
Siltcoos R.				healthy[2]	unknown[1]		unknown[1]
Tahkenitch Cr.				healthy[2]	unknown[1]		unknown[1]
Umpqua Estuary	–			-	-		
-Smith R.	sp. concern[2]	healthy[2]		depressed[2]	depressed[2]		
Umpqua R.		-	-	-	-		-
-Basin to N. Fk.	sp. concern[2]	healthy[2]		depressed[2]	unknown		unknown
-N. Umpqua R.		healthy[2]	healthy[2]	sp. concern[2]	healthy[2]	healthy[2]	unknown
-S. Umpqua R.		healthy[2]	depressed[2]	depressed[2]	unknown	unknown[1]	unknown[1]
Tenmile Cr.				depressed[2]	unknown		unknown[1]
Coos Bay	-			-	-		-

Table 10, cont'd.

Basin -River	Chum	Fall Chinook	Spring Chinook	Coho	Winter Steelhead	Summer Steelhead	Sea-run Cutthroat
SOUTH MID COAST (Heceta Head to Cape Blanco) cont'd...							
-Coos R.	sp. concern[2]	healthy[2]	healthy[2]	healthy[2]	depressed[2]		unknown[1]
-Millicoma R.		healthy[2]	healthy[2]	depressed[2]	unknown		unknown[1]
Miner Cr.				unknown[1]	unknown[1]		unknown[1]
Big Cr.				unknown[1]	unknown[1]		unknown[1]
Whiskey Run Cr.				unknown[1]	unknown[1]		unknown[1]
Cut Cr.				unknown[1]	unknown[1]		unknown[1]
Coquille R.	sp. concern[2]	healthy[2]	depressed[2]	healthy[2]	healthy[2]		unknown[1]
South Fork Coquille R.		healthy[2]		depressed[2]	unknown		unknown[1]
Johnson Cr.				unknown[1]	unknown[1]		unknown[1]
Crooked Cr.							unknown[1]
China Cr.				unknown[1]	unknown[1]		unknown[1]
Twomile Cr.				unknown[1]	unknown[1]		unknown[1]
Floras Cr.		unknown[2]		unknown[1]	unknown		unknown[1]
Sixes R.		sp. concern[2]		depressed[2]	depressed[2]		unknown[1]
SOUTH COAST (Cape Blanco to California border)							
Elk R.		sp. concern[2]		depressed[2]	unknown		unknown[1]
Hubbard Cr.				unknown[1]			unknown[1]
Brush Cr.				unknown[1]	unknown[1]		unknown[1]
Mussel Cr.				unknown[1]			unknown[1]
Euchre Cr.		depressed[2]		depressed[2]	unknown[1]		unknown[1]
Rogue R.		-	unknown	-	healthy[2]	depressed[2]	-
-Basin, mouth to Illinois R.		depressed[2]		depressed[2]	unknown		unknown[1]
-Illinois R.		depressed[2]		depressed[2]	depressed[2]		unknown[1]
- Il. to Gold Ray Dam		healthy[2]		depressed[2]			unknown[1]
-Applegate R.		healthy[2]		depressed[2]	unknown	unknown	
- above Gold Ray Da		healthy[2]	healthy[2]	depressed[2]	unknown		
Hunter Cr.		depressed[2]		depressed[2]	unknown[1]		unknown[1]
Pistol R.		depressed[2]		depressed[2]	depressed[2]		unknown[1]
Chetco R.		depressed[2]		depressed[2]	depressed[2]		unknown[1]
Winchuck R.		depressed[2]		depressed[2]	healthy[2]		unknown[1]
LOWER COLUMBIA R. (Below Bonneville Dam)							
Young's Bay	-	-		-	-		-
-Skipanon R.				unknown	unknown[1]		unknown[1]
-Lewis and Clark R.	unknown[1]	unknown[1]		unknown	unknown		unknown[1]
-Young's R.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]
-Klaskanine R.	unknown[1]	unknown[1]		unknown	unknown		unknown
-Walluski R.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]
Mill Cr.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]
John Day R.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]
Mary's Cr.	unknown[1]			unknown			unknown[1]
Bear Cr.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]

Table 10, cont'd.

Basin -*River*	Chum	Fall Chinook	Spring Chinook	Coho	Winter Steelhead	Summer Steelhead	Sea-run Cutthroat
LOWER COLUMBIA R. (Below Bonneville Dam) cont'd...							
Ferris Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Big Cr.	unknown[1]	unknown		unknown	unknown		unknown
Fertile Valley Cr.	unknown[1]			unknown	unknown[1]		unknown
Gnat Cr.	unknown[1]			unknown	unknown		unknown
Hunt Cr.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]
Plympton Cr.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]
Clatskanine Bay	–	–		unknown	–		–
-Clatskanine R.	unknown[1]	unknown[1]			unknown		unknown[1]
-Beaver Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Green Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Nice Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Fox Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Goble Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Tide Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Milton Cr.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown[1]
McBride Cr.	unknown[1]			unknown	unknown[1]		unknown[1]
Scappoose Cr.	unknown[1]	unknown[1]		unknown	unknown[1]		unknown
Sandy R.		unknown[3]	unknown	unknown	unknown		unknown[1]
Latourell Cr.							unknown[1]
Multnomah Cr.		unknown[1]		unknown			unknown[1]
Tanner Cr.				unknown	unknown[1]		unknown[1]
WILLAMETTE R. (Below Falls)							
Clackamas R.		unknown	unknown	unknown	unknown		unknown[1]
-Clear Cr.							unknown[1]
-Deep Cr.							unknown[1]
Abernathy Cr.				unknown[1]	unknown[1]		unknown[1]
Beaver Cr.							unknown[1]
WILLAMETTE (Basin above Willamette Falls)							
Tualatin R.				unknown	unknown		
Molalla R.					unknown		
Yamhill R.					unknown[1]		
Rickreall Cr.					unknown[1]		
Luckiamute R.					unknown[1]		
Santiam R.			-		-		
-N. Fork Santiam below Detroit Dam			unknown		unknown		
-S. Fork Santiam			unknown		unknown		
-Calapooia R.					unknown[1]		
McKenzie R.			unknown				
MID COLUMBIA (Bonneville Dam to Snake R.)							
Eagle Cr.		unknown[1]		unknown	unknown[1]		
Herman Cr.		unknown[1]		unknown	unknown[1]		

Table 10, cont'd.

Basin -*River*	Chum	Fall Chinook	Spring Chinook	Coho	Winter Steelhead	Summer Steelhead	Sea-run Cutthroat
MID COLUMBIA (Bonneville Dam to Snake R.) cont'd...							
Lindsay Cr.				unknown	unknown[1]		
Viento Cr.				unknown			
Hood R.		unknown		unknown	unknown	unknown	unknown[1]
Mosier Cr.				unknown	unknown[1]		
Chenowith Cr.				unknown	unknown[1]		
Mill Cr.				unknown	unknown[1]		
Threemile Cr.				unknown	unknown[1]		
Fifteenmile Cr.					unknown[1]		
Deschutes R.		unknown	–			unknown	
- mouth to Pelton Dam			unknown				
-Warm Springs			unknown				
John Day R.			–			–	
-Mainstem below S. Fork						unknown	
-N. Fork John Day R.			unknown			unknown	
-M. Fork John Day R.						unknown	
-S. Fork John Day R.			unknown			unknown	
-Mainstem, above S. Fork			unknown			unknown	
Umatilla R.						unknown	
Walla Walla R.						unknown	
SNAKE RIVER							
Basin, stateline to Hells Canyon Dam		unknown				unknown	
Grande Ronde R.		unknown	–			–	
-Basin below Wallowa R.						unknown[1]	
-Joseph Cr.						unknown	
-Wenaha R.			unknown			unknown[1]	
-Wallowa R.			unknown			unknown[1]	
-Minam R.			unknown			unknown[1]	
-Basin above Wallowa R.			unknown			unknown	
Imnaha R			unknown			unknown	
-Big Sheep Cr.			unknown			unknown	

Salmonids in Oregon Estuaries

Estuaries provide critical habitat for several species of salmonids (Table 11). During their stay in the estuary salmonids are susceptible to a number of cumulative effects from upland land uses or local land uses including dredging, filling, introduction of exotic species in ballast water, and pollution.

Major Effects of Commercial Gravel Harvest on Salmonids and Their Habitats

Research that directly links gravel fill-removal operations with effects on salmon is rare, although a few studies have been completed in other states and will be summarized in this report. Studies are available that relate gravel extraction to direct and indirect effects on salmon habitat. The effects of forest practices on salmon in Oregon have been well-documented through numerous scientific studies. Several of the physical changes and habitat degradation caused by gravel operations are similar to specific effects of forest practices and a logical connection can be made to infer possible effects upon salmon and their habitat. Much is known about the habitat requirements of salmon at different stages in their life cycle. Any changes in geomorphic or hydrologic conditions that affect essential habitat by altering desired conditions would also impact salmon populations.

The primary methods of gravel removal from the active channel, as summarized elsewhere in this report, are dry pit, wet pit, and bar scalping. Floodplain mining and terrace mining account for the majority of gravel extraction in Oregon. Due to their direct presence in salmon habitat, the most potentially detrimental to salmon habitat would be wet pit and dry pit active channel mining. Bar scalping, depending upon the site and operational procedures, may be detrimental to salmon habitat,. If extraction is limited to gravel above the summer low flow level and the site is not worked when wet, direct impacts would be minimized. Floodplain extraction at first consideration may appear to avoid in-channel impacts. Depending upon the position of the site within the floodplain, however, problems may occur during floods if the gravel pits are reoccupied by the active channel. Dredging and fill operations are also regulated by ODSL. Dredging may have impacts similar to in-channel gravel extraction. Fill in channels has caused loss of valuable wetland habitat.

Overview of Possible Effects of Gravel Extraction on Aquatic Habitat

Extraction of sand, gravel, and cobbles from waterways may have both direct and indirect effects upon salmonids and their habitat (Clavel & Bouchaud, 1980; Cuinat, 1980). This summary of possible effects presents a worst-case scenario. Many of the acute effects described here can be minimized by careful regulation and monitoring of effects over time. On-site, direct effects related to salmonid habitat may include: standardization and destabilization of the river bed, increased suspended material and water turbidity, decreased light penetration, removal of spawning gravel from streams, changed substrate composition, disturbance of redds, and destruction of eggs or developing embryos. Downstream effects related to salmonid habitat may include: increased suspended material; increased water turbidity; decreased light penetration; embedded stream bottom; covering of the bed with sand, silt and mud, especially in deep or slow-moving parts of the river; and alteration of the aquatic community composition, leading to cumulative effects upon the food chain. Cumulative effects on aquatic community interactions, compounded by additional extraction sites or interaction with other land uses may include: decreased primary productivity due to decrease in diatoms and other benthic algae and increased densities of rooted aquatic plants, unusable to most aquatic invertebrates; changed invertebrate assemblages due to change in species composition, reduction in drifting organisms (primary food sources for many salmon), and slow biotic colonization onto substrates; reduced food availability to fish; loss of well-aerated gravels for spawning and incubation of eggs leading to increased fish egg and fry mortality; and decrease in fish biomass and fish species diversity due to less food and covering of spawning grounds with fine sediment.

The extent of these effects depends upon conditions present in the watershed prior to removal or fill operations, natural disturbances and other land use disturbances that interact with removal or fill operations, and the safeguards that are undertaken by the operators to protect against anticipated impacts (e.g., gravel extraction above summer low flow, avoidance of salmon spawning and rearing habitats, etc.).

Table 11. Temporal Distribution Data Summary

	Columbia River	Nehalem Bay	Tillamook Bay	Netarts Bay	Siletz River	Yaquina Bay	Alsea River	Siuslaw River	Umpqua River	Coos Bay	Rogue River
Month	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
Species/Life Stage											
Cutthroat Trout *Oncorhynchus clarki* A S J L E											
Species/Life Stage											
Cutthroat Trout Kelts *Oncorhynchus clarki (K)* A S J L E											
Species/Life Stage											
Steelhead Half Pounder *Oncorhynchus mykiss (H)* A S J L E											
Species/Life Stage											
Steelhead Summer *Oncorhynchus mykiss (S)* A S J L E											
Species/Life Stage											
Steelhead Winter *Oncorhynchus mykiss (W)* A S J L E											
Species/Life Stage											
Coho Salmon *Oncorhynchus kisutch* A S J L E											
Species/Life Stage											
Chinook Salmon Fall *Oncorhynchus tshawytscha (F)* A S J L E											
Species/Life Stage											
Chinook Salmon Spring *Oncorhynchus tshawytscha (Sp)* A S J L E											
Species/Life Stage											
Chinook Salmon Summer *Oncorhynchus tshawytscha (Su)* A S J L E											
Species/Life Stage											
Chum Salmon *Oncorhynchus keta* A S J L E											
Species/Life Stage											
Sockeye Salmon *Oncorhynchus nerka* A S J L E											

Relative Abundance

- Highly Abundant
- Abundant
- Common
- Blank — Not present, Rare, or No Data Available

Life Stage

- A - Adults
- S - Spawning
- J - Juvenile
- L - Larvae
- E - Eggs

Direct Effects of Gravel Removal

Mechanical disturbance of redds increases mortality of eggs. In one study, angler wading two times per day on brown, rainbow, and cutthroat trout redds killed up to 96% and once per day just before hatching killed up to 43% of the alevins (Roberts & White, 1992). Gravel extraction procedures are much harsher than angler wading and would probably kill close to 100% if conducted while redds contain incubating eggs.

Removal of spawning gravel may limit the number of fish able to inhabit the affected stream. Reduced spawning habitat could limit salmon production in a stream. Introduction of spawning gravel is not a universal solution to limited spawning because hydraulic conditions must allow the gravel to stay in place through high flow events and other natural retention structures must be present.

Other areas of the world have documented detrimental effects of gravel mining. In a study on Lake Lucerne, whitefish and char (related to salmon) spawning in an area exploited for gravel only yielded 1.6% fertilized, viable eggs as compared to 33.3% egg success in a neighboring, unexploited area (Meng & Mueller, 1988). Unfavorable currents created by craters formed from gravel mining were thought to account for the difference in egg survival.

Riffles may scour upstream of a scalped bar (Pauley et al., 1989). If these riffles contain redds with incubating eggs, salmon eggs would be disturbed and possibly destroyed.

If gravel is removed from deposits above the level of annual high flows (bar skimming), leaving gravel of suitable size within the active channel, the available spawning area may be increased. This newly exposed gravel will not be hydraulically stable for at least one year, until worked upon by stream flows. If spawners use this gravel before it stabilizes, successful incubation of embryos may be difficult due to shifting of gravel. Under these conditions colonization by invertebrates would be restricted to highly mobile, short-lived organisms.

Fish species other than salmonids use gravel for spawning and rearing; many are dependent upon macroinvertebrates that are found in gravel. Some of these fish species are also sensitive, threatened or endangered (e.g., Umpqua chub and Oregon chub). In Europe the common sturgeon is endangered due to a combination of land uses, including extensive gravel extraction (Rochard et al., 1990). Refer to Table 9 for information on Oregon fish species, their status, habitat, and spawning requirements. Note the number and variety of other Oregon fishes that depend upon gravel for spawning.

Effects of Suspended Sediments on Fish

Suspended sediment deserves special mention for its harmful effect on salmonids and the potential connection of sediment to removal and fill operations. Reported effects of inorganic sediments on fish include:

1. Avoidance of suspended sediment, cessation of normal activities (Bisson & Bilby, 1982).
2. Reduced reactive distance during foraging bouts (Barrett et al., 1992).
3. Increased mortality of eggs due to smothering and accumulation of metabolic waste products (Neave, 1947, Cordone & Kelley, 1960).
4. Clogging or damage of buccal and/or gill membranes (Stuart, 1953; O'Connor et al., 1977).
5. Suppressed fish production (Crouse et al., 1981).
6. Increased mortality of fish at high concentration of sediment (Rogers, 1969; O'Connor et al., 1976).
7. Change of fish communities originally dominated by species requiring clear and/or vegetated waters to one dominated by species tolerant of turbidity, and of lower quality as human food (Trautman, 1957).

Sublethal levels of turbidity interfere with respiration, feeding, and orientation of larval and juvenile fish. Sublethal effects can become intolerable if levels of turbidity are maintained for longer periods of time, or if the fish must compete for food and avoid predators. Physiological

tolerance is irrelevant if the ability of the species to reproduce is hindered (Odum, 1970).

There is evidence that suspended sediment has short-term, detrimental effects on salmon and trout and may decrease growth (Figure 36). Slight increases in turbidity levels can cause avoidance or cessation of normal activities as upstream migration. Heavy egg mortality in chinook salmon, chum salmon, sockeye salmon, and brown trout has been directly linked to silting of the bottom and attendant reduction of water circulation in the gravel. Smaller sediment particles (less than 0.84 mm) are most detrimental to incubating eggs of chinook salmon and steelhead (Reiser & White, 1988).

Newly emerged salmonid fry are more susceptible to turbidity than older fish. Exposure to moderate turbidity (25-50 Nephalometric Turbidity Units - NTU) may slow growth and cause fry to leave the area. Juvenile salmonids tend to avoid chronically turbid streams unless they must cross them to migrate (Lloyd et al., 1987). Juvenile coho avoid turbid water (>70 NTU) (Bisson & Bilby, 1982). Feeding and territorial behavior of juvenile coho may be disrupted by short-term exposure (i.e., a few days) to turbid water (up to 60 NTU). Turbidity associated with storms and snowmelt has little effect on larger juvenile and adult salmon and trout due to the short-term, episodic nature of these events.

Many studies have shown the relationship between increasing siltation and decreasing success of egg incubation and emergence of salmonids (Bjornn, 1968; Hall & Lantz, 1969; Hausle, 1973; Phillips et al., 1975) (Figure 37). In a laboratory study of steelhead and chinook egg survival, the poorest survival occurred in fine sediments less than 0.84 mm in diameter (Reiser & White, 1988). Siltation from coal mining caused more than 98% egg mortality during incubation of brown trout, due to gravel impermeability and low dissolved oxygen (Turnpenny, 1980). Brook char and brown trout alevin survival and time to emergence varied directly with gravel size and inversely with sand concentration in a laboratory study of spawning gravel composition (Witzel & MacCrimmon, 1983). The best egg survival was found in larger substrate that allowed intragravel water velocities between 36 and 1550 cm/h (Reiser & White, 1988).

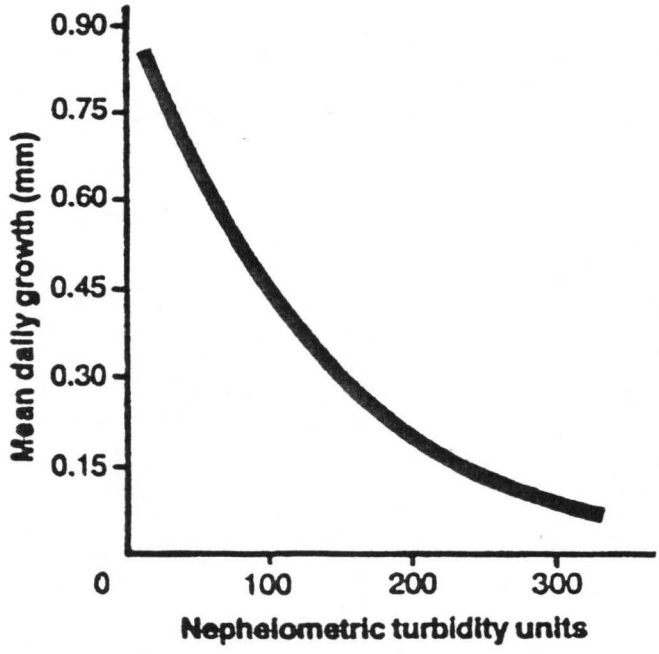


Figure 36. Relation of water turbidity to growth of steelhead trout fry (after Sigler & Bjornn, 1980)

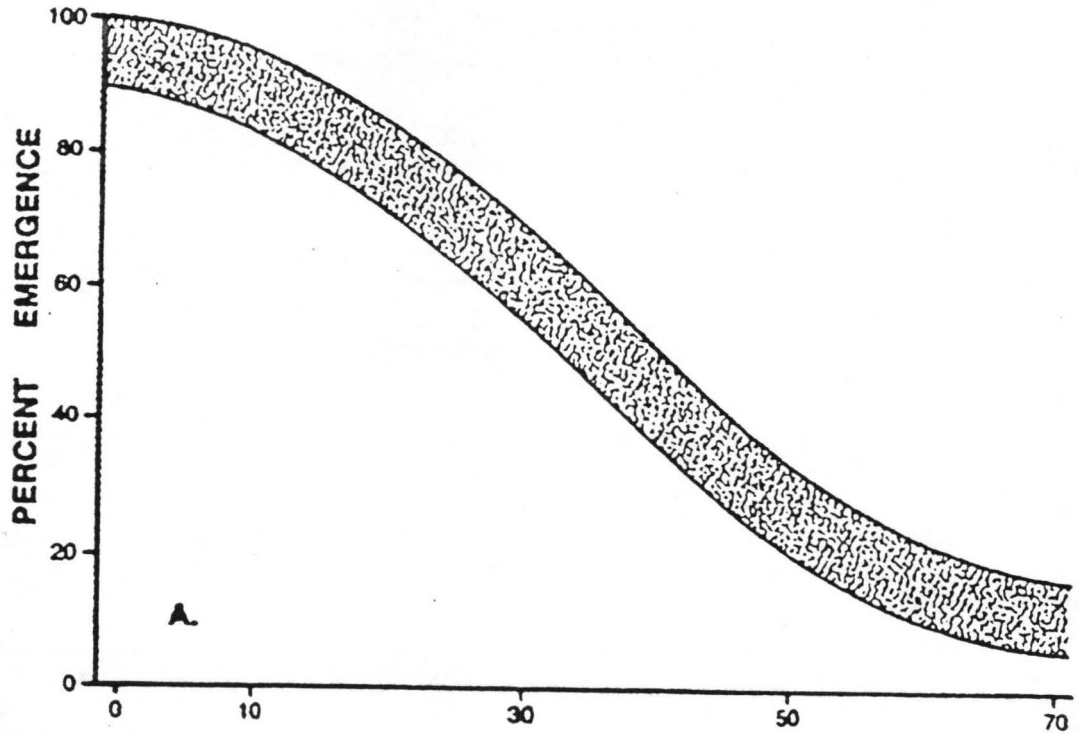


Figure 37. Relationship between increasing siltation and decreasing success of egg incubation and emergence of salmonids (Bjorn, 1968; Hall & Lantz, 1969; Hausle, 1973; Phillips et al., 1975).

There are many factors that determine the sedimentation rates within a basin and influence the quality of salmon habitat (Table 12). An understanding of watershed land use history, geology, and biota is necessary to predict the sediment budget of the basin and how it could be altered by a gravel operation. How a gravel operation alters the sediment budget and influences salmon habitat depends on the salmon species involved, current state of the basin, and type and location of the operation.

Effects of Increased Sediment Upon Other Fish Species and on Fish Interactions

Species with similar ecological requirements have common responses to siltation. As the percent of fine sediments increase in a river reach, the number of aquatic individuals typically inhabiting riffles decreases (Berkman & Rabeni, 1987). The types of fishes most affected by increasing fines are those that consume benthic invertebrates (e.g., salmon and trout) and those fish that eat aquatic plants. Fish that need clean gravel for spawning also decrease in number as the percent of fine sediments increases.

Table 12. Factors influencing risk that sediment will limit salmonid populations by degrading spawning habitat (Swanson et al., 1987).

Factor	decreasing	Level of Risk <---------->		increasing
Hydrology	winter rain hydrograph	summer rain or winter snow hydrograph	spring snowmelt hydrograph	spring-fed hydrograph
Erosive process	Surface erosion	Surface and mass erosion, channel erosion		Mass erosion
Geology	Metavolcanics or volcanics	Sandstone, siltstones		Granitics
Hillslope geomorphology	Gentle terrain	Moderate terrain		Steep lands
Stream gradient	High gradient (>5%)	Moderate gradient (1-5%)		Low gradient (<1%)
Stream geometry	Narrow–deep	<----------		Shallow–wide
Streamside forest, woody debris	Abundant	<----------		Scarce
Salmonid species	Trout, Dolly Varden	Coho, spring and summer chinook	Fall chinook, sockeye salmon	Pink and chum salmon

Effects of Sedimentation upon Salmonid Food Resources

The recovery of macroinvertebrate populations from siltation or sedimentation disturbances appears to be related to the timing and duration of scour and deposition events. If silt is not flushed out of a stream, invertebrate abundance remains low until sediments are flushed by storm flows (Tebo, 1955). If a scour event occurs as a pulse with heavy sediments and debris, a very different scenario can develop. For example, algal production and small, mobile invertebrates were high following a debris torrent in the Cascades (Lamberti et al., 1991). Areas with high disturbance tend to have invertebrate communities with higher abundance, smaller individuals, and lower biodiversity than areas with low rates of disturbance (Newbold et al., 1980; Murphy et al., 1981; Hawkins et al., 1982; Molles, 1982). Though invertebrates may be very abundant in disturbed situations, their small sizes translate to less biomass available as food to fish, in comparison to more diverse communities that would have large-bodied, longer-lived organisms in a less disturbed setting.

Invertebrate recolonizations of disturbed streams also depend on availability and stability of substrates (Williams, 1978). If substrates are shifting or cycles of sedimentation and scour are chronic, invertebrates available as fish food are likely to be lower in number and diversity than in more stable habitats. The spatial extent of disturbances will influence how long it will take for colonizers to arrive. If an area is to be successfully recolonized, small, mobile species such as baetid mayflies, midges, and elmid beetles, must be able to reach the site.

Changing the substrate composition can affect the feeding relationships in that area. Preferences for substrate size and need for small spaces between gravels vary between stream invertebrates (Li, 1989; Minshall, 1984). Removal of commercial-sized gravel most likely will alter available prey to fish (Allan, 1975; Wise & Molles, 1979). A study by Savino and Miller (1991) showed that predation of crayfish on trout was most severe when no rocks were present and was least when gravel was present in spawning grounds. The ability for strongly parr-marked (juvenile) fish to blend into their surroundings and hide from predators may depend upon the presence of gravel rather than sandy substrates (Donnelly & Whoriskey, 1993).

Effect of Temperature Upon Habitat

Temperature increases in eastern Oregon streams can be severe because of damage to riparian vegetation. Temperatures often approach or exceed upper incipient lethal limits (Li et al., 1994). Trout are temperature stressed, but some are able to seek coldwater refuges. Over time, the food web becomes dominated by invertebrates that can not be ingested by small trout. Instead, the food base of the system is redirected to birds rather than fish (Tait et al., 1994).

Removal of Riparian Vegetation and Large Woody Debris

Algal growth is stimulated by increased light intensities that occur because of riparian canopy removal (Lyford & Gregory, 1975; Gregory, 1980; Murphy et al., 1981; Shortreed & Stockner, 1982). These conditions could occur following disturbance to streambanks or floodplains associated with gravel operations. Though stream temperatures also increase, the net effects on algal production are much less than those of higher light (Brown & Krygier, 1970; Gregory et al., 1987). When both light and temperature increase, effects on other biota depend on the intensity of change and climatic conditions. In the mountains of the Cascades and Alaska for example, increased herbivorous invertebrates provided an improved food base for higher numbers of young trout and salmon (Murphy et al., 1981; Hawkins et al., 1982). Under those conditions, cool water was readily available and higher light levels enhanced algal growth. In semi-arid eastern Oregon, maximum daily temperatures exceeding 25 °C and shallow flows increase numbers of herbivorous rock-cased caddisflies and snails, but small trout do not eat these invertebrates (Tait et al., 1994). Moreover trout cannot tolerate temperatures much greater than 25 °C and will escape to coldwater seeps when possible.

Riparian vegetation provides source material for large woody debris in streams. Removing these structural materials alters hydraulics and retention in the stream. When large wood is not available for retaining debris in the stream export downstream will mean a loss of food resources at upstream sites (Golladay et al., 1987). Decrease in substrate availability for invertebrates and cover for fish will also be likely. Riparian vegetation retains soils and filters nutrients through rooting networks. When riparian vegetation is removed erosion and nutrient inputs to the stream probably will increase.

The part of the aquatic food web dependent on leaf and woody litter will be altered when riparian vegetation is removed, depending upon the extent of removal. Changes in stream retention without renewal of wood can result in lowered production for as long as 100 years (Webster et al., 1990). Observations of old streamside mine tailing sites suggest that there may not be riparian regrowth if soils are not available for plants to root. Under those extreme conditions floodplain processes, stream retention, and litter input may be reduced permanently.

Bed Degradation, Channelization, and Loss of Habitat Heterogeneity

If removal of gravel exceeds deposition, the bed of the channel may degrade (cut down) and become coarsened, unsuitable for spawning. Gravels may be depleted and transported away from the area of bed degradation. Changes in size and location of bars downstream will alter channel habitats. If the bed is lowered substantially (as in Cache Creek, CA) the river may be further isolated from its floodplain because it will take a higher flow for the river to flow out of the banks onto the floodplain.

Another condition which tends to isolate the river from its floodplain is prevention of floodplain connection by reinforcement of banks between the

pit and the river, thus channelizing the river. Channelization serves to fix the position of the channel and may narrow and simplify the channel, leading to simplification of available aquatic habitat. If the river cannot reach its floodplain, the supply of gravel and sand from the floodplain is reduced or eliminated.

If the river is not held to its engineered channel during high flow events, the river may shift into floodplain gravel pits, leading to rapid scour up and downstream from the site. If floodplain ponds have been stocked with exotic species, they will be released into the river during these high flows. If floodplain mining has affected groundwater level, the summer low-flow might be lowered, which would cause problems for fish passage and thermal regulation. Bar mining can also change adjacent channel conditions and habitat.

Gold Dredging and Mining Impacts

Information in this section was summarized from the following studies: Davies-Colley et al., 1992; Griffith and Andrews, 1981; Harvey, 1986; LaPerriere et al., 1985; van Nieuwenhuyse and LaPerriere, 1986; Quinn et al., 1992; Somer and Hassler, 1992; Starnes, 1983; and Thomas, 1985.

The studies that have been conducted on the effects of gold dredging and mining have not differentiated between chronic vs. acute effects. The acute impacts of dredge mining appear to be localized to within 100-120 meters downstream of the impact. As dredges bore down to bedrock, dredge holes become a prominent feature of the stream channel. If dredging is allowed after fish have deposited their eggs, eggs will die. Dredged silt is deposited downstream from 30-113 meters and has a negative impact on benthic invertebrates and benthic fishes. There is some ambiguity as to how dredging might affect spawning quality of the gravel. On one hand, water percolation increases, while on the other hand, dredged substrates can be less stable, which would be unsuitable for spawning. Prevention of bank scouring from dredge materials is necessary to protect riparian vegetation.

Reports from Alaska suggests that placer mining in streams may result in suspension of heavy metals and arsenic. Whereas, arsenic may or may not be a problem in Oregon, the possibility of heavy metal suspension should be monitored.

Changes in the community structure of invertebrates suggest that stream metabolism is affected to some extent (Table 13). It was suggested in these studies that prey invertebrates were more exposed in sites below dredging operations, therefore predator densities were higher. Siltation can reduce primary production for algae-feeding grazers, bury the food sources for shredders, clog nets of filterers, while increasing organic matter for gatherers. Recovery rates of aquatic insect density appears to range from one month to three months, although effects of chronic disturbance have not been well studied. Siltation can reduce interstitial dissolved oxygen in the hyporheos. Acute mortality experienced by aquatic

Table 13. Relative abundance of stream invertebrates above and below areas dredged for gold.

Invertebrate Functional Guild	Above dredging	Below dredging
predators	higher	lower
grazers	higher	lower
gatherers	lower	higher
filterers	higher	lower
shredders	higher	lower

invertebrates as a direct effect of dredging may be less than 1% over a 24-hour holding period; but in the aquatic ecosystem drift-feeding fishes would greatly increase mortality rates of these disturbed, drifting invertebrates.

Effects of Gravel Operations, Compounded by Other Land Uses

Road-building and clear-cutting can increase siltation and alter peak flows in a watershed, lowering gravel permeabilities and interfering with salmonid egg survival (Moring, 1982; Scrivener & Brownlee, 1989). Increased sedimentation within the watershed (from gravel operations, road-building, grazing, mining, clear-cutting, and dams) may cause a cascade of cumulative effects by inducing a change in the channel, decreased pool depth and number, decreased habitat space, and decreased juvenile survival by filling spaces needed for winter habitat.

Dams alter the hydrologic patterns downstream, moderating the flow so that peak flows do not occur at historical magnitudes or frequency, and thus altering the disturbance regime to which aquatic organisms have adapted over thousands of years. Competency of flows below the dam to carry sediment are also decreased. Construction of dams on the mainstem McKenzie River, Oregon and two major tributaries, Blue River and South Fork, in the 1960s altered the flow regime and sediment supply with possible negative impacts on aquatic habitat characteristics and availability (Minear, 1994). Gravel mining operations existed in the floodplain near Blue River during dam construction in the 1960s. From 1949 to 1986, exposed gravel bars between Trailbridge Dam and Leaburg Dam decreased 57% as measured from aerial photographs, and possible substrate coarsening was noted. It appears that the McKenzie River gravel is not being regenerated with winter flows due to dam interception of peak flows and sediment. Trinity and Lewiston dams and land uses encouraging severe erosion on the Trinity River in northern California have jeopardized chinook and steelhead populations by filling pools and accumulating coarse sediment on riffle gravel (Nelson et al., 1987). Another effect of dams is to cut off sediment supply, restricting recruitment of new gravels to traditional spawning areas (Reisenbichler, 1989).

Construction of Flaming Gorge Dam lowered both peak flows and competency in the Green River and led to deposition of sediment in the channel below the dam, reducing channel width and depth. Since the dam was constructed in, 1962 native fishes have declined severely due to several factors: gravel bed material has decreased (Andrews, 1983), spawning areas were inundated by the reservoir, and decreasing temperatures below the dam have been too cold for native fish. Degradation below Flaming Gorge Dam has decreased sand bars and backwater areas, which serve as refuge for aquatic organisms in the winter.

Invertebrate assemblages are altered dramatically below dams that release water in surges to produce electricity according to peak demand. Severe changes in flow occurring over short intervals reduce availability of stable habitats. These conditions result in increased numbers of short-lived, mobile invertebrates and favors those organisms able to use suspended fine food particles.

Restoration/Reclamation of Riverine and Floodplain Function

Potential Gravel Removal Operations for Restoration

It is uncertain if specialized methods of gravel extraction or dredging can bring benefits to salmon and trout. Zedler and Nordby (1986) suggested that dredging was necessary to restore the function of the channels within the Tijuana Estuary, but then cautioned that dredging disrupts benthic and peripheral habitat and that studies were needed to determine the effects of dredging on the fishes and benthic organisms. To date, studies to examine the potential benefits and deficits of this proposed technique have not be instigated. If performed, studies must be done with care because gravel bars are important channel features responsible for the formation of thermally stratified pools (Nielsen et al., 1994).

Some river morphologies lend themselves to open pit gravel operation in the near floodplain. University of California at Humbolt, has experimented with this methodology on the Eel and Mad Rivers in California. Basically, a pit (approximately 200' x 400' x 8' deep) is excavated

within the 20-year flood zone. This pit is biologically productive and will be "reclaimed" by the river in the next large flood event. Depending upon the sediment transport in the watershed, this type of extraction may be considered "sustainable."

Gravel operations could be used as a flood control tool, to enhance habitat complexity, to increase wetland habitat, or as a component in floodplain restoration. Rivers in which lateral habitat has been filled or altered could benefit from carefully designed gravel operations to restore the original habitat complexity such as the lost channels in the Willamette River. (*See caution below regarding restoration project design.*)

Some of the reclamation suggestions from (OCAPA) have potential for partial restoration of riverine and floodplain function and include: reclamation for fish habitat/rearing areas, off-channel habitat, side channels, wildlife refuge, wetlands, educational study areas, interpretive centers, and community open space (Dick Angstrom and K.C. Klosterman, personal communication). Gravel pits may have some potential for wetland habitat and use by wildlife (Svedarsky & Craford, 1982), but should not become sources of non-native fishes that would colonize adjoining rivers and compete with native fish for food. Mitigation and reclamation measures should include restoration of riparian vegetation with native species only. The following are management recommendations to enhance species diversity in gravel pits reclaimed for wetlands (Swanson, 1980):

1. Enhance large rather than small areas.
2. Maximize shoreline lengths by use of irregular, undulating edges.
3. Retain variety in topography and avoid high banks on all sides of a pond, because ducks avoid steep sides.
4. Manage the vegetation for both horizontal and vertical heterogeneity.
5. Retain some unvegetated areas.
6. Use some dead vegetation: snags, logs, and leaf litter.
7. Have some parts of a pond or lake shallow and some deep, with uneven bottoms.
8. Increase primary productivity with hay, straw, top soil, mulch or other organic matter to increase invertebrate production needed by wildlife. Temporary flooding may be useful.
9. Reduce predator consumption by using brush piles for cover underwater or on land. Islands as nesting sites may reduce predator loss. Waterfowl brood rearing areas must be close to nesting sites to reduce excessive duckling losses.
10. Provide perches and loafing sites for birds: snags, floating rafts, and rocks or small islands.
11. Encourage nesting by leaving dead trees with woodpecker cavities, adding nest boxes and by reducing human disturbances.
12. If accelerating plant succession is desirable, it can be favored by: (a) planting, (b) seeding and fertilizing some areas, (c) grading some lake edges with shallow slopes which encourage rapid vegetation, and (d) moving in muddy substrate from other areas, with its seeds, propagules, and fertility to speed up plant growth.
13. If slowing plant succession is desirable, it can be accomplished by: (a) not reforesting, (b) placing ponds where they will not be flooded, and (c) use of fire or moving to set back succession. In this case the pond must have a good clay seal so it will hold permanent open water.
14. Special management tools may be employed for particular species such as raw vertical banks for nesting bank-and rough-winged swallows and kingfisher.

Cautions on Restoration/Reclamation Project Design

Much energy and large amounts of public funding are going into stream restoration projects to restore degraded salmon habitat. There may be opportunities for industry and the ODSL to enhance habitats for sensitive, endangered and threatened vertebrates associated with ponds, sloughs, and backwaters. The industry appears to be willing to do so, judging from OCAPA's interest in establishing premium reclamation procedures. However, any projects undertaken of this nature must be carefully designed and monitored to enhance, rather than detract from, natural riverine and floodplain function. For instance, the 1:3 gradient suggested in the premium reclamation practices is far too steep to create good wetlands. Introductions of game fishes or bullfrogs can work against sensitive native species by introducing exotic predators or undesirable levels of competition. Species such as the western pond turtle are vulnerable because of these predators. In fact, approximately 70% of species listed as threatened or endangered acquired this status because of introduced game fishes (Lassuy, 1994).

It is tempting to promote in-channel gravel extraction as a means to restore stream habitat, particularly large pools. Sedell and Everest (1991) found that the quality and number of deep pools had diminished in eastside streams that had erosive land uses. Pools greater than 0.9 m deep are important resting habitats for migrating spring chinook salmon (Berman & Quinn, 1991). When pools are greater than 3 meters deep, one of two conditions may develop: (1) discharge to volume ratio is low or (2) mixing of the water column is inhibited by channel structure. In either of these cases, thermal stratification occurs, with cooler water found deeper in the pool. This cooler water provides thermal refuge for spring chinook salmon or summer steelhead trout (Nielsen et al., 1994). Thus, construction and maintenance of large, deep pools that function ecologically as salmonid habitat has promising potentials, but is a more complicated matter than merely pulling gravel out of a shallow pool.

Reliance on stream restoration should be put in proper perspective. The processes of in-stream and ecological succession are not well understood (Fisher, 1983). These processes are not understood well enough to allow manipulation of an altered system to a more predictable, desired state. Without this understanding a discussion of stream restoration can not be made with any confidence, especially the use of harvesting gravels to restore streams suffering from increased bedload deposition into the stream channel. Recovery times following disturbance as measured by different criteria can vary from a few short weeks (Larimore et al., 1959) to a few short months (Bramblett & Fausch, 1992; Pearsons et al., 1992), to years (Hanson & Waters, 1974), and centuries (Naiman & Sedell, 1980), depending on the size of stream, the magnitude of the flood, the season, and the availability of colonizing sources. Recolonization of the stream can take on different patterns depending on these variables, and is not strictly a linear process; it is probably more regulated by physical factors than biotic ones (Fisher, 1983).

For these reasons stream restoration projects must work within the watershed context from established baseline conditions, be carefully planned and fully monitored for effects and impact upon salmon populations.

Oregon Estuaries

Potential Impacts of Estuarine Dredging and Gravel Extraction

Ecological impacts of gravel removal have not been monitored in Oregon estuaries. Yet, gravel removal has been a major use of the Chetco River estuary, where a company constructed temporary gravel dikes around a gravel removal area to minimize pollution (ODSL, 1973; Ratti & Kraeg, 1979). Three gravel removal areas have been reported in the Rogue estuary (ODSL, 1973).

Permanent damage to estuarine sediments is usually due to poorly planned or ill-advised dredging and filling (Odum, 1970). Dredged materials have been dumped in the bay subsystem of some Oregon estuaries. This dumping into waters has been linked to: (1) smothering of benthic organisms (Bottom et al., 1979), (2) low productivity and toxic effect on the biota caused by resuspension of toxic chemicals and pesticides from sediments (Anthony et al., 1993), and (3) turbidity increase and oxygen depletion (Odum, 1970).

Long-term increase in the gradual deposition of sediment particles in estuaries can increase the intertidal area and marshes at the expense of submerged habitat (provided that no net loss of estuarine area occurs by other causes). Johannessen (1964) reported that the appearance of abundant circular clumps of vegetation, 0.3 to 15 meters in diameter, in aerial photographs of estuarine mud flats indicates marsh expansion caused by filling of the estuary with sediments. Replacement of submerged habitat by marshes has been reported at least for Nehalem, Tillamook, Umpqua, Coos, Coquille and Alsea estuaries. This pattern strongly suggests accelerated sedimentation and turbidity in many Oregon estuaries. The increase in sedimentation can also reduce the influence of saltwater in the estuary (providing downstream flow patterns are maintained). Increases of intertidal area and freshwater inflow in the estuary can result in many species being displaced or removed by fewer species pre-adapted to less productive habitat (Gaumer et al., 1985).

Potential Impacts of Estuarine Filling on Salmonids

Primary sources for this section are: Odum, 1970; Simenstad et al., 1982; and Gaumer et al., 1988.

The long-term effects of commercial, urban, agricultural, and industrial development adjacent to estuaries and upstream areas have significantly reduced vast acreages of estuarine marshland in many Oregon estuaries (e.g., Alsea, Coquille, Coos, Netarts, Tillamook, Umpqua, Chetco, Sand Lake, Siletz, Yaquina). Huge areas of Oregon marsh have been diked to create upland for pasture and other uses (Bottom et al., 1979). In the Coquille estuary, for example, about 96% of the marshes that historically covered the estuary were filled by the 1970s.

The significance of estuarine rearing to juvenile salmon has only recently been recognized. All Pacific salmon species utilize deeper water in bays, but sub-yearling chum salmon and chinook salmon utilize shallower habitats closer to the shoreline, which are more susceptible to filling operations. The effects of filling for the creation of new land are destructive to the estuarine environment. Dikes and port structures can impair productive fish habitats as well as fish access to rearing areas. Roads built across estuarine salt marshes affect water interchange. In Oregon, channelization and jetty construction in the Rogue estuary have been involved in the loss of estuarine habitat for Rogue River spring chinook.

Young salmon smolts have commonly been considered to be strictly planktivorous (i.e., feeding on floating organisms) and the importance of benthic (bottom-dwelling) food resources has only recently been recognized. Intertidal banks and mudflats are more productive than most of the oceans. Thus, a landfill may permanently remove the most critical feeding areas for salmonids and impair the food webs that support them.

Shallow water affords greater protection for juvenile fish and crustaceans. Because of high productivity levels, concentration of detritus, and protection factors, these edges are typically areas of high abundance of organisms. Chinook salmon in marsh habitats prefer tidal channels with low banks and many subtidal refugia. Reductions in salmon prey resources have resulted in part from the destruction of invertebrate habitat by dredging and filling activities.

Filling of productive areas may also be implicated in the reduction of salmon populations as a result of changes in the amount and sources of organic carbon entering detritus-based food webs. Food supply is a critical factor that influences the maximum number of juvenile salmon an estuary can support (carrying capacity). Production of chum salmon and chinook salmon juveniles is limited by food availability in some estuaries. Thus, filling operations could reduce the carrying capacity of estuaries.

Any process which re-suspends oxidable sediment particles in the water column is capable of reducing the oxygen concentration and result in unsuitable conditions for the normal biota. Filled areas may restrict circulation to the point where stratification occurs and the bottom layer oxygen levels are too low. Degradation in water quality may force juvenile and adult fish to avoid areas of low oxygen or high waste levels and be forced to migrate to other areas where they are subjected to higher predation.

Suspended solids from filling or dredging activities can kill or injure fish by clogging and coating gill filaments, by producing abrasive

injuries, or by releasing toxic substances. Reduction of light penetration and changes in primary production due to increase in turbidity can favor ecologically less desirable species that affect food webs reducing availability of key food organisms, decrease growth of juvenile salmon or modify normal residence times in altered habitats.

Losses and alterations of estuarine habitat have probably contributed substantially to the decline of many salmon runs. Survival of juvenile chinook salmon seems to depend on a threshold size that fish must attain prior to ocean entry. In turn, size at ocean migration depends in part on available habitat and prey resources. Although it is possible to distinguish and/or infer several consequences of filling operations, these factors and other cumulative impacts on salmonids (e.g., logging, mining, dams, fishing) cannot be treated separately to quantify the relative importance of different impacts on the long-term abundance trends of salmonids.

Cumulative Impacts in Estuaries

Ecological processes in the most pristine estuaries are tightly linked to physical and chemical characteristics as a result of long periods of adaptation and evolution of organisms. Changes in carrying capacity (i.e., ability to support organisms) in one habitat can also affect populations in nearby habitats. The carrying capacity of estuaries has been dramatically reduced from historical levels by human activities (e.g., filling, diking, dredging, logging, bulkheading, pollution and other impacts). Altered estuaries also show more unpredictable variations than those seen in more pristine estuaries (Copeland, 1970).

The tremendous human demands on estuaries not only have decimated many commercially important species, but also their habitat and their food organisms. Invertebrates, in particular, are essential links in virtually every major food chain. Therefore, critical habitat for organisms in lower trophic levels (e.g., invertebrates and plants) is essential habitat for the maintenance of salmonids. The central element in the extinction of estuarine and marine invertebrate species is habitat destruction (Carlton, 1993). Invertebrate species are disappearing in great numbers from nearly all habitats on earth and entire invertebrate biotas have most likely vanished (Hadfield, 1993). The decline in commercial catches of many populations of estuarine-dependent fish and shellfish since the last century coincide with the loss of estuarine habitat and the decline in the quality of remaining habitats.

Many cumulative disturbances have been caused by unprecedented increases in human activities along estuaries and upstream areas. Their effects include:

- Filling destroys wetland habitat and directly reduces carrying capacity.
- Diking eliminates sources of organic matter and prevents migration of organisms between habitats.
- Removal of gravel and sand can destroy or damage fish spawning habitat. Additional turbidity can cause short-term and long-term adverse changes in fish habitat.
- Dredging creates sediment instability, removes substrate, increases turbidity, reduces primary production and may kill planktonic and benthic organisms. Dredging destroys benthic plants that stabilize sediment, prevent excess water turbidity, and aid in nutrient recycling.
- Pollution: The fine sediment particles found in estuaries not only concentrate nutrients and minerals useful to organisms, but also toxic substances such as petroleum byproducts, persistent pesticides, and radioactive pollutants. Species composition may change significantly due to sewage.
- Biological magnification: Many organisms ingest detritus particles in estuarine sediments. These particles can increasingly concentrate pollutants toward higher levels in the food web. An example is the concentration of DDT in birds of prey.
- Fresh water diversions: Reduced fresh water inflow to estuaries eliminates nursery areas for fish and shellfish and allows marine forms to replace more productive estuarine species and valuable fisheries.

- Biological invasions: Exotic species are a great threat to the function of natural communities of plants and animals and have had catastrophic impacts on native species, fisheries, and local economies. Ocean-going ships carry ballast water containing a broad spectrum of species that are taken on in another port and released at subsequent ports of call. Many species have also been intentionally or accidentally introduced through aquaculture and human propagation.

- Alteration of the food webs: The low diversity of species and the harsh natural environmental conditions in estuaries explain why the entire energy flow of estuaries can be altered by impacts such as pollution and introduction of non-native species. Modified food webs are unstable and may favor ecologically and economically less desirable species.

- Depletion of dissolved oxygen: Resuspension of estuarine sediments by dredging, filling, diking or other activities can result in removal of dissolved oxygen from the water as these sediments oxidize.

- Turbidity: Many of the sediment problems have been due to large-scale discharges of sediment from gravel washing or mining operations. The damage caused by operations involving sediment manipulation (mining, bulkheading, dredging) in many cases has exceeded the perceived benefits of development. Suspended sediment resulting from removal of materials or filling may not necessarily reduce primary production, but it can reduce the growth of algae ingested by most species and increase the growth of types of algae which have little or no importance as food for herbivores.

Summary

Essential Indigenous Anadromous Salmonid Habitat

How is "essential indigenous anadromous salmonid habitat" defined? Critical or "essential" habitats are those habitats required for each stage of an organism's life cycle. Essential habitats vary from species to species and from stream to stream depending on the characteristics of the streams and the life-cycle requirements of each species. Fish populations are often controlled or limited by available spawning, rearing, and overwintering habitat. Several types of habitats may be critical at different times in the seasonal cycle of salmonids and throughout their life cycle. Thus, any disturbance that degrades these habitats may reduce the essential, critical habitat of salmon.

Determining critical minimum stream habitat for salmon and trout is difficult because communities of salmonids utilize different portions of a stream network. For instance, some streams will have spawning of pink and chum salmon in the lower part of the river, chinook salmon in the mainstem, coho salmon and steelhead trout in lower elevation tributaries, steelhead, rainbow, cutthroat, and bull trouts in higher elevation sites within the basin. In addition, each species utilizes different portions of the stream network depending on the life stage. For example, subyearling chinook, pink, and chum salmon rear in the estuary. Competition among species for spawning gravels, food, and rearing area is minimized by either using different habitats during the same time span or by using similar habitats at different time spans. Most of a particular river system may be used by the various salmon and trout species throughout the year.

Another difficulty in determining essential habitats is that both habitats and populations are dynamic, changing over time. Gravel beds form and flush out, depending upon disturbance events, erosive geology, and stream geomorphology. Mortality at each life stage of salmon varies due to different limiting factors. For example, spawning gravels may be a limiting factor for one generation; another generation may face a relative shortage of overwinter rearing habitat.

Based upon the analysis of this study, it can be concluded that essential indigenous anadromous salmonid habitat should be defined as the entire

watershed from the headwaters through the estuary, as they are ecologically linked and each component is critical to ecosystem function and salmon survival.

After a thorough review of salmon status and habitat requirements relative to in-channel gravel operations and their potential effects, there is no ecological basis for the suggestion that 20% of Oregon waterways will provide adequate habitat for remaining salmonids. Under the present circumstances, no areas have been identified where gravel can be mined without constraints.

Impacts of Gravel Removal on Salmon Habitats

Oregonians need to act quickly to save their native fish fauna and associated habitats. Forty-four percent of Oregon's native fishes are either endangered, threatened or of special concern (Williams et al., 1989; Warren & Burr, 1994). A major reason for this decline is that watershed catchments have deteriorated in quality because of poor land-use practices (FEMAT, 1993; McIntosh et al., 1994; Li et al., 1994; Karr & Chu, 1994; Wissmar et al., In Press). At least 268 anadromous salmonid stocks are at risk or of special concern in Oregon. (Nehlsen et al., 1991). It has been only 18 years between a peak in Oregon coastal coho fisheries and the petitioning of all coho stocks from northern California to the Canadian border for listing under the Endangered Species Act. All stocks of chum salmon are on the State sensitive species list at the critical level. South coast steelhead are being considered for listing under the federal Endangered Species Act. Many populations of cutthroat trout are in decline. Snake River chinook salmon are threatened and south coast stocks are declining. Other native fish species are imperiled, and while not all of these species are economically important, each of them represents an important thread in the interconnected ecosystem of which salmon are a part. This warning is loud and clear -- aquatic habitats must be protected to maintain ecological function and to support salmonids.

While a wide number of potential impacts are known for gravel removal and fill/alteration projects, a focus on such impacts will miss the "larger picture." While not minimizing such effects, it must be stressed that new management approaches need to be developed for all activities affecting Oregon's streams, including the removal of gravel. There simply is too much uncertainty in predicting permit-by-permit impacts to manage effectively under present methods.

Although natural resource management in the face of uncertainty is unavoidable, management policy should be considered an experiment where critical knowledge is obtained and better management results. This philosophy is the essence of adaptive management. However, there are several caveats to adaptive management:

1. Adaptive management should not be used as an excuse to maintain present practices without review (i.e., "business-as-usual").
2. Goals, milestones, red flags (possible problems) and decision points should be clearly identified.
3. Objectives should be explicitly stated as testable hypotheses.
4. Effects of policy must be monitored so that red flags can be detected early.
5. Clearly, the purpose of adaptive management is to preserve future options. If the policy is in error, the salmonid resources must not be placed at increased risk.
6. Most of the new field of restoration ecology is premised on the notion that ecological succession is predictable and that with cessation of disturbance, everything will return to "normal," which is often impossible to define. In fact, the understanding of succession in streams is still in its infancy. There is a distinct possibility that a stream ecosystem can be so damaged that it will not return to its previous state.

Adaptive management is important because ecological interactions within salmon and trout ecosystems are complex. Management actions designed to favor only salmon at the expense of other species can backfire badly, and history has provided excellent examples. In short, best management practices for salmonids result from managing to benefit all species within the fish community.

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WATER QUALITY PROCESSES

Types of Water Quality Effects

Water quality effects are discussed in terms of **on-site** and **cumulative effects**. **On-site effects** are those that are immediately associated with the gravel removal operation both in space and time. Spatially, on-site water quality effects are usually localized in the vicinity of the operation and include immediate downriver changes such as turbidity plumes. Temporally, on-site water quality effects are those that occur during or immediately following the removal operation, such as decreased dissolved oxygen due to resuspension of organic matter and its subsequent assimilation by bacteria.

Cumulative water quality effects are those generally removed either in space or time from the gravel removal operation. For example, induced changes in channel morphology resulting from gravel removal operations may occur at considerable distances both upstream and downstream of the gravel removal site and may occur over an extended period of time after gravel removal has ceased.

Water quality effects may vary depending on the type of gravel removal operation. General categories that will be used to differentiate gravel removal operations are: in-channel removal, bar scalping, and floodplain mining. In-channel removal refers to subsurface operations in which gravel and other substrate is removed to control river hydraulics (navigation, flow channeling, and diversion) and possibly for gravel harvesting. Bar skimming or scalping refers to removal of gravel at point-bars on bends in rivers and usually occurs above the water surface (during low-water periods) within the active river channel. Floodplain mining refers to gravel removal operations above the normal high-water line of the river channel, but within the historical floodplain of the river (100-500 year frequency flood).

On-site water quality effects from gravel removal operations may produce changes in several water quality parameters, including: turbidity (clarity), dissolved oxygen, pH, toxic compounds (metals and synthetic organic compounds), and nutrients (nitrogen, phosphorus). Other water quality effects may occur in unique situations, such as release of pathogenic bacteria and other microorganisms. Cumulative water quality effects resulting from different processes than those causing on-site effects include changes in water temperature, dissolved oxygen, and turbidity. The creation of low velocity "holes" leads to the accumulation of sediment fines with associated sorbed toxic compounds to form poorly consolidated "fluff zones" prone to anaerobiosis. The interrelationships between gravel removal and on-site and cumulative water quality effects are illustrated in Figure 38 and Figure 39.

Sources of Contaminants in Sediments

Point Sources

In many gravel removal operations, water quality effects result from contaminated sediments that are released to the water column after sediments are resuspended. For this reason it is useful to have a knowledge of general sources of contaminants in the river to better predict their presence in sediments.

Point sources of contamination are those that are discharged into the river or its tributaries in a specific, identifiable, artificial conduit such as a pipe or channel. These include discharges of wastewater effluents from municipal treatment plants, from industrial treatment plants, and possibly from commercial or agricultural activities. All legal point-source discharges should have NPDES permits that list contaminants in the discharge that are regulated.

For municipal discharges, regulated parameters include oxygen-demanding materials (organic compounds) usually measured as biochemical oxygen demand (BOD) or chemical oxygen demand (COD), pathogenic bacteria and viruses, nutrients where eutrophication is a problem (nitrogen and phosphorus in various forms), and

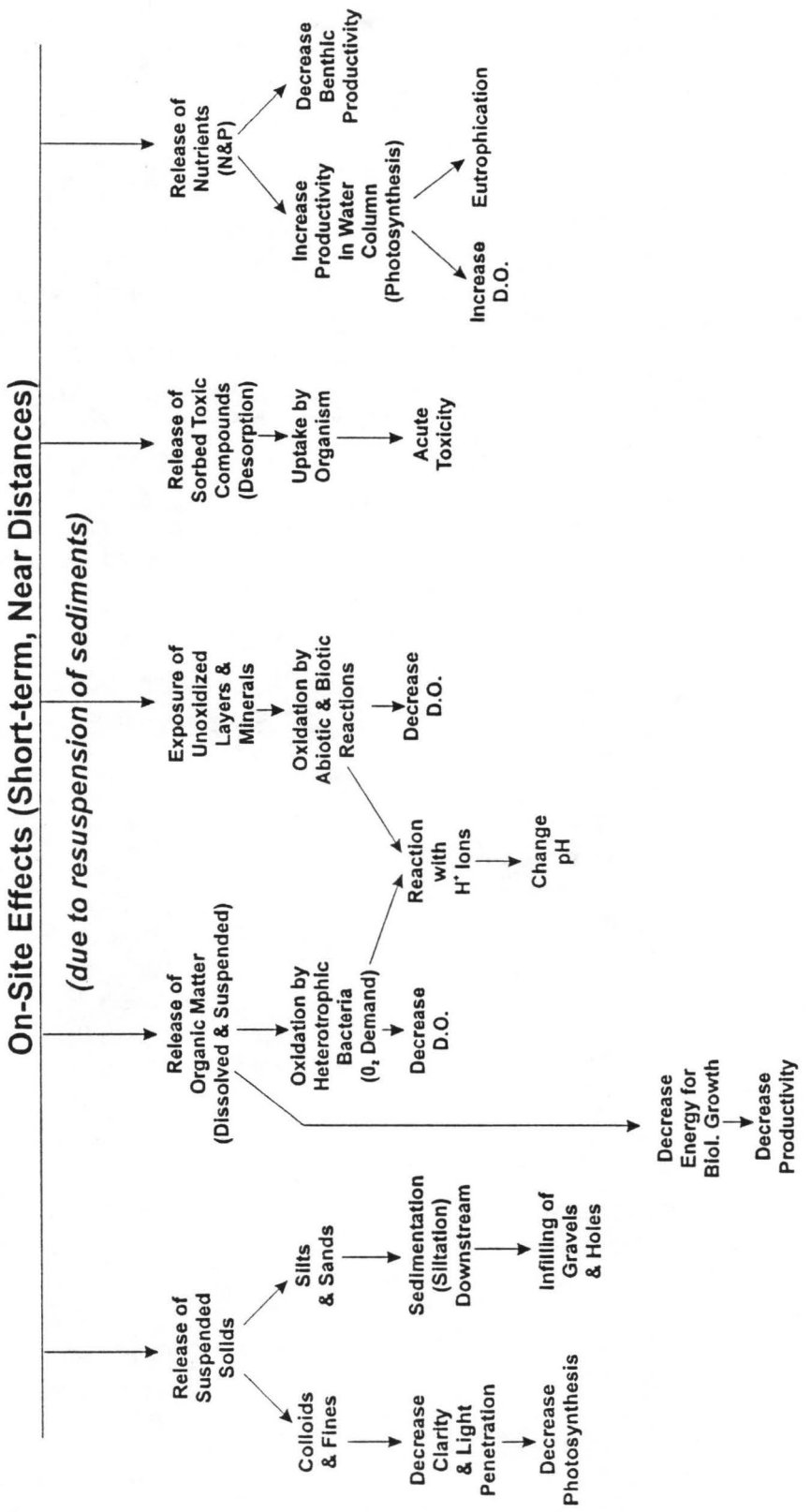

Figure 38: Potential On-Site Water Quality Effects Associated with Gravel Removal

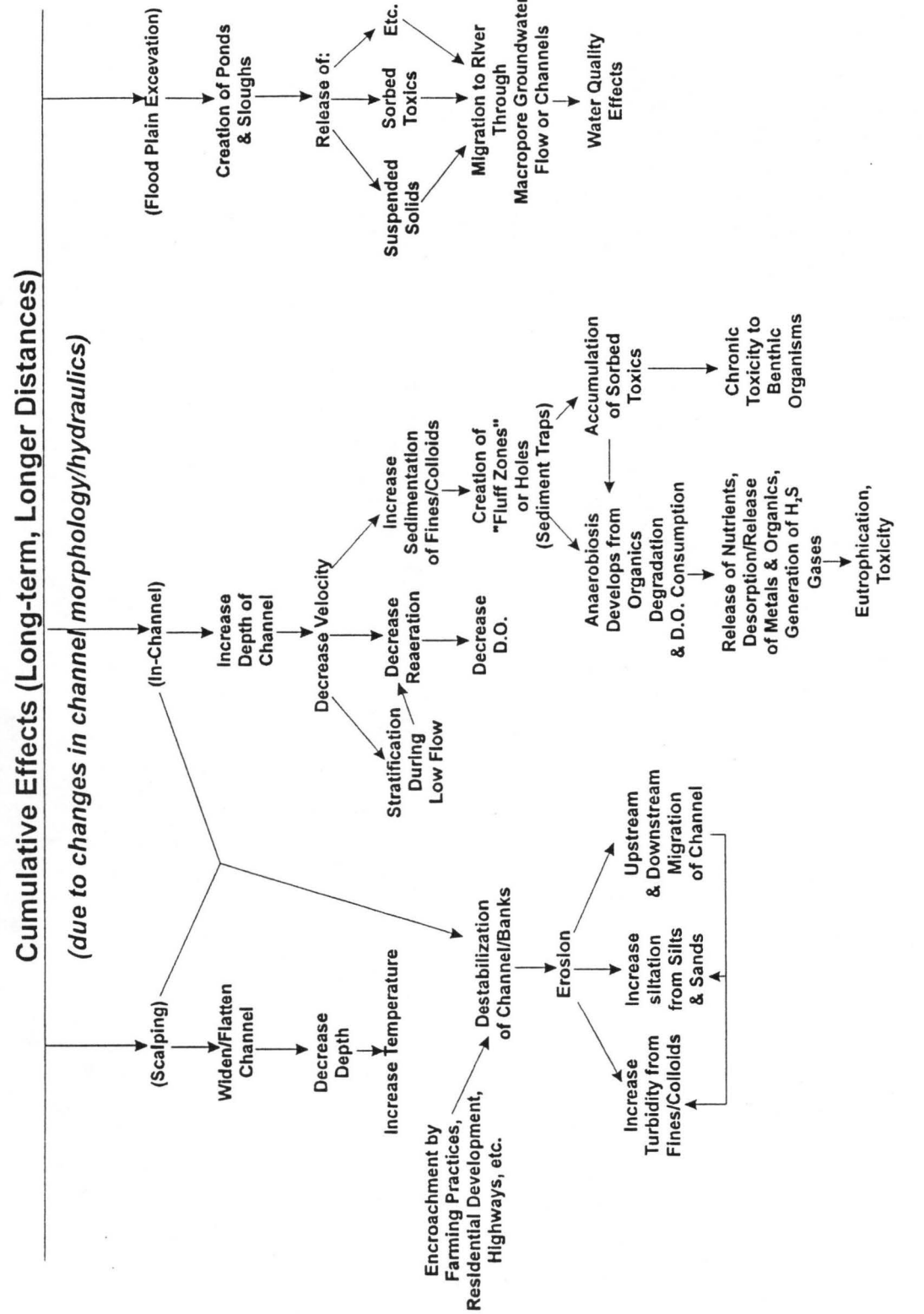

Figure 39: Potential Cumulative Effects Associated with Gravel Removal

toxic compounds (heavy metals and synthetic organic compounds). Of these, the contaminants of greatest concern in terms of potential contamination of sediments that may affect gravel removal operations are toxic compounds. Specific knowledge of suspected toxic compounds for a municipality may be available in the NPDES permit if industrial or commercial wastewaters are processed in the municipal treatment plant. In general, municipal discharges are a source of heavy metals due to their ubiquitous presence in municipal wastewater even if only of domestic (household) origin. Metals are usually present because they originate from corrosion of water distribution systems and include cadmium, lead, copper, and zinc. Other metals that may be present at elevated levels in municipal systems include chromium, mercury, tin, nickel, cobalt, and silver.

Toxic organic compounds that may be present in municipal wastewater discharges are best described by classification into groups of compounds. A variety of pesticide compounds may be present from domestic uses around the home and yard, from municipal uses in facilities such as parks, from commercial and industrial uses (usually requiring a permit), and occasionally from agriculture practices within the urban boundary. Pesticide compounds of greatest concern are those that are persistent because they resist biodegradation in the environment. Most persistent pesticides are chlorinated organic compounds. The most notorious example of a persistent pesticide is DDT. Although DDT use has been banned for more than 20 years now, its metabolic residues such as DDE, often as toxic and more mobile in the environment than DDT, are still found in the sediments of major river systems. Other persistent pesticides include pentachlorophenol and its metabolic residues, aldrin, dieldrin, chlordane, 2,4-D, and 2,4,5-T. Besides pesticides, industrial organic compounds may be present but these would have to be suspected from the type of industry or from NPDES permit information. Other industrial organic compounds, such as PCBs, may be present from their widespread use in electrical equipment in residential, commercial, and industrial sectors. In general, most industrial contaminants are most likely to enter the river directly from industrial point source discharges.

Industrial point source discharges require an NPDES permit which should provide information on the nature of the effluent compounds discharged. If combustion or incineration processes are involved, such as in coal-fired thermal electric power plants, polyaromatic hydrocarbons (PAHs) are a concern. In the pulp and paper industry, chlorine bleaching of wood pulp results in formation of a suite of chlorinated organic compounds, of greatest concern being the highly toxic dioxins and dibenzofurans that are formed in the process and discharged in minute quantities.

Overall, a thorough review should be undertaken of point source discharges upstream of gravel removal operations to determine whether contaminants of concern, particularly toxic compounds, may have contaminated sediments in the river bed where gravel removal operations are proposed or in the zone of influence where bed sediments may be affected (upstream and downstream) by gravel removal operations.

Nonpoint Sources

Nonpoint sources (NPS) are defined as those diffuse sources of water contamination that are not directly discharged to the receiving water from specifically identifiable, artificial conduits (points) such as pipes. Most NPS discharges result from stormwater runoff from various land use practices, although contaminated groundwater may also become a NPS. General categories of NPS are runoff from land use practices in agriculture, forestry, mining, and residential-urban areas. Contaminants contributed directly from precipitation that may contain air pollutants (such as acid rain) are also considered a NPS. Recently, the EPA has reclassified stormwater runoff in urban areas as a point source that is controllable if it is discharged through storm or combined sanitary-storm sewers.

As for point sources, contaminants of greatest concern from NPS are toxic compounds that may have accumulated in sediments. The type of land use practice is usually indicative of contaminants to be expected. For agriculture, pesticides are of great concern including insecticides, herbicides, fungicides, rodenticides, and soil fumigants. Since agricultural operations generally do not require NPDES permits, specific practices need to be

reviewed to determine which pesticides are used. Besides pesticides, agriculture is also the major NPS for nutrients. Fertilizers are relatively inexpensive and heavily applied in most agricultural practices. Runoff of nutrients from fertilizers may occur through surface runoff and erosion, especially where bare soils exist such as row crops, and through groundwater that becomes contaminated from excess nutrients that leach and migrate through the soil to the water table. Irrigated agriculture return flows can be a major source of contamination to rivers.

Forestry operations (silvicultural practices) are major sources of suspended solids and turbidity from disturbed and bare soils that are created, principally from road excavations and from logging skid roads. Wide-spread use of herbicides for brush control may also contaminate runoff waters. Herbicides applied are numerous and include silvex, 2,4-D, and 2,4,5-T. Specific sites and operations need to be reviewed to determine herbicide practices. Silvicultural practices may also call for the use of fertilizers which will increase nutrient concentrations in forest runoff.

Mining operations are major sources of metals and of strong acids. Sulfuric acid is created in mine tailings from oxidation of pyrites, primarily iron pyrite (FeS_2). This strong acid dissolves and leaches metals from minerals in the tailings piles, the runoff from which can be extremely toxic. Specific mine operations need to be reviewed to ascertain the type of operation involved and possible contaminants. One mining practice of particular concern is heap-leach mining for gold, in which hydrogen cyanide solutions are used to leach gold and other metals from low-grade ore piles. If not properly contained, spent leachates containing toxic quantities of cyanides and metals could contaminate groundwater and surface waters.

Residential and urban runoffs are important sources of a variety of water contaminants, most important among them being toxic substances, nutrients, and pathogenic organisms. Residential developments, especially if unsewered, can be important sources of nutrients and pathogenic organisms from septic tank leach fields that contaminate groundwaters and possibly surface waters (failing systems). Heavy use of fertilizers and pesticides in residential lawns and gardens also contaminate runoff waters and groundwater with nutrients and toxic substances. Stormwater runoff in residential, and especially urban areas, may be heavily contaminated with a variety of contaminants, including nutrients, oxygen-demanding substances, and toxic compounds. Important toxic substances include lead from gasoline and other metals from industrial activities and combustion processes, chlorinated industrial organic compounds such as solvents, and combustion products such as PAHs and dioxins.

On-Site Water Quality Effects from Gravel Removal Operations

On-site water quality effects from gravel removal operations are those that occur during or immediately following the removal activity, and are localized to the site vicinity and immediately downriver from the site. On-site water quality effects result primarily from the resuspension of sediments. Resuspended sediments can be generally fractionated into colloidal particles and fines (particles sized less than about 10 to 50 micrometers) that have low settling velocities and thus remain in suspension for hours to days, and silts and sands that have relatively rapid settling velocities and settle within minutes to hours. Resuspended colloids and fines cause turbidity and constitute a water quality problem both directly and from the decreased clarity and light penetration in the water column. Suspended solids are harmful to aquatic organisms and fish either by their smothering action, reducing oxygen and other gas transfer through the gills, and by their abrasive action on gills and other sensitive organs. Turbidity decreases the euphotic zone depth and results in decreased photosynthetic activity and lowered production of oxygen, hence, a decrease in the dissolved oxygen concentration in the water column. Silts and sands have short residence times and travel distances downriver from the removal operation but are relatively easily scoured and move as bedload along the river bottom until they reach the next low-velocity zone.

Release of particulate organic materials and dissolved organic compounds occurs as sediments are resuspended. The biodegradable fractions of these organic compounds are assimilated by aerobic, heterotrophic bacteria as a food source. During this metabolism, dissolved oxygen (DO) is

consumed and the DO concentration in the water column is reduced. For sensitive organisms such as salmonids, dissolved oxygen concentrations must remain above a threshold value of about 5 mg/L (depending on temperature, organism type and life stage, etc.). Often, other sources of oxygen-demanding materials (e.g., point source effluent discharges) have already consumed DO to the point that no further reduction can be tolerated.

Sediments in rivers, estuaries, reservoirs, and lakes can be described as consisting of layers of sediment deposited over time. The surface layers usually consist of the most recently deposited materials, while subsurface layers represent sediments buried under more recently deposited materials. This regime may be altered by scouring of surficial deposits, removing more recent sediments and exposing subsurface sedimentary layers. Processes that mix sedimentary layers are also possible, including natural bioturbation of benthic organisms and unnatural turnover of sediments by human activities. The latter events include gravel removal operations, dredging, anchor dragging, channelization, and many other activities. Most water columns in rivers are oxygenated and therefore surface layers in sediments contain oxygen and are exposed to aerobic oxidation reactions, dominated by biologically mediated heterotrophic bacterial metabolism of organic materials. However, in sediments that contain readily oxidizable organics, oxygen is rapidly consumed as it diffuses from the water column into the sediments and often only penetrates a short distance before it is depleted and anaerobic conditions (anaerobiosis) develop.

Anaerobiosis in sediments results in a radically different biochemical metabolic regime, dominated (in ecological succession) by nitrate reduction, sulfate reduction, fermentation reactions to produce organic acids, and finally methane generation. Important among these reactions in terms of toxicity are sulfate reduction to produce hydrogen sulfide, and solubilization of ammonia from fermentation of proteinaceous materials, such as wastewater sludges. Free sulfide forms (hydrogen sulfide and bisulfide) and ammonia are acute toxins to most fish and aquatic organisms. Both sulfides and ammonia, depending on concentration, can severely deplete DO from exertion of oxygen demand as they are re-oxidized to sulfate and nitrate, respectively (the latter process known as nitrogenous oxygen demand, or NOD).

Exposure of unoxidized (anaerobic) layers of sediments by gravel removal and other operations can lead to appreciable oxygen demand, both as biochemical oxygen demand (BOD) and as chemical oxygen demand (COD) from oxidation of reduced inorganic compounds (e.g., ferrous iron, sulfides, ammonia). Oxygen depletion of the water column occurs in the vicinity of and downriver from the gravel removal operation. Sediments with high organic matter fractions and with high fractions of fine materials would be most likely to exert high oxygen demands. This oxygen depletion effect will be greatest during and for a short period after the gravel removal operation, depending on river flow rate and the extent of sediment reconsolidation.

Sediments that are reactive and that undergo chemical reactions when resuspended, such as oxidation reactions of organic compounds and unoxidized layers as described above, also react with hydrogen ions during these reactions and can experience changes in pH. The extent of pH change is governed by two dominant factors, the alkalinity (buffering capacity) of the water, which resists changes in pH, and the concentration and reactivity of unoxidized materials in the water column, which determines the rate at which hydrogen ions are produced or consumed. Under most circumstances, unless sediments are highly altered in composition by point source effluents as in the vicinity of wastewater outfalls, pH changes are not expected to be great enough to be of concern from gravel removal operations.

Release of sorbed toxic materials during gravel removal operations is a water quality effect of great concern that needs careful evaluation. Toxic compounds present in point and nonpoint source discharges (discussed above) are generally associated with particulates (suspended solids) as sorbed or precipitated forms. As such, toxic compounds can become highly concentrated in sediments as suspended solids settle from the water column. Chemical and biochemical reactions in the sediments release some toxic compounds from particulate forms back into solution. Resuspension of sediments during gravel removal operations subsequently releases solubilized toxic compounds back into the water column as well as allowing

desorption and solubilization of particulate-associated forms. The net result of these reactions is the release of toxic compounds from the sediments back into the water column where acute exposure of aquatic organisms to these compounds may result. Toxic metals, synthetic organic compounds, ammonia, and hydrogen sulfide are among the toxic compounds that may be important for their potentially acute toxic effects.

Aerobic and especially anaerobic degradation reactions in sediments (discussed above) release nutrients back into solution and are subsequently released into the water column as sediments are resuspended by gravel removal operations. Most important among nutrients that may be released are nitrogen and phosphorus forms because either nitrogen or phosphorus is usually the limiting nutrient for biological growth. Increasing the concentration of the limiting nutrient enables greater photosynthetic growth of algae (phytoplankton and periphyton) which may produce deleterious water quality and aesthetic effects. This enrichment process of excessive fertilization by nutrients is most important in rivers whose water quality is limited by eutrophication.

Cumulative Water Quality Effects from Gravel Removal Operations

Cumulative water quality effects from gravel removal operations are those that have longer duration than immediate or direct effects, continuing for an extended time period (months to years) after the removal operation has ceased, and may extend over greater distances both upriver and downriver from the removal site (Figure 26). Most cumulative water quality effects result from modifications in channel morphology and river hydraulics.

Bar skimming operations, the removal of gravel at bars on the inside of river bends, generally occur during river low-flow conditions to minimize on-site water quality effects. Removal of the bar has the effect of widening the flow channel during increased flow conditions, leading to an overall widening and flattening of the river channel. The resultant shallower river channel is more susceptible to insulation and warming and therefore can increase the average temperature of the river, particularly during lower flow summer conditions.

In-channel gravel removal occurs subsurface and includes operations in which gravel and other substrate is removed to control river hydraulics (navigation, flow channeling and diversion) and possibly for gravel harvesting. The resultant deepening of the river main flow channel and possibly of the side channels and pools leads to a decrease in average flow velocity. One important effect of decreased velocity is a decrease in the reaeration rate, leading to a decrease in dissolved oxygen concentration which could be critical in an oxygen-limited river. Deep river channels and pools are also prone to stratification during low-flow conditions in which turbulence is minimal. Stratified water columns do not mix throughout their depth and can lead to severe oxygen depletion in the lower layer, or hypolimnion.

A second effect of decreased flow velocity is an increase in the sedimentation of fines and colloidal particles. These tend to collect in low-velocity zones or holes, that are created and function as sediment traps leading to the build-up of a "fluff" layer of unconsolidated sediments. An ecological consequence of the fluff layer in sediments is an inability of many benthic organisms to colonize the unconsolidated sediments where no clear interface exists with the water column. Anaerobiosis develops readily in sediment-trap, low-velocity zones by the combined effects of low reaeration and oxygen transfer and the concentration of high-organic fines. Anaerobic metabolic processes lead to the release of nutrients, possible desorption or release of sorbed or precipitated metals and organic toxic substances, and the possible generation of hydrogen sulfide (H_2S), ammonia (NH_3), methane (CH_4), and other gases. Perhaps the most important effect of sediment-trap, low-velocity zones is the creation of chronic toxicity conditions from both the accumulation and release of toxic substances and from the production of toxic H_2S, NH_3, and other gases. The contribution of released nutrients to chronic eutrophication conditions may also be important.

Floodplain Gravel Operations

Few studies have been reported on potential water quality effects in rivers of flood plain excavation of gravels. Many gravel removal operations in the flood plains of rivers occur below

the groundwater table and result in the creation of ponds and sloughs. Hydraulic connection to the river is usually semi-direct through a gravel aquifer that is river-influenced and fluctuates directly with river level. Direct open channel connections may also exist to the river. Water quality effects in the river thus depend on the directness of the hydraulic connection to the river, possible removal processes, and the extent of water quality effects generated by the gravel removal operations in the side ponds and sloughs. Flood plain water quality effects would generally be long-term and chronic as the gravel removal operations are typically continuous, and thus ponds are continuous sources connected to the river. Possible water quality effects are those associated with the on-site effects of resuspension of sediments, the most important probably being release of suspended solids and turbidity, release of sorbed toxicants, and release of nutrients.

Water Quality Impact Analysis

Some of the relevant questions about sediment transport include:

1. Will the gravel removal operation result in resuspension of sediments? If so, what quantities are expected to be released and what concentrations are expected in the stream after dilution?
2. Do the gravel deposits to be removed or altered contain readily degradable organic compounds or reduced compounds that could affect the dissolved oxygen level in the stream?
3. Do the gravel deposits to be removed or altered contain high levels of sulfides or ammonia?
4. Have any toxic materials from point or non-point source activities accumulated in the gravel deposits to be removed or altered?
5. Is any eutrophication of the stream expected from the release of nutrients from the gravel removal operation?
6. Will the effects on channel morphology potentially result in an increase of temperature in the stream to an undesirable level?
7. Will the effects on channel morphology result in low velocity zones that may concentrate fine organic materials and sorbed toxic compounds?
8. Will changes in stream channel morphology/hydraulics result in destabilization of the stream channel or banks, increasing erosion rates?

Example Methodology for Salmon Habitat Investigation

The following is a proposed list of items that might be included in the water quality investigation of salmon habitat.

Stream or river quantity:

- *water flow rates by month*
- *water flow rates by year*

Stream or river water quality:

- *water quality parameters from Department Environmental Quality records (particularly dissolved oxygen, turbidity, toxics)*
- *temperature*
- *seasonal variations*
- *important upstream point and non-point sources*
- *presence of algal blooms or other eutrophication problems*
- *evidence of toxicity in animal or plant communities*

Stream or river sediment quality:

- *sieve analysis*
- *sediment analysis of selected samples for:*
  - presence of ammonia or sulfides
  - presence easily degraded or reduced compounds

- *sediment bioassay results if toxicants are known to be present*
- *presence of suspected toxic compounds*

Stream morphology:

- *presence of low velocity zone that will trap fine sediments*

Summary

Water quality impacts from gravel removal and fill/alteration projects can be divided into on-site effects (short-term, near distance) and cumulative effects (long-term, longer distances from site). Of these, potential on-site effects can be evaluated based on either existing water quality and sediment quality data, if available, or may require further data collection, particularly of sediment quality data.

Cumulative effects are more difficult to assess and may require modeling or other estimates of suspected changes in channel morphology and hydraulics. Particular attention should be given to the presence of sorbed toxic materials that may be either resuspended in the water column or assimilated in low velocity zones created by gravel removal. This section has summarized potential water quality effects that should be considered for any proposed project, have been summarized, and specific questions to be addressed and data requirements for impact analyses have been listed.

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CASE STUDIES

The following section contains a listing of examples of impacts of gravel removal and fill/alteration that are taken from pertinent literature or personal experience of the investigators. These examples serve as a background for the direction that this study has taken and the list of final recommendations.

Changes in Streambed Elevation

Review of Literature

The causes of river-bed degradation were studied by Galay (1983) who noted that whether a riverbed degraded upstream or downstream depended upon what caused the degradation. He reviewed degradation case histories and concluded the following:

1. Degradation is usually more complicated than engineers have been inclined to assume.
2. Downstream progressing degradation is generally the result of a change to one or more of the independent river variables: increased water discharge, decreased bed material discharge, or decreased size of bed material.
3. Upstream progressing degradation is generally caused by an imposed increase in river slope, which may be achieved by lowering a base level, such as in a lake or main river, by decreasing the river length, or by removing a control point.
4. Upstream progressing degradation, in general, develops more quickly than downstream progressing degradation.
5. Downstream and upstream progressing degradation may occur within the same river reach at the same time.
6. Any type of degradation on a main river generally produces upstream progressing degradation on a tributary. The degradation of the tributary can interfere with the degradation process on the main river.
7. Degradation can occur very rapidly, within one flood event, and can proceed for many kilometers up or down a river.
8. The design of water resource projects should include a careful analysis of all possible degradation processes along the main river, as well as along major tributaries.

Willamette River

A brief investigation was made of possible streambed elevation changes in the Willamette Basin (Klingeman, 1993). The purposes of the work were to develop analytical techniques for such studies and to make a preliminary assessment of the extent of any indicated problems of streambed degradation and their likely causes.

Records from 11 U.S. Geological Survey (USGS) gauging stations were subjected to a "specific gage" analysis to detect changes in rating curve characteristics. Supplemental information from flood records, aerial photographs, maps, and other sources was then used to attempt an explanation for any indicated changes in the specific gage curves for each station. To support this work conceptually, several characteristics and circumstances which might be shown by specific gage curves were developed from general consideration of processes involved. These curves were compared with the actual curves developed from data for the given sites so that changes might be interpreted.

The main-stem Willamette River and nearby portions of some tributaries were subject to water-stage lowering during the study period. However, other stream reaches did not experience any such

effects. Streambed degradation along the main-stem Willamette River was found to be approximately one foot per decade. The locations where this was observed to occur included all four USGS gauging stations: Harrisburg, Albany, Salem, and Wilsonville. The period of record used varied from 20 to 30 years, ending in each case in 1965.

Such degradation was believed to be due to several factors. Possibilities included natural geological events, sand-and-gravel extraction, bank stabilization along the main-stem, supply interception on tributaries due to dams, and watershed changes. Among these, local effects were believed to be far more important than distant effects because tributaries did not show such degradation. The notable excéption was the lower McKenzie River near Coburg, where gravel extraction and the decay of a wooden irrigation diversion sill were considered to be major factors. This reach was found to be subject to severe streambed degradation which has amounted to 6 feet in 26 years.

Tunjunga Wash, California

In 1969, floods caused both main channels of the Tujunga Wash, in southern California, to flow into or 'capture' the neighboring gravel pits (Scott, 1973). This lowered the channel's base level and created a knickpoint. In the process of smoothing the longitudinal profile, there was a net channel elevation change from $14^{+/-2}$ of scour to $16^{+/-2}$ of fill. The scour migrated about 3,000 feet upstream from the knickpoint, resulting in the failure of three highway bridges. Lateral scour destroyed an entire residential street and seven homes. Scott stated that "Damage at most, if not all, of the localities could be indirectly ascribed to man's disregard of natural geomorphic processes on alluvial fans and in fanhead valleys."

Changes of Stream Morphology from Channelization

West Tennessee

In West Tennessee, channelized streams caused upstream degradation, downstream aggradation, and bank failures; resulting in gradient decreases (Simon & Robbins, 1985). The authors noted that channelization induces an increase in energy conditions which cause greater transporting power and significant morphologic change. These effects are absorbed by reducing the gradient in the straightened channel. This is "accomplished by the establishment of upstream moving knickpoints, or knick areas, in the channel that produce upstream degradation and downstream aggradation." This in turn causes bank failure, causing riparian and aquatic habitat destruction.

Yuba and Sacramento Rivers

Channel morphology on the Bear River continues to be affected by the sediment produced from 1853 to 1884 from hydraulic gold mining in California (James, 1991). The Yuba and Sacramento Rivers had stabilized by 1950.

Effect of Gravel Removal Exceeding Supply

Lagasse performed two studies on river system morphology. One relates to dredging and has a section specific to gravel mining (Lagasse & Simmons, 1976), and the other relates specifically to gravel mining effects (Lagasse et al., 1980). The general idea is that gravel mining can significantly damage a river system when the extraction exceeds the supply. Part of the reason is because gravel *armors* the bed, stabilizing banks and bars, thus retarding excessive scour and sediment movement. The authors assert that "Gravel armored bars can serve as semi-permanent channel controls that define river form. Removal of the gravel armor from such features can lead to erosion and loss of this control. As a result, meandering reaches may tend toward a braided character, velocity and bed-material transport may increase, and localized changes may contribute to the deterioration of adjacent reaches."

Effects of Channelization

The hydrogeomorphic effects along and upstream from the channelized region affect the riparian areas and the biotic environment on the adjacent flood plains. Hupp (1991) performed a study on riparian vegetation recovery patterns

following stream channelization in West Tennessee. He determined that aggradation of the channel beds, establishment of woody bank vegetation, and bank accretion signal the beginning of the recovery period following channelization. Based on tree-ring analyses, it was suggested that about 65 years may be required for recovery after channelization.

Cumulative Impacts on Bridge Structures in California

California uses the most aggregate per capita and supports a $500 million aggregate industry which mines 128 million tons of aggregate per year. Although Caltrans is the largest gravel consumer in California, it has the concern of monitoring the gravel-mining damage done to 150 bridges on 25 streams in addition to assessing the damage to water supply systems and gas lines. Recent data reveals:

- In Glenn County: 10 times as much gravel is extracted than is washed from the hills. About a ton of gravel is harvested from Stony Creek every 30 seconds. As a result, the erosion-damaged bridge on Highway 32 has had to be repaired by Caltrans three times at a cost of $2 million.
- In Tehama County: $1 million is being spent by the federal government to replace the threatened Thomes Creek crossing of the Corning irrigation canal.
- In San Diego County: "Sand mining in the San Luis Rey River has forced two emergency repairs costing $1.3 million to the region's drinking water aquaduct."
- Russian River gravel mining has undermined the Highway 101 bridge at Healdsburg. The replacement cost is $7 million to $9 million.
- In Humbolt County: "Officials say gravel mining has caused $1 million in damage to Highway 299 and threatens the region's drinking water intake." The riverbed has dropped 20 feet.
- In Humbolt County: Recent mining has been curtailed to one-fourth of what was extracted before and it is believed that this may save the bridge and Eureka's water intake.

Alteration of Streambed Particle Size

A flume experiment which utilized a gravel bed river model was employed to show the response that a channel with alternate bars would have if the supply of a mixed load bed was decreased (Lisle et al, 1993). The authors discovered that when the bedload transport contracted and the local transport rates decreased, there was an increase in bed surface particle size. After their first feed rate reduction, they noted that the channel incised by twice the mean water depth and caused distal bar surfaces to emerge as terrace-like features. However, after a second feed rate reduction, little incision occurred. They also determined that the bar roughness decreased, and that the mean boundary shear stress exerted on the bed surface particles increased.

Environmental Impacts

Central Valley, California

The most recent plan to save salmon in the Central Valley requires spending $10 million to put gravel back into streams so fish can spawn (Mayer, 1994).

Humptulips, Wynoochee, and Satsop Rivers, Washington

The Humptulips, Wynoochee, and Satsop Rivers provide habitat for anadromous fish. In an effort to predict "the rate at which gravel could be harvested without diminishing the long-term availability of gravel for spawning redds," Collins and Dunne (1989) conducted a study on how to determine the long-term sediment mass balance and gravel transport for a given river. In these three rivers they determined that the rate of gravel removal from bars exceeded the replenishment rate by more than tenfold over the 20 to 30 years preceding the study.

In an earlier study assessing gravel transport and harvesting on the same rivers (Collins & Dunne, 1986), they had determined the annual volumes of gravel transport by three independent methods. Their analysis indicated that the river bed had been lowering at a rate of about 0.1 feet/year in the reaches of each river that had been subject to intensive harvest within the past 20 to 30 years.

Reduction in Spawning Beds

Gravel bar skimming effects are assessed as follows (Kondolf, 1994): gravel bar skimming causes sediment to be withdrawn from the transport system. This alters supply to the downstream reaches. Even when the extraction rates are dwarfed by the supply rates, a wide flat cross section is created which impacts aquatic habitat by "eliminating confinement of the low flow channel and resulting in a thin sheet of water at baseflow." Kondolf asserts that skimming removes the coarse surface layer which regulates bedload transport rates, thus exposing finer subsurface material which becomes entrained, compromising spawning habitat downstream.

Effect of Increase in Stream Sediments

Effects of gravel removal operation that increase sediment loadings are similar to effects of forest and agricultural activities that also produce sediment loadings (Hicks et al., 1991). Namely, there is a similarity in the effect that fine sediment has on stream biology and in the changes in stream productivity brought about by nutrient loading. Also, when riparian vegetation is removed, the light and temperature in a stream changes, causing changes in primary and secondary production. This can occur during salmonid fry emergence and also has adverse affects on the summer and winter survival of juvenile salmonids.

Effects of Gravel Removal on Pools and Riffles

Pools and riffles are important to fish habitat and riffles have been built in gravel-bed streams to improve trout and salmon habitat. Keller (1978) studied pools and riffles as they relate to channelization. He concluded that statistical comparison of pool spacing with channel width in natural streams versus those affected by limited human use did not usually suggest a significant difference. However, the exception lay in situations such as those which in-stream gravel mining would cause large alterations.

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BURDEN OF PROOF: AN EXPLORATION

Introduction

The decline, decimation, and extinction of salmon stocks in the Pacific Northwest is a consequence of many activities extending over large spans of time and space. This section claims that the assessment and management of such activities has too often been hindered by fundamental misperceptions. In brief, assessments and management and policy have been dominated by presumptions that fail to grasp the nature of cumulative impacts. It is doubtful that effective assessment, management, and policy can arise without facing up to these misperceptions. This section describes such problems in ways that are broadly understandable yet technologically sound. This is a working document. It is not intended to provide final answers but to promote, perhaps provoke, a less traveled path of discourse and inquiry. It is intended as an invitation to explore territory where the trails are neither worn nor well marked and the traveler can easily become lost. Three sections are provided.

The first section addresses the challenging topic of nonlinear interactions. Nonlinear dynamics has become one of the most challenging frontiers of science crossing virtually all disciplines from the social sciences to the physical sciences. Chaos theory is a more familiar product of such nonlinear inquiries. In brief, such studies have revealed the deficiencies of many linear presumptions.

The second section seeks to provide some explanation for the present predicament. Drawing upon the first section, it is shown how linear presumptions lead to misperceptions of the relationship of evidence to decisions. Such pervasive misperceptions serve to explain the decline of salmon stocks in spite of the scientific effort to protect them.

The third section outlines a strategy to better address the problems described in the first two sections. This strategy does not claim to solve the problems, but instead seeks to improve upon established ways of approaching problems based upon linear misperceptions.

Linear presumptions in a nonlinear world

Cumulative Impacts: Linear and Nonlinear Perspectives

The word "impact" refers, herein, to adverse environmental consequences of human activities. The decimation and extinction of salmon stocks is the broad impact examined in this study. The word "cumulative" is defined as "increasing by successive additions." The term "cumulative impact" refers to the long term and collective consequences of many activities. The decimation and extinction of salmon stocks is a cumulative impact, because it is a collective consequence of many activities over time.

When addressing cumulative impacts, a key question is: how do the individual activities combine to produce the cumulative impacts? Two general approaches to this question can be taken. First, a linear approach presumes the addition of impacts. Second, a nonlinear approach sees the emergence of impacts through the interactions of many activities. Consider the general implications of both approaches.

A linear understanding of cumulative impact would proceed as follows: given a set of n activities, $A_1, A_2, A_3, \ldots A_n$. Each individual activity would be associated with a direct impact. Thus, a set of n direct impacts, $I_1, I_2, I_3, \ldots I_n$, could be identified. The cumulative impact, I_c, would be given as the sum of the direct impacts. Linear understanding can be stated:

$$I_c = I_1 + I_2 + I_3 \ldots I_n \qquad (1)$$

From this linear perspective (Equation 1), one can estimate the cumulative impact by estimating all the individual impacts and adding them up. Managing cumulative impacts involves limiting impacts with large positive magnitudes, promoting impacts with negative magnitudes (benefits) and permitting impacts with low magnitudes so that the total, the sum, remains below some acceptable level.

If the cumulative impact I_c is large, the linear perspective implies conclusive statements about the direct impacts that add up to produce the cumulative impact can be made. As an example, if an individual claims to have a total of a thousand dollars in several savings accounts, then one should be able to know how much is in each separate account. The idea that an individual could summarize the total amount but not the amounts in separate accounts does not make much sense. Moreover, to determine the total, it seems reasonable to assign a reliable person to each account, and then add up the amounts they each report. The amount that one accountant determines in one account should not depend upon the amount any other accountant determines for any other account. Dividing up the work should be no problem as long as each accountant can count and somebody can add up the total.

From a linear perspective, understanding the whole implies an understanding of parts. A reasonable way to gain conclusive evidence on the whole is to gather conclusive evidence on each of the parts and then add up. It is reasonable to divide up tasks to gather such evidence.

A nonlinear understanding of cumulative impacts is radically different. Again, we can assume a set of n activities $A_1, A_2, A_3 \ldots A_n$. In a nonlinear system, impacts emerge through the interactions of activities. One cannot separate the impacts of each activity and add them up to obtain the total impact. Thus, the cumulative impact, I_c, must be given as some nonlinear function of all activities. That is:

$$I_c = E\,(A_1\,,\, A_2\,,\, A_3\,,\, \ldots\, A_n) \qquad (2)$$

in which E is a nonlinear function that defines the interaction of all activities to yield a cumulative impact. The cumulative impact I_c, is said to "emerge" from all activities and their interrelationships. The emergent impact, I_c, cannot be reduced to the sum of direct impacts. To estimate the contribution of any single activity to the cumulative impact, one must consider the interactions of all activities. Because activities are changing, such an estimate would also change.

To illustrate emergent outcomes, consider jokes. Jokes are made up of words. From a linear perspective, the "humor content" of each word could be measured and then the individual contents added up, thus telling if a joke is funny. Of course, this is absurd. The funniness of a joke is an outcome of the entire joke; it cannot be reduced to the sum of its individual word properties. The emergent whole is clearly something quite than the sum of the parts. Nonlinear thinking demands recognition of emergent outcomes that cannot be described as mere properties of parts or part that can be added up like money in savings accounts.

The nonlinear interactions expressed as the function E, can yield strange results. As an example, a set of activities might produce a relatively small cumulative impact, I_c. Even as activities are added and changed, I_c remains small. A seemingly insignificant change of activities or a delayed effect might suddenly shift the system, causing I_c to jump to unacceptably high and even catastrophic levels. The change of the cumulative impact, I_c, can be far out of proportion to the change of activity. In nonlinear systems, proportionality does not hold. As an example, a moderate loss of habitat may lead to only a slight loss of biological diversity. But then, with only a small additional loss of habitat, biological diversity may plunge. Moreover, this non-proportional shift may become apparent only after a lag time.

In nonlinear systems, one can often observe cumulative impacts yet the contributions of each individual activity remains undefined. In other words, scientific evidence might conclude that cumulative impacts are occurring and are likely to continue and yet scientific evidence remains inconclusive concerning the specific contributions of each individual activity. In the case of salmon, the evidence can say conclusively that salmon stocks are decimated and threatened with extinction through the interactions of many activities, yet, the evidence concerning the specific contribution of each activity is often inconclusive. This occurs because the nonlinear interactions are acted out in the real world regardless of whether science understands them or not. Scientists observe these real world outcomes (e.g., declines of salmon) but they are unable to define a nonlinear function, E, that precisely relates cumulative impacts to specific activities. Moreover, the function E shifts and changes as the system changes. The nonlinear

properties of systems lead to the following general tendencies.

- Evidence concerning the cumulative impacts of many activities is often more conclusive than evidence concerning the specific contributions of each contributing activity.
- Evidence of the decline, decimation, and extinction of salmon stocks due to many activities is relatively conclusive; evidence that defines the specific contribution of each individual activity tends to be relatively inconclusive.

Given such tendencies, linear presumptions lead to widespread misperceptions often expressed as blame. Evidence for the overall impact (decline of salmon) is acknowledged but each interest group sees little evidence that its own particular activities contribute in significant ways to this impact. Thus, each party blames other parties for the overall impact. Mutual blame, (everyone pointing the finger at someone else) arises when linear expectations concerning evidence is applied to nonlinear outcomes. Rather than recognizing that outcomes emerge through the interactions of many activities (Equation 2), each party defends its own particular activity. The lack of evidence meeting unrealistic linear presumptions is taken by each group as proof of its own innocence. Each group believes that constraints and limits imposed on its own activities are unjustified and "unscientific."

Widespread and persistent blame is a social indicator that the perception of problems is far more linear than the problems themselves. As an example, the gravel industry blamed agricultural and forestry practices for salmon decline. Those in agriculture or forestry point the blame elsewhere, each away from themselves. This report seeks to examine linear misperceptions that make such blame all but inevitable and misdirect people's best intentions.

Nonlinear Challenges

Clearly, linear presumptions simplify matters. Activities and their impacts can be addressed one at a time. Solutions to problems appear easier and more straight forward. But, if the world is in fact nonlinear, then linear presumptions may be misleading and actions misguided. Is the world nonlinear? A colleague answered this question in the following way: "The world consists of bananas and non-bananas, the bananas are the linear systems." In other words, the world is nonlinear.

To recognize that the world and its problems are nonlinear in nature is a disturbing realization that challenges many of society's habits, practices, and presumptions. As an example, dividing up tasks into manageable pieces is a practical way to approach problems but a nonlinear perspective warns that, eventually, nonlinear interactions may disturb and overwhelm efforts. In science, linear presumptions have prevailed because the inability to solve nonlinear equations. Computers now allow approximation of nonlinear solutions with numeral techniques. The results reveal unusual behaviors (e.g., deterministic chaos, strange attractors, self-organization) not compatible with linear habits and expectations.

Intuitively, society tends to resist such notions preferring to point out how linear presumptions often lead to practical results. How can the inconsistency be resolved between (a) human experience that depends upon linear presumptions (i.e., dividing up tasks as practical and effective) and (b) cognitive understanding that the world is nonlinear and cannot be counted on to behave according to linear presumptions. This apparent paradox is removed if piece-wise linearity which often serves as a close approximation in the short-run is recognized within nonlinear systems. This is illustrated in Figure 40.

Figure 40 relates two variables, x and y, in two ways: linear (straight line) and nonlinear (curved line). Notice that for a small variation of x, the linear (straight line) approximation is very close to the nonlinear relationship (curved line). Over small values of Δx, the linear relationship works quite well. Now imagine that Δx represents time intervals, space intervals and sets of activities. For local and short-term conditions involving single activities (small Δx) the linear approximation often works quite well. Thus, if tasks are divided up so that each person only looks at local, short-term, and direct outcomes of individual activities, linear approximation appear sufficient. If, however non-local, long-term and interactive consequences (large values of Δx) are considered, the linear (straight

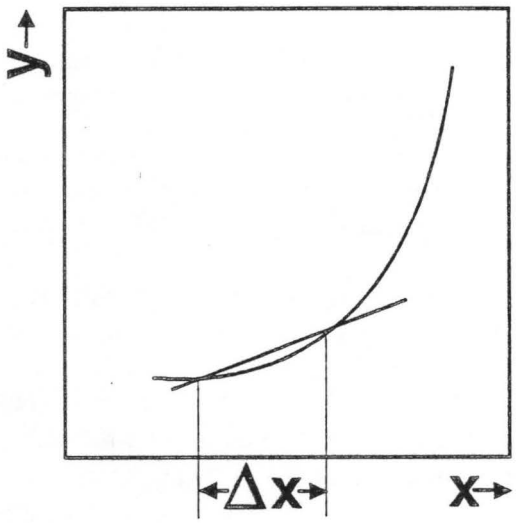

Figure 40. "Piece-Wise Linearity." Note how the straight line (linear) approximation is close to the curved (non-linear) relationship when Δx is small.

line) relationship departs in significant ways from the nonlinear (curved line) relationship. The larger the value of Δx, the greater the departure is likely to be.

As variables expand the simple curve shown in Figure 40 no longer applies. Nevertheless, the general lesson remains applicable. For local, short-term and direct impacts, linear approximations will often suffice; piece-wise linearity can yield local and short-term results that are useful. In effect, one assumes the broader world as a given; then, one estimates the local and short-term impacts of a particular action. This presumption is common to cost-benefit and risk analysis and other established forms of assessment. However, the world is not a given. It changes through the non-local and non short-term interactions of many activities. Nonlinear consequences do eventually emerge. These are cumulative impacts that cannot be understood by simply adding up the local and short-term consequences of individual activities.

The assessment of direct (local, short-term, immediate) impacts tends to be more consistent with linear presumptions. Cumulative impacts emerge through nonlinear interactions. When linear presumptions drive problem solving, tasks are greatly simplified. Linear problem solving is appropriate for a wide range of direct impacts, but cumulative impacts are not adequately addressed. This general assessment fits the experience of salmon management. The management of direct impacts (e.g., short-term turbidity increases and dissolved oxygen decreases due to a specific activities) have been adequately addressed and actions to prevent and mitigate such direct impacts have been taken. In contrast, the cumulative impacts have been less well defined and managed (such as the cumulative loss of habitat). The challenge is to address such cumulative impacts which requires scrutiny of nonlinear characteristics of the environmental problems. While the evidence of cumulative impacts increases, the available evidence to define the contribution of each particular activity to this cumulative impact will remain far less than conclusive.

If We Value The Salmon And Apply Scientific Evidence To Protect Them, Then Why Have They Been Decimated And Driven To Extinction?

History: The "Why E?" Question

In 1892, Livingston Stone warned that the salmon of the Pacific Northwest faced the same threat of decimation and extinction that the buffalo had faced decades before. Drawing upon the lessons from the demise of New England salmon, Stone warned that, "it was not overfishing that did it." More damaging to salmon were the cumulative habitat losses that came from a wide range of activities accompanying population growth and development. Stone specifically mentioned mining, road building, and saw mills. To protect the salmon and the habitats they depended upon, Stone argued for the establishment of a Salmon National Park.

Since Stone's warning, a great deal has been learned about salmon and their requirements. Many laws have been passed to prevent some of the most damaging activities that Stone described. Stone was not alone in his concern for salmon. In fact, protection of salmon has been widely supported to this day. In 1957, Ross L. Leffler, Assistant Secretary of the Interior within the Eisenhower

Administration wrote a forceful statement on the need to protect salmon runs. He called for an expanded research program and greater protection of habitats and ecosystems. Echoing Stone's call, Leffler stated, "We can and should forthrightly declare that certain river basins of the Pacific Northwest should be dedicated to the conservation and development of fish and wildlife resources as their highest and best use."

In April 1991, nearly a century after Stone's warning, Nelsen, Williams, and Lichatowich wrote a paper, "Crossroads on the Status of the Pacific Salmon." This "Crossroads" paper began with a 1937 quote from M.C. James that stated, "No possibilities, either biological or engineering have been overlooked in devising a means to assure perpetuation of Columbia River salmon." This statement reflects both the commitment to protect the salmon and the confidence that scientific and engineering knowledge could and would be applied to assure such protection. More than 50 years after this statement was made, scientific knowledge was applied to demonstrate that this was not the case. The "Crossroads" paper found:

> In the 1990s, native anadromous Pacific salmonids (*Oncorhynchus spp.*) are at a crossroads, the habitats of these once wide-ranging fishes are severely curtailed, many stocks are extinct, and many remaining stocks face a variety of threats.

Again, a century long echo of Stone's warning could be heard. Again, the cumulative impacts of many activities were cited, now including hydropower, fishing, logging, mining, agriculture and urban growth. Again, we heard that "management efforts should focus on conservation of ecosystems." These historical references demonstrate several themes that reoccur through the history of the salmon decline in the Pacific Northwest.

A. The protection of salmon has been a long-term and widespread concern that has been expressed in laws and regulations designed to protect the salmon.

B. Research and the use of its results in decision-making dates back many decades.

C. The cumulative loss of habitat by many different activities has been recognized as a significant danger for more than a century.

D. The protection of habitats, river basins, and ecosystems has been advocated for more than a century.

E. The habitats of these once wide ranging species are severely curtailed, many stocks are decimated or extinct, and remaining stocks face a variety of threats.

When examining the current salmon crisis, it is prudent to consider this historical condition and then ask: given A, B, C, and D, "Why E?" Without asking such questions, decision-makers will continue along the pathway that leads to the decimation and extinction of salmon runs (Statement E) while proclaiming commitment to the opposite (Statement A) and supporting research to this end (Statement B). That is, proclaiming Statement A, and employing Statement B which, in turn, supports Statements C and D, will nevertheless bring about Statement E. Such a scenario is not speculative! On the contrary, it represents long established patterns. If research is to make some positive contribution that reduces the probability and extent of Statement E, serious attention needs to be devoted to the fundamental question of "Why E?"

Burden of Proof

What is the relationship of evidence to decisions? In general, it is presumed that research and monitoring lead to better evidence concerning the outcomes of activities. Better evidence leads to better decisions. These presumed relationships are illustrated in Figure 41.

Given the "Why E?" question, one should suspect that something crucial is missing from this model. To examine what this might be, briefly consider an incident unrelated to the salmon: the 1986 explosion of the shuttle Challenger. This incident has the advantage that the failure was sudden and obvious. Thus, the relationship of

available evidence to decisions could more easily be traced and flaws identified. Prior to the fatal launch, engineer Rodger Boisjoly strongly objected to the "O" ring design that became the technical cause of the accident. Boisjoly presented evidence but it did not influence the launch decisions. Why? Consider how his objections were suppressed. Pre-launch meetings were held to examine safety issues. Boisjoly testified:

> This was a meeting where the determination was to launch and it was up to us to prove beyond a shadow of a doubt that it was not safe to do so. This was a total reverse to what the position usually is in a preflight conversation or a flight readiness review. It is usually exactly opposite that. (U.S. Commission, 1986)

Robert Lund, an engineer and manager who played a key role in this meeting, also testified:

> We had to prove to them that we weren't ready, and so we got ourselves into the thought process that we were trying to find some way to prove to them it wouldn't work, and we were unable to do that. We couldn't prove absolutely that the motor wouldn't work. (U. S. Commission, 1986).

Given the pressures placed upon individuals, the burden of proof shifted so that the launch was presumed. It was accepted as a given that any delay of launch should require strong, overriding and exceptional justifications. Rodger Boisjoly was unable to meet this burden of proof. Once this shift in the burden of proof occurred, the "decision" to proceed with the launch "in effect" been made. Safety objections could not meet the impossible burden of proof that had arisen. The launch proceeded. Now, the interesting part of this "decision process" is that the shift in the burden of proof did not arise from deliberate decisions. In fact, deliberate policy had been quite the opposite, placing the burden of proof upon those arguing to proceed with a launch. Those caught up within the system, however, came to think in a different way more accommodating to the pressures that favored launch. The burden of proof shifted and a "*de facto*" policy to launch emerged without deliberation or intent. With this lesson in mind, we can expand our model (Figure 41) as shown in Figure 42.

In this model (Figure 42), evidence from research and monitoring was inconclusive concerning "O" ring failure under launch conditions. Given that the available evidence was inconclusive, the burden of proof in effect determined the outcome. Because the burden of proof had shifted, without deliberation, to those arguing to delay the launch (Rodger Boisjoly), the launch proceeded with

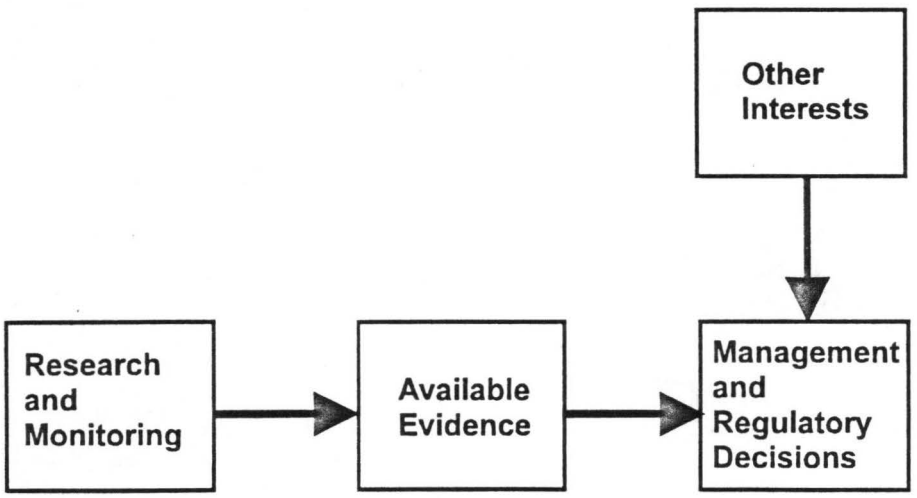

Figure 41: Model Relating Evidence to Decisions

disastrous consequences. A general lesson can be expressed in two statements:

1. When available evidence is inconclusive, the outcomes of decisions tend to be determined by the way the burden of proof shifts.
2. The burden of proof (the degree of evidence required to influence a decision a particular way) can shift in subtle ways with destructive consequences.

Available Evidence and Burden of Proof

The shuttle explosion provides a tragic lesson: decisions are influenced not only by available evidence but by the burden of proof applied to decisions (Figure 42). Failure to learn from this lesson sets the stage for ongoing tragedies. The relationship between available evidence and burden of proof can be examined by employing a decision phase plane as shown in Figure 43.

Position on the vertical (y) axis describes the ability of available evidence to define the impact of a proposed activity. Conclusive evidence fits the deterministic ideal. Such evidence allows one to determine the outcomes of different alternatives so that benefits and costs can be precisely defined. A decision can thus be based upon "the facts." Conclusive evidence of this kind is indicated by a position high on this dimension (vertical axis). Inconclusive evidence is located at lower positions.

The horizontal axis defines the burden of proof applied to this same decision. If a heavy burden of proof is required to deny the activity (approval presumed), the decision would be located to the far left of the horizontal (x) axis. If, however, a heavy burden of proof is required to approve the activity (disapproval presumed), then a position on the right end of the horizontal axis would be required.

Assuming that decisions involving the approval or disapproval of an activity are largely based upon the available evidence at the time of the decision, each decision can be characterized by a position on the decision phase plane. The character of decision outcomes are indicated by three different regions of the plane shown in Figure 43. When available evidence is conclusive, position on the burden of proof dimension becomes insignificant, with respect to decision outcomes. The available evidence, "the facts," determine the decision. However, when available evidence is inconclusive (limited, incomplete, etc.), decision outcomes are dominated by position on the burden of proof dimension. As an example, when the available evidence is inconclusive and the burden of proof presumes approval (lower left region of the phase plane), the decision is likely to be approval unless those calling

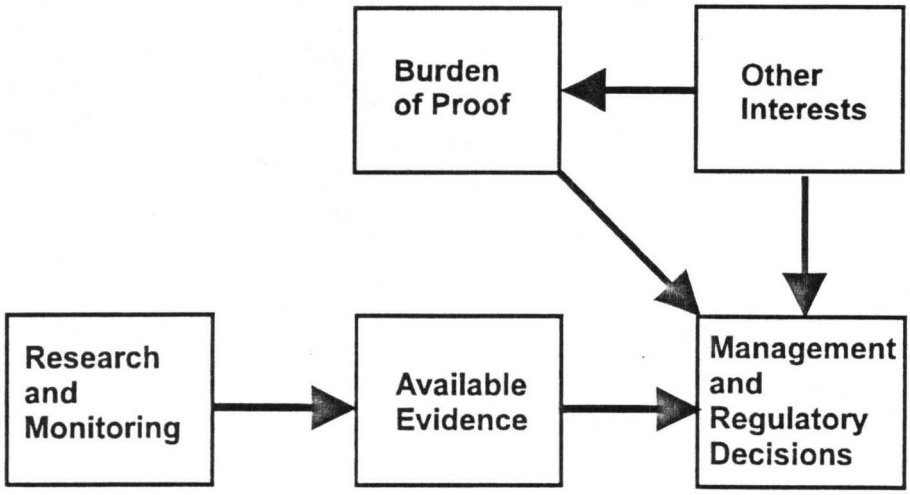

Figure 42: Expanded Model Relating Evidence to Decisions

for disapproval can marshal sufficient evidence to relocate the decision in the upper region of the plane.

In the case of the shuttle explosion, the established policy located decisions within region I of Figure 44. Approval of activities (i.e., the launch) were to proceed only with strong evidence that safety had not been compromised. Given questionable evidence, the burden of proof should have shifted onto those favoring launch. Thus, with insufficient evidence, the launch would be delayed or canceled. In reality, however, without intention or design, critical decisions shifted toward region II of the phase plane. Thus, when inconclusive evidence of a possible failure arose, the burden of proof fell upon those seeking to terminate or delay the launch. Approval of the launch was presumed. Because the evidence was not found to be well-defined and conclusive, the decision was made to proceed with the launch (approve the activity as shown in Figure 43). The tragic outcome can be seen as an unintended shift on the phase plane, from region I to region II.

Consider decisions on activities relevant to the survival of the salmon. Gravel removal activities will serve as a example of the much larger class of activities with potential impacts to salmon. With respect to the direct impacts of an individual activity -- such as turbidity increases in the area of a gravel removal at the time of the activity -- decisions appear to be located in the upper right region of the plane as shown in Figure 45. That is, available evidence is often sufficient to show that serious immediate impacts will likely be avoided. Where such evidence is lacking, the burden of proof often does fall upon those favoring the activity; they are often required to modify their actions in ways that assure that significant direct impacts do not occur. Direct (immediate, local) impacts decisions appear to be reasonable and properly cautious. In some cases, the burden of proof (for direct impacts only) may have even shifted too far in the "disapproval presumed" direction.

With respect to cumulative impacts, however, the situation is quite different. Decisions related to cumulative impacts are located in the lower left region of the plane. For any specific Activity, evidence of cumulative impact at the time of decision is far from conclusive. This lack of evidence serves to allow activities to proceed. Without evidence to the contrary, approval tends to be presumed. With respect to cumulative impacts, the shift on the decision plane (Figure 45) is similar to the shift that led to the Challenger explosion (Figure 44). In the cases of salmon, the consequences are not as sudden and dramatic. Nevertheless, the evidence is now clear that the cumulative impacts of many decisions upon salmon have been severe. As with the shuttle explosion, the tragic outcome can be seen as arising from a shift in the character of decisions. An overlay of Figure 45 with Figure 43 demonstrates this shift. With respect to cumulative impacts (Figure 45), activities tend to be approved (Figure 43). Cumulative impacts do accumulate despite effective management of direct impacts. The consequences are seen in declining salmon stocks.

The decline of salmon in the Pacific Northwest can be seen as the enactment over time of decisions similar to those that lead to the 1986 explosion of the shuttle Challenger. In both cases, the burden of proof was crucial. In the case of the salmon, however, the losses accumulated over many decades. Rather than leading to a sudden and dramatic event, the decline of the salmon has been gradual and impossible to trace to specific decisions. The decline of salmon has emerged from many decisions most of which appear reasonable from a linear perspective. Eventually, however, the nonlinear effects take their toll.

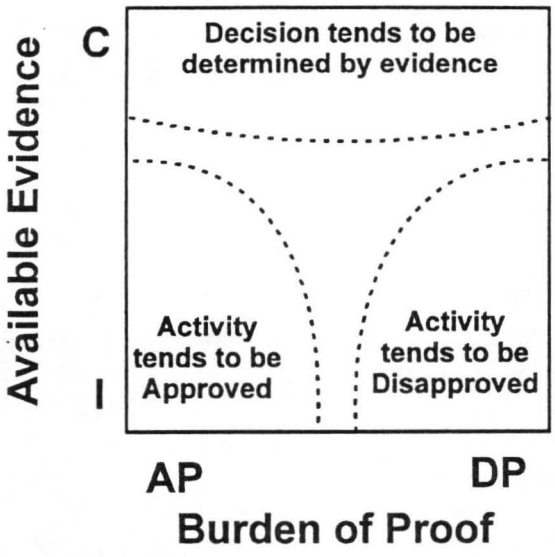

Figure 43: Decision Plane. Decisions can be characterized by positions on this plane:

AP = Approval Presumed, strong, overriding, and exceptional justification must be given for disapproval

DP = Disapproval Presumed, strong, overriding, and exceptional justification must be given for approval

C = Conclusive evidence

I = Inconclusive and incomplete evidence

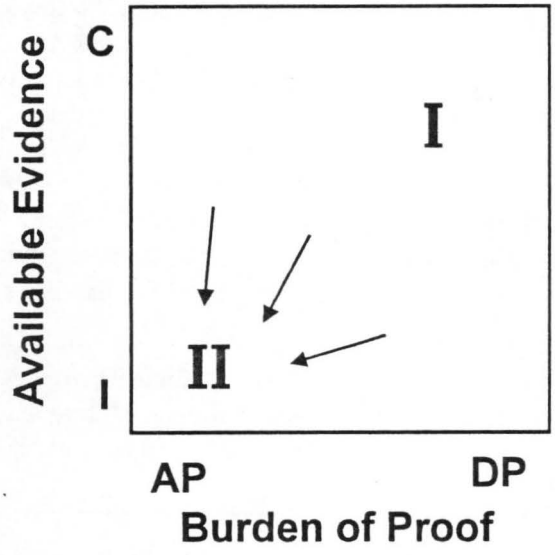

Figure 44: The Challenger Explosion. The shift of Decisions, from I to II, contributing to the Explosion of the Shuttle Challenger.

(I) - Intentional Policy

(II) - Policy resulting from Institutional Pressures shown as arrows.

Overlay this Figure with Figure 43 above.

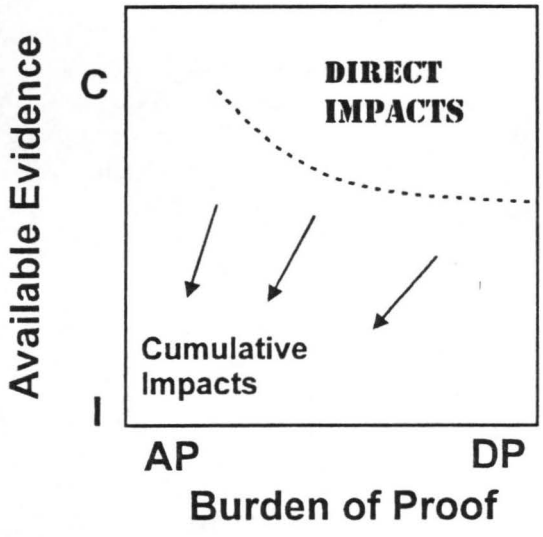

Figure 45: Institutional Shift of Cumulative Impacts on Decision Plane.

Overlay this Figure with Figure 43 above. Note that the position of Direct Impacts is different than the position of Cumulative Impacts.

Linear presumptions prevail as a basis for answering the "Why E?" question. In terms of language, logic, institutions, regulations and even education a common presumption has prevailed: the way to evaluate the impact of activities is to isolate the tasks and examine each activity. The quality of overall management (the whole) is reduced to the quality of individual management decisions (the parts). Equation 1 is presumed. Given such presumption, nonlinear cumulative impacts are not adequately considered when decisions are made. Attention is focused upon direct impacts. The imbalance shown in Figure 45 has prevailed. Decisions have allowed activities without adequate consideration of cumulative impacts. With time, nonlinear cumulative impacts have taken their toll on the salmon.

Institutional Imbalance

When institutions are based upon linear presumptions, it is reasonable and practical to divide up tasks so that each specific activity is assessed in itself. Generally, management is not disturbed when the specialists assigned to these tasks have little time to interact with each other. Instead, efforts are directed to increase "productivity," the rate of task completion. Institutions not only fail to manage nonlinear cumulative impacts (Equation 2), they fail to even consider them. Individuals are too busy with the specific tasks assigned to them and the productivity demands placed upon them. Then, with respect to cumulative impacts, the burden of proof shifts as shown in Figure 45.

Consider the predicament of state resource coordinators who must process fill and removal permits for sand and gravel. Resource coordinators have high work loads. Statutory time frames are imposed. Should a coordinator fall behind in the review of permits then "the bells start ringing," complaints arise, pressures grow and management demands that "the problem" be fixed. The system automatically responds when permit processing falls behind. Accountability for productivity (the processing of permits) is strong and automatic.

In contrast, accountability for the cumulative impacts of many activities is nearly non-existent. Activities that contribute to cumulative impacts do not start "bells ringing." The systematic feedback to head off cumulative impacts is not automatic; it is nearly non-existent. Indeed, the information that might track cumulative impacts is not gathered in usable forms. When facing particular activities, state coordinators "don't have a clue on how this fits into the bigger picture." To illustrate, consider goal and policy statements (Table 14). These statements are perceptive and relevant to cumulative impacts.

The intent of these review draft statements is appropriate. However, the information to assess activities is not being gathered, analyzed and placed in usable form. The mechanisms to sustain accountability to such goals and policies are not in place. As an example, Oregon Department of Fisheries and Wildlife statements 3205 and 3301 (Table 14) seek to limit gravel removal below the recharge capacity, the annual recruitment rate of streams and sites. Literature reviews fail to identify a single drainage basin, sub-basin or watershed where a mass balance of gravel had been conducted sufficient to estimate recharge capacity and recruitment rates. Moreover, information has not been gathered to track the cumulative rates of gravel extraction from different streams and basins. Thus,

Table 14. Policy and Standards Statements (Review Draft) Relevant to Cumulative Impacts: Oregon Department of Fish and Wildlife (Fosberg et al., 1989)

Policy
3205. ODFW shall consider streamborne gravels as a limited renewable resource that may degrade fish and wildlife habitat if harvested at rates exceeding the annual capacity of the stream to recharge the resource.
3201. Commercial gravel removal shall result in no net loss of fish and wildlife resources, their habitat, or public use of these resources.
Standards
3301. The volume of material removed from salmonid spawning waterway reaches shall be less than the annual recruitment rate at each removal site.

Table 15: Summary of Current Practices

	Direct Impacts (local, short-term)	Cumulative Impacts (interactive, long-term)
Linear Presumptions (see equation 1)	Often sufficient (see Figure 40); allow practical allocation of tasks	Deficient, misleading; allows impacts to accumulate
Accountability	Reasonably good, highly focused	Seriously deficient
Management Effectiveness	Reasonably good	Seriously deficient
Available Evidence (see Figure 45)	Reasonably good	Seriously deficient
Burden of Proof (see Figure 45)	Balanced; in some cases may be imbalanced toward "Disapproval Presumed"	Imbalanced toward "Approval Presumed"

the basic information needed to assess the cumulative impact is not available to those who must review fill and removal permits.

The same situation occurs with "no net loss" of fish and wildlife and their habitats. The statements are relevant. However, the information needed to track cumulative losses is not assembled in usable form. Accountability for cumulative losses is not in place. An imbalance of institutional accountability is present. Accountability for productivity of permit processing is automatic and strong. If a coordinator falls behind, the pressure to "correct the problem" increases. Accountability for cumulative losses over time, however is weak; indeed, it is nearly non-existent. The general effect of such imbalance is a tendency to approve activities without adequate consideration of cumulative impacts. This is the systematic path of least resistance. When one opposes this path, pressures tend to mount. One's actions can be criticized as unjustified on the basis of available evidence. Statements from several state employees support this premise: "If we take the time (to gain evidence on cumulative impacts) we get nailed because we don't meet productivity requirements;" "We have to rely on the review of others, but they're in the same boat."

The net result is that reviews tend to focus management efforts upon direct impacts of specific activities. The state appears to do a good job with respect to direct impacts. Its standards are thoughtful and have served to prevent direct impacts that would have certainly contributed to the decline of salmon stocks. With respect to cumulative impacts, an imbalance in the burden of proof is not apparent. Cumulative impacts must be viewed from a nonlinear perspective. From this perspective, the interactions of many activities over time can become significant. The burden of proof does have a significant influence over time. Given the accountability imbalance described above, the burden of proof shifts in ways that make it difficult to deny approval of activities that contribute to cumulative impacts. Although direct impacts of individual activities are managed reasonably well, cumulative impacts of interacting activities tend to escape control. The shift shown in Figure 45 tends to prevail. The shift (Figure 45) that answers the "Why E?" question arises from institutional behaviors that are likely to continue if linear presumptions prevail. This assessment is summarized in Table 15.

Strategy and Tactics in a Nonlinear World

Strategies and Tactics

Consider two terms from military science: strategy and tactics. Both terms refer to decisions and actions. Strategies address comprehensive and broad concerns. Tactics address immediate and local concerns. Strategies are required to deal with the interactions of activities that cannot be seen or addresses from the tactical level. Tactics are required to deal with the unique and particular demands of specific situations that cannot be seen or addressed at the strategic level. Success comes when strategies and tactics complement each other so that the unique demands of immediate and local situations are effectively addressed in ways that combine to produce favorable emergent outcomes in the long run.

In a linear world, tactics would dominate. Each activity could be planned and directed on the basis of local and immediate conditions. Each proposed activity could be assessed in itself. Efforts to improve outcomes would be directed toward the development of procedures and information applied to individual activity decisions. In a linear world, strategies would involve little more than administrative arrangements to assure that the specific tasks of individuals and groups were done in a productive and effective manner. Such a linear world is an illusion! Unfortunately, it is a well ingrained illusion. Within this illusionary world, assurances are given that current practices serve to protect salmon. But, in the real nonlinear world, salmon stocks have been devastated. The strategy outlined herein seeks to abandon the illusionary linear world to claim responsibility for actions in the real, nonlinear world.

Stated simply, this strategy shifts existing practices toward more realistic directions. Under existing practices, the burden of proof exerts an influence upon decisions particularly with respect to cumulative impacts (recall Figure 43 and Figure 45). This influence arises from linear misperceptions. The proposed strategy employs research and monitoring so that the burden of proof applied to decisions is better informed (See Figure 46).

The strategy seeks to shift inquiry, review, and accountability toward a more realistic understanding of nonlinear interactions and the cumulative impacts that emerge from them. Under this strategy, research and monitoring are employed to develop more informed strategic guidelines and constraints that shift the burden of proof toward more realistic balance, that is, a balance that better reflects the nonlinear real world that salmon live within. This

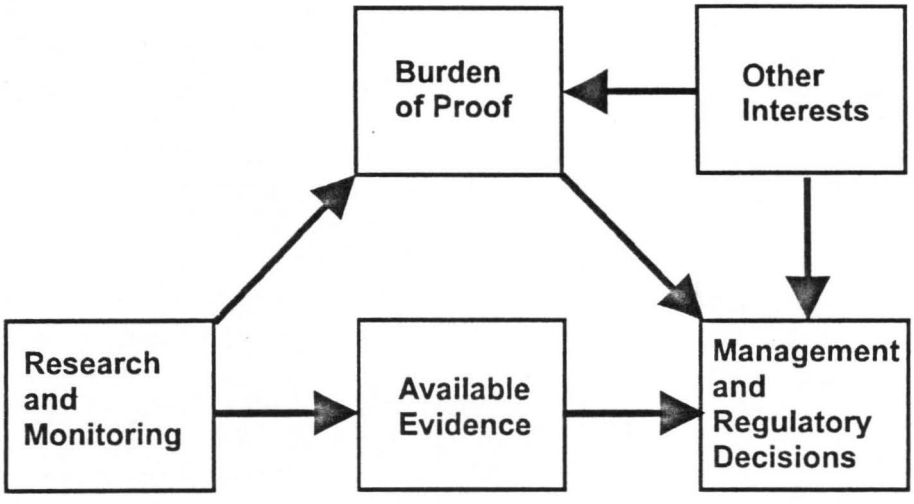

Figure 46: Expanded model showing the use of research and monitoring to develop a more balanced burden of proof.

shift is illustrated by the dashed arrows in Figure 47.

Figure 47 illustrates a fundamental difference between the "healthy strategy" proposed herein and the "conventional tactics" now widely applied. Conventional tactics presume that through research and monitoring, evidence will become more conclusive (illustrated by the solid arrows on Figure 47). With time, decisions will rely upon more conclusive evidence, decisions will shift to the upper region of the decision plane (Figure 43) where burden of proof becomes less important. From the perspective of conventional tactics, research and monitoring reduce the significance of burden of proof in the long run. In contrast, the strategy outlined claims that burden of proof has been and will continue to be a deciding factor with respect to cumulative impacts. Research and monitoring should serve to shift burden of proof (illustrated by the dashed arrows of Figure 47) in more informed ways.

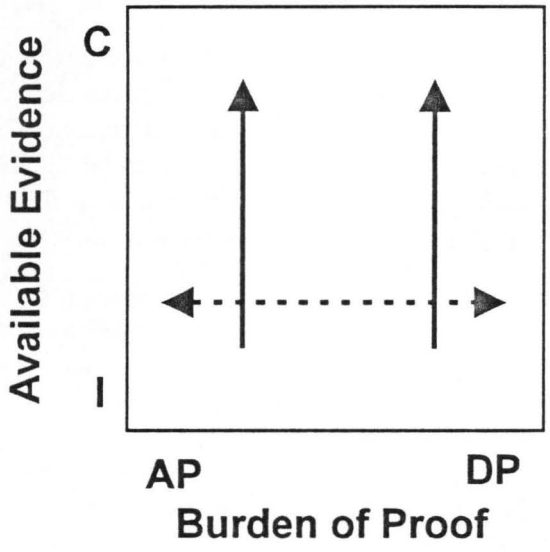

Figure 47: Two Approaches for Addressing Inconsluive Evidence.

Conventional Tactics and Proposed Strategy. Solid arrow indicates convention tactics, the shift toward conclusive evidence through research and monitoring. Dashed arrow indicates the proposed strategy, the use of research and monitoring to establish a more balanced burden of proof as sketched in Figure 47. Overlay this Figure with Figure 43.

Healthy Strategies

To illustrate such a strategy, consider the decisions each person faces with regard to personal health. For some people, smoking a cigarette involves direct and immediate benefits. The smoking itself may be enjoyable. In addition, people might enjoy acting out a desirable identity such as those reinforced through the advertisements of the tobacco industry, the rugged "Marlboro Man" as an example. Addicted smokers experience direct and immediate personal cost if they forgo smoking; to smoke a cigarette "just this time" provides no insignificant amount of short term relief. In contrast to these immediate benefits, cumulative impacts arise over time. Declining health, loss of physical fitness, addiction, and early death are clearly significant impacts. But, the immediate impact of smoking "just one more cigarette" is, by itself, so small as to be immeasurable. Thus, when faced with the individual decision , "should I smoke a cigarette, just this time" a smoker can identify direct benefits but, the impact on health of this single action is remote and immeasurable. Advertisements reinforce a "just this time" perspective by glamorizing the immediate benefits while pushing the cumulative costs out of sight.

From a tactical perspective, each decision is faced independently of all other decisions. That is, each decision is seen from a "just this time" perspective; each decision is independent of other decisions. When considering the decision to smoke a cigarette "just this time," it is not at all unreasonable for a smoker to see benefits as clearly apparent and costs as remote and immeasurable. In linear terms (Equation 1), the cumulative result of repeatedly smoking a cigarette "just this time" is also beneficial. After all, if each individual decision involves net benefits, the sum of all decisions will also involve net benefits. Therefore, each decision can be made one at a time, each "net benefit" added to the next.

Of course, non-smokers face similar "just this time" choices. Several of these are posed as questions such as, "Should I, just this time,"

- Put off exercising?
- Take the elevator instead of the stairs?
- Have dessert?

- Have one more beer?
- Add salt to my dinner?
- Drive the car instead of walking?

Most people often do answer "yes" to some of these "just this time" questions. The choices implied in these questions are called "temptations." Temptations are choices that offer net benefits when viewed from a "just this time" perspective but which eventually result in destructive cumulative impacts when repeated over time. Under linear presumptions, the notion of a "temptation" makes little sense.

The illustrated "just this time" decisions do not immediately cause irreparable harm. However, cumulative impacts of all such decisions can degrade health and eventually, the cumulative impacts can kill. How does a healthy person address such nonlinear consequences? Stated simply, the healthy person must face up to the cumulative impacts of many decisions and must develop good habits and practices that place guidelines and constraints upon decisions. One must live in a way that does not give into "just this time" temptations. Health depends upon making decisions that sacrifice immediate benefits that are readily apparent for benefits that are remote and difficult to precisely define.

The strategic lessons from personal health illustrate the approach to the proposed healthy environmental strategy. A healthy strategy begins when responsibility for living a healthy life is accepted. "How to live" is a strategic question; it demands recognizing the cumulative consequences of all decisions. Many decisions will still need to be addressed one-at-a-time. When assessing individual choices and making particular decisions, the burden of proof is shifted to favor healthy living. As an example, when facing the decision, "should I have a drink just this time," the recovering alcoholic who has faced up to the cumulative consequences of drinking shifts the burden of proof from "approval presumed": to "disapproval presumed" (See Figure 43 and Figure 47). Thus, disapproval is most likely to occur despite the net benefits seen from a "just this time" perspective. With respect to other temptations (e.g., should I take the elevator rather than walk up the stairs), a healthy shift in the burden of proof - toward "disapproval presumed" - would not be as great. With a less extreme shift, it would be easier to marshal evidence to meet the burden of proof and thus justify approval (i.e., one has limited time to get to a meeting on the fiftieth floor; take the elevator).

A healthy strategy that shifts the burden of proof does not negate tactical (local, immediate) assessments and initiatives required to deal with unique situations that cannot be understood from a strategic (broad, long-term) perspective. A healthy strategy is not micromanagement. This is important to recognize because in a complex world, one can always find unique situations where strategic guidelines and constraints appear unreasonable and absurd. If these guidelines and constraints are seen as strict rules (much as scientific laws) then, these unique situations will "prove" strategic guidelines and constraints to be unreasonable and absurd (much like a single exception can "falsify" a scientific law) But, if strategic guidelines and constraints serve to shift the burden of proof, then the obvious response to these unique situations is, "fine, you have met the burden of proof; thus, approval is not at all inconsistent with the strategy." A strategy that shifts the burden of proof can, through tactical initiatives, respond to unique situations that could not possibly be anticipated. At the same time, a healthy strategy can guide the cumulative outcomes of many tactical decisions.

A healthy strategy requires monitoring so exceptions that meet an appropriate burden of proof do not become habits that yield to temptations. Healthy people do make exceptions; they may have dessert or put sour cream on their potatoes. But, having made such exceptions, it is a good idea to get on the scale occasionally to "monitor" the cumulative impacts of such exceptions. Under a healthy strategy, monitoring involves checking to see if the cumulative outcomes of actual activities over time have been consistent with the spirit of the strategy. With respect to cumulative environmental impacts, such monitoring is terribly neglected in the State of Oregon. By analogy, environmental protection as practiced in Oregon is like a person who gives lip service to a very fine diet but then refuses to get on a scale least he or she be confronted with the consequences of many "just this time" choices that too often yielded to temptations. Instead of such strategic monitoring , one finds a proliferation of tactical monitoring that keeps people

so busy with immediate tasks that they have no time to ask "where are we going."

Toward a Healthy Environmental Strategy

As in personal health, a healthy environmental strategy requires society to face the question "how should we live." To honestly face this question demands taking responsibility for the cumulative consequences of many "just this time" temptations. A healthy environmental strategy must shift the burden of proof to guide and constrain "just this time" decisions and monitor cumulative changes as a check on continuing behaviors.

Of course, a strategy cannot possibly anticipate the unique situations that will inevitably arise. When a particular situation arises that yields good reasons to act contrary to strategic guidelines and constraints, the appropriate response is, "you have met the burden of proof in this particular situation." This response is quite different from rejecting the strategy on the basis of "exceptional" situations that will always arise regardless of how thoughtful a strategy is. But, such accommodation of exceptions demands strategic monitoring that traces decisions to assure that exceptions do not become little more that repeated "just this time" behaviors that yield to temptations over time.

Earlier this report claimed that with respect to cumulative impacts, decisions have been shaped by a shift in the burden of proof. The decline and decimation of salmon stocks are largely a consequence of this persistent shift. Burden of proof has been and will continue to exert a significant influence upon decisions. Currently, this influence is for the most part hidden, implicit in common practices, and based upon linear misperceptions. By seeking a more informed (i.e., more realistic with respect to the nonlinear nature of the problems) shift in the burden of proof with strategic monitoring, the proposed strategy seeks to improve upon existing practices

The nonlinear perspective of this proposed strategy is fundamentally different from current practices. Established practices based upon linear misperceptions have resulted in a strategic void. Rather than facing up to the strategic challenges posed by a nonlinear world, it is commonly presumed that problems will be solved by doing more at the tactical level. The erroneous assumption is that more information, more analyses and more rules applied at the tactical level will somehow, by themselves, allow proper management of problems without facing up to the messy nonlinear consequences that demand more comprehensive strategies. As cumulative impacts arise, the proliferation of tactical laws, rules, and regulations expand. Participants become so busy with tactical demands that they have no time to address cumulative impacts. It is nearly impossible to sustain discourse on strategic concerns, people are too busy -- "We have no time, to even discuss where all this business is leading us." This condition, grounded in linear presumptions, is defined as "conventional tactics."

Conventional Tactics

The term "conventional tactics" refers to established practices based upon linear presumptions. Under conventional tactics, tasks are divided up so that activities are for the most part, assessed independent of each other and the assessors have little time, ability, or incentives to consider the cumulative effects of their actions. Notions of nonlinearity and emergent outcomes are seldom considered, indeed, they tend to be dismissed as irrelevant and esoteric. Raise such concerns and "eyes glaze over." Under conventional tactics, the burden of proof shifts in a persistent, significant and largely unexamined way (Figure 45). Nevertheless, under linear presumptions, conventional tactics make sense. Under conventional tactics, research and monitoring serve to provide decision-makers with the information needed to make more informed decisions. With more information available, one presumes that evidence becomes more conclusive as sketched in Figure 47. Decisions are based upon the evidence and the burden of proof appears to have less influence upon decision outcomes as can be seen by overlaying Figure 47 onto Figure 43.

If indeed research and monitoring can shift evidence toward the "conclusive" region of the phase plane as shown by the solid arrows in Figure 47, then concern for burden of proof would become less relevant with time. Research and monitoring would shift decisions toward the upper region of Figure 43 where decisions are based upon the facts and burden of proof has little influence upon

decision outcomes. If decisions are not yet within this region, then, according to conventional tactics, they are heading in that direction as more information is gathered. As the information base expands, Figure 41 rather than Figure 46 becomes the more reasonable model.

At first glance, conventional tactics appear to make sense. It seems reasonable to assume that as more information is collected, the ability to foresee consequences will improve. With time, evidence concerning impacts should become more conclusive. As evidence is gathered to predict consequences, society's collective ability to produce change also increases. The gap between the ability to produce change and the ability to foresee the consequences of change can be defined as the "relative ignorance" If relative ignorance decreases, Figure 48 (a), then it is reasonable to assume that available evidence concerning the impacts of proposed activities will become more conclusive. This is the view presumed by conventional tactics. Consider the different view sketched in Figure 48 (b).

In 1973, a strategy for Oregon's estuaries claimed that relative ignorance should <u>not</u> be expected to decrease as with time. Instead, relative ignorance might even increase with time as illustrated in Figure 48 (b). The ability to foresee the consequences of actions would not get ahead of the ability to produce consequences. Instead, the ability to foresee consequences could fall behind the ability to produce consequences. Available evidence would not become evermore conclusive with time as conventional tactics would lead one to believe. From this perspective, an environmental predicament arises: society's ability to produce change will increasingly exceed its ability to foresee the consequences of such change. In other words, relative ignorance grows with time as shown if Figure 48 (b). The environmental predicament is briefly explained as follows.

To foresee impacts of activities requires that the interactions between them be understood. Nonlinear interactions (recall Equation 2) must be addressed. To produce a change, these same nonlinear interactions need not be assessed. The ability to produce change can grow more rapidly than the ability to foresee the consequences because this later ability requires an understanding of nonlinear interactions that the former ability does not. As activities expand in scope and number, the interactions between them expand at ever greater rates. The complexity of forecasts increases as the scope and scale of interacting impacts accumulate.

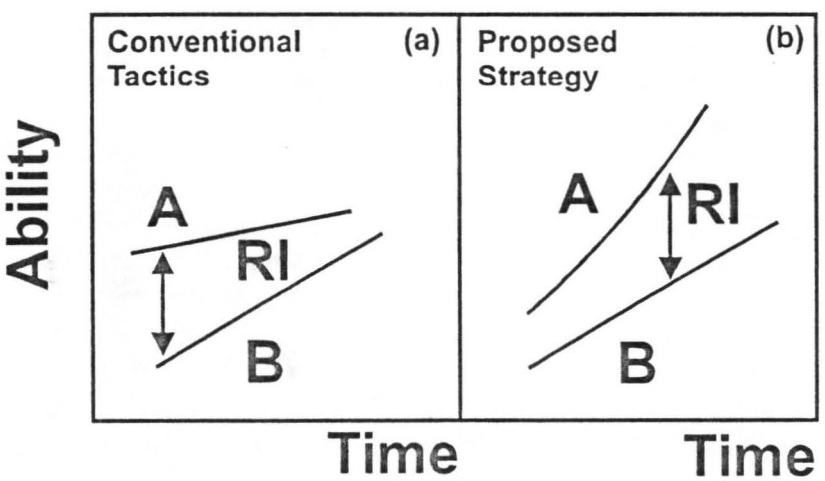

Figure 48: Two different views comparing (A) ability to produce environmental change and (B) the ability to foresee the consequences of change. The gap between these abilities is defined as relative ignorance. Conventional tactics (a) see relative ignorance decreasing with time, thus leading to ever more conclusive evidence. The proposed strategy (b) sees relative ignorance as non-decreasing and even increasing, it does <u>not</u> assume ever more conclusive evidence.

Thus, the slope of curve *B* on Figure 48 (b) is less than the slope of curve *A* to reflect this growing complexity.

The environmental predicament was a prediction (made in 1972-74) that claimed that the available evidence concerning the impacts of activities would not become more conclusive as implied in conventional tactics [Figure 48(a)]. Of course, a realistic strategy should include efforts to gather and apply evidence to decisions. But, such a strategy must also be based upon the recognition that, despite best efforts, available evidence will be far less than conclusive. Engineers have long applied safety factors to deal with inconclusive information. In effect, safety factors employed by engineers serve to shift the burden of proof so the health and welfare of society is held paramount. In similar manner, environmental strategies must also recognize the inconclusive nature of evidence and shift the burden of proof accordingly. In comparison to engineering designs, however, the systems that should be addressed by a realistic environmental strategy are more complex, adapting, and nonlinear. Such systems demand new ways of thinking that this report has briefly explored. The exploration needs to be continued.

It has been more than 20 years since this prediction was made. During this time, support for research, monitoring, and assessment studies expanded dramatically. More than two decades of experience in environmental impact assessment has transpired. The number of assessment reports completed is impressive; the number of pages written is staggering. An army of environmental consultants has grown up. Laws have been passed Agencies have been formed and reformed. Regulations have been developed. The number of specialists, professional journals, and experts dealing with environmental impacts has grown dramatically. Many thousands of professionals have earned graduate degrees from an expanding range of disciplines devoted to environmental assessment, management and monitoring. Most of this activity has been explained, justified, administered, and directed from the perspective of conventional tactics. A great deal has been learned, but after more than twenty years of such efforts, has the available evidence concerning the impacts of our activities become more conclusive? Can decisions now be based upon "the facts?" Has the burden of proof become less relevant with time, less of a concern for those seeking to protect the environment? Has the ability to predict outcomes exceeded the ability to produce outcomes on vast and complex scales? Has relative ignorance declined? Has the need for a healthy environmental strategy declined? Has confidence in long established practices (conventional tactics) grown over the years? The answer is "No" to each of these questions. These past decades provided ample evidence for the following claims:

- Linear presumptions are widespread, naïve, and mistaken.
- Cumulative impacts have indeed accumulated.
- Available evidence concerning expanding activities has not become evermore conclusive as implied by conventional tactics.
- With respect to cumulative impacts, the burden of proof has repeatedly shifted the outcomes of decisions not unlike the shift that led to the explosion of the shuttle, Challenger.
- The environmental consequences of all this has been destructive, including the decline and decimation of wild salmon stocks throughout the Pacific Northwest.

In brief, the history of the last several decades, reveals that conventional tactics are seriously deficient. The environmental predicament is a statement of realistic trends. The evidence points toward Figure 48 (b) rather than Figure 48 (a) as a general assessment of the condition. A realistic strategy needs to build upon such lessons.

Strategic Guidelines: A Beginning

The current salmon crisis is largely a cumulative consequence of numerous decisions (over time and across watersheds) made with implicit burdens of proof that tended to protect institutions rather than ecosystems. If aquatic ecosystem protection and restoration are required to arrest or reverse declines in salmonid populations, then strategic guidelines are needed to shift the burden of proof so that cumulative effects are

addressed in more effective ways. The development of strategic guidelines is no simple matter. Such guidelines must be based upon continuing research on cumulative impacts and the lessons gained from historical case studies. Nevertheless, this report would be remiss if it only concluded that "more research is needed." Therefore, the following three guidelines are proposed, not as a final recommendation but rather as a beginning, calling for discussion and revision.

1. Activities that are likely to shift ecosystems away from natural processes and disturbance regimes call for a burden of proof that shifts toward "disapproval presumed." However, where an activity tends to shift a system toward more natural processes and disturbance regimes, the burden of proof should shift toward "approval presumed."

2. Activities more likely to result in irreversible environmental departures from natural conditions (see 1 above) call for a burden of proof that shifts toward "disapproval presumed." To overcome this position, an agency or project proponent would have to provide a relatively high level of justification and understanding of environmental consequences for the project to move forward.

3. When activities occur within or threaten relatively natural (less disturbed) ecosystems, the shifts in burden of proof indicted above should be greater.

In a healthy environmental strategy, such guidelines would exert a persistent and pervasive influence over time, much as good habits influence healthy living. The greater the disagreement over available evidence, the more relevant the burden of proof becomes. When making choices on how to distribute limited resources, such guidelines could make meaningful differences. As an example, with roughly equal benefits (per dollar expended) in terms of fish survival, ecosystem protection and restoration would be favored over downstream barging of juveniles. Riparian zone protection would be favored over hatchery operations. Loss of natural habitat would be considered a greater threat than increased turbidity during dredging operations. Research and monitoring could provide information relevant to the implementation of such guidelines not by determining precise predictions but rather by assessing choices in terms of relative reversibility, influence upon natural disturbance regimes, and departures from natural conditions. Such information would provide a more reasonable basis for shifting the burden of proof (see Figure 46).

Even in this limited form, strategic guidelines could shape the course of decisions, opening up possibilities that in the past had been overlooked, dismissed, or neglected. As an example, under such strategic guidelines, an updated version of Stone's (1891) call for a "Salmon National Park" would make sense. Of course, such a "park" would need to be spatially distributed to reflect the far reaching life cycles of salmon. Leffler's (1957) statement also deserves serious consideration: certain river basins in the Pacific Northwest should be dedicated to the conservation and development of fish and wildlife resources as their highest and best use. Variations of such recommendations and methods to implement them are found in recent reports (Henjum, et al., 1994; Botkin, et al., 1994). Where such recommendations call for the protection and restoration of natural ecosystems, habitats, riparian zones, and disturbance regimes, burden of proof should shift toward "approval presumed." Where development activities threaten to alter such systems irreversibly, burden of proof should shift toward "disapproval presumed." The reverse appears to have been the dominant tendency, particularly in Oregon which has the smallest protected areas (measured in either protected area or percent area protected) among the States, regions, and Provinces of the Pacific Northwest (Ryan, 1994).

Such guidelines could influence decisions in less dramatic ways. As an example, they would tend to support the policy standards and statements shown in Table 14. Strategic monitoring, particularly with respect to irreversible losses, would become a higher priority. The guidelines could serve as a basis for allocating limited resources. As an example, if under these guidelines the burden of proof for an action strongly favored disapproval, then it might be wise to allocate resources (for gathering of evidence) to other

decisions where additional evidence might more realistically make a difference in decision outcomes.

A private consultant recently commented that his clients become most frustrated when the requirements for approval or disapproval are highly uncertain. Strategic guidelines would allow a consultant to provide relevant information early in the process before clients invested time, money, and effort. Referring to strategic guidelines, a consultant could warn a client that one course of action would likely be an "uphill effort" in comparison to another. Therefore, strategic choices could be made early in the assessment process before time, money, and effort were committed.

In closing, these strategic guidelines could help shift current practices toward a more healthy environmental strategy. They would not solve present problems, but with respect to cumulative environmental impacts, they would improve upon the current practices. The concepts discussed in this chapter could help break out of conventional tactics that are clearly deficient. A more nonlinear way of thinking could help to correct linear misperceptions and the practices that now arise from them.

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STUDY CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions are made related to the charge given for this study:

1. Excessive gravel removal from streams can adversely affect stream health through a variety of physical and biological impacts. Many of these impacts will directly or indirectly affect essential indigenous salmonid habitat. Except for isolated sites of permitted deep water dredging, streams should be managed so that gravel removal rates are less than natural gravel recruitment rates in order to maintain or re-establish aquatic habitat.

2. Material removal from streams does not appear to result in any general ecosystem benefits. Examples of using gravel removal to improve habitat and water quality are limited and isolated.

3. Present removal-fill operations by the gravel industry, in conjunction with the ODSL permitting process, have limited direct impacts such as sedimentation of spawning beds, high turbidity during salmon migration, direct removal of spawning beds, and destabilization of streambeds and streambanks. However, uncontrolled activities including gravel removal, push-up dams, water diversion, and bank stabilization appear to have resulted in significant direct impacts.

4. The potential indirect (off-site, multiple-causes, long-term, cumulative) impacts of removal-fill operations are a threat to the sustained health of Oregon's streams. Typical impacts include aggregate siltation and changes in size distribution, altered channel morphology, lost diversity of habitat, and reduction of bed elevation. These interactions are poorly understood and are not effectively addressed in the present ODSL-permitting process. Removal-fill operations are just one of many other human activities in-streams that are contributing to cumulative effects associated with the decline in salmon populations.

5. Indirect effects can be managed by adopting conservative evaluation of permits for removal-fill operations. For proposed operations that are likely to significantly shift streams away from natural conditions, it is recommended that the burden of proof of insignificant impact be shifted to the permit applicant.

6. Deep pools created by material removal in-streams appear to attract migrating salmon for holding. From experiences on the Chetco River, such concentration of fish tends to result in high losses due to predation and recreational fishing.

7. Generation of fine material and resulting sedimentation from gravel removal can range from minimal to extensive. Gravel removal from those parts of channels where fines tend to accumulate, such as on upper portions of channel bars and the margins of streams, tends to create siltation problems because of the large quantities of entrapped fine materials released. Sedimentation may be a delayed impact because gravel removal typically occurs at low flow when the stream has the least capacity to transport the fines out of the system.

8. In specific cases, gravel removal can be effectively used to remove stresses on streambanks and streambeds resulting in greater stabilization. In this manner, gravel removal can result in reduced needs for fill, less streambank stabilization, and greater stability of some spawning beds.

9. Gravel removal from streams in excess of natural recruitment is likely to cause long-term shifts in-channel morphology, including reduced surface area of usable spawning gravel, channel diversity, and lowered bed elevation.

Recommendations to Improve Present Management of Removal-Fill Operations

Removal-Fill operations are presently managed primarily to control direct (local, single-cause, short-term) impacts through regulation by the Oregon Division of State Lands and the U.S. Army Corps of Engineers. The objective of this regulatory process is to avoid large-scale environmental impacts, while allowing those removal-fill operations necessary to support Oregon's economy. Such regulation typically is applied on a site-by-site basis through individual permits and clearly defined requirements for approval. The following recommendations are related to proposed improvements in this "business-as-usual" regulatory process that would assist the achievement of the regulatory objectives.

1. Improve Data Collection Related to Removal-Fill Operations

1.a. Conduct monitoring and research to evaluate impacts.

Despite the statement in Oregon's removal-fill law mandating state officials to provide "protection, mitigation, minimizing, rectifying or reducing impacts," not a single Oregon-specific study was found to evaluate and/or monitor the environmental impacts of material extraction or filling. This lack of specific field data to support the removal-fill permit process thwarts the goals of protection, preservation, and best use of water resources stated under ORS 196.805.

This lack of monitoring and research support related to impacts on natural resources is not in the best interest of Oregon's citizen. Regulators simply need more information to manage Oregon's natural resources effectively. The adaptive, watershed-wide management approach proposed in this study will require greatly improved information and analysis. A mechanism is needed to continually support such monitoring related to removal-fill operations.

In addition to monitoring of permitted operations, a research and technology transfer program is needed to continually develop methods for removal-fill operations that result in reduced environmental impacts. A myriad of new approaches to removal-fill operations are being applied throughout the Pacific Northwest; a mechanism needs to be developed such that the results of innovative approaches can be disseminated to natural resource managers in this regulatory process. For example, new biological methods for stabilizing streambanks hold immense promise for reducing fill activities with secondary benefits of increased shading and production of large woody debris. Such methods need to be encouraged by the regulatory process at all levels.

1.b. Improve ODSL database capabilities and use.

ODSL needs to develop methods for better removal-fill documentation and incorporate these records into Geographic Information System (GIS) supported analysis. The present ODSL data collection process is incapable of adequately monitoring removal-fill activities. For example, the database containing permitted volumes for gravel extraction is not connected to the database containing actual amounts extracted and royalties collected. ODSL lacks easy retrieval of either quantity or location of removal-fill operations. This information is vital to understanding and managing ecological effects of ODSL-permitted operations. Personal computers and off-the shelf database programs could handle these records at a relatively low cost. These database records should be readily available to assist outside agencies' planning efforts.

1.c. Implement GIS-based resource management.

ODSL needs to further implement a GIS-based resource management system for removal-fill activities. Such a system could be used to address a variety of issues. Entire regions, watersheds, or the State could be viewed using GIS technology to evaluate areas of highest resource use. Areas identified as essential habitat for sensitive, threatened or endangered species could be viewed and compared to areas of resource use or permit application. Aggrading/degrading reaches could be identified by plotting water gage heights state-wide. Sediment

budget information could identify watersheds or reaches with depleted gravel reserves and inadequate gravel re-supply from upstream sources. Estuaries could be evaluated for fill rates over time. Maps could be constructed showing prospective permittees areas open for permit application and areas restricted due to habitat importance or reduced resource abundance. Permitted amounts could be compared to actual extraction rates by watershed or region. Watershed restoration projects might be displayed to avoid inadvertent gravel extraction.

As ODSL continues its transition to GIS-resource management, expert opinion should be solicited on recommended hardware, software, training, import of data to GIS, and best monitoring procedures. After the GIS is fully in place, permit records for the past decade(s) should be updated and geo-referenced as accurately as possible for inclusion. A GIS coverage for fill and another for removal should be constructed and examined in conjunction with the ODFW GIS-layer on essential salmon habitat to avoid disturbance of these critical areas. The GIS information on sensitive species should be expanded to include habitat of other sensitive, threatened or endangered fish and aquatic-dependent species.

To import the updated database information from ODSL permit and royalty records into the GIS, an accurate geographic location must be associated with each permit. Presently, the permit application asks only for drawings of "general location" of the project and a plan view showing location of waterways, wetlands, high water and low water lines, location of fill or removal, adjacent properties, and a cross-section. This method of locating the site is not sufficiently geo-referenced to incorporate into GIS. The permit requirements need to be altered to require decimal latitude-longitude coordinates of the site obtained by a global positioning system. Inclusion of aerial photos in permit applications would assist in geo-referencing the site and could be used for measurements of extraction volumes and evaluation of impacts over time. Such data should be required as soon as possible in anticipation of future GIS mapping systems.

1.d. Allocate sufficient financial resources and staff to monitor resource abundance, condition, and use.

ODSL personnel often lack time for site visits to monitor operations and verify extraction amounts and environmental safeguards. Royalties from gravel extraction appear adequate to collect information to insure permit compliance and minimal environmental impacts. However, such royalties presently are not used directly for staff, but are transferred to the general school fund. It is recommended that a direct linkage be developed between royalties and support for staff who monitor and issue permits for removal operations.

All monitoring should be addressed towards testing of specific, identified hypotheses. ODSL resource management staff should develop long-term research plans that can be supported by the monitoring program. A linkage of monitoring and research would support an adaptive management approach for removal-fill operations. Such an improved information base resulting from long-term monitoring could be achieved at nearly zero additional cost by proper coordination and planning.

2. Minimize Additional Degradation of Salmonid Habitat

2.a. Prohibit, regulate, or otherwise manage small operations.

Small operations (less than 50 cubic yards) presently are not regulated by ODSL. Such operations can potentially contribute to direct and indirect impacts and should be prohibited, regulated, or otherwise managed. For example, 50 cubic yards (four or five dump truck loads) of gravel from a prime salmon spawning gravel bed (redd) during egg incubation could result in a large impact.

The recent enactment of the "Excavation Rule" by the U.S. Army Corps of Engineers under Section 404 of the Clean Water Act should provide the regulation of such small operations. Under this rule, persons desiring to remove small gravel quantities will be required to show that such operations are the "least environmentally damaging practicable sites." In addition, sites can not be in wetlands or riffle/pool complexes. Proposed operations by resource agencies can not conflict with ESA recovery plans, cultural and historic protection, requirements under the Coastal Zone Management Act, or the Oregon DEQ's water quality requirements. It is recommended that strong support be given to the U.S. Army Corps of Engineers to use the "excavation rule" to regulate these small gravel removal operations.

2.b. Conduct removal-fill operations in a manner to minimize potential impacts on salmonid habitats.

Methods to minimize impacts of removal-fill operations on salmonids include several obvious items. No gravel extraction operation should be permitted in or upstream of salmon spawning grounds except when such operation could benefit salmon survival (e.g., if deposition after a major flood has threatened a spawning area). Gravel removal quantities should be limited so that accumulation rates are adequate to avoid extended impacts on channel morphology and salmonid habitat. Gravel removal-fill operations should not interfere with salmon migration past the particular site.

Because of the adverse or even lethal effects of suspended sediment on salmonids and other species and their habitats, removal-fill operations causing sediment re-suspension should be monitored and maximum allowed turbidity levels strictly enforced. Extracted sediments should never be washed directly in the stream or river.

Many of these approaches are present standard practice for ODSL. It is recommended that ODSL develop a manual-of-practice that records and describes successful methods to minimize impacts to salmonid habitats. Such practices are presently maintained by individuals and various "gray" literature publications. This approach has the distinct disadvantages of inaccessibility to new personnel and potential loss due to lack of institutional memory. The "handbook" could be supported by periodic conference presentations and academic journal publications. ODSL personnel should be regional experts in minimization of removal-fill impacts and, as a disciplinary community, they should have written documents that support and foster that expertise.

2.c. Allow bar skimming gravel removal under restricted conditions.

It is recommended that bar skimming be allowed under the following restricted conditions:

- the gravel bar is not an active spawning, rearing, or feeding area for salmonids;
- adequate gravel recruitment exists so that the bar is typically replenished each year;
- berms and buffer strips be used to control stream flow away from the location of gravel removal;
- gravel is removed only during low flows and from above the low-flow water level; and
- the final grading of the gravel bar does not significantly alter the flow characteristics of the river at high-flows.

It needs to be noted that present management practices that allow removal of seasonal gravel accumulations may not adequately protect streams because such accumulation may represent only a local non-equilibrium condition. This may not be an indication that excess gravel accumulation is occurring in the watershed or in long stream reaches. If in-stream reaches show a recent history of rapidly eroding bars or lowering of streambeds, bar skimming should not be allowed.

A continual review of management practices for bar skimming is recommended. Bar skimming operations need to be monitored to insure that such operations are not adversely affecting gravel recruitment downstream or stream bed profiles either upstream or downstream. Field studies coupled with monitoring should be used to test proposed new improved techniques for this gravel removal technique.

2.d. Restrict deep water dredging for gravel production to areas where presently practiced

Deep water dredging of gravel represents a significant and permanent alteration of the elevation of streambeds. The potential environmental effects resulting from such practices are often chronic and difficult to assess at downstream sites. However, effects do occur such as the collection of fine materials within the Newberg Pool. Such materials may result in localized exposure of fish and invertebrates to high levels of toxic compounds and transfer of such compounds through food chains.

Deep water dredging should not be initiated at new sites or extended beyond its present application without extensive review because of the lack of knowledge of long-range direct and indirect impacts of this practice. Present locations of such practices on the Columbia, the lower Willamette, and the Umpqua

Rivers should be allowed to continue since the existing environmental damage, at least in the short run, is judged to be not incrementally altered by present operations.

2.e. Do not allow a net loss of wetlands for all removal-fill operations.

Riverine wetlands provide essential salmonid rearing habitat and also support the aquatic food web necessary for salmonids. Preference should be given to protection and preservation of natural wetlands over reconstructed wetlands resulting from mitigation. This recommendation should be supported by careful monitoring over time as wetland loss is often an unintended, insidious process. Wetlands produced from flood-plain gravel removal should be used for mitigation of other necessary fill operations, thus providing incentive for the conversion of former gravel removal sites into functioning wetland systems.

2.f. Use biological streambank stabilization methods where possible.

The technology of biological streambank stabilization has advanced in recent years to where it is a viable alternative to "harder" approaches such as riprap or concrete groins or abutments. Biological methods should be recommended because they provide benefits to salmonid populations including shading and generation of large woody debris.

Recommendations to Improve Comprehensive Management of Removal-Fill Operations

The serious decline of salmonid populations in the Pacific Northwest can be attributed to a wide range of natural and man-related activities. Forestry, agriculture, fishing, and power production practices are undoubtedly major factors in fishery decline and habitat loss. Removal-Fill operations in-stream are also a contributing factor through both direct and indirect impacts. While most direct impacts from removal-fill operations are presently regulated and hopefully minimized, indirect impacts resulting in cumulative loss of aquatic productivity are of significant concern. It is recommended that some significant shifts in present regulatory approaches be adopted to control these far-field, multiple-cause, long-term, cumulative impacts. *Failure to adopt such regulatory changes will probably result in continued decline of salmonid populations in the State of Oregon regardless of how effective the "business-as-usual" regulatory process controls direct impacts. "Business-as-usual" management of Oregon streams can not continue, nor is there time to wait for more definitive studies.*

Even though a total understanding of the impacts of gravel removal on salmonids is not available, adequate information is present to improve present policy. The following recommendations are related to proposed improvements in regulating indirect impacts; such regulation can be considered a "not-business-as-usual approach." As such, opposition to these recommendations can be expected from persons or organizations that are accustomed to interacting with state and federal agencies with a focus on direct impacts.

In addition, present political climates expounding "less government" are not expected to be receptive to these recommendations. It must be realized, however, that these complex indirect impacts typically result from negative externalities resulting from private sector activities, the classic "tragedy of the commons" problem. The only rational response is to regulate these indirect impacts, returning as many external costs as possible back to the private sector decision-making process. A clear example is the long-term, gradual streambed erosion from gravel extraction undermining bridge piers resulting in increased state highway costs (Kondolf, 1994).

1. Improve Present Policy by the Burden of Proof of "No Significant Impact" Shifting to Permit Applicants

The indirect impacts of removal-fill operations on specific salmon stocks cannot be either accurately predicted or measured because of the complex mix of affected variables. For example, salmonid populations vary greatly from year to year and from watershed to watershed. Data on salmon populations can only be analyzed over time periods of decades to provide statistically-significant measures of decreases (Bledsoe et al., 1989). The adequate sampling of such populations including definition of each stocks and important environment conditions would require immense resources. Resources to clearly identify such linkages between removal-fill operations and various indirect impacts are not currently, and may never be, available.

In the absence of a clear understanding of removal-fill impacts, salmonids and their habitats need to be conservatively protected. For those proposed activities that are projected to result in significant indirect impacts, it is recommended that the burden of proof of "no significant impact" be shifted to the persons proposing the activities. "In the absence of statistically significant data trends, the burden of proof should favor conservative management; no activity that could (significantly) harm habitat or stocks should be allowed unless monitoring data indicate it is safe to proceed" (Bolle Center, 1993). Resource agencies cannot be expected to prove definitively that a stock has been or would be harmed by a particular removal-fill operation. Permit applicants need to demonstrate that a required level of environmental protection will be achieved.

Resource coordinators for ODSL need to develop and adopt criteria that will assess what proposed activities can be adequately regulated by "business-as-usual" approaches, and which ones cannot. It is proposed that all activities that will shift streams significantly away from natural habitat conditions be considered ineligible for the normal permitting process. This scheme needs to adapted, refined, and expanded by natural resource managers based upon further experiences and new knowledge.

2. Do Not Allow Gravel Extraction From Reaches of ODSL-Managed Streams that Support Sensitive, Threatened or Endangered Species

Gravel extraction should not be allowed in reaches of ODSL-managed streams that support spawning, rearing, and feeding of sensitive, threatened or endangered fish species (salmonid and others). The "sensitive, threatened or endangered" designation is society's legal manifest to stop "business-as-usual." In addition, it is recommended that this restriction be applied to streams supporting chum or coho salmon because of their seriously declining populations. The severity of the population declines and the lack of definite predictions as to potential impacts of removal-fill operations make this recommendation the only reasonable and prudent approach to responsible management of these populations.

3. Do Not Allow Gravel Extraction from Reaches of ODSL-Managed Streams that are Part of Aquatic Diversity Areas or Support Source Salmon Populations

Gravel extraction should not be allowed from ODSL-managed rivers and streams that support the best remaining examples of aquatic biodiversity and salmon populations (i.e., the aquatic diversity areas identified by the Oregon Chapter of American Fisheries Society and the source watersheds for salmon being identified by the Oregon Department of Fish and Wildlife). Because such areas represent focal points for recovery of important ecosystems and need to be protected from additional degradation, it is important to protect these remaining, relatively intact, aquatic ecosystems. These areas have become few in number due to development, yet are significant baseline representations of healthy ecosystems against which to measure the impacts of activities such as gravel disturbance.

4. Promote Recycling Efforts

ODSL needs to work cooperatively with other state agencies such as the Department of Geology and Mineral Industries (DOGAMI), Department of Environmental Quality (DEQ), and the Department of Transportation (ODOT) to encourage aggregate recycling to reduce the demand for stream gravel resources.

Recommendations for Research Activities Related to Removal-Fill Operations

Some activities appear to offer positive solutions to reduce or mitigate the impacts of removal-fill operations. Clearly, the win-win situation for all stakeholders is to develop management practices that support salmonid and ecosystem sustainability, while continuing to conduct removal-fill operations necessary for the Oregon economy. However, many of the activities developed by the research team can only be labeled as "unproved." As such, it is recommended that means be developed to support research such that such ideas can be demonstrated and accepted by regulatory agencies.

1. Develop Plans to Increase Gravel Availability

Nearly all current removal-fill activities in Oregon's streams result in a decrease of streambed gravel. While gravel removal is increased or maintained, gravel production from upstream sources is often reduced through erosion control, much of which is fill activities. Coupled with large-scale flood-control projects that reduce upland flooding, erosion, and bed-load transport, the availability of gravel in-streams is clearly declining.

Expansion of "meander zones" to more natural widths should be examined as a long-term proactive management strategy for streams undergoing gravel removal or large-scale bank protection. For example, many presently controlled streams are limited with respect to the overall width of bottomlands through which the streams are free to meander. ODSL in conjunction with the U.S. Army Corps of Engineers should attempt to develop substantial areas of meander zones along streams. The wider meander zones should again approach the natural pre-statehood widths of active and abandoned channels mixed with low-lying flood plain lands. This wider zone would need to be protected from development. Revetments and other constraining structures would be removed over time and the river would be allowed to re-establish meander forming processes during high-flow, resulting in erosion of adjacent streambanks. This would allow for an increase in gravel availability within a river system which could result in increased areas for salmonid spawning and replenishment of depleted reaches. A portion of the increased gravel from erosion could be allocated for removal by the gravel industry.

2. Develop Strategies to Increase Salmonid and Aquatic Habitat

2.a. Develop methods to convert former flood plain gravel pits into productive habitat.

Lakes and ponds remaining from floodplain gravel operations may represent a valuable resource for creation of additional aquatic habitat. ODSL needs to work cooperatively with the gravel mining industry and local planning authorities to develop efforts to re-establish and restore these areas for aquatic habitat. Every effort should be made to have these lands transferred to state ownership and to have restoration projects initiated to develop healthy, active aquatic habitat. The restoration of these ponds and lakes, and associated riparian plant communities, into aquatic habitat should become a top priority for local planning agencies. Residential development should be discouraged.

Such former gravel removal sites should be considered for hydraulic connection to the riverine systems where ecological benefits to riparian/aquatic ecosystems can be attained. These areas could provide significant juvenile rearing areas and adult feeding. Pilot projects should be initiated to demonstrate best methods of development and the advantages and disadvantages of specific approaches.

2.b. Use gravel mining as a potential method for developing wetlands, off-stream channels, lakes and ponds, and potential salmonid spawning beds.

Resource maps should be developed by ODSL of old stream channels in the flood plain that contain economically-recoverable quantities of gravel. Cooperative ventures should be developed so that portions of such gravel can be removed to form needed wetlands, channels, lakes, ponds, and spawning areas. ODSL and the DOGAMI should develop cooperative plans to facilitate permit applications for such efforts.

Restoration plans should be included into the initial plans for development, similarly to approaches used in upland mining. Restoration of areas from which gravel has been removed should be conducted immediately after the final removal. Research should be conducted to monitor the effectiveness of these areas to support wildlife. Little is known about how well such areas would re-populate or support healthy salmonid populations.

3. Ensure Compatibility of Policies with Existing Watershed Initiatives in Oregon

ODSL needs to develop a watershed approach to management of gravel resources and this effort needs to be closely coordinated with other state watershed programs. A number of programs are underway to assess conditions and integrate multiple interests within watersheds in Oregon.

Restoration programs can be quite expensive and should be protected from interference by contradictory actions. ODSL policies should not erode options of future watershed initiatives nor create conditions requiring subsequent restoration. Removal-fill

operations must be consistent with these watershed programs to ensure efficient use of public funds. ODSL needs to continue to be an active participant in these programs:

- The Oregon Watershed Health Program. This involves eleven state agencies at a cost of ten million and is concentrating initially on two watersheds, the Grande Ronde and South Coast, in this eighteen-month program. Goals are to restore watershed health and economic viability, increase positive community and government interactions through formation of watershed councils, and produce visible results. Coordination efforts need to be included in ODSL's gravel management activities.

- The Watershed Assessment, Oregon Strategic Water Management Group (SWMG) and the Governor's Watershed Enhancement Board (GWEB). Stage 1 has been completed in draft form and is an assessment of watershed conditions using common evaluative criteria to prioritize watersheds for the Watershed Health Program, set funding goals for enhancement, and coordinate agency efforts. The GIS map products from this project depict watershed conditions by hydrologic unit and display risk of potential loss of functional attributes in each watershed (Steve Daggett, personal communication) and should be adopted by ODSL for their management efforts.

- The Oregon Coastal Salmonid Restoration Plan. This has two components: a primary strategy to identify priority watersheds as either source watersheds to be protected or recovery watersheds for restoration to alleviate potentially limiting conditions, and a secondary strategy to apply short-term interim measures in critical areas (Nichelson et al., 1993). ODSL needs to coordinate this effort.

- A committee of nearly thirty scientists and specialists from state and federal agencies, Indian tribes, private land owners and environmental groups. They were originally convened by Senator Bill Bradbury to recommend a process to prioritize state watersheds for restoration and protection (Willa Nehlsen, personal communication). The committee will develop a framework targeting strategies that provide the greatest ecological benefits for native fishes and ecosystems. This framework is expected to help in the prioritization of restoration projects and funds across the Pacific Northwest.

- Watershed Councils. These are being formed in various areas of the state, either in conjunction with the Oregon Watershed Health Program, mentioned above, or as part of a separate process. The McKenzie River Integrated Watershed Management Plan is designed to build consensus, define common problems, and seek solutions to watershed health issues in the McKenzie River Basin. Several other community groups are forming similar watershed partnerships (e.g., the Applegate Partnership, Siuslaw Institute of Watershed Arts and Sciences, Coquille Watershed Association).

- Ecosystem management of federal lands, which make up a large percentage of the state. Both the Forest Ecosystem Management Assessment Team (FEMAT, 1993) and the Eastside Forest Ecosystem Health Assessment (EFEHA) (Everett, 1993) prescribe management of federal lands based on ecosystems as delineated by watersheds. These programs advocate the use of adaptive management, an experimental approach for managing complex ecosystems under changing environmental conditions and social priorities.

ODSL should anticipate management changes needed to cope with additional listings of species under the Endangered Species Act. It is anticipated based upon present trends that more salmonid species in expanded geographical regions will be listed as threatened or endangered under the Endangered Species Act. The State of Oregon decided in 1994 not to list the coho salmon, but ODSL should develop a high-level proactive team to plan for the consequences of such listings to their operations. In relation to gravel removal, such an approach could help transition the gravel industry to a new set of rules and regulations with reduced dislocations and financial impacts.

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APPENDIX I. TYPICAL PERMIT PROCESS

Permitting in the State of Oregon

The following information is based on documents, pamphlets, and brochures published by the State of Oregon, Division of State Lands (ODSL). The primary sources for these documents are the Oregon Revised Statutes and the Oregon Administrative Rules. Hence document citations are not specifically given unless from a different basic source.

Waterway Ownership and Responsibilities

The State of Oregon owns most land beneath tidal and commercially navigable waters, extending up to mean or ordinary high water. Title to these lands came from the federal government when Oregon was admitted to the Union in 1859. The public trust doctrine gives public waterway rights to navigate on or over the water, to harvest fish and shellfish, and to use the water as a highway of commerce (OSU Extension, 1982).

For non-navigable streams, private ownership includes the beds and banks, but not the water.

Several public agencies at federal, state, and local levels are involved in regulating development activities and uses along streams where the bed ownership may be either public or private. The basis for such responsibilities derives from various laws.

Section 10 of the Rivers and Harbors Act of 1899 gave authority to the U.S. Army Corps of Engineers to regulate obstructions to navigable waters. This is done through a permit system.

Section 404 of the Clean Water Act (and its amendments) regulates the disposal of dredged or fill material in "waters of the United States." This is a broader term than the "navigable waters" of Section 10, covering traditionally navigable waters, tributary streams, and wetlands.

The U.S. Army Corps of Engineers administers the Section 10 permit program jointly with the Section 404 program. This broadens the jurisdiction considerably. The Environmental Protection Agency reviews and must approve or disapprove each permit under its Section 404 responsibilities.

Every decision on Section 10 and/or Section 404 permits involves other federal laws. The National Environmental Policy Act of 1969 requires that all federal actions, including decisions on permits, be evaluated in terms of effects on the quality of the human environment; if significant effects are perceived, then an Environmental Impact Statement must be prepared. The Fish and Wildlife Coordination Act requires consultation by the U.S. Army Corps of Engineers with the U.S. Fish and Wildlife Service and Oregon Department of Fish and Wildlife. National Marine Fisheries Service is also involved. The Coastal Zone Management Act of 1972 affects permit decisions and, in Section 307, requires that the Section 10/404 permits be consistent with Oregon's federally approved coastal management plan.

Beyond the federal involvement, the State of Oregon and local jurisdictions have laws and rules that affect waterways. Collectively, there is a multi-layered pattern of responsibilities that affect and constrain the actions that may be taken by waterway owners.

Why a Permit?

Oregon places a high value on clean water, healthy aquatic life and habitats, and natural scenic areas. State policy emphasizes "the protection, conservation and best use of the water resources of this state." The policy covers not only water and materials for domestic, agricultural, and industrial use but also habitats and spawning areas for fish, avenues for transportation and sites for commerce and recreation.

Consequently, any activity that is likely to lessen the use and value of water and aquatic

resources is cause for state concern and management action. Because salmonids are particularly regarded as species of great cultural, recreational and commercial value, particular emphasis is given to the protection of salmon habitat in the waters of the State.

Oregon has developed a "Removal-Fill Law" and a supporting administrative program to regulate the removal and filling of materials in waters of the State. The program is designed to conserve, protect, and manage Oregon's water resources for the benefit of present and future generations. Authority is centralized in the Director of the Division of State Lands for control of the removal of material from the beds and banks or filling of the waters of the State. The Director must consider all beneficial uses of water when administering fill and removal statutes.

This program emphasizes the use of permits to regulate activities that could pose potential concern for water and aquatic systems. The permit process gives government agencies and the general public opportunities to become aware of activities that could jeopardize the State's water resources before the permits are implemented. Through this process, unsuitable activities may be prevented and acceptable activities may be regulated to assure that they are conducted under conditions that protect the beneficial values inherent in the impacted natural resources.

The federal permit process, when it applies to a proposed action, has been combined with the State's permit process. Thus, the U.S. Army Corps of Engineers and the ODSL have a joint permit application for the numerous proposed activities that involve federal and state jurisdictions. The joint process facilitates application processing and review. Ultimately if the proposed action needs federal and state action and is approved, separate permits are issued from the U.S. Army Corps of Engineers and ODSL. A permit must be obtained from both agencies before the applicant proceeds.

For What Activities is a Permit Needed?

A State permit is needed for any activity that would cause the removal or movement by artificial means (alteration) of more than 50 cubic yards of material or the fill by artificial means of 50 or more cubic yards of material within the bed and banks of the waters of the State of Oregon unless specifically exempted by Statute. "Removal" means the taking of material in any waters of this state or the movement of material on or within the bed of such waters, including channel relocation. "Fill" means the deposit by artificial means of material at one location in any waters of this state. "Material" means rock, gravel, sand, silt, and other inorganic substances removed from waters of this state and any materials, organic or inorganic, used to fill waters of this state.

In addition, the State Land Board approval is required for the filling or removal of any material, regardless of the amount, within the bed and banks of any waterway designated as a State Scenic Waterway.

Typical examples of activities and projects requiring State permits include:

- gravel removal,
- dredging,
- gold mining,
- riprap placement,
- land reclamation,
- channel alteration or relocation,
- pipeline crossings, and
- construction of bulkheads.

The need for a State permit is based upon the magnitude of activity. The fill-removal-alteration activity must exceed 50 cubic yards of material before a permit is required by law. Because the location for the activity must be stated in the application for a permit, it is assumed that all such activity occurs at one site.

Exemptions exist for emergency repairs, although the Director of ODSL must be notified within 24 hours and shall inspect the site and deny or approve the emergency activity.

Exemptions exist for fill or removal in non-navigable waterways for forest management practices in forest lands. Exemptions also exist for the purpose of constructing, operating and maintaining dams or other diversions for which permits, preliminary permits, licenses or certificates

are issued under separate statutes. And the "Fill-Removal Law" does not apply to the federal government acting in its capacity of navigational servitude.

For What Water Bodies and Within What Boundaries are Permits Needed?

The expression "waters of the State of Oregon" means all natural waterways of the State. These include rivers, constantly flowing streams, intermittent streams, lakes, ponds, wetlands, tidal and nontidal bays, other bodies of water in this state, navigable or nonnavigable, and even that part of the Pacific Ocean within the jurisdiction of the State. State applicability should be clear for large lakes and for perennial rivers (those flowing year-around). But the Law also applies to small natural ponds, intermittent streams (those that seasonally go dry), overflow channels, and wetlands. Wetlands include swamps, bogs, freshwater marshes, and saltwater marshes; they are defined as those areas that are inundated or saturated often enough to support a prevalence of vegetation adapted for life in standing water or saturated soil.

Permits are needed for activities within the bed and banks of these waters.

The vast majority of aquatic settings for which a fill-removal permit may be needed are illustrated in Figure 49. The landward limits of "Fill-Removal Law" jurisdiction are shown in each case.

For non-tidal rivers and lakes, the bankfull stage or the upper edge of a wetland represents the boundary for fill-removal permits. For tidal waters the highest measured tide applies to tidelands and the line of non-aquatic vegetation applies to wetlands. Along the Pacific Ocean coast, fill-removal permits are needed ocean-ward of the highest measured tide or the upland vegetation line, whichever is higher.

In all cases, jurisdiction extends across the area typically reached by water during high water stage, but not across the floodplain unless wetlands are present. However, outside of these limits land-use and zoning statutes apply.

Who Issues Permits?

The Fill-Removal Law is administered by the ODSL. This agency has responsibility to review applications for permits and to make decisions on whether to issue or deny permits.

Where are Permits Obtained?

Applications for fill-removal permits can be obtained from the ODSL. They are also available from most city and county planning offices, from the Soil and Water Conservation District offices, and from district and regional offices of the Oregon Department of Fish and Wildlife (ODFW). On the Oregon coast, permit applications can also be obtained from the Region II State Parks office in Tillamook and the Region III State Parks office in Coos Bay.

Who Enforces Permits and Violations of Fill-Removal Law?

Enforcement of the "Fill-Removal Law" is the responsibility of the ODSL. Criminal and civil proceedings are available for this enforcement.

The conditions of permits are enforced by the ODSL. Enforcement includes work done in a manner contrary to the conditions set out in the permit. Where a permit is in effect, penalties can include revocation, suspension, or refusal to renew the permit.

Activities undertaken without a permit are also subject to enforcement and penalties. Removal or filling without a permit is a criminal misdemeanor punishable by a fine of up to $2,500 and one year in jail. Violations are also subject to a civil penalty of up to $10,000 per day of violation. Cease and desist orders and restoration orders may also be issued by the ODSL.

Violations of the fill-removal law can be reported by anyone. This is done by contacting the Permits Section of the ODSL.

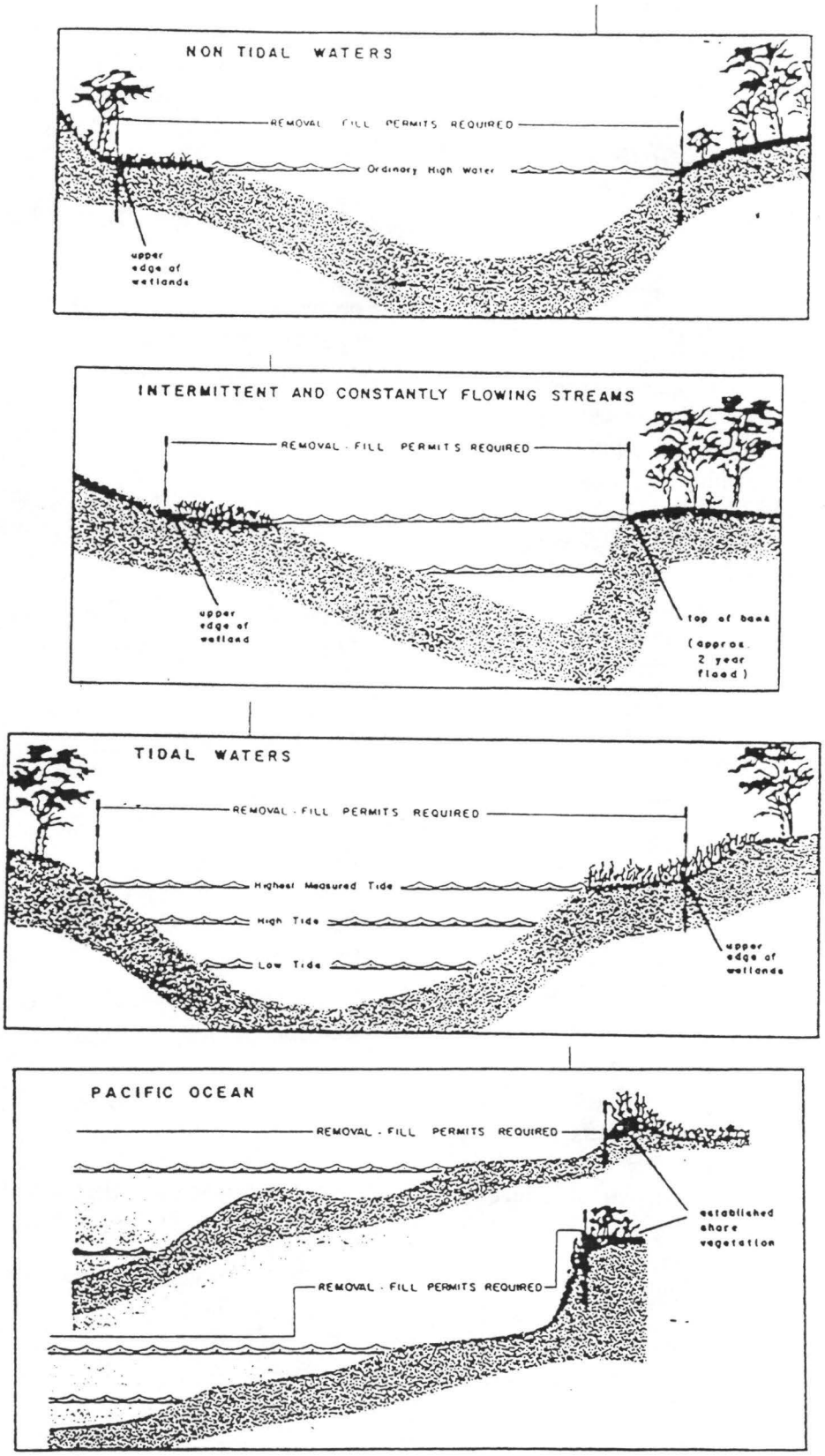

Figure 49. Jurisdictions for State Removal and Fill Permits.

Permit Process

Individuals or entities wishing to undertake an activity that falls within the purview of the Oregon's "Fill-Removal Law" must make application to the Director of the ODSL for a permit. The application must be made on forms provided by the Director. An application fee must be paid. This pays for the review of the application. The fee is not refundable if the application is denied.

The completed application is reviewed by the staff of the ODSL. The necessary investigations must be made to develop a factual basis for a permit decision. As part of this process, the ODSL must consult with and obtain the views of others through a formal process of public notices and mailings. The application is circulated to the appropriate local governments, state and federal agencies, adjacent property owners, and interested citizens for review and comments. Agencies and other units of government are given 45 days to submit comments after receiving a request for comment from the ODSL.

Oregon State agencies included in this process include the Department of Fish and Wildlife, the Department of Environmental Quality, the Department of Land Conservation and Development, the Department of Agriculture Division of Soil and Water Conservation, the Water Resources Department, the Department of Economic Development, the State Parks Division, the State Historic Preservation Office, the Department of Geology and Mineral Industries, and any other affected State agency.

Federal agencies are provided with application notice for projects where no separate U.S. Army Corps of Engineers notice has been issued. These agencies include the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the U.S. Army Corps of Engineers, and the Environmental Protection Agency.

The comments received from all sources help the ODSL to evaluate the proposed project against the requirements in law and administrative rules, as well as to prepare operating conditions under which a project can be approved.

For removal projects, the ODSL decision time is 45 days from receipt of a completed application. For fill projects, the decision time is 90 days.

Permits are either denied or issued with conditions.

Approval of the project by the appropriate local government planning office is necessary before the ODSL will issue a permit. Therefore, it is recommended that the applicant start the local approval process before applying to the ODSL for a fill-removal permit.

If the application is denied, the reason for denial is stated in writing. If known, acceptable alternatives are pointed out. An applicant whose application has been denied has the right to request a hearing before the ODSL.

If the applicant receives a permit but the applicant objects to the conditions, there is also the opportunity for a hearing before the ODSL.

The process for requesting a hearing is stated on the denial letter or on the front sheet of the permit.

Hearings before the ODSL to challenge a permit that has been issued can be requested by adjacent property owners and by others who can show legal standing. In certain cases, a permit can be suspended by the Director of the ODSL during the hearing process or during any subsequent appeal to the Oregon Court of Appeals or the State Supreme Court.

The State permit application process and the relationship between local, state and federal processes for waterway development activities is shown in Figure 50.

Permit Contents

The basic information required in the written application form includes the following:

- name, address and phone number of landowner;
- names and addresses of adjacent landowners;
- location of the project;
- description of the proposed actions and purposes for the project;
- description of the proposed actions to restore the site; and
- mitigation plan, if the project involves inter-tidal or tidal marsh areas.

Drawings and maps must accompany the application. These must show the following:

- the location of the proposed project site with sufficient accuracy to allow easy location;
- a plan view of the project site and proposed alterations, including:
  - *locations of waterways and wetlands involved*
  - *lines of high water and low water*
  - *the location of removal or fill*
  - *adjacent properties*
- cross-section views showing details of the proposed project.

The instruction forms and attached example drawings indicate to the applicant what information should appear and how it might be presented on the application form.

Certain types of proposed activities require that the applicant provide additional information in the application. For example, a permit application for maintenance dredging must include a detailed long-range spoils disposal plan. An application to place fill in an estuary for a non-water-dependent use requires an evaluation of public use and need, an impact evaluation, and consideration of alternative sites. An application to permit a project which may cause substantial change in the hydraulic characteristics of a water body may require an investigation into such changes and a plan to minimize the adverse effects.

If the Director determines that the proposed project may cause substantial adverse effects to aquatic life and habitat, the applicant may be required to provide documentation of existing conditions and resources, and to identify the potential impacts of the proposed project.

Assistance in Developing Permits

The ODSL's policy is to work with applicants. This is done to assist in the design of worthwhile projects so that they will have a minimum impact on water resources and adjacent properties. In so doing, the ODSL seeks to avoid adverse impacts while looking for opportunities to restore or even enhance resources that have been left in poor condition by prior natural and human activities.

The ODSL can provide assistance in several ways. It can arrange pre-application conferences with appropriate agencies to discuss design issues, mitigation requirements, and procedural matters. It can also assist in identifying regulatory jurisdictions that may be involved in a particular proposed project or activity.

Examples of situations where this assistance has been particularly beneficial involve wetlands and aquatic habitats. Mitigation and enhancement have helped restore some of the State's wetland resources that had been converted to other uses years to decades ago. The ODSL and other State agencies (e.g., ODFW and GWEB) have worked closely with permit applicants and landowners to achieve important improvements in degraded fish habitat as part of permitted activities.

Such assistance represents a "pro-active" approach to natural resource management by working through individuals and other entities at times when they have specific plans and needs that fall within the purview of the "Fill-Removal Law."

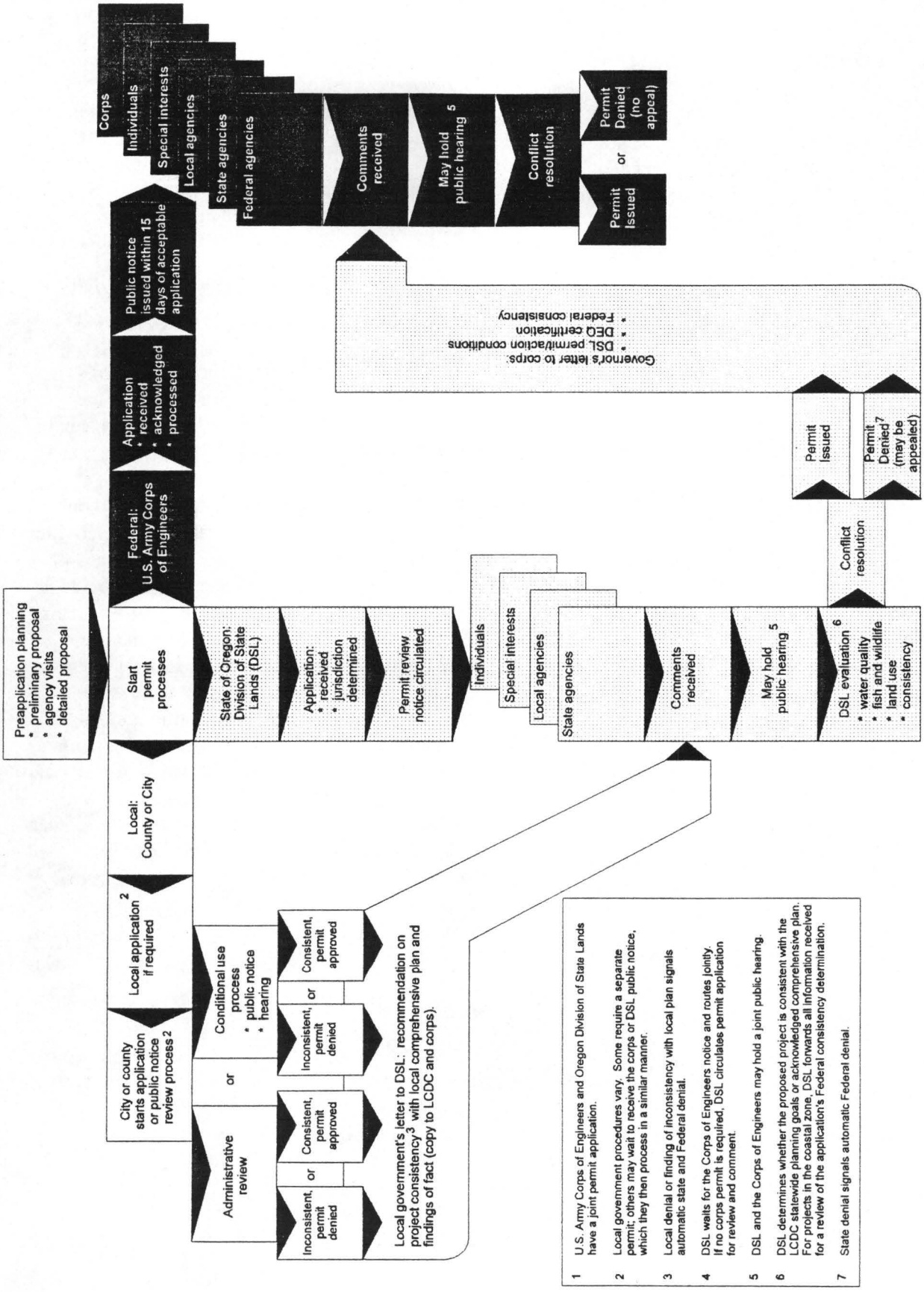

Figure 50. Local, State, and Federal Permit Processes (OSU Extension, 1982)

Permit Issuance, Period of Validity, and Renewal

Permits are generally issued for a one year period. Within that period, however, a much narrower time period may be specified for the work. This restriction is established where it may be necessary to protect aquatic species during the period of their presence in the waters at the project site, during sensitive parts of organism life cycles, or for protection of water quality.

Permits may be renewed by the Director of the ODSL if they expire for activities that occur annually or that require an extended period of time to be completed. First, there must be a review to determine the status of project completion. Also, the permit holder is contacted prior to permit expiration to see if permit renewal is desired. If renewal is needed, information on any project changes must be sent to the ODSL, along with the required application fee. A notice of intent to renew is sent to the same wide range of agencies and interested parties as for a new permit application. If no adverse review comments are received within 15 days and the project is still found to be acceptable, a renewal permit is issued. Otherwise, the renewal of the application receives further processing.

In some cases, a multi-year permit may be issued, with a duration of up to five years. This may happen for projects that occur on a continuing basis or will take more than one year to complete.

For commercial aggregate removal projects, the ODSL Director may issue a permit of up to five years upon determination that (a) a sufficient aggregate resource or annual recharge exists to allow the proposed volumes to be removed and (b) the applicant has conducted removal activities within permit conditions for at least one year preceding the multi-year application. Such permits shall require annual reporting of the physical character of the site. If the aggregate source is non-renewable, reports shall be in the form of a long-range restoration plan. If the aggregate source is renewable, the permittee shall demonstrate annually to the Director of the ODSL the capacity of the removal site to sustain the requested level of aggregate harvest.

Dredging projects may also receive permits for up to five-year periods. To do so, there must first be a determination that there is an adequate soil disposal site in an approved location. There must also be no indication that toxic or polluted materials would enter the waterway to the extent that State's water quality standards would be violated.

Some Perceived Problems with the Current Permit Process

There is an implied inference that for fill-removal volumes of 50 cubic yards or less, the impact will be local and minor. However, this need not be the case -- particularly where there is a lack of attention to the condition of the aquatic ecosystem as an activity or project is carried out. Hence, it behooves those undertaking such activities to follow good resource management practices. Otherwise, other laws may become applicable that carry penalties for infractions of the law -- such as violation of state/local water quality standards, water rights, or zoning ordinances that set limits on what may or may not be done. Yet there is no assurance, nor any in-place inspection process, to guarantee the protection of the aquatic ecosystem when volumes of 50 or less cubic yards of material are removed, filled, or altered. On the contrary, many examples can be found of small activities that disrupt the local ecosystem. Bulldozing the streambeds against the banks of small creeks to retard bank erosion is one of the more common examples.

Summary

Gravel removal and fill/alteration projects are an important factor in the management of Oregon's rivers and streams. The level of proposed activities is high and is expected to grow with Oregon's population and economy.

The permit process has been well thought out and appears to be very sound. However, the natural systems are complex and those submitting the applications for permits typically do not have the needed background to provide technically sound projects and supporting assessments of impacts. The assistance available through the ODSL helps to fill this gap. Nevertheless, the DSL's staff must

often review seemingly complete but less-than-optimum applications. This burdens the staff with decisions that potentially involve risk. A risk assessment must be made and reliance must also be placed upon reviews from knowledgeable staff from review agencies. Impacts may be overlooked in situations were there is this interdependency in the decision-making process. The alternative is to conduct impact assessments for most permits or to devise a means where the risks can be categorized and a burden of proof approach can be implemented.

The permit process was designed to facilitate the process of obtaining a permit by the applicant. As such, the review tends to focus upon localized effects and impacts. Such an approach appears not to be in agreement with the new watershed approach being adopted by natural resources agencies within the State. Such a watershed approach would focus upon determining the appropriate fill-removal/alteration activities that can be assimilated within a given watershed and still maintain the health of the watershed. Such management should be done within a system of adaptive management involving numerous pilot projects, extensive monitoring, and cooperative efforts with all stakeholders. It is our opinion that the ODSL should move as rapidly as possible to such a management system.

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APPENDIX II. PROPOSED GRAVEL REMOVAL AND FILL/ALTERNATION ASSESSMENT

The following forms are provided as an initial attempt at developing a procedure for assessment of gravel removal and fill/alteration assessments.

PROPOSED FILL/REMOVAL ASSESSMENT PROCEDURE

Introductory material/project background.

Items to be included in this section are:

- A map of the project area with a scale, decimal latitude and longitude, or UTM coordinates indicated.
- On-site photo points from established photo points.
- Aerial photos of the site.
- On the site map, indicate cross-sections that will be used for monitoring.
- Method of removal/fill and other information contained in existing permit procedure.
- If this is a renewal, what is the actual amount of material removed/filled last year? Also, attach a figure of this years cross-sections from previously established cross-section points.

LEVEL 1: LANDSCAPE/REACH LEVEL ASSESSMENT.

CHARACTERISTICS

Is the stream or river designated as water quality limited by the Department of Environmental quality?

Are there sensitive, threatened, or endangered species?

Is the watercourse designated as wild and scenic?

Does this watercourse contain known salmon spawning habitat?

Other_____

_____

_____

_____

_____

_____

LEVEL 2: DIRECT/IMMEDIATE SITE OR NEAR SITE ASSESSMENT.
WILL THE GRAVEL REMOVAL PROJECT CAUSE ANY OF THE FOLLOWING?

	Not Applicable	*Effects Unknown*	*Minor Effects*	*Moderate Effects*	*Major Effects*
PHYSICAL EFFECTS					
Destabilize banks	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

_____

If the effects will be moderate or major, what steps will be taken to minimize impacts?

_____

Lower channel bed	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

_____

If the effects will be moderate or major, what steps will be taken to minimize impacts?

_____

Alter channel shape	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

_____

If the effects will be moderate or major, what steps will be taken to minimize impacts?

_____

Removal of large wood	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

_____

If the effects will be moderate or major, what steps will be taken to minimize impacts?

_____

	Not Applicable	*Effects Unknown*	*Minor Effects*	*Moderate Effects*	*Major Effects*
Increase habitat uniformity	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

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If the effects will be moderate or major, what steps will be taken to minimize impacts?

Lowering of water table	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

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If the effects will be moderate or major, what steps will be taken to minimize impacts?

Removal of large wood	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

---

If the effects will be moderate or major, what steps will be taken to minimize impacts?

WATER QUALITY

Increased sedimentation of fines	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

---

If the effects will be moderate or major, what steps will be taken to minimize impacts?

LEVEL 2: DIRECT/IMMEDIATE SITE OR NEAR SITE ASSESSMENT. WILL THE GRAVEL REMOVAL PROJECT CAUSE ANY OF THE FOLLOWING?

	Not Applicable	*Effects Unknown*	*Minor Effects*	*Moderate Effects*	*Major Effects*
PHYSICAL EFFECTS					
Destabilize banks	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

If the effects will be moderate or major, what steps will be taken to minimize impacts?

Lower channel bed	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

If the effects will be moderate or major, what steps will be taken to minimize impacts?

Alter channel shape	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

If the effects will be moderate or major, what steps will be taken to minimize impacts?

Removal of large wood	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

If the effects will be moderate or major, what steps will be taken to minimize impacts?

	Not Applicable	*Effects Unknown*	*Minor Effects*	*Moderate Effects*	*Major Effects*
BIOLOGICAL EFFECTS					
Indirect loss of riparian vegetation	☐	☐	☐	☐	☐

Comments or justification for indicating project will have minor or insignificant effects

---

If the effects will be moderate or major, what steps will be taken to minimize impacts?

Check any potential effects expected:

GENERAL TYPE OF MODIFICATION	SPECIFIC ENVIRONMENTAL EFFECT
Stream Channel	☐ Alteration of habitat: • creation of deep pools • loss of riffle habitat • loss of large woody debris ☐ Alteration of bedload transport ☐ Increased head cutting ☐ Alteration of channel flow ☐ Bank destabilization
Aquatic Populations	☐ Elimination of benthic invertebrates ☐ Destruction of spawning beds and nursery habitat ☐ Reduction/elimination of silt intolerant species (e.g., salmonids) ☐ Increase of silt tolerant organisms ☐ Disruption of food webs
Water Quality	☐ Increased turbidity ☐ Reduced light penetration ☐ Reduced photosynthesis ☐ Higher water temperature due to: • ponding • removal of riparian vegetation ☐ Increased oxygen demand due to resuspension of organic material ☐ Resuspension of toxic materials from sediments (e.g., pesticides, metals)
Recreation	☐ Change in fish species composition ☐ Reduced fishing success ☐ Aesthetics

APPENDIX III: SENATE BILL 81

57th Oregon Legislative Assembly - 1993 Regular Session

CONFERENCE COMMITTEE AMENDMENTS TO

C-ENGROSSED SENATE BILL 81

August 5

FISH HABITAT (SB 192)

"SECTION 101. ORS 196.810 is amended to read:

"196.810. (1)(a) Except as otherwise specifically permitted under ORS 196.600 to 196.905, no person or governmental body shall remove any material from the beds or banks or fill any waters of this state without a permit issued under authority of the Director of the Division of State Lands, or in a manner contrary to the conditions set out in an order approving a wetlands conservation plan.

"(b) Notwithstanding the permit requirements of this section and notwithstanding the provisions of ORS 196.800 (5) and (12), if any removal or fill activity is proposed in essential indigenous anadromous salmonid habitat, except for those activities customarily associated with agriculture, a permit is required. 'Essential indigenous anadromous salmonid habitat' as defined under this section shall be further defined by rule by the division in consultation with the State Department of Fish and Wildlife and in consultation with other affected parties.

"(c) No permit shall be required under paragraph (b) of this subsection for construction or maintenance of fish passage and fish screening structures that are constructed, operated or maintained under ORS 498.248 to 498.268 or 509.600 to 509.645.

"(d) Nothing in this section shall limit or otherwise change the exemptions under ORS 196.905.

"(e) As used in this section:

"(A) 'Essential indigenous anadromous salmonid habitat' means the habitat that is necessary to prevent the depletion of indigenous anadromous salmonid species during their life history stages of spawning and rearing. The habitat shall not exceed more than 20 percent of any particular waterway.

"(B) 'Indigenous anadromous salmonid' means chum, sockeye, Chinook and Coho salmon, and steelhead and cutthroat throat, that are members of the family Salmonidae and are listed as sensitive, threatened or endangered by a state or federal authority.

"(2) No governmental body shall issue a lease or permit contrary or in opposition to the conditions set out in the permit issued under ORS 196.600 to 196.905.

"(3) Subsection (1) of this section does not apply to removal of material under a contract, permit or lease with any governmental body entered into before September 13, 1967. However, no such contract, permit or lease may be renewed or extended on or after September 13, 1967, unless the person removing the material has obtained a permit under ORS 196.600 to 196.905.

"(4) Subsection (1) of this section does not apply to removal of material from the beds or banks or filling of any waters of this state in an emergency, for the purpose of making repairs or for the purpose of preventing irreparable harm, injury or damage to persons or property, when notice of such emergency removal or filling is given to the Division of State Lands within 24 hours following the start of such activity. The division, not later than 24 hours following notice, shall inspect the emergency activity, and deny or approve; provided, however, that in emergency actions involving highways, the appropriate highway authority having jurisdiction over the highway in which the work is being performed, shall notify the division within 72 hours following the start of such activity.

"Section 102. The Division of State Lands shall conduct a study to examine the relationship between removal of material from streams and stream health in support of essential indigenous anadromous salmonid habitat for purposes of carrying out the provisions of ORS 196.810 as amended by section 101 of this Act. For purposes of this section, 'essential indigenous anadromous salmonid habitat' has the meaning given that term under ORS 196.810.