Watershed Management in the Pacific Northwest: The Historical Legacy

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Abstract.—The last 100 years marks a period of accelerating land use and consequent effects upon the water resources of the Pacific Northwest. In contrast, federal and state efforts to reduce land use impacts to water resources have largely emerged only during the last 35 years. While university courses in watershed management were generally available in the 1950s, the number of courses increased greatly through the late 1970s. Research productivity (i.e., published results) in watershed management was relatively low until the 1970s. Educational programs and research efforts that provide a better understanding of land use effects to the region's water resources is needed for the 21st century.

Introduction

A watershed can be simply defined as a portion of the landscape that drains to a common point. Hence the Columbia River Basin, perhaps the largest of the Pacific Northwest (PNW) watersheds, encompasses all area upriver of the Columbia estuary, including a significant portion that extends well into Canada. Within the various biophysical regions of the Columbia Basin are a multitude of subwatersheds of various sizes.

While watersheds are also areas within a landscape that cycle water, energy, nutrients, sediment and organic matter over time and under the influence of gravity, the predominant characteristics, functions, and processes associated with a given watershed may be similar to adjacent watersheds or be highly varied relative to those located elsewhere across the PNW. The degree to which various ecosystem functions and processes operate often provide an important perspective regarding the overall integrity of a particular watershed (i.e., the quality or state of being unimpaired, sound) (Committee of Scientists 1999).

The phrase "watershed management" is often used to recognize a broad array of land use activities that might occur across a landscape. However, in the context of this paper I will use a somewhat narrower scope. The focus herein will be primarily on management practices that influence the water resources of the Pacific Northwest, with some emphasis regarding forest and range lands. Within this context there exists an array of activities employed by society to obtain, distribute, use, regulate, treat, and dispose of water (Satterlund and Adams 1992). In some instances, water resources impacts or changes are simply a byproduct of land use, in others the protection, alteration, or use of the water resource may be the primary management target.

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Watershed Management in the 20th Century

The management of Pacific Northwest (PNW) watersheds over the last 100 years, and longer, is a checkered history. Unfortunately, our understanding of past practices, their occurrence in time, their spatial distribution, and their relative importance to water resources is often incomplete. While we may know that millions of board feet of old-growth timber were removed from forests of the PNW to meet economic and social demands or that hundreds of thousands of domestic ungulates foraged across rangeland watersheds of the region, our understanding of the ecological and environmental consequences of these widespread practices are imperfect. Similarly, the effects of urbanization and industrial activities of an emerging society upon the water resources of the PNW have not always been chronicled or evaluated. Nevertheless, it is important to look backward in time, albeit briefly, if we are to move forward into the next century with a heightened awareness and reasonable expectations of societal wants and needs regarding the region's water and other natural resources.

Historical Land Uses

Prior to 1800, native peoples of the PNW utilized the vast resources of the region to meet their social, cultural, and day-to-day needs for living (Ontko 1998). Their use of the land was predominantly nonagricultural. However, the expanding wants and needs of an EuroAmerican culture were soon destined to alter the long-term development of this area. While fur traders roamed the PNW in the

late 1700s, the westward expedition of Meriwether Lewis and William Clark in the early 1800s provided additional impetus for increased exploration and immigration into the region by EuroAmericans. The bountiful natural resources of the PNW and a strong desire by the prevailing EuroAmerican culture to extensively utilize these resources were precursors to the widespread development and use of the region's forests, forage, water, wildlife, fisheries, minerals, and other resources. By 1900, the EuroAmerican culture was well entrenched in the PNW with a population of approximately one million people.

During the last 100 years, EuroAmerican influences upon the natural resources of the PNW have been extensive. While a detailed listing of EuroAmerican effects is not the purpose of this paper, it is important to at least consider some of the changes that have occurred so that future generations can better judge the appropriateness of both historical and projected water resources decisions. Excluding the direct effects of a burgeoning EuroAmerican population and culture upon the indigenous tribal cultures and peoples, perhaps one of the first impacts to the region was the general decimation of beaver populations. Today, we realize that beavers have an important role in a wide array of hydrologic and ecological functions for many headwater streams and associated floodplains. The full extent to which beaver were a factor in the long-term development of floodplains, riparian areas, and aquatic habitats not known, but it was likely significant in many areas of the PNW.

Utilization of the region's anadromous fish stocks by EuroAmericans began in earnest with establishment of canneries along the Columbia River in the late 1800s. These canneries continued through the 1940s when they were largely replaced by ocean harvests. In combination, various harvesting approaches have removed millions of pounds of fish annually from anadromous runs in the PNW. Once thought to be a limitless resource, fisheries stocks today are much reduced; many stocks have recently been listed as threatened or endangered under the Endangered Species Act. While the potential extirpation of these stocks is a major concern, perhaps just as importantly is their role as an indicator status regarding the impacts of land uses on instream habitats and water quality that continue to occur across many PNW watersheds.

Other natural resources also felt the development pressures of an EuroAmerican culture. As ranchers and settlers entered the PNW, livestock numbers rapidly increased. Although total numbers of livestock ranging public lands have decreased since the 1900s, increased grazing of private lands has occurred. The riparian and aquatic impacts from grazing have been significant and have often occurred over many decades (Meehan 1991).

Timber harvesting along lowland rivers and streams, which began prior to 1900, quickly spread upriver with the use of splash dams and railroad logging in the early part of the 20th century. The advent of improved cable logging systems, including the relatively recent availability of helicopters and other aerial systems, essentially made accessible to timber harvest most of the mountain terrain in the PNW (except areas specifically reserved for other purposes). From 1940 to 1990, approximately 14 billion board feet of timber from the forests of Oregon and Washington were removed annually (National Research Council 1996); tens of thousands of logging roads were constructed to access mountain lands.

Perhaps one of the most significant changes to occur in the PNW during the 1900s was the construction of dams. It is soon apparent to anyone who has traveled the western United States that PNW rivers represent an important resource of the region. With the advent of an engineering technology that made the construction of large dams possible and an increasing demand to regulate rivers for navigation, irrigation water, hydropower, and flood control, many of the major rivers and tributary streams of the PNW were to be rapidly transformed. From 1900 to 1920, the total volume of water impounded behind dams in northern California, Idaho, Oregon, and Washington went from essentially zero to 15 million acre feet. By 1975, this total had increased to approximately 65 million acre feet and included 14 mainstem Columbia River and 13 Snake River dams. While the economic benefits to the region from an extensive system of dams have been substantial, they have not been without significant effects and impacts. For example, 55% of the area and 31% of the stream miles of the original anadromous fish habitat in the Columbia Basin have been eliminated by dam construction; access to all Canadian Habitats has been eliminated (National Research Council 1996). Much of the mainstem Columbia "River" is now represented by a series of connected impoundments.

Looking back, there can be little doubt that a prominent social policy of the United States throughout the 1900s was one of "winning the west". In the beginning this policy was directed at suppressing and controlling the native populations. Once accomplished, the development and use of the region's natural resources became a high priority. To a major extent, society was successful in these endeavors. But the impacts to water resources have been significant. Loss of aquatic productivity, loss of riparian and wetland functions, degraded water quality, depleted instream flows, and other adverse effects have been all too prevalent.

Watershed Protection and Regulations

The general exploration, development, and use of the PNW's resources over the last 100 years have caused numerous adverse consequences to water and aquatic

habitats. For example, agricultural users could essentially "dry-up" a stream since the maintenance of an instream flow for purposes of protecting water quality or aquatic habitats was not an acknowledged beneficial use. The "use it or lose it" approach to water resource management is well embodied in western water law *via* the doctrine of prior appropriation. In other situations, the "tragedy of the commons" occurred repeatedly as stock growers competed for a decreasing forage base with increasingly larger herds. Whereas early railroad logging efforts often chose "easy" terrain for tree harvesting, the widespread availability of construction equipment (e.g., bulldozer) after World War II saw the expansion of road systems into steep and often unstable terrain. Changing technologies eventually allowed access to timber on even the steepest of mountain slopes. In yet other instances, the conversion of lands from forest to agricultural or urban uses contributed to the loss of wetlands (National Research Council 1995). Separately and cumulatively, the wide variety of land uses in the PNW, and elsewhere across the United States, sufficiently provoked society such that a series of laws and regulations have been promulgated over the last 35 years for the protection of water quality and wetlands. While some of the legislative approaches have been national in scope, they have influenced state regulations and regional approaches to a variety of water resources issues.

In 1965, the federal Clean Water Act (CWA) required states to submit, for federal approval, water quality standards for all interstate waters and estuaries. This legislation essentially acknowledged that the nation's waters had experienced significant change and impairment from the demands of an agricultural/industrial economy. In 1967, Oregon was the first state to adopt water quality standards: the Oregon regulations were directed at both interstate and intrastate water quality standards for bacteria, dissolved oxygen, pH, turbidity, temperature, dissolved chemical substances, and others. While these standards theoretically pertained to all waters of the State, in reality they were more focused on water quality problems associated with "point-sources".

Passage of the 1972 amendments to the Federal Water Pollution Control Act (FWPCA) indicated an important need to improve the treatment of sewage, industrial effluents, and other point-source pollutants being discharged into the nation's waters. Two important goals of the 1972 FWPCA were to:

- By 1983, have water quality sufficient to promote fish life and be of general high quality (i.e., fishable and swimable)
- By 1985, eliminate the discharge of all pollutants (i.e., zero pollution)

This legislation not only gave the U.S. Army Corps of Engineers and the Environmental Protection Agency authority to regulate polluted waters of the United States, but expanded their authority into non-point sources of pollution, included those generated from forestry, range, and agriculture, and the status of wetlands. With regard to wetlands, coverage of the 1972 act was narrowly construed at first and extended to only 15% of the total wetland acreage in the United States. However, judicial decisions between 1972 and 1977 greatly broadened the coverage of the statute. Section 404 of the 1977 Clean Water Act amendments confirmed the national commitment to regulation of wetlands and broad federal application of the 1977 act to wetlands was upheld judicially in 1985 (National Research Council 1995).

Most of the mountainous areas in the PNW and elsewhere in the western United States are covered with predominantly forest vegetation types. It is these same mountain watersheds from which most of the region's streamflow is generated. For much of the 20th century, the forest industry in the PNW has been a major component of many local and state economies. Forest harvesting, site preparation, and roading have been widespread. Hence, there has been considerable interest in forest practices from a regulatory perspective. In addition, a significant amount of published research became available late in the 20th century that addressed basic ecological processes associated with forested watersheds (e.g., natural fires and disturbances) and the effects of forest operations (e.g., road construction, harvest systems, site preparation).

An important consequence of the 1972 FWPCA regarding non-point source pollution is that many western states began to look more closely at various land use activities and their potential impact upon water quality. In particular, forestry activities came under scrutiny. While water quality standards have been widely and often successfully used for addressing a wide range of point-source water quality problems, their application in the non-point water quality arena is often more difficult. Because of the often unpredictable nature of some non-point source occurrences, an "after-the-fact" use of water quality standards may not always be effective. For example, possible adverse consequences to water quality from road construction and logging on an erosion prone site might not become evident until major rainfall events occur the following winter or even several years later. Because of the challenges often associated with using water quality standards to control non-point sources of pollution, an alternative philosophical and regulatory approach to water quality issues associated with forestry was formulated. This alternative approach culminated in the promulgation of Forest Practices Acts by individual states. These regulations have been largely used to specify forest practices (sometimes referred to as best management practices) that are intended to prevent significant adverse impacts to water resources and water quality. In 1972, Oregon enacted into law the nation's first Forest Practices

Act; since then California, Idaho, Washington, and other states have also done so. Forest practices acts undergo periodic revisions to incorporate new knowledge or to address specific concerns. For example, in 1994 the Oregon Forest Practices Act was substantially modified to provide for substantially increased stream protection. In contrast, land use practices for rangelands, agricultural areas, estuaries, and urban areas practices have remained outside a similar regulatory framework.

The 1987 federal Water Quality Act continued to emphasize Congressional intent for controlling point and non-point sources of pollution to the nation's waters. This legislation introduced additional concepts related to such issues as water quality limited streams, total maximum daily loads (TMDLs), and non-degradation. Currently, the State of Oregon has undertaken several basin-wide assessments in an attempt to better understand the extent of water quality limited streams and the use of TMDLs for pollution prevention. Furthermore, in 1992, as required under Section 303 of the federal Clean Water Act, the Oregon Department of Environmental Quality initiated a water quality standards review of temperature, dissolved oxygen, and bacteria; these efforts resulted in new standards being issued in 1994. Thus, the pathways of regulatory development during the last 35 years have continued to evolve at both federal and state levels, and there is little indication that this evolution has yet run its full course.

Education and Research

Formal education in wildland watershed management in North America began around 1932 when a course entitled "forest influences" was first taught by Dr. Joseph Kittredge at the University of California (Ponce 1979). The course focused on the effects of woody vegetation on microclimates, soils, and water resources. By 1953, 17 of 36 forestry schools in the United States were offering one or more courses in forest influences and watershed management (Dils 1954). By the late 1970s, seven universities in California, Idaho, Oregon, Washington, and British Columbia were teaching 39 courses in watershed management, forest hydrology, range hydrology, and related subjects; there were over 180 such courses at 50 colleges and universities across North America (Ponce 1979). While it is likely that the relative educational effort of various colleges and universities has shifted somewhat in the last two decades, there is no doubt that educational programs in the PNW regarding the influence of management practices upon the region's water resources continue to be a high priority.

Similar to the general mushrooming of formal education in wildland hydrology that occurred in the last half of the 20th century, much of the published understanding of water resources management associated with forested and rangeland watersheds began to emerge in the last half of the 20th century, and most of that in the last 30 years. In 1994, Adams and Ringer compiled an annotated bibliography on the effects of timber harvesting and roading upon water quantity and quality in the PNW; they emphasized original reports of field research in their selection of published studies with a priority for peer reviewed publications. While their annotated bibliography was not intended to be fully comprehensive, it does provide an overview of research emphasis related to forestry and water resources in the published literature and when it occurred. The earliest cited publication was a study by Anderson and Hobba (1959) which analyzed streamflow data for streams in the Willamette Basin of western Oregon. From that early start, the knowledge base, as indicated by relative numbers of publications in Table 1, has expanded greatly. The vast majority of the early publications reported results from paired watershed studies. These types of studies involved monitoring water quantity/quality from two or more adjacent watersheds over a period of several years, imposing a treatment on one or more watersheds while retaining one watershed in an untreated condition (i.e., control), monitoring them for several more years, and finally analyzing for watershed responses due to treatment.

Table 1. Number of publications by topic and date that address the effects of timber harvesting and forest roads on water quantity and quality in the Pacific Northwest, for the period 1950-1989 (from Adams & Ringer 1994). [a]

	Decades			
Topics	**1950-59**	**1960-69**	**1970-79**	**1980-89**
Water quantity				
Timber harvest	1	2	11	16
Forest roads	0	2	3	7
Water quality				
Timber harvest	0	3	18	12
Forest roads	0	0	9	12
Totals	**1**	**7**	**39**	**47**

[a] *Publications cited by Adams and Ringer after 1990 are not included in the above table.*

The experimental watershed studies that occurred primarily in the 1950s, 60s, and 70s, and their inclusion of an untreated control watershed for separating treatment effects from natural variations in watershed outputs, was of fundamental importance in providing an improved understanding regarding the potential for forest practices to influence water resources. Results provided and continue

to provide important sideboards on possible changes in quantity or quality of water following specific forest practices, or combinations of forest practices. Although paired watershed results often indicated the direction and magnitude of a hydrologic response, they seldom provided confirming information as to the processes that might have caused such a change. Thus, much of the hydrologic research on forested watersheds in the PNW since approximately the mid-1970s has attempted to address specific processes and functions occurring at various spatial and temporal scales (Adams and Ringer 1994). These studies have considered such processes or topics as snow accumulation and melt, interception, infiltration, subsurface flow, channel morphology, stream temperatures, nutrient dynamics, hyporheic flow, and others.

A general listing of some of the symposium and workshop proceedings related to land use and water resources that have occurred over the last several decades is shown in Table 2. While the tabulation does not provide a complete listing of all symposia and workshops associated

Table 2. Listing of selected symposia, workshops, and related publications that address some aspect of natural resources management and water in the Western United States, with emphasis on forests and rangelands of the Pacific Northwest.

Date	Title	Publisher	Number of pages
1956	**Snow hydrology**	Corps of Eng., Portland, OR	437 pp.
1966	**Practical aspects of watershed management**	School of Forestry, Oreg. State Univ., Corvallis, OR	135 pp.
1967	**International symposium on forest hydrology**	Permagon Press; Oxford, UK	813 pp.
1970	**Interdisciplinary aspects of watershed management**	Amer. Soc. Civil Eng, New York	411 pp.
1971	**Forest land uses and stream environment**	School of Forestry, Oreg. State Univ., Corvallis, OR	252 pp.
1975	**Watershed management**	Amer. Soc. Civil Eng., New York	781 pp.
1976	**Symposium and specialty conference on instream flow needs: Voumes 1 & 2**	Amer. Fish. Soc., Bethesda, MD	551 & 657 pp., respectively
1979	**Livestock grazing management and water quality protection**	USEPA, #910/9-79-67, Region 10, Seattle, WA	147 pp.
1980	**Symposium on Watershed Management: Volumes 1 & 2**	Amer. Soc. Civil Eng, New York;	1100 pp.
1981	**Cumulative effects of forest management on California watersheds: an assessment of status and need for information**	Special pub. 3268, Univ. Calif., Berkeley, CA	109 pp.
1982	**Sediment budgets and routing in forested drainage basins**	USDA Forest Service, Gen. Tech. Report PNW-141, Portland, OR	165 pp.
1983	**The potential for water yield augmentation through forest and range management**	American Water Resources Association, Reprint of Water Resour. Bull.	19 (3): 359-402.
1984	**Range watersheds, riparian zones, and economics: interrelationships in management and use**	Proceedings of Pacific Northwest Range Management Short Course, Dept. Rangeland Resour., Oreg. State Univ., Corvallis, OR	98 pp.
1984	**Symposium on effects of forest land use on erosion and slope stability**	Environment and Policy Institute, Univ. Hawaii, Honolulu, HA	310 pp.
1985	**Forest riparian habitat study: phase I report**	Dept. of Ecology, Olympia, WA	203 pp.
1985	**Riparian ecosystems and their management: reconciling conflicting uses**	First North American Riparian Conference, USDA Forest Service, Gen. Tech. Report RM-120, Fort Collins, CO	523 pp.
1986	**Wetland functions, rehabilitation, and creation in the**	Wash. Dept. of Ecology, Olympia, WA	184 pp.

Table 2. Cont'd.

Date	Title	Publisher	Number of pages
	Pacific Northwest: the state of our understanding		
1987	**Erosion and sedimentation in the Pacific Rim**	Internat. Assoc. Hydrol. Sciences, Pub. No. 165, Wallingford, Oxon, UK	510 pp.
1987	**Methods for evaluating riparian habitats with applications to management**	USDA Forest Service, Gen. Tech. Report INT-221	177 pp.
1987	**Proceedings of the workshop: applying 15 years of Carnation Creek results**	Pacific Biological Station, Nanaimo, British Columbia	239 pp.
1987	**Streamside management: forestry and fisheries interactions**	College of Forest Resources, Univ. Wash., Seattle, WA	471 pp.
1987	**Wetland and riparian ecosystems of the American West**	Proceedings of Society of Wetland Scientists, Wilmington, NC	349 pp.
1988	**Proceedings of California riparian systems conference**	USDA Forest Service, Gen. Tech. Report PSW-110, Berkeley, CA	544 pp.
1989	**Proceedings of symposium on headwaters hydrology**	Amer. Water Resour. Assoc., Bethesda, MD	708 pp.
1989	**Riparian resource management**	USDI, Bureau of Land Mgmt., Billings, MT	193 pp.
1990	**Case studies and catalog of watershed projects in western provinces and states**	Wildland Resources Center, Univ. Calif., Berkeley, CA	188 pp.
1991	**Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska**	USEPA, #910/9-91-001, Seattle, WA	166 pp.
1992	**Interdisciplinary approaches in hydrology and hydrogeology**	Amer. Instit. Hydrol., Minneapolis, MN	618 pp.
1992	**National hydrology workshop proceedings**	USDA Forest Service, Gen. Tech. Report RM-GTR-279, Fort Collins, CO	210 pp.
1993	**Management impacts on water quality of forests and rangelands**	USDA Forest Service, Gen. Tech. Report RM-239, Fort Collins, CO	114 pp.
1993	**Monitoring protocols to evaluate water quality effects of grazing management on western rangeland streams**	USEPA, #910/R-93-017, Seattle, WA	179 pp. plus appendices.
1993	**Riparian management: common threads and shared interests**	USDA Forest Service, Gen. Tech. Report RM-226, Fort Collins, CO	419 pp.
1993	**Symposia proceedings on water resources education: a lifetime of learning & changing roles in water resources policy management**	Amer. Water Resour. Assoc., Bethesda, MD	715 pp.
1994	**Effects of human-induced changes on hydrologic systems**	Amer. Water Resour. Assoc., Bethesda, MD	1182 pp.
1994	**National symposium on water quality**	Amer. Water Resour. Assoc., Bethesda, MD	322 pp.
1995	**North American workshop on monitoring for ecological assessment of terrestrial and aquatic ecosystems**	USDA Forest Service, Gen. Tech. Report RM-GTR-284, Fort Collins, CO	305 pp.
1998	**Specialty conference on rangeland management and water resources**	Amer. Water Resour. Assoc., Bethesda, MD;	474 pp.

with the hydrology of forest and rangeland areas, it does provide an overview of research direction and emphasis that emerged in the 1970s, 1980s, and early 1990s. Hydrologic and water quality responses to management practices, and the measurement and monitoring of such responses, are some of the common themes. Also important are topics related to riparian and wetland functions, processes, and management. Increasingly, these technical symposia and workshops integrate research results across a variety of social, economic, and environmental themes.

Watershed Management in the 21st Century

As we are about to embark on a new century, we need to recognize that the historical effects of land use upon the water resources of the Pacific Northwest during the last 100 years have been relatively extensive. A social philosophy of "winning the west" has accumulated numerous changes in the forests and rangelands, in the streams, rivers, and estuaries, and in the economies and cultures of the region. While the forests, rangelands, and rivers are still present, they have often been altered or transformed in ways that would have been unimaginable only decades ago. It is from this "inherited" landscape that the region's current population of ten million people will forge their legacy for the generations that follow.

With increasing population and economic pressures, the need for PNW watersheds to help satisfy the various social, economic, and environmental demands of a modern society will become increasingly important. Thus, perhaps this is an appropriate time to ask how society in the PNW will view water and other natural resources during the coming years? For example, will society embody and implement "sustainability" as an overarching objective in land and resource stewardship? The 1987 Brundtland Commission Report (The World Commission on Environment and Development, *Our Common Future*) indicates that sustainability involves meeting "the needs of the present without compromising the ability of future generations to meet their own needs." More recently a Committee of Scientists (1999), commissioned to provide technical and scientific advice on land and resource planning on the national forests and grasslands, commented on the ecological, economic, and social aspects of sustainability:

"These different aspects of sustainability are interrelated: the sustainability of ecological systems is a necessary prerequisite for strong, productive economies; enduring human communities; and the values people seek from wildlands. Most basically, we compromise human welfare if we fail to sustain vital, functioning ecological systems. It is also true that strong economies and communities are often a prerequisite to societies possessing the will and patience needed to sustain ecological systems." (Committee of Scientists, 1999, p. 13)

Whatever future goals society elects to pursue in the PNW, and nationally, there is no doubt that demands upon the scientific and research community will continue to increase. Our understandings of how watersheds process incoming precipitation, where the water goes and when, who uses it, and the effects of land use on quantitative outflows (e.g., annual yields, peakflows, low flows, timing of runoff) and water quality (e.g., sediment, nutrients, water temperature, dissolved oxygen, introduced chemicals) will intensify. Researchers will need to have a much better grasp of hydrologic processes; modeling will be increasingly be needed to fill information gaps and to project the consequences of activities at multiple spatial scales.

Much of the PNW land base is in federal ownership. Policies and management practices on these ownerships are often quite different from the intermingled and adjacent private lands. These mixed ownerships create special challenges for attempting to satisfy multiple demands and perspectives of a changing society. Perhaps nowhere is this more apparent in the PNW than with regard to pacific salmon. These anadromous fish have been a cultural and ecological hallmark of the region for thousands of years during which they have repeatedly migrated through thousands of miles of streams and rivers, through estuaries and oceans, and back. They have not only been important culturally and economically, but they have provided a valuable indication of environmental conditions of riparian and aquatic habitats. While in the region's freshwater environments, these fish essentially synthesize information on a complex of management, political, social, and biological factors influencing the sustainability of aquatic biodiversity (Stouder et al. 1997).

Other indicators of the status of water resources in the PNW might include systematic evaluations of water temperatures, sediment levels, flow alterations, and others. Because of the high spatial and temporal variability often associated with many of these naturally occurring water characteristics or phenomena, there is an increasing need to better understand "background" conditions. Without a firm grasp of natural variations and disturbance regimes, it is often difficult to decipher the hydrologic effects of individual or cumulative management practices. With increasing regional interest directed at improving or restoring streams, riparian areas, and overall watershed conditions, there is a corresponding increasing need to better understand how relatively undisturbed watersheds function and the extent to which they can provide reference conditions for comparison against current responses. Concurrent with this need to better comprehend natural disturbance regimes at local and landscape scales is an

improved understanding of the historical trajectories of resource development and land use at local and landscape scales, particularly as they pertain to water resources. Such historical information is essential before undertaking actions to "improve" or "restore" aquatic habitats or watershed functions (Natural Research Council 1992; 1996). Unfortunately, the large number of watershed councils that have recently emerged throughout much of the PNW are often faced with trying to project future watershed management needs based upon an imperfect understanding of natural watershed functioning and the effects of historical land uses.

Today's water resources issues and problems in the PNW increasingly involve multiple objectives and perspectives. Thus, in the coming years researchers may no longer have the luxury of working in isolation on narrowly defined water resources topics. Instead, interdisciplinary efforts that cross physical, biological, economic, and social subjects will be needed that involve more collaborative efforts in the scientific and research community. An important goal of such collaborative efforts will be the synthesis of research results and conclusions across disciplines for policy analysts and the general public. To be successful, a wide range of educational programs and research efforts will be needed to help society understand, manage, and conserve water resources of the PNW during the 21st century.

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Literature Cited

Adams, P.W., and J.O. Ringer. 1994. The effects of timber harvesting & forest roads on water quantity & quality in the Pacific Northwest: summary & annotated bibliography. Forest Eng. Dept., Oregon State Univ., Corvallis. 147 pp.

Committee of Scientists. 1999. Sustaining the people's lands: recommendations for stewardship of the national forests and grasslands into the next century. US Dept. Agric., Washington, D.C. 193 pp.

Dils, R.E. 1960. Status of college instruction in forest influences and watershed management. Jour. Forestry 52(10): 727-729.

Meehan, W.R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. Amer. Fish. Soc., Bethesda, MD. 751 pp.

National Research Council. 1992. Restoration of aquatic ecosystems; science, technology, and public policy. Committee on the Restoration of Aquatic Ecosystems-Science, Technology, and Public Policy, Natl. Acad. Sci., Washington, D.C. 552 pp.

National Research Council. 1995. Wetlands: characteristics and boundaries. Committee on the Characterization of Wetlands, Natl. Acad. Sci., Washington, D.C. 307 pp.

National Research Council. 1996. Upstream: salmon and society in the Pacific Northwest. Committee on the Protection and Management of Pacific Northwest Anadromous Salmonids, Natl. Acad. of Sci., Washington, D.C. 452 pp.

Ontko, G. 1993. Thunder over the Ochoco: volume I, the gathering storm. Maverick Pub., Bend, Oregon. 436 pp.

Ponce, S.L. 1979. Formal education in wildland hydrology and watershed management in North America. Water Resour. Bull. 15(2): 530-535.

Stouder, D.J., P.A. Bisson, R.J. Naiman (eds). 1997. Pacific salmon and their ecosystems: status and future options. Chapman & Hall, New York. 685 pp.