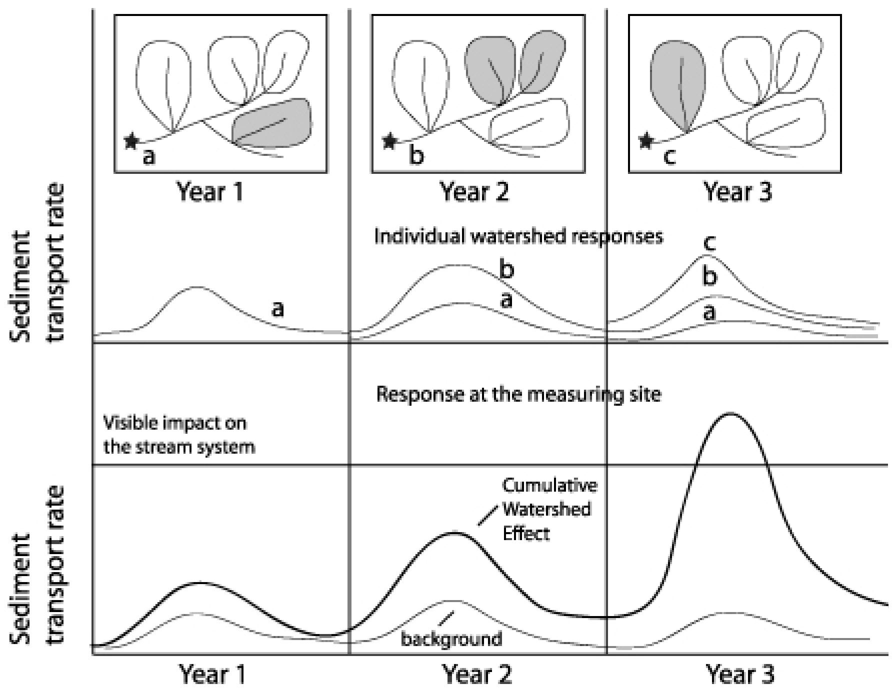
Assessing cumulative watershed effects

The preceding section on forest management and water quality provides examples of how land management can change environmental conditions and produce what is termed Cumulative Watershed Effects (CWE). CWE are defined as the combined effect of multiple activities over space and/or time (MacDonald, 2000). Figure 19 illustrates how the individual sediment production of three land management activities can accumulate over time and space to produce a large enough cumulative impact that can be visually detected in the stream system.

In California, cumulative effects associated with timber harvesting are evaluated for each timber harvesting plan (THP) submitted for approval. Various biophysical, legal, and institutional aspects of this approach have been reviewed and evaluated by a number of authors (Henly, 1993; Cromwell et al., 1999; Ligon et al., 1999; Dunne et al., 2001).

Figure 19. Conceptual diagram of cumulative watershed effects for three watersheds



Source: National Council for Air and Stream Improvement, 1999

Working at the request of CDF, a blue ribbon panel addressing the scientific basis for predicting cumulative effects found that an evaluation of impacts from land use in forested watersheds needs to consider them in their entirety (Dunne et al., 2001). Within a watershed context, CWE address the degree to which multiple management activities can alter watershed processes. The concept of CWE is important for protecting natural resources in that it recognizes that individual projects can collectively result in broader and more significant impacts on the natural resources within a watershed. It requires land managers to evaluate a proposed activity's potential when it is combined with other activities in a watershed (past, present, and future) to collectively impact beneficial uses (Reid, 1993). The goal of a CWE analysis is to identify the impacts associated with multiple land management activities and by doing so, make informed decisions that will reduce the risk to natural resources within a watershed.

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CWE are not necessarily associated with a specific type of environmental impact. They can consider all of them. Detecting CWE can be extremely difficult. The impacts can be both on-site and off-site, with respect to the project area. For many environmental factors, there can be a lag time between when the landscape was altered and when a watershed response is detected. In addition, the natural background variability for environmental parameters (e.g., sediment, water, wood, air, and wildlife) can be very high. There have been a number of studies that address CWE resulting from land management in forest and range watersheds (Schnackenberg and MacDonald, 1998; Jones and Grant, 1996; Reid and Dunne, 1984).

CWE associated with sediment delivery are of primary concern in forested watersheds as they directly affect aquatic resources. Hillslope erosion and sediment transport are characterized by high variability and are strongly influenced by infrequent but intense disturbance events (e.g., intense or prolonged rainstorms and wildfires). This variability and the uncertainty of estimation procedures limits our ability to detect differences in sediment yield and their association with management practices over relatively small time frames. However, even with the complexity and variability surrounding watershed processes, major controls on hillslope and channel processes have been identified through the use of simulation models. These models are used to examine sediment production and transport across longer time frames and at different spatial scales (Benda and Dunne, 1997).

Although there is broad agreement that management activities within a watershed can produce cumulative effects, a consensus is lacking on how to measure, evaluate, or monitor CWE. Approaches range from simple checklists to complex models that are spatially explicit (MacDonald, 2000). In between the two extremes are a host of metrics and indices that serve as proxies of environmental conditions not directly measured. Central to any evaluation of CWE is a broadly agreed upon conceptual model of how land use can alter the risk of damaging natural resources within a watershed (Dunne et al., 2001). The more specific the conceptual model, the less the uncertainty associated with the decision-making process. Stakeholder involvement is critical in formulating a credible, conceptual model. Stakeholders include both public and private entities that typically have different uses for a watershed, but can be united by common goals and benefits from improving water quality (see the Assessment section Institutional Framework: Governance Shifts during the 1990s).

The confidence in predicting CWE increases when looking at longer temporal scales and broader spatial scales. In many cases it is not practical to conduct long-term studies of CWE that are associated with forest management. Instead computer simulation models can be used to evaluate the potential impact of different management scenarios across a range of spatial and temporal scales (Dunne et al., 2001; Ziemer et al., 1991). To make the simulations as realistic as possible, Geographic Information System (GIS) and related data sets are required that will provide a detailed, spatially explicit description of watershed characteristics.

The purpose of using models and making predictions with regard to CWE is to explicitly consider and reduce, to the extent possible, the environmental risks of management decisions. The notion of risk and probability is central to the decision-making process. The concept of risk combines a statement of probability of an event occurring and its magnitude. For example, a risk-based analysis might determine that there is a 10 percent chance of five channel-intersecting landslides per km^2 of watershed area within five years of a timber harvest. The necessary components for a risk-based approach to assessing CWE include the following (modified from Dunne et al., 2001).

- establish causal linkages between land use and ecosystem condition;
- models should be spatially registered (i.e., GIS-based);
- account for disturbance occurring in a stochastic environment;
- prediction should emphasize causal relations based upon an understanding of biophysical processes;
- CWE analysis should be based on a broadly agreed-upon conceptual model of how the watershed works as a system;

- conceptual models should be formalized through mathematical relations and applied to GIS maps of the watershed;
- spatial scale; incorporating both fine and coarse-grained studies;
- models should be run in a format that leads to a probability statement;
- models should evaluate different land use scenarios; and
- consider a limited number of land management options.

CWE analysis should not be expected to eliminate risk to natural resources from forest management activities, but it has the potential to both quantify and reduce that risk, thus improving the decision-making process.

A great deal of research has been conducted to better understand forest management impacts on key environmental parameters. However, detailed quantitative data is often limited to a few watersheds. This leads to uncertainty in the rates and variability in watershed processes. Even less is known with regard to the biological response to land use activities. There is abundant research focused on fine-grained and life-stage specific responses by fish to environmental change, such as the effect of increasing fine sediment on incubation survival. However, there are few studies that extrapolate site-specific relationships to fish populations across watersheds and larger regions, referred to as evolutionary significant units. Operating with limited information and substantial uncertainty, CWE analysis should not be expected to eliminate risk to natural resources from forest management activities, but it has the potential to both quantify and reduce that risk, thus improving the decision-making process (Dunne et al., 2001). Dunne and coauthors make it clear that it is the job of scientists to predict the environmental risk levels posed by different management scenarios. At the same time, they emphasize that it is the job of policy makers to determine what levels of environmental risk are socially acceptable.

Cummulative Watershed Effects on privately owned forest lands: For the last two decades in California and other states, one of the most difficult forest policy issues has been how to resolve concerns about different harvest intensities and their potential impacts on watersheds. These concerns have increased as more people move into forested watersheds where timber removal has the potential to affect drinking water supplies or increase the risk of flooding. They have been further accentuated by listings of anadramous fish species under the federal and State Endangered Species Acts. These concerns have also been the subject of review by BOF rule amendments, the California State Legislature, and the Little Hoover Commission.

It is very hard to generalize about the response in specific watersheds (see the Assessment document Institutional Framework: Governance Shifts during the 1990s). California is very large with many different kinds of watersheds and agencies with jurisdiction (see the Assessment document Legal Framework). However, in general, the response to these increased concerns over watershed level impacts has been threefold: 1) collection of more watershed information, better watershed assessment, and improved identification of potential cumulative watershed impacts; 2) avoidance of these impacts or implementation of improved harvesting and road management practices and/or mitigations that will lessen impacts; and 3) development of new technologies and equipment that will cause less damage.

Absent quantitative estimates of linkages between management actions and changes in complex watershed responses, for the last decade California has relied on a largely qualitative approach in its FPRs for describing potential cumulative impacts from timber harvesting on nonfederal lands. The approach has relied on a series of question to be answered in the THP by Registered Professional Foresters based on guidance from a Technical Rule Addendum in the FPRs. Where the need is identified, mitigations for CWE are included in THPs. The analysis and proposed mitigations are then reviewed by California agencies as part of the review team process (see Institutional Framework: Governance Shifts during the 1990s). Obtaining coordinated review by State agencies and letting foresters know what to look for in advance have been consistent challenges (Cromwell et al., 1999).

The quality of analyses throughout the 1990s was highly varied (Little Hoover Commission, 1994; Cromwell et al., 1999). This variability has been due to many factors including the following: 1) lack of watershed data; 2) lack of background information on natural processes; 3) no standard watershed level analysis protocols; 4) ambiguous guidance on cumulative impacts analysis and mitigation measures; and 5) limited resources for training and subsequent monitoring (Little Hoover Commision, 1994; Cromwell et al., 1999). In addition, while mitigations to deal with commonly associated impacts to the beneficial uses of water on a plan-specific basis have been found to be successful, monitoring to date has not allowed conclusions to be drawn about whether the existing rules and their implementation adequately provide properly functioning habitat to aquatic species (see Notice of Decision for Amendments to the Forest Practice Rules Watershed Protection Extension, 2002). Lastly, some have criticized this process as being far too reliant on rules rather than promoting problem solving (Dunne et al., 2001).

In 1992, BOF also passed a rule (14 CCR 916.8) that allowed for listing of individual watersheds that have special issues and for the development of mitigations to deal with these issues. To be listed, watersheds must meet a restrictive set of criteria that define why the current FPRs do not adequately deal with the issue (14 CCR 916.8). To date, only one major watershed (the Mattole) has been considered for Sensitive Watershed status; however, it has not been listed.

More recently in 1999, 2001, and 2002, BOF further strengthened its rules related to the watershed level impacts of timber harvesting. This was in response to continuing concerns about this issue, especially as it related to listed anadromous fish species and watersheds listed as “impaired” under the federal CWA. Many of the rules are based on the finding of the Science Review Panel in 1999 that the FPRs (including their implementation) did not insure the protection of anadromous salmonid populations on the North Coast (Ligon et al., 1999).

One major thrust of the new Statewide rules has been the development of an interim Watershed Mitigation Addendum that can be used until December 2003 to permit landowners to use a watershed level approach for analysis and mitigation of timber harvest impacts. The goal of the rules is to foster maintenance and restoration of anadromous salmonids. They also provide a test of watershed or site-specific rules. The rules require identification of the limiting factors for the resource to be protected (water quality/salmonids). Furthermore, they mandate that either the limiting factors be avoided or that all feasible alternatives be used in the design of proposed timber operations. The rules also promote consultation between the responsible agencies and the timberland owners to address specific limiting factors for anadromous salmonids within the evaluation areas prior to the development and review of individual harvest plan proposals (see Notice of Decision – Findings Interim Watershed Mitigation Addendum – 2001).

Other new rule language (CCR §§ 916.9 [936.9, 956.9](a)) specifies resource protection goals for each timber operation in a watershed with threatened or impaired water-related values, and lists objectives for meeting these goals. They address those natural factors that are most significant for water-related values and are most likely to be impacted by timber operations. These include sediment, bank and channel stability, migratory fish passage, stream flow, riparian zone vegetation, critical near-stream areas, thermal loading, recruitment of LWD, and changes in peak flow or flood frequency. New language (14 CCR §§ 916.9 [936.9, 956.9] (b)) also indicates that listing of an anadromous fish species is the cumulative result of many events over time and space; the new rules are thus aimed at bringing about recognition of pre-plan adverse CWE and of the need for land managers to take responsibility for reducing them. Further language (14 CCR §§ 916.9 [936.9, 956.9](d)) permits the use of measures to offset sediment or thermal loading or other CWE that may exist throughout a planning watershed where they are fully delineated and the parties responsible are identified in the THP.

Watershed assessment

Much work has been done in the western states to improve assessment of watersheds in both rural and urban landscapes. Watershed assessment on forests and rangelands typically focuses on establishing the linkages among past and ongoing land management activities, geomorphic and hydrologic processes, aquatic and terrestrial habitat, and salmonid population responses (Ligon et al., 1999). Examples of formal watershed assessment approaches include the State of Washington Watershed Analysis, the Oregon Watershed Assessment Manual, and the Federal Interagency Watershed Assessment methodology used on public lands in western states.

Watershed assessment typically focuses on establishing the linkages among land management activities, geomorphic and hydrologic processes, aquatic and terrestrial habitat, and salmonid population responses.

Within California earlier watershed assessment efforts were associated with restoration efforts on the Klamath and Trinity rivers and less formal cooperative efforts on French Creek, a tributary to the Scott River in Siskiyou County (see the Assessment document Institutional Framework: Governance Shifts during the 1990s). Similarly, the Watershed Protection and Restoration Council, which was convened in 1996 to better coordinate and strengthen efforts to protect salmonids, recognized the need for sound assessments of baseline watershed conditions (California Environmental Resources Evaluation System, 1998). They also recommended that California do the following: 1) compile and make available existing information regarding watershed conditions and history; 2) provide guidance documents to assist community-based groups; 3) participate in watershed assessment with local stakeholders; 4) determine the status of fisheries and water quality within a watershed; and 5) determine potential impacts and develop positive measures to reach these goals.

In 1998, the California Resources Agency began to create an infrastructure for a coordinated State watershed program in forested watersheds. In addition to providing State agencies with substantial staff increases in order to enforce the Headwaters Agreement, the program provided for the following: 1) "coarse" watershed assessment of key North Coast watersheds using GIS information and available or easily enhanced data layers; and 2) funds to administer federal grants for salmonid restoration. Subsequently, significant work has taken place under NCWAP (see Institutional Framework: Governance Shifts during the 1990s).

In 2000, the California Resources Agency in coordination with the California Environmental Protection Agency initiated NCWAP partially in response to specific requests from landowners and watershed groups that the State of California take a leadership role in conducting scientifically credible, interdisciplinary assessments that could be used for multiple purposes. See the online document North Coast Watershed Assessment Program for more information. The need for comprehensive watershed information has grown in importance with listings of salmonids as threatened species, the TMDL consent decree, and the increased availability of assistance grants for protecting and restoring watersheds. Concerns about the potential impacts of salmonid listings and TMDLs on the economy are particularly strong on the North Coast where natural resource-dependent industries (such as timber production, commercial and sport fishing, tourism, and recreation) dominate the economy. Watershed assessments were conducted to better understand the linkages among management activities, dominant ecological processes and functions, and factors limiting salmonid populations and their habitat.

Each of NCWAP's participating departments developed data collection and analysis methods used in their basin assessments. They also developed a number of tools for an interdisciplinary synthesis of collected information. These included models, maps, and matrices for integrating information on basin, sub-basin, and stream reach scales to explore linkages among watershed processes, conditions, and use. These tools provided a framework for identifying watershed refugia areas and factors limiting salmonid productivity, as well as providing a basis for understanding the potential for cumulative impacts from natural and man-caused impacts. This information provided guidance for developing restoration, management, and conservation recommendations. To date, NCWAP has completed assessments for the Mattole (see following sidebar) and Gualala Rivers. Assessments for Redwood Creek, Big River, and Albion River are nearing completion. The information from the assessment was used to identify the underlying causes of stream habitat deficiencies and establish linkages to watershed processes and land use activities. Results of assessments conducted by various agency personnel were brought together in an integrated synthesis process. This process attempts to describe spatial and temporal relationships between watershed and stream conditions with respect to their suitability to support salmonids. The findings identified deficiencies in stream habitat, but also documented on-going recovery in channel conditions. Due to California budget problems, the NCWAP program has been largely eliminated, effective July 1, 2003.

Mattole: The Mattole River Basin encompasses approximately 296 square miles of Northern California's Coast Range. See the online document North Coast Watershed Assessment Program for more information. Although nearly three percent of the Mattole's headwaters are in Mendocino County, the vast majority of the basin is within Humboldt County. The mainstem Mattole River is approximately 62 miles long and receives water from over 74 tributary streams. There are approximately 545 perennial stream miles in the basin. The basin drains into the Pacific Ocean just south of Cape Mendocino. Elevation within the basin ranges from sea level at the estuary to 4,088 feet at Kings Peak. The basin receives one of the highest amounts of annual rainfall in California, averaging 81 inches.

NCWAP conducted a watershed assessment on the Mattole that was completed in 2002 (see North Coast Watershed Assessment Program). A main component of the NCWAP assessment was the analysis of stream and watershed factors to identify whether any of them are at a level that limits production of anadromous salmonids in North Coast watersheds. A limiting factor can be anything that constrains, impedes, or limits the growth and survival of a population. The information from the assessment was used to identify the underlying causes of stream habitat deficiencies and establish linkages to watershed processes and land use activities. Results of assessments (Table 14) conducted by various agency personnel on the Mattole team were brought together in an integrated synthesis process. This process attempts to describe spatial and temporal relationships between watershed and stream conditions with respect to their suitability to support salmonids.

Table 14. Summary of Mattole sub-basins stream and watershed conditions and recommended action

	Estuary sub-basin	Northern sub-basin	Eastern sub-basin	Southern sub-basin	Western sub-basin
Identified conditions					
Instream sediment	-/R	-/R	-	-/R	-
Water temperature	-	-	~	+	~
Pools	-	-	-	~	-
Flow	+	~	~	-	~
Escape cover	-	-	-	-	-
Fish passage barriers	+	~	~	~	~
Natural sediment sources	-	-	~	+	+
Management-related sediment sources	-	-	+	-	+
Recommended improvement activity focus areas					
Flow				X	
Erosion/sediment		X	X	X	X
Riparian/water temperature	X	X	X		X
Instream habitat	X	X	X	X	X
Gravel/substrate			X	X	X
Fish passage barriers				X	X

+ ***Condition is favorable for anadromous salmonids***
- ***Condition is not favorable for anadromous salmonids***
~ ***Condition is mixed or indeterminate for anadromous salmonids***
R ***Trend indicates improved conditions 1984-2000***
X ***Recommended improvement activity focus areas***

Source: Downie et al., 2002

Figure 20. Mattole Basin

Source: Downie et al., 2002

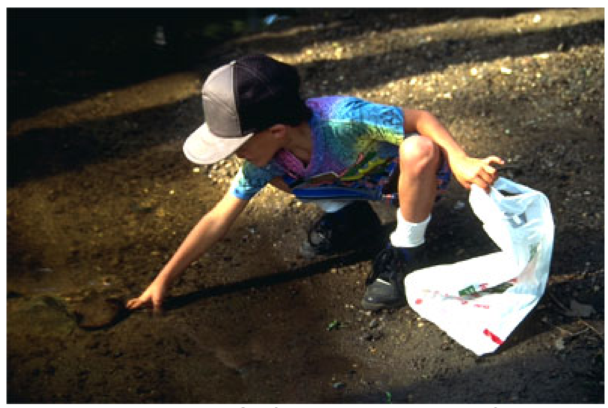
Watershed assessment has also taken place by watershed groups at the local level (see Institutional Framework: Governance Shifts during the 1990s). Two examples of assessment efforts also exist at the multi-county level: 1) the Fishery Network of Central California Coastal Counties (FishNet4C); and 2) the Five Counties Salmonid Conservation Program. A broader regional context for local watershed assessment has been created as part of CALFED (see Institutional Framework: Governance Shifts during the 1990s).

Two examples of locally-based regional efforts: The Five Counties Salmonid Conservation Program includes Humboldt, Mendocino, Siskiyou, Del Norte and Trinity Counties while FishNet4C includes Mendocino, Sonoma, Marin, San Mateo, Santa Cruz, and Monterey Counties. The efforts of these counties include the following:

- developing inventories of county roads and the fish passage problems as part of their efforts to make certain that county operations comply with federal Endangered Species Act requirements;
- providing training and guidance manuals to county staff on how to manage county road systems to minimize impacts on salmonids;
- developing model grading ordinances and facilitating their adoption in the member counties that do not have such measures in place to protect aquatic resources from development, road building, and agricultural activities; and
- working with other agencies to identify priority watersheds for restoration projects.

Both efforts reflect the fact that some of the most important environmental management innovations take place at the local watershed level. The achievement of these innovations often involves collaboration between State and local governments and a wide variety of non-governmental entities (Born and Genskow, 1999). See the online document Institutional Framework: Governance Shifts during the 1990s for more information.

Landowners and private companies have also been involved in watershed assessment. An example is the Fish, Farm and Forest Communities Forum (see the online document Fish, Farm and Forest Communities Forum), a landowner and industry-based group that works with Humboldt State University to develop standardized protocols for assessment and monitoring. They have worked closely with DFG and will help to identify the best ways to implement and monitor factors critical for fish protection under any State regulation. Private companies have also conducted watershed assessments on their lands. Two examples are Pacific Lumber Company and Mendocino Redwoods Company.


Volunteer restoration in California. Photo: Bureau of Land Management.

Watershed restoration

Watersheds are functional units of ecosystems and best treated as whole systems. They provide a wide range of ecosystem services, including clean air and water, flood control, habitat, and recreation. Degraded watersheds may show numerous symptoms, including excessive erosion, loss of plant and animal species, increased flooding, habitat fragmentation, and impaired water quality. This reduction in the quality of ecosystem services can have significant economic and social implications as well. By recognizing the services that watersheds provide, it is possible to create economic and social incentives to protect and restore them.

By recognizing the services that watersheds provide, it is possible to create economic and social incentives to protect and restore them.

Watershed restoration is the process of restoring fully functional ecosystems at the watershed scale. The success of a restoration project is not the return of a watershed to pre-human disturbance, but rather to relax the constraints, or limiting factors, that current management has placed on watershed processes and conditions. Restoration allows the watershed, as a system, to express a range of conditions that mimic the biological and physical characteristics of the watershed under its natural disturbance regime (Frissell and Ralph, 1998).

Historically, California has had a number of watershed restoration efforts. The goals of these efforts have varied, from stabilizing soils to improving the water quality for drinking water, fish habitat, and recreation consistent with goals of the federal CWA. These efforts are covered in detail in a number of historic and current sources (Kier Associates, 1995; DFG, 1998).

Restoration of fish habitat has been a dominant theme. For example, policies have called for a doubling of the number of salmon in California's coastal watersheds (Kier Associates, 1995). This doubling of the number of salmon was incorporated into a Statewide salmon conservation program developed by the California Advisory Committee on Salmon and Steelhead Trout, a panel of fishery experts authorized by the California Legislature. A similar call for increasing the long-term sustainable natural production of salmon in Central Valley rivers is contained in the Central Valley Project Improvement Act of 1992. The Act applies to the system of dams, reservoirs, and canals that diverts water from the Klamath-Trinity, Sacramento, and San Joaquin rivers and sends it to farms and towns on the coast and in the Central Valley (Kier Associates, 1995). Doubling the number of salmon has been adopted for federal fish restoration programs in the Klamath River Basin.

Within the Klamath Basin itself, Congress adopted the Klamath River Basin Act in 1986, authorizing a million dollars a year for 20 years to restore the river's fish resources. The Act created a 14-member Klamath River Basin Fisheries Task Force representing federal, State, and county governments, Indian tribes, commercial fishermen, and anglers. The task force's role is to advise the U.S. Secretary of the Interior on precisely how the Restoration Program should address the problems identified in the Act.


Klamath River, California. Photo: U.S. Fish and Wildlife Service.

The largest watershed restoration program in California today is the CALFED Bay-Delta Program whose goal it to restore the ecosystem functions of the San Francisco Bay-Delta system. See the online document California Bay-Delta Authority for more information. The scope of the program reaches throughout the Sacramento and San Joaquin River basins and beyond. CALFED's Ecosystem Restoration Program provided $63 million in funding for ecosystem restoration projects in 2002 alone. CALFED's Watershed Program, which supports watershed assessment and restoration activities, has an annual budget of about $34 million.

At the State level, DFG has been the leading force. It has worked with government agencies, landowners, watershed groups, and local communities to develop and discover funding for fish restoration efforts. The Inland Fisheries Division, now in the Native Anadromous Fish and Watershed Branch of DFG has published a stream restoration manual (DFG, 1998). Funding for watershed enhancement and restoration projects have been available through a variety of sources, such as DFG's Coastal Recovery Program, the CALFED Watershed Program and Ecosystem Restoration Program, and grant programs of the SWRCB and the Natural Resources Conservation Service (California Resources Agency and SWRCB, 2002). See the Assessment document Institutional Framework: Governance Shifts during the 1990s.

Individual landowners have been active in watershed restoration in a number of ways, from participation in watershed groups focused on watershed restoration to implementing restoration projects on their own lands. In some cases, these restoration projects have been supported through State and federal grant funding. In other cases, the landowners have done these projects using their own resources, such as timberland owners upgrading road systems to reduce sediment delivery potential as an element of conducting a timber harvest. An increasing number of private forest land owners in California have been systematically inventorying their road systems for current or potential sediment and fish passage problems, assessing the inventory information to developing plans and priorities for road improvements, and then moving forward to implement these improvements.

Restoration work has been completed and is ongoing in a number of watersheds across California. Significant progress has been made through voluntary, collaborative efforts (California Resources Agency and SWRCB, 2002). However, absence of useful watershed assessments and plans can lead to the failure of restoration projects to address priority problems and their causes (California Resources Agency and SWRCB, 2002). This suggests the importance of increased coordination and planning both within and across watersheds.

In California, watershed restoration has economic significance, with hundreds of millions of dollars allocated to salmon, wetland, forest, and grassland restoration. It remains an imprecise science, but holds enormous promise to preserve and improve the natural capital of watersheds.

Mattole Restoration Programs: The Mattole watershed, located along the North Coast, has a long history of watershed restoration. Declining salmon populations led to the formation of the Mattole Salmon Group (MSG) in 1980 and the Mattole Restoration Council (MRC) in 1983. The MRC is a community-based, not-for-profit public organization with headquarters in Petrolia. Its mission is the protection and restoration of natural systems in the Mattole River watershed and their maintenance at sustainable levels of health and productivity, especially in regard to forests, fisheries, soils, and other native plant and animal communities. For more information see the Home Page of the Mattole Restoration Council.

Restoration projects on the Mattole have centered on protecting aquatic resources. A summary of the types of projects is provided here and discussed in detail in the Mattole Watershed Assessment Report (Downie et al., 2002).

Stream surveys provide basic information about a stream and identify salmonid habitat problems. Stream surveys done in the Mattole Basin include spawning surveys, habitat typing and channel typing surveys, and LWD surveys.

Road assessments help identify current and potential sources of erosion related to roads. One current road assessment project in the Mattole Basin is a DWR funded assessment of roads in the eastern subbasin. DFG is also funding erosion assessments in the eastern subbasin.

Revegetation is important both in riparian areas, to stabilize stream banks, provide cover for salmonids, and provide shade, and in upslope areas, to help stabilize hillslopes. Examples of revegetation activities in the Mattole Basin include tree planting in the Middle Creek headwaters, funded by Sunlaw Cogeneration Partners in 1996, lower Mattole Basin riparian reforestation funded by DFG in 1996, and willow planting in the estuary funded by DFG in 1993.

Instream improvement structures add habitat diversity, complexity, escape, and ambush cover needed by salmonids. The MSG has added instream structures to the Mattole headwaters, the mainstem Mattole River, and various tributaries since 1980 with funding from DFG.

Fish rearing projects can be a way to supplement salmonid populations before habitat restoration activities can improve conditions. Beginning in 1981, MSG has trapped and raised native Chinook and Coho salmon in the Mattole Basin on a limited basis. In the 14 years between 1981 and 1995, 338,000 Chinook salmon and 52,550 Coho salmon have been released between the program's upstream and estuarine operations.

Public education programs are effective in expanding awareness about day-to-day activities that impact a watershed. Two important public education campaigns in the Mattole Basin are the MRC's "Good Roads, Clear Creeks" initiative, and the MSG's campaign to encourage water conservation.

Stream monitoring is important for restoration work in the same way that stream surveys are important; however, monitoring also allows restoration workers to study stream conditions over time. U.S. Geological Survey-sponsored and MSG-conducted sediment sampling at the Petrolia Bridge is an example of a monitoring program in the Mattole Basin. This program has been conducted since the year 2000.

Concluding Observations

Despite continuing advances in the field of watershed science and salmonid habitat needs, current knowledge limits the ability to confidently establish quantitative linkages between management actions, changes to channel dynamics, altered aquatic habitats, and responses of aquatic biota. This has been the case in both the Washington Watershed Analysis and with the Federal Interagency Watershed Analysis Frameworks. Both approaches have their strengths but they do not provide quantitative linkages among management actions, changes in watershed processes and channel dynamics, alterations in aquatic conditions, and response of the aquatic biota (Ligon et al., 1999). This is not surprising given the complexity of watersheds and the many ways that land management (past and present) can adversely affect environmental processes in a watershed. All of these factors take place in a stochastic environment. Further complicating the decision-making process is the lack of agreement on methods. Currently, there is no commonly accepted method for evaluating CWE. However, regardless of the approach taken, the goal of assessing CWE is to reduce risk and minimize impacts to natural resources. With this in mind, the methods of assessing CWE fall along a continuum, ranging from a more qualitative review found in checklists to spatially explicit models that can lead to a quantitative statement of risk (MacDonald, 2000).

To a large degree, these same limits experienced in Washington and Oregon seem true for watershed assessment in California. Over time, improvements occur according to enhancement of such items as: 1) information on historical disturbances; 2) more detailed spatial watershed data; 3) integrated analysis of management activities, channel processes, and salmonid habitat; 4) creation of a biological response model that links changes in habitat conditions to responses of salmonids (usually referred to as a limiting factors analysis); 5) evaluation of all watershed land management activities, water diversions, etc.; and 6) conduct of analysis at multiple, biologically relevant scales (Ligon et al., 1999). Advancements in assessment methods have been limited as there has been little effort to focus research on the fundamental problems of CWE analysis and prediction (Dunne et al., 2001).

To date, the conclusions of NCWAP suggest that integrated analysis is possible and can contribute to a comprehensive watershed assessment. Each report includes a synthesis of the findings from analysis of key watershed processes (geology, erosion, vegetation, fish habitat, water quality, etc.). This included a comparison of land management activities and environmental processes for each sub-basin within a watershed. Reports address factors that limit salmonid populations but do not predict the biologic response to changes in habitat conditions. The watershed reports provide specific recommendations that can lead to future restoration opportunities in a watershed.

However, even with more information, better technical models, and more complete description of linkages, activities in watersheds will have a level of uncertainty and risk. There probably will always be questions even about how established principles from ecology, geomorphology, hydrology, and related landscape sciences will apply to specific watersheds or sites. Even sediment budgeting, which is an approach used by an increasing number of agencies to assess CWE, addresses only sediment and the related physical changes in habitat conditions and water quality; however, it does not address biological impacts and is thus not an adequate measure, by itself, to address cumulative effects.

The difficulties in watershed assessment have led scientists at the University of California to propose a new framework for analyzing and predicting CWE. Because cumulative impacts are difficult to detect at the project scale, they advocate the assessment being done for entire watersheds. The approach would be based on extensive consultation between scientists, agencies, landowners, and interested parties in watersheds. It would use extensive, region-wide surveys of landscape conditions that could highlight critical watersheds by set criteria. Technical models, a number of which could be developed or applied in a relatively short time, would be used to conduct a watershed-scale gaming strategy to predict cumulative effects. The models would involve modeling of natural processes and risk analysis to provide a basis for land management decisions. Policy makers would be called on to determine what levels of land management-related risk to the environment is socially and politically acceptable. Quantifying the uncertainty associated with management activities could reduce, but not eliminate the risk of degrading natural resources. Over time, targeted research would address lingering uncertainties about linkages between management actions and natural process (Dunne et al., 2001).

Glossary

aggrade: The geologic process in which stream beds, floodplains, and the bottoms of other water bodies are raised in elevation by the deposition of material eroded and transported from other areas.

anadromous: Moving from the sea to fresh water for reproduction.

anadromous salmonids: Salmon species, including steelhead, that use both fresh waterbodies and oceans for various life stages.

anthropogenic: Caused by humans.

biotic: Having to do with living things; Caused by, or produced by living things; Having to do with the biological aspects of an environment (as opposed to geological, etc. Aspects).

BOF: California State Board of Forestry and Fire Protection.

CVP: Central Valley Project.

CWA: Clean Water Act.

CWE: Cumulative Watershed Effects.

DFG: California Department of Fish and Game.

DWR: California Department of Water Resources.

eutrophication: The gradual increase in nutrients in a body of water. Natural eutrophication is a gradual process, but human activities may greatly accelerate the process. Eutrophic waters are rich in mineral and organic nutrients that promote a proliferation of plant life, especially algae, which reduces the dissolved oxygen content and often causes the extinction of other organisms.

evapotranspiration: Loss of water by evaporation from the soil and transpiration from plants.

fill: Material that is placed in low areas, compacted and built up to form the roadbed or landing surface.

FishNet4C: Fishery Network of Central California Coastal Counties.

floodplain: The area bordering a stream over which water spreads when the stream overflows its banks at flood stages.

GIS: See Geographic Information System.

Geographic Information System: A computer based system used to store and manipulate geographical (spatial) information

gradient: The slope of a streambed or hillside. For streams, gradient is quantified as the vertical distance of descent over the horizontal distance the stream travels.

ha: Hectacre.

km^2: Square kilometers.

loading: Volume of material (i.e., sediment, wood, thermal) per unit area.

LSF: Late successional forests. A regulatory term for forests with characteristics of CWHR 5, 6 MD, 20 forest stand size minimum, and continuing snags and down logs.

LWD: Large woody debris.

m^3: Cubic meters.

mass wasting: A high incidence of landslides.

MFA: Million acre-feet.

mg/L: Milligram per liter.

microclimate: The climate of a small, specific place within an area as contrasted with the climate of the entire area.

MRC: Mattole Restoration Council.

MSG: Mattole Salmon Group.

MT: Metric Tons.

NCWAP: North Coast Watershed Assessment Program.

nonpoint: Pollution whose source cannot be ascertained including runoff from storm water and agricultural, range, and forestry operations, as well as dust and air pollution that contaminate waterbodies.

refugium: An area that has escaped ecological changes occurring elsewhere and so provides a suitable habitat for relict species.

riparian: Relating to or located on the banks of a river or stream.

RWQCB: Regional Water Quality Control Board.

sidecast: The excess earthen material pushed or dumped over the side of roads or landings.

silviculture: Generally, the science and art of cultivating (such as with growing and tending) forest crops, based on the knowledge of silvics. More explicitly, silviculture is the theory and practice of controlling the establishment, composition, constitution, and growth of forests.

smolt: A young salmon at the stage intermediate between the parr and the grilse, when it becomes covered with silvery scales and first migrates from fresh water to the sea.

stream: A body of water that flows at least periodically or intermittently through a bed or channel having banks and supports fish or other aquatic life—includes creeks and rivers.

stochastic: Pertaining to a series of random processes; involving chance or probability.

substrate: The woody material or substance in dead trees used by wildlife for life functioning activities such as nesting cavity construction or host habitat for food source.

Superfund: Congress established the Superfund Program in 1980 to locate, investigate, and clean up the worst instances of uncontrolled or abandoned hazardous waste sites, such as abandoned warehouses and landfills. The U.S. Environmental Protection Agency administers the Superfund program in cooperation with individual states and tribal governments.

SWP: State Water Project.

SWRCB: California State Water Resources Control Board.

terrace: A level plain, usually with a steep front, bordering a river, a lake, or sometimes the sea.

THP: Timber Harvesting Plan.

TMDL: See **Total Maximum Daily Load**.

Total Maximum Daily Load: A calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, as well as an estimation of the percentage originating from each pollution source. A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the waterbody can be used for State-designated purposes. The calculation must also account for seasonal variation in water quality.

watershed: The land area drained by a particular stream course.

wildfire: Any fire occurring on undeveloped land; the term specifies a fire occurring on a wildland area that does not meet management objectives and thus requires a suppression response. Wildland fire protection agencies use this term generally to indicate a vegetation fire. Wildfire often replaces such terms as forest fire, brush fire, range fire, and grass fire.

Literature cited

Benda, L. 1998. Dynamic landscape systems. In: Naiman, R.J. and R.E. Bilby (editors). River ecology and management: Lessons from the Pacific coastal ecoregion. New York: Springer-Verlag.

Benda, L. and T. Dunne, 1997. Stochastic forcing of sediment routing and storage in channel networks. Water Resources Research 33(12):2865-2880.

Benda, Lee E., Paul Bigelow, and Thomas M. Worsley. 2002. Recruitment of wood to streams in old-growth and second-growth redwood forests, northern California, U.S.A. Canadian Journal of Forest Research 32(8):1460-1477.

Berg, N., A. Carlson, and D. Azuma. 1998. Function and dynamics of woody debris in stream reaches in the central Sierra Nevada, California. Canadian Journal of Fisheries and Aquatic Science 55:1807-1820.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. pp. 191-232. In: Salo, E.O. and T.W. Cundy (editors). Streamside management: Forestry and fisheries interactions. Institute of Forest Resources Contribution number 59. Seattle, WA: Institute of Forest Resources University of Washington.

Binkley, Dan. 2001. Patterns and processes of variation in nitrogen and phosphorus concentrations in forested streams. Technical Bulletin Number 836. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc. Web site accessed May 14, 2003. http://www.ncasi.org/forestry/research/watershed/tb836.pdf.

Born, Stephen M. and Kenneth D. Genskow. 1999. Exploring the watershed approach: Critical dimensions of state-local partnerships. The Four Corners Watershed Innovators Initiative: Final Report. Portland, OR: River Network. Web site accessed May 14, 2003. http://www.rivernetwork.org/library/libriviss_4corners.pdf.

Bradford, D.F., D.M. Graber, and F. Tabatabai. 1993. Isolation of remaining populations of the native frog, *Rana mucosa*, by introduced fish in Sequoia and Kings Canyon National Parks, California. Conservation Biology 7(4):882-888.

Brosofske, K.D., J. Chen, R.J. Naiman, and J.F. Franklin. 1997. Harvesting effects on microclimate gradients from small streams to uplands in western Washington. Ecological Applications 7(4):1188-1200.

Cafferatta, P. 1990. Temperature regimes of small streams along the Mendocino coast. Jackson Demonstration State Forest. Fort Bragg, CA: California Department of Forestry and Fire Protection.

California Department of Forestry and Fire Protection (CDF). 1999. Draft Habitat Conservation Plan and Sustained Yield Plan for Jackson Demonstration State Forest dated June 1999. Prepared by Stillwater Sciences, Berkeley, California.

California Department of Fish and Game. 1998. California salmonid stream habitat restoration manual, third edition. Sacramento, CA. Web site accessed April 4, 2003. http://www.dfg.ca.gov/nafwb/pubs/manual3.pdf.

California Department of Fish and Game, Native Anadromous Fish and Watershed Branch. 2002. Sacramento River Winter–run Chinook salmon. Sacramento, CA.

California Department of Water Resources. 1998. The California water plan update. Bulletin 160-98. Sacramento, CA.

California Environmental Resources Evaluation System. 1998. Watershed Protection and Restoration Council: Protecting Califonia's anadromous fisheries. Sacramento, CA. Web site accessed April 3, 2003. http://ceres.ca.gov/watershed/wprc.

California Resources Agency and California State Water Resources Control Board. 2002. Addressing the need to protect California's watersheds: Working with local partnerships. Report to the Legislature as Required by AB 2117, Chapter 735, Statutes of 2000. Sacramento, CA. Web site accessed April 4, 2003. http://resources.ca.gov/watershedtaskforce/AB2117LegReport_041102.pdf.

California State Water Resources Control Board. 2000a. Laws/regulations. Web site accessed February 24, 2003. http://www.swrcb.ca.gov/water_laws/index.html.

California State Water Resources Control Board. 2000b. The section 303(d) list of water quality limited segments. Sacramento, CA. Web site accessed February 28, 2003. http://www.swrcb.ca.gov/tmdl/303d_lists.html.

Clark, G.M., D.K. Mueller, and M.A. Mast. 2000. Nutrient concentrations and yields in undeveloped stream basins of the United States. Journal of American Water Resources 36(4):849-860.

Cromwell, Dean, Norm Hill, Tom Hoffman, Marc Jameson, John Munn, Bill Snyder, and Bill Stewart. 1999. Cumulative impacts analysis: A report of the CDF director's THP task force. Sacramento, CA: California Department of Forestry and Fire Protection.

Dahlgren, R. 1998. Effects of forest harvest on stream-water quality and nitrogen cycling in the Caspar Creek Watershed. Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story; May 6, 1998, Ukiah, CA. General Technical Report PSW-GTR-168. Albany, CA: Pacific Southwest Research Station, U.S. Forest Service.

Downie, Scott T., C.W. Davenport, E. Dudik, F. Yee, and J. Clements. 2002. Mattole River watershed assessment report. North Coast Watershed Assessment Program. Sacramento, CA: California Resources Agency and California Environmental Protection Agency.

Drost, C.A. and G.M. Fellers. 1996. Collapse of a regional frog fauna in the Yosemite area of the California Sierra Nevada, USA. Conservation Biology 10(2):414-425.

Dunne, T., J. Agee, S. Bessinger, W. Dietrich, D. Gray, M. Power, V. Resh, and K. Rodrigues. 2001. A scientific basis for the prediction of cumulative watershed effects. Report Number 46. Berkeley, CA: Wildland Resource Center, Agricultural and Natural Resources, University of California. Web site accessed March 20, 2003. http://danr.ucop.edu/wrc/default.htm.

Euphrat, Frederick D. 1992. Cumulative impact assessment and mitigation for the Middle Fork of the Mokelumne River, Calaveras County, California. Ph.D. Dissertation. Berkeley, CA: University of California, Berkeley.

Fenn, M.E., M.A. Poth, J.D. Aber, J.S. Baron, B.T. Bormann, D.W. Johnson, D.A. Lemly, S.G. McNulty, D.F. Ryan, and R. Stottlemyer. 1998. Nitrogen excess in North American ecosystems: Predisposing factors, ecosystem responses, and management strategies. Ecological Applications 8(3):706-733.

Fire and Resource Assessment Program (FRAP). 2002a. FRAP multi-source vegetation. Sacramento, CA. Web site accessed June 5, 2003. http://frap.cdf.ca.gov/projects/frap_veg/index.asp.

Fire and Resource Assessment Program (FRAP). 2002b. Management Landscapes, v1.0. Sacramento, CA. http://frap.cdf.ca.gov/data/frapgisdata/select.asp.

Fire and Resource Assessment Program (FRAP). 2003. FRAP re and Resource Assessment Program (FRAP). 2003g. Special Management Zones, created from CA Coastal Commission Coastal Zone (STATEWIDECZB, date unknown); FRAP Multi-Source Land Cover v02_1; FRAP 2000 SWRCB 303d List, v03_1; FRAP NCCP/HCP Areas v03_1; FRAP Teale Data Center Government Ownership (GOVTOWNA, 1999); Teale Data Center Digital Elevation Model (DEM90MA, 1999); FRAP Integrated Hardwood Rangeland Management Program Oak Ordinances, v03_1; FRAP Timberland Production Zones, v03_1.Fire and Resource Assessment Program (FRAP). 2003. Timberland Production Zones, v03_1. Sacramento, CA.

Frissell, C.A. and S.C. Ralph. 1998. Stream and watershed restoration: Lessons from the Pacific coastal ecoregion. In: Naiman, R.J. and R.E. Bilby (editors). River ecology and management. New York: Springer-Verlag.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41(8):541-551.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkamper, K. Cromack, Jr., K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. pp. 133-302. In: MacFadyen, A., E.D. Ford (editors). Advances in ecological research. New York: Harcourt Brace Jovanovich.

Henly, Russell K. 1993. Policy, legal, and institutional considerations in the control of cumulative environmental impacts on forested watersheds in California. Ph.D. Dissertation. Berkeley, CA: University of California, Berkeley.

Jennings, M.R. 1995. Native ranid frogs in California. pp. 131-134. In: LaRoe, E.T., G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac (editors). Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. Washington, DC: U.S. Department of the Interior, National Biological Service.

Jennings, M. R. 1996. Status of amphibians. pp. 921-944. In: Sierra Nevada Ecosystem Project, final report to Congress, vol. II, assessments and scientific basis for management options. Davis, CA: University of California, Centers for Water and Wildland Resources.

Jennings, M.R. and M.P. Hayes. 1994. Amphibian and reptile species of special concern in California. Sacramento, CA: California Department of Fish and Game.

Jones, J.A. and G.E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. Water Resources Research 32(4):959-974.

Keller, E.A. and A. MacDonald. 1983. Large organic debris and anadromous fish habitat in the coastal redwood environment: The hydrologic system. Technical Completion Report. Davis, CA: California Water Resources Center, University of California, Davis.

Kelsey, H.M. 1980. A sediment budget and an analysis of geomorphic process in the Van Duzen River basin, north coastal California, 1941-1975. Geological Society of America Bulletin 91(2):1119-1216.

Kier (William M.) Associates. 1995. Watershed restoration: A guide for citizen involvement in California. Sausalito, CA: National Oceanic and Atmospheric Administration. Web site accessed April 4, 2003. http://ceres.ca.gov/watershed/restoration/Kier95.PDF.

Lassettre, N.S. and R.R. Harris. 2001. The geomorphic and ecological influence of large woody debris in streams and rivers. Sacramento, CA: California Department of Forestry and Fire Protection.

Lewis, J. and R.M. Rice. 1991. Critical sites erosion study, volume II: Site conditions related to erosions on private timberlands in northern California. Sacramento, CA: California Department of Forestry and Fire Protection.

Lewis, T.E., D.W. Lamphear, D.R. McCanne, A.S. Webb, J.P. Krieter, and W.D. Conroy. 2000. Regional assessment of stream temperatures across northern California and their relationship to various landscape-level and site-specific attributes. Forest Science Project. Arcata, CA: Humboldt State University Foundation. Web site accessed February 27, 2003. http://www.humboldt.edu/~ifwm/RSTARindex.shtml.

Ligon, Frank, Alice Rich, Gary Rynearson, Dale Thornburgh, and William Trush. 1999. Report of the Scientific Review Panel on California Forest Practice Rules and salmonid habitat. Sacramento, CA: The California Resources Agency and National Marine Fisheries Service.

Lisle, T.E. 2002. How much dead wood in stream channels is enough? General Technical Report PSW-GTR-181. U.S. Forest Service. Web site accessed March 21, 2003. http://www.psw.fs.fed.us/Tech_Pub/Documents/gtr-181/009_Lisle.pdf.

Little Hoover Commission. 1994. Timber harvest plans: A flawed effort to balance economic and environmental needs. Report 124. Sacramento, CA.

MacDonald, L. 2000. Evaluating and managing cumulative effects: Process and constraints. Environmental Management 26(3):299-315.

Montgomery, D.R., and J.M. Buffington. 1998. Channel processes, classification, and response. In: Naiman, R.J. and R.E. Bilby (editors). River ecology and management: Lessons from the Pacific coastal ecoregion. New York: Springer-Verlag.

Morgan, A. and D. Smith. 1997. Trends in disturbance and recovery of selected salmonid habitat attributes related to forest practices: A literature review and monitoring recommendations. Olympia, WA: Northwest Indian Fisheries Commission. Web site accessed February 27, 2003. http://www.nwifc.wa.gov/TFW/documents/dr.html.

Mount, J.F. 1995. California rivers and streams. Berkeley, CA: University of California Press.

Murphy, Dennis D. and Christopher M. Knopp (technical editors). 2000. Lake Tahoe watershed assessment: Volume I. General Technical Report PSW-GTR-175. Albany, CA: Pacific Southwest Research Station, U.S. Forest Service.

Naiman, R.J., K.L. Fetherston, S.J. McKay and J. Chen. 1998. Riparian forests. In: Naiman, R.J. and R.E. Bilby (editors). River ecology and management: Lessons from the Pacific coastal ecoregion. New York: Springer-Verlag.

Naiman, R.J., T.J. Beechie, L.E. Benda, D.R. Berg, P.A. Bisson, L.H. MacDonald, M.D. O'Connor, P.L. Olson, and E.A. Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In: Naiman, R.J. (editor). Watershed management: Balancing sustainability and environmental change. New York: Springer-Verlag.

National Council for Air and Stream Improvement. 1999. Scale considerations and the detectability of sedimentary cumulative watershed effects. Technical Bulletin Number 776. Research Triangle Park, NC.

Natural Resources Conservation Service. 2003. CalWater – the California Interagency Watershed Mapping Committee. CalWater 2.2. Web site accessed June 5, 2003. http://www.ca.nrcs.usda.gov/features/calwater/.

O'Conner, M. 2000. Garcia River large woody debris instream monitoring. Ukiah, CA: Mendocino County Resource Conservation District.

Poole, G. and C.H. Berman. 2000. Pathways of human influence on water temperature dynamics in stream channels. Environmental Management February(2000).

Reid, Leslie M. 1993. Research and cumulative watershed effects. General Technical Report PSW-GTR-141. Albany, CA: U.S. Forest Service.

Reid, Leslie M. and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20(11):1753-1761.

Robison, E.G. and R.L. Beschta. 1990. Coarse woody debris and channel morphology interactions for undisturbed streams in southeast Alaska, USA. Earth Surface Processes and Landforms 15:149-156.

Santa Clara Basin Watershed Management Initiative. 2000. Watershed characteristics report: Volume one. San Jose, CA. Web site accessed May 14, 2003. http://www.scbwmi.org/downloads-wmi.htm.

Schnackenberg, E.S. and L. H. MacDonald. 1998. Detecting cumulative effects on headwater streams in the Routt National Forest, Colorado. Journal of American Water Resources Association 34(5):1163-1177.

Southwest Fisheries Science Center. Santa Cruz Laboratory. 2001. Status review update for Coho salmon (*Oncorhynchus kisutch*) from the Central California coast and the California portion of the Southern Oregon/Northern California coasts evolutionarily significant units. Pacific Grove, CA: National Oceanic and Atmospheric Administration, Pacific Fisheries Environmental Laboratory. Web site accessed May 14, 2003. http://www.pfeg.noaa.gov/tib/files/pubs/Coho_status_2001.pdf.

Spies, T.A., J.F. Franklin, and T.B. Thomas. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington, USA. Ecology 69:1689-1702.

Strahler, A.N. 1957. Qualitative analysis of watershed geomorphology. Transactions American Geophysical Union 38:913-920.

Sullivan, K., J. Tooley, K. Doughty, J. Caldwell, and P. Knudsen. 1990. Evaluation of prediction models and characterization of stream temperature regimes in Washington. TFW-WQ3-90-006. Olympia, WA: Washington State Department of Natural Resources.

U.S. Environmental Protection Agency. 2002. Wetlands, oceans, and watersheds. Web site accessed February 21, 2003. http://www.epa.gov/OWOW/.

U.S. Forest Service. 1999. Roads analysis: Informing decisions about managing the national forest transportation system. Miscellaneous Report FS-643. Washington, DC. Web site accessed March 21, 2003. http://www.fs.fed.us/eng/road_mgt/documents.shtml.

U.S. Geological Service. 2003. National Hydrography Dataset. Web site accessed June 5, 2003. http://nhd.usgs.gov.

Veirs, Jr., S.D. and P.A. Opler. 1998. California. pp. 593-644. In: Mac, M.J., P.A. Opler, C.E. Puckett Haecker, and P.D. Doran. Status and trends of the nation's biological resources. Reston, VA: U.S. Geological Survey.

Watershed Sciences, LLC. 2002. Aerial surveys in the Klamath and Lost River basins: Thermal infrared and color videography. Report to North Coast Regional Water Quality Control Board and Oregon Department of Environmental Quality. Corvallis, OR. Web site accessed May 14, 2003. http://www.deq.state.or.us/wq/tmdls/FLIR/KlamathFinalReport.pdf.

Weaver, W.E. and D.K. Hagans. 1994. Handbook for forest and ranch roads: A guide for planning, designing, construction, reconstruction, maintaining, and closing wildland roads. Ukiah, CA: Mendocino County Resource Conservation District. Web site accessed March 21, 2003. http://mrcd.ca.nacdnet.org/pubs.html.

Welch, E.B, J.M. Jacoby, and C.W. May. 1998. Stream quality. In: Naiman, R.J. and R.E. Bilby (editors). River ecology and management: Lessons from the Pacific coastal ecoregion. New York: Springer-Verlag.

Wooster, J. 2000. Large woody debris volumes and accumulation rates in cleaned streams in redwood forests near confluence of South and Mainstem Eel River, California. Unpublished Report. Arcata, CA: U.S. Forest Service.

Watershed Professionals Network. 2001. Freshwater Creek Watershed Analysis. Prepared for Pacific Lumber Company (PALCO), Scotia, California.

Ziemer, Robert R. 1998. Flooding and stormflows. pp. 15-24. In: Ziemer, Robert R. (technical coordinator). 1998. Proceedings of the conference on coastal watersheds: The Caspar Creek story, 6 May 1998; Ukiah, California. General Technical Report PSW-GTR-168. Albany, CA: U.S. Forest Service.

Ziemer, Robert R., J. Lewis, R.M. Rice, and T.E. Lisle. 1991. Modeling the cumulative watershed effects of forest management strategies. Journal of Environmental Quality 20(1):36-42.