RICHARD KATTELMANN
Sierra Nevada Aquatic Research Lab
University of California
Mammoth Lakes, California

MICHAEL EMBURY
Sierra Nevada Aquatic Research Lab
University of California
Mammoth Lakes, California

Appendix on management and land use
Buffers by Don C. Erman,
Nancy A. Erman, Larry Costick, and
Steve Beckwitt

5

Riparian Areas and Wetlands

Sierra Nevada Ecosystem Project: Final report to Congress, vol. III, *Assessments and scientific basis for management options.* Davis: University of California, Centers for Water and Wildland Resources, 1996.

Back to CD-ROM Table of Contents

CONTENTS

by D. C. Erman, N. A. Erman, L. Costick, and S. Beckwitt

ABSTRACT

Riparian areas are the focal point of many resource conflicts in the Sierra Nevada because they are a critical ecological link between land and water. Although scarcity of quantitative information and unaltered reference sites currently limit the development of quantitative conclusions about riparian health across the entire Sierra Nevada, a few generalities emerged from this assessment. Riparian areas have been changed by human activities to varying degrees throughout much of the range. The basic functions of riparian systems, such as providing shade, stability, and organic matter to streams and habitat for avian and terrestrial wildlife, still remain in most places although often in impaired form. These functions have been largely lost in thousands of localities. The loss of functions is particularly evident in mountain meadows throughout the Sierra Nevada. A survey of riparian cover from aerial photographs showed that fragmentation is common along most riparian corridors. Riparian areas lacking vegetation cover identified in the aerial photograph analysis were usually associated with vehicular access. Roads and urban development have converted riparian areas to impermeable surfaces and channelized streams. Stream crossings by roads impact riparian areas at thousands of places and are the main current impact associated with timber harvesting. Many, if not most, of the broad valleys with formerly extensive riparian areas have been developed or inundated. About 1,000 km (600 miles) of riparian corridors have been submerged under reservoirs throughout the Sierra Nevada. These reservoirs and other gaps break the continuity of the riparian corridors and impair wildlife migration. Overgrazing has altered riparian communities throughout much of the Sierra Nevada. Impacts from overgrazing vary from subtle changes in plant vigor to conversion of wet meadows into sparsely vegetated and eroding landscapes. Besides these continuing impacts, future risks to riparian areas include accelerated urban development and additional water development. There are thousands of opportunities for restoration of locally degraded riparian areas. Streamside vegetation has remarkable ability to recover from disturbance, but artificial disturbances need to be removed or relaxed to give the natural recovery processes a chance.

PREFACE: SCOPE AND TERMINOLOGY

Although riparian areas are an integral part of stream ecosystems (e.g., National Research Council 1992; California State Lands Commission 1993), our separation of riparian from aquatic systems is artificial and merely for the purpose of report preparation. In this report, we are examining the riparian subsystem of riverine-riparian ecosystems (Jensen and Platts 1989). These subsystems are mutually interdependent in terms of ecological processes and consequences of impacts. For example, artificial regulation of streamflow alters the availability of water in riparian areas, and changes in riparian vegetation can alter physical and biological characteristics of streams. Assessments of other aspects of water resources and aquatic ecology are discussed in several chapters of the SNEP report (Erman 1996; Jennings 1996; Kattelmann 1996a; Knapp 1996; Moyle 1996a; Moyle 1996b; Moyle et al. 1996a). Further treatment of riparian areas is found in Kondolf et al. 1996; Menke et al. 1996; and Moyle et al. 1996b. Assessments of terrestrial vegetation and wildlife that have some association with riparian areas are found in additional chapters (Davis et al. 1996; Franklin and Fites-Kaufmann 1996; Graber 1996; McDonald and Tappeiner 1996; Schwartz et al. 1996; Shevock 1996). We have attempted to discuss riparian systems in the context of the entire Sierra Nevada, which is admittedly awkward because riparian properties, processes, and problems are local in nature.

In this report, we will use the terms riparian area and streamside area interchangeably to refer to the transition between the upslope terrestrial ecosystem and the adjacent aquatic ecosystem. We will use the term riparian corridor to refer to the land on either side of the stream and including the stream. The term riparian (or streamside) management zone has been used by agencies in a management or protection context to include some upland areas that may influence or buffer the riparian corridor. In our context, watersheds are units of land that potentially contribute water to a given point along a stream. Although our perspective in this riparian report is biased toward streams, we are not excluding those associated with lakes, reservoirs, springs, seeps, etc. Definitions of riparian terms are discussed by Warner and Hendrix (1984: xxv-xxvi), Anderson (1987), DeBano and Schmidt (1989), and Gregory et al. (1989). In this report, the terms grazing and overgrazing will be used in reference to commercial grazing of domestic livestock.

A brief assessment of wetlands has been included in this report. Because many wetlands are found in riparian corridors, much of the general discussion in this report applies to wetlands. However, wetlands have distinct characteristics and management problems and therefore receive some additional discussion.

INTRODUCTION AND BACKGROUND

Riparian areas are water-dependent lands along streams and lakes where transitions occur between terrestrial and aquatic parts of a watershed. They may be best described as the zone of direct interaction between land and water (Swanson et al 1982; Gregory et al. 1991; Cummins 1992). Riparian corridors connect the headwaters to the valley and facilitate transfer of materials (Gregory et al. 1991). Water, energy, and organic matter move downstream through a continuum of changing ecological processes along each stream (Vannote et al. 1980). The continuity of riparian areas is one of their critical characteristics, which is readily disrupted by human activities.

Riparian areas do not have precise boundaries because of temporal fluctuations of stream levels and intermixed vegetation types on the upland side. During most of the year, riparian areas are clearly separate from (though intimately connected to) their adjacent stream. However, during periods of high water, the topographically-lower sections of a riparian area that constitute a floodplain become part of the stream. Riparian communities usually contain a gradient in soil moisture from the stream through the floodplain and sometimes up into the terraces, depending on geomorphology and hydrology of the particular site. Typical riparian vegetation requires the high soil moisture usually found along streams, and some can even tolerate saturated soils and occasional inundation.

Riparian systems are distinct in mountain areas because they traverse broad vegetation belts that are arranged largely by elevation. They connect all the major life zones and are often dramatically different in vegetation composition and microclimate from the lands they cross. At variable distances away from the stream, riparian vegetation grades into upland vegetation. In some cases, there is little obvious difference in the composition of vegetation between the streamside area and the adjacent hillslopes. Elsewhere, there are marked contrasts between deciduous species in the riparian area and conifers or chaparral on the hillsides. In the lower margins of the east side of the Sierra Nevada, riparian areas appear oasis-like in comparison to the surrounding sagebrush scrub. In all cases, the vegetation near streams has profound influences on the aquatic system.

The thin, linear nature of riparian areas in the Sierra Nevada limits their total area to a small fraction of any watershed. Because habitat elements associated with riparian areas are relatively rare compared to the entire landscape, modification of even small areas has a proportionally greater impact in riparian areas than elsewhere in the watershed (Graber 1996). Depending on criteria used for delineation, estimates of the riparian fraction of total area in different river basins of the Sierra Nevada range from 0.1 to 1 percent (Langley 1984; Federal Energy Regulatory Commission 1986; Kondolf et al. 1987). National Forests use definitions of Streamside Management Zones that are different than typical biophysical delineations and consider that about 3-4 percent of the area of their Forests is "riparian" (e.g., Plumas National Forest 1988; Stanislaus National Forest 1988). The total amount of land in the Sierra Nevada classified as the Holland type *riparian forest* by Davis et al. (1996) is quite limited: 58 km^2 plus 119 km^2 of riparian scrub.

In general, streamside areas are the most productive and diverse parts of the landscape (e.g., Meehan et al. 1977; Naiman et al. 1992b; Risser 1995). Microclimates and soil moisture regimes found along streams are highly favorable for plant growth to be sustained for longer periods of each year than in other geographic locations. The frequent disturbance by floods and variety of physical habitats promotes much greater diversity of species than on more uniform hillslopes (Odum 1978; Gregory et al. 1991). Under natural flow regimes, frequent disturbance by various levels and durations of flooding results in riparian vegetation with a patchy distribution of species and ages (Swanson et al. 1990). The diversity of species and habitat structure may be reduced by human impacts that tend to simplify ecological processes and components.

Plant species of the riparian area are usually different from those found upslope. The plants considered typical of riparian areas (Appendix 1) generally share a set of distinct ecological characteristics: broad-leaved; winter-deciduous; fast-growing; often short-lived; requirement for high soil-moisture to support high rates of transpiration; ability to tolerate seasonal flooding and low-oxygen root environments that are often saturated; and ability to produce sprouts, suckers, and new root systems (California State Lands Commission 1993). Among riparian plants, there are substantial differences in their tolerance for flooding, which stratifies different species at different elevations along the floodplain and terraces.

Hydrologic and Geomorphic Controls on Development of Riparian Areas

Riparian vegetation at a particular location and time results from interactions between the physical conditions created by geomorphic and hydrologic processes in the stream channel and responses by the plants (California State Lands Commission 1993). The development of riparian communities is also influenced by hydrologic conditions in adjacent uplands, such as infiltration capacity and subsurface water movement (LaFayette and DeBano 1990). In turn, physical and biological processes in the riparian area can modify water and its constituents enroute from upland hillslopes to a stream as well as from upstream to downstream areas (Karr and Schlosser 1978).

Some of the physical factors that influence the structure of riparian communities include channel pattern, slope, and morphology; flood frequency and magnitude; timing and duration of flooding; sediment transport and deposition; and streamflow-groundwater interactions (Leopold 1994; Grant and Swanson 1995). Channel pattern and valley shape are important to vegetation by providing the substrate for vegetation establishment adjacent to the stream. These influences shift over time, and some are episodic. In response, riparian areas are highly dynamic.

Many stream reaches in the Sierra Nevada are confined within relatively narrow canyons. However, in deep glacial valleys (e.g., Kings Canyon and Yosemite Valley), broad flats (e.g., Sierra Valley and Kern Plateau), and scattered meadows (e.g., Hope Valley and Tuolumne Meadows), channels may meander and form multiple channels across a broad area. In these relatively flat valleys and meadows, there is ample opportunity for an extensive riparian community to develop. Unfortunately, these wider valleys have also been attractive areas for various human activities, with corresponding loss of some of the best riparian habitat. Braided conditions can also develop on the alluvial fans of the eastern slope. Sierra Nevada streams tend to have confined reaches of steep gradients alternating with those of low gradient and a wider floodplain (Janda 1966).

Flood events influence riparian vegetation directly through inundation, mechanical damage, and indirectly through changes in channel morphology. Floods in Sierra Nevada streams are produced by a variety of mechanisms depending on geographic location (Kattelmann 1990, 1992, 1996b). The period of saturation of the root zone during high water can result in a stratification of plant species along a microtopographic gradient up the floodplain (Walters et al. 1980). If the plants are dormant at the time of flooding, there may be little effect (Jones and Stokes Associates 1983). Most of the physical damage during floods results from the mechanical stress on the plant leading to uprooting or impacts from debris and bedload. Erosion of streambanks during floods also carries away the vegetation. Conversely, the vegetation dramatically increases the resistance of the streambanks to erosion (Zimmerman et al. 1967). The removal or death of some plants during peak flows creates opportunities for other plants to grow, ensuring regeneration and contributing to a structurally diverse canopy. Sediment deposition can bury and damage some plants that may be able to resprout above the new surface and provide fresh substrate for other plants that thrive where competition has been reduced (Sigafoos 1964).

Sediment deposition occurs both as channel bars, which add new substrate for colonization, and layers on the floodplain during overbank flows. If the bars continue to grow vertically, they become more suitable for continued growth. As plants grow on the new substrate, they can minimize loss of the early deposits by reinforcement with their roots and enhance additional deposition by slowing the current and physically trapping materials. As bars and the floodplain aggrade, soil moisture may become limiting to shallow-rooted plants as the surface height above the stream increases (Jones and Stokes Associates 1983).

Soil moisture along the floodplain and its relation to streamflow depend on the hydraulic gradient in the riparian area. Water moving down from adjacent hillslopes often saturates the floodplain area, maintains high soil moisture, and contributes to streamflow (Hewlett and Hibbert 1967; Dunne et al. 1981). In other situations, such as streams on alluvial fans, water may flow out of the stream into the bed and banks. The water that circulates between the stream and its bed and banks also promotes nutrient exchange and provides important habitat for some macroinvertebrates and microbes (Stanford and Ward 1988, 1993; Hakencamp et al. 1993). During periods of high runoff, water can spread over the floodplain and infiltrate or flow into the upper portions of streambanks, thereby raising the local water table. Some of this bank storage may return to the channel as streamflow declines. Streams in intact meadows are often supplied with water through this mechanism during the summer. If meadow streams become incised and water tables fail to rise during wet periods, the source of low-season streamflow is lost. Similarly, if the natural delivery of water and sediment is disrupted by human activities, the normal disturbance and development of riparian areas are also disrupted (Faber and Holland 1988).

Riparian-Dependent Animals

The diversity and structural complexity of riparian vegetation creates a wide variety of habitats for animals (e.g., Zeiner et al. 1988, 1990a, 1990b). More species and greater numbers of wildlife are found in riparian environments than any other habitat type (Sands and Howe 1977; Thomas et al. 1979; Brinson et al. 1981; Kauffman and Krueger 1984). Many species are completely dependent on riparian and adjoining aquatic environments. Of about 400 species of terrestrial vertebrates found in the Sierra Nevada, about one-fifth (84 species) are dependent on riparian areas (Graber 1996). On the Stanislaus National Forest, the number of wildlife species associated with riparian areas numbered 177 below 900 m (3,000 ft), 165 between 900 and 1,800 m (3,000 and 6,000 ft), and 77 above 1,800 m (6,000 ft) (Stanislaus National Forest 1988). In the well-studied Sagehen Creek basin, which is a tributary of the Little Truckee River, almost 40 percent of the vertebrates are strongly dependent on riparian habitat (Morrison et al. 1985). All of the 6 amphibians, 5 of 12 reptiles, 17 of 54 mammals, and 46 of 120 birds found in the Sagehen Creek basin are believed to depend on riparian areas. General habitat relationships for two amphibians, one snake, six mammals, and eleven birds strongly associated with streamside areas are reviewed by Carlson et al. (1991).

Although riparian environments are often considered as a single unit, they are usually composed of a mosaic of habitats and microhabitats with distinctive characteristics and organisms. The typical riparian microclimate of cool temperatures, high humidity, shade, and relatively constant air movement is favorable for many species. Additionally, many wide-ranging wildlife species spend time in the riparian area seeking water, food, or cooler temperatures. The linear nature of riparian areas gives them a high edge to area ratio, which seems to be desirable to some species. Relatively mature riparian communities tend to be well-stratified, which increases diversity and edge-effect (Thomas et al. 1979). Their configuration as natural corridors promotes their use as migratory routes for animals and aids in plant dispersal.

The vegetation of riparian areas supports complex habitats and abundant food resources for insects and other herbivores, which in turn, support a wide variety of vertebrates. Emerging aquatic insects contribute to the great abundance of invertebrates in riparian areas (Erman 1996). Aquatic invertebrates are a critical food supply for fish, amphibians, mammals, and birds. The density and diversity of birds, in particular, tends to be much greater in riparian areas than in adjacent uplands (e.g., Miller 1951; Small 1974; Gaines 1977). The variety of plant canopies at different heights that are common in riparian areas provides many ecological opportunities for individual species and coexistence among species (Krzysik 1990). Deciduous vegetation provides two seasonally contrasting structural conditions (Reynolds et al. 1993). The presence of open water and associated edge effects, abundant food resources of terrestrial and aquatic invertebrates, and diversity of vegetation contribute to the desirability of riparian areas for birds (Carlson et al. 1991). Riparian habitat is important for both breeding birds and migratory species. Numbers of migratory birds found in riparian areas can be more than ten times greater than in adjacent uplands (Stevens et al. 1977).

Changes in riparian areas along Sierra Nevada rivers has been associated with decreases in bird populations (e.g, Klebenow and Oakleaf 1984; Ohmart 1994; Manley and Davidson 1995). Among the birds thought to be declining in riparian habitats of the Sierra Nevada, the Willow Flycatcher has received considerable study and may be suggestive of the plight of other species.

Willow Flycatchers depend on dense thickets of riparian vegetation for breeding and foraging. The geographic range and numbers of Willow Flycatchers have shrunk dramatically in recent decades (Harris et al. 1987). A few small remaining populations inhabit isolated meadows of the Sierra Nevada, such as along the Little Truckee River (Flett and Sanders 1987). Overgrazing of meadows has been suggested as a major cause of the decline of Willow Flycatchers (Ohmart 1994). Cattle can directly disturb Willow Flycatchers and other birds nesting in montane meadows by knocking over nests in willows or crushing eggs on the ground (Sanders and Flett 1989). Parasitic brown-headed cowbirds lay their eggs in the Willow Flycatcher nests at lower elevations and occasionally at higher elevations where the breeding seasons have less overlap (Airola 1986). Opportunities for nest parasitism are increased by thinning or clearing riparian vegetation (Laymon 1987). The extirpation of Bell's vireo from the Sierra Nevada was associated with the spread of brown-headed cowbirds. Destruction of willow-dominated riparian areas also contributed to the decline of Bell's vireo (Graber 1996).

Mammals also take full advantage of riparian habitats because of the availability of water, food (vegetation, invertebrates, fish, other mammals, and carrion), cover, shelter, and a favorable microclimate (Cross 1988; Raedeke et al. 1988). Deer, beaver, raccoons, ringtail, skunks, shrews, and wood rats are relatively common in riparian areas. Although fur-bearing animals such as weasels, ermine, pine marten, and fishers are commonly associated with riparian areas, only mink and beaver are truly dependent on riparian habitat (Graber 1996). The role of beaver in riparian systems of the Sierra nevada has been debated for decades (e.g., Hall 1960) and is yet to be resolved. Several species of bats are an important component of the riparian community and feed on the abundant insects. Because bats use lower elevations for part of the year, loss of high-quality riparian habitat in the foothills and eastern part of the Central Valley may be a factor in the decline of some species (Graber 1996). Many mammals depend on riparian habitats seasonally in summer when uplands have dried out. Riparian areas serve as something of an oasis for wildlife during the hot, dry summer. Streamside areas also provide access to food, water and a favorable microclimate during winter. The obvious travel and migration corridors provided by riparian areas are becoming even more important as uplands are also modified by human activities (Nelson et al. 1994).

Riparian areas are also prime habitat for reptiles and amphibians (Jennings 1995), but relatively little is known about their ecological relationships (Reynolds et al. 1993). Many species of turtles, lizards, and snakes occupy or travel through riparian areas. Several types of lizards tend to stay very close to the water's edge to maximize feeding opportunities (Krzysik 1990). The presence of open water, damp soils, and a cool, moist microclimate make riparian areas particularly important for amphibians (Brode and Bury 1984; Jennings 1995). Almost all the 21 species of salamanders and 9 species of frogs and toads native to the Sierra Nevada spend significant portions of their life cycles in riparian areas (Jennings 1995). Riparian areas offer the damp soil necessary for lungless salamanders. Dense vegetation provides the cover and microclimate needed by many amphibians, especially frogs. For example, mountain yellow-legged frogs (Rana muscosa) require perennial water and, before their sudden decline, were abundant in dense herbaceous vegetation along streams (Mullally and Cunningham 1956). Amphibians going to the water to breed and juveniles emerging from the water, at least travel through riparian areas (Jennings 1995). The linear connectivity of riparian corridors has contributed to genetic continuity of reptiles and amphibians (Brode and Bury 1984; Carlson et al. 1991). Dramatic declines in amphibian populations are often related to deterioration and fragmentation of riparian habitat (Jennings 1995).

Several endangered species are associated with riparian areas in the Sierra Nevada. About one-quarter of the species dependent on riparian habitat are at risk of extinction (Graber 1996). The fact that these species are in severe decline is suggestive that their habitat has been seriously degraded. A list of threatened and endangered species dependent on riparian habitat is included in Appendix 2

Influences on Streams

Besides their ecological value for terrestrial biota, riparian areas provide critical functions for the adjacent stream (Meehan et al. 1977). Riparian vegetation both limits radiant energy reaching streams by shading (affecting temperature and primary productivity within the stream) and adds chemical energy and nitrogen compounds through plant materials and insects that fall into the stream (Cummins et al. 1989). In headwaters, these organic materials from outside the stream provide most of the base of the aquatic food chain (e.g., Knight and Bottorff 1984; Cummins 1992). Aquatic insects depend on this food source and the riparian habitat for parts of their life cycles (Erman 1984, 1996). Riparian vegetation provides habitat for both prey and predators of aquatic organisms (California State Lands Commission 1993). Streamside soils and vegetation regulate the entry of groundwater, surface runoff, nutrients, sediments and other particulates, and fine and coarse organic matter to streams. During floods, plant roots and fallen trees help stabilize the soil and streambanks. Vegetation and organic debris slow the movement of flood waters and dissipate stream energy, allowing deposition of sediments on the floodplain. Vegetative protection of streambanks against erosion effectively reduces sediment delivery to downstream reaches. Fallen trees and large branches that enter streams strongly influence channel pattern and structure and velocity distribution. Riparian areas also moderate the adverse effects of increased movement of water, sediments, and nutrients generated from upslope disturbances (Schlosser and Karr 1981). This role as a buffer and filter is often relied upon to limit stream degradation from land use activities in the uplands. Riparian soils and vegetation can capture a large fraction of the nutrient load entering from upslope and prevent its release to streams. Even the large inputs of nutrients from agricultural fields can be controlled with an adjacent healthy riparian forest (Peterjohn and Correll 1984; Pinay and Decamps 1988).

Streambank vegetation, especially dense overhanging rootwads, sod, bushes, and undercut banks, provides cover for fish. Submerged vegetation and dead wood contribute to the structural complexity of underwater habitat. Even intermittent streams can offer spawning habitat for trout (Erman and Hawthorne 1976) and cannot be ignored in consideration of riparian areas. For many years, removal of vegetative cover and related physical damage to streambanks by livestock has been considered one of the main impacts causing the decline of trout in upland streams of western states (Behnke and Zarn 1976; Platts 1991). The most obvious impacts to fish habitat from degradation of the riparian area are reduction of shade and cover with consequent changes in water temperature, sediment delivery, and channel morphology (Platts 1979; Baltz and Moyle 1984).

The degree of influence on a stream and the width of the zone of greatest interactions depend largely on the size of the stream, the shape and size of the valley, soil conditions, and the local surface and subsurface hydrology (Bilby 1988; Gregory et al. 1991). Streams with steeper gradients and steeper side slopes tend to have narrower riparian areas than streams of shallow gradient in broad valleys. Bedrock and boulder substrates offer little opportunity for establishing higher riparian vegetation but are colonized by mosses and lichens.

Riparian vegetation probably exerts the greatest influence on streams of small to moderate size, where local groundwater discharge and overland flow contribute a biologically significant fraction of the water and dissolved load of the stream, primary food sources are external to the stream, shading by trees is effective, and the vegetation affects geomorphic processes (Swanson et al. 1982; Knight and Bottorff 1984). In headwater areas, the riparian area usually provides water, sediment, nutrients, and energy to the stream, whereas the direction of these influences is often reversed in larger river-floodplain systems (Swanson and Sparks 1990). As the size of the stream increases, riparian vegetation provides less shade and primary food to the stream and has less influence on geomorphic processes. Nevertheless, upstream interactions still influence downstream conditions through the net transfer of water, energy, and organic matter downstream through a continuum of changing communities and ecological processes along the stream (Vannote et al. 1980). Energy, water, and nutrient balances of larger rivers are more affected by the mixing of their tributaries than by local riparian influences.

Other Riparian Studies in the Sierra Nevada

Until about 30 years ago, riparian areas were barely recognized as places of special ecological significance, except by ornithologists. Some books on natural history of the Sierra Nevada do not even mention the word riparian. There was remarkably little scientific literature on riparian areas anywhere in North America until the 1970s, when riparian areas became widely recognized as critical bird habitat. Throughout the country, there has been comparatively little research on riparian systems in mountain areas (Kauffman 1988). Although there has been widespread interest and concern about riparian areas in California, the bulk of research work presented at a series of conferences has concerned riparian systems in the Central Valley and Coast Range (Sands 1977; Warner and Hendrix 1984; Abell 1989). Most papers in these three proceedings relevant to the Sierra Nevada contributed to and are cited in this report. Much of the research on riparian areas of the Sierra Nevada has been associated with hydroelectric projects and was largely sponsored by the Pacific Gas and Electric Company and Southern California Edison (e.g., Harris et al. 1987; Patten 1986; Jones and Stokes Associates 1989).

Several other assessments of riparian conditions are in progress in different parts of the Sierra Nevada. Refinements of the National Wetland Inventory continue under the auspices of the U.S. Fish and Wildlife Service (now incorporated largely within the new biological division of the Geological Survey). Local jurisdictions, such as Mono County, are also mapping wetlands at a finer scale (Robert Curry, personal communication 1995). The Bureau of Land Management continues to assess riparian conditions on the lands they administer (Gradek et al. 1989; Myers 1989). Detailed riparian assessments are performed during hydroelectric relicensing procedures. Considerable activity is in progress in relation to riparian restoration projects on streams tributary to Mono Lake (e.g., Los Angeles Department of Water and Power 1995).

A variety of riparian evaluation and monitoring programs are in progress on National Forest lands. Most Forests have ongoing stream survey projects, both systematic and project-driven. Unfortunately, little of this data was collected or archived in a consistent format in the past. A new procedure, currently called Stream Condition Inventory, may see wide application throughout the National Forests of California (U.S. Forest Service 1994). On the Sequoia National Forest, field surveys of riparian areas are generating assessments of riparian conditions (Hot Springs Ranger District 1994). In this procedure, riparian ecotypes are identified on the basis of channel type and plant community. A stability value of each stream reach is determined by evaluation of vegetative bank protection and channel morphology (Kaplan-Henry et al. 1995). A monitoring program of effects of hydroelectric operation on riparian systems, involving periodic measurement of a suite of physical and vegetative attributes, is underway on the Inyo National Forest (Hicks 1995). Two intensive riparian studies are in progress in the Lake Tahoe Basin Management Unit that are funded by the California Tahoe Conservancy. In one project, high-resolution remotely sensed images from helicopters are being analyzed to evaluate health of riparian vegetation. The other project is studying indicators of biodiversity in riparian areas with detailed field surveys performed by a ten-person team. In this program, data collection is structured to allow examination of the effects of data at different resolutions on optimal sampling strategy (Manley 1995). A major effort at classifying riparian vegetation is underway on the southern portion of the west slope of the Sierra Nevada between the Mokelumne and Kern Rivers. Almost 300 riparian sites were sampled in 1995. A report on this work is expected to be issued by the Ecology Program of the Region 5 office of the U.S. Forest Service in 1997 (Don Potter, Stanislaus National Forest, personal communication, 1996).

Threats to Riparian Systems of the Sierra Nevada

There are a variety of threats to the natural integrity of riparian areas because they are valuable in economic as well as ecological terms. Floodplains and terraces held vast quantities of gold 150 years ago and are still important sources of sand and gravel. Reservoirs, roads, and urban areas break up the continuity of riparian corridors, one of their critical ecological attributes. Dams inundate riparian corridors and their included streams. Storage, controlled release, and diversion of water alter the flow regime and, consequently, affect plant establishment, growth, reproduction, and removal. Some streamside forests have been logged where trees were accessible and of high quality for lumber. Roads, railways, and flumes near streams can eliminate the valuable ecological functions of the riparian area from a substantial fraction of their original area. The broader valleys are desirable for conversion to pastures and agriculture. Construction may remove vegetation, expose and compact soils, decrease infiltration capacity, convert some areas to impervious surfaces, and alter channel morphology. Fire can damage the entire community for several years. Increased peak flows following intense and widespread fire can scour stream channels and alter the land base for re-establishment of riparian communities. Virtually all the Sierra Nevada has been grazed at some time (Kinney 1996; Menke et al. 1996). Livestock consume plants that hold the streambanks and soil together; mechanically alter the form, structure, and porosity of soils; and change the composition of the plant community. While all these disturbances occur throughout much of the Sierra Nevada and have changed the form, composition, and continuity of riparian areas, the extent of such changes has not been quantified. Except for grazing, the immediate scope of these threats is usually local, but they often have other downstream consequences. These different on-site and downstream impacts can take a cumulative toll on riparian systems.

METHODS

Three approaches were taken to assessing the current status of riparian systems in the Sierra Nevada: literature review, examination of video tapes of river corridors, and analysis of conventional aerial photography. Literature sources included studies that were part of the Pacific Gas and Electric and Southern California Edison research program of the 1980s, a few independent scientific studies, reports made for hydropower relicensing requirements and applications for proposed projects, and various reports of the Forest Service and Bureau of Land Management. Stream surveys, reports for evaluation of cumulative watershed effects, project environmental assessments, and miscellaneous documents of these agencies provided information about selected stream reaches. The geographic coverage of the available material was scattered throughout the range. The region with the most complete coverage from a variety of sources was the Mono Lake and Owens River basins. Otherwise, project reports covered a few parts of some river basins, while no information was found for other regions. The most detailed information was available for the vicinity of a few hydroelectric projects that have recently prepared environmental documentation for relicensing procedures. The literature review provides our primary information about changes that are short of total destruction of the riparian community. This information is limited and localized. The available literature (and this assessment) do not provide a comprehensive evaluation of riparian health.

A fundamental disturbance of riparian ecosystems is removal of vegetation. Elimination of riparian vegetation as a result of other land uses is the principal impact discussed in general literature on riparian systems (e.g., Johnson 1971; Bakker 1972; Smith 1977; Katibah et al. 1984). Therefore, the task we focused on was to determine the presence or absence of tree overstory along streams of the Sierra Nevada. Even such basic information about riparian areas has not been previously developed on a large scale for the Sierra Nevada (Nelson et al. 1994).

Video tapes of river and riparian conditions were recorded from helicopters flying through the canyons of many of the principal rivers and their tributaries of the Sierra Nevada in 1979, 1981, and 1987. This work was done by the National Park Service as part of an evaluation of the suitability of different rivers for inclusion in the National Wild and Scenic River system. Twenty-four of these tapes were available from the Water Resources Center Archives at the University of California at Berkeley. The tapes were used in our assessment to identify areas lacking streamside vegetation and describe possible causes of those gaps. Additional changes may be assumed to have occurred since the tapes were recorded.

Our attempt at assessing the extent of large-scale removal of riparian vegetation relied on interpretation of aerial photos. Aerial photography is commonly used for evaluations of riparian conditions (e.g., Nelson and Nelson 1984; Cuplin 1985; Cuplin et al. 1985; Walsh et al. 1987; Batson et al. 1987; Grant 1988; California Rivers Assessment 1995). Aerial photography is also being used to assess riparian vegetation in the current Interior Columbia River Basin Project.

The procedure we used was only suitable for identifying obvious gaps in an otherwise continuous riparian forest of large trees. It was not suitable for identifying changes in meadows, headwater areas, small tributaries, community composition or local disturbance below a canopy, except in extreme cases. Because of the length of all watercourses in the Sierra Nevada, only a sample could be examined. Nevertheless, more than 9,500 km (5,900 mi) of streams were examined in about 130 watersheds out of a total of 694 in the SNEP core study area. Riparian areas in each of the 24 major river basins of the Sierra Nevada were studied. Sequoia/Kings Canyon and Yosemite National Parks were not examined to allow us to focus on areas with greater potential impacts.

The geographic units of analysis were watersheds of 40 to 80 km^2 (10,000 to 20,000 ac) that are delineated and called Super Planning Watersheds (SPW) in the Calwater system of the California Resources Agency. The SPW were stratified into three broad elevation categories (high, medium, and low) in each river basin, and approximately one-quarter of the SPW in each elevation category were randomly selected as samples for photo analysis.

Maps of the SPW boundaries prepared by the SNEP GIS staff were used to transfer the boundaries to 1:100,000 scale maps. Aerial photographs at 1:12,000 or 1:15,840 scales from 1991, 1992, or 1993 were available for all national forests in the Sierra Nevada except for portions of the Inyo and wilderness portions of the Sierra National Forest. Photographs of the lower-elevation portions of the range were available from the Bureau of Land Management at 1:12,000 scale and at a 1:24,000 scale from the California Department of Forestry and Fire Protection. Photography was unavailable for a few areas originally selected, and those areas were not sampled.

Stereo images of stream reaches designated on the 1:100,000 scale maps within the selected SPW were examined to visually identify areas with apparently unnatural discontinuities in riparian vegetation. There were many more streams visible on the photos that were not marked on the maps. Those smaller streams were not explicitly studied, but major impacts to such areas were noted separately. The ecological importance of small streams is not to be overlooked; however, practical difficulties in examining unmapped tributaries prevented a detailed analysis. Reaches of 1 to 4 km in length were examined at one time. The approximate percentage of each reach that was obviously impacted or artificially void of vegetation was recorded. The threshold for deciding when an area was sufficiently affected to score it as impacted was based on subjective interpretation of the image. In most cases, the decision was easy: vegetation was present and fairly dense or nearly absent. Areas naturally devoid of riparian vegetation (such as bedrock stream channels) were readily distinguished most of the time from those that had been disturbed. In cases where the reason for absence of vegetation was uncertain (such as intermittent streams at low elevation or high-elevation meadows), the reaches were not included in either the percent-void estimates or the total. Inundated areas were not included in these totals, but were handled separately for the entire range. The first few SPW to be examined were later redone to ensure consistency throughout the study area.

The principal problems and uncertainties of this approach were inability to determine reason for absence of vegetation in all cases, inability to rate partial impairment of the riparian vegetation, inability to identify changes in species composition, inability to see below tree tops, and a lack of field verification. We were unable to compare changes in vegetation over time. Impacts to upper headwaters and small streams were not assessed by this method. Only impacts that removed riparian canopy were discernible. Such a technique tells us nothing about the finer-scale impacts and changes. These less dramatic, though ecologically critical changes could not be studied over any appreciable fraction of the mountain range within the scope of this project. However, the method did allow an assessment of complete removal of riparian vegetation throughout the Sierra Nevada with a sampling strategy that included more than 9,500 km (5,900 mi) of riparian corridors out of about 72,000 km (45,000 mi) of streams mapped at a scale of 1:100,000. Although this large-scale analysis with aerial photography is only suggestive about the presence or absence of riparian trees and possible causes of any decline, outside reviewers found the method to be inadequate to quantify the extent of riparian degradation. Therefore, only qualitative observations are reported in this document.

HISTORICAL IMPACTS TO RIPARIAN AREAS

Different aspects of the history of impacts to riparian areas in the Sierra Nevada are described in several chapters (Beesley 1996; Kattelmann 1996; Kinney 1996; Larson 1996). The following is a brief overview based on those chapters of the SNEP report. Prior to Euro-American exploration and settlement, Native Americans made considerable use of riparian areas where food and other resources were available (Anderson and Moratto 1996). The overwhelming majority of prehistoric sites in the foothills are located along streams. Wet meadows were horticulturally managed for food plants and game habitat (Anderson and Moratto 1996). On the east side of the Sierra Nevada, the Paiute built dams and irrigation canals to irrigate areas exceeding 5 km^2 (2 mi^2) in the bottomlands of the Owens Valley to enhance the growth of native vegetation (Steward 1934; Lawton et al. 1976).

The discovery of gold in 1848 had swift and dramatic consequences to streams and rivers of the Sierra Nevada, especially in the central portion of the western slope. Streams were dammed, diverted, dewatered, excavated, polluted, and filled with debris of enormous hydraulic mines. Virtually all streams on the central western slope were prospected (Averill 1946; Clark 1970). These excavations destabilized channel beds and banks and devastated riparian vegetation over a vast area. Mining debris was redeposited throughout the channels, but often formed tailings dams at confluences where channel gradients lessened (James 1994). Temporary reservoirs formed behind these debris accumulations, which occasionally failed catastrophically, releasing large volumes of sediment and further scouring and burying riparian areas. Dredging was an important source of gold within the riparian area of the lower reaches of the main rivers where the Sierra Nevada meets the Central Valley (Aubury 1910).

Acquisition of water for hydraulic mines developed engineering technology and physical works that have had lasting impacts on California's water distribution system and riparian areas. Generation of power for mines and mills led to one of the world's most extensive hydroelectric networks. Irrigated agriculture in the foothills initially occurred in or near riparian areas with frequent drainage of wetlands. Continued water development for hydropower, irrigation, flood control, and municipal supply installed hundreds of dams, large and small, throughout riparian areas of the Sierra Nevada.

Grazing was a nearly ubiquitous impact as cattle and sheep were driven virtually everywhere in the Sierra Nevada that forage was available (Kinney 1996; Menke et al. 1996). Anecdotal accounts describe vast herds and severe overgrazing (Sudworth 1900; Leiberg 1902). Overgrazing has been blamed for accelerated erosion beginning in the late 1800s and massive gullying of meadows in the decades that followed (Wagoner 1886; Hughes 1934). Widespread deterioration of meadows led to efforts by the Forest Service to reduce the degradation (Kraebel and Pillsbury 1934). However, continuing presence of large herds did not allow riparian vegetation to recover enough to reduce erosion of streambanks.

Timber harvesting in the 19th century impacted local streams, but perhaps mainly because of its typical location: near streams. We can assume that riparian and near-channel forests were targeted during the mining era because they grew on gold-bearing stream deposits and wood was needed where most of the activity was: along streams. Rivers were also used for log transport. Railroads facilitated log removal and were often located within riparian areas for efficiency of construction and routing. Meadows were drained for railway and road placement, as well as for homes and agriculture. Most of the bridges and stream crossings for roads that currently fragment riparian areas were built between 1945 and 1975 (Nelson et al. 1994).

CONTINUING IMPACTS TO RIPARIAN RESOURCES

Cumulative Interactions of Impacts

The great variety of impacts to riparian areas outlined below often work in combination to further degrade a particular site or an extended length of the riparian corridor and downstream aquatic systems. Some impacts are chronic or persistent like water diversions or roads. Other effects are short-term or periodic, such as fire or timber harvest. The different impacts usually result in a simplified system of fewer species or individuals or reduced habitat diversity. Multiple impacts generally increase the fragmentation of habitat. A couple of short breaks in the continuity of a riparian area (small bridges, for example) may not be too important, but several road crossings and reservoirs produce a highly fragmented riparian system. Present uses are superimposed on the legacy of placer and hydraulic mining. Streamflow regulation by dams alters channel conditions on all downstream reaches that may also have local impacts, such as logging or grazing. The possible combinations of effects from cows in campgrounds to off-road vehicle use of logging roads are manifold. Nevertheless, pieces of the riparian area are affected by all the different uses, influences, and impacts that occur at a particular site. In addition, downstream areas are affected by degradation of upstream sites through changes in water or sediment delivery; changes in water temperature; lack of leaves, logs, or seeds; etc. With streams, the concept of everything being connected to everything else is easy to visualize, especially in the downstream direction.

Dams and Water Management

Water-resource development activities necessarily take place in stream channels and riparian corridors. Construction of a dam and filling of a reservoir eliminate riparian habitat directly. Downstream of a dam or diversion, riparian conditions are affected by project-induced changes in water availability, substrate, and flood frequency and magnitude. Most water projects alter the natural hydrograph and create a different regime of seasonal water availability for riparian plants. The most common change in streamflow is substantial reduction of peak flows -- often an order of magnitude or more. Plant species that require high flows for seed dispersal and moist soil for germination may decline where peak flows are controlled. However, plant establishment and growth can also be enhanced by reductions in flood frequency and magnitude (Harris et al. 1987). Changes in sediment delivery and the capability to move sediments downstream of dams further influence riparian communities.

Some common effects of construction and operation of dams on riparian vegetation include:

- breaking the continuity of riparian habitat and its wildlife migration routes;
- loss of vegetation to roads, penstocks, canals, transmission lines, dams, and other facilities;
- temporary loss of vegetation during construction activities;
- non-native plants may encroach on areas cleared of native vegetation;
- loss of upstream vegetation under continual or seasonal inundation;
- where peak flows are reduced, riparian cover can increase (except on very steep or flat reaches);
- reduced flooding allows formerly flood-suppressed plants (often non-native) to flourish;
- colonization of the formerly active channel can stabilize sediments there and constrict the channel;
- during very large events, flood levels may be increased by the decline in channel capacity;
- lack of routine floods can reduce seed dispersal and germination of many native plants;
- when discharge during low flow periods is reduced, there is less recharge of floodplain aquifers;
- when less water is available, moisture stress can decrease riparian cover, esp. on uphill edges;
- in such cases, the riparian area will contract toward the channel;
- more xeric plant species may move into the outer margin of the formerly wet soils;
- when water availability is limited, deep-rooted trees are favored over shallow-rooted species;
- channel incision caused by stream rerouting during construction may lower ground water levels;
- delivery of sediment from upstream is reduced, and fine-grained substrate may be lost eventually;

(Williams and Wolman 1984; Federal Energy Regulatory Commission 1986; Harris et al. 1987; Jones and Stokes Associates 1989; Kondolf and Matthews 1993; Mount 1995).

Because broad valleys with wide riparian areas were often optimum reservoir sites, much of the best former riparian habitat in the Sierra Nevada is now under water. The extent of inundation across the range becomes apparent when one realizes that virtually all flatwater on the western slope of the Sierra Nevada below 1,500 m (5,000 ft) is artificial.

The many possible combinations of environmental conditions and flow regimes have resulted in a variety of vegetation responses to water management throughout the Sierra Nevada (Harris et al. 1987; Smith et al. 1991; Stromberg and Patten 1992). More than a century of excessive diversion combined with other impacts on the Little Truckee River has resulted in a wide unstable channel unprotected by riparian vegetation (Erman 1992). Riparian width has decreased dramatically in many eastern Sierra Nevada streams on alluvial fans (Taylor 1982). Riparian communities along stream reaches that lose water through seepage into their bed or banks are at particular risk from diversions (Jones and Stokes Associates 1989; Kondolf 1989). About one-third of all stream reaches in Inyo and Mono counties have been dewatered with severe consequences for riparian environments (Taylor 1983). Riparian vegetation has essentially disappeared where no water is permitted to flow in the natural channel (e.g., segments of Rush Creek in the Mono basin [Stine 1991]). In channels depleted of riparian vegetation, floods have caused severe bank erosion, channel migration, and road failures (Vorster and Kondolf 1989). The loss of riparian vegetation contributed substantially to the instability of the channels (Vorster and Kondolf 1989). Where peak flows have been reduced, both width of the riparian area and species richness on some diverted segments of Bishop Creek were significantly greater than on some undiverted reaches (Harris et al. 1987). The loss of daily fluctuations in streamflow during the snowmelt season below dams has probably altered ecological processes in the floodplain that was wetted on a daily basis, but these effects are not known to have been studied. Reduced flow in the lower Owens River allowed exotics to invade and native vegetation to move into the former channel (Brothers 1984). Augmentation of flows at the receiving end of trans-basin diversion has widened channels and has pushed back riparian vegetation, as in the case of the upper Owens River (Stromberg and Patten 1991). Below many dams, streamflow during summer and autumn is usually many times greater than the natural inflow to the reservoir because the high flows of winter and spring captured by the dam are gradually released from storage to meet water demands not synchronized with the Mediterrenean climate. These managed flows further alter the development of riparian communities.

Encroachment of vegetation into river channels has been noted below many dams and diversions on the west slope of the Sierra Nevada such as below Tulloch, Don Pedro, La Grange, and McClure reservoirs (Pelzman 1973), but it is not a universal response. Canopy cover increased and vegetation encroached upon the formerly active channel below a diversion on the North Fork of the Kings River (Taylor and Davilla 1985). In the same river basin and same study, no change was noted on Black Rock Creek below a partial diversion, but little vegetation remained in a tributary where all summer streamflow was diverted. Where peak flows were reduced on upper forks of Willow Creek, canopy cover apparently increased from about 78 percent above diversions to about 94 percent below, although other confounding factors may have been involved (Taylor and Davilla 1986). Farther downstream on Willow Creek, where most flow is diverted, riparian vegetation was substantially depleted. On Cherry Creek, aerial photographs indicated an increase in woody riparian vegetation after reservoir completion (Federal Energy Regulatory Commission 1994). As these examples illustrate, vegetation responds differently to river management depending on site conditions and the nature of regulation (Jones and Stokes Associates 1989). Variability in channel morphology, groundwater regime, and flow conditions confounds generalization about the extent of change of riparian vegetation in response to water management (Harris et al. 1987).

Creation of a reservoir with fluctuating water level eliminates the original riparian area and prevents establishment of a new one. Therefore, most dams destroy the continuity of riparian corridors. The lengths of these gaps along streams range from tens of meters to tens of kilometers. More than 150 riparian gaps greater than 0.5 km (0.3 mi) in length were found by inspecting maps of water developments. More than 20 reservoirs with pools greater than 0.5 km (0.3 mi) in length occur in highly developed river basins such as the Feather and American Rivers. This large-scale fragmentation is worst in the northern river basins of the west slope and numerically limited in the three southern basins (Kaweah, Tule, and Kern), which have one major reservoir apiece. Crude measurements from maps assuming straight-line channels in the absence of knowledge of the route of original river courses under the reservoirs provided a total estimate of 900 to 1,200 km (550 to 750 mi) of inundated riparian corridors throughout the Sierra Nevada. In addition, hundreds of small stockponds seasonally inundating intermittent stream channels at elevations below 1,000 m (3,300 ft.) were observed on the aerial photographs.

The artificial waterways created by the miners and their successors have also created riparian areas where they would not otherwise exist. Acquisition and delivery of water to mines was to become a huge industry that was probably more profitable than mining. In the 1860s, more than 8500 km (5300 mi) of main canals and about 1280 km (800 mi) of branch ditches had been constructed (Browne 1868; Logan 1948; McPhee 1993). Many of these old ditches and canals still supply water for hydroelectric generation, municipal use, or irrigation and have become a secondary channel system. Leakage is a significant and persistent difficulty with many of these waterways. In a 160 km (100 mile) long canal network in El Dorado County, about half of the initial water plus any gains enroute are lost to seepage (Soil Conservation Service 1984). However, the leakage has been found to benefit wildlife habitat by creating artificial riparian areas. This application of water may have acquired some legal status that prevents the ditch owner from converting to a pipe and drying up the leaks. A decision is pending on such a case involving the Crawford Ditch of the El Dorado Irrigation District (Borcalli and Associates 1993). Another aspect of water management that affects riparian vegetation is groundwater pumping. In a few areas of the Sierra Nevada, such as the Owens Valley, the water table has been artificially lowered by pumping, thereby reducing the availability of water to plants and changing the composition of riparian communities (Perkins et al. 1984; Groeneveld and Or 1994).

<u>Grazing</u>

A much more comprehensive assessment of range conditions and grazing in the Sierra Nevada is available in Menke et al. (1996). Impacts of overgrazing are considered second only to dams and river regulation as causing degradation of riparian areas in the Sierra Nevada foothills (Nelson et al. 1994). Grazing by sheep and cattle is widely believed to have been virtually ubiquitous throughout the Sierra Nevada before 1930 (Vankat and Major 1978; McKelvey and Johnston 1992; Kinney 1996), and almost all accessible riparian areas were impacted (Dudley and Embury 1995). Historical analysis of grazing allotment records found persistent patterns of overstocking in many areas (Menke et al. 1996). This period of overgrazing may have had dramatic impacts on stream systems. If these historical inferences are correct, current riparian conditions reflect that history of use and impact on the vast majority of streams in the Sierra Nevada. Therefore, we are unsure of exactly what constitutes natural riparian vegetation in most parts of the range. A reasonable approximation of natural riparian conditions may exist along many streams that have been grazed only lightly or have been rested for many years. Riparian areas in the national parks have been rested from commercial grazing since about 1930, although pack stock continue to be used for recreational and administrative purposes. Pack stock are now the primary impact in some high-elevation meadows, but there is little monitoring of their effects (Menke et al. 1996). Only those rare areas that were physically inaccessible or offered insignificant forage were not affected by grazing. Anecdotally, those ungrazed reference sites tend to have much denser vegetation. Some highly altered systems may be perceived as natural. Because livestock grazing has been such an extensive activity over the past 150 years, many people today have never seen an ungrazed stream and assume that present conditions are natural (Elmore and Beschta 1987). In some places, streams that are shallow and wide with a minimal amount of riparian vegetation have existed for so long that those situations are often regarded as normal.

The interrelated impacts commonly attributed to overgrazing include:

- reduction in vegetative cover,

- changes in species composition,
- introduction of exotics,
- reduction or elimination of regeneration,
- compaction and cutting of meadow sod,
- depletion or elimination of deeply rooted vegetation that strengthens banks,
- loss of litter and soil organic matter,
- erosion of stream banks, beds, and flood plains,
- loss of overhanging streambanks,
- destabilization of alluvial channels and transformation to wide shallow channels,
- initiation of gullies and headcuts,
- channel incision and consequent lowering of water tables,
- desiccation of meadows,
- increased water temperature during summer due to reduction of shade,
- increased freezing in winter from reduction of insulation and snow trapping efficiency,
- siltation of streams,
- bacterial and nutrient pollution,
- and decline of summer streamflow

(e.g., Platts 1984; Blackburn 1984; Kauffman and Krueger 1984; Skovlin 1984; Elmore and Beschta 1987; Armour et al. 1991; Platts 1991; Chaney et al. 1993).

Impacts to riparian areas are now widely recognized as a principal issue in range management (U.S. General Accounting Office 1988; National Research Council 1994). Riparian conditions were the only key range elements not found to be recovering in the national Range Reform '94 report (U.S. Bureau of Land Management 1994). Adequate methods to quantitatively assess impacts of overgrazing in evaluations of cumulative watershed effects are yet to be developed (e.g., U.S. Environmental Protection Agency 1993).

Riparian areas often suffer from overgrazing because their vegetation tends to be grazed more heavily than upland vegetation because of consumption preference and availability of water and shade. Fenced exclosures along streams illustrate vegetation recovery after grazing, which has been dramatic in some areas. Although geomorphic recovery can take decades longer than vegetative recovery (Kondolf 1993), there can be some response after plants are sufficiently re-established to provide bank stability and sediment trapping (Elmore and Beschta 1987). For example, after only five years of rest within a fenced exclosure, bank stability and bank undercut were greater on rested reaches of Silver King Creek and Coyote Valley Creek (tributaries to the Carson River) than on grazed reaches (Overton et al. 1994). Channels in the rested areas were also deeper and narrower than channels in nearby grazed areas (Overton et al. 1994). However, on the Kern Plateau, stream morphology has not recovered after 12 years of exclosure (Dudley and Dietrich 1995). A recent study of channel characteristics between pairs of currently grazed areas on National Forests and long-rested areas in National Parks in the Sierra Nevada found significant differences in bank angle, unstable banks, undercut banks, bed particle size, and pool frequency (U.S. Forest Service 1995b). Significant differences in undercut banks and unstable banks were also observed between grazed areas and adjacent fenced exclosures with a few years of rest. A recent evaluation of a sample of 24 locations throughout the Sierra Nevada found 13 to be at risk of loss of critical functions and 4 to be not functioning (Menke et al. 1996). That evaluation also found a strong association between the condition of meadow vegetation and the condition of adjacent streams.

Healthy riparian vegetation is critical to the maintenance of channels in alluvium. Vegetation deflects the erosive power of flowing water and shields the soil. Roots add substantial structural strength to the soil. Floodplain vegetation also enhances deposition of sediments above the active channel. The North Fork Feather River provides an example of severe streambank degradation from overgrazing. The Plumas National Forest was heavily grazed from the 1860s into the early 20th century and began to show signs of degradation by 1920 (e.g., Hughes 1934; Clifton 1992). Severe gullying was already in progress by 1900 (Leiberg 1902). Soil losses from overgrazed meadows in the North Fork Feather River basin have been estimated as 15-30 cm (6-12 in) since grazing began (Soil Conservation Service 1989). Alluvial channels without vegetation protection along their banks have increased in width severalfold and downcut as well. About 60 percent of the sediment delivered down a major tributary to the North Fork Feather River has been attributed to bank erosion where vegetation has been eliminated (Soil Conservation Service 1989). A major program of channel stabilization and vegetation re-establishment has been started on tributaries to the North Fork Feather River (Wills and Sheehan 1994).

Combination of lack of vegetative cover, increased channel width, absence of undercut banks, increased sedimentation, decreased streamflow in summer, and higher water temperatures can dramatically decrease fish production in grazed streams (Behnke and Raleigh 1979). Many studies throughout the western United States have demonstrated impairment of fisheries in streams with overgrazed riparian areas (e.g., various papers in Menke 1977; Elmore 1989; Platts 1991; Armour et al. 1991). The more open vegetation resulting from grazing may expose amphibians to predation and desiccation. Direct trampling by livestock may be an important cause of amphibian mortality (Jennings 1995). Effects on benthic invertebrate communities are currently being investigated on streams of the eastern Sierra Nevada (Herbst and Knapp 1995).

Riparian areas with dense vegetation are sometimes credited with enhancing late-season streamflow. In the absence of gullying, this assertion is probably only true when surface conditions are greatly altered. Removal of vegetation and compaction of soils by cattle can decrease infiltration and consequently increase surface runoff and augment local peak flows (Behnke and Raleigh 1979; Platts 1984). Natural riparian vegetation and undisturbed soils allow more infiltration than compacted soils (e.g., Dudley and Dietrich 1995). Therefore, soil moisture and bank storage would be greater and could contribute more water to the adjacent stream than if water were not allowed to enter the soil in the first place. However, transpiration by riparian vegetation also depletes soil moisture. Therefore, base flow amounts depend on a balance between additions to soil moisture through high infiltration and depletion through transpiration.

Riparian vegetation also protects streambanks against erosion and the vicious cycle of degradation that leads to a deeply incised channel and a lowered water table. When the water table drops as a result of channel incision, streamflow in the summer and autumn can be drastically reduced. Avoidance of gullying and resultant drops of the water table can more than compensate for evapotranspiration depletion of potential releases of water to streams from adjacent alluvial aquifers (Elmore and Beschta 1987).

Riparian vegetation degraded by overgrazing generally recovers within a decade once grazing pressure is removed (e.g., Platts and Nelson 1985; Chaney et al. 1993; Nelson et al. 1994). As long as gullying has not lowered the water table, riparian and meadow plants will regrow in a few years if not consumed (Odion et al. 1990). However, there are many potential successional pathways, and some systems do not necessarily recover to pre-disturbance states (Menke et al. 1996). Channel morphology responds to the cessation of the disturbance much more slowly (Kondolf 1993). Decades to centuries may be required. Rates of recovery tend to be highly variable between locations and depend on ability of riparian vegetation to trap sediment and build streambanks. A variety of structures have been installed in channels throughout the Sierra Nevada in attempts to halt gully progression (Kraebel and Pillsbury 1934; Hagberg 1995). By locally raising the water table, check dams can also increase bank storage and baseflow (Ponce and Lindquist 1990). Among land managers, a trend is beginning away from instream structures and toward patience with allowing vegetative recovery and geomorphic processes to rebuild damaged meadows and streams (e.g., Elmore and Beschta 1989). The structural approach has involved substantial expenditure of public funds to repair damage caused in pursuit of private profits and has avoided or delayed making changes in grazing practices. Small check dams and other in-channel structures often fail in dynamic alluvial systems (Elmore and Beschta 1989; Odion et al. 1990). Allotment management plans are now under review or revision on several national forests of the Sierra Nevada following a legal decision in 1994 that the grazing program of the Sierra National Forest was in violation of regulations relating to the National Environmental Policy Act. Throughout the Sierra Nevada, riparian conditions may continue to decline if current practices are not improved (U.S. Bureau of Land Management 1994). There is tremendous potential for improvements in both ecosystem functions and forage production through more careful range management (Menke et al. 1996).

Roads

When roads are located in riparian areas, the ecological impacts are often severe. Generally, roads are intended to last for decades, at least. Roads are a true conversion in land cover with little hope of natural recovery unless they are abandoned. Early roads were often located near streams simply to take advantage of the flat ground of the valleys. Such roads running parallel to streams can replace a large fraction of the riparian area with an unvegetated impermeable surface. Bridges, culverts, revetments to protect roads, and other engineering works associated with roads near streams impact riparian vegetation directly and indirectly. Direct effects include removal or burial during construction and compaction of adjacent soil. Indirect effects include alterations in surface and subsurface hydrologic flow paths and erosion and redeposition within the riparian area (Furniss et al. 1991). With each new road crossing, a piece of riparian habitat is lost directly, and the riparian corridor is further fragmented. Secondary effects of the construction may extend upstream and downstream, as well.

The availability of digital maps of roads and streams allowed the SNEP GIS group to calculate how often roads are found near streams. The analysis was based on a grid of one-hectare (100 x 100 m) [2.47 ac; 328 x 328 ft] cells. Sources of digital road information were the U.S. Forest Service road layer of so-called "system roads" and a road layer at 1:100, 000 scale provided by the Teale Data Center for areas outside the proclaimed boundaries of the National Forests. At the resolution of these maps, if a road touched any part of a cell, that cell was designated a road and similarly for streams. Although the analysis at this resolution is somewhat awkward, it provides a basis for comparing the proximity of roads and streams between river basins. The quantity of interest was the number of cells containing both a road and a stream expressed as a percentage of the cells containing a stream. For the 24 river basins in the SNEP study area, the values ranged between 3 and 11 percent. Basins with the lowest values (3-4 %) were the Kings, Kern, Kaweah, Carson, Mono, Tuolumne, Merced, and San Joaquin. Basins with the highest values (8-11 %) were the Cosumnes, Walker, Truckee, Yuba, and Mokelumne. Smaller analysis areas would be expected to have a much wider range (no roads to roads following most streams in a small watershed). Results for 141 Calwater (California Department of Forestry and Fire Protection 1996) "hydrologic subareas" from the same analysis are reported in Kondolf et al. 1996. The equivalent values ranged from 2 to 33% with a median of 14%.

A study of logging impacts on stream invertebrates showed that the worst effects occurred below failures of roads and culverts (Erman et al. 1977). Road construction activities seemed to affect the aquatic communities much less than did the repeated failure of poorly designed and constructed roads. Riparian corridors along major rivers affected by highways for long distances include the Feather, North Yuba, South Yuba, Truckee, South Fork of the American, Merced, Kaweah, Tule, and Kern Rivers. In several cases, what remains of the riparian corridor is sandwiched between a highway and a railway or secondary road on the opposite bank. Along the Truckee River, additional riparian vegetation has been replaced by a large flume.

Timber Harvest and Buffer Strips

During the Gold Rush, riparian areas were intentionally denuded to allow access to stream gravels or to relocate the stream in a flume for riverbed mining. When most mining activity was located along streams, trees in the riparian areas were also more accessible than those farther upslope. In some cases, such as the Truckee and Little Truckee Rivers (Erman 1992), water courses were used to transport logs downstream. Where riparian forests were not harvested during the mining era, subsequent timber operations obtained high-quality trees from the productive soils of valley flats. Apparently, little thought was given to consequences of near-stream logging until after World War II, and serious concern did not develop until the 1960s. Removal of trees from the riparian area continued through the 1970s when "best management practices" and "streamside management zones" were adopted. Forest practices of the past 25 years have become progressively more cautious near riparian areas (Adams et al. 1988). Today, clearcut harvesting near streams is rare in the Sierra Nevada, though not absent. Our aerial photograph survey revealed a substantial number of harvested units that included riparian areas, but their age could not be determined. On national forests, streamside management zones have been removed from the timber base of scheduled harvest, but may be entered for salvage logging, thinning, and special management needs. The timber base, lands where scheduled harvesting may occur, still includes the smallest channels that may not support fish or carry water all year. California's Forest Practice Rules (California Department of Forestry and Fire Protection 1994) set goals for maintaining buffer strips in streamside areas on private timberlands and set some limits on timber removal and heavy-equipment operations near water courses.

The riparian area has been identified as a critical area for minimizing sediment input into streams (e.g., Brown 1980; Megahan and King 1985). Under current forest practices, riparian areas on fish-bearing streams are usually partially protected by standards and guidelines that affect management activities in streamside management zones between the stream and timber harvest activities. Buffer strips have benefits for both the adjacent stream environment as well as that downstream by reducing pulses of sediment (Mahoney and Erman 1984). In a study of several streams in the northern Sierra Nevada, effects of logging on invertebrates were not noticed in streams with wide bufferstrips (Erman et al. 1977; Newbold et al. 1980). Streams with narrow buffer strips (less than 30 m) had impacted invertebrate communities to about the same extent as streams without any residual forest (Erman et al. 1977) and did not recover more quickly than those without buffer strips (Erman and Mahoney 1983).

Maintaining the effectiveness of streamside buffer strips requires careful consideration of their design and the influence of other management activities. Concern exists about the potential for wind damage to narrow strips of trees formerly surrounded by a dense forest. Susceptibility of buffer strips to windthrow should be carefully evaluated prior to harvesting adjacent timber. Denser streamside stands may have shallower roots reflecting a mutual dependency in dissipating wind forces (Steinblums et al. 1984; Brown 1980). Herbicide use near buffer strips can potentially cause severe damage to the riparian vegetation. Similarly, grazing in streamside areas seems counterproductive to the intended functions of buffer strips for timber management but occurs throughout most of the Sierra Nevada.

Considerable uncertainty exists about whether buffer strips act as a filter for upslope effects or simply avoid disturbance in the zone that is most likely to contribute water, sediment, nutrients, or introduced chemicals to the stream (Brown 1980). Although reduction of undesirable inputs to an adjacent stream occur in either case, improved understanding of the processes is needed. One of the presumed actions of riparian buffer strips is their ability to reduce the speed of overland flow and cause some of the stormwater's sediment to be deposited before reaching the stream (e.g., Adams 1993; Nelson et al. 1994). Comparisons have been made between slopes with and without buffer strips, and those without riparian vegetation usually produce far more sediment than those with streamside vegetation (e.g., Heede 1990). However, the mechanisms of erosion, sediment transport, and sediment deposition are rarely studied directly. Although riparian vegetation can function in a sediment trapping mode, conditions for sediment delivery in sheet wash are probably rare in the Sierra Nevada except occasionally on agricultural fields, construction sites, and roads. Any sediment in motion on a hillslope that has not been redeposited within a few meters of its starting point is probably in channelized flow (Brown 1980). Channels are likely to pass through riparian areas unhindered because the streamside land usually has high soil moisture and may be generating saturated overland flow itself during a storm. An alternative hypothesis to explain the lower sediment yield commonly observed below buffer strips is that the riparian area itself is not producing any sediment that would be available for immediate delivery to the stream. When riparian vegetation is cleared, conditions favorable for sediment production and delivery are established (e.g., Megahan and King 1985). This streamside erosion is likely to overwhelm any contributions from upslope under typical conditions of climate and logging in the Sierra Nevada.

<u>Stream Temperature</u> The temperature of streams has several direct and indirect effects on fish and other aquatic organisms. The metabolic activity of fish is most efficient within a limited range of temperatures. Water temperature partially determines how much oxygen is contained in

the water and available to fish. The amount of a gas dissolved in a liquid is inversely proportional to its temperature. Therefore, streams at higher water temperatures contain less dissolved oxygen. Many aquatic bacteria thrive in warm water, and some of these bacteria are pathogenic to fish. Increased light penetration to streams stimulates growth of aquatic plants and increases overall productivity. However, the resulting higher water temperatures (above 20 to 24^{o}C [68 to 75^{o}F]) can be lethal to salmonids.

The temperature of small forest streams depends primarily on availability of solar energy. Sunlight striking the water surface and exposed rocks that can reradiate and conduct energy to the stream warms the water. Water temperature follows a sinusoidal pattern on a daily and seasonal basis associated with radiant energy received by the stream. Creeks exposed to sunlight have much more dynamic temperature patterns than those receiving little direct solar radiation. Little heat is exchanged with most streams by convection, conduction, or evaporation (Brown 1969). Therefore, shading provided by riparian vegetation is critical to the energy balance of small streams. When shade is removed, maximum stream temperatures can increase by several degrees (Brown 1970; Brown and Krygier 1970; McGurk 1989). Average daily maximum temperatures for the warmest ten-day period of each year of a stream draining a 325 km^2 (125 mi^2) watershed in Oregon increased 6^{o}C (11^{o}F) between 1955 to 1984, apparently in response to timber harvesting (Beschta and Taylor 1988). Stream temperature is also influenced by the initial temperature of the sources of water, volume of water to be heated (small streams warm faster than large streams with the same energy input), surface area (wide, shallow streams warm faster than narrow, deep streams), and bed and bank materials (dark rock will absorb and retain more heat than will light-colored fine sediments). Larger rivers have more thermal inertia, and their temperature depends more on the temperature of tributary waters than on their surface energy balance. Releases from reservoirs can dramatically alter downstream water temperatures, depending on whether water is discharged from deep cold layers or warm near-surface layers. Groundwater inputs can also affect stream temperatures, especially near hot springs!

Stream temperature can be affected by changing stream shading. By maintaining the integrity of riparian vegetation, natural levels of sunlight will reach the stream. The orientation of the stream in different reaches will determine the optimum location of riparian vegetation for maximum shading. Canopy closure above and to the south of the stream is perhaps the best overall measure of shading efficiency. Avoidance of undesired warming along all reaches is necessary because once the stream gains extra heat, it does not readily cool. Even by flowing through long distances of well-shaded channel in mid-summer, little heat is lost. In rangeland streams, maintenance of riparian vegetation is critical even though canopy closure is rarely attained even on ungrazed streams. Loss of riparian vegetation and undercut banks from overgrazing removes whatever shade might be available and may lead to stream widening as well. Riparian vegetation also reduces the radiational loss of heat from streams during cold periods and can reduce freezing. During winter in the snow zone, riparian vegetation may help to trap more snow over the channels and reduce the depth of ice formation by insulating the stream. Simple models of temperature response to energy input are available to predict impacts of altering shade (Brown, 1969; Brown 1980; Beschta 1984).

<u>Large Woody Debris</u> Fallen trees and branches in stream channels influence movement of sediment and water through channels, dissipate energy of flowing water, create pools, provide micro-habitat for some organisms, and act as substrates for microbes and invertebrates (Harmon et al. 1986; Naiman et al. 1992a). The presence of large woody debris in channels can dramatically alter channel morphology and sediment storage (Keller and Swanson 1979; Nakamura and Swanson 1993; Keller and MacDonald 1995). Large wood can provide a stepped profile, which dissipates potential energy from the stream and stores large quantities of sediment (Marston 1982). For example, more than 70 percent of the potential energy of forested streams in a Colorado study area was dissipated in vertical falls over logs (Heede 1972). Woody debris can be an important means of forming pool habitat and variability in depth and velocity (Sedell 1984; Bilby and Ward 1989). Wood can be a reliable source of food for decomposers when leaves and other fine organic matter are unavailable (Maser and Sedell 1994) as well as a physical habitat for invertebrates

(Erman 1996). Because of the slow decay processes and episodic movement, consideration of wood in streams requires a time perspective of decades to centuries. Changes in the composition and size of trees in riparian areas affect the potential delivery of wood to streams (Robinson and Beschta 1990). Large woody debris from logging tends to be less stable than natural snags because of the lack of rootwads and limbs on logging waste (Ralph et al. 1994).

In the past, large woody debris was often removed from streams because it was thought to be a problem with respect to fisheries and flooding (Maser and Sedell 1994). Wood was removed from the Merced River in Yosemite Valley until 1989 because it could be a hazard to recreationists (Madej et al. 1994). Wood continues to be removed from streams by the highway departments and local flood control agencies. Removal of wood from channels can dramatically alter the morphology of channels and reduce the diversity of micro-habitats for aquatic organisms (Keller and MacDonald 1995).

Only a few studies have measured large woody debris in streams of the Sierra Nevada. Accumulations of woody debris were not found to be significantly different between logged and control reaches of a couple of streams in the northern Sierra Nevada because logging waste compensated for the decrease in natural supply (O'Connor 1986). The abundance of wood accumulations in streams might be expected to decrease downstream of riparian harvests after the first pulse of logging waste is flushed out of the channel. Data on large wood were collected on 93 plots on 17 streams of the Stanislaus National Forest between 1,100 m (3,600 ft) and 2300 m (7,500 ft) (Ruediger 1991). Plots that reflected either unlogged or light salvage logging contained about the three times the volume of wood per unit area that was contained on plots that had been logged a few decades ago (152 m^3 ha^{-1} unlogged vs. 52 m^3 ha^{-1} logged). On 18 of the plots, the volume of large woody debris exceeded 200 m^3 ha^{-1} and was as high as 1,175 m^3 ha^{-1}, values that are more typical of the Pacific Northwest (Ruediger 1991). On unlogged plots, both the volume per unit area and number of pieces per 100 m decreased with large stream size. On the average, the number of stable pieces (those that had at least one end buried and were storing sediment) per 100 m were 11, 6, 4, and 3 on 2nd, 3rd, 4th, and 5th order streams, respectively (Ruediger 1991). A study of wood in headwater streams on the Tahoe National Forest suggests that although wood improves fish habitat and can protect streambanks, it has little influence on current deflection or pool formation in the reaches examined (Carlson et al. 1995). Data collected on 29 channel reaches in the Sierra Nevada including harvested areas during a comprehensive study (Hawkins et al. 1994) found about 8 pieces of large wood (more than 0.3 m by 3 m) per 100 m of channel on the average in small streams of the forest zone of the Sierra Nevada. The number of pieces per 100 m ranged from 1 to 16. Woody debris is often a problem for reservoir managers in the Sierra Nevada after peak flows move large quantities of logs and branches out of the channels and into reservoirs.

Fire

Catastrophic fire can produce intensive and extensive changes in watershed conditions. Riparian areas that would not be harvested under current forest practices may be burned in intense fires. As with other impacts, the proportion of a catchment that is modified by fire and the location of the burned area with respect to the channel largely determine the effects on streams. Fire intensity is often highly variable over the landscape, and patches of unburned or lightly burned vegetation (especially near streams) can reduce the adverse effects of upslope areas that were intensely burned. Recovery of riparian vegetation usually occurs within a few years after a fire.

Fire suppression during this century in combination with logging and grazing has created forests with much greater density of vegetation than in the past (Skinner and Chang 1996). The dense vegetation also increases the opportunity for intense conflagrations (Skinner and Chang 1996) that could produce major increases in water and sediment yields.

Wildfires often burn less intensely in riparian areas than in upland areas because of the generally moist conditions near streams (Nelson et al. 1994; Toth et al. 1994). Riparian areas may serve as effective barriers to the spread of low severity fires across the landscape (Skinner and Chang 1996). Narrower riparian areas are at greater risk of burning than wider areas, and riparian sites with less water are more likely to burn than wetter sites (Agee 1993). Although riparian areas tend to burn less frequently and less severely than adjacent uplands, they can burn under more intense fire conditions. For example, riparian vegetation was killed on 72 km (45 mi) of perennial streams and partially burned on another 86 km (54 mi) of streams within the Stanislaus Complex burn of 1987 (Stanislaus National Forest 1988). The 1992 Cleveland fire on the Eldorado National Forest and the 1994 Cottonwood/Crystal fire on the east side of the Tahoe National Forest also thoroughly burned many kilometers of riparian corridors. Greater lengths of stream channel escaped serious burning than were actually burned during these fires. Some fires burn relatively little riparian vegetation, such as the Silver Fire Complex in southern Oregon, which occurred at the same time as the Stanislaus Complex fire (Amaranthus et al. 1988). Even light fires can be damaging to susceptible streamside vegetation. Fire is another disturbance factor that contributes to the diverse mosaic of riparian vegetation. Riparian areas are often the first areas to resprout following catastrophic wildfires, and therefore, are usually the first areas to be reoccupied by wildlife.

In general, sediment yields increase markedly after fires, particularly where slopes are steep, fire intensity was severe, and riparian vegetation was burned. Most of the sediment response seems to be from the channels and adjacent areas. In the absence of streamside vegetation, soil particles move into the channels and the banks become less stable. Increases in total discharge and peak flows result in channel erosion. Debris torrents may scour streams if extreme climatic events follow the fire (Helvey 1980; Kuehn 1987). If the fire is particularly hot, woody debris which helped stabilize the channel may be destroyed. Until revegetation occurs following a fire, many riparian functions are seriously impaired. The water table usually raises after a fire in the absence of transpiration demand, leading to increased streamflows against banks with diminished vegetative protection. Dramatic increases in flow of a small spring and a creek in the Sierra Nevada were observed following burning of riparian vegetation (Biswell 1989). Without vegetation and leaf litter as ground cover, erosion can be severe in the saturated near-stream areas. Food supplies for the stream are greatly reduced. Mobile wildlife will seek other unburned riparian areas.

Even when fires are limited to upslope areas, the loss of ground cover on the hillsides can increase water and sediment delivery to the riparian area. Downslope runoff may increase with the reduced transpiration and decreased infiltration where the fire produces hydrophobic conditions. Surface erosion will increase without the vegetative cover and leaf-litter layer. Landslides into the riparian area may increase after roots of dead trees decay.

Studies of the aquatic effects of a fire on the Plumas National Forest demonstrate how both physical and biological features of the stream change over time (Roby 1988; Roby and Azuma 1995). The lower two-thirds of this catchment including riparian vegetation were thoroughly burned. Initially, the channel widened in response to presumed higher flows of water and sediment. However, as vegetation became established and the watershed recovered, the cross sections of the channel returned to their pre-fire areas within six years of the burn. Partial recovery of the invertebrate community seemed to have occurred relatively quickly. No differences in community similarity were noted between burned and unburned reaches one year after the fire, and density and taxa richness were comparable within three years. However, significant (though declining) differences in species diversity between the burned and unburned reaches remained throughout eleven years of monitoring (Roby and Azuma 1995). Aquatic recovery following the 1988 Yellowstone fires in areas that were severely burned is expected to take decades with subtle changes in response to vegetation succession in the riparian area and uplands (Minshall et al. 1989).

Following fires, there is usually a strong desire by land owners, agencies, and the public to do something. Allowing natural recovery processes to function may often be the best policy (Beschta et al. 1995). Salvage logging after a fire is often proposed to recover some financial return from the burnt timber. However, logging operations disturb soils when they are particularly sensitive to erosion in the absence of cover and organic matter. Significant ground disturbance during a salvage sale of the Clark Burn in the Last Chance Creek watershed of Plumas County led to severe erosion during a thunderstorm (Cawley 1991).

The principal objectives of post-fire rehabilitation work should be to avoid making things worse, repair potential problems from fire-fighting activities (bulldozed fire breaks), enhance establishment of native vegetation to provide soil cover and organic matter and streambank stability and shade as quickly as possible, attempt to stabilize channels by non-structural means, minimize adverse effects from the existing road network, schedule operations to minimize exposure of bare soil, and allow natural processes to heal the landscape. Although we have created forests that carry a high risk of damage to aquatic resources, pursuit of quick fixes in an atmosphere of crisis carry substantial risks as well (Beschta et al. 1995).

Exotics

Non-native species have invaded many riparian areas, particularly in the foothills and Owens Valley (Schwartz et al. 1996). Replacement of many native perennials with annuals in meadows (Burcham 1970) may have been facilitated by regulation of streamflow and overgrazing (Nelson et al. 1994). Excessive grazing reduces plant density and increases availability of bare ground for invasion of exotic species if they are present in the area. Kentucky bluegrass is the primary invader of montane meadows throughout the Sierra Nevada (Menke et al. 1996). Salt cedar (Tamarisk) is a major problem (Robinson 1965) along some streams of the eastern Sierra Nevada. The extent of salt cedar along the Owens River has expanded markedly over just the past eight years (Inyo County Water Department 1995). Salt cedar has competitive advantages over cottonwood and other natives in the absence of floods (Krzysik 1990). Salt cedar produces seed over a longer period of the year and is relatively drought tolerant. Dense thickets of salt cedar prevent growth of seedlings of other species. The thickets tend to support fewer insects than other riparian vegetation and are not conducive to foraging by birds (Krzysik 1990). Elimination of native riparian vegetation in the lower Owens River allowed salt cedar and russian olive to invade (Brothers 1984). Attempts at eradication of salt cedar have been made along the Owens River. Both salt cedar and Russian olive have proved to be very difficult to eradicate once established (Schwartz et al. 1996). A few common weedy plants, such as bull thistle, Canadian thistle, scotch broom, and medusa head, have invaded disturbed riparian areas in the Sierra Nevada (Dudley and Collins 1995). Himalayan blackberry and Tree-of-heaven have been able to outcompete native riparian plants. Some exotic aquatic plants have also made their way into Sierra Nevada streams, but growth rates seem to be slow, so eradication is possible if they are discovered before expanding too far (Dudley and Collins 1995).

Alien animals, such as Brown-headed cowbirds, that have invaded riparian areas of the Sierra Nevada have had significant impacts on native riparian species (Graber 1996). Introduced bullfrogs have become widely distributed in ponds and slow-moving streams in the foothills of the Sierra Nevada and are regarded as an important factor in the rapid decline of native frog species and the western pond turtle (Graber 1996). Bullfrogs have largely replaced red-legged frogs and foothill yellow-legged frogs in many locations.

Drainage Programs

Wetlands in the Sierra Nevada have been drained since the earliest settlers attempted to "reclaim" meadows and other seasonally wet areas. Mountain meadows were commonly drained with the intent of improving forage conditions and to permit agriculture (Hughes 1934). Galen Clark, the fabled Guardian of Yosemite Valley, dynamited a moraine to drain the El Capitan meadow in 1879 to open more land for grazing and eliminate mosquito breeding areas (Greene 1987). This action of lowering the base level caused the Merced River to downcut several feet. Vegetation near the river was probably altered as a result. Drainage activities have continued until recent times. The Soil Conservation Service and Plumas County removed a natural control on Indian Creek near Crescent Mills in the North Fork Feather River basin during the 1950s and set in motion progressive channel degradation in Indian Creek and Wolf Creek (Greenville Ranger District 1985). Drainage activities on small lots progressively reduce the total amount of wetlands. Road construction in or near meadows often involves drainage measures to stabilize the roadbed.

Phreatophyte Control

Riparian vegetation can account for a disproportionate fraction of total transpiration in small watersheds because it has access to almost unlimited water and favorable conditions for an extended growing season. Phreatophytes (plants with roots extending below the water table) are particularly thirsty. Reductions in this water loss have long been sought by downstream water users, especially in arid regions (Dunford and Fletcher 1947). Although most of these phreatophyte-control projects were in Arizona and New Mexico (e.g., Hibbert 1983), some were also carried out in the Sierra Nevada (e.g., Biswell 1989). Such programs were soon realized to involve some serious environmental consequences (Campbell 1970) and have been largely discontinued. The use of non-destructive chemicals to inhibit transpiration has been studied (e.g., Davenport 1977), but operational programs in the Sierra Nevada are not known.

Residential Development

Development of individual parcels and large subdivisions continues to damage and fragment riparian areas. Areas around streams are aesthetically attractive to people, and riparian areas become preferred locations for our facilities, homes, roads, trails, etc. Obvious effects of residential development on riparian areas include removal of riparian vegetation and construction of roads and structures near streams. Wetlands are routinely drained or filled to make room for structures. However, just the proximity of dwellings to streams leads to a variety of secondary effects. Frequent travel within the riparian area disturbs wildlife. Domestic pets and farm animals interfere with native wildlife. Alien plants from farms and gardens compete with natural flora. Wood is removed from the riparian forest floor and standing trees and snags for fuel. Much of our waste ends up in the riparian corridor. Development of local water supplies for even small communities can significantly reduce streamflow, especially during low flow periods (medina 1990). For example, Sierra City on the North Yuba River, with only a hundred service connections, uses about 185,000 m^3 (20 AF) of water annually, with most of that use during the summer (Don Erman, University of California at Davis, personal communication 1995).

Hydrologic effects of residential development alter riparian areas by changing the streamflow regime that influences riparian plants and animals. Vegetation both near and away from streams is commonly removed in the process of development. Loss of its interception and transpiration functions results in higher soil moisture levels and a tendency toward more rapid runoff. Construction of roads, driveways, gutters, and roofs increases the impervious surface area of a catchment, which leads to more water arriving in channels in less time from even modest rainfall than under natural conditions (Leopold 1968). More frequent floods of larger magnitude can lead to channel enlargement and removal of riparian vegetation (Dunne and Leopold 1978; Booth 1990). If the total area of limited infiltration is a significant fraction of a catchment, ground water levels will decline. Riparian vegetation in many areas depends on subsurface water that is enroute from uplands to streams and may suffer if ground water is less available. Streamflow during non-storm periods that was formerly generated by this mechanism will also decline. Ground water pumping for domestic and irrigation supply can exacerbate the problems of restricted recharge. In some cases, irrigation return flows may augment summer streamflow.

Despite the initial attraction of streams, people are often not satisfied with the location of streams and their tendency to flood on occasion. Therefore, urban and suburban streams are often rebuilt in an attempt to exercise some control over them. Riparian areas suffers both from the construction activities and the artificial waterway in the long term. Around roads and towns, the usual objective of channelization is to get water away from a place where it was not wanted. Creeks of all types and sizes have been relocated, smoothed and straightened to get water away from roads and homes as quickly as possible. These ditches, canals, and storm sewers enhance the flood-producing effects of general land conversion by routing the extra runoff away from the town or road much more quickly than under natural conditions. Peak flows are augmented downstream, but that is typically beyond the concern of the local channelization project. Flooding in Roseville during January 1995 was a classic example of this phenomenon.

Changes in runoff are closely related to declines in water quality associated with urban development. Enhanced runoff washes various contaminants off of roofs, streets, parking lots, gutters, horse corrals, and golf courses and into streams. Diminished baseflow increases the concentration of residual pollution entering after the floods. Urban pollutants include soil particles, nutrients, heavy metals, toxic organic chemicals including pesticides, oil and grease, fertilizers, oxygen-demanding materials such as yard waste, and bacteria and other pathogens (Terrene Institute 1994). Development of riparian areas limits opportunities for filtering, uptake, and assimilation of contaminants. The combined effects of changes in runoff regime, water quality, and channel structure resulting from urbanization has profound effects on aquatic and riparian organisms. Eliminating infiltration on as little as a tenth of the catchment area led to declines in population of fish and amphibians near Seattle (Booth and Reinelt 1993).

Residential development requires water supplies that are sometimes developed from local surface water. Creation of reservoirs and diversion structures directly damage riparian areas, and reduced streamflow reduces water availability to the aquatic and riparian communities. Excessive water withdrawals from local streams can threaten recreational fisheries that form part of the economic base supporting the communities seeking the extra water for more development (Kattelmann and Dawson 1994). Development of additional water supplies is likely to become increasingly costly in both financial and environmental terms. The projected demand for additional water in the foothills in the next few decades is staggering (Duane 1996). For example, the Georgetown Divide Public Utilities District expects a 50 percent increase in water use in the next 30 years, and the El Dorado Irrigation District anticipates demand to double in the same period (Borcalli and Associates 1993).

Recreation

Many recreationists have a strong affinity for water, both for visual and direct-contact enjoyment. This desire to be close to streams and lakes has resulted in the riparian location of roads, vacation cabins, campgrounds, trails, and other facilities. River-based recreation can have substantial impacts on riparian vegetation (e.g., Martin 1984). Off-road vehicle tracks were occasionally noted in the river video tapes. Widespread vehicle impacts were found in the South Fork of the Kern River basin. Use of old skid trails and stream fords by off-road vehicles was a frequently noted impact to riparian areas in notes on stream surveys of the Tahoe National Forest. Repeated trampling by hikers eventually kills low plants and compacts the soil (Liddle 1975). Foot traffic has destroyed riparian vegetation and accelerated streambank erosion in Yosemite Valley (Madej et al. 1994). Bank erosion and channel widening were found to be more common around areas of concentrated use, such as campgrounds (Madej et al. 1994). A simple count from USFS maps indicated that more than 75 percent of the National Forest campgrounds in the Sierra Nevada are located within a riparian area or in close proximity. Soil compaction, chemical and bacterial pollution, litter, vegetation damage, wildlife disturbance, and fire ignition are impacts associated with recreational sites in riparian areas (Nelson et al. 1994). Gathering of firewood from riparian areas around campgrounds can also eliminate much of the potential wood supply to streams (Madej et al. 1994).

Mining

Placer and hydraulic mining in the 19th century devastated many of the riparian corridors on the western slope of the Sierra Nevada. As discussed in Kattelmann 1996a, gold mining in the creeks and rivers totally destabilized their riparian systems. Affected streams and hillslopes have been recovering ever since (e.g., James 1994). In most cases, the degree of recovery is remarkable. Much of the region appears to have partially healed over the past century. Some form of riparian vegetation has become re-established, and there has been partial return of aquatic biota to the streams (e.g., Marchetti 1994). Nevertheless, there are still many localities lacking soil and vegetation. One may assume that the present form of the riverine-riparian ecosystems is simplified compared to the pre-Gold Rush situation, but we really do not know what the west slope of the Sierra Nevada might have looked like had gold not existed in the range.

The legacy of gold mining continues to influence riparian ecology. Hydraulic mine pits are slowly becoming revegetated, but continue to release unnaturally high volumes of sediment as their walls continue to collapse until a stable slope angle is attained (Senter 1987). The unnaturally high sediment loads continue to affect aquatic biota (Marchetti 1994). Massive riverbed dredging operations at the lower margins of the foothills persisted until 1967 (Clark 1970). The spoil piles may remain as a peculiar landscape feature for centuries. Rapid drainage and minimal soil development limit opportunities for vegetation establishment on the dredging debris. Some modern mines adversely affect the localities of the mines and their access routes.

Small-scale suction dredging continues in many streams of the Gold Country. This activity has become widespread wherever there is easy access to the streams (McCleneghan and Johnson 1983). Powerful vacuums mounted on rafts remove stream gravels from the bed for separation of any gold particles, and the waste slurry is returned to the river where the plume of sediment stratifies in the flowing stream. Some characteristics of small tributaries, such as bed particle size, armoring, microtopography, streambanks, woody debris, and channel plan form, can be dramatically altered by suction dredging (Harvey 1986; Harvey et al. 1995). Where streambanks are excavated, the potential for damage is much greater. A study of effects of suction dredging on benthic macroinvertebrates showed local declines in abundances and species richness, but biota rapidly recolonized the disturbed sites after dredging stopped (Harvey 1986).

California's Surface Mining and Reclamation Act of 1975 and amendments should prevent future disasters (Pomby 1987), but remediation of past problems requires massive investments. Scores of small mines have been established under the terms of the antiquated 1872 Mining Act. In many cases, the properties are sources of sediment and toxic chemicals. Reform of portions of the Mining Act could finally alleviate some major land and water management problems associated with mining. Conversely, legislation has been introduced in California to weaken the state's regulations regarding reclamation of mined land.

Sand and gravel are the most economically important non-fuel minerals mined in California. The $560 million value of sand and gravel produced in California in 1992 far surpassed the combined total value of all metallic minerals mined in the state (McWilliams and Goldman 1994). More aggregate is used per capita in California than in any other state, and the State Department of Transportation is the largest single consumer (California State Lands Commission 1993). Excavation within stream channels will obviously have direct effects on the fluvial system (Sandecki 1989; Kondolf and Matthews 1993). Removal of part of the streambed alters the hydraulic characteristics of the channel and interrupts the natural transport of bedload through the stream. Where deeper channels form, they can lower the local water table and kill riparian vegetation as the former floodplain dries out. Loss of the vegetation in turn makes the banks more susceptible to erosion. Incision of the channel limits the opportunity for overbank flooding to deposit sediments on the floodplain. These combined effects can result in dramatic changes in the overall form and structure of the channel and dependent aquatic and riparian habitat (Collins and Dunne 1990; Kondolf and Matthews 1993). Human structures in the channel such as bridges, culverts, pipelines, and revetments may be damaged by the geomorphic changes. Gravel is also mined from streams by skimming a shallow layer off of gravel bars. Depending on the flow regime, distribution of particle sizes, and opportunities for establishment of riparian vegetation, a variety of complex channel and vegetation responses may occur (Kondolf and Matthews 1993).

RESTORATION OF RIPARIAN SYSTEMS

The various impacts to riparian areas outlined above have been recognized by some agencies, groups, and individuals for many years. This recognition of impaired streamside areas has led to a variety of attempts to restore some of the functions of some damaged riparian areas (National Research Council 1992). Much of this work has been called watershed restoration but has usually focused on riparian areas. Rehabilitation efforts began in the Sierra Nevada during the 1930s (e.g., Kraebel and Pillsbury 1934). Fish habitat improvement also began in the 1930s in the Kaweah River (Ehlers 1956) and has been a strong tradition in many parts of the Sierra Nevada (e.g., Gard 1972). Fisheries continue to be a primary justification for watershed restoration work. The California Wildlife Conservation Board has funded more than 70 watershed and aquatic habitat improvement projects in the Sierra Nevada in the past decade under the Fish and Wildlife Habitat Enhancement Act of 1984 (Schulenburg 1994). Restoration projects have been initiated throughout the Sierra Nevada for a host of other reasons as well (Pawley and Quinn 1995). Projects lumped together as riparian restoration include augmentation of flows impaired by diversion; re-establishment of willows, cottonwoods, and other riparian vegetation; road closures and obliteration; long-term rest from grazing; fenced exclosures and riparian pastures; channel realignment; excavation of pools and side channels; installation of rock or log sills and check dams; bank protection with plantings, geotextiles, woody debris, and/or rock; addition of boulders or logs for altering microhabitats; prescribed fire; seeding; etc. (Elmore and Beschta 1989; Lindquist and Bowie 1989; Hunter 1991; National Research Council 1992; Kondolf 1995a).

Many projects have been undertaken to treat symptoms and results of poor land-use practices instead of the causative factors. Although this approach has been long recognized as inefficient and often futile (VanHaveren and Jackson 1986; Elmore and Beschta 1989), some land managers are finally paying more attention to the causes of degradation and relying more on natural recovery after the disturbance is halted (Kauffman et al. 1995). A holistic watershed approach is usually needed to identify all the causes of aquatic and riparian degradation and investigate comprehensive solutions rather than just treating a few isolated sites (Hunter 1991).

In many impaired streams, the fundamental problem is providing adequate water to the channel and riparian area. Where excessive diversions have damaged riparian systems, carefully-planned release of additional water can allow rapid recovery of riparian vegetation (Stromberg and Patten 1989, 1992; Ridenhour et al. 1995). Some shifts back toward a natural hydrograph, such as seasonally fluctuating flows, occasional flushing flows, maintenance of adequate (and non-constant) low flows, or whatever is appropriate in a particular situation will be beneficial to the ecological health of the stream. Simply maintaining constant minimum flows is rarely sufficient. Stream habitat conditions and aquatic biota have developed in response to a highly variable natural flow regime. Restoring some aspects of that variability in managed streams should have ecological benefits in most cases. Adequate channel-maintenance flows that allow streams to behave in a dynamic manner usually meet the needs of riparian plants as well (Troendle 1993; Ridenhour et al. 1995). The critical factor is often raising riparian ground water levels into the root zone of streamside plants. Where that can be accomplished, the growth of suppressed vegetation is usually quite rapid (e.g., Odion et al. 1990; Kauffman et al. 1995).

Depression of the local water table because of channel incision is a common problem in heavily-grazed areas and is difficult to repair. Check dams of various construction have been used for decades in attempts to retain sediment and raise the bed of incised channels (Kraebel and Pillsbury 1934; Lindquist and Bowie 1989). However, such structures routinely wash out and create problems elsewhere in the channel (Beschta and Platts 1986; Swanson 1989). Re-establishment of vegetation within gullies and incised channels can eventually allow aggradation to raise the local water table, but may take decades (Elmore and Beschta 1989; Swanson 1989; Kondolf 1993). Removal of the disturbance that led to the incision is essential to allowing the natural resilience of riparian vegetation to restore damaged channels (VanHaveren and Jackson 1986; U.S. General Accounting Office 1988; Kauffman et al. 1995).

Perhaps the most widespread riparian restoration work in the Sierra Nevada has been attempted by the U. S. Forest Service. National Forest engineering and watershed staffs have been attempting to reduce the sediment yield produced by roads and stabilize gullies on a piecemeal basis where problems are identified in "watershed improvement needs inventories" (e.g., Myers 1992). Although techniques for retiring roads and limiting their impacts are continuing to improve (e.g., Furniss et al. 1991; Costick 1993; Harr and Nichols 1993), actual progress has been slow. For example, a few years ago, restoration projects were being implemented on about 40 acres per year by the Inyo National Forest (1988). Most of those projects involved structural headcut and gully control, with mixed results. Meadow restoration and gully stabilization on one just district of the Sierra National Forest has cost more than $100,000 in each of the past few years (Hagberg 1995). At the same time, funds for such work appear to be declining. Decreases in the timber receipts that partially financed road maintenance and obliteration and rehabilitation of other consequences of the timber program have not been compensated by rebudgeting.

Several riparian restoration campaigns with tighter geographic focus exist around the Sierra Nevada. The Lake Tahoe basin probably has the greatest array of watershed rehabilitation efforts in California and Nevada (e.g., Todd 1989). With sediment yields perhaps up to twenty times natural background rates (Goldman 1993), extraordinary efforts have been taken to slow the rate of cultural eutrophication of Lake Tahoe. The level of investment aimed at slowing deterioration of the aquatic system of the basin is unique in the West with more than $250 million dollars spent on acquisition of private property, stormwater management, slope stabilization, wetland restoration, and revegetation. Restoration of riparian areas as a means of improving water quality has been a primary emphasis of the combined programs, but work has been much slower than planned (Tahoe Regional Planning Agency 1988; Hill 1994). Another example of interagency and private cooperation on riparian rehabilitation is the pilot program of channel stabilization and vegetation re-establishment along tributaries to the North Fork Feather River (Lindquist and Bowie 1989; Wills and Sheehan 1992; Wills and Schramel 1994). Along the South Fork Kern River, the Nature Conservancy has been extensively planting cottonwoods and willows and studying site conditions in relation to survival and growth of the plants to assist future restoration efforts (Tiller and Tollefson 1992). In the Kings River basin, catastrophic failure of a large pipeline between two reservoirs devastated the canyon downstream and led to some novel revegetation efforts that appear to be highly successful (Chan 1993).

Recent legal developments regarding water management in the eastern Sierra Nevada have led to the restoration of several stream segments that have been dewatered for decades. In 1994, the State Water Resources Control Board amended the water rights licenses on streams tributary to Mono Lake to increase flows and require restoration of the channels and associated habitat (Los Angeles Department of Water and Power 1995). Restoration work completed between 1991 and 1995 focused on physical habitat improvements for fish and reestablishing riparian vegetation (e.g., Trihey and English 1991; Stine 1994). The next phase of restoration proposes to return large flows to the channels and allow natural stream dynamics to control the redevelopment of these long-dry channels (Ridenhour et al. 1995). Re-establishment of riparian vegetation would also be part of the continuing program, but considerable controversy surrounds the potential role of channel maintenance and flushing flows (Los Angeles Department of Water and Power 1995). Failure of a penstock and accidental release of water into the Owens Gorge in 1991 led to the rewatering of this section of the Owens River, which had been dry for about four decades. Saturation of the river bed took several months, but since then, riparian vegetation under active management has been thriving and the fishery is being restored.

Restoration of riparian areas and streams is still an emerging field with relatively little theory or experience to guide restoration work. Careful monitoring and evaluation of results, and especially failures, is critical to advancing our collective knowledge (Beschta and Platts 1986; Hunter 1991; National Research Council 1992; Kondolf 1995b; Kondolf and Micheli 1995). Elimination of the disturbance mechanisms is usually the most important step in riparian restoration. Economic and ecological analyses of the tradeoffs involved in removing or modifying disturbances and rehabilitating damaged areas would be instructive to managers. Evaluations should include determination of what activities are essential, desirable, convenient, or irrelevant to locate in riparian areas. In most cases, avoidance of riparian damage will be found to be far less expensive than eventual mitigation or restoration.

WETLANDS AND MEADOWS

Wetlands are of wide public concern because of the tremendous loss of wetlands throughout the United States and the relatively recent acknowledgment of their ecological importance (National

Research Council 1995). Drainage and destruction of wetlands continued to be an accepted and often encouraged practice across the country until the mid-1970s. A perception of wetlands as more valuable to nature and society in general than to individuals and landowners has led to conflicts over their use and development. The greatest fractional loss of wetland area of all states has occurred in California, where only 9 percent or about 183,700 ha (454,000 ac) remains of an estimated unimpaired wetland area of about 2 million ha (5 million ac) (National Research Council 1992). They are characterized by presence of the water table at or near the surface, which may result in a periodic cover of shallow water. A common characteristic of wetlands is oxygen-deficient conditions in the root zone during some substantial fraction of the year resulting from seasonal saturation. The low-oxygen conditions result in distinctive soils and plant associations.

The most widely valued function of wetlands is providing habitat for invertebrates, fish, birds, and other wildlife. Riparian wetlands have been considered the most important habitat type in California for mammals (Reynolds et al. 1993). Wetlands also provide several hydrologic and water quality functions or ecological services. Floodplain wetlands allow flood waters to spread over a large area, thereby providing additional conveyance capacity and detention storage that can decrease peak flows downstream. Some wetlands provide source areas for streams while others contribute to recharge of ground water, depending on local hydraulic gradients (Carter 1986). Sediment moving from adjacent uplands or borne in flood waters can be deposited in wetlands where flow velocities are reduced by vegetation and as water spreads out. Rapid vegetation growth stabilizes deposited sediments. Nutrients can also be retained or transformed by wetlands, leading to lower nutrient loads downstream (e.g., Johnston 1991, 1993). A variety of biochemical processes in wetlands can precipitate or volatilize assorted compounds and ions from detained water. Accumulation of organic peat can act as a long-term sink for many substances (Mitsch and Gosselink 1986). Wetlands that accumulate peat have a wide range of conditions from fens that are alkaline and supported by emerging groundwater to bogs that are acidic, maintained mostly by precipitation, and largely vegetated by sphangum moss. These different types of peatlands support diverse communities of invertebrates (Erman 1973, 1976; Erman and Erman 1975).

Wetlands in mountain areas have received much less attention than their counterparts in lowlands and coastal areas. Much of the research and applications work in mountain wetlands has been done in the Lake Tahoe basin in efforts to improve the quality of water entering the lake (e.g., Rhodes et al. 1985; Whitall and Champion 1989). Water in Squaw Creek is depleted of the excess nitrate load acquired from Squaw Valley developments as is passes through a meadow reach (Woyshner and Hecht 1989). Detailed investigations of wetlands in Mono County began in 1991 with a study of the Bridgeport Valley (Curry 1992). Mono County and the Lahontan Regional Water Quality Control Board continue to advance wetland mapping and planning with another field effort in 1995 by Curry and his associates. Initial results include discovery of a variety of unusual types of wetlands and their associated floras. One particular wetland in southern Mono County, Fish Slough, has attracted attention for at least 40 years because of its value as a refuge for rare fish and plants (Pister and Kerbavaz 1984; Odion et al. 1992; Mary DeDecker, botanist, Indepenedence, personal communication, 1995). Water diversions and groundwater development have reduced wetlands in much of the Owens Valley (e.g., Perkins et al. 1984; Groeneveld and Or 1994). Loss of springs, seeps, and remnant marshes around Owens Lake has reduced important habitat for resident and migratory bird populations (Kohen et al. 1994). Physical modification (i.e., draining, dredging, or filling) on a piecemeal basis has steadily contributed to the loss of wetland functions throughout the Sierra Nevada.

Montane meadows are a distinct type of riparian community comprised of relatively low vegetation usually dominated by sedges. Some sedges have extraordinarily long and dense root and rhizome networks that produce a sod inherently resistant to erosion. Other meadow plants include rushes, grasses, and broad-leaved forbs. Meadows of the Sierra Nevada range in size from a few square meters to several square kilometers (Allen 1987). Most meadows are found in glaciated basins of the subalpine zone, but scattered meadows occur down to about 1,200 m (4,000 ft) in the northern part of the range and 1,800 m (6,000 ft) in the southern Sierra Nevada (Whitney 1979). All meadow types are characterized by high ground water levels that limit suitability of the site for most plant species. In most cases, depth to the water table is the sole distinction between the presence of conifers or meadow vegetation (Wood 1975). Soil and drainage characteristics differentiate three prominent types of montane meadows. Poorly drained sites with organic, oxygen-deficient soils create wet meadows that often have standing water for most of the summer. Moist meadows occur on well-drained loam soils that are saturated only briefly during the final part of the snowmelt season. Dry meadows are found on rapidly drained coarse soils that are often dry and dormant by August and are typified by Tuolumne Meadows (Whitney 1979). So-called stringer meadows are narrow features along streams (Allen 1987).

Mountain meadows are particularly important habitats for birds in the Sierra Nevada. Besides the species that are limited to meadows, population densities of many species of birds that live within the forest are greatest along the forested edges of montane meadows (Graber 1996). During summer, montane meadows may be the single most important habitat in the Sierra Nevada for birds that breed elsewhere (Graber 1996).

Conversion of meadows to dry flat areas with an incised channel as a result of overgrazing is a widespread concern in the Sierra Nevada (e.g., DeBenedetti and Parsons 1979; Ratliff 1985; Hagberg 1995). The large meadows of the upper South Fork of the Kern River provide dramatic examples of deep channel incision (Odion et al. 1990). Meadow restoration and gully stabilization on the Kings River Ranger District of the Sierra National Forest alone has cost more than $100,000 in each of the past few years (Hagberg 1995). Until about 1900, meadows in the Sierra Nevada had been aggrading (building up) for the past 10,000 years (Wood 1975). Overgrazing in the late 1800s seems to have reversed that trend. One hypothesis suggests that as meadows were compacted and depleted of vegetation near the main channel in the meadow, streams began to cut a deeper channel progressively upstream. As streams got deeper, the local water table dropped below the root zone of the original meadow vegetation. The native grasses and other plants could no longer survive. Plants better adapted to low soil moisture conditions colonized the former meadows, but usually did not provide complete ground cover. Exposure of bare soil can accelerate erosion by sheetwash, rill formation, gullying, and wind erosion. The gullying itself moves large quantities of soil. At higher elevations, oversnow flow may be another important erosion process in disturbed meadows (Kattelmann 1989). Recent studies suggest that destruction of sod even over limited areas may be sufficient to initiate gully erosion in montane meadows (Wood 1975; Hagberg 1995). Progressive headward cutting tends to be episodic and associated with large flood events when plunge pool erosion (progressive upstream collapse as the head of the gully is undermined by excavation of a pool at its base) is the principal mechanism (Hagberg 1995).

In natural meadows, runoff tends to spread out through a network of small channels. Meadows act as wide floodplains, capable of detaining large volumes of water, thereby reducing peak flows downstream. By slowing and spreading streamflow, meadows allow sediment to be deposited where it adds mass and nutrients. Meadows have been heavily used for forage and agriculture since the Gold Rush, and many have been greatly altered over the past century and a half, still remaining in poor condition (Ratliff 1985). Following the intense overgrazing of the 19th century, meadows in the east side of the Feather River basin began to erode during the wet years of 1890-1920 (Clifton 1994). Some small meadows washed out and were lost completely during this period (LeBoa et al. 1994). The legacy of the loss of meadow sod and other bank-stabilizing vegetation is that instead of being sites of sediment deposition and storage, many meadows are now sources of sediment (LeBoa et al. 1994). Broken meadow sod, trampled streambanks, and widened streambeds are commonly documented in Sierra Nevada meadows under excessive grazing pressure (e.g., Allen 1989; Hagberg 1995; Range Watch 1995). An example is found in Nichols Meadow on the Sierra National Forest where gully dimensions have reached 6 m (20 ft) in depth, 18-27 m (60-90 ft) in width, and 105 m (350 ft) in length (Myers 1993). Given the historical pattern of abuse, severely degraded conditions could be much more widespread if not for the resilience of meadows where the sod remains intact (Hagberg 1995). Meadows are more responsive to management and rest than any other type of range ecosystem (Menke et al. 1996). Removal of commercial livestock and decreasing use of pack stock in Sequoia, Kings Canyon and Yosemite National Parks have led to significant recovery of mountain meadows in the parks (DeBenedetti and Parsons 1979; Holmes 1979). Poor trail location and off-trail hiking continue to cause local problems in some high-elevation meadows (Lemons 1979). An inventory of wet meadows by the Inyo National Forest (1988) indicated that 90% were damaged or threatened with damage by accelerated erosion.

RIPARIAN CONDITIONS FROM AERIAL PHOTOGRAPHY AND VIDEOGRAPHY

Examination of aerial photography of more than 9,500 km (5,900 mi) of streams throughout the Sierra Nevada showed that riparian corridors are depleted of vegetation in thousands of individual locations. Although the total distance of these gaps in riparian continuity is a limited fraction of the entire stream length of the Sierra Nevada, this fragmentation was common to almost all watersheds examined. The complete removal of riparian vegetation documented in this analysis represents only the worst case of loss of riparian vegetation. Areas of partial impairment of riparian vegetation can be assumed to be much more extensive than these sites of total loss.

Riparian vegetation removal was especially common between about 100 and 1,000 m (330 and 3,300 ft) elevation. Even on the smallest scale photographs (1:24,000), streams that traversed pastures had dramatically less riparian vegetation than on adjacent lands that were fenced and not grazed. Local water development and diversion on to pastures appeared to dewater downstream reaches enough to impair growth of riparian plants in combination with other grazing impacts. Roads and residential development were the next most-often observed causes of riparian impairment. Impacts of roads were localized but often had secondary effects contributing to a broader zone of impact than the road itself. Streams in urban areas, such as Jackson and Sonora, were obviously channelized and devoid of vegetation in spots. Riparian vegetation was commonly removed from individual lots as well.

Areas of impact in the forest zone identified from the aerial photograph analysis were localized and were usually associated with roads. Obvious exceptions to these local impacts were the extensive development of the broader valleys and widespread overgrazing (which was not discernible from the aerial photograph analysis). The larger and more obvious impacts of mining and logging in the riparian area were found on private land. The intensity and extent of impacts tended to decrease with increasing elevation. Overall, there were fewer major gaps in riparian canopy on public lands than on private lands. Wilderness areas had the least visible impacts. Again, fine-scale impacts and changes, as in meadows and small tributaries, could not be discerned with this approach.

The degree of impact varied greatly between watersheds. A few watersheds had no observed impacts at all while others were substantially affected. The smaller watersheds tended to have higher fractions affected, simply because a single impact could occupy a greater proportion of the total stream length.

The video tapes of the main (e.g., Yuba) river channels and their primary tributaries provided qualitative impressions of the extent, intensity, and types of impacts. In general, there were few obvious impacts along the main rivers except where roads crossed or paralleled the river. In those cases, riparian vegetation was largely destroyed.

One of the few other pieces of regional information about riparian conditions was an aggregate of riparian canopy density measurements from 13 unlogged first and second order streams in the northern Sierra Nevada (Erman et al. 1977). This survey in 1975 found that angular canopy density over streams that had not been logged ranged from 50 to 100 percent with a mean of 75 percent.

INTERPRETATIONS

<u>Historical Development and Current Status</u>

As is the case with hydrology, the most significant impacts to the riparian systems of the Sierra Nevada started with the Gold Rush. The effects of riverbed and hydraulic mining were devastating to the rivers of the western slope. Regrowth of riparian vegetation has provided the appearance of natural rivers, but the aquatic and riparian systems may remain quite simplified compared to the pre-1848 conditions. However, we will never know if recovery proceeded along a different trajectory than if riparian areas of the west slope had not been shredded in pursuit of gold among the stream gravels. Along streams not laden with gold, domestic livestock may have transformed riparian areas into their present form. Because grazing seems to have occurred virtually everywhere in the Sierra Nevada there was accessible forage, we do not know what riparian communities would look like had they never been grazed. Areas long devoid of substantial riparian vegetation, such as in the eastern part of the Feather River basin, are accepted by many people as the normal, natural condition.

This assessment focused on obvious, dramatic changes in riparian areas. We may assume that there are a variety of more subtle changes in riparian areas that require field inspection at the least, and possibly rigorous scientific investigation to discern. Such studies could not even be contemplated in the context of a range-wide evaluation. Instead, we chose to search for large-scale impacts that are easily recognized and have caused dramatic changes in the riparian areas. Throughout the Sierra Nevada, riparian areas have been altered to varying degrees by human activities. The basic functions (providing shade, organic matter, root stability, habitat, etc.) of riparian areas appear to have been maintained at least in part where vegetation has not been obliterated. However, fragmentation was found to be common in every river basin during our aerial photography analyses. Although we lack any quantitative measures of its extent, meadow degradation is another widespread problem that we have observed and that is frequently mentioned by resource managers. Severe alterations have occurred in meadows that have become incised and have suffered a consequent drop in the water table. In those cases, the original meadow vegetation has been replaced by xeric species such as sagebrush.

Water development has impacted a considerable amount of the riparian areas of the mountain range. About 1,000 km of riparian areas are inundated under artificial reservoirs. Many of these reservoirs destroyed some of the best riparian areas in the Sierra Nevada. Almost every water project results in a break in the continuity of the riparian vegetation. The overall effects of this fragmentation are unknown. Regulation and diversion of streamflow have markedly altered riparian vegetation over thousands of kilometers. Where streams have been totally or seasonally dewatered, such as lower Rush and Parker Creeks in the Mono Basin until a few years ago, riparian vegetation died out. In streams with diminished volumes, the riparian area becomes thinner as groundwater recharge from the stream is not as great as before diversion. In streams below dams that reduce flood peaks, the riparian vegetation usually encroaches upon the channel.

Roads and urban development have converted riparian areas to impermeable surfaces and channelized streams. Concrete replaced soil, grasses, and trees. Although these impacts are particularly severe, they do not cover vast areas. Riparian corridors along some major rivers are impacted by highways for long distances. Stream crossings by roads adversely affect riparian areas at thousands of places and are the main current impact associated with timber harvesting. Although forest practices of the past often removed nearly all trees in some riparian areas and exposed the stream, logging in streamside areas is less common and is subject to a variety of controls. The effectiveness of such controls is often debated (Moyle et al. 1996). Salvage logging can still occur within riparian areas and poses a threat to the integrity of riparian forests.

Trends in the condition of riparian systems in the Sierra Nevada are mixed. Recovery continues from the wholesale destruction of the gold mining era, short-term construction projects, and streamside timber harvests. Although various geomorphic and biological adjustments continue in response to permanent structures (e.g., dams, canals, roads, and houses) in the riparian area, such changes are not necessarily recovery toward a former condition. Persistent or recurring disturbance, such as grazing and off-road vehicle traffic usually impedes or prevents recovery from perhaps more intensive disturbances of the past. Few major mining and water projects are expected in the next couple of decades. Compared to the road-building boom of the 1960s and 1970s, relatively little additional road construction is anticipated with tightly constrained budgets. In the past few years, forest practices have improved with respect to reducing negative impacts in riparian areas. Grazing practices on public lands are finally under environmental review, as required by the 1969 National Environmental Policy Act. This process could eventually result in improved range management and long-term rest for unsuitable lands. If road building is indeed restricted, if timber harvests are precluded from streamside management areas, if grazing pressures on riparian areas are reduced, and if all existing laws and regulations that are intended to minimize resource damage are implemented and enforced, then there could be a trend of substantial recovery in riparian corridors of the Sierra Nevada. However, urban development may accelerate rapidly in the foothills (Duane 1996) and could present the greatest risk of large-scale destruction of riparian areas.

Some Implications

Growing public awareness of riparian areas should help slow and perhaps reverse degradation. For example, the NEPA process for review of grazing practices on public lands allows a major opportunity for public involvement. The vast majority of identified impacts to riparian areas other than grazing were associated with roads. Although these impaired areas may expand somewhat, new foci of riparian damage should be limited in the absence of new roads. Where access is not available, major impacts aside from grazing should be few. Some of the adverse effects of the existing road network can be reduced by relocation and reconstruction of roads and stream crossings that are known to be damaging to the stream environment. Hundreds of such sites have already identified by National Forest staffs in their “watershed improvement needs inventories”. However, new sources of funding must be identified for road maintenance, realignment, and obliteration. So far, the costs of extensive environmental improvements in the road system have not been included in budgets of the entire National Forest system or individual timber sales. Many county roads and state and federal highways located in riparian areas could also be re-engineered to reduce their impacts to riparian resources. Depending on the value that society puts on riparian areas, there is no shortage of individual sites in need of rehabilitation or restoration. Prioritization of such needs to maximize the effectiveness of limited funding requires agreement between riparian ecologists, engineers, and the public. Declines in resource and recreation management and road maintenance budgets imply fewer funds available to maintain facilities, mitigate damage, and control use.

Direct effects of urban and exurban development and associated gravel mining are likely sources of additional riparian degradation. The extent and severity of these potential impacts is somewhat controllable through rigorous enforcement of existing laws and regulations. However, citizens must insist upon such enforcement. Improved planning and zoning and acquisition of conservation easements could reduce the pressure for development of riparian lands.

Catastrophic fire involving unnaturally large fuel loads represents a risk to some riparian areas even when burned areas are confined to upslope areas. Any fuels management program (Weatherspoon and Skinner 1996) for upland forest and chaparral will have strong implications for the riparian area as well. Reductions in upland stand density and ground cover could increase runoff and sediment delivery to streams unless carefully designed. As part of the investment in fuels management programs, a team of aquatic ecologists, soil scientists, and hydrologists must be actively involved to minimize damage to the riparian area. Although the artificial build-up of fuels throughout the Sierra Nevada seems to have created the potential for severe fires (Weatherspoon and Skinner 1996), society’s response must not ignore the potential consequences of any fuels treatment program (Beschta et al. 1995).

There is tremendous potential for rehabilitation of degraded riparian areas. Some riparian vegetation tends to become reestablished rapidly once a chronic disturbance is removed, provided adequate water is available. Often, the chronic disturbance simply is the lack of water below a diversion. Even where streams have been completely dewatered for decades, resumption of streamflow rapidly returns life to the riparian area. Rewatering of long-diverted streams in the Mono Basin and the Owens Gorge below Crowley Lake have had dramatic results in just a few years. Geomorphic and wildlife recovery will require decades, but the re-establishment of a basic vegetation canopy is a fundamental step to ecosystem recovery.

Time-Significance

Halting the decline of riparian-dependent endangered species (e.g., Kern Canyon Slender Salamander, Yosemite Toad, and Willow Flycatcher) is the most urgent priority of riparian-area management. Protection and enhancement of critical riparian habitat for those species at risk must happen as soon as possible to reduce the possibility of their extinction. For example, the refuges for foothill yellow-legged frogs seem to be small perennial streams with well-developed riparian canopies and intact understory vegetation (Jennings 1996). Besides the threat to particular species, which may have some regional implications, the riparian system at the scale of the entire mountain range does not seem to be breaking down as in the case of the Central Valley. Nevertheless, there are thousands of local problems needing attention with various degrees of urgency. These localized issues, which may have far-reaching cumulative effects, require site-specific solutions. These problems must be addressed through a watershed by watershed approach.

The relative urgency of particular problems depends on the resources at risk and whether the impact can be discontinued or reduced. In general, riparian vegetation tends to begin to re-establish itself within a few years to a decade if given the opportunity and appropriate hydrologic conditions (e.g., Nelson et al. 1994). A prime problem with respect to grazing is that areas degraded in past decades have never had a chance to recover, even though grazing intensity may have greatly diminished. Such areas have to be rested for at least a few years if recovery is to begin. The sooner that rest begins, the sooner the riparian areas will heal. As mentioned by Kattelmann (1996a), reducing streambank erosion in the North Fork Feather River is clearly an important goal. As long as serious action is delayed, productive alluvial land will continue to be lost, streams will continue to carry high sediment loads, and downstream reservoirs will continue to fill with sediment at unnaturally high rates. Allowing riparian vegetation to become re-established would significantly slow the rate of streambank erosion.

Gaps in Knowledge

The aerial photography analysis only examined the most severe impacts where riparian cover has been completely lost. We know little about the real health of riparian areas, even where vegetative cover seems to be continuous. Our knowledge is especially limited in the foothills where impacts and threats appear to be extensive. A thorough assessment is needed that can progress beyond the anecdotes and inferences presented here.

Although there are dozens of examples of seriously degraded meadows with deeply incised channels, we have not inventoried the extent of such damage. Examples of severe degradation on the Kern Plateau and in the North Fork Feather River basin stand out, but we do not know whether situations of similar severity are common. Extensive field investigations are necessary to advance our knowledge. For example, a widespread field reconnaissance could sample a large number of stream reaches in areas of concern. A procedure proposed by Terry Hicks of the Inyo National Forest (personal communication 1995) would establish a functional ranking for riparian corridors based on observations of surface erosion, channel downcutting, bank stability, potential vegetation, and habitat quality. This approach would also identify factors affecting function, human uses, sensitive areas, potential for improvement, means for achieving potential and improving functions, and mitigation possibilities. More comprehensive surveys of physical habitat, fish populations, and aquatic invertebrates would help identify problem areas and critical ecological processes (e.g., Rinne 1990; Herbst and Knapp 1995).

Ecosystem Sustainability and Management

Riparian vegetation seems to recover relatively fast after damage because of favorable conditions for plant growth along streams and its rapid recolonization and growth in response to natural flooding (Nelson et al. 1994). A critical condition for recovery is that the disruption of natural processes must be halted. Persistent impacts such as seasonal grazing never provide the opportunity for recovery to really get started. Recovery of other ecosystem properties and processes following an impact requires more time and possibly some management to accelerate the schedule if desired. In particular, channel morphology and aquatic organisms may require several decades to recover following vegetative re-establishment.

Riparian communities that are reestablished after cessation of some human-induced disturbances may be quite simplified in composition and structure compared to community development under fully natural conditions. Unfortunately, we lack many undisturbed reference areas for comparison, and the high degree of inherent variability between sites can confound any understanding of natural recovery trajectories. In light of limited understanding of natural processes and conditions and specific habitat relationships, setting broad goals may be the best strategy for now. Maintaining the obvious elements of sound riparian areas, such as natural streamflow regimes and unaltered soils, should allow other processes and interactions to recover from impacts and reestablish fully functioning communities. If basic ecological conditions can be maintained or rehabilitated, then wildlife should respond in a positive manner (e.g., Carlson et al. 1991).

Complex ownership patterns and organizational jurisdictions in the riparian area will complicate efforts to perform integrated watershed-scale management and planning (Nelson et al. 1994). Institutional evolution does not seem to keep pace with shifting notions of ecosystem management and conservation biology. Even the intuitively powerful concept of adaptive management is frustrated by our administrative inability to initiate and maintain adequate monitoring programs. One initial step path toward conservation of riparian resources is simply for society to recognize the ecological importance of riparian corridors. Public education about natural resources has had some profound effects in changing social values and, despite current political setbacks, will hopefully continue to promote more effective policies and management.

Remaining Questions

One fundamental question regarding the status of riparian areas in the Sierra Nevada is the degree to which they have been altered in their composition and structure. Our analysis of aerial photography merely dealt with extent of severely damaged riparian areas. We may assume that even where riparian vegetation appears to be healthy, it may be quite different from that existing 150 years ago. We do not know how different it might be in various parts of the range or the ecological importance of those differences to various species and processes. The absence of reference conditions from areas unmodified over the past 150 years is a difficult problem for ecosystem management in general (Kaufmann et al. 1994).

Another set of important unknowns are the ecological consequences of fragmentation of the riparian corridors. We have observed a lot of longitudinal discontinuities in riparian areas, but we do not know how those breaks affect the ecosystem beyond generalities from studies in other regions.

As efforts to rehabilitate damaged riparian areas (hopefully) become more common, we need better measures of ecological success. Although every restoration effort is something of an uncontrolled experiment, adequate pre- and post- project monitoring is usually lacking (Kondolf 1995b). Therefore, the collective learning process is stifled, and there is little additional information available for designing the next project.

An ambitious research initiative has recently been proposed as a basis for enlightened management of water resources (Naiman et al. 1995). The entire package as proposed would potentially provide a greatly improved foundation for management of land and water resources. Among the dozens of lines of suggested research are several that would improve conservation of riparian resources: hydrologic processes in the riparian area, especially ground water - surface water interactions; nutrient cycling; mechanisms of filtering functions and water quality protection in wetlands; sediment - vegetation interactions; and sensitivity to land use change (Naiman et al. 1995). Several important research questions relating to riparian areas have also been identified by the Sierra Nevada Research Planning Team (Parrish and Erman 1994).

CONCLUSIONS

The health of Sierra Nevada watersheds depends on the ecological integrity of riparian areas. These lands along water courses influence the entry of water, energy, sediment, nutrients, and pollutants into streams. Fully-functioning riparian areas are critical to aquatic biodiversity and good water quality.

Riparian areas in the Sierra Nevada have been degraded by a long history of placer mining, dam construction, streamflow regulation, overgrazing, logging, road construction, urban development, recreation, and other impacts. Although most of these effects are initially local in extent, riparian systems suffer from combinations of multiple impacts over time and influences from upstream. Chronic impacts, such as roads and water diversions, do not allow opportunities for recovery, while riparian communities usually become re-established after short-term disturbances such as fire or timber harvest. Streamside areas have been sufficiently impaired to place several riparian-dependent species in danger of extinction. Many of the best riparian areas that once existed along the wide floodplains of the relatively few broad valleys in the Sierra Nevada has been lost to reservoirs and conversion to pastures, farms, highways, and towns.

Despite the variety of impacts, some canopy cover is still in place or has partially recovered in most riparian areas of the Sierra Nevada. However, the continuity of this vegetation has been lost, and the canopy structure has been simplified in a large, though unquantified, fraction of riparian corridors. Although fragmented and simplified, current riparian vegetation still appears to provide some level of shade, stability, and organic matter to streams and habitat for avian and terrestrial wildlife along most streams. Compared to pre-Gold-Rush conditions, these and other functions have been impaired to varying degrees on a site-specific basis. Widespread changes in riparian vegetation are believed to have occurred as a result of overgrazing, but their nature and extent have not been quantified. Persistent grazing often prevents the re-establishment of riparian plants that could retard erosion of devegetated streambanks. If meadows and other riparian areas could be rested from grazing and restored to their full productivity, livestock could be reintroduced to far more resilient and vigorous pastures than exist under current conditions. Although there has been considerable vegetative recovery in some areas of past river mining and overgrazing, geomorphic and hydrologic recovery has proceeded more slowly, especially in former wetlands. There is great potential for active restoration of riparian elements and processes to augment and accelerate natural recovery processes.

Water development has damaged riparian systems in all river basins of the Sierra Nevada. More than 1,000 km (600 mi) of riparian corridors have been submerged under reservoirs throughout the range. These reservoirs and other large gaps break the continuity of the riparian corridors and impair wildlife migration. Below dams, the usual response of riparian vegetation has been to encroach upon the formerly active channel because high flows that once scoured the channel have been almost eliminated. In cases where little or no water has been left in the natural channel below a diversion, the riparian area has narrowed and even disappeared in totally dewatered channels. Wetlands have been drained, filled or submerged throughout the Sierra Nevada.

The lower foothills seem to have suffered widespread impacts. At elevations below about 1,000 m (3,300 ft), riparian vegetation continues to be a casualty of overgrazing and both large and small water development projects. With the loss of the original riparian habitat in the Central Valley, riparian areas in the lower foothills may be critical to several riparian-dependent species with low populations (Graber 1996). Major losses of riparian areas have occurred in the Kern and Feather River basins, particularly in their broad alluvial valleys. Meadows have been greatly altered throughout the Sierra Nevada, with many of them converted to dry terraces above a deeply incised stream.

With minimal research information available about baseline or current conditions, we focused on the most fundamental issue: whether or not riparian canopy still exists. A survey of riparian vegetation cover from aerial photographs showed vegetation has been removed at thousands of locations that seriously fragment the continuity of riparian vegetation. The majority of these sites where riparian vegetation has been converted to other land uses are associated with roads. Vehicular access is generally necessary to generate impacts besides grazing. Roads and urban development have converted riparian areas to impermeable surfaces and channelized streams. Continued development will undoubtedly damage additional areas. Riparian corridors along several major rivers are impacted by major highways for long distances. Stream crossings by roads impact riparian areas at thousands of places and are currently the main impact associated with timber harvesting. Although forest practices of the past often removed riparian trees and exposed the stream, logging in riparian areas is now somewhat restricted compared to past abuses. Nevertheless, examples of riparian harvesting were still evident on recent aerial photographs.

The future health of riparian areas in the Sierra Nevada will depend on interactions between recovery from past degradation by natural processes and restoration efforts, reduction of ongoing chronic disturbances, and new impacts. Some fuels management proposals could create considerable disturbance and must be weighed against the risk of fire damage to watersheds and riparian areas. An accelerated salvage logging program with little oversight could pose a serious threat. Other potential risks to riparian areas include catastrophic fire where fuel loads are unnaturally high, persistent grazing of riparian vegetation, accelerated residential development, and new water projects.

Riparian areas are likely to remain a critical environmental issue for the foreseeable future. Because of their broad ecological values, riparian areas should be a high priority in any type of watershed analysis, project planning, land management or construction activity, and restoration work. Riparian areas are influenced by almost any environmental change because of their position in the landscape, their value to most plants and animals, and their regulation of interactions between land and water. Conservation of riparian areas is central to sound watershed management.

MANAGEMENT IMPLICATIONS

Improved management of riparian areas is needed to halt and ultimately reverse the degradation of streams and areas that influence them. Simply pulling back from streams and out of riparian areas should be a guiding philosophy to allow natural recovery processes to repair damaged functions of streamside areas. Although location of land disturbing activities in riparian areas has often been more convenient or slightly more economical than location upslope, close proximity to water is rarely necessary for many of our activities that degrade riparian areas. Any further modification of riparian areas should be done with careful deliberation and full understanding of the potential consequences. Much of the damage to streamside areas of the Sierra Nevada has been done in ignorance and without any evaluation of alternative locations.

Conservation of aquatic and riparian resources will require better protection and management of streamside lands. A strategy for identifying the areas of influence along streams is described in Appendix 3 by Erman and others. Ideally, the management alternatives for such lands should be evaluated on a local basis (Sullivan 1994). Several protective strategies for riparian areas have recently been proposed (e.g., Association of Forest Service Employees for Environmental Ethics 1995; Doppelt et al. 1993; Pacific Rivers Council 1995; Palmer 1994; Sedell et al. 1994). The applicability of such concepts to streams of the Sierra Nevada need to be evaluated in detail. On federal lands, establishment of a riparian management team with adequate funding on each national forest and BLM district should be considered. On private lands, financial incentives and technical assistance from the state along with better coordination and enforcement of existing laws and regulations could improve riparian conditions and functions. The Resources Agency should designate a lead agency for riparian zone management and coordination of watershed management activities. Instream flow conditions need to be evaluated for the riparian community as well as minimum fish survival and should be considered in a cumulative context for entire watersheds. Relicensing of hydroelectric projects provides an opportunity for improving flow conditions below many dams and diversions.

Where riparian functions are impaired, rehabilitation options need to be explored. Removal of the source of disturbance is usually the critical management decision. Once the disturbance is halted, natural recovery processes are often sufficient to largely restore the site. Cessation of disturbance is particularly important with respect to overgrazing. Long-term rest of riparian areas should usually result in a much more resilient and productive pasture that could support carefully managed grazing in the future. However, these areas must be allowed to recover first. Potential benefits of relocation of incompatible land-uses, such as roads, campgrounds, residential and commercial development, should be weighed against the costs of rehabilitating the site. Such costs will generally be quite high, as will public purchase of land title and conservation easements. A potential mechanism for raising revenue for a watershed management and restoration trust fund would be a tax on water diversions. The most obvious human beneficiaries of watershed and stream improvement are downstream water users. Reinvesting a small proportion of the economic value of water in the watersheds that produce it seems worthy of public support.

A primary goal of future riparian management should be to reduce the direct and indirect impacts of roads on riparian and aquatic systems. A thorough evaluation of road effects should be conducted on a watershed by watershed basis. In most cases, better road maintenance and minor modifications to culverts, ditches, and drains along with revegetation of cut and fill slopes would greatly reduce accelerated sediment delivery associated with roads. Elsewhere, seasonal and long-term road closures will be appropriate. A piecemeal approach after identification of problems may be more politically acceptable than comprehensive closure programs (e.g., Inyo National Forests 1993). Where particularly serious impacts exist, road obliteration and relocation (if necessary) should be undertaken. All road maintenance, re-engineering, and obliteration activities will be very expensive. Declines in timber receipts on national forests are already limiting road maintenance budgets. New sources of funds for rehabilitating roads must be identified. In addition to a possible tax on water diversion for general watershed improvement needs, a gas tax should be considered as a connected funding source to reduce the negative impacts of roads.

ACKNOWLEDGMENTS

Several members of the SNEP team took an unusual interest in this particular chapter and helped improve the product. The assistance of Peter Moyle, Don Erman, Nancy Erman, and Dave Graber is particularly appreciated. Matt Kondolf was added to the team late in the game to write a more acceptable riparian report for volume 2 after an early version of this document was found wanting in the review process. Discussions with Matt were very helpful in upgrading this report. Apologies go to the anonymous reviewers and key contacts who were burdened with a very premature draft, and no thanks go to whoever scheduled it for release at that time. Detailed comments by Lynn Decker and Diana Jacobs on later drafts were most helpful even though we disagreed on a few issues. Discussions with most of the SNEP team on matters relating to riparian areas over the past two years were very useful in refining some of the ideas presented here. In particular, we wish to acknowledge Michael Barbour, Larry Costick, Frank Davis, Mike Diggles, Tim Duane, Hap Dunning, Debbie Elliott-Fisk, Jerry Franklin, Bill Kinney, Roland Knapp, Jonathan Kusel, Doug Leisz, Dennis Machida, Bruce McGurk, John Menke, Kurt Menning, Connie Millar, Rowan Rowntree, Jim Shevock, Bill Stewart, and Susan Ustin.

We appreciate the help of Sarah Marvin and the staff of the Water Resources Center Archives at U.C. Berkeley in obtaining and analyzing the National Park Service video tapes of selected rivers. The staff of the Geometronics Division of the Engineering Department of the Region 5 office of the U.S. Forest Service in San Francisco were extraordinarily helpful on an almost daily basis for several months in 1995. Without their assistance, guidance, and access to photographs and equipment, the aerial photography analysis would not have been possible. Critical aerial photographs and assistance were also provided by the Toiyabe National Forest; offices of the Bureau of Land Management in Folsom, Bakersfield, and Bishop; and the California Department of Forestry and Fire Protection. The California Department of Fish and Game in Bishop provided a wealth of information and documents.

Other folks who provided data, information, ideas, and reviews included Jane Baxter, Clay Brandow, Caroline Christian, Christine Christiansen, Bob Curry, Gayle Dana, Dan Dawson, Mary DeDecker, Brett Emery, Jim Frazier, Gary Freeman, Anna Halford, Terry Hicks, Terry Kaplan-Henry, Brett Matzke, Luci McKee, Sally Miller, Mike Prather, Ken Roby, Terry Russi, and Darrell Wong.

The assistance of Steve Beckwitt, Mary Cunha, Lian Duan, Sue Enos, Erin Fleming, John Gabriel, Karen Gabriel, Russ Jones, Jen Lucas, Mike Oliver, Paul Randall, Cindy Seaman, and Robert Zomer with various analytical, graphical, communications, and logistical matters is gratefully acknowledged. Mignon Moskowitz is warmly thanked for her invaluable help with the mass (and mess) of references.

REFERENCES

Abell, D. L. ed. 1989. Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Adams, M. B. 1993. Movement of sediment and nutrients through riparian areas. In Proceedings technical workshop on sediments, 41-44. Washington, DC: Terrene Institute.

Adams, P. W. , R. L. Beschta, and H. A. Froehlich. 1988. Mountain logging near streams: Opportunities and challenges. In Proceedings, international mountain logging and Pacific Northwest skyline symposium, 153-62. Corvallis, OR: Oregon State University, College of Forestry.

Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press.

Airola, D. A. 1986. Brown-headed cowbird parasitism and habitat disturbance in the Sierra Nevada. Journal of Wildlife Management 50(4): 571-75.

Allen, B. H. 1987. Forest and meadow ecosystems in California. Rangelands 9(3): 125-28.

_______. 1989. Ten years of change in Sierran stringer meadows: An evaluation of range condition models. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 102-108. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Amaranthus, M., H. Jubas, and D. Arthur. 1988. Stream shading, summer streamflow and maximum water temperature following intense wildfire in headwater streams. In Proceedings of the symposium on fire and watershed management, edited by N. H. Berg, 75-78. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Anderson, E. W. 1987. Riparian area definition--a viewpoint. Rangelands 9: 70.

Anderson, M. K., and M. J. Moratto. 1996. Native American land-use practices and ecological impacts. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 9. Davis: University of California, Centers for Water and Wildland Resources.

Armour, C. L., D. A. Duff, and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. Fisheries 16(1): 7-11.

Association of Forest Service Employees for Environmental Ethics. 1995. The AFSEEE-sponsored ecosystem management alternative for the Interior Columbia River Basin. Eugene, OR: Association of Forest Service Employees for Environmental Ethics

Aubury, L. E. 1910. Gold dredging in California. Bulletin 57. San Francisco: California State Mining Bureau.

Averill, C. V. 1946. Placer mining for gold in California. Bulletin 135. San Francisco: California Division of Mines.

Bakker, E. S. 1972. An island called California. Berkeley: University of California Press.

Baltz, D. M., and P. B. Moyle. 1984. The influence of riparian vegetation on stream fish communities of California. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 183-87. Berkeley: University of California Press.

Batson, F. T., P. E. Cuplin, and W. A. Crisco. 1987. Riparian area management: The use of aerial photography to inventory and monitor riparian areas. Technical Reference 1732-2. Denver: U.S. Bureau of Land Management.

Beesley, D. 1996. Reconstructing the Sierra Nevada landscape: An environmental history, 1820-1960. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 1. Davis: University of California, Centers for Water and Wildland Resources.

Behnke, R. J., and R. F. Raleigh. 1979. Grazing and the riparian zone: Impact and management perspectives. General Technical Report WO-12. Washington, DC: U.S. Forest Service.

Behnke, R. J., and M. Zarn. 1976. Biology and management of threatened and endangered western trouts. General Technical Report RM-28. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Benedict, N. B. 1982. Mountain meadows: Stability and change. Madrono 29(3): 148-53.

_______. 1984. Classification and dynamics of subalpine meadow ecosystems in the southern Sierra Nevada. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 92-95. Berkeley: University of California Press.

Beschta, R. L. 1984. TEMP84: A computer model for predicting stream temperatures resulting from the management of streamside vegetation. Report WSDG-AD-00009. Fort Collins, CO: U.S. Forest Service, Watershed Systems Development Group.

_______. 1990. Effects of fire on water quantity and quality. In Natural and prescribed fire in Pacific Northwest forests, edited by J. D. Walsted, S. R. Radosevich, and D. V. Sandberg, 219-32. Corvallis: Oregon State University Press.

Beschta, R. L., and W. S. Platts. 1986. Morphological features of small streams: Significance and function. Water Resources Bulletin 22(3): 369-79.

Beschta, R. L., and R. L. Taylor. 1988. Stream temperature increases and land use in a forested Oregon watershed. Water Resources Bulletin 24(1): 19-24.

Beschta, R. L. et. al. 1995. Wildfire and salvage logging: Recommendations for ecologically sound post-fire salvage logging and other post-fire treatment on federal lands in the west. Corvallis: Oregon State University.

Bilby, R. E. 1988. Interactions between aquatic and terrestrial systems. Journal of Forestry 82: 609-13.

Bilby, R. E., and J. W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society 118: 368-78.

Biswell, H. H. 1989. Prescribed burning in California wildlands vegetation management. Berkeley: University of California Press.

Blackburn, W. H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and response. In Developing strategies for rangeland management, 927-83. Boulder: Westview Press / National Research Council.

Booth, D. B. 1990. Stream-channel incision following drainage-basin urbanization. Water Resources Bulletin 26: 407-17.

Booth, D. B., and L. E. Reinelt. 1993. Consequences of urbanization on aquatic systems- measured effects, degradation thresholds, and corrective strategies. In Watershed '93: A national conference on watershed management, 545-50. Report EPA 840-R-94-002. Washington, DC: U.S. Environmental Protection Agency.

Borcalli and Associates. 1993. Draft county water resources development and management plan. Placerville, CA: El Dorado County Water Agency.

Brinson, M. M., B. L. Swift, R. C. Plantico, and J. S. Barclay. 1981. Riparian ecosystems: Their ecology and status. FWS/OBS-81/17. Washington, DC: U.S. Fish and Wildlife Service.

Brode, J. M., and R. B. Bury. 1984. The importance of riparian systems to amphibians and reptiles. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 30-36. Berkeley: University of California Press.

Brothers, T. S. 1984. Historical vegetation change in the Owens River riparian woodland. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 75-84. Berkeley: University of California Press.

Brown, G. W. 1969. Predicting temperatures on small streams. Water Resources Research 5: 68-75.

_______. 1970. Predicting the effect of clear-cutting on stream temperatures. Journal of Soil and Water Conservation 25: 11-13.

_______. 1980. Forestry and water quality. Corvallis: OSU Book Stores.

Brown, G. W. and J. T. Krygier. 1970. Effects of clear-cutting on stream temperature. Water Resources Research 6(4): 1133-40.

Browne, J. R. 1868. Mineral resources of the West. cited by Coleman 1952.

Bull, W. B. and K. M. Scott. 1974. Impact of gravel mining from urban streambeds in the southwestern United States. Geology 2: 171-78.

Burcham, L. T. 1970. Ecological significance of alien plants in California grasslands. Proceedings of the Association of California Geographers 11: 36-39.

California Department of Forestry and Fire Protection. 1994. California forest practice rules. Title 14, California code of regulations. Sacramento: California Department of Forestry and Fire Protection.

_______. 1996. Calwater database online. Sacramento: California Environmental Resource Evaluation System. Available from http://ceres.ca.gov/watershed/

California Rivers Assessment. 1995. Rivers assessment progress report. Davis: University of California.

California State Lands Commission. 1993. California's rivers: A public trust report. Sacramento: California State Lands Commission.

Campbell, C. J. 1970. Ecological implications of riparian vegetation management. Journal of Soil and Water Conservation 25: 49-52.

Carlson, A. et. al. 1991. Review of literature addressing wildlife and fish habitat relationships in riparian and stream habitats. Nevada City, CA: U.S. Forest Service, Tahoe National Forest.

Carlson, A., N. Berg, and D. Azuma. 1995. Function and dynamics of woody debris in stream reaches in the central Sierra Nevada. Manuscript in review. Albany, CA: U.S. Forest Service, Pacific Southwest Research Station.

Carter, V. 1986. An overview of the hydrologic concerns related to wetlands in the United States. Canadian Journal of Botany 64: 364-74.

Cawley, K. 1991. Cumulative watershed effects in the Last Chance Creek watershed. Milford, CA: U.S. Forest Service, Plumas National Forest, Milford Ranger District.

Chan, F. J. 1993. Response of revegetation on a severely disturbed decomposed granite site. In Proceedings of the conference on decomposed granite soils: Problems and solutions, edited by S. Sommarstrom, 140-51. Davis: University of California Extension.

Chaney, E., W. Elmore, and W. S. Platts. 1993. Livestock grazing on western riparian areas. Eagle, ID: Information Center, Inc.

Chapel, M., A. Carlson, D. Craig, T. Flaherty, C. Marshall, M. Reynolds, D. Pratt, L. Pyshora, S. Tanguay, and W. Thompson. 1992. Recommendations for managing late-seral-stage forest and riparian habitats on the Tahoe National Forest. Nevada City, CA: U.S. Forest Service, Tahoe National Forest.

Clark, W. B. 1970. Gold districts of California. Bulletin 193. San Francisco: California Division of Mines and Geology.

Clifton, C. 1992. Stream classification and channel condition survey, with an inventory of sediment sources from roads and stream crossings conducted in the Last Chance and Spanish Creek watersheds. Quincy, CA: U.S. Forest Service, Plumas National Forest.

_______. 1994. East Branch North Fork Feather River erosion control strategy. Quincy, CA: U.S. Forest Service, Plumas National Forest, East Branch North Fork Feather River Coordinated Resource Management Group.

Coleman, C. M. 1952. Pacific Gas and Electric of California: The centennial story of Pacific Gas and Electric Company 1852-1952. New York: McGraw-Hill Book Company.

Collins, B., and T. Dunne. 1990. Fluvial geomorphology and river-gravel mining: A guide for planners. Special Publication 98. Sacramento: California Division of Mines and Geology.

Costick, L. A. 1993. Lower south fork timber harvest plan: A decomposed granite restoration case study. In Proceedings of the conference on decomposed granite soils: Problems and solutions, edited by S. Sommarstrom, 171-73. Davis: University of California Extension.

_______. 1996. Indexing current watershed conditions using remote sensing and GIS. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 57. Davis: University of California, Centers for Water and Wildland Resources.

Cross, S. D. 1988. Riparian systems and small mammals and bats. In Streamside management: Riparian wildlife and forestry interactions, edited by K. Raedeke, 93-112. Contribution 59. Seattle: University of Washington, Institute of Forest Resources.

Cummins, K. W. 1992. Catchment characteristics and river ecosystems. In River conservation and management, edited by P. J. Boon, P. Calow and G. E. Petts, 125-35. Chichester: John Wiley and Sons.

Cummins, K. W., M. A. Wilzbach, D. M. Gates, J. B. Perry, and W. B. Taliaferro. 1989. Shredders and riparian vegetation. BioScience 39(1): 24-30.

Cuplin, P. 1985. Riparian area inventory and monitoring using large scale color infrared photography. In Riparian ecosystems and their management symposium, 69-71. Tucson: University of Arizona.

Cuplin, P., W. S. Platts, O. Casey, and R. Masinton. 1985. A comparison of riparian area ground data with large scale airphoto interpretation. In Riparian ecosystems and their management symposium, 67-68. Tucson: University of Arizona.

Curry, R. R. 1992. Eastern Sierra Nevada wetland assessment: Bridgeport basin study site - climatic change, irrigation, and wetland boundaries. In The history of water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains, edited by C. A. Hall Jr., V. Doyle-Jones and B. Widawski, 396-414. Los Angeles: University of California, White Mountain Research Station.

Davenport, D. C. 1977. A nondestructive approach to reducing riparian transpiration. In Riparian forests in California: Their ecology and conservation, edited by A. Sands, 103-10. Publication 15. Davis: University of California, Institute of Ecology.

Davis, F. W., and D. M. Stoms. 1996. Sierran vegetation: A GAP analysis. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 25. Davis: University of California, Centers for Water and Wildland Resources.

DeBano, L. F., and L. J. Schmidt. 1989. Improving southwestern riparian areas through watershed management. General Technical Report RM-182. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

DeBenedetti, S. H., and D. J. Parsons. 1979. Mountain meadow management and research in Sequoia and Kings Canyon National Parks: a review and update. In First conference on scientific research in the national parks, edited by R. M. Linn, 1305-11. Washington, DC: National Park Service.

Doppelt, B., M. Scurlock, C. Frissell, and J. Karr. 1993. Entering the watershed: A new approach to save America's river ecosystems. Washington DC: Pacific Rivers Council / Island Press.

Duane, T. P. 1996. Human settlement, 1850-2040. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 11. Davis: University of California, Centers for Water and Wildland Resources.

Dudley, T., and B. Collins. 1995. Biological invasions in California wetlands: The impacts and control of nonindigenous species (NIS) in natural areas. Oakland: Pacific Institute for Studies in Development, Environment, and Security.

Dudley, T., and W. E. Dietrich. 1995. Effects of cattle grazing exclosures on the recovery of riparian ecosystems in the southern Sierra Nevada. Technical Completion Report UCAL-WRC-W-831. Davis: University of California, Water Resources Center.

Dudley, T., and M. Embury. 1995. Non-indigenous species in wilderness areas: The status and impacts of livestock and game species in designated wilderness in California. Oakland: Pacific Institute for Studies in Development, Environment, and Security.

Dunford, E. G., and P. W. Fletcher. 1947. Effect of removal of streambank vegetation upon water yield. Transactions American Geophysical Union 28: 105-10.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. San Francisco: W. H. Freeman.

Dunne, T., T. R. Moore, and C. H. Taylor. 1975. Recognition and prediction of runoff-producing zones in humid regions. Hydrological Sciences Bulletin 20: 305-27.

Ehlers, R. 1956. An evaluation of stream improvement devices constructed eighteen years ago. California Fish and Game 42: 203-17.

Elmore, W. 1989. Rangeland riparian systems. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 93-95. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Elmore, W., and R. L. Beschta. 1987. Riparian areas: Perceptions in management. Rangelands 9(6): 260-65.

________. 1989. The fallacy of structures and the fortitude of vegetation. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 116-19. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Erman, D. C. 1973. Invertebrate movements and some diel and seasonal changes in a Sierra Nevada peatland. Oikos 24: 85-93.

________. 1976. Peat depth of Sierra Nevada fens, and profile changes from 1958 to 1972 in Mason Fen. Great Basin Naturalist 36(1): 101-107.

________. 1992. Historical background of long-term diversion of the Little Truckee River. In The history of water in the Eastern Sierra Nevada, Owens Valley and White Mountains, edited by C. A. Hall, V. Doyle-Jones and B. Widawski, 415-27. Los Angeles: University of California Press.

Erman, D. C. and N. A. Erman. 1975. Macroinvertebrate composition and production in some Sierra Nevada minerotrophic peatlands. Ecology 56: 591-603.

Erman, D. C., and V. M. Hawthorne. 1976. The quantitative importance of an intermittent stream in the spawning of rainbow trout. Transactions of the American Fisheries Society 105: 675-81.

Erman, D. C., and D. Mahoney. 1983. Recovery after logging in streams with and without bufferstrips in northern California. Contribution 186. Davis: University of California, Water Resources Center.

Erman, D. C., J. D. Newbold, and K. B. Roby. 1977. Evaluation of streamside bufferstrips for protecting aquatic organisms. Contribution 165. Davis: University of California, Water Resources Center.

Erman, N. 1984. The use of riparian systems by aquatic insects. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. Hendrix, 177-82. Berkeley: University of California Press.

________. 1996. Status of aquatic invertebrates. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 38. Davis: University of California, Centers for Water and Wildland Resources.

Faber, P. M., and R. F. Holland. 1988. Common riparian plants of California. Mill Valley: Pickleweed Press.

Federal Energy Regulatory Commission. 1986. Owens River basin: Seven hydroelectric projects, California. Final environmental impact statement. Washington DC: Federal Energy Regulatory Commission, Office of Hydropower Licensing.

________. 1994. Draft environmental impact report / draft environmental impact statement: Clavey River project (FERC 10081-002). FERC/EIS-0074D. Washington DC: Federal Energy Regulatory Commission, Office of Hydropower Licensing.

Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8(3): 629-44.

Flett, M. A., and S. D. Sanders. 1987. Ecology of a Sierra Nevada population of Willow Flycatchers. Western Birds 18: 37-42.

Franklin, J. F., and J. Fites-Kaufmann. 1996. Analysis of late successional/old growth forests. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 23. Davis: University of California, Centers for Water and Wildland Resources.

Furniss, M. J., T. D. Roelofs, and C. S. Yee. 1991. Road construction and maintenance. In Influences of forest and rangeland management on salmonid fishes and their habitats, edited by W. R. Meehan, 297-323. Bethesda, MD: American Fisheries Society.

Gaines, D. A. 1977. The valley riparian forests of California: Their importance to bird populations. In Riparian forests in California: Their ecology and conservation, edited by A. Sands, 57-85. Publication 15. Davis: University of California, Institute of Ecology.

Gard, R. 1972. Persistence of headwater check dams in a trout stream. Journal of Wildlife Management 36: 1363-67.

Goldman, S. 1993. Achieving effective erosion control at Lake Tahoe. In Proceedings of the conference on decomposed granite soils: Problems and solutions, edited by S. Sommarstrom, 152-60. Davis: University of California Extension.

Graber, D. 1996. Status of terrestrial vertebrates. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 27. Davis: University of California, Centers for Water and Wildland Resources.

Gradek, P., L. Saslaw, and S. Nelson. 1989. An application of BLM's riparian inventory procedure to rangeland riparian resources in the Kern and Kaweah River watersheds. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 109-15. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Grant, G. 1988. The RAPID technique: A new method for evaluating downstream effects of forest practices on riparian zones. General Technical Report PNW-220. Corvallis, OR: U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station.

Grant, G., and F. J. Swanson. 1995. Morphology and processes of valley floors in mountain streams, western Cascades, Oregon. In Natural and anthropogenic influences in fluvial geomorphology: The Wolman volume, edited by J. E. Costa, A. J. Miller, K. W. Potter, P. R. Wilcock, 83-101. Geophysical Monograph 89. Washington, DC: American Geophysical Union.

Gregory, S. V., G. A. Lamberti, and K. M. S. Moore. 1989. Influence of valley floor landforms on stream ecosystems. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 3-8. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41(8): 540-51.

Greene, L. W., 1987. Yosemite: The park and its resources; A history of the discovery, management and physical development of Yosemite National Park, California. San Francisco: National Park Service.

Greenville Ranger District, 1985. Watershed condition survey and restoration plan for the Wolf Creek watershed. Greenville, CA: Plumas National Forest, Greenville Ranger District.

Groeneveld, D. P., and D. Or. 1994. Water table induced shrub-herbaceous ecotone: hydrologic management implications. Water Resources Bulletin 30(5): 911-20.

Hadley, R. F. 1961. Influence of riparian vegetation on channel shape in northeastern Arizona. Professional Paper 424-C. Reston, VA: U.S. Geological Survey.

Hagberg, T. 1995. Relationships between hydrology, vegetation and gullies in montane meadows of the Sierra Nevada. Master’s thesis. Humboldt State University, Arcata.

Hakencamp, C. C., H. M. Valett, and A. J. Boulton. 1993. Perspectives on the hyporehic zone: Integrating hydrology and biology. Concluding remarks. Bulletin of the North American Benthological Society 12(1): 94-99.

Hall, J. G. 1960. Willow and aspen in the ecology of beaver on Sagehen Creek, California. Ecology 41:485-94.

Harmon, M. E., et al. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15: 133-302.

Harr, R. D., and R. A. Nichols. 1993. Stabilizing forest roads to help restore fish habitats: A northwest Washington example. Fisheries 18(4): 18-22.

Harris, J. H., S. D. Sanders, and M. A. Flett. 1987. Willow Flycatcher surveys in the Sierra Nevada. Western Birds 18: 37-42.

Harris, R. R., C. A. Fox, and R. Risser. 1987. Impacts of hydroelectric development on riparian vegetation in the Sierra Nevada Region, California, USA. Environmental Management 11(4): 519-27.

Harvey, B. C. 1986. Effects of suction dredging on fish and invertebrates in two California streams. American Journal of Fisheries Management 6: 401-409.

Harvey, B. C., T. E. Lisle, T. Vallier, and D. C. Fredley. 1995. Effects of suction dredging on streams: A review and evaluation strategy. Washington, DC: U.S. Forest Service.

Hawkins, C. P. et. al. 1994. Cumulative watershed effects: An extensive analysis of responses by stream biota to watershed management. Final report on cooperative agreement PSW-88-0011CA. Albany, CA: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Heede, B. H. 1972. Flow and channel characteristics of two high mountain streams. Research Paper RM-96. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Heede, B. H., 1990. Vegetation strips control erosion in watersheds. Research Note RM-499. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Research Station.

Helvey, J. D. 1980. Effects of a north central Washington wildfire on runoff and sediment production. Water Resources Bulletin 16(4): 627-34.

Herbst, D. and R. Knapp. 1995a. Biomonitoring of rangeland streams under differing livestock grazing practices. Bulletin of the North American Benthological Society 14(1): 176.

________. 1995b. Evaluation of rangeland stream condition and recovery using physical and biological assessments of nonpoint source pollution. Technical Completion Report UCAL-WRC-W-818. Davis: University of California, Water Resources Center.

Hewlett, J. D., and A. R. Hibbert. 1967. Factors affecting the response of small watersheds to precipitation in humid areas. In International symposium on forest hydrology, edited by W. E. Sopper and H. W. Lull, 275-90. New York: Pergamon.

Hibbert, A. R., 1983. Water yield improvement potential by vegetation management on western rangelands. Water Resources Bulletin 19: 375-81.

Hicks, T. 1995. Riparian monitoring plan for hydropower projects. Bishop, CA: U.S. Forest Service, Inyo National Forest.

Hill, K. J. 1994. Annual water quality report. Zephyr Cove, NV: Tahoe Regional Planning Agency.

Holmes, D. O. 1979. Cultural influences on subalpine and alpine meadow vegetation in Yosemite National Park. In First Conference on scientific research in the national parks, edited by R. M. Linn, 1267-72. Washington, DC: National Park Service.

Hot Springs Ranger District. 1994. South Creek ecosystem analysis. Porterville, CA: U.S. Forest Service, Sequoia National Forest.

Hughes, J. E. 1934. Erosion control progress report. Milford, CA: U.S. Forest Service, Plumas National Forest, Milford Ranger District.

Hunter, C. J. 1991. Better trout habitat: A guide to stream restoration and management. Washington, DC: Island Press / Montana Land Reliance.

Ice, G. G. 1995. Managing riparian zones and watersheds with state forest practice programs. In Watershed management: Planning for the 21st century, edited by T. J. Ward, 290-99. New York: American Society of Civil Engineers.

Inyo County Water Department. 1995. Owens Valley Water Reporter 8 (2).

Inyo National Forest. 1988. Land and resource management plan. Bishop, CA: U.S. Forest Service, Inyo National Forest.

________. 1993. Interagency motor vehicle use plan revision- draft environmental impact statement. Bishop, CA: U.S. Forest Service and Bureau of Land Management.

James, L. A. 1994. Channel changes wrought by gold mining: Northern Sierra Nevada, California. In Effects of human-induced changes on hydrologic systems, edited by R. Marston and V. R. Hasfurther, 629-38. Bethesda, MD: American Water Resources Association.

Janda, R. J. 1966. Pleistocene history and hydrology of the upper San Joaquin River. Ph.D. dissertation, University of California, Berkeley.

Jennings, M. R. 1996. Status of amphibians. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 34. Davis: University of California, Centers for Water and Wildland Resources.

Jensen, S. E., and W. S. Platts. 1989. Restoration of degraded riverine/riparian habitat in the Great Basin and Snake River regions. In Wetland creation and restoration: The status of the science, edited by H. A. Kusler and M. E. Kentula, 377-416. Corvallis: U.S. Environmental Protection Agency.

Johnson, R. R. 1971. Tree removal along southwestern rivers and effects on associated organisms. American Philosophical Society Yearbook 1970 : 321-322.

Johnston, C. A. 1991. Sediment and nutrient retention by freshwater wetlands. Critical Reviews of Environmental Control 21: 491-565.

_______. 1993. Material fluxes across wetland ecotones in northern landscapes. Ecological Applications 3: 424-40.

Jones and Stokes Associates. 1983. Characteristics of riparian vegetation at streamflow diversion sites on the eastern slope of the Sierra Nevada mountains. 84-RD-87. Rosemead, CA: Southern California Edison.

_______. 1989. Downstream effects of hydroelectric development on riparian vegetation: a joint PG&E /SCE research project. Sacramento: Jones and Stokes Associates.

Kaplan-Henry, T. A., H. A. Eddinger, and T. W. Henry. 1995. South Creek riparian ecosystem analysis, Hot Springs Ranger District, Sequoia National Forest. In Watersheds '94: Respect, rethink, restore; Proceedings of the fifth biennial watershed management conference, edited by R. R. Harris, R. Kattelmann, H. Kerner and J. Woled, 132-33. Davis: University of California, Water Resources Center.

Karr, J. R., and I. J. Schlosser. 1978. Water resources and the land-water interface. Science 201: 229-34.

Katibah, E. F., K. J. Dummer, and N. E. Nedeff. 1984. Current condition of riparian resources in the Central Valley of California. In California riparian systems: Ecology, conservation, and productive Management, edited by R. E. Warner and K. M. Hendrix, 314-21. Berkeley: University of California Press.

Kattelmann, R. 1989. Oversnow flow in the Sierra Nevada. In Proceedings international mountain watershed symposium: Subalpine processes and water quality, edited by I. G. Poppoff, C. R. Goldman, S. L. Loeb and L. B. Leopold, 220-25. South Lake Tahoe, CA: Tahoe Resource Conservation District.

_______. 1990. Floods in the high Sierra Nevada, California. In Hydrology in mountainous areas, vol. 2, edited by R. O. Sinniger and M. Monbaron, 311-17. Publication 194. Wallingford, England: International Association of Hydrological Sciences.

_______. 1992. Historical floods in the eastern Sierra Nevada. In The history of water in the Eastern Sierra Nevada, Owens Valley and White Mountains, edited by C. A. Hall, V. Doyle-Jones and B. Widawski, 74-86. Los Angeles: University of California Press.

_______. 1996a. Hydrology and water resources. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 33. Davis: University of California, Centers for Water and Wildland Resources.

_______. 1996b. Impacts of floods and avalanches. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 52. Davis: University of California, Centers for Water and Wildland Resources.

Kattelmann, R., and D. Dawson. 1994. Water diversions and withdrawal for municipal supply in the eastern Sierra Nevada. In Effects of human-induced changes on hydrologic systems, edited by R. A. Marston and V. R. Hasfurther, 475-83. Bethesda: American Water Resources Association.

Kauffman, J. B. 1988. The status of riparian habitats in Pacific Northwest forests. In Streamside management: riparian wildlife and forestry interactions, edited by K. J. Raedeke, 45-55. Seattle: University of Washington, Institute of Forest Resources.

Kauffman, J. B., R. L. Case, D. Lytjen, and D. L. Cummings. 1995. Ecological approaches to riparian restoration in northeast Oregon. Restoration and Management Notes 13(1): 12-15.

Kauffman, J. B., W. C. Krueger, and M. Vavra. 1983. Impacts of cattle on streambanks in northeastern Oregon. Journal of Range Management 36(6): 683-91.

Kauffman, J. B., and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications...a review. Journal of Range Management 37(5): 430-37.

Kaufmann, M., et al. 1994. An ecological basis for ecosystem management. General Technical Report RM-256. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Keller, E A., and F. J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4: 361-80.

Keller, E. A., and A. MacDonald 1995. River channel change: The role of large woody debris. In Changing river channels, edited by A. Gurnell and G. Petts, 217-235. Chichester: John Wiley and Sons.

Kinney, B. 1996. Conditions of rangelands before 1905. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 3. Davis: University of California, Centers for Water and Wildland Resources.

Klebenow, D. A., and R. J. Oakleaf. 1984. Historical avifauna changes in the riparian zone of the Truckee River, Nevada. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 203-209. Berkeley: University of California Press.

Knapp, R. A. 1996. Non-native trout in natural lakes of the Sierra Nevada: An analysis of their distribution and impacts on native aquatic biota. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. III. Davis: University of California, Centers for Water and Wildland Resources.

Knight, A. W., and R. L. Bottorff. 1984. The importance of riparian vegetation to stream ecosystems. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 160-67. Berkeley: University of California Press.

Kohen, D. S. et. al. 1994. Shaping the Future of Owens Lake. Pomona: California State University, Landscape Architecture, 606 Studio.

Kondolf, G. M. 1989. Stream-groundwater interactions along streams of the eastern Sierra Nevada, California: Implications for assessing potential impacts of flow diversions. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 352-59. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

________. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. Restoration Ecology 1: 226-30.

________. 1995a. Five elements of effective stream restoration. Restoration Ecology 3(2):133-36.

________. 1995b. Learning from stream restoration projects. In Proceedings of the fifth biennial watershed management conference, edited by R. Harris, R. Kattelmann, H. Kerner, and J. Woled, 107-10, Report 86. Davis: University of California, Centers for Water and Wildland Resources.

Kondolf, G. M., G. F. Cada and M. J. Sale. 1987. Assessing flushing-flow requirement for brown trout spawning gravels in steep streams. Water Resources Bulletin 23(5): 927-35.

Kondolf, G. M., G. F. Cada, M. J. Sale and T. Felando. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the eastern Sierra Nevada. Transactions of the American Fisheries Society 120: 177-86.

Kondolf, G. M., R. Kattelmann, M. Embury, and D. C. Erman. 1996. Status of riparian habitat. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 36. Davis: University of California, Centers for Water and Wildland Resources.

Kondolf, G. M., and W. V. G. Matthews. 1993. Management of coarse sediment on regulated rivers. Report 80. Davis: University of California, Water Resources Center.

Kondolf, G. M., and E. R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19(1):1-15.

Kraebel, C. J., and A. F. Pillsbury. 1934. Handbook of erosion control in mountain meadows in the California region. Berkeley: U.S. Forest Service, California Forest and Range Experiment Station.

Krzysik, A. J. 1990. Biodiversity in riparian communities and watershed management. In Watershed planning and analysis in action, edited by R. E. Riggins, E. B. Jones, R. Singh and P. A. Rechard, 533-48. New York: American Society of Civil Engineers.

Kuehn, M. H. 1987. The effects of exceeding "probable maximum precipitation" on a severely burned watershed in the Sierra Nevada of California. In Landslide activity in the Sierra Nevada during 1982 and 1983, edited by J. V. De Graff, 27-40. San Francisco: U.S. Forest Service, Pacific Southwest Region.

LaBoa, J. et. al. 1994. Eastside pine. In Ecological support team workshop proceedings for the California spotted owl environmental impact statement, edited by E. Toth, J. LaBoa, D. Nelson and R. Hermit. San Francisco: U.S. Forest Service, Pacific Southwest Region.

LaFayette, R. A., and L. F. DeBano. 1990. Watershed condition and riparian health: Linkages. In Watershed planning and analysis in action, edited by F. E. Riggins, E. B. Jones, R. Singh and P. A. Rechard, 473-84. New York: American Society of Engineers.

Langley, R. D. 1984. SOFAR: A small-town water diversion project on the South Fork American River. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 505-14. Berkeley: University of California Press.

Larson, D. J. 1996. Historical water use priorities and public policies. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 8. Davis: University of California, Centers for Water and Wildland Resources.

Lawton, H. W., P. J. Wilke, and W. M. Mason. 1976. Agriculture among the Paiute of Owens Valley. Journal of California Anthropology 3:13-50.

Laymon, S. A. 1987. Brown-headed cowbirds in California: Historical perspectives and management opportunities. Western Birds 18: 63-70.

Leiberg, J. B. 1902. Forest conditions in the northern Sierra Nevada, California. Professional Paper No. 8, Series H, Forestry 5. Washington DC: U.S. Geological Survey.

Lemons, J. 1979. Visitor use impact in a subalpine meadow, Yosemite National Park, California. In First conference on scientific research in the national parks, edited by R. M. Linn, 1287-92. Washington, DC: National Park Service.

Leopold, L. B. 1968. Hydrology for urban land planning: a guide book. Circular 554. Washington DC: U.S. Geological Survey.

Leopold, L. B. 1994. A view of the river. Cambridge: Harvard University Press.

Liddle, M. J. 1975. A selective review of the ecological effects of human trampling on natural ecosystems. Biological Conservation 7: 17-36.

Lindquist, D. S., and Y. Bowie. 1989. Watershed restoration in the northern Sierra Nevada: A biotechnical approach. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 436-40. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Logan, C. A. 1948. History of mining and milling methods in California. In Geologic guidebook along highway 49-Sierran gold belt the mother lode country, edited by O. P. Jenkins, 31-34. San Francisco: California Division of Mines.

Los Angeles Department of Water and Power. 1995. Draft Mono Basin stream and stream channel restoration plan. Los Angeles: Department of Water and Power.

Loredo, I., D. Van Vuren, and M. L, Morrison. In press. Habitat use and migration behavior of the California tiger salamander. Journal of Herpetology.

Madej, M. A., W. E. Weaver, and D. K. Hagans. 1994. Analysis of bank erosion on the Merced River Yosemite Valley, Yosemite National Park, California, USA. Environmental Management 18(2): 235-50.

Mahoney, D. L., and D. C. Erman. 1984. The role of streamside bufferstrips in the ecology of aquatic biota. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 168-74. Berkeley: University of California Press.

Mahoney, D. L., and D. C. Erman. 1984. An index of stored fine sediment in gravel bedded streams. Water Resources Bulletin 20(3): 343-48.

Manley, P. N. 1995. Biological diversity and its measure: An assessment in lotic riparian ecosystems of the Lake Tahoe basin. San Francisco: U.S. Forest Service, Pacific Southwest Region.

Manley, P. N. and C. Davidson. 1995. Assessing risks and setting priorities for neotropical migratory birds in California. Draft manuscript on file, San Francisco: U.S. Forest Service, Pacific Southwest Region.

Marchetti, M. P.1994. Suspended sediment effects on the stream fauna of Humbug Creek. Master's thesis, University of California, Davis.

Marston, R. A. 1982. The geomorphic significance of log steps in forest streams. Annals of the Association of American Geographers 72: 99-108.

Martin, K. E. 1984. Recreation planning as a tool to restore and protect riparian systems. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 748-57. Berkeley: University of California Press.

Maser, C., and J. Sedell. 1994. From the forest to the sea: The ecology of wood in streams. Delray Beach, FL: St. Lucie Press.

McCleneghan, K., and R. E. Johnson. 1983. Suction dredge gold mining in the mother lode region of California. Administrative Report 83-1. Sacramento: Department of Fish and Game, Environmental Services Branch.

McDonald, P. M., and J. C. Tappeiner. Hardwood silviculture and ecology. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. III. Davis: University of California, Centers for Water and Wildland Resources.

McGurk, B. J., 1989. Predicting stream temperature after riparian vegetation removal. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 157-64. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

McGurk, B. J., and D. R. Fong. 1995. Equivalent roaded area as a measure of cumulative effect of logging. Environmental Management 19(4): 606-21.

McKelvey, K. S., and J. D. Johnston. 1992. Historical perspectives on forests of the Sierra Nevada and the Transverse Ranges of southern California: Forest conditions at the turn of the century. In The California Spotted Owl: A technical assessment of its current status, edited by J. Verner et al., 225-46. Albany, CA: U.S. Forest Service, Pacific Southwest Research Station.

McWilliams, B., and G. Goldman. 1994. The mineral industries in California: Their impact on the state economy. Publication CNR 003. Berkeley: University of California, Division of Agriculture and Natural Resources.

McPhee, J. 1993. Assembling California. New York: Farrar, Straus, and Giroux.

Medina, A. L., 1990. Possible effects of residential development on streamflow, riparian plant communities, and fisheries in small mountain streams in central Arizona. Forest Ecology and Management 33/34: 351-61.

Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influence of riparian vegetation on aquatic ecosystems with particular reference to salmonids and their food supply. In Importance, preservation, and management of riparian habitat: A symposium, edited by R. R. Johnson and D. A. Jones, 137-45. General Technical Report RM-43. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Megahan, W. F., and P. N. King. 1985. Identification of critical areas on forest lands for control of nonpoint sources of pollution. Environmental Management 9(1): 7-18.

Menke, J. W. ed. 1977. Proceedings of the workshop on livestock and wildlife-fisheries relationships in the Great Basin. Davis: University of California.

Menke, J. W., C. Davis, and P. Beesley. 1996. Public rangeland / livestock grazing assessment. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. III, chapter 22. Davis: University of California, Centers for Water and Wildland Resources.

Miller, A. H. 1951. An analysis of the distribution of birds in California. University of California Publications in Zoology 50: 531-643.

Minshall, G. W. 1994. Stream-riparian ecosystems: Rationale and methods for basin-level assessments of management effects. In Ecosystem management: Principles and applications; eastside forest ecosystem health assessment, edited by M. E. Jensen and P. S. Bourgeron, 149-73. General Technical Report PNW-318. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station.

Minshall, G. W., J. T. Brock, and J. D. Varley. 1989. Wildfires and Yellowstone's stream ecosystems. BioScience 39(10): 707-15.

Mitsch, W. J., and J. G. Gosselink. 1986. Wetlands. New York: Van Nostrand Reinhold.

Morrison, M. L., et al. 1985. Natural history of vertebrates of Sagehen Creek basin, Nevada County, CA. Berkeley: University of California, Department of Forestry and Resource Management.

Mount, J. F. 1995. California rivers and streams: The conflict between fluvial processes and land use. Berkeley: University of California Press.

Moyle, P. B. 1996a. Biotic integrity of watersheds. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 34. Davis: University of California, Centers for Water and Wildland Resources.

________. 1996b. Status of aquatic habitat types. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 32. Davis: University of California, Centers for Water and Wildland Resources.

Moyle, P. B., R. M. Yoshiyama, and R. A. Knapp 1996. Fish and fisheries of the Sierra Nevada. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 33. Davis: University of California, Centers for Water and Wildland Resources.

Moyle, P., R. Kattelmann, R. Zoomer, and P. Randall. 1996. Management of riparian areas in the Sierra Nevada. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. III. Davis: University of California, Centers for Water and Wildland Resources.

Mullally, D. P., and J. D. Cunningham. 1956. Ecological relations of *Rana mucosa* at high elevations in the Sierra Nevada. Herpetologica 12(3): 189-98.

Murphy, M. L., and W. R. Meehan. 1991. Stream ecosystem. In Influences of forest and rangeland management on salmonid fishes and their habitats, edited by W. R. Meehan, 17-46, Special Publication 19. Bethesda, MD: American Fisheries Society.

Myers, L. H. 1987. Riparian area management: Inventory and monitoring riparian areas. Technical Reference 1737-3. Denver, CO: U.S. Bureau of Land Management.

Myers, M. 1992. Watershed improvement implementation schedule, Miami Basin. Mariposa, CA: U.S. Forest Service, Sierra National Forest, Mariposa Ranger District.

_______. 1993. Nichols Meadow restoration project, Mariposa Ranger District, Sierra National Forest. In Riparian management: Common threads and shared interests, edited by B. Tellman, H. J. Cortner, M. G. Wallace, L. F. DeBano and R. H. Hamre, 191. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Naiman, R. J., et. al. 1992a. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecosystem. In Watershed management: Balancing sustainability and environmental change, edited by R. J. Naiman, 127-88. New York: Springer-Verlag.

Naiman, R. J., D. G. Lonzarich, T. J. Beechie, and S. C. Ralph. 1992b. General principles of classification and the assessment of conservation potential in rivers. In River conservation and management, edited by P. J. Boon, P. Calow and G. E. Petts, 93-123. Chichester: John Wiley and Sons.

Naiman, R. J., H. DeCamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications 3: 209-12.

Naiman, R. J., J. J. Magnuson, D. M. McKnight, and J. A. Stanford. 1995. The freshwater imperative: A research agenda. Washington, DC: Island Press.

Nakamura, F., and F. J. Swanson. 1993. Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon. Earth Surface Processes and Landforms 18: 43-61.

National Research Council. 1992. Restoration of aquatic ecosystems: Science, technology, and public policy. Washington DC: National Academy Press.

_______. 1994. Rangeland health: New methods to classify, inventory and monitor rangelands. Washington DC: National Academy Press.

_______. 1995. Wetlands: Characteristics and boundaries. Washington DC: National Academy Press.

Nelson, C. W., and J. R. Nelson. 1984. The Central Valley riparian mapping project. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 307-13. Berkeley: University of California Press.

Nelson, D. et. al. 1994. Foothill riparian. In Ecological support team workshop proceedings for the California spotted owl environmental impact statement, edited by E. Toth, J. LaBoa, D. Nelson and R. Hermit. San Francisco: U.S. Forest Service, Pacific Southwest Region.

Newbold, J. D., D. C. Erman, and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Canadian Journal of Fisheries and Aquatic Sciences 37: 1076-85.

Newbury, R., and M. Gaboury. 1993. Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behavior. Freshwater Biology 29: 195-210.

O'Connor, M. D. 1986. Effects of logging on organic debris dams in first order streams in northern California. Master’s thesis, University of California, Berkeley.

Odion, D. C., T. L. Dudley, and C. M. D'Antonio. 1990. Cattle grazing in southeastern Sierran meadows: Ecosystem change and prospects for recovery. In Plant Biology of Eastern California, edited by C. A. Hall and V. Doyle-Jones, 277-92. Los Angeles: White Mountain Research Station, University of California.

Odion, D. C., R. M. Calloway, W. R. Ferren, and F. W. Davis. 1992. Vegetation of Fish Slough, an Owens Valley wetland ecosystem. In The history of water in the Eastern Sierra Nevada, Owens Valley and White

Mountains, edited by C. A. Hall, V. Doyle-Jones and B. Widawski, 171-79. Los Angeles: University of California Press.

Odum, E. P. 1978. Ecological importance of the riparian zone. In National symposium on strategies for protection and management of floodplain wetlands and other riparian ecosystems, 2-4. Washington, DC: U.S. Forest Service.

Ohmart, R. D. 1994. The effects of human-induced changes on the avifauna of western riparian habitats. In A century of avifaunal change in western North America, edited by J. R. Jehl, Jr. and N. K. Johnson, 273-85. Studies in Avian Biology No. 15.

Overton, K. C., G. L. Chandler, and J. A. Pisano. 1994. Northern/Intermountain regions' fish habitat inventory: Grazed, rested, and ungrazed reference stream reaches, Silver King Creek, California. General Technical Report INT-311. Ogden, UT: U.S. Forest Service, Intermountain Research Station.

Pacific Rivers Council. 1995. The urgent need for watershed protection and restoration in the Sierra Nevada: Native fish and streams at risk in California. Sacramento: Pacific Rivers Council.

Palmer, T. 1994. Lifelines: The case for river conservation. Washington, DC: Island Press.

Parrish, J. L., and D. C. Erman. 1994. Critical questions for the Sierra Nevada: Recommended research priorities and administration. Report 34. Davis: University of California, Centers for Water and Wildland Resources.

Patten, D. T. 1986. Riparian workshop, November 13-14, 1985. San Ramon, CA: Pacific Gas and Electric and Southern California Edison.

Pawley, A., and J. F. Quinn. 1996. California watershed projects inventory database online. Davis: University of California, Division of Environmental Studies. Available from http://ice.ucdavis.edu.

Pelzman, R. J. 1973. Causes and possible prevention of riparian plant encroachment on anadromous fish habitat. Administrative Report 73-1. Sacramento: California Department of Fish and Game, Environmental Services Branch.

Perkins, D. J., B. N. Carlsen, M. Fredstrom, R. H. Miller, C. M. Rofer, G. T. Ruggerone, and C. S. Zimmerman. 1984. The effects of groundwater pumping on natural spring communities in Owens Valley. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 515-26. Berkeley: University of California Press.

Peterjohn, W. T., and D. L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observation on the role of a riparian forest. Ecology 65: 1466-75.

Petranka, J. W., M. P. Brannon, M. E. Hopey, and C. K. Smith. 1994. Effects of timber harvesting on low elevation populations of southern Appalachian salamanders. Forest Ecology and Management 67:135-47.

Pinay, G., and Decamps H. 1988. The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: A conceptual model. Regulated Rivers: Research and Management 2: 507-16.

Pister, E. P., and J. H. Kerbavaz. 1984. Fish Slough: A case study in management of a desert wetland system. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 929-33. Berkeley: University of California Press.

Platts, W. S. 1979. Livestock grazing and riparian-stream ecosystems--an overview. In Proceedings, grazing and riparian-stream ecosystems forum, edited by O. B. Cope, 39-45. Vienna, VA: Trout Unlimited.

_______. 1984. Riparian system/livestock grazing interaction research in the intermountain west. In California riparian systems: Ecology, conservation, and productive management, edited by R. E. Warner and K. M. Hendrix, 424-29. Berkeley: University of California Press.

_______. 1991. Livestock grazing. In Influences of forest and rangeland management on salmonid fishes and their habitats, edited by W. R. Meehan, 389-423. Bethesda, MD: American Fisheries Society.

Platts, W. S., and R. L. Nelson. 1985. Streamside and upland vegetation use by cattle. Rangelands 7: 5-7.

Plumas National Forest. 1988. Land and resources management plan. Quincy, CA: U.S. Forest Service, Plumas National Forest.

Pomby, J. 1987. Mined land reclamation program. California Geology 40(1): 3-6.

Ponce, V. M., and D. S. Lindquist. 1990. Management strategies for baseflow augmentation. In Watershed Planning and Analysis, edited by R. E. Riggins, E. B. Jones, R. Singh and P. A. Rechard, 313-22. New York: American Society of Civil Engineers.

Raedeke, K. J., R. D. Taber, and D. K. Paige. 1988. Ecology of large mammals in riparian systems of Pacific Northwest forests. In Streamside management: Riparian wildlife and forestry interactions, edited by K. Raedeke, 113-32. Contribution 59. Seattle: University of Washington, Institute of Forest Resources.

Ralph, S. C., G. C. Poole, L. L. Conquest, and R. J. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Canadian Journal of Fisheries and Aquatic Sciences 51: 37-51.

Range Watch. 1995. Sierra Nevada grazing impacts. Video tape. Posey, CA: Range Watch.

Ratliff, R. D. 1985. Meadows in the Sierra Nevada of California: state of knowledge. General Technical Report PSW-84. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Reid, L. M. 1993. Research and cumulative watershed effects. General Technical Report PSW-141. Albany, CA: U.S. Forest Service, Pacific Southwest Research Station.

Reid, L. M., and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20: 1753-61.

Reynolds, F. L., T. J. Mills, R. Benthin, and A. Low. 1993. Restoring Central Valley streams: A plan for action. Sacramento: California Department of Fish and Game.

Rhodes, J., C. M. Skau, D. Greenlee, and D. L. Brown. 1985. Quantification of nitrate uptake by riparian forests and wetlands in an undisturbed headwaters watershed. In Proceedings of the North American Riparian Conference, 175-79. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Ridenhour, R. L., C. Hunter, and W. J. Trush. 1995. Workplan: Mono Basin stream restoration (Rush Creek, Lee Vining Creek, and Parker Creek). Los Angeles: Department of Water and Power.

Rinne, J. N. 1990. The utility of stream habitat and biota for identifying potential conflicting forest land uses: Montane riparian areas. Forest Ecology and Management 33/34: 363-83.

Risser, P. G. 1995. The status of the science of examining ecotones. Bioscience 45(5): 318-25.

Risser, R. J., and R. R. Harris. 1987. Mitigation for impacts to riparian vegetation on regulated headwater streams. In Sierran Riparian Conference, edited by D. T. Patten, 42-47. San Ramon: Pacific Gas and Electric Company and Southern California Edison Company.

Robinson, G. E., and R. L. Beschta. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. Forest Science 36: 790-801.

Robinson, T. W. 1965. Introduction, spread and aerial extent of saltcedar (Tamarix) in the western States. Professional Paper 491-A. Washington, DC: U.S. Geological Survey.

Roby, K. B. 1989. Watershed response and recovery from the Will Fire: Ten years of observation. In Proceedings of the symposium on fire and watershed management, edited by N. H. Berg, 131-36. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Roby, K. B., and D. L. Azuma. 1995. Changes in a reach of a northern California stream following wildfire. Environmental Management 19(4): 591-600.

Roby, K. B., D. C. Erman, and J. D. Newbold. 1977. Biological assessment of timber management activity impacts and buffer strip effectiveness on national forest streams of northern California. San Francisco: U.S. Forest Service, Pacific Southwest Region.

Ruediger, R. 1991. Distribution and abundance of large wood in central Sierra streams. Sonora, CA: U.S. Forest Service, Stanislaus National Forest.

Sandecki, M. 1989. Aggregate mining in river systems. California Geology 42(4): 88-94.

Sanders, S. D., and M. A. Flett. 1989. Montane riparian habitat and Willow Flycatcher: Threats to a sensitive environment and species. In Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's, edited by D. L. Abell, 262-66. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Sands, A. ed. 1977. Riparian forests in California: Their ecology and management. Publication 15. Davis: University of California, Institute of Ecology.

Sands, A., and G. Howe. 1977. An overview of riparian forests in California: Their ecology and conservation. In Importance, preservation, and management of riparian habitat: A symposium, edited by R. R. Johnson and D. A. Jones, 98-115. General Technical Report RM-43. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Schlosser, I. J., and J. R. Karr. 1981. Water quality in agricultural watersheds: Impact of riparian vegetation during base flow. Water Resources Bulletin 17(2): 233-40.

Schulenburg, R. 1994. Program status report, 1984 fish and wildlife habitat enhancement act (prop. 19). Sacramento: Wildlife Conservation Board.

Schwartz, M. W., D. J. Porter, J. M. Randall, K. E. Lyons. 1996. Impact of non-indigenous plants. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 47. Davis: University of California, Centers for Water and Wildland Resources.

Sedell, J. R. 1984. Evaluating fish response to woody debris. In Pacific Northwest Stream Management Workshop, 222-45. Arcata: Humboldt State University.

Sedell, J. R., and G. H. Reeves. 1992. An ecosystem approach to the conservation and management of freshwater habitat for anadromous salmonids in the Pacific Northwest. Transactions of the North American Wildlife and Natural Resources Conference 57: 408-15.

Sedell, J. R., G. H. Reeves, and K. M. Burnett. 1994. Development and evaluation of aquatic conservation strategies. Journal of Forestry 92(4): 28-31.

Senter, E. 1987. Erosion control at Malakoff Diggings State Historical Park. Sacramento: Department of Water Resources, Central District.

Shevock, J. R. 1996. Status of rare and endemic plants. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 24. Davis: University of California, Centers for Water and Wildland Resources.

Sigafoos, R. S., 1964. Botanical evidence of floods and floodplain deposition. Professional Paper 485A. Washington, DC: U.S. Geological Survey.

Skinner, C. N., and C. Chang. 1996. Fire regimes, past and present. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 38. Davis: University of California, Centers for Water and Wildland Resources.

Skovlin, J. M. 1984. Impacts of grazing on wetlands and riparian habitat: A review of our knowledge. In Developing Strategies for Rangeland Management, 1001-1113. National Research Council. Boulder, CO: Westview Press.

Small, A. 1974. The Birds of California. New York: MacMillan Publishing Company.

Smith, F. E. 1977. A short review of the status of riparian forests in California. In Riparian forests in California: Their ecology and management, edited by A. Sands, 1-2. Davis: University of California, Institute of Ecology.

Smith, S. D., A. B. Wellington, J. L. Nachlinger, and C. A. Fox. 1991. Functional response of riparian vegetation to streamflow diversion in the eastern Sierra Nevada. Ecological Applications 1: 89-97.

Stanford, J. A., and J. V. Ward. 1988. The hyporehic habitat of river ecosystems. Nature 335: 64-66.

Stanford, J. A., and J. V. Ward. 1993. An ecosystem perspective of alluvial rivers: Connectivity and the hyporehic corridor. Journal of the North American Benthological Society 12: 48-60.

Stanislaus National Forest. 1988. Land and resources management plan. Sonora, CA: U.S. Forest Service.

Steinblums, I. J., H. A. Froehlich, and J. K. Lyons. 1984. Designing stable buffer strips for stream protection. Journal of Forestry 82(1): 49-52.

Stevens, L. E., B. T. Brown, J. M. Simpson, and R. R. Johnson. 1977. The importance of riparian habitat to migrating birds. In Importance, preservation, and management of riparian habitat: A symposium, edited by R. R. Johnson and D. A. Jones, 156-64. General Technical Report RM-43. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station.

Steward, J. 1934. Ethnography of the Owens Valley Paiute. American Archaeology and Ethnology 33:233-324.

Stine, S. 1991. Extent of riparian vegetation on stream tributary to Mono Lake, 1930-1940: an assessment of the streamside woodlands and wetlands, and the environmental conditions that supported them. Sacramento: California State Water Resources Control Board and Jones and Stokes Associates.

_______. 1994. Restoration conceptual plan: The concepts and principles guiding the restoration of Rush and Lee Vining Creeks, Mono County, California. Los Angeles: Department of Water and Power, Restoration Technical Committee.

Stine, S., D. Gaines, and P. Vorster. 1984. Destruction of riparian systems due to water development in the Mono Lake watershed. In California Riparian Systems: Ecology, Conservation, and Productive Management, edited by R. E. Warner and K. M. Hendrix, 528-33. Berkeley: University of California.

Stromberg, J., and D. Patten. 1989. Early recovery of an eastern Sierra riparian system after forty years of stream diversion. In Proceedings of the California riparian systems conference: Protection, management, and restoration of the 1990's, edited by D. L. Abell, 399-404. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

_______. 1991. Response of *Salix lasiolepis* to augmented streamflows in the upper Owens River. Sacramento: Jones and Stokes Associates.

_______. 1992. Mortality and age of Black Cottonwood stands along diverted and undiverted streams in the eastern Sierra Nevada, California. Madrono 39(3): 205-23.

Sudworth, G. B. 1900. Stanislaus and Lake Tahoe Forest Reserves, California, and adjacent territory. In Annual Reports of the Department of the Interior, 21st Annual Report of the U.S. Geological Survey, 505-61. Washington, DC: Government Printing Office.

Sullivan, K. 1994. An alternative view of riparian area management. Journal of Forestry 92(4): 29.

Swanson, F. J., J. F. Franklin, and J. R. Sedell. 1990. Landscape patterns, disturbance and management in the Pacific Northwest, U.S.A. In Changing landscapes: An ecological perspective, edited by I. S. Zonneveld and R. T. T. Forman, 191-213. New York: Springer-Verlag.

Swanson, F. J., S. V. Gregory, J. R. Sedell, and A. G. Campbell. 1982. Land-water interactions: The riparian zone. In Analysis of Coniferous Forest Ecosystems in the Western United States, edited by R. L. Edmonds, 267-291. Stroudsburg, PA: Hutchinson Ross Publishing Company.

Swanson, F. J., and R. E. Sparks. 1990. Long-term ecological research and the invisible place. Bioscience 40(7): 502-508.

Swanson, S. 1989. Using stream classification to prioritize riparian rehabilitation after extreme events. In Proceedings of the California riparian systems conference: Protection, management, and restoration of the 1990's, edited by D. L. Abell, 96-101. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Tahoe Regional Planning Agency. 1988. Water quality management plan for the Lake Tahoe region. Zephyr Cove, NV: Tahoe Regional Planning Agency.

Taylor, D. W. 1982. Riparian vegetation of the Eastern Sierra: Ecological effects of stream diversions. Bishop, CA: U.S. Forest Service, Inyo National Forest.

________. 1983. Assessing potential environmental impacts of small-hydro on riparian vegetation. Paper presented at workshop on small-hydro projects. Bishop, CA: Inyo County.

Taylor, D. W., and W. B. Davilla. 1985. Riparian vegetation in the Crane Valley project. San Ramon: Pacific Gas and Electric Company.

________. 1986. Evaluation of riparian vegetation along the Lower North Fork Kings River and tributaries, Fresno County, California. San Ramon, CA: Pacific Gas and Electric Company.

Terrene Institute. 1994. Urbanization and water quality. Washington DC: Terrene Institute.

Thomas, J. W., C. Maser, and J. E. Rodiek. 1979. Riparian zones. In Wildlife habitat in managed forests: The Blue Mountains of Oregon and Washington, edited by J. W. Thomas. Agriculture Handbook 553. Washington, DC: U.S. Forest Service.

Tiller, R. L., and R. Tollefson. 1992. Restoration of riparian habitat on the Kern River Preserve. Watershed Management Council Newsletter 4(3): 10.

Todd, A. H. 1989. Watershed restoration and erosion control: Making it work in subalpine areas. In Proceedings international mountain watershed symposium: Subalpine processes and water quality, edited by I. G. Poppoff, C. R. Goldman, S. L. Loeb and L. B. Leopold, 290-99. South Lake Tahoe, CA: Tahoe Resource Conservation District.

Toth, E. et. al. 1994. Mixed conifer. In Ecological support team workshop proceedings for the California spotted owl environmental impact statement, edited by E. Toth, J. LaBoa, D. Nelson and R. Hermit. San Francisco: U.S. Forest Service, Pacific Southwest Region.

Trihey, E. W., and S. English. 1991. A conceptual plan for the restoration of aquatic and riparian habitats in Rush and Lee Vining Creeks, Mono County, California. Concord, CA: Trihey and Associates.

Troendle, C. A. 1993. Sediment transport for instream flow / channel maintenance. In Proceedings technical workshop on sediments, 31-34. Washington, DC: Terrene Institute.

U.S. Bureau of Land Management. 1994. Rangeland reform '94; draft environmental impact statement. Washington, DC: U.S. Department of the Interior.

U.S. Environmental Protection Agency. 1993. Monitoring protocols to evaluate water quality effects of grazing management on western rangeland streams. EPA 910/R-93-017. Washington, DC: Environmental Protection Agency, Water Division, Surface Water Branch.

U.S. Forest Service. 1995a. Pacific Southwest Region stream condition inventory handbook. Version 3.0. San Francisco: U.S. Forest Service, Pacific Southwest Region.

_______. 1995b. Results of stream condition inventory of grazed and ungrazed meadow streams. Unpublished report. San Francisco: U.S. Forest Service, Pacific Southwest Region.

U.S. General Accounting Office. 1988. Public rangelands: Some riparian areas restored but widespread improvement will be slow. Washington, DC: U.S. General Accounting Office.

U.S. Soil Conservation Service. 1984. Foothills watershed area study, El Dorado unit. Placerville, CA: U.S. Soil Conservation Service.

_______. 1989. East Branch North Fork Feather River erosion inventory report, Plumas County, California. Davis, CA: U.S. Soil Conservation Service, River Basin Planning Staff.

Van Haveren, B. P. and W. L. Jackson. 1989. Concepts in stream riparian rehabilitation. Transactions of the North American Wildlife and Natural Resources Conference 51: 280-89.

Vankat, J. L., and J. Major. 1978. Vegetation changes in Sequoia National Park, California. Journal of Biogeography 5: 377-402.

Vannote, R. L, G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-37.

Vorster, P., and G. M. Kondolf. 1989. The effect of water management and land use practices on the restoration of Lee Vining and Rush Creeks. In Proceedings of the California riparian systems conference: Protection, management, and restoration of the 1990's, edited by D. L. Abell, 405-10. General Technical Report PSW-110. Berkeley: U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station.

Wagoner, L. 1886. Report on forests of the counties of Amador, Calaveras, Tuolumne, and Mariposa. In First biennial report of the California State Board of Forestry for the years 1885-1886, 39-44. Sacramento: State Board of Forestry.

Walsh, K., R. Bowen, and H. Skibitzke. 1987. Aerial photograph interpretation of riparian vegetation/geomorphology relations on Bishop Creek. In Sierran Riparian Conference, edited by D. T. Patten, 2-4. San Ramon: Pacific Gas and Electric Company and Southern California Edison Company.

Walters, M. A., R. O. Teskey, and T. M. Hinckley. 1980. Impact of water level changes on woody riparian and wetland communities, volume VII, Mediterranean region, western arid and semi-arid region. Washington, DC: U.S. Fish and Wildlife Service.

Warner, R. E., and K. M. Hendrix eds. 1984. California riparian systems: Ecology, conservation, and productive management. Berkeley: University of California Press.

Weatherspoon, C. P., and C. N. Skinner. 1996. Landscape-level strategies for forest fuel management. In Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, chapter 56. Davis: University of California, Centers for Water and Wildland Resources.

Welsh, H. H. 1993. A hierarchical analysis of the niche relationships of four amphibians from forested habitats in northwestern California. Ph.D. Dissertation, University of California, Berkeley.

Whitall, D. R., and S. S. Champion. 1989. Wetland enhancement in Blackwood Canyon. In Proceedings international mountain watershed symposium: Subalpine processes and water quality, edited by I. G. Poppoff, C. R. Goldman, S. L. Loeb and L. B. Leopold, 83-90. South Lake Tahoe, CA: Tahoe Resource Conservation District.

Whitney, S. 1979. A Sierra Club naturalist's guide to the Sierra Nevada. San Francisco: Sierra Club Books.

Williams, G. P., and M. G. Wolman. 1984. Downstream effects of dams and alluvial rivers. Professional Paper 1286. Reston, VA: U.S. Geological Survey.

Wills, L. and J. Schramel. 1994. A grass roots perspective: Feather River coordinated resource management. In Overcoming obstacles: Proceedings of the fourth biennial watershed management conference, edited by J. Woled, 53-61. Davis: University of California, Centers for Water and Wildland Resources.

Wills, L. and J. C. Sheehan. 1994. East Branch North Fork Feather River, Spanish Creek and Lost Chance Creek non-point source water pollution study. Quincy, CA: Plumas Corporation.

Wolman, M. G. 1959. Factors influencing erosion of a cohesive river bank. American Journal of Science 257: 204-16.

Wood, S. H. 1975. Holocene stratigraphy and chronology of mountain meadows, Sierra Nevada, California. Ph.D. Dissertation, California Institute of Technology, Pasadena, California.

Woyshner, M. and B. Hecht. 1990. Sediment, solute and nutrient transport from Squaw Creek, Truckee River Basin, California. In Proceedings international mountain watershed symposium: Subalpine processes and water quality, edited by I. G. Poppoff, C. R. Goldman, S. L. Loeb and L. B. Leopold, 190-219. South Lake Tahoe, CA: Tahoe Resource Conservation District.

Zeiner, D. C., W. F. Laudenslayer, K. E. Mayer, and M. White eds. 1988. California's wildlife, volume II, birds; California Statewide Wildlife Habitat Relationships System. Sacramento: Department of Fish and Game.

________. 1990a. California's wildlife, volume I, amphibians and reptiles; California Statewide Wildlife Habitat Relationships System. Sacramento: Department of Fish and Game.

________. 1990b. California's wildlife, volume III, mammals; California Statewide Wildlife Habitat Relationships System. Sacramento: Department of Fish and Game.

Zimmerman, R. C., J. C. Goodlett, and G. H. Comer. 1967. Influence of vegetation on channel form of small streams. 255-75. Publication 75. Wallingford, England: International Association of Scientific Hydrology.

Appendix 1. Larger plants typical of riparian areas in the Sierra Nevada.

Trees

Alnus rhombifolia	white alder
Celtis reticulata	hackberry
Fraxinus latifolia	Oregon ash
Pinus ponderosa	ponderosa pine
Populus fremontii	Fremont cottonwood
Populus trichocarpa	black cottonwood
Salix laevigata	red willow

Shrubs

Baccharis glutinosa	water wally
Betula occidentalis	western birch
Cornus stolonifera	red osier dogwood
Forestiera neomexicana	desert olive
Phragmites communis var. *berlandieri*	reed
Rosa californica	wild rose
Rosa woodsii	wild rose
Salix exigua	coyote willow
Salix lasiolepis var. *bracelinae*	willow
Salix ligulifolia	willow
Salix lutea var. *watsonii*	willow

(from Walters et al. 1980; Faber and Holland 1988)

Appendix 2. Threatened and endangered species dependent on riparian habitat (from Graber 1996)

Ambystoma californiense	California Tiger Salamander
Ambystoma macrodactylum	Long Toed Salamander
Hydromentes sp.	Owens Valley Web-Toed Salamander
Bufo canorus	Yosemite Toad
Rana aurora draytonii	Red-legged Frog
Rana boylei	Foothill Yellow-legged Frog
Rana muscosa	Mountain Yellow-legged Frog
Rana pipiens	Northern Leopard Frog
Scaphiopus hammondi	Western Spadefoot
Clemmys marmorata	Western Pond Turtle
Plegadis chihi	White-faced Ibis
Histrionicus histrionicus	Harlequin Duck
Bucephalia islandica	Barrow's Goldeneye
Pandion haliaetus	Osprey
Haliaetus leucocephalus	Bald Eagle
Empidonax trailii	Willow Flycatcher
Geothlypis trichas	Common Yellowthroat
Icteria virens	Yellow-breasted Chat
Agelaius tricolor	Tricolored Blackbird
Sorex lyelli	Mt. Lyell Shrew

Appendix 3.

MANAGEMENT AND LAND USE BUFFERS

by D. C. Erman, N. A. Erman, L. Costick, and S. Beckwitt

The region near streams and other aquatic ecosystems is defined in three ways: a transition or ecotone, a discrete habitat or community, and an area of special management or buffer between upslope land uses and the aquatic environment. No wonder that the terms and definitions vary with the context. Scientists and managers agree on the special nature of riparian areas. Both federal and California forest practice standards or rules specify restrictions and practices intended to protect streams and moderate disturbance from land use. The main issues are not about the special nature of riparian areas but rather how much area belongs in this category and what activities are acceptable. The ecological functions and process should be guides to use and protection.

The functions and processes take place in three areas at varying distances from the aquatic system: a community area, an energy area, and a land-use influence area The size of these areas will change depending on the characteristics that define them. Any one of the areas may be larger than the others; in other words the three areas are nested within each other but the order is determined by the characteristics which define them rather than an arbitrary hierarchy. One other fact is important in understanding the dimensions of the riparian area: it is not proportional to the size of the aquatic system. Ephemeral ponds, intermittent streams, and small springs are as important to the suite of species that depend upon them as large rivers are to another suite of species. Smaller aquatic systems in forested environments are dominated by the land system. Consequently, the impacts from changes in riparian forest structure and composition and from land disturbance result in major changes in the aquatic system (Erman et al. 1977, Minshall 1994).

The direction of state and federal protection of riparian areas has been based on broad classification of the aquatic system--presence of a life-form (fish-bearing vs. non-fish bearing, for example), size (rivers vs.spring runs), or permanence (year-round streamflow in most years vs. temporary flow in most years). Classification of aquatic habitats for management in this way does not recognize the connected nature of aquatic systems (upstream-downstream), does not recognize the needs of riparian dependent species, cannot work for the protection of aquatic biodiversity (which is particular to the type of system), or properly assist in the management of interconnected land-water systems. Shifting to a recognition of the community, energy, and buffering requirements of riparian areas will aid in protection and management of these areas.

The community area

For any aquatic habitat there is a suite of species that depend on the combination of land and water. Some spend most of their life in the water, some on the land. Most aquatic insects, for example, develop in water but spend a portion of the life cycle on land--feeding, mating, and resting (Erman 1996). Alder and cottonwood trees are always associated with nearby water--spring, lake, stream, or groundwater near the surface. Of the total 401 Sierran species of mammals, birds, reptiles, and amphibians combined, 21% (84 species) depend on this community area near water, and of course many more use it occasionally or regularly to find food, water, shelter (Graber 1996). Nearly one-quarter (24%) of those dependent on the riparian area are at risk of extinction. From a knowledge of the habitat requirements and life connections of the dependent species we should be able to define the general dimensions of this community area in the various regions and elevation zones of the Sierra. However, the exact requirements and hence the dimensions for many species are unknown. The water shrew (Sorex palustris) is likely confined to the virtual stream bank. Beaver (Castor canadensis) may move tens of meters from water to cut aspen or other trees, and cottonwood on relatively flat floodplains extend over 100 m from low-water channels. The California tiger salamander (Ambystoma californiense) which occurs in the foothills zone (Jennings 1996) lives in terrestrial habitats near temporary and permanent water used for breeding. Adults migrate up to 129 m (average 36 m) and juveniles up to 57 m (average 26 m) between their breeding site and terrestrial burrows (Loredo, et al. in press). Studies elsewhere on amphibians have found some species that live only in the cool, damp conditions near streams and up to several hundred meters from surface flow (Welsh 1994). Dramatic changes in riparian conditions by logging forests near headwater streams have greatly reduced populations of riparian-dependent and terrestrial salamanders in the Appalachians (Petranka, et al. 1994).

Thus, to provide for the living requirements of those organisms dependent for their survival on the special conditions of the riparian area, the primary management should be maintenance of these conditions. Even the natural role of disturbance, documented in this chapter and others, does not require in most situations, active restoration of the landscape in order to secure the habitat conditions necessary for the area.

The Energy Area

Major scientific understanding of the energy linkages between upstream and downstream (e.g., the "river continuum concept" [Vannote et al. 1981]) and exchanges between the land area and aquatic systems has emerged in the last two decades (see review by Murphy and Meehan 1991). Riparian areas contribute a year-round supply of organic material that ranges from nearly the total supply of food at the base of the food chain (small forested streams and springs) to critical quality food (transported organic matter into larger streams from smaller upstream sources). Wind-blown seeds and leaves are a significant source of material entering meadow reaches with little forest canopy. The type of organic material is also important. Easily decomposed plant material (e.g., parts with a relatively low carbon to nitrogen ratio such as alder leaves), those slow to decompose (such as Douglas-fir), as well as terrestrial insects carried in are needed to support a food web throughout the year. The surrounding riparian area also blocks energy from the sun and reradiation from the water (thus reducing temperature changes). And the role of large organic matter (trees, root-wads, debris dams) is of major importance to the structure of stream channels and complexity, to the routing of sediment, to the retention of nutrient supplies, and to the diversity of aquatic habitats. The dimensions of this region vary by the season (leaf fall of deciduous plants), by the hydrologic conditions (out of channel floods, size of stream), by the contributing area (large wood that can fall into the channel, plant parts and insects that blow in), and by the species mix (organic material breaks down and is useful as aquatic food at different times). A useful summary index of this area is the slope distance around the aquatic system equivalent to the height of the site potential tree. For the Sierra Nevada that height in many forest types is approximately 150 ft (46 m). However, the incorporation of wood and other organic material into streams will occur also during inundation of the flood plain. For larger streams in regions of gentle gradient, the width of a stream during major floods may extend much beyond 150 ft.

Riparian Buffer Area

Effects of land use disturbance are reduced by keeping such activities at a distance from the aquatic system and by maintaining a buffer area capable of absorbing disturbance. The likelihood of disturbance to a stream from most land uses increases as a function of proximity to a stream, the steepness of surrounding hillsides and the erodability of soils. These relationships, as in many risk factors, are probably multiplicative and therefore a doubling of slope has more than twice the risk of disturbance to the stream (i.e., an exponential change). Current practice for designing buffer systems based on risk rely on classification of the aquatic system (as mentioned above) and creating three or four categories of slope. As a consequence, a fixed width is chosen even though conditions on the land and requirements of the community would suggest a variable width. We propose a more direct system for estimating a variable width buffer system based on the community and energy area in combination with slope and other measurable risk factors.

For example, let us assume that a stream is in the mixed conifer zone. The determination of hillside slope can be made from topographic maps or from GIS. The SNEP GIS team has prepared a program that will calculate slope at 30 m increments along a stream channel. At each point, slope from five successive 30 m segments out from a channel are computed from the 30 m Digital Elevation Model. Slopes are then weighted 5, 4, 3, 2, 1 from closest to farthest away and divided by five to produce a weighted average slope over the 150 m (slopes closest to the stream have the greatest effect on the average). Let's also assume the stream has a community area defined by species as 110 ft (33.5 m) and an energy area that is 150 ft (46 m). Thus, a minimum region with maintenance of forest structure and minimal land disturbance is 150 ft for these two areas. This distance is then multiplied by the base of natural logs (e) raised to a power equal to 1+slope (in decimal form). If, for example, the slope were 25%, the equation is

$$\text{Buffer width (ft)} = 150 * e(1+0.25)$$

giving a value of 524 ft (160m). If the average slope were 50%, the buffer would be 672 ft (205 m). In the first case, an additional 374 ft (114 m) of buffer would be needed. Soil erodability, also available from soil maps and GIS, can be incorporated as the detachability value (Costick 1996) and the exponent would be expanded to 1+slope+detachability -slope x detachability. For example, if detachability were 0.30, the equation is

$$\text{Buffer width (ft)} = 150 * e(1+0.25+0.30-0.075)$$

giving a value of 656 ft (200 m). Extreme cases, when slope and detachability are both high, would result is even larger buffer zones and as slope and detachability approach zero buffer zones would become smaller--exactly the outcome common sense would indicate is appropriate. This additional area beyond 150 ft would not have the same land use restrictions as the community and energy areas. Its purpose is to highlight a region in which probability of disturbance may affect these areas and the aquatic system. Silvicultural procedures should minimize soil disturbance and in general retain sufficient forest structure to ameliorate microclimate change within the community area and minimize abrupt transition from upslope to the community area. Described as a "probability of disturbance" region places the responsibility on managers for designing practices that have higher standards and are more carefully matched to conditions where mistakes will matter more.

Current information and computer aided analytic methods are sufficient for layout of such a buffer system for many regions of the Sierra. Refinements in scale of Digital Elevation Models from 30 m to 10 m are underway and soil mapping continues to expand and be incorporated into GIS layers. Most forest and land managers today could determine first approximations based on habitat requirements, energy inputs, and hillside slope calculations to produce a logical, ecologically-based riparian management-protection system along the lines we have described. It would lead to better protection of riparian dependent organisms, of energy linkages between the land-water systems, and assist managers in tailoring land use activities to regions of greater need than is presently the case.

Back to CD-ROM Table of Contents