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Status of Riparian Habitat

ABSTRACT

Despite their ecological importance, riparian areas in the Sierra Nevada have been the subject of very little research and no systematic data collection at a scale adequate to directly evaluate the status of the resource over the entire range. In this chapter, we review the functioning and ecological importance of riparian areas, the effects of human activities on riparian areas, and the extent of these effects in the Sierra Nevada. Riparian areas in the Sierra Nevada have been directly removed or have had their functions impaired by gold mining, gravel mining, hydroelectric development, land clearance and diversions of water for irrigation, land drainage, phreatophyte removal programs, timber harvest, construction of roads and railroads, urbanization, livestock grazing, and groundwater abstraction. From a GIS (Geographic Information Systems) analysis of road influence on streams, we calculated the percentage of 100 by 100 m pixels containing streams that also contained a road, which we designated as the Road Influence Index (RII). RII values, a measure of stream length with a road within 100 m, range from 2% to 33%, with a median value of 14% for the Sierra Nevada. Aerial photographic analysis indicated that 121 of 130 study watersheds displayed obvious gaps in the riparian corridor, primarily from road and railroad crossings, timber harvesting, clearing of private lots, dewatering by dams and diversions, and livestock grazing. Examination of 1:100,000-scale topographic maps for the entire Sierra Nevada showed more than 150 gaps over 0.5 km long created by reservoirs and at least 1,000 km of riparian corridor eliminated by reservoir inundation. Management strategies to minimize effects on the riparian zone include buffer strips, flushing flows, and restoration of riparian habitat. Streamside management zones or land-use buffers may be used to filter pollutants and sediment from upland runoff and to provide adequate recruitment of organic matter to the channel. Deliberate release of high flows from reservoirs (flushing flows) may be used to mimic the effects of natural floods in maintaining bed substrate and active channel width. Riparian vegetation can also be replanted in sites from which it has been cleared.

INTRODUCTION

Riparian habitats are among the most ecologically productive and diverse terrestrial environments, by virtue of an extensive land-water ecotone, the diversity of physical environments resulting from moisture gradients, and a mosaic of habitats created by dynamic river changes (Naiman et al. 1993). Moreover, the importance of the physical and biological interchanges between aquatic and riparian habitats is increasingly recognized, so any consideration of aquatic habitat quality must account for the riparian conditions so influential upon the channel itself (Gregory et al. 1991). Riparian habitats are especially important in semiarid regions, where the availability of moisture and a cool, shaded microclimate gives these habitats an ecological importance disproportionate to their areal extent. For example, in the Inyo National Forest, riparian areas constitute less than 0.4% of the land area but are essential for at least one phase of life for about 75% of local wildlife species (Kondolf et al. 1987b). In this forest, many recreational activities for its annual seven million visitors are also concentrated in riparian zones (Federal Energy Regulatory Commission 1986). Of the total 401 Sierran species of mammals, birds, reptiles, and amphibians combined, 21% (84 species) depend on the riparian area near water, and of course many more use it occasionally or regularly to find food, water, and shelter (Graber 1996). Nearly one-quarter (24%) of

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

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those dependent on the riparian community area are at risk of extinction (Graber 1996).

Until the 1960s, the ecological importance of riparian areas in mountain regions was largely undescribed in the scientific literature (Kauffman 1988). In the Sierra Nevada, little has been published on riparian areas per se, although the importance of riparian areas is implied by the habitat descriptions for many species. Interest in riparian areas in California has been growing over the past two decades, but most research has focused on the Central Valley or Coast Ranges. For example, in the proceedings of a conference held in 1988 on riparian habitat in California (Abell 1989), 46 papers concerned the Central Valley or Coast Range riparian systems and only 17 concerned Sierra Nevada (mostly eastern or southern) riparian systems.

In the 1980s, a proliferation of proposals for small hydroelectric developments generated a number of mostly site-specific studies on the environmental effects of proposed hydroelectric projects (e.g., Taylor 1983; Harris et al. 1987; Kondolf et al. 1987b; Jones and Stokes Associates 1989; Smith et al. 1989; Nachlinger et al. 1989; Leighton and Risser 1989; Hicks 1995).

Land-management agencies have conducted studies of riparian areas as a component of other assessments or planning studies. Mono County is conducting detailed mapping of wetlands, including riparian areas (R. Curry, University of California, Santa Cruz, communication with R. Kattelmann, 1995). Riparian areas along streams tributary to Mono Lake have been studied by a National Academy of Sciences committee (National Research Council 1987), on behalf of parties to litigation over flow requirements for resident trout (Stromberg and Patten 1990), in support of a water rights adjudication (Stine 1991; State Water Resources Control Board 1994), and in related studies (Kondolf and Vorster 1993). The California Tahoe Conservancy is attempting to evaluate the health of riparian vegetation along streams tributary to Lake Tahoe using remotely sensed data and field observations (Manley 1995). In many cases, these site-specific studies have been sufficiently well funded and implemented that they provide valuable insights into the physical and ecological processes controlling the distribution and functioning of riparian vegetation. However, most have been concentrated in the Mono Basin, Lake Tahoe, or Kern River regions.

Attempts at a broader scale assessment of riparian conditions have been undertaken by the Bureau of Land Management (Myers 1987) and the U.S. Forest Service (e.g., U.S. Forest Service 1995). Unfortunately, inconsistencies in data collection, analysis, and reporting have inhibited the compilation of these various data into a coherent assessment of riparian conditions across the entire range. Moreover, many assessments, such as those undertaken by the national forests, have been conducted without the benefit of peer review of procedures or results, and some are based largely on subjective judgments of channel stability by nongeomorphologists and thus contribute little to a scientifically based understanding of the status of riparian systems in the Sierra Nevada.

METHODS AND SCOPE

This chapter provides an overview of the functioning and ecological importance of riparian areas, the effects of human activities on riparian areas, and the extent of these impacts in the Sierra Nevada, based largely on a more detailed report (Kattelmann and Embury 1996). Although the continuity of riparian corridors was assessed from aerial photography of a sample of river systems over the entire Sierra Nevada, the effects of human activities upon riparian areas are merely inferred from the extent of human activities known to affect the extent or functioning of riparian vegetation. Direct measurement of riparian condition over a region as large as the Sierra Nevada was beyond the scope of this study.

A literature review was conducted on the ecological role of riparian areas, the physical conditions on which they depend, and the effect of human activities on riparian areas in general. These extensive references are summarized in tables (reviewed in more detail in Kattelmann and Embury 1996), and are generally not repeated in the text. Literature documenting physical and biological aspects of riparian areas in the Sierra Nevada was also reviewed, but this literature is relatively modest and does not reflect the full range of conditions found in the Sierra Nevada.

The courses of all rivers and streams appearing on U.S. Geological Survey (USGS) 1:100,000 topographic maps were examined to identify gaps greater than 0.5 km (0.3 mi) in the riparian corridor produced by reservoirs. The total length of inundated channel was estimated by assuming straight-line distances for channels under existing reservoirs.

More than 9,500 km (5,900 mi) of river and stream channel was examined on aerial photographs to identify gaps in the riparian corridor. Out of 694 Sierra Nevada Calwater Super-Planning Watersheds, as designated by the California Department of Forestry and Fire Protection (1996), 130 were selected for aerial photographic study. All blue-line channels appearing on USGS 1:100,000 scale maps were examined. Aerial photographs for most national forests were taken in 1991–93, but coverage for other watersheds dates back as far as 1981. Details of coverage, scale, and methods of assessment are presented in Kattelmann and Embury 1996. Aerial photographs provide little or no information on the condition of riparian vegetation below the canopy, and the small scale of the photos used limited the utility of this analysis to an assessment of canopy continuity (riparian fragmentation).

A more systematic analysis was conducted using a geographic information system (GIS) developed for the Sierra Nevada Ecosystem Project. For 141 Calwater Hydrologic Subareas (California Department of Forestry and Fire Protection

1996) in the Sierra Nevada study region (four subareas were omitted because they were reservoirs), the number of pixels (each 100 m by 100 m, or 1 ha [2.47 acres]) in which a road occurs was counted, and the number of pixels with a stream was counted. Sources of the digital road information were the U.S. Forest Service road layer of "system roads" for areas inside proclaimed boundaries of national forests and the Teale data center (1:100,000) for areas outside the proclaimed boundaries. Of the total number of pixels with streams, the percentage that also had roads was calculated, a statistic that can be restated as the percentage of stream length with a road within 100 m (328 ft) of the channel—a gross measure of the potential impact of roads upon streams. These percentages for each watershed were compiled for the entire Sierra Nevada and for the northern (north of Interstate 80), central (Merced River basin to I-80), southern (south of Merced River basin), and eastern (east of the divide, excluding Lake Tahoe) Sierra Nevada. For each data set, percentile values (10th, 25th, 50th, 75th, and 90th percentiles) were determined and box-and-whisker plots (modified from Tukey 1977) were generated to display the spread of values among individual watersheds.

We also convened a group of scientists familiar with riparian management issues in the Sierra Nevada to review an early draft of Kattelmann and Embury 1996, to discuss the topic, to contribute ideas and other published research to the review, and to consider how best to approach this broad subject. The comments received from this group were extremely helpful in preparing this chapter.

FINDINGS

Ecological Role of Riparian Areas

Riparian vegetation is vegetation associated with rivers, streams, and other aquatic systems (lakes, springs, seeps, wet meadows). The term has been variously defined, from meanings that restrict the term to vegetation occurring on the river banks (as implied by the Latin root ripa, bank) to more inclusive definitions that encompass floodplain and terrace vegetation as well. Bottomland vegetation is another term for the latter, more inclusive definition of riparian vegetation (e.g., Hupp 1986). Water-dependent vegetation found at springs and seeps is often referred to as riparian despite the lack of association with a stream or river. Our review and assessment has concentrated on the riparian areas associated with running water. Riparian vegetation is also distinguished as obligate, for species found only in riparian areas, and facultative, for species that commonly occur in riparian areas but that also occur in upland environments.

Individual riparian species are adapted to a range of conditions within the riparian zone, along gradients of water table depth, soil moisture, and frequency of disturbance. Characteristics typical of obligate riparian vegetation are dependence on a high water table, tolerance to inundation and soil anoxia, tolerance to physical damage from floods, tolerance to burial by sediment, ability to colonize flood-scoured surfaces or fresh deposits, and ability to colonize and grow in substrates with few soil nutrients. The relative importance of these characteristics varies with the river system. In the Sierra Nevada, dependence on high water tables and ability to survive physical damage from high-velocity flood flows are important characteristics of riparian vegetation, whereas along the coastal plain rivers of southeastern North America, tolerance of prolonged inundation is more important.

The ecological importance of riparian areas derives from a range of attributes, such as moisture availability, structural complexity, linear continuity (for migration corridors), distinct microclimate (cooler in summer, protected in winter), diverse food resources (terrestrial and aquatic), and influence on aquatic habitat (table 36.1). Riparian vegetation has a greater influence on channel processes and aquatic habitat in smaller channels than in larger ones. The effect of roots in stabilizing banks, the role of large woody debris in channel processes, the importance of terrestrial food sources as opposed to autochthonous (within channel) food production, and the shading effect of bank vegetation are all relatively more important in small channels (Vannote et al. 1980).

Geomorphic and hydrologic processes and conditions important to riparian ecology include flood inundation, the physical effects of high-velocity flood flows, stream-groundwater interactions, and the extent and texture of alluvium and adjacent hill-slope soils (table 36.2). The relative importance of these physical controls, like that of vegetation, differs among riparian systems. Altering these controls can be expected to alter the distribution and structure of riparian vegetation.

Human Impacts on Riparian Areas

A wide range of human activities can affect riparian areas, either by direct removal of riparian vegetation or by altering the factors controlling the distribution and structure of riparian vegetation (table 36.3). The following paragraphs briefly review these impacts and consider their relative importance in the Sierra Nevada.

Gold mining has numerous effects on riparian vegetation, including the destruction of riparian bottomland forests for gold dredging, the damming and diversion of rivers, and increased sediment yield from hydraulic mining. Gold mining was extensive in the Sierra Nevada beginning in about 1850 (see Beesley 1996). To provide water and pressure for hydraulic mining, ambitious water diversion projects were undertaken, resulting in the dewatering of some reaches and the creation of new riparian habitats along artificial canals. The mining itself released more than 42 million m^3 (46 million yards^3) of sediment into steep canyons, burying existing vegetation before being flushed downstream for deposition in channels and on floodplains of rivers in the Central Valley

TABLE 36.1

Ecological attributes of riparian areas.

General Attribute	Specific Attributes	References
Moisture availability	Shallow water table supports phreatophytes	California State Lands Commission 1993
	Evapotranspiration, shading increase humidity	
	Moist environments for amphibians, reptiles	Reynolds et al. 1993; Jennings 1996
Structural complexity	Vegetation provides cover for wildlife, birds	
	Multiple plant canopies create multiple niches	Krzysik 1990
	Seasonal changes in deciduous vegetation	Reynolds et al. 1993
Periodic disturbance	Floods disrupt existing organisms, providing opportunities for pioneer species	Resh et al. 1988; Sparks et al. 1990; Junk et al.1989
Linear nature	Edge effect: terrestrial-aquatic ecotone	Schimer and Zalewski 1992
	Riparian zones serve as wildlife migration corridors	Thomas et al. 1979
Food resources	Diverse vegetation yields diverse foods	Cross 1988
	Diverse habitat harbors diverse prey	Raedeke et al. 1988
	Open water available for wildlife	
Microclimate	Shaded, cool, moist in summer	Raedeke et al. 1988
	Protected in winter: overwintering habitat	
Influences on aquatic habitat	Shading moderates water temperatures	Brown 1969
	Shading moderates algal growth	
	Plant materials and insects fall into stream, adding chemical energy and nitrogen	Cummins et al. 1989; Knight and Bottorff 1984
	Riparian zone “buffers” stream from upland	Erman and Mahoney 1983; Mahoney and Erman 1984
	Riparian vegetation stabilizes stream banks	Kondolf and Curry 1986

and San Francisco Bay (Gilbert 1917; Mount 1995). Along the Yuba River above Marysville, the “debris plain” built of these sediments exceeds 64 km^2 (40 mi^2) in area.

A later phase of mining involved dredgers. These reworked the natural floodplains or hydraulic mining debris and left behind elongated mounds of tailings, which are still largely unvegetated because their surfaces consist of open cobbles in which plants cannot become established. The dredgers required extensive, deep, relatively flat deposits to work, so they were concentrated in the lower Central Valley reaches of western Sierra Nevada rivers.

Gravel mining for construction aggregate from river channels and floodplains results in the direct removal of riparian vegetation for the creation of process yards, haul roads, and pits. Indirect effects of in-channel extraction typically include channel incision, which propagates both upstream and downstream, lowering the alluvial water table and inducing channel instability.

Gravel mining for construction aggregate is the largest mining industry in the state (see Diggles et al. 1996). More than 100 million metric tons are produced annually, virtually all from river channels and floodplains. Large gravel depos-

TABLE 36.2

Selected geomorphic and hydrologic processes in riparian areas.

Process	Physical Effect	Ecological Consequence	Reference
Flooding			
Inundation	Soil anoxia	Selects for plants tolerant of anoxia	Walters et al. 1980; Gill 1970
	Saturation of soil	Increases soil moisture	
High-velocity flow	Scour of seedlings	Prevents establishment of woody vegetation in channel	
	Physical damage to plants	Selects for tolerant plants	Sigafoos 1964
	Bank erosion and undercutting of mature vegetation	Creates new habitats for colonization	
Deposition	Burial of plants	Selects for tolerant plants	Sigafoos 1964
	Sand-gravel bar deposition	Selects for plants capable of colonizing sandy substrates	
	Fine-grained overbank deposition	Provides silty substrates	
Stream-Groundwater Interactions			
Drainage from hill slope	Maintains high water table	Supports vegetation independent of streamflow	
Bank storage	Recharges alluvial water table	Supports vegetation	Kondolf et al. 1987a
	Maintains base flow	Provides water downstream	

TABLE 36.3

Human activities, physical effects, and ecological consequences in riparian areas.

Activity and Potential Direct Physical Effects	Potential Ecological Consequences	References
Gold Mining		
Former floodplain forests reworked by placer mining into unvegetated dredger tailings	Riparian vegetation removed and replaced with unvegetated gravel	Clark 1970
Rivers and streams dammed and diverted through canals	Water stress in dewatered reaches, riparian vegetation established along canals and ditches	Averill 1946; Pagenhart 1969
Increased sediment from hydraulic mining debris leads to aggradation of sand and gravel in valley bottoms	Burial of existing vegetation	Gilbert 1917
Continued erosion from hydraulic mine sites	Elevated fine sediment loads affect aquatic biota	Marchetti 1994
Gravel Mining		
Direct removal of vegetation for gravel yards, processing plants, haul roads, pits	Riparian vegetation replaced by roads and industrial land use	Poulin et al. 1994
Mining-induced channel incision lowers alluvial water table	Increased mortality, decreased growth rate and crown volume in woody riparian vegetation	Kondolf 1994b; Scott et al. in press
Mining-induced channel instability results in increased bank erosion	Erosion of banks supporting riparian vegetation	Todd 1989
Mining tops of gravel bars (“skimming”) lowers ground surface relative to water table	Riparian vegetation established in channel where water table was formerly too deep	Kondolf and Matthews 1993
Dams		
Reduced flood flows lead to reduced rate of channel migration	Reduced diversity of riparian habitats	Johnson 1992, 1994; Ligon et al. 1995; Hesse and Sheets 1993
Reduced flood flows eliminate frequent scour of active channel	Riparian vegetation encroaches into active channel	Williams and Wolman 1984; Bergman and Sullivan 1963; Brothers 1984
Increased base flows and raised alluvial water table	Waterlogging of vegetation	Parrish and Matthews 1993
Base flows reduced or eliminated, stream dries up	Riparian vegetation severely stressed or dies	Kondolf and Vorster 1993; Stine et al. 1984
Trapping of bedload sediments behind dam, release of sediment-starved water, channel incision	Alluvial water table drops and overbank flooding is less frequent due to channel incision	Williams and Wolman 1984
Reservoirs drown existing vegetation, fluctuating water levels may limit establishment of new vegetation along margins	Longitudinal continuity of riparian corridor interrupted	Hagan and Roberts 1973
Hydroelectric Generation		
Rivers and streams dammed and diverted through canals	Water stress in dewatered reaches, riparian vegetation established along canals and ditches	Harris et al. 1987; Kondolf et al. 1987b
Hydroelectric dams and associated canals, penstocks, power-houses, and access roads constructed within riparian zone	Riparian vegetation removed and replaced with roads and structures	Federal Energy Regulatory Commission 1986
Flow fluctuates rapidly to generate peak hydroelectric power	Rapid stage changes can lead to increased bank erosion	
Irrigation		
Water diverted from streams	Water stress in dewatered reaches, riparian vegetation established along canals and ditches	Erman 1992
Irrigation water may infiltrate, recharging groundwater	Excess irrigation water may support vegetation	Kondolf and Vorster 1993
Land Drainage		
Alluvial water table lowered by land drainage	Riparian plants desiccated	Hughes 1934
Land Clearance for Agriculture		
Removal of floodplain forest	Riparian vegetation removed and replaced with agricultural land	Katibah et al. 1984
Phreatophyte Removal		
Removal of riparian vegetation	Riparian vegetation removed, may require herbicides to prevent regrowth	Dunford and Fletcher 1947; Biswell 1989
Navigation		
Channel dredged, resulting in incision	Alluvial water table drops and overbank flooding is less frequent due to channel incision	Brookes 1988
Channel straightened and stabilized	Length, complexity, and dynamic nature of channel reduced	Brookes 1988
Timber Harvest		
Harvest of timber in riparian areas, removal of trees for logging road construction	Direct loss of large trees in riparian areas, reduction in structural complexity, elimination of supply of large woody debris to channel	Gregory et al. 1991; Maser and Sedell 1994
Log transport on rivers erodes banks, simplifies channel geometry	Habitat complexity reduced	Sedell and Luchessa 1981
Removal of timber on hill slopes, resulting in increased peak runoff and erosion	Bank erosion, conversion of vegetated bottomland into open gravel-bed channel	Lyons and Beschta 1983; Grant 1988

continued

TABLE 36.3 (continued)

Activity and Potential Direct Physical Effects	Potential Ecological Consequences	References
Road and Railroad Construction		
Railroads and highways often follow rivers, built along banks of river	Riparian habitat replaced by railroad or highway for long distances along one bank	Scheidt 1967
Railroads and highways cross rivers	Continuity of riparian corridor interrupted by gaps at crossings	Furniss et al. 1991
Failure of roads and culverts delivers sediment to channel	Sediment reduces invertebrate habitat and populations	Erman et al. 1977
Urbanization		
Settlement along riverbanks and on bottomlands	Riparian habitat replaced by urban infrastructure	Medina 1990
Increased impervious surface upstream increases peak runoff, induces channel widening, incision	Water table may fall with incising channel, resulting in moisture stress to vegetation	Dunne and Leopold 1978; Booth 1990
Land drainage to make land suitable for development	Desiccation of riparian vegetation	National Research Council 1992
Channel relocation or channelization for flood control	Engineered channel margins rarely provide suitable conditions for establishment of riparian vegetation	Brookes 1988
Grazing		
Livestock trample and compact banks	Prevent establishment of vegetation, crush amphibians	Armour et al. 1991; Chaney et al 1990; Jennings 1996
Livestock hooves chisel banks	Destroy existing vegetation, destroy undercut banks, contribute to channel widening	USFS 1995; Overton et al. 1994; Kondolf 1994c
Livestock browse seedlings	Recruitment of young woody riparian plants prevented	Platts 1991
Removal of vegetation and compaction in watershed leads increased peak runoff and erosion, possibly to decreased to base flow	Erosion of banks supporting riparian vegetation	Behnke and Raleigh 1979; Platts 1991; Dudley and Dietrich 1995
Previously listed factors lead to incision of channels, especially in meadows	Water table drops, desiccating wetland species	Odion et al. 1990
Lack of bank vegetation and undercut banks, channel widening,and higher water temperatures	Reduced fish populations, reduced invertebrate populations	Behnke and Raleigh 1979; Armour et al. 1991; Herbst and Knapp 1995
Groundwater Abstraction		
Groundwater pumping lowers alluvial water table	Water table may fall below root zone of riparian plants, inducing moisture stress or death	Kondolf and Curry 1986
Recreation		
Heavy foot traffic tramples vegetation, compacts soil, and physically damages bank	Loss of riparian vegetation, creation of bare banks prone to erosion	Liddle 1975; Madej et al. 1994
Trails (foot, horse, bicycle, motorcycle) often follow streams	Riparian vegetation removed and replaced by trail; continuity of riparian corridor interrupted at crossings	Holmes 1979; Lemons 1979

its tend to occur in wider alluvial reaches, and thus mining is concentrated in foothill and valley reaches of Sierran rivers, although mines are also active along the upper reaches of the Feather and Yuba Rivers (California State Lands Commission 1993) and the American River (Kondolf and Matthews 1993).

Dams have direct effects from the permanently removal of riparian habitat to construct roads, penstocks, powerhouses, canals, and dams. Reservoirs drown existing riparian vegetation, and fluctuating water levels usually prevent the establishment of comparable new vegetation stands along reservoir margins. Thus, reservoirs constitute significant gaps in the riparian corridors. The largest reservoirs are located in the foothills, but reservoirs large enough to constitute significant gaps occur at virtually all elevations, as reflected in plots of reservoirs by elevation for the Sacramento and San Joaquin River basins (figures 36.1 and 36.2). Maps of reservoir numbers and capacity by watershed reflect the widespread occurrence of reservoirs throughout the range, with greater capacity in the central Sierra Nevada (figure 36.3).

Indirect effects of dams derive from changes in the flow regime and sediment load on downstream channels. Reduction in floods leads to reduced rates of channel migration (which in turn reduces the diversity of riparian habitats) and to the encroachment of vegetation into (and thus the narrowing of) the active channel. Most vegetation encroachment and channel narrowing in Sierran rivers has been reported below large reservoirs in the foothills (Pelzman 1973), whose storage is adequate to substantially reduce flood flows. Large reservoirs are less common but do occur at higher elevations. Most have not been studied, but many would likely evince encroachment and narrowing downstream, as observed on the North Fork Kings River (Taylor and Davilla 1985).

By storing water during winter and spring for subsequent release, reservoirs can increase base flows, which can, in turn, waterlog riparian vegetation accustomed to well-drained conditions in late summer and fall. Summer base flows on the North Fork Stanislaus River have increased tenfold as a result of storage in a hydroelectric project, and mortality of many riparian trees has been predicted (Parrish and Matthews 1993). Where reservoir water is exported from the basin, base flows can be reduced. On Rush Creek, the principal tributary to Mono Lake, no regular base flow releases were made from

Grant Lake Reservoir from 1941 to 1981, and a massive die-off of woody riparian vegetation ensued (Stine et al. 1984).

Reservoirs also trap the coarser (sand and gravel) portion of the sediment load and some fraction of the suspended load (depending upon the capacity of the reservoir relative to inflow). As a result, reservoir releases are typically sediment starved—they have the energy to transport sediment but are deprived of this load. As a result they tend to erode their bed and banks (Williams and Wolman 1984). If the channel incises, the alluvial water table will probably drop, resulting in moisture stress for the riparian vegetation adapted to the previous water table.

Hydroelectric generation entails most of the effects of dams where storage is involved, but has a somewhat different suite of effects if the project involves diversion but no storage—a run-of-the-river project (figure 36.4). Small diversions are common in the Sierra Nevada, either for small run-of-the-river projects, or for seasonal diversion via tunnels into storage reservoirs in adjacent drainages (see Kattelmann 1996).

Irrigation usually involves storage reservoirs so that water is available during the growing season. Thus, irrigation projects typically involve many of the same effects as those described for dams, and because they cause a net decrease in river flow, irrigation projects dewater river reaches. Small fish can be pulled into unscreened diversions and killed when they are discharged onto agricultural fields. Excess irrigation water can support riparian vegetation in artificially created wetlands, fed either by surface flows or groundwater recharged by excess irrigation waters. Along Rush Creek in Mono Basin, excess irrigation water infiltrated into permeable bedrock and reemerged downstream as springs. This process maintained high water tables, reestablished perennial flow, and thereby supported riparian vegetation even when diversion had completely dried the channel upstream (Kondolf and Vorster 1993). The combination of dams and diversions results in impacts in the majority of watersheds of the Sierra Nevada (figure 36.3d). Although few large dams are found in the northern region of the study area, this region has in general a higher density of diversions than other regions.

Most large irrigation storage reservoirs on Sierran rivers are in the foothills; irrigation diversion from Friant Dam and downstream diversions completely dries up the San Joaquin River annually at Gravelly Ford. Seasonal diversions without storage were used to irrigate farmland on the Bishop Creek alluvial fan by Native Americans and subsequent European settlers. These irrigation canals now support lush riparian vegetation (Federal Energy Regulatory Commission 1986). A seasonal irrigation diversion on the Little Truckee River reduced flows and resulted in channel widening downstream (Erman 1992).

Land drainage (usually for agriculture or urbanization) results in desiccation of wetland plants. Drainage of former meadows has been common around Lake Tahoe, resulting in loss of many riparian plants and invasion by upland species. Probably the most widespread land drainage in the Sierra Nevada has been in wet meadows, which have been drained deliberately (documented as early as the 1870s, as in the dynamiting of a moraine in Yosemite Valley by Galen Clark to drain upstream meadows) (Greene 1987) and inadvertently because of channel incision (generally attributed to effects of livestock grazing) (e.g., Odion et al. 1990).

Land clearance for agriculture has been most common in wide alluvial reaches in the foothills and Central Valley, where formerly extensive bottomland forests were cleared, leaving only a narrow band of riparian vegetation (if any) along the bank.

Removal of vegetation was undertaken in the southwestern United States, mostly on an experimental basis, to reduce water “losses” to evapotranspiration by phreatophytes. Although some phreatophytes were eliminated in the Sierra Nevada (Biswell 1989), the environmental impacts of this practice (Campbell 1970) are generally acknowledged to be too great to justify it. Nonetheless, an increased water yield anticipated as a result of forest harvesting (mostly upland) has been factored into the national forest planning process in California. The Sequoia National Forest attributed 30% of the “benefits” from its preferred alternative of the latest forest plan to the supposed value of increased water expected as a by-product of timber harvest (U.S. Forest Service 1988).

Navigation by large ships commonly requires channel dredging and straightening, mostly undertaken in lower, valley reaches of rivers, downstream of the study area.

Timber harvest affects riparian vegetation directly and indirectly. Riparian vegetation has been removed in harvests of bottomland forests, and the construction of logging roads along bottomlands replaces riparian vegetation with road surface. Past log drives down rivers resulted in extensive battering of banks, reducing habitat complexity along the water’s edge. Removal of timber on hill slopes, along with road construction and skid trail compaction, typically results in increased peak runoff and increased erosion. These so-called cumulative effects can degrade aquatic habitat and can potentially lead to the erosion of banks supporting riparian vegetation and the conversion of well-vegetated valley bottoms into wide, open, gravel bed channels (Grant 1988; Lyons and Beschta 1983).

Timber harvest has been extensive in the Sierra Nevada. Riparian trees, notably giant sequoia and other old-growth stands on bottomlands of Sierran rivers have been harvested, directly affecting bank vegetation and aquatic habitat. Franklin and Fites-Kaufmann (1996) found that 95% of the 1,200 ha (3,000 acres) separately mapped as riparian hardwood forest type had no late successional/old growth characteristics left, although deep, inaccessible river canyons with other forest types contained some of best remaining examples of old growth. Given that average angular canopy densities (canopy measured at an angle that effectively blocks summer sun) of 75% were observed on unlogged first- and second-order channels in the northern Sierra Nevada (Erman et al. 1977), removal of riparian trees has a tremendous effect on aquatic habitat.

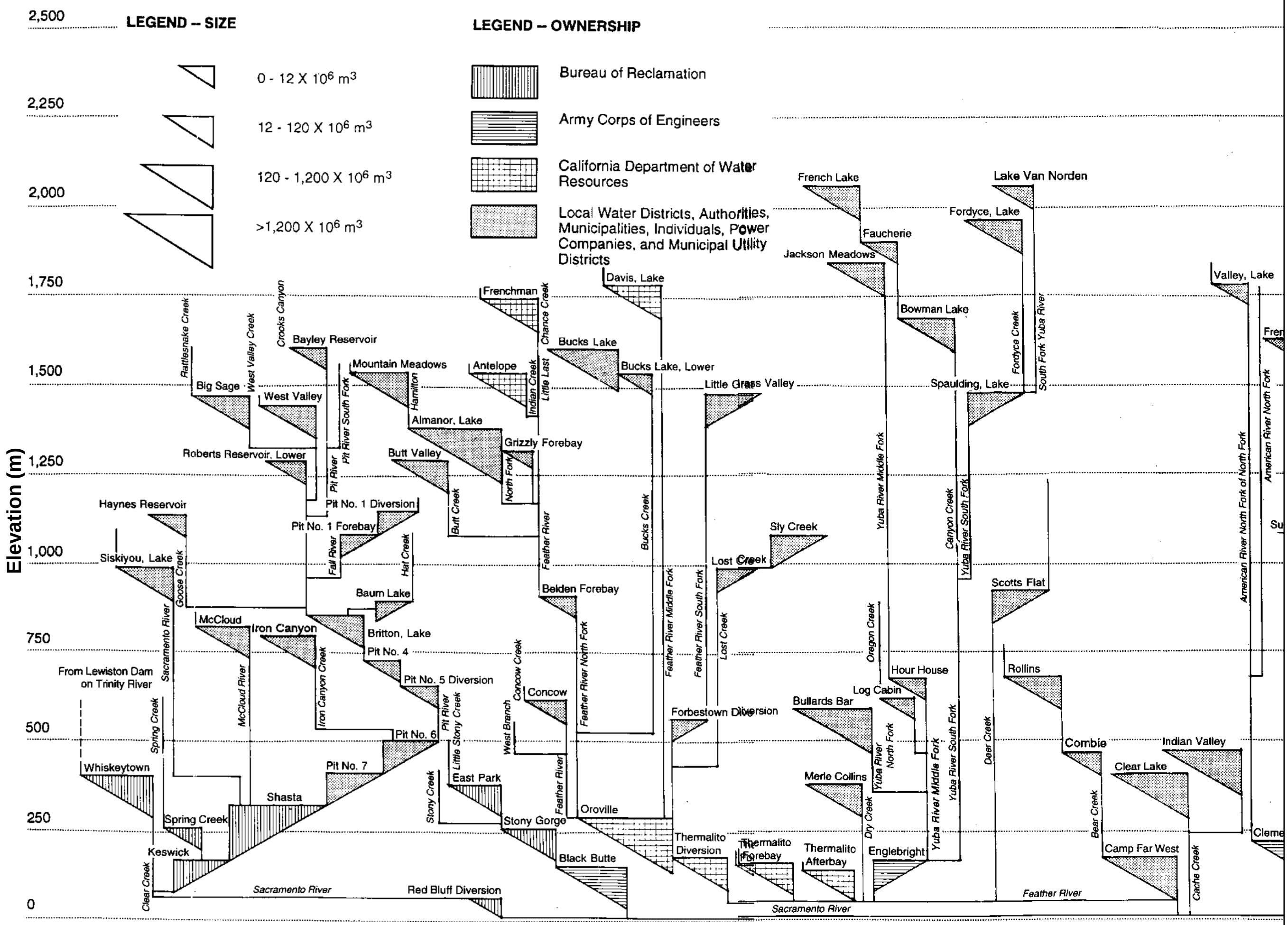


FIGURE 36.1

Schematic diagram of reservoirs in the Sacramento River basin, plotted by elevation. Reservoirs are included from two Coast Range drainages: Stony Creek (East Park, Stony Gorge, and Black Butte) and Putah Creek (Lake Berryessa and Solano Lake) and from the upper Sacramento River drainage that lies north of the Sierra Nevada. Otherwise, all reservoirs shown are in the Sierra Nevada or its foothills. (Adapted from a plot prepared by the California State Water Resources Control Board, Graphic Unit.)

The cumulative effects of timber harvest are widespread but poorly documented in the Sierra Nevada. Most of the timberlands in the Sierra Nevada lie within national forests. Despite this single ownership of large areas, and despite the mandate for the Forest Service (and other agencies) to analyze cumulative impacts of forest management activities, very little basic data collection on peak stream flow and sediment yield (the variables likely to be affected by timber harvest) is undertaken on the forests. Most field data collection and office analyses are apparently devoted to cumulative effects "assessment methods" (see Berg et al. 1996) that primarily involve office-based computations of such variables as area of road surface and timber harvest within a watershed to predict cumulative impacts. These computations of effects are not verified by actual field measurements of peak flow or sediment yield, and in some cases, the results of these "methods" have been contradicted by field observations of Forest Service biologists (Kondolf 1994a).

Railroads and roads commonly follow rivers, taking advantage of flat bottomland and linking riverside settlements. These railroads and roads (and the additional settlement generated along them) displace riparian vegetation on the floodplain. In narrow canyons with limited bottomland, roads and railroads are commonly located along the riverbank itself,

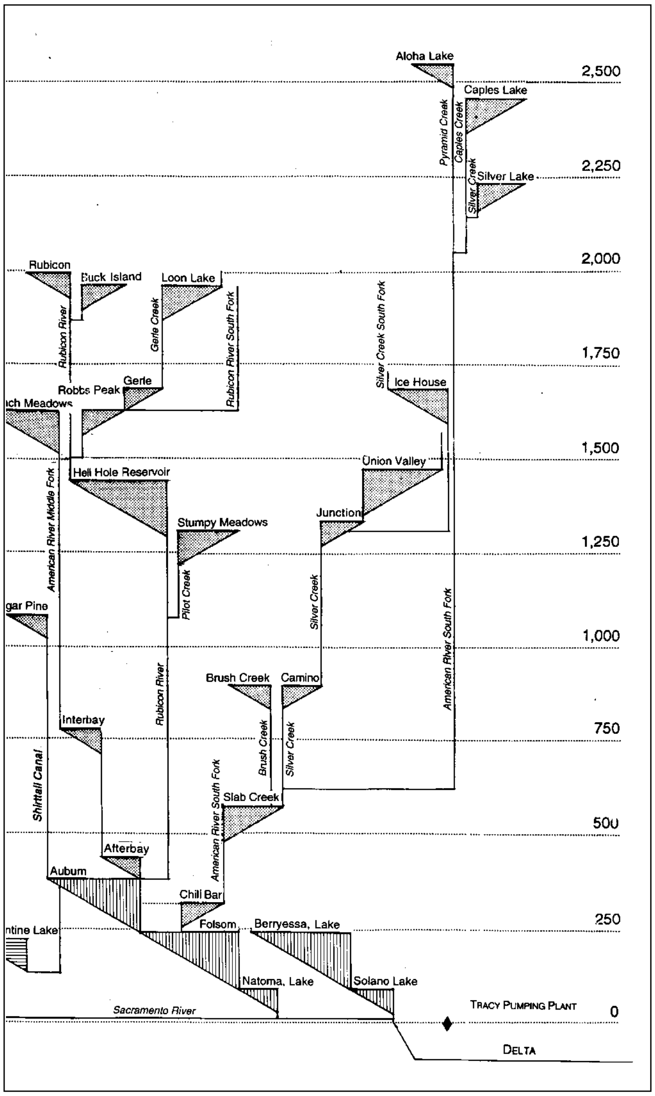


FIGURE 36.1 (continued)

replacing overhanging bank vegetation with riprap, which tends to narrow the channel with artificial fill. Even in the absence of these longitudinal impacts, the continuity of the riparian corridor is interrupted at each bridge crossing. Concentrated road runoff commonly carves gullies, and unpaved logging roads and their culvert crossings may wash out during storms, delivering pulses of sediment to the channel and degrading aquatic habitat and water quality.

Roads and railroads cross most of the Sierra Nevada, as indicated by the results of the GIS analysis of road influences on streams and by the aerial photographic analysis of riparian corridor gaps discussed later.

Urbanization has occurred historically along bottomlands because of the flat land, proximity to water, and connection to communication and trade routes that often followed rivers. When such urbanization occurs, buildings, streets, parking lots, and other urban infrastructure directly displace riparian vegetation. The impervious surfaces of rooftops and pavement result in greater surface runoff per unit of precipitation, increasing peak flows and commonly inducing channel incision, bank erosion, and a drop in the water table (which may desiccate riparian plants) (Dunne and Leopold 1978). Sites with shallow water tables may be deliberately drained to permit development, resulting in desiccation of riparian vegetation. As floodplains are urbanized, flood damages increase by virtue of the increased value of the flood-prone land (whether the floods be naturally occurring or exacerbated by land-use change). Thus, urbanization commonly creates a demand for flood control, which involves structural measures such as channelization or levee construction, in turn reducing or eliminating riparian habitat.

Since the 1940s, California has experienced tremendous population increases and corresponding urbanization. From 1980 to 1990, the state’s population increased from 24 million to 30 million (California Department of Finance 1990). From 1984 to 1990, urban land area increased by 123,000 ha (303,810 acres) in the 42-county state Office of Land Conservation farmland mapping area (California Office of Land Conservation 1988, 1990, 1992). In the last two decades an increasing proportion of the population increase has been accommodated by dispersed “ranchette” settlement in rural counties of the Sierra Nevada (see Duane 1996). This increased urbanization pressure has effects on riparian areas ranging from direct urbanization (riparian areas are often preferred sites for ranchettes), to fragmentation by roads and other infrastructure to support urbanization in uplands, to hydrologic changes induced by urbanization in the watersheds, to increased use of riparian areas by humans and domestic pets.

Grazing by livestock results in the trampling and compaction of riparian areas, the direct destruction of bank vegetation by bank through the chiseling of banks by hooves, and the elimination of recruitment of young woody riparian plants through browsing (Armour et al. 1991; Platts 1991; Menke et al. 1996). The lack of bank vegetation eliminates shading and terrestrial food sources for the channel, and reduces the stability of the bank. Grazing throughout a watershed can increase peak runoff and erosion rates, leading to channel incision (and thus lowered alluvial water tables and desiccation of riparian plants), bank erosion, and increasing fine sediment content in channels (Behnke and Raleigh 1979). Grazing is commonly concentrated in riparian areas because of vegetation supported by the greater moisture availability and because the stream provides drinking water.

Grazing by livestock was virtually ubiquitous in the Sierra Nevada from the nineteenth century through 1930 (Vankat and Major 1978; McKelvey and Johnston 1992; Kinney 1996),

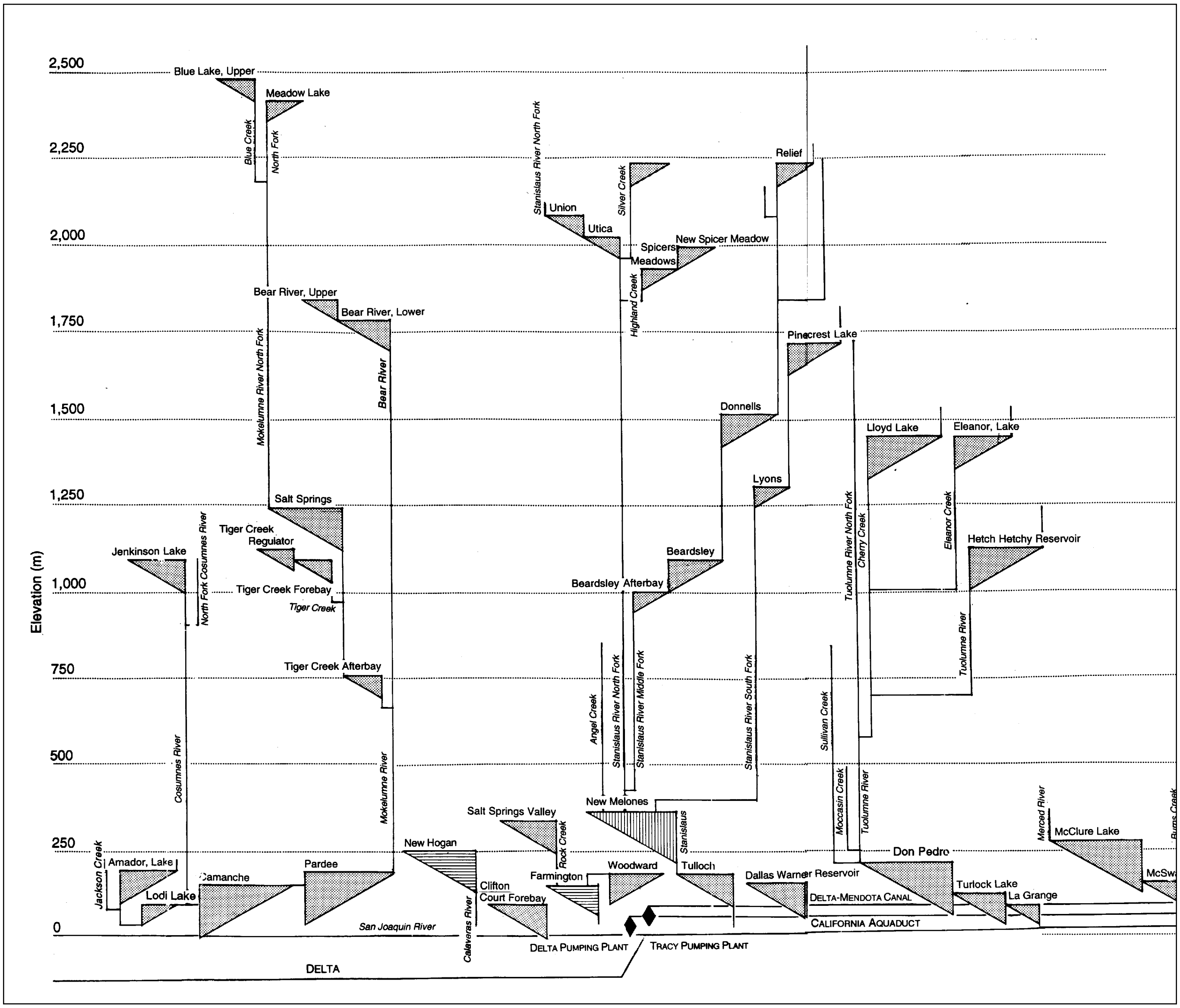


FIGURE 36.2

Schematic diagram of reservoirs in the San Joaquin River basin, plotted by elevation. Clifton Court forebay and four storage reservoirs in the Coast Ranges (San Luis, Little Panoche, O'Neil, and Los Banos) are included. Otherwise, all reservoirs shown are in the Sierra Nevada or its foothills. (Adapted from a plot prepared by the California State Water Resources Control Board, Graphic Unit.)

with heavy grazing even in many high-elevation meadows that remain inaccessible to vehicles today (Dudley and Embury 1995). As a result, channel incision and desiccation of meadow vegetation has been widespread in the Sierra Nevada. Grazing and its effects have been so pervasive and ubiquitous throughout the American West that virtually no unaffected "control" conditions exist for comparison, and what most people would regard as "natural" conditions are in fact influenced by historical (if not current) grazing (Elmore and Beschta 1987). Our best comparisons are derived from studies of vegetation and channel recovery when streams are excluded from grazing, but channel conditions may be slow to recover from grazing effects (Kondolf 1993).

Groundwater abstraction for municipal or agricultural use can reduce alluvial water tables, stressing or killing riparian vegetation (Kondolf and Curry 1986; Wright and Berrie 1987). Groundwater pumping in the Owens Valley has had the greatest documented effects on vegetation known in the Sierra Nevada region (Perkins et al. 1984; Groeneveld and Or 1994).

Recreation can affect riparian corridors through the concen-

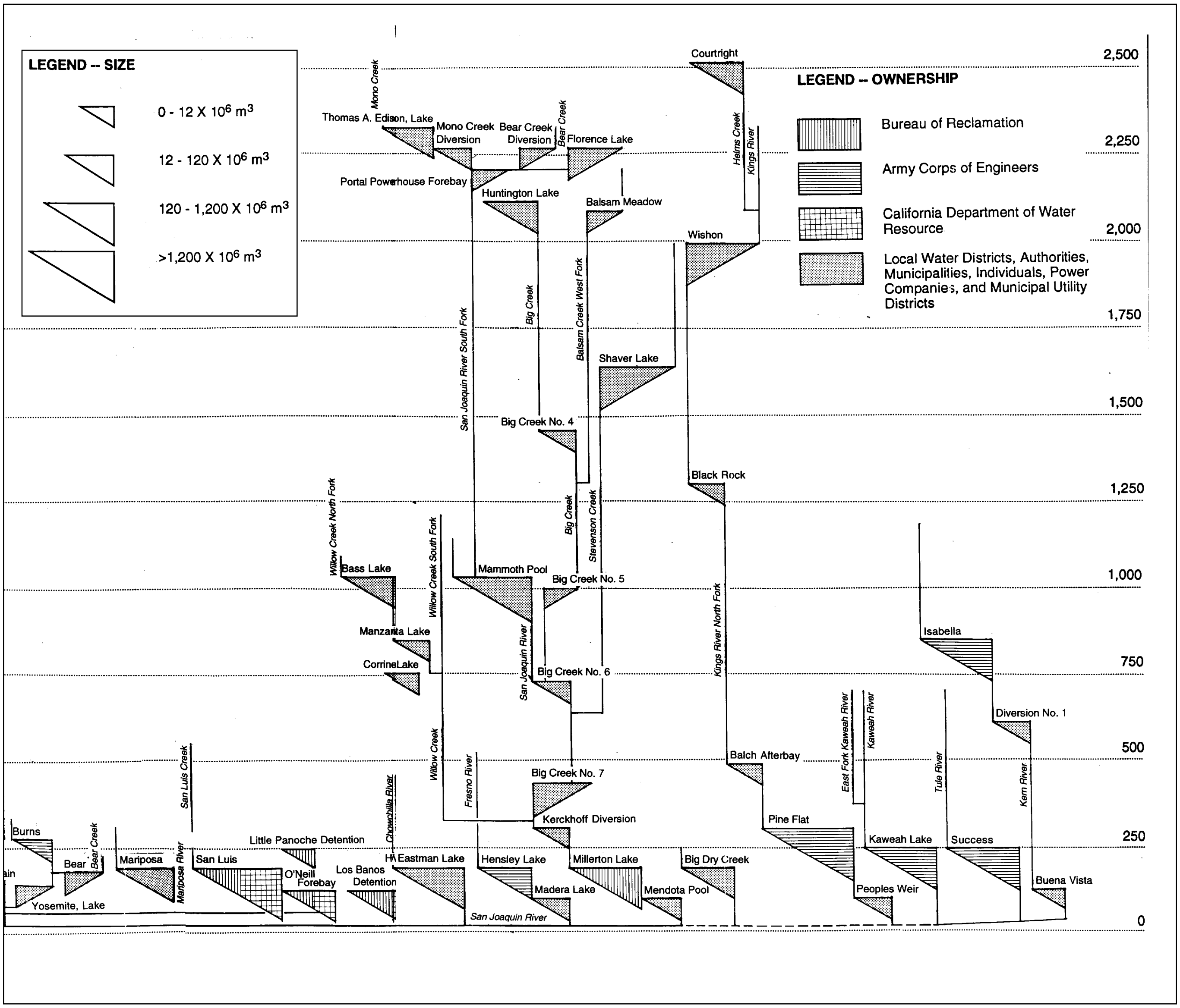


FIGURE 36.2 (continued)

tration of people along riverbanks: heavy foot traffic tramples vegetation, compacts soils, and can physically damage banks (Liddle 1975). Trails (foot, horse, bicycle, or motorcycle) replace riparian vegetation with pavement or bare, compacted earth and bring people into the riparian zone where they are then more likely to concentrate on banks, with the effects just described. Heavy concentration of anglers on the banks may have similar effects. These effects have been documented along the Merced River in Yosemite National Park (Madej et al. 1994) and are probably concentrated near popular campgrounds throughout the Sierra Nevada, but their overall extent has not been documented. Most national forest campgrounds in the Sierra Nevada are located in or near riparian areas.

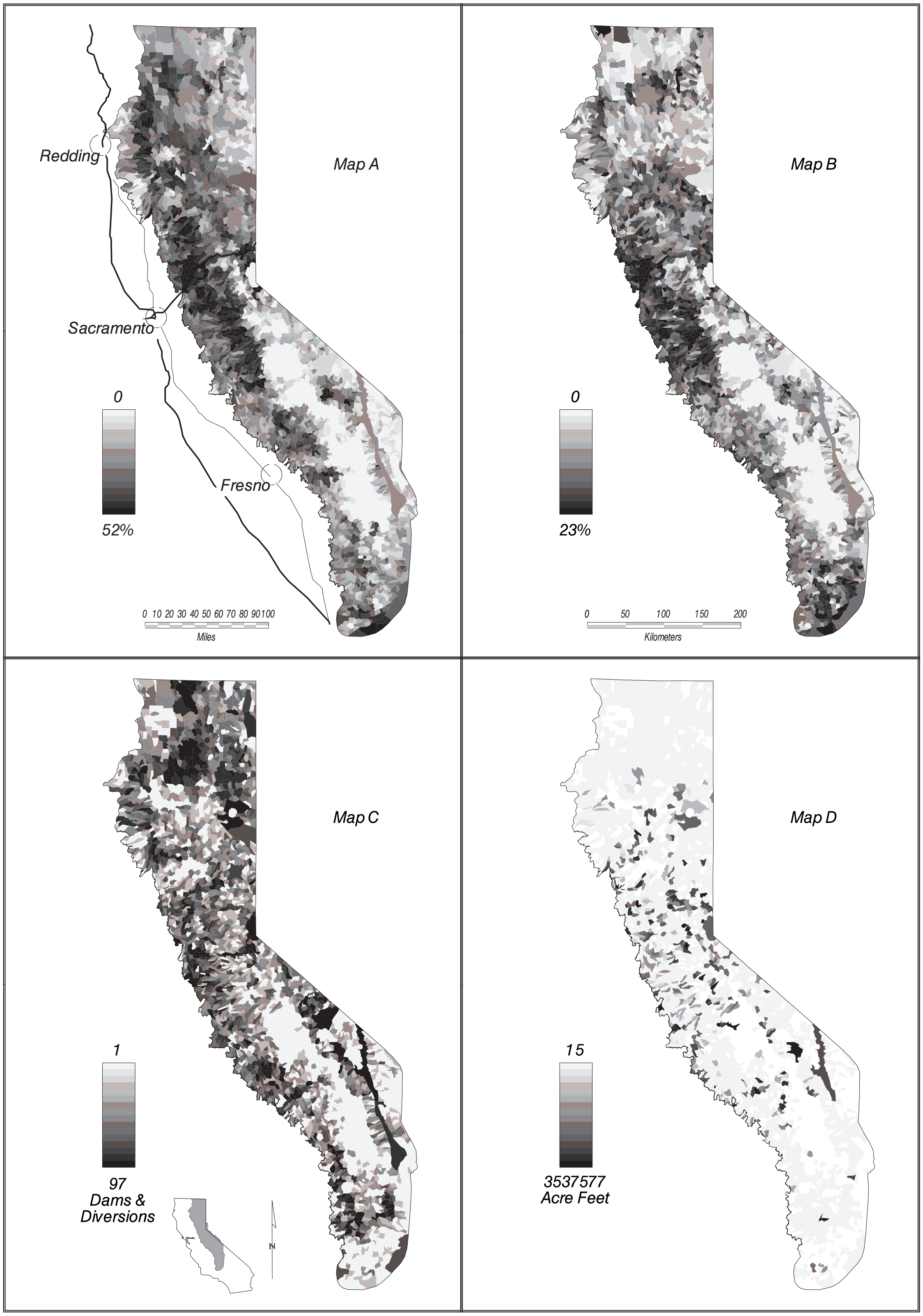


FIGURE 36.3

GIS plots of percentages of pixels (100 m x 100 m blocks) in each watershed that contain a road (map *a*), contain a road near a stream (map *b*), and contain a dam or diversion (map *c*). Map *d* shows dam capacity by watershed.

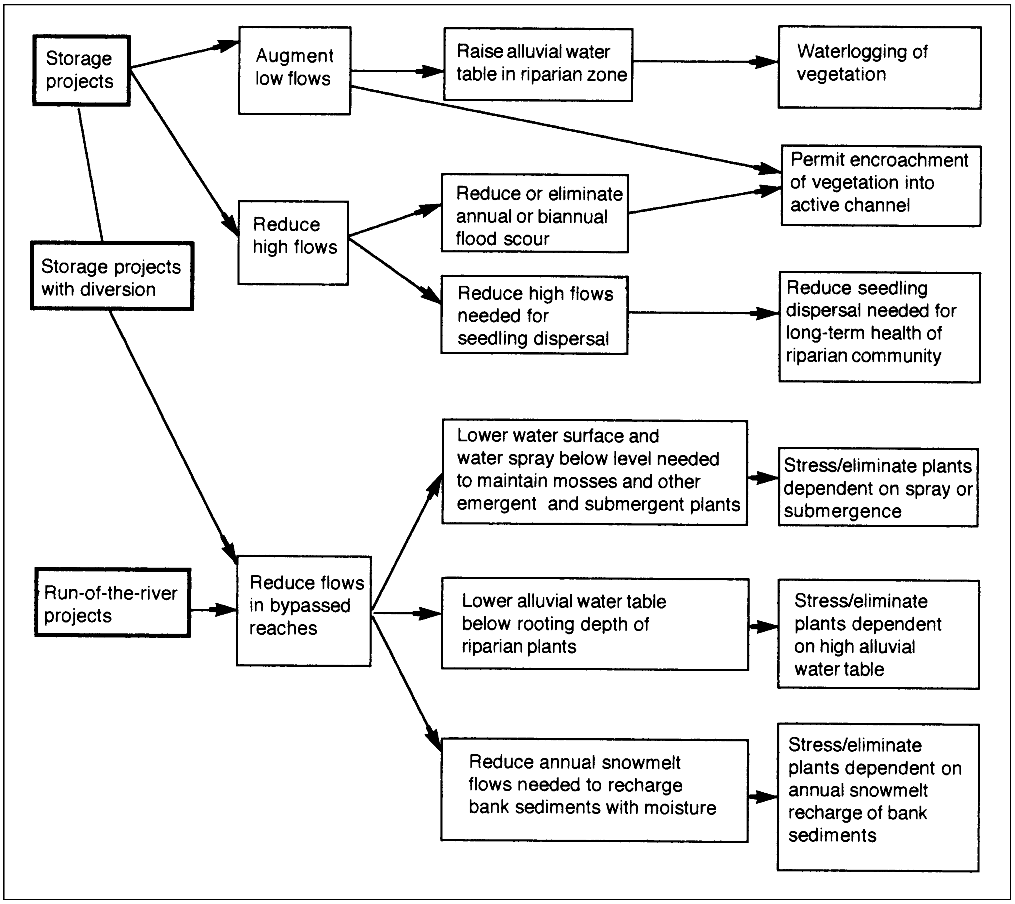


FIGURE 36.4

Effects of hydroelectric dams and diversions on riparian vegetation.

GIS ANALYSIS OF ROAD INFLUENCE ON STREAMS

An indication of the pervasiveness of road influence on Sierran rivers and streams is provided by the GIS analysis of 100 m by 100 m pixels in 141 watersheds (Calwater Hydrologic Subareas). In each watershed, the percentage of pixels with a road ranged from less than 0.6% to 31%, and the percentage with a stream ranged from 4% to 19% (figure 36.5). The results for roads are displayed for each watershed in figure 36.3a. When these patterns are overlaid, the more interesting result is obtained: the percentage of pixels with a stream that also contain a road, which we designate here as the Road Influence Index (RII) (figure 36.3b) The RII is a measure of the percentage of stream length with a road within 100 m. The RII ranges from 2% to 33%, with a median value of 14.1% (figure 36.5). The central 50% of the distribution (i.e., the 71 watersheds that fall in the center of the RII) have RII values between 10.8 and 17.4, and the central 80% have RII values between 8.7 and 21.3 (figure 36.5). Thus, in the vast majority (80%) of Sierra Nevada watersheds, 8% to 21% of stream reaches are potentially influenced by a road within 100 m. Additional detail, including values for this index, for thirty-three watersheds in the Eldorado National Forest is given in Costick 1996. He refers to this index as the percentage of roaded area inside a 100 m stream buffer.

The RIIs for watersheds in the northern Sierra Nevada (north of Interstate 80) are lower (median value 10) than those for watersheds in the central (median value 14), southern (median value 14), and eastern (median value 16) Sierra Nevada (figure 36.6).

The true values of RII are certainly higher than indicated here because the data sets used for roads were derived in large part from road maps, which do not show all roads. The total stream length would also be greater if smaller-scale maps (e.g., 1:24,000) were used to identify streams, as only larger streams are shown on the 1:100,000 scale maps.

Aerial Photograph and Map Analysis of Gaps in Riparian Corridors

Of the 130 Calwater Super-Planning Watersheds selected for assessment by aerial photography, 121 displayed obvious gaps in the riparian corridor. These gaps were caused primarily by road and railroad crossings, timber harvesting, clearing of private lots, dewatering by diversions and dams, and grazing.

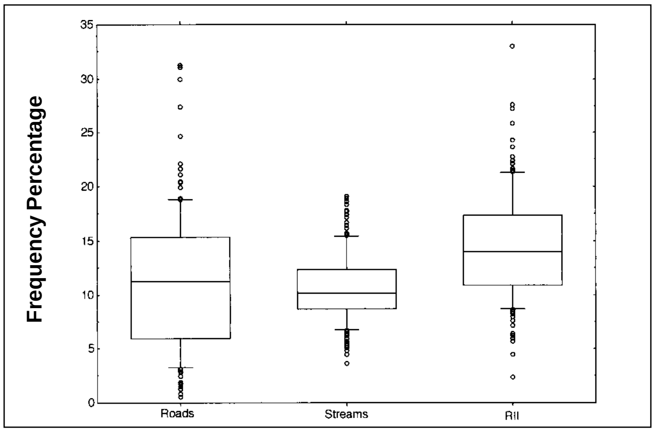


FIGURE 36.5

Box-and-whisker plots showing the percentage of pixels (100 m x 100 m) containing roads, the percentage of pixels containing streams, and the percentage of pixels containing streams that also contain roads in Sierra Nevada Calwater planning watersheds (*n*=141). The latter statistic can be restated as the percentage of streams with a road within 100 m of the channel, an index of the potential impact of roads upon streams, or Road Influence Index (RII).

The longest gaps (and thus perhaps the most influential ecologically) were created by reservoirs. USGS 1:100,000 topographic maps showed more than 150 reservoir gaps at least 0.5 km (0.3 mi) long. Highly developed basins such as the Feather and American Rivers had more than 20 reservoirs exceeding 0.5 km (0.3 mi) in length. The total length of riparian corridors inundated by reservoirs exceeds 1,000 km (600 mi).

MANAGEMENT IMPLICATIONS

Management Strategies

Management strategies can be used to minimize the impact of human activities on riparian areas or to restore ecological values of riparian areas. As described in preceding sections, human impacts to riparian systems have occurred by the direct removal or replacement of riparian vegetation or by the alteration of the physical conditions supporting riparian vegetation.

The most commonly applied, most straightforward, and probably most effective strategy is to define a riparian management zone or riparian buffer strip within which vegetation cannot be disturbed and ground compaction is avoided. This strategy serves not only to protect riparian vegetation for its own sake but also to maintain the beneficial influence of riparian vegetation upon aquatic habitat through shading, contribution of terrestrial food and nutrients, and filtering of sediments and pollutants from runoff flowing to the channel from surrounding uplands.

Because of the profound effect of dams in reducing natural high flows that support diverse assemblages of riparian vegetation, deliberate high flow releases are increasingly being required from reservoirs to maintain riparian habitat. Bottomland and bank areas that have been cleared for agricultural or urban uses are in some cases being restored to riparian habitat.

These management and restoration strategies are discussed in the following sections.

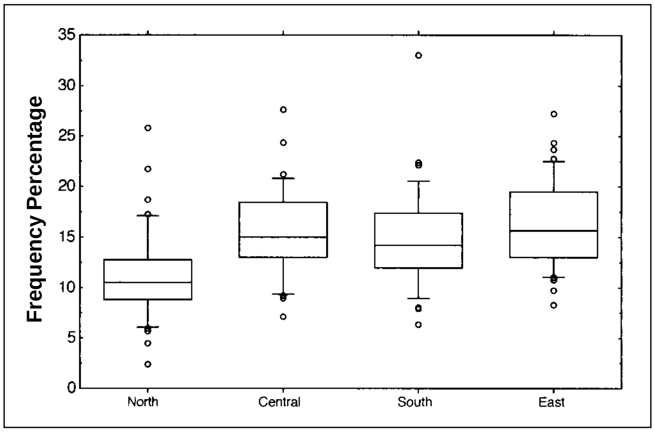
Land-use Buffers

The region near streams and other aquatic ecosystems, that is, the riparian region, is defined in three conceptually distinct 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 their disturbance from land use (see Moyle et al. 1996). The main issue is not 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.

Riparian ecological functions and physical processes take

FIGURE 36.6

Box-and-whisker plots showing the percentage of pixels (100 m x 100 m) with streams that also contain roads (Road Influence Index) in northern (north of Interstate 80, *n*=38), central (from Interstate 80 south through the Merced River Basin, *n*=29), southern (south of the Merced River Basin, *n*=35), and eastern (east of the divide, *n*=35) Sierra Nevada watersheds. This statistic can be restated as the percentage of streams with a road within 100 m of the channel, an index of the potential impact of roads upon streams.



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 depends on the local 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 that define them rather than an arbitrary hierarchy. One other fact is important in understanding the dimensions of the entire 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 (see Erman 1996). 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 stream flow 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, and 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 the protection and management of the entire riparian system.

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 (see Erman 1996). Alder and cottonwood trees are always associated with nearby water—a spring, a lake, a stream, or groundwater near the surface. 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. Beavers (Castor canadensis) may move tens of meters from water to cut aspen or other trees, as well as cottonwood on relatively flat floodplains that extend more than 100 m from low-water channels. The California tiger salamander (Ambystoma californiense), which occurs in the foothills zone (see Jennings 1996), lives in terrestrial habitats near temporary and permanent water used for breeding. Adults migrate up to 129 m (423 ft) (average 36 m [118 ft]) and juveniles up to 57 m (187 ft) (average 26 m [85 ft]) 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 1993). Dramatic changes in riparian conditions due to the logging of 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 (see also Kattelmann and Embury 1996) 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. 1980) and exchanges between the land area and aquatic systems has emerged in the last two decades (see reviews by Cummins et al. 1989; Carlson et al. 1991; Murphy and Meehan 1991). Riparian energy 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 (organic matter transported 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), material that is slow to decompose (such as Douglas fir), as well as terrestrial insects carried in are needed to support an aquatic food web throughout the year. Flows of energy from the aquatic to surrounding terrestrial system (especially emerging insects) is also substantial (see Erman 1996) 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 and complexity of stream channels, 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 (i.e., the height a mature tree can attain given the soil and other conditions at its location) (Chapel et al. 1992). For the Sierra Nevada, that height in many forest types is approximately 46 m (150 ft). However, the incorporation of wood and other organic material into streams will occur also during inundation of the floodplain. For larger streams in regions of gentle gradient, the width of a stream during major floods may extend much beyond 46 m.

The Riparian Buffer Area

The 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 erodibility 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 was mentioned earlier) and the creation of 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 (Bisson et al. 1987). 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 (98.5 ft) 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 5 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 that 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 would be

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

giving a value of 524 ft (160 m). 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 erodibility, also available from soil maps and GIS, can be incorporated as the detachability value (see Costick 1996), and the exponent would be expanded to 1+slope+detachability – (slope * detachability). For example, if detachability were 0.30, the equation would be

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

giving a value of 656 ft (200 m). Extreme cases, when slope and detachability are both high, would result in 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 the community or energy 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 the abrupt transition from the area upslope to the community area. Describing the buffer zone 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. An example is shown in figure 36.7 that illustrates a fixed buffer representing the energy area (150 ft) and the wider variable buffer area computed from the equation given earlier. Notice in the selected region along the North Yuba River near the town of Downieville that State Highway 49 lies within both areas for nearly all the distance illustrated. Stream channels in this case represent those modeled by GIS because existing USGS maps omit many actual streams. Refinements in scale of Digital Elevation Models from 30 m to 10 m are underway, and soil mapping (for estimating soil detachability and other factors) 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 these lines. It would lead to better protection of riparian-dependent organisms and of energy linkages between the land-water systems, and would assist managers in tailoring land-use activities to regions of greater need than is presently the case.

Riparian Maintenance Flows

The interrelations between physical channel processes and riparian vegetation are only now becoming better understood, and in any event the precise nature of these interrelations varies from river to river. Thus, specifying riparian maintenance flows (or "channel maintenance" or "flushing") can be viewed as essentially experimental at present.

To evaluate the effectiveness of riparian maintenance flows

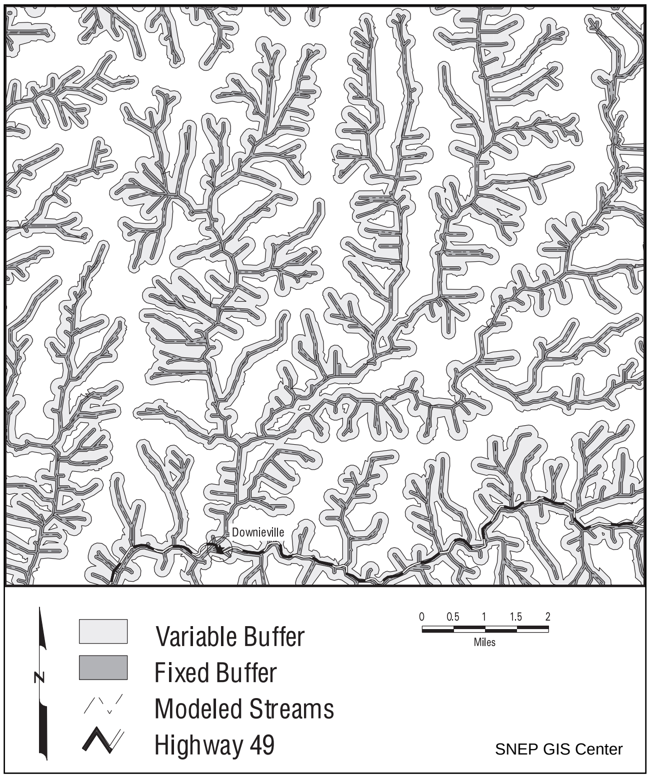


FIGURE 36.7

Fixed-width buffer (150 ft) and variable-width buffer computed from an equation for slope adjacent to stream channels for a region of the North Yuba River. Channel locations are determined from geographic information system models.

requires that the broad goal of maintaining riparian vegetation be restated as specific objectives from which flows can be specified and actual effects observed (Kondolf and Wilcock in press). For example, to maintain diversity of riparian habitat may require continued lateral migration of a meandering alluvial channel, which in turn requires adequate flows to erode banks and deposit point bars. Similarly, to prevent invasion of xeric plants onto bottomlands may require periodic flooding and high river stages that maintain seasonally high water tables. The magnitude of the flows required to achieve these objectives can be determined from stage-discharge relations by reach.

Hill and colleagues (1991) suggested that floods with a return period of 25 years under natural, predam conditions might be needed to maintain valley form and riparian habitat.

Restoration of Riparian Vegetation

Riparian revegetation projects may be limited to revegetation of banks to increase bank stability, channel shading, and overhanging vegetation. Artificial floodplains (essentially the second stage of two-stage flood channels), designed to be inundated every one to two years, are ideal sites to establish native riparian vegetation species (e.g. Matthews 1990). Much riparian revegetation has been undertaken to mitigate losses in riparian habitat elsewhere (Munro 1991), with mixed results in California. In general, riparian revegetation has been most successful along the banks of the low flow channel, less on higher surfaces. This difference is probably because of the nearly ubiquitous effect of reservoirs in reducing natural flood flows, eliminating hydrologic conditions needed for riparian vegetation on higher surfaces.

Probably the most ambitious riparian revegetation projects in the Sierra Nevada are being undertaken by the Nature Conservancy along the Cosumnes and South Fork Kern Rivers. Both rivers were chosen because their flood regimes are relatively natural, thus potentially maintaining near-natural hydrologic conditions on bottomlands.

Along the Cosumnes River, 80 ha (200 acres) have been replanted in valley oak (Quercus lobata) and other areas have been permitted to naturally revegetate in cottonwood (Populus fremonti) and various species of willow (Salix spp.). The suitability of various sites for different species was determined from flood inundation regime, soil type, and historical evidence of riparian vegetation present before these woodlands were cleared for agriculture (Griggs et al. 1994).

Along the South Fork Kern River, 130 ha (340 acres) were replanted, from 1987 to 1993 primarily, in Fremont cottonwood and red willow (S. lavigata) on floodplain sites from which these species had been cleared for agriculture. In large measure, the project was undertaken to create habitat for the yellow-billed cuckoo (Coccyzus americanus) and other avian species. Survival rates for plantings from 1991 to present have exceeded 90% (R. Tollefson, the Nature Conservancy, conversation with G. M. Kondolf, 1996).

CONCLUSIONS

Riparian areas are sites of exceptional ecological importance, typically having greater species diversity (floral and faunal) than surrounding uplands and providing essential food sources or habitat at certain life stages for upland wildlife species. Riparian areas also play a key role in maintaining water quality and aquatic habitat in streams and rivers, and because of their linear nature, riparian corridors are important routes for wildlife migration.

The riparian areas of the Sierra Nevada have been extensively affected by direct removal or inundation of riparian vegetation and by alterations to the conditions on which the riparian vegetation depends. Unfortunately, the field data base necessary to properly assess the health of riparian areas throughout the Sierra Nevada does not exist. However, from the extent of human activities known to affect riparian areas, we can infer substantial impacts. Moreover, map and aerial photograph analyses of a large sample of Sierran watersheds show that virtually all riparian corridors are interrupted by gaps caused by such human activities such as construction of road or railroad crossings, human settlements, dewatering of streams, grazing, timber harvest, and mining. The largest gaps are caused by reservoirs, many of which exceed 0.5 km (0.3 mi) in length, and which occur at a wide range of elevations in the Sierra Nevada.

Establishing riparian management zones (or "buffer strips") of adequate width is probably the single most effective strategy for protection and maintenance of the ecological values of riparian areas. Vegetation removal and ground disturbance should be prohibited in these zones, both to preserve the riparian habitat itself and for its beneficial influence upon aquatic habitat. Although the width of these zones has most commonly been set arbitrarily, variable-width buffer strips (based on attributes of the river itself, the riparian community, and hill-slope gradients) can be established to better protect riparian resources.

For channels below reservoirs, deliberate high flow releases can be made to mimic the hydrologic effects of natural floods in maintaining riparian vegetation. Restoration of riparian habitat, if based on careful analysis and on experience, can re-create many lost values to riparian and aquatic habitats.

ACKNOWLEDGMENTS

We are indebted to Lynn Decker, Nancy Erman, Diana Jacobs, and Peter Moyle for their constructive criticism of an early draft of Kattelmann and Embury (1996) and for their insightful suggestions on how to approach the broad, complex, yet very important topic of riparian areas in the Sierra Nevada. Many others contributed substantially to the literature review or provided useful background information. The Geometrics Division of the Engineering Department of the U.S. Forest Service Region V office in San Francisco contributed to the analysis of riparian corridors on aerial photographs, providing access to aerial photographs and use of office space and equipment. The Bureau of Land Management resource offices in Folsom, and the district offices in Bakersfield and Bishop, also provided access to aerial photographs. Sarah Marvin reviewed videotapes of riparian corridors, held by the Water Resources Center Archives, University of California, Berkeley. Steve Beckwitt conducted the GIS analysis of watersheds.

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