Forest Management

Cover photo. Restored meadow near Clarks Creek in Plumas National Forest.

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Chapter 23. Forest Resource Management Strategy

California's major water development projects rely on water produced in forested watersheds. The state's major rivers and a substantial portion of its runoff originate in these high elevation forests. Forests in California are used for sustainable production of resources such as water, timber, native vegetation, fish, wildlife, and livestock, as well as outdoor recreation. The economic value of water produced by forests equals or exceeds that of any other forest resource (Krieger, 2001; CDF, 2003).

Almost all forest management activities can affect water quantity and quality. This strategy focuses on those forest management activities that are designed to improve the availability and quality of water for downstream users, on both publicly and privately owned forest lands.

Forest Management in California

California has over 30 million acres of forest (CDF, 2003; Christensen, 2008) located primarily in the major mountain ranges of the state. Forests in California are owned and managed by a wide array of federal, state, Tribal, and local agencies, private companies, families and individuals, and non-governmental organizations (Table 23-1), each of whom has a different forest management strategy with different goals and constraints.

The largest public forest landowner in the state is the US Department of Agriculture Forest Service (USFS). The national forests in California were established under

Table 23-1 Acres of forest land by ownership in California

Landowner	Acres	Percentage
Private non-corporate	8,448,000	22.5
Private corporate	4,719,000	12.6
County	330,000	0.9
State	726,000	1.9
USFS[1]	20,166,000	53.7
BLM	1,650,000	4.4
NPS	1,287,000	3.4
Other federal	231,000	0.6
Total	**37,557,000**	**100.0**

Note: Acres reported are "real" forest rather than total ownership. See Christensen, et al.

[1] Land Areas of the National Forest System (USFS) as of September 30, 2007, USDA Forest Service FS-383, USDA Forest Service, Washington, DC, January 2008, 131 p.

Box 23-1 Acronyms and Abbreviations

BAER	Burned Area Emergency Response
BMP	Best Management Practices
BOF	California State Water Board of Forestry and Fire Protection
CAL FIRE	California Department of Forestry and Fire Protection
CEQA	California Environmental Quality Act
FPR	forest practice rules
GHG	greenhouse gas emissions
HFI	Healthy Forest Initiative
NEPA	National Environmental Policy Act
NFP	National Fire Plan
NPS	National Park Service
Regional Boards	Regional Water Quality Control Boards
SEAT	State Emergency Assessment Team
State Water Board	State Water Resources Control Board
TMDL	Total Maximum Daily Load
USBLM	US Bureau of Land Management
USEPA	US Environmental Protection Agency
USFS	US Department of Agriculture Forest Service
WDR	Waste Discharge Requirements
WLPZ	watercourse and lake protection zones

the Organic Act of 1897, which states that a primary purpose of these lands is to "secure favorable conditions of water flow." Secretary of Agriculture Tom Vilsack emphasized the role of the USFS in protecting water sources in his remarks made on August 14, 2009:

> "We must work and must be committed to a shared vision, a vision that conserves our forests and the vital resources important to our survival while wisely respecting the need for a forest economy that creates jobs and vibrant rural communities. Our shared vision must begin with a complete commitment to restoration. Restoration, for me, means managing forest lands first and foremost to protect our water sources while making our forests far more resilient to climate change." Secretary Vilsack described restoration of forest ecosystems, improvement or decommissioning of roads, and rehabilitation of streams and wetlands as components of forest restoration.

The USFS Pacific Southwest Region manages roughly 20 million acres in 18 national forests in California for multiple uses including timber and livestock production and outdoor recreation. These national forests include a wide variety of ecological communities, including subalpine and montane forests, alpine shrublands, chaparral,

and wetlands. Timber on national forests is produced through commercial timber sales to private contractors, and livestock are grazed under a permit system. Environmental issues related to resource management on national forests are addressed under the National Environmental Policy Act.

Resource management on each national forest is guided by a Land and Resource Management Plan (LRMPs). These plans are revised and updated roughly every 15 years. The content and format of LRMPs is governed by national planning rules, which are also revised periodically. The most recent planning rule, which was completed in 2008, was recently ruled invalid in federal court. The USFS is in the process of developing a new planning rule. In the meantime, LRMPs are guided by earlier planning rules that predate the 2008 rule. All future LRMPs will emphasize sustainability, restoration, and forest health.

The US Bureau of Land Management (USBLM) manages 1,650,000 acres of forest in the state, primarily in the North Coast region. The USBLM is a multiple-use land management agency that produces timber through commercial sales and manages livestock grazing through a permit system. Environmental issues related to resource management on public lands administered by the USBLM are addressed under the National Environmental Policy Act (NEPA).

The National Park Service (NPS) manages 1,287,000 acres of forest in 23 units in California. Unlike the USFS and USBLM, the NPS is not a multiple-use management agency. Rather, the NPS mission is to preserve natural and cultural resources for public enjoyment and scientific purposes. Commercial timber harvests and livestock grazing are not allowed in national parks, although vegetation may be managed for forest health and fire protection purposes and pack stock grazing is allowed.

Commercial timberlands (forests used or suitable for producing timber) comprise 16.6 million acres of forest land across the state (CDF, 2003), nearly half of which are in non-federal ownership. Over five million acres are zoned for timber production and are primarily managed by large, industrial landowners (CDF, 2003). The remaining non-federal timberlands are owned by small non-industrial landowners with a wide range of management objectives. Timber production is the primary use of privately-held forests, but some company-owned forest lands are used for livestock grazing and permitted outdoor recreation, including fishing and hunting. In addition, with the passage of recent climate change legislation (AB 32), some forests are likely to be managed to enhance carbon sequestration and provide offsets to greenhouse gas emissions (GHG).

Timber harvesting on non-federal forest lands is regulated by the California State Board of Forestry and Fire Protection (BOF) and the California Department of Forestry and Fire Protection (CAL FIRE). The BOF adopts regulations that CAL FIRE has enforced on the ground since 1975.

Urban forestry, although geographically distinct from forests in mountainous regions, offers important benefits for water resources and mitigation of climate change. Urban forests are managed by municipal parks and public works departments, as well as by many private organizations and individuals. Trees in urban environments provide much more than aesthetic benefits, including interception of rainfall, reduction of urban runoff, and energy-efficient shade during hot weather.

Surface water rights are managed and enforced by the State Water Resources Control Board (State Water Board). Surface water rights in California are a complicated mixture of riparian, overlying and appropriative rights. Groundwater rights are assigned to landowners. The USFS uses federal reserved, appropriative, riparian and overlying water rights to manage forest lands. A large percentage of water flowing from forests is appropriated by State and federal water projects, municipal water agencies, irrigation districts and hydropower companies. Stream systems in forested areas may be fully appropriated. A list of fully appropriated stream systems for California is available on the State Water Board web site.

Water quality in California is protected by the State Water Board and nine Regional Water Quality Control Boards (Regional Boards). The Regional Boards regulate compliance with the federal Clean Water Act through designation of beneficial uses, development of numeric and narrative water-quality objectives, water quality control policies, basin plans, basin plan prohibitions, issuance of various types of permits, and enforcement actions. The State Water Board prepares lists of impaired water bodies every two years, as required by Section 303(d) of the Clean Water Act. After the US Environmental Protection Agency (USEPA) reviews and approves water bodies on the list for pollution reduction, then either the USEPA or the appropriate Regional Board, in conjunction with stakeholders, prepares Total Maximum Daily Load (TMDL) reports and implementation plans to reduce pollutants in these waters. TMDLs target pollution from both current activities and "legacy" sources resulting from past land management or resource extraction activities. Abandoned roads and mines are the most widespread "legacy" problems on forest lands. Impaired water body listings, as well as State and federal listings of threatened and endangered fish and wildlife species, have greatly influenced forestry practices on non-federal lands during the past decade (Cafferata, et al., 2007b).

Forest management agencies also have responsibilities for water-quality protection. Both the USFS and CAL FIRE implement water-quality management plans that have been certified by the State Water Board[1]. Both agencies have been designated by the State Water Board as water-quality management agencies for implementing water-quality management plans on lands that they administer or regulate. The USFS and CAL FIRE water-quality management programs incorporate Best Management Practices (BMPs) or forest practice rules (FPRs) that are designed to prevent adverse impacts to water quality from forest management activities. These programs also include monitoring programs to

1 The State Water Board and USFS are beginning an update of that water quality management plan to improve its consistency with current legal requirements, policies, and scientific knowledge, as well as streamlining the manner in which it is implemented.

evaluate BMP/FPR implementation and effectiveness. The USFS water-quality program also includes restoration of "legacy" sources of pollution.

Extensive monitoring of California's FPRs on non-federal timberlands for water-quality protection was conducted from 1996 through 2004 by two State programs—one using independent contractors acting as third-party auditors to collect field data, and one using CAL FIRE forest practice inspectors (Cafferata and Munn, 2002; Ice, et al., 2004; Brandow, et al., 2006). Together, these projects inspected over 600 randomly selected timber harvest plans that had gone through one or more over-wintering periods after the completion of logging, with consistent results. Both projects found that hillslope surface erosion features were almost always associated with improperly implemented forest practice rules on forest roads and at watercourse crossings, and that watercourse and lake protection zones (buffer strips) retained high levels of post-harvest canopy and surface cover, which prevented harvest-related erosion. Approximately 20 percent of stream crossings were found to have significant problems with forest practice rule implementation or effectiveness. Overall, California forest practice rule implementation rates have been found to be among the highest of any of the western states, and when properly implemented, these practices have been found to be highly effective in preventing hillslope erosion features (Ice, et al., 2004; CWSF, 2007).

The USFS reported on monitoring data collected from 1992 through 2002 at roughly 3,100 randomly located sites to evaluate the implementation and effectiveness of its water-quality BMPs on national forests (USFS, 2004). The BMP Evaluation Program used 29 different onsite monitoring protocols to evaluate BMP implementation and effectiveness, with the majority related to timber and engineering practices. Results showed that while some improvements to current practices were necessary, the program performed reasonably well in protecting water quality on national forest lands. BMP implementation and effectiveness were relatively high for most activities (including timber and engineering) and impacts on water quality were relatively rare, particularly in recent years. Significant water-quality impacts, when they occurred, were typically caused by inadequate BMP implementation. Roads, and in particular stream crossings, created the greatest number of problems.

Potential Benefits of Forest Management

Forests are central to human landscapes, and civilizations have vanished because they failed to protect forests that, in turn, protected fragile soils and water sources (Diamond, 2005). Present-day forest managers have a responsibility to spare California a similar fate.

Forests are popularly believed to reduce flooding and increase dry-season base flows, as romanticized in the novel "The Man Who Planted Trees" (Giono, 2005). The scientific evidence for relations between forests and water supply, however, has been inconclusive (Dudley and Stolton, 2003; Troendle, et al., 2007). Research has shown that forests have

had a limited role in flood protection and variable effects on total water yields and base flows (Ziemer and Lisle, 1998; USFS, 2000; Calder, et al., 2007; Moore and Wondzell, 2005). In contrast, several studies have convincingly demonstrated that forests protect water quality by protecting the land surface from erosion and filtering pollutants (for example, USFS, 2000; Dudley and Stolton, 2003; Calder, et al., 2007).

Winter snowpack presently stores enormous quantities of water in the forested watersheds of interior California. Water stored as snow is released slowly during spring snowmelt, in contrast to rainfall that runs rapidly to streams. Snowpack therefore supplies water when it is most needed by humans and the environment, and reduces the need for additional downstream dams and reservoirs.

Predicted changes in climate for California are likely to result in more rainfall and less snowfall at mid-elevations in the Sierra Nevada, according to the California Department of Water Resources (http://water.ca.gov/climatechange). Climate change is already producing more rapid spring snowmelt in the Sierra Nevada (Peterson, et al., 2008).

The predicted shift toward more rain and less snow is of critical importance for water management because the existing water-development infrastructure relies on regulation of streamflow through gradual release of water during snowmelt. As snow is replaced by rain at mid-elevations, winter flood peaks will become larger and more frequent, and reservoir storage is likely to be exceeded in wet months when demand is low. Summer baseflows will be correspondingly lower when demand is high. These climate-driven impacts will likely lead to proposals for many new dams and reservoirs on forest streams, with their resulting environmental impacts.

Climate change directly affects forests through increased drought stress, which makes trees more vulnerable to insect attack. Wildfires are also likely to increase in frequency, size, and severity as climate warms. These stresses on forests will affect their capacity to naturally regulate streamflow and buffer water quality. Many streams that are now perennial are likely to become intermittent with the resulting loss of riparian zones, aquatic habitats, and other beneficial uses of water that depend on perennial flows.

Recent concerns with increased demand for water, extended drought, economic and environmental costs of new water-supply infrastructure, effects of water transfers on endangered species, and effects of climate change on water supply and hydropower generation have raised the importance of forest management for protection and improvement of water resources. New research and public perceptions may provide opportunities that were not available in the past to forest and water managers. Although the current scientific consensus supports the perception of forests primarily as protectors of water quality, the potential for improvements in the availability of water should not be overlooked. Forest management activities that alter streamflow regimen to benefit downstream water users may be more successful than attempts to increase total water yield. The following sections discuss forest management actions that have potential for improving water resources in California.

Meadow Groundwater Storage

Meadows within the forests of California are small alluvial landforms that are located along streams in the mountainous headwaters of the state. Owing to geologic factors that favor meadow formation, most of California's meadows are located in the Sierra Nevada, which has more than 10,000 meadows comprising a total of roughly 300,000 acres. In contrast to the surrounding terrain, meadows have gentle slopes and support flood-tolerant herbaceous plants and shrubs rather than conifers (Ratliff, 1985). Under natural conditions, meadows lack incised stream channels, and high flows spread across the meadow surfaces, recharging meadow aquifers (Wood, 1975).

Meadows with intact vegetative cover act as natural reservoirs, regulating streamflow regimen[2] through storage and release of snowmelt and rainfall runoff that passes over and through fine-grained, sod-covered meadow deposits. These meadows attenuate flood peaks and prolong dry-season base flows (Liang, et al., 2007). Meadows therefore increase available water for downstream farms, communities, and hydropower facilities. The importance of meadows in regulating streamflow is likely to increase as climate change results in a shift from snowmelt to rainfall-dominated runoff at mid-elevations in the Sierra Nevada.

Meadows also provide critical aquatic and riparian habitats for fish and wildlife. Montane meadows of the Sierra Nevada are very important to amphibians such as the mountain yellow-legged frog and birds including the willow flycatcher and Bell's vireo that utilize nesting habitats in meadows to successfully rear young. Kattelmann and Embury (1996) stated that about 20 percent of the 400 Sierra Nevada terrestrial vertebrates are dependent on riparian areas. Field studies have shown that the health of benthic macroinvertebrate and fish communities is strongly correlated with riparian conditions (Erman, et al. 1977; Newbold, et al., 1980; Knapp and Matthews, 1996; Herbst and Kane, 2004; Bayley and Li, 2008).

Most of the meadows throughout the Sierra Nevada were eroded by incised channels, or gullies, prior to 1940 as a result of early unrestricted livestock grazing, roadbuilding, railroad construction, elimination of beavers, and other causes (Wood, 1975; Kattelmann and Embury, 1996; Martin 2006). Although current activities on national forests are carefully managed to avoid damage to meadows, the effects of earlier practices remain on the landscape and will not heal without active restoration (Ratliff, 1985). Future disturbances resulting from wildfires, intense storms, and illegal activities could cause further damage that will require restoration.

Eroded meadows lose their capacity to store and release water (Loheide and Gorelick, 2007; Cornwell and Brown, 2008; Hammersmark, et al., 2008). Gullies convey and concentrate flood peaks more rapidly than well-vegetated meadow surfaces, and therefore aggravate downstream flooding and reduce recharge of meadow aquifers

2 Streamflow regimen means the distribution of streamflow through time. Meadow restoration could improve streamflow regimen by decreasing the volume of snowmelt flood peak flows, thereby delaying the release of water until the summertime. The total amount of water flowing in streams may not change much on an annual basis, but the distribution of flow over the year would change.

Forest researchers inspect an eroded meadow in Plumas National Forest along Last Chance Creek.

(Liang, et al., 2006; Hammersmark, et al., in review). Gullies drain groundwater stored in meadows, decreasing the amount of water available to sustain streams during dry summer months, although reduced evapotranspiration may offset drainage to an unknown extent. Channel erosion in meadows adds to stream sediment loads through bank erosion and headcut retreat, adversely affecting downstream water quality and reservoir capacity (Micheli and Kirchner, 2002).

Erosion of meadows adversely affects aquatic and riparian habitats by altering meadow hydrology. Fish passage is not possible through incised channels that are dry for much of the summer months, and the reduced discharge of cold water stored in meadows is likely to increase downstream water temperatures, to the detriment of cold-water aquatic species such as trout. Wildlife species that depend on wet-meadow plant communities are displaced when meadow water tables drop below rooting depths. According to the Sierra Nevada Ecosystem Project (1996), aquatic and riparian habitats are the most altered and impaired systems in the Sierra Nevada Range geomorphic province.

Drying of meadow soils allows invasion by drought-tolerant brush and conifer species that contribute to heavy fuels loading and add to the risk of catastrophic wildfires (Allen-Diaz, 1991; Dwire, et al., 2006; Berlow, et al., 2002; Loheide and Gorelick, 2007). Loss of high-quality forage provided by wet-meadow sedges, rushes, and grasses decreases forage value for meadows that are grazed by livestock (Ratliff, 1985; Stohlgren, et al., 1989).

Meadow restoration is a form of groundwater banking that can provide a wide array of ecological benefits in addition to enhancing water supplies. California's forests encompass the headwaters of the major rivers within the Sierra Nevada, and include thousands of meadows. A regional approach to meadow restoration could help to meet the State's needs for high-quality water and aquatic habitat and help offset the effects of climate change.

The USFS manages many Sierran meadows on national forest system lands, and has been actively working with partner agencies and organizations to restore the hydrologic,

A restored meadow on private land near Antelope Lake along Clarks Creek

geomorphic, and biologic functions of meadows damaged by channel downcutting since 1940. Several projects using the new "plug and pond" approach have been successfully implemented in the past 10 years in the Shasta-Trinity, Plumas, Tahoe, and Sequoia National Forests, as well as the Lake Tahoe Basin Management Unit. The "plug and pond" method involves preventing headcut migration, filling or plugging gullies, routing surface flows over the meadow surface, and raising meadow water tables.

In most cases, livestock grazing has been temporarily halted during and after restoration projects. Permanent exclusion of livestock is not generally necessary to protect riparian resources if pastures are effectively managed to limit cattle numbers, distribution, and seasons of use.

Encroaching conifers will generally be unable to survive the wet conditions that are likely following meadow restoration. Land managers will need to consider whether removal of these trees is warranted.

Like dams, meadow restoration does not create "new" water, but alters the temporal distribution of streamflow so that less water flows downstream during peak runoff periods in the winter and spring when water is not in high demand and more is released during the summer low-flow season when demand is great. Based on the limited available information and a reasonable range of assumptions, meadow restoration in the Sierra Nevada could increase the amount of groundwater stored in meadows by 50,000 to 500,000 AF annually. The wide range in these estimates results from uncertainties in channel depths and specific yields of meadow alluvium. Increased groundwater storage in meadows would be likely to enhance summertime instream flows (Liang, et al., 2007), a function that will become increasingly important because of climate change.

Meadows are often considered to be "sponges" that absorb and release water. This analogy is appropriate for meadows that are supplied by streams and local snowmelt. Meadows that are supplied by groundwater flowing through surrounding hillslopes and underlying fractured bedrock, however, may more accurately be characterized as "valves" that regulate the discharge of regional groundwater as it flows through relatively low-permeability, organic-rich, fine-grained alluvium. Meadow restoration is likely to be most effective in prolonging the duration of base flows in meadows that act as "valves" in regional groundwater flow systems (Hill, 1990; Jewett, et al., 2004). On the basis of bedrock permeability (Peterson, et al., 2008), meadows that function as "valves" are more likely to be found in volcanic and weathered granitic watersheds than in glaciated granitic watersheds.

Meadow restoration offers a number of other benefits in addition to improving summertime streamflows (Ponce and Lindquist, 1990). Some of these benefits are directly related to water resources, including attenuation of downstream flooding, improvements in downstream water quality, and reduction of reservoir siltation. Additional benefits related to natural resources other than water include improvements in fish and wildlife habitat, protection of sensitive species, reduction of fuels loading, carbon sequestration, and improvements in range conditions.

Alluvial valleys in mountainous areas throughout the world, including Africa, Australia, Europe, and South America, are faced with erosion and water-supply problems similar to those facing California's Sierra Nevada montane meadows. Many of these alluvial valleys provide water, crops, and forage that sustain local communities and economies. Successful restoration of meadows in California could provide methodologies that are applicable to critical land and water degradation problems around the world.

Riparian Forests

Riparian forests are forested lands that are located immediately adjacent to streams, lakes, or other water bodies. Riparian areas represent a transitional zone between aquatic and terrestrial habitats. These habitats are related to and influenced by surface or subsurface waters, especially the margins of streams, lakes, ponds, wetlands, and seeps. Boundaries between riparian and upland forests are not always distinct. The spatial extent of riparian areas varies laterally throughout the channel network and is strongly influenced by geomorphology (Naiman, et al., 1998).

Riparian floodplains in forested watersheds may affect or be affected by hydrologic processes in several ways. Due to flow resistance associated with a forested stand condition, flood flow velocities are reduced considerably. Additionally, when flow on the floodplain occurs, there is a large increase in the cross-sectional flow area. Once a stream rises above the floodplain surface, the slope of the line defining the relationship between river stage and discharge markedly decreases due to increased surface roughness and shallow water depth. In most instances, both the velocity and depth of water flowing outside the channel declines with distance away from the channel. This

allows flood waters to recharge alluvial groundwater aquifers and attenuates downstream flood flows (Cafferata, et al., 2005).

Floodplains are very important in providing habitat for riparian-dependent species (Ligon, et al. 1999). Floodplains are zones of very high biological diversity, having the highest biodiversity for both terrestrial and aquatic species of any part of the landscape at the watershed scale (Naiman, et al., 1998). In light of this high biodiversity, the California Forest Practice Rules require that native aquatic and riparian-associated species and the beneficial functions of riparian zones must be maintained where they are in good condition, protected where they are threatened, and restored where they are impaired (in so far as is feasible). Harvest of coast redwoods on riparian floodplains in the northern Coast Range has been controversial (Cafferata, et al., 2005) because redwoods on alluvial flats have both abundant timber and unique ecological benefits.

Studies have shown that riparian forests can improve water quality. As surface runoff passes through riparian forests, materials carried in suspension are filtered by riparian trees that act as buffers to reduce the amount of sediment, nutrients, and pesticides entering watercourses. Riparian trees also lower stream water temperatures through canopy shading. Shade is important for many fish species that can be adversely affected by elevated water temperatures at different life stages. In addition, riparian forests deliver large wood to streams that contribute to pool formation and provide cover for fish.

Riparian forests are protected on federal, State, and private timberlands through riparian buffers that limit management actions such as timber harvesting and roadbuilding near streams. The width of riparian buffers, and restrictions on management activities within them, are based largely on land ownership. Within the national forests, riparian buffer widths vary based on provincial[3] plan standards and guidelines. Riparian protection is most extensive for the six forests that operate under the Northwest Forest Plan. Even with these protections, the amount of riparian forests is greatly diminished from its historical extent. This is particularly true in lowland valleys where riparian forests have been converted to orchards and other agricultural uses. In the Central Valley, riparian forests historically covered over 900,000 acres but presently account for less than 100,000 acres (Barbour, et al., 1993).

Fuels reduction within riparian buffers may be needed in some cases to reduce threats of catastrophic wildfires (USFS, 2007). Removal of trees from riparian buffers remains highly controversial, and forest management and regulatory agencies are carefully evaluating monitoring data particularly with regard to the use of mechanical equipment in streamside zones (Norman, et al., 2008).

Some riparian forests are used for livestock grazing, usually within allotments that are primarily upland pasture. The availability of water and forage make riparian areas

3 Provincial refers to the three major planning provinces used in the national forest system in California—the Northwest Forest Plan province, the Sierra Nevada Framework province, and the Southern California province.

attractive to livestock, which can damage riparian forests through trampling, browsing, and contamination of streams with fecal material (Campbell and Allen-Diaz, 1997). BMPs for range management and national forest standards and guidelines for riparian management are designed to protect riparian forests from damage by livestock. Although exclusion of cattle may be needed during and immediately after restoration of riparian forests, grazing strategies that minimize impacts on riparian forests through restrictions on livestock numbers, distribution, and season of use can be used to eliminate the need for permanent fencing.

Riparian forests include phreatophytes (trees dependent on availability of shallow groundwater, such as aspens, cottonwoods, and willows) as well as upland species such as oaks, maples, and conifers that utilize moisture above the water table. Riparian forests therefore may affect and be affected by channel incision and groundwater storage in much the same ways as meadows. Riparian trees can also be directly impacted by changes in channel geomorphology, including bed aggradation and channel widening that are frequently linked to upstream land uses, including forest harvesting and roadbuilding (Madej and Ozaki, 1996). Invasive nonnative vegetation also threatens native riparian forests.

The water quantity and quality benefits provided by riparian forests can be preserved and enhanced through actions that maintain natural channel geomorphology. Protection of riparian forests therefore depends heavily on effective management of upland watersheds to prevent excessive runoff and sedimentation, as well as control of nonnative invasive species.

Vegetation Management

Management of forest vegetation to improve water supplies has a long history in the western United States. Early efforts attempted to reduce transpiration or increase snowpack by removal of trees. Most of these efforts had limited success (Ziemer, 1987).

Previous studies have shown that increases in water yields resulting from vegetation management are highly variable and difficult to measure, and that treatments must remove at least 20 percent of the vegetation to have a measurable effect on streamflow (Troendle, et al., 2007). Using computer simulation work, Troendle, et al. (ibid.) reported that every 12 acres of forest thinning (fuels reduction) could theoretically produce an increase of 1 AF of runoff. They suggested that the water yield response to large scale forest thinning in the northern Sierra Nevada forests would be short lived with a single treatment (perhaps only 15 years), but that an active management program perpetuated over time could result in subtle increases in water yield (ibid.). Studies have provided limited evidence that measurable water-yield increases have occurred in larger watersheds in the past. For example, Blanchard (1962—as cited by Zinke, 1987) calculated the cumulative effect of 30 years of logging on the South and Middle Forks of the Mokelumne River in the central Sierra Nevada. He reported that from 1930 to 1961, water yields from these watersheds gradually increased. Approximately 40,000 acres were logged during that time period.

Innovative approaches that utilize selective thinning of younger, smaller trees show some promise for limited improvement in streamflow regimen, as well as reducing fuel loading and increasing carbon sequestration (Troendle, et al., 2007; Holst, Eric, Environmental Defense, written communication, 2007). These treatments, however, also have potential to increase surface runoff and erosion from disturbed soils (Cram, et al., 2007).

Fuels/Fire Management

Wildfires affect water resources through removal of vegetation and alteration of soils and ground cover. Removal of forest canopies by fire temporarily reduces transpiration and interception losses, and may increase streamflow until vegetative regrowth increases transpiration to or above pre-fire rates (Driscoll et al., 2004). Burning of schlerophyllous vegetation can lead to development of hydrophobic soils that have reduced infiltration rates. Hydrophobic soils, in conjunction with the lack of ground cover remaining after fires, can increase surface runoff and erosion and reduce infiltration and baseflows (Neary, et al. 2005, Onda, et al., 2007; Moody, et al., 2008). The effects of wildfires on infiltration and runoff are positively related to fire severity (Moody, et al., 2008). Wildfires can also temporarily affect municipal water supplies when large quantities of water are needed to fight fires in wildland-urban interface areas.

Although increased water yield is a potential impact of large, intense wildfires, it is generally not significant. Where 75 percent to 100 percent of the vegetative cover is removed, runoff may increase from 0.1 acre foot (AF) per acre of burned watershed for basins receiving 15 inches of mean annual precipitation to 0.8 AF per acre burned for watersheds receiving 40 inches of mean annual precipitation (based on Turner, 1991). In forested areas, water-yield increases are minimal until basal area loss to fire exceeds 50 percent (Potts, et al., 1989).

The additional water yields that result from catastrophic wildfires are generally considered to have little value for water supply and hydroelectric energy generation. Almost all of the additional runoff occurs during the wet season and must be regulated for dry season use by surface reservoir storage (Ziemer, 1987). Typically, flows increase during large storm events when water is intentionally allowed to pass through reservoirs owing to flood-management concerns. The additional water yield, however, does not contribute to a dependable water supply since the additional water is only a very temporary increase in yield. The occasional, short-term positive gains from increased water yield are more than offset by the frequent short and long-term negative impacts of increased peak flows, increased sedimentation and decreased water quality (BOF, 1996).

High fuel loads that develop in the absence of fire or fuel-reduction treatments eventually lead to catastrophic high-intensity stand-replacing fires that generate large volumes of eroded soil and ash (Robichaud, 2000; Reneau, et al., 2007; Rulli and Rosso, 2007; Carroll, et al., 2007), as well as nutrients such as nitrate nitrogen, ammonium

nitrogen and phosphate phosphorus (Miller, et al., 2006). Fire exclusion[4] can also lead to negative effects on water quality owing to unnaturally large accumulations of forest litter that increase concentrations of nutrients in runoff from forests (Miller, et al., 2005). Fire exclusion can also be detrimental to plants harvested by Native Americans for traditional and cultural purposes.

Fuel reduction projects, including thinning, mastication, and prescribed fires, are used to decrease the intensity, extent, and negative consequences of wildland fire. Forest management to reduce fire severity on national forests is currently administered under the National Fire Plan (NFP) and the Healthy Forest Initiative (HFI). About 70 percent of the 20 million acres of national forest system lands in California, or 14 million acres, are in need of treatments to reduce fuel loads to natural levels. The USFS is currently treating about 200,000 acres per year, while an average 400,000 acres are burned annually by wildfires (Rob Griffith, USFS, personal communication, 2008). The most effective fuel reduction treatments for decreasing the spread and intensity of wildfires have been combinations of mechanical treatments and prescribed burning (Stephens and Moghaddas, 2005; Dailey, et al., 2008).

Fuel reduction projects can have adverse effects on water quality (for example, McClurkin, et al., 1987; Wondzell, 2001; Grace, et al., 2006), but these effects are generally minor and temporary, and are far exceeded by the adverse effects of catastrophic wildfires (Benavides-Solorio and McDonald, 2001; USFS, 2005; Madrid, et al., 2006; Hatchett, et al., 2006; Cram, et al., 2007; Robichaud, et al., 2007; Gokbulak, et al., 2008). The adverse impacts of wildfire are generally much greater per unit of affected area than the impacts of fuel reduction projects, and also affect much larger areas than those included in fuel reduction treatments.

Firefighting tactics are increasingly being modified to protect water quality and aquatic organisms (NWCG, 2004). Rapid restoration of areas disturbed by fire suppression actions is routinely included in suppression efforts. Following fire containment, burned areas associated with large wildfires are assessed and, if necessary, high-risk areas with downstream values-at-risk[5] are treated to prevent adverse effects on water quality and other resources (Robichaud, et al., 2000). The USFS uses its Burned Area Emergency Response (BAER) program to restore areas burned by wildfires, while CAL FIRE participates in the State Emergency Assessment Team (SEAT) program on State and private lands. These programs focus primarily on the protection of lives and property, as well as the re-establishment of forest vegetation to reduce erosion potential. The BAER and SEAT programs will become increasingly important owing to projections of higher frequency and intensity of wildfires related to climate change. Federal purchase of inholdings within national forest administrative boundaries is an alternative approach to reducing fire risks in the wildland-urban interface.

4 Fire exclusion means the prevention of wildfires through active fire prevention and suppression.

5 Values-at-risk refers to natural resources such as salmonid habitat and human communities that may be adversely affected by the movement of water and sediment from burned areas.

Road Management

Watershed research and monitoring work in California have shown that unpaved roads and road stream crossings are usually the dominant source of management-related sedimentation in forested environments (Cafferata and Munn, 2002; USFS, 2004; MacDonald, et al., 2004; Coe 2006). Past work has shown that a relatively small proportion of the total road length produces most of the road-related sediment delivered to streams (McCashion and Rice, 1983; Coe, 2006). Road-related sediment-transport processes include surface erosion, gullying, and mass wasting. Sediment may be delivered to streams either episodically when roads or road-stream crossings catastrophically fail, or chronically due to incremental surface erosion. Excessive sedimentation associated with roads is of concern because of potential impacts on stream habitat and water quality.

Thousands of miles of roads have been constructed through forests in California, primarily to provide access for timber harvests. The eighteen national forests in California alone contain about 50,000 miles of forest roads. Of these, roughly 20,000 miles may no longer be needed for their original purposes (Dombeck, 2007). Private forestlands contain many additional thousands of miles of roads. Forest roads generate overland flow and intercept subsurface flow, adding to flood peaks (Jones and Grant, 1996) and decreasing recession flows. Stream crossings are vulnerable to damage by high flows (Furniss, et al., 1998) and can divert streams from their natural channels, resulting in serious erosion and water-quality problems (Best, 1995).

Many of the roads on private timberlands were built decades ago to very low design standards, often in environmentally sensitive locations such as unstable hillslopes and riparian areas. A significant number of the older roads are part of the current road network, while others were neglected and abandoned with no consideration of ongoing erosional impacts (Cafferata, et al. 2007a). These “legacy” roads are particularly susceptible to catastrophic failure during high magnitude, low frequency storm events, such as the one in 1997 that caused extensive flooding throughout a large part of northern and central California (Furniss, et al., 1998, Madej 2001).

Similarly, much of the existing national forest road network was constructed under standards less protective of water resources than present standards, and maintenance of roads has not been completely effective at preventing runoff interception and erosion. Adverse hydrologic and water-quality impacts of roads can be reduced by upgrading and replacing culverts, outsloping road treads, and installation of road drainage structures such as waterbars and rolling dips at appropriate spacing, particularly near stream crossings (Furniss, et al., 1991; Weaver and Hagans, 1994; Keller and Sherar, 2003). Roads no longer necessary for resource management or recreation can be effectively decommissioned by removal of fills at stream crossings and partial or total outsloping of road treads, including cuts and fills (Madej, 2001; Cook and Dresser 2007).

Detailed field surveys are the main tool available to identify the road segments of greatest concern (Weaver, et al., 2006; Korte and MacDonald, 2007). Public and private

landowners in California are actively inventorying their road networks, prioritizing road segments requiring road improvement or decommissioning work, and completing projects. A considerable amount of road upgrade work has been completed to date with both public and private financing. While there are short-term impacts associated with road decommissioning, particularly at stream crossings, road treatments will reduce the long-term sediment production from older roads (Madej, 2001). Improved operator practices are required for stream crossing installation at high-risk sites and at decommissioned crossing sites (PWA, 2005; Cafferata, et al., 2007a).

Urban Forestry

Trees planted in city parks, lots, private residences, and along streets collectively form urban forests. Although urban forests are not managed specifically for natural resource production or conservation, they have environmental benefits that extend well beyond aesthetics. Trees reduce storm water runoff by intercepting rainwater on leaves, branches, and tree trunks. Rainwater intercepted by trees soaks into the ground, reducing peak flows, surface runoff, erosion, and contaminant transport. Canopy interception from urban trees changes runoff quantity and pollutant loads in several ways (Xiao, et al., 1998; USFS, 2002):

1. **Evapotranspiration.** Increases soil water storage potential;

2. **Interception.** Reduces the volume and timing of runoff;

3. **Infiltration.** The root system of trees can increase soil infiltration rates; and

4. **Erosion.** Through interception trees reduce the soil impacts from raindrops.

Comprehensive urban forest management can lead to improved storm water control and promote efficient water use in urban areas.

Urban trees have multiple co-benefits. For example, a large deciduous canopy tree can intercept 760 gallons of rainfall in its crown annually and aid in runoff of polluted storm water and flooding. This benefit is valued annually at $6 based on local expenditures for water-quality management and flood control. Benefits increase with interception potential. An evergreen camphor tree is estimated to intercept 4,000 gallons annually, providing even greater benefits (USFS, 1999). In addition, shade from urban forests provides energy-saving by reducing temperatures. Urban trees also provide climate benefits through sequestering carbon and offsetting greenhouse gas emissions.

Accrued benefits from an urban forest vary with tree age, species, canopy coverage, growth rate, tree health, urban setting, and climatic zone. In a study of five municipal cities, each dollar invested in management returned an annual benefit ranging from $1.37 to $3.09 (McPherson, et al., 2005). Many tree community interest groups, including GreenPrint, Sacramento Tree Foundation and others quote an average tree

return of $2.70 in benefits for every $1 of community investment, based upon 40-year average lifespan. This average benefit standard was developed by the Center for Urban Forest Research, USFS Pacific Southwest Research Station in Davis, California. In the San Joaquin Valley, average annual net benefits per tree for a 40-year period increased with mature tree size:

- $1-8 for a small tree
- $26-37 for a medium tree
- $48-63 for a large tree.

Potential Costs of Forest Management

Meadow Groundwater Storage

Costs of recent meadow restoration projects, including planning and environmental compliance, range from roughly $1,000 to $2,500 per acre. The higher costs are for projects that require construction of new channels using heavy equipment and end-hauled materials. Maintenance costs for meadow restoration projects are generally very low.

Riparian Forests

No unit cost information is available for riparian forest protection, improvement, or restoration. Actions to benefit riparian forests include appropriate management in the riparian zone and upland watershed improvement projects. Unit costs for upland projects should reasonably represent unit costs for riparian forests.

Vegetation Management

Unit costs for vegetation management on private forest lands in California vary between $20 and $1,200 per acre, depending on the methods used. Manual removal of undesirable species ranges from $70 to $1,200 per acre. Herbicide applications range from $20 to $250 per acre. Herbivory ranges from $500 to $1,200 per acre. Mechanical treatments cost between $800 and $1,200 per acre. Unit costs for vegetation management on national forest system lands in California are generally higher, ranging from approximately $1,000 to $2,000 per acre (Mike Land ram, USFS, personal communication, 2008).

Fuels/Fire Management

Unit costs for prescribed fire on private forest lands in California are as high as $500 per acre for grass and shrub fuels and higher for heavier fuels. Unit costs for fuel reduction projects on national forest system lands in California ranged from $144 to $2,476 per acre between 2004 and 2006. Average unit cost was $593 per acre (Rob Griffith, USFS, personal communication, 2008).

Road Management

Road upgrading or "storm-proofing" is used to reduce the potential for sediment delivery to stream channels for roads that will remain in service. Recent unit cost estimates for storm-proofing roads on national forest lands in the Coast Range ranged from $6,520 to $13,580 per mile. Road decommissioning is generally much more expensive owing to greater costs for planning, heavy equipment use, and endhauling.

Urban Forestry

The costs of urban tree planting and maintenance can vary greatly with location, site conditions, and the type of tree planted. Total planting cost in California can vary between $45 and $160 per tree.

Once trees are established, maintenance costs are initially minimal, but begin to accrue after roughly 10 years, as trees need to be pruned and hardscape needs to be repaired from root damage. Additional maintenance costs include inspection, administration, legal claims, disease control, removals, and storm litter clean-up. Maintenance costs are typically higher for trees planted in public spaces, since they require more frequent pruning to avoid interference with power and telecommunications lines, and are also generally adjacent to streets and sidewalks. From the findings of the Forest Service's Center for Urban Forest Research, annual maintenance costs in California averaged $19 per tree for public land and $14 per tree for private landowners. Previous studies have estimated the combined costs, including planting and maintenance at $13 - $65 annually per tree (McPherson, et al., 2005). Maintenance costs can be reduced by selecting trees and planting sites carefully.

Major Issues Facing Forest Management

The issues described in this section are challenges for implementing one or more of the activities described in the Benefits section.

Information Needs

Forest management agencies and private timber companies have conducted a number of long-term studies in experimental forest watersheds, including Caspar and South Fork Wages Creeks in the northern Coast Range, Little River in the central Coast Range, Judd Creek in the northern Sierra Nevada, and the Kings River Experimental Watershed in the southern Sierra Nevada. These studies have provided valuable information on the effects of forest management activities, particularly timber harvesting, roadbuilding, and fuel treatments.

Continued monitoring and additional studies are needed to better understand the effects of forest management activities on water quantity and quality over the wide range of climatic and physiographic conditions found in California. The processes and pathways by which water that arrives at the land surface as rain or snow reaches

stream channels profoundly affect streamflow regimen, erosion, and contaminant transfer. These processes in general are poorly understood. Methods for estimating evapotranspiration from different vegetation types need refinement and field verification. Knowledge of groundwater recharge, flowpaths, and storage is limited for mountainous forested watersheds, especially those underlain by fractured rocks. Sources of sediment, transport mechanisms, and the relative importance of erosional processes are not well documented.

A statewide network of streamflow monitoring stations is operated by the US Geological Survey (USGS). Monitoring of streamflow to detect effects of land use is most useful on headstreams (MacDonald and Coe, 2007) that are not affected by artificial regulation or diversion. Currently the USGS operates 886 streamgages in California, but only 214 are on streams with more than 50 percent forest cover, and of these, only 31 are long-term (20 or more years of record) stations on unregulated and undiverted streams (Parrat, Charles, US Geological Survey, written communication, 2008). This is equivalent to one long-term streamgage on an unregulated and undiverted stream for every 1,893 square miles of forest in the state. Very few of these stations include water-quality monitoring. A higher density of streamgages and water-quality monitoring stations would be helpful for understanding the distribution, timing, and quality of streamflow from forested watersheds across the state.

Coordination Needs

Forest owners and management agencies have disparate management objectives and constraints, and forest ownership boundaries rarely coincide with watershed boundaries. For example, USFS funds and staff can generally be used, with limited exceptions, only for work on national forest lands. Similarly, State agencies are frequently prohibited from working on federal lands, and many watershed improvement grant programs are limited to non-federal agencies and organizations. Increased coordination between State and federal forest-management agencies and Tribal forestry and watershed programs would provide opportunities to increase protection of water quality.

Limited Funding for Forest Watershed Restoration

The rate of progress for meadow restoration and road stormproofing and decommissioning is largely limited by available funds. With current levels of appropriated funding, restoration of all degraded meadows on national forests would take roughly 200 years, and decommissioning of unneeded roads would require almost 400 years. In recent years, appropriated federal funding for watershed programs on national forests has decreased, and revenue-generating timber sales have declined since the mid-1980s.

A large proportion of funding for watershed restoration is now supplied through state bond measures and grant programs. Some grant programs, however, require non-federal matching funds, which limits the eligibility of projects on federal forest lands.

Management of forest resources incurs costs to forest owners and managers, and often results in benefits to downstream communities that do not contribute to the funding of forest management. In most cases, downstream residents are unaware of the benefits of upstream forest management for flood control and flow regulation, but might be willing to contribute if the costs and benefits were explained to them.

Regulatory Requirements

Forest management actions that affect the amounts or timing of streamflow may affect existing surface-water rights. Rights to groundwater are held by landowners, whereas surface waters may be appropriated by landowners and other users. Projects that attenuate flood peaks and store groundwater could be viewed as threats to existing appropriated rights, and could potentially result in water-rights litigation. Water rights may need to be resolved for additional water made available by meadow restoration, vegetation management, and fuels management, but in most cases, reduced flood peaks will not result in less available water for downstream users.

As noted by the California-Nevada Tahoe Basin Fire Commission in 2008, duplicative environmental reviews required for vegetation management and fuels projects can slow the rate of progress and increase costs. On private lands, Timber Harvesting Plans are reviewed by CAL FIRE foresters for compliance with the California Forest Practices Rules as well as the California Environmental Quality Act (CEQA) and other State regulations. On federal lands, timber harvests and other vegetation and fuel management projects are analyzed following National Environmental Policy Act guidelines, and appropriate BMPs are determined for protection of water quality. Federal and non-federal timber harvests, vegetation management, and fuels projects are also regulated by the Regional Boards through Waste Discharge Requirements or waivers of Waste Discharge Requirements. Regulatory requirements between water-quality regions are not consistent. In some regions, permits are not required for non-commercial timber and fuels projects, while in other regions all vegetation management projects require Regional Board permits. Monitoring requirements are inconsistent between Regions as well.

For 303(d)-listed impaired waters, Category 4B of the USEPA's Integrated Reporting Guidance would allow use of an adequate water-quality protection program of another entity to attain water-quality standards in lieu of establishing a TMDL. On the other hand, the State Water Board's Water Quality Control Policy for Addressing Impaired Waters does not allow that option. Instead, it allows that, after a TMDL is adopted, a Regional Board may certify that another agency's regulatory program will correct the impairment in lieu of adopting a redundant TMDL implementation program. The Category 4B option potentially would be much less time-consuming and expensive to implement.

Prescribed fires are conducted on days approved for burning by the California Air Resources Board and local air pollution control agencies, based on air quality

conditions. The USFS is currently working cooperatively with the regional Air Quality Control Boards to increase opportunities for prescribed burning.

Recommendations to Promote Forest Management

The following recommendations are intended to address the issues identified in the previous section.

Monitoring and Research

Long-term monitoring is needed to understand hydrologic changes resulting from climate change and management actions. The following types of data-collection stations would provide useful information:

1. Additional streamgages are needed to adequately represent the range of hydroclimatic and geologic conditions throughout the forested regions of California. In particular, gages would be helpful on small (first to third order) unregulated and undiverted managed and pristine watersheds.

2. Additional precipitation stations and snow courses would be helpful in determining climatic trends and evaluating effects of management activities.

3. Water-quality and sediment monitoring stations would allow quantification of the effects of climate change as well as forest management activities on surface-water quality.

4. Long-term monitoring wells would be useful for understanding groundwater resources in forested watersheds.

Forest management for water resources could benefit from additional research on:

5. Effectiveness of Best Management Practices in protecting beneficial uses.

6. Effects of vegetation and fuels management on soil moisture, groundwater recharge, and streamflow. More quantification of both the short and long-term effects of prescribed fire on soil and water nutrient status is needed to determine the most beneficial and most ecosystem "friendly" return interval as a management strategy. Determination of the impacts of burn frequency on soil and vegetative properties that influence infiltration, percolation, surface runoff, and groundwater discharge would also be advantageous (Tahoe Science Consortium 2007).

7. Effects of wildfires and wildfire control measures on water quantity, water quality, and aquatic organisms.

8. Quantification of groundwater storage and streamflow regulation in meadows, and potential benefits of meadow restoration for water quantity and quality; assessment

of sediment sources and erosion processes in managed and unmanaged forested watersheds.

9. Effects of riparian forests in maintaining stream temperatures and cycling nutrients.

10. Effects of urban trees in reducing nonpoint source pollution.

Coordination

Actions that would provide for better multi-party coordination of forest management include:

11. Involvement of forest managers in integrated resource water management plan development.

12. Determination of mutually-agreeable objectives for forest and meadow protection and restoration in terms of land area and timelines, and commitments from forest managers to meet these objectives.

13. Expanded authority and interagency agreements to allow federal, State, and non-governmental agencies to share expertise, staff time, and funding across jurisdictional boundaries for the purposes of watershed and water-quality protection and improvement.

Funding

The following recommendations are intended to improve communications between downstream water users and communities and upstream forest managers, residents, and workers:

14. Develop a public education campaign directed at water users and communities in the Central Valley, Bay Area, and southern California.

15. Resolve water rights issues and develop mechanisms for marketing of water made available by restoration projects in forested watersheds.

16. Expand the scope of state water resource development and conservation measures to include headwaters areas of the state and urban forestry in metropolitan areas.

17. Increase eligibility of federal agencies for grant programs, and allow federal funds and in-kind services to be used as grant matches.

Regulatory Requirements

The water-quality management plans between the State Water Board and forest management agencies can be revised to address concerns with impaired water bodies

while at the same time providing consistency and cost-effectiveness. Regulatory workloads can be reduced by combining environmental compliance into a single streamlined procedure that would apply to all projects that meet criteria for low risk of adverse watershed effects or net beneficial water-quality effects.

The following recommendations are directed at regulatory oversight of forest water resources:

18. Revise forest management agency water-quality programs as necessary to identify, prioritize, and repair existing pollution sources, improve BMPs, and modify monitoring programs.

19. Incorporate existing Management Agency Agreements between the State Water Board and forest management agencies into cost-effective and consistent regulatory mechanisms compliant with current State law.

20. Deregulate low-risk noncommercial vegetation and fuels management projects that reduce the risks of catastrophic wildfires and therefore have net beneficial effects on water quality.

21. Complete a water-quality management plan for the USBLM.

22. Change the State Water Board's Water Quality Control Policy for Addressing Impaired Waters to incorporate Category 4B of US Environmental Protection Agency's Integrated Reporting Guidance, thereby allowing water-quality management programs of other entities to be used to attain water-quality standards in 303(d)-listed impaired waters in lieu of adopting TMDLs and duplicative TMDL implementation plans.

Special Author's Note

The forest management chapter, a new feature of the Water Plan, was first proposed by Melvin Carmen of the North Fork Mono Tribe at a special Tribal regional plenary session. He recounted from his personal history the changes in watersheds directly linked to forest practices. Melvin monitored the chapter development, led by the United States Department of Agricultural Forest Service in partnership with DWR, CAL FIRE, the State Water Board, and the University of California, Merced, and participated in the public workshops. Melvin passed away in 2009 without seeing the final chapter. This chapter is dedicated to Melvin.

References

Allen-Diaz, BH. 1991. Water table and plant species relationships in Sierra Nevada meadows. American Midland Naturalist. 126:30-43.

Barbour, M; Pavlik, BS; Lindstrom, S. 1993. California's Changing Landscapes: Diversity and Conservation of California Vegetation. Sacramento (CA): The California Native Plant Society. 244 p.

Battany, MC; Grismer, ME. 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope cover and surface roughness. Hydrological Processes. 14:1289-1304.

Bayley, PB; Li, HW. 2008. Stream fish response to grazing exclosures. North American Journal of Fisheries Management. 28:135-147.

Benavides-Solorio, J; MacDonald, LH. 2001. Post-fire runoff and erosion from simulated rainfall on small plots, Colorado Front Range. Hydrological Processes. 15(15):2931-2952.

Berlow, EL; D'Antonio, CM; Reynolds, SA. 2002. Shrub expansion in montane meadows: the interaction of local-scale disturbance and site aridity. Ecological Applications. 12(4):1103-1118.

Blanchard, FB. 1962. Logging and water supply in the Mokelumne River basin—a preliminary appraisal. File Report. Oakland (CA): East Bay Municipal Utilities District, Water Resources and Planning Division. 3 p.

Brandow, CA; Cafferata, PH; Munn, JR. 2006. Modified Completion Report monitoring program: monitoring results from 2001 through 2004. Monitoring Study Group Final Report. Sacramento (CA): California State Water Board of Forestry and Fire Protection. 80 p.

Cafferata, PH; Munn, JR. 2002. Hillslope Monitoring Program: monitoring results from 1996 through 2001. Monitoring Study Group Final Report. Sacramento (CA): California State Water Board of Forestry and Fire Protection. 114 p.

Cafferata, PH; Coe, DBR; Harris, RR. 2007a. Water resource issues and solutions for forest roads in California. Hydrological Science and Technology. 23(1-4):39-56.

Cafferata, PH; Hall, DO; Gentry, GD. 2007b. Applying scientific findings to forest practice regulations in California. Proceedings of the 1997 NCASI West Coast Regional Meeting. Special Report No. 97-13. 1997 NCASI West Coast Regional Meeting; 2007 Sep 26-27; Portland (OR). Research Triangle Park (NC): National Council for Air and Stream Improvement, Inc. p. H-39 to H-46.

Cafferata, P; Berbach, M; Burke, J; Hendrix, J; Klamt, R; Macedo, R; Spittler, T; Vyverberg, K; Wright-Shacklett, C. 2005. Flood prone area considerations in the coast redwood zone. Final Report of the Riparian Protection Committee. Sacramento (CA): California Department of Forestry and Fire Protection. 67 p.

Calder, I; Hofer, T; Vermont, S; Warren, P. 2007. Towards a new understanding of forests and water. Unasylva 229. 58:3-43.

[CALFIRE]. California Department of Forestry and Fire Protection, Fire and Resource Assessment Program. 2003. The Changing California: forest and range 2003 assessment technical report, forest land base. [Internet]. Sacramento (CA): California Department of Forestry and Fire Protection, Fire and Resource Assessment Program. [cited: 2009 Nov 10]. Chapter 2. Productive Capacity. Available at: http://www.frap.cdf.ca.gov/assessment2003/Chapter2_Area/forestlandbase.html

[CALFIRE]. California Department of Forestry and Fire Protection. 2003. The changing California: forest and range assessment: assessment summary, Fire and Resource Assessment Program. Sacramento (CA): California Department of Forestry Fire Protection. Variously paged. Available at: http://www.frap.cdf.ca.gov/assessment2003/index.html

[CSBOF]. California State Board of Forestry and Fire Protection. 1996. Assets at risk and their role in the fire plan: water and watersheds. Sacramento (CA): California State Board of Forestry and Fire Protection. (California Fire Plan: A Framework for Minimizing Costs and Losses from Wildland Fires). p. 73-82.

Campbell, CG; Allen-Diaz, B. 1997. Livestock grazing and riparian habitat water quality: an examination of oak woodland springs in the Sierra foothills of California. In: Pillsbury, NH; Verner, J; Tietje, WD, editors. Proceedings of a symposium on oak woodlands: ecology, management, and urban interface issues. Gen. Tech. Rep. PSW-GTR-160. 1996 Mar 19-22; San Luis Obispo (CA). Albany (CA): USDA Forest Service, Pacific Southwest Research Station. p. 339-346. Available at: http://www.treesearch.fs.fed.us/pubs/28193

Carroll, EM; Miller, WW; Johnson, DW; Saito, LS; Qualls, RG; Walker, RF. 2007. Spatial analysis of a high magnitude erosion event following a Sierran wildfire. Journal of Environmental Quality. 36:1105-1111.

Christensen, GA; Campbell, SJ.; Fried, JS, technical editors. 2008. California's forest resources 2001–2005: five-year Forest Inventory and Analysis report. Portland (OR): USDA Forest Service, Pacific Northwest Research Station. 183 pp. Gen. Tech. Rep. PNW-GTR-763.

Coe, DBR. 2006. Sediment production and delivery from forest roads in the Sierra Nevada. [master's thesis]. [Fort Collins (CO)]: Colorado State University. 110 p.

Cook, C; Dresser, A. 2007. Erosion and channel adjustments following forest road decommissioning Six Rivers National Forest. In: Furniss, M; Clifton, C; Ronnenberg, K, editors. Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference. Forest Service National Earth Sciences Conference; 2004 Oct 18-22; San Diego (CA). Portland (OR): USDA Forest Service, Pacific Northwest Research Station. p. 297-309.

Cornwell, K; Brown, K. 2008. Physical and hydrological characterization of Clark's Meadow in the Last Chance Watershed of Plumas County. Sacramento (CA): California State University Sacramento, Department of Geology. 38 p. Report to the Natural Heritage Institute Mountain Meadows IRWMP.

[CWSF]. Council of Western State Foresters. 2007. Forestry Best Management Practices for Western States: A summary of approaches to water quality implementation and effectiveness monitoring. Final Report. Lakewood (CO): Council of Western State Foresters. 20 p. Available at: http://www.wflccenter.org/news_pdf/240_pdf.pdf

Cram, DS; Baker, TT; Fernald, AG; Madrid, A; Rummer, B. 2007. Mechanical thinning impacts on runoff infiltration and sediment yield following fuel reduction treatments in a southwestern dry mixed conifer forest. Journal of Soil and Water Conservation. 62(5):359-366.

Dailey, S; Fites, JA; Reiner, A; Mori, S. 2008. Fire behavior and effects in fuel treatments and protected habitat on the Moonlight Fire. [Internet]. Vallejo (CA): USDA Forest Service, Pacific Southwest Region, Adaptive Management Service Enterprise Team. [cited: 2009 Nov 10]. 60 p. Available at: http://www.fs.fed.us/r5/hfqlg/monitoring/resource_reports/fire_and_smoke/dfpz_effectiveness/moonlight_fire_effects_assessment.pdf

Diamond, JM. 2005. Collapse: how societies choose to fail or succeed. New York: Viking Press. 575 p.

Driscoll, DG; Carter, JM; Ohlen, DO. 2004. Hydrologic effects of the 1988 Galena Fire, Black Hills area, South Dakota. Denver (CO): US Geological Survey. 67 p. Water-Resources Investigations Report 03-4323. Available at: http://pubs.water.usgs.gov/wri034323

Dudley, N; Stolton, S. 2003. Running pure: the importance of forest protected areas to drinking water. Washington (DC): World Bank/WWF Alliance for Forest Conservation and Sustainable Use. 114 p. Available at: http://www.panda.org/what_we_do/how_we_work/conservation/forests/publications/?uNewsID=8443

Dwire, KA; Kauffman, JB; Baham, JE. 2006. Plant species distribution in relation to water-table depth and soil redox potential in montane riparian meadows. Wetlands. 26(1):131-146.

Erman, DC; Newbold, JD; Roby, KB. 1977. Evaluation of streamside buffer strips for protecting aquatic organisms. Davis (CA): University of California, Davis, California Water Resources Center. 48 p. Contribution No. l65.

Furniss, MJ; Roelofs, TD; Yee, CS. 1991. Road construction and maintenance. In: Meehan, WR, editor. Influences of forest and rangeland management. Special Publication 19. Bethesda (MD): American Fisheries Society. p. 297-324.

Furniss, MJ; Ledwith, TS; Love, MA; McFadin, BC; Flanagan, SA. 1998. Response of Road-Stream Crossings to Large Flood Events in Washington, Oregon and Northern California. Washington (DC): USDA Forest Service, Technology and Development Program. 14 p.

Giono, J. 2005. The man who planted trees. 20th anniversary edition. White River Junction (VT): Chelsea Green Pub. 61 p.

Gokbulak, F; Serengil, Y; Ozhan, S; Ozyuvaci, N; Balci, N. 2008. Effect of timber harvest on physical water quality characteristics. Water Resources Management. 22(5):635-649.

Grace, JM; Skaggs, RW; Chescheir, GM. 2006. Hydrologic and water quality effects of thinning loblolly pine. Transactions of the American Society of Agricultural Engineers. 49(3):645-654.

Hammersmark, CT; Rains, MC; Mount, JF. 2008. Quantifying the hydrological effects of stream restoration in a montane meadow, Northern California USA. River Research and Applications. 24(6):735-753. Available at: DOI: 10.1002/rra.1077

Harris, RR; Cafferata, PH. 2005. Forest Loss and Fragmentation; Session 2: Impacts and Implications—Impacts on water quantity and quality [Abstract]. Powerpoint presentation. California Forest Futures 2005 Conference. 2005 May 24-25. Sacramento (CA).

Hatchett, B; Hogan, MP; Grismer, ME. 2006. Mechanical mastication thins Lake Tahoe forest with few adverse impacts. California Agriculture. 60(2):77-82.

Herbst, DB; Kane, JM. 2004. Responses of Stream Channels Riparian Habitat and Aquatic Invertebrate Community Structure to Varied Livestock Grazing Exposure and Management in the West Walker River Watershed (Mono County California). South Lake Tahoe (CA): Lahontan Regional Water Quality Control Board. 41 p. Final report submitted in partial fulfillment of Lahontan Regional Water Quality Control Board contract numbers 9-046-256-0 9-118-160-0 and 0-091-160-0. Available at: http://www.swrcb.ca.gov/rwqcb6/water_issues/programs/swamp/docs/herbst_kane_wwgs_2004.pdf

Hill, BR. 1990. Groundwater discharge to a headwater valley northwestern Nevada USA. Journal of Hydrology. 113:265-283.

Jewett, DG; Lord, ML; Miller, JR; Chambers, JC. 2004. Geomorphic and hydrologic controls on surface and subsurface flow regimes in riparian meadow ecosystems. In: Chambers, JC; Miller, JR, editors. Great Basin Riparian Ecosystems. Covelo (CA): Society for Ecological Restoration International, Island Press. Chapter 5, p. 124-161.

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

Kattelmann, R; Embury, M. 1996. Riparian Areas and Wetlands. Sierra Nevada Ecosystem Project. Final Report to Congress, Volume III: Assessments, Commissioned Reports and Background Information. Davis (CA): University of California, Centers for Water and Wildland Resources. Chapter 5, p. 201-274. Available at: http://ceres.ca.gov/snep/pubs/

Kellar, G; Sherar, J. 2003. Low volume roads engineering: best management practices field guide. US Agency for International Development. Available at: http://www.zietlow.com/manual/gk1/web.doc

Knapp, RA; Matthews, KR. 1996. Livestock grazing, golden trout, and streams in the Golden Trout Wilderness, California: Impacts and management implications. North American Journal of Fisheries Management. 16:805-820.

Korte, A; MacDonald, LH. 2007. Preliminary summary: sediment production and delivery in the southern Sierra Nevada. 5 p. Unpublished paper dated March 1, 2007. Watershed Science Program, Colorado State University, Fort Collins (CO).

Krieger, DJ. 2001. The economic value of forest ecosystem services: a review. Washington (DC): The Wilderness Society. 40 p. Available at: http://wilderness.org/content/economic-value-forest-ecosystem-services

Liang, L; Kavvas, ML; Chen, ZQ; Anderson, M; Ohara, N; Wilcox, J; Mink, L. 2007. Modeling River Restoration Impact on Flow and Sediment in a California Watershed. In: Kabbes, KC, editor. Proceedings of the 2007 World Environmental and Water Resources Congress. 2007 World Environmental and Water Resources Congress; 2007 May 15-19; Tampa (FL). Reston (VA): American Society of Civil Engineers. p. 1-10. Available at: DOI 10.1061/40927(243)353

Ligon, F; Rich, A; Rynearson, G; Thornburgh, D; Trush, W. 1999. Report of the Scientific Review Panel on California Forest Practice Rules and salmonid habitat. Sacramento (CA): California Natural Resources Agency and the National Marine Fisheries Service. 181 p.

Loheide, SPII; Gorelick, SM. 2007. Riparian hydroecology: a coupled model of the observed interactions between groundwater flow and meadow vegetation patterning. Water Resources Research. 43:W07414. Available at: DOI:10.1029/2006WR005233.

MacDonald, LH; Coe, D. 2007. Influence of headwater streams on downstream reaches in forested areas. Forest Science. 53(2):148-168.

MacDonald, LH; Coe, D; Litschert, S. 2004. Assessing cumulative watershed effects in the central Sierra Nevada: hillslope measurements and catchment-scale modeling. In: Murphy, DD; Stine, PA, editors. Proceedings of the Sierra Nevada Science Symposium. Sierra Nevada Science Symposium; 2002 Oct 7-10; Kings Beach (CA). Albany (CA): USDA Forest Service, Pacific Southwest Research Station. p. 149-157. Available at: http://www.treesearch.fs.fed.us/pubs/26449

Madej, MA. 2001. Erosion and sediment delivery following removal of forest roads. Earth Surface Processes and Landforms. 26:1-16.

Madej, MA; Ozaki, V. 1996. Channel response to sediment wave propagation and movement, Redwood Creek, California, USA. USA Earth Surface Processes and Landforms. 21(10):911-927.

Madrid, A; Fernald, AG; Baker, TT; Vanleeuwen, DM. 2006. Evaluation of silvicultural treatment effects on infiltration, runoff, sediment yield, and soil moisture in a mixed conifer New Mexico forest. Journal of Soil and Water Conservation. 61(3):159-168.

Martin, S. 2006. Topics in mountain meadows. Powerpoint presentation. Class presentation. University of California, Merced. Merced (CA). 45 p.

McCashion, JD; Rice, RM. 1983. Erosion on logging roads in northwestern California: How much is avoidable? Journal of Forestry. 81(1):23-26.

McClurkin, DC; Duffy, PD; Nelson, NS. 1987. Changes in forest floor and water quality following thinning and clearcutting of 20-year-old pine. Journal of Environmental Quality. 16:237-241.

McGurk, BJ; Berg, NH; Davis, ML. 1996. Camp and Clear Creeks El Dorado County: predicted sediment production from forest management and residential development. Sierra Nevada Ecosystem Project. Final Report to Congress, Volume II: Assessments and Scientific Basis for Management Options. Davis (CA): University of California, Centers for Water and Wildland Resources. p. 1407-1420. Available at: http://ceres.ca.gov/snep/pubs/

McPherson, EG; Simpson, JR; Peper, PJ; Xiao, QF. 1999. Tree Guidelines for San Joaquin Valley Communities. Davis (CA): USDA Forest Service, Pacific Southwest Research Station, Western Center for Urban Forest Research and Education. 59 p.

McPherson, G; Simpson, J; Peper, P; Maco, S; Xiao, Q. 2005. Municipal Forest Benefits and Costs in Five US Cities. Journal of Forestry. 2005(Dec):411-416.

Micheli, ER; Kirchner, JW. 2002. Effects of wet meadow riparian vegetation on streambank erosion. 2. Measurements of vegetated bank strength and consequences for failure mechanics. Earth Surface Processes and Landforms. 27:687-697.

Miller, WW; Johnson, DW; Denton, C; Verburg, PSJ; Dana, GL; Walker, RF. 2005. Inconspicuous nutrient laden surface runoff from mature forest Sierran watersheds. Water, Air and Soil Pollution. 163:3-17.

Miller, WW; Johnson, DW; Loupe, TM; Sedinger, JS; Carroll, EM; Murphy, JD; Walker, RF; Glass, D. 2006. Nutrients flow from runoff at burned forest site in Lake Tahoe Basin. California Agriculture. 2006(Apr-Jun):65-71.

Moody, JA; Martin, DA; Cannon, SH. 2008. Post-wildfire erosion response in two geologic terrains in the western USA. Geomorphology. 95:103-118.

Moore, RD; Wondzell, SM. 2005. Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review. Journal of the American Water Resources Association. 2005(Aug):763-784.

Murphy, DD; Stine, PA, editors. 2004. Proceedings of the Sierra Science Symposium. General Technical Report PSW GTR-193. 2002 Oct 7-10; Kings Beach (CA). Albany (CA): USDA Forest Service, Pacific Southwest Research Station. 287 p.

Naiman, RJ; Fetherston, KL; McKay, SJ; Chen, J. 1998. Riparian forests. In: Naiman, RJ; Bilby, RE, editors. River ecology and management: lessons from the Pacific Coastal Ecoregion. New York: Springer-Verlag. p. 289-323.

[NWCG]. National Wildfire Coordinating Group Training Working Team. 2004. Resource advisor's guide for wildland fire. Boise (ID): National Interagency Fire Center. 14 p. PMS 313 NFES 1831. Available at: http://www.nwcg.gov/pms/pubs/pubs.htm

Neary, DG; Ryan, KC; DeBano, LF, editors. 2005. Wildland fire in ecosystems: effects of fire on soils and water. Ogden (UT): USDA Forest Service, Rocky Mountain Research Station. 250 p. General Technical Report RMRS-GTR-42, vol. 4.

Newbold, JD; Erman, DC; Roby, KB. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Canadian Journal of Fisheries and Aquatic Science. 37:1076-1085.

Norman, S; Loupe, T; Keely, J. 2008. Heavenly Creek SEZ demonstration project 2007 soil monitoring report. South Lake Tahoe (CA): Lake Tahoe Basin Management Unit, USDA Forest Service. 24 p. Available at: http://www.fs.fed.us/r5/ltbmu/documents/ecd/2008/Heavenly_Creek_SEZ_Report_Final.pdf

Onda, Y; Dietrich, WE; Booker, F. 2007. Evolution of overland flow after a severe forest fire Point Reyes California. Catena. 72:13-20.

[PWA]. Pacific Watershed Associates. 2005. Evaluation of road decommissioning CDFG Fisheries Restoration Grant Program 1998 to 2003. Arcata (CA): Pacific Watershed Associates. 56 p. Final Report submitted to the California Department of Fish and Game under Contract #P0210559. Available at: http://www.pacificwatershed.com/images/stories/CDFG_PWA_decom_report.pdf

Peterson, DH; Stewart, I; Murphy, F. 2008. Principle hydrologic responses to climatic and geologic variability in the Sierra Nevada, California. San Francisco Estuary and Watershed Science. 6(1):Article 3.

Ponce, VM; Lindquist, DS. 1990. Management of baseflow augmentation: a review. Water Resources Bulletin. 26(2):259-268.

Potts, DF; Peterson, DL; Zuuring, HR. 1989. Estimating postfire water production in the Pacific Northwest. Berkeley (CA): USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. 9 p. USDA Forest Service Research Paper PSW-197.

Ratliff, RD. 1985. Meadows in the Sierra Nevada of California: state of knowledge. Berkeley (CA): USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. 52 p. General Technical Report PSW-84. Available at: http://www.treesearch.fs.fed.us/pubs/27313

Reneau, SL; Katzman, D; Kuyumjian, GA; Lavine, A; Malmon, DV. 2007. Sediment delivery after a wildfire. Geology. 35(2):151-154.

Robichaud, PR. 2000. Forest fire effects on hillslope erosion: what we know. Watershed Management Council Networker. [Internet]. Winter 2000. Moccasin (CA): Watershed Management Council. [cited: 2009 Nov 12]. 9(1). Available at: http://www.watershed.org/news/win_00/2_hillslope_fire.htm

Robichaud, PR; Beyers, JL; Neary, DG. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. 85 p. General Technical Report RMRS-GTR-63. Available at: http://www.fs.fed.us/rm/publications/titles/rmrs_gtr.html

Robichaud, PR; Pierson, FB; Brown, RE. 2007. Runoff and erosion effects after prescribed fire and wildfire on volcanic ash-cap soils. In: Page-Dumroese, D; Miller, R; Mital, J; McDaniel, P; Miller, D, editors. USDA Forest Service Proceedings RMRS-P-44. Volcanic-Ash-Derived Forest Soils of the Inland Northwest: Properties and Implications for Management and Restoration; 2005 Nov 9-10; Coeur d'Alene (ID). Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. p. 83-94. Available at: http://www.treesearch.fs.fed.us/pubs/26215

Rulli, MC; Rosso, R. 2007. Hydrologic response of upland catchments to wildfires. Advances in Water Resources. 30(10):2072-2086.

Sierra Nevada Ecosystem Project. 1996. Volume I. Assessment Summaries and Management Strategies. Chapter 8- Watersheds and Aquatic Biodiversity. Final Report to Congress. Davis (CA): University of California, Centers for Water and Wildland Resources. p. 123-133. Available at: http://ceres.ca.gov/snep/pubs/

Stephens, SL; Moghaddas, JJ. 2005. Experimental fuel treatment impacts on forest structure potential fire behavior and predicted tree mortality in a California mixed conifer forest. Forest Ecology and Management. 215:21-36.

Stohlgren, TJ; DeBenedetti, SH; Parsons, DJ. 1989. Effects of herbage removal on productivity of selected high-Sierra meadow community types. Environmental Management. 13(4):485-491.

Troendle, CA; Nankervis, JM; Peavy, A. 2007. The Herger-Feinstein Quincy Library Group Project—Impacts of Vegetation Management on Water Yield. Final report. Fort Collins (CO): USDA Forest Service Pacific Southwest Region. (Resource Reports - Hydrology and Fisheries). 23 p. Contract AG 3187 D 05 0043. Available at: http://www.fs.fed.us/r5/hfqlg/monitoring/resource_reports/hydrology_and_fisheries/Water_Yield_Full_Report_Feb242007.pdf

Turner, KM. 1991. Water salvage from Mediterranean-type ecosystems. In: Bailey, HE; Forrest, C; Snow, L, editors. Water Supply and Water Reuse: 1991 and Beyond. Proceedings of the American Water Resources Association Annual Symposium. American Water Resources Association Annual Symposium; 1991 Jun 2-6; San Diego (CA). Middleburg (VA): American Water Resources Association. p. 83-90.

[USFS]. USDA Forest Service, Pacific Southwest Research Station,, Center for Urban Forest Research. 1999. Fact Sheet #1: Benefits of the Urban Forest. Davis (CA): USDA Forest Service. 2 p.

[USFS]. USDA Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. 2002. Fact Sheet #4: Control Stormwater Runoff with Trees. Davis (CA): USDA Forest Service. 2 p.

[USFS]. USDA Forest Service, Pacific Southwest Region. 2004. Best management practices evaluation program: 1992-2002 monitoring results. Final Report. Vallejo (CA): USDA Forest Service Pacific Southwest Region. 76 p.

[USFS]. USDA Forest Service, Pacific Southwest Research Station. 2007. An Assessment of fuel treatment effects on fire behavior, suppression effectiveness, and structure ignition on the Angora Fire. [Internet]. Vallejo (CA): USDA Forest Service, Pacific Southwest Research Station. [cited: 2009 Nov 10]. Available at: http://www.fs.fed.us/r5/angorafuelsassessment/

[USFS]. USDA Forest Service, Pacific Southwest Research Station. 2009. An Integrated Science Plan for the Lake Tahoe Basin: Conceptual Framework and Research Strategies. Albany (CA): USDA Forest Service Pacific Southwest Research Station. (Hymanson, ZP; Collopy, MW, editors. Chapter 4.11). p. 117-123. General Technical Report PSW-GTR-XXX. Available at: http://tahoescience.org/EventImage.aspx?sa=1&id=194

[USFS]. USDA Forest Service. 2000. Water and the Forest Service. Washington (DC): USDA Forest Service. 26 p. FS-660. Available at: http://www.fs.fed.us/publications/policy-analysis/water.pdf

[USFS]. USDA Forest Service. 2005. A strategic assessment of forest biomass and fuel reduction treatments in Western states. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. 17 p. Gen. Tech. Rep. RMRS-GTR-149. Available at: http://www.fs.fed.us/rm/pubs/rmrs_gtr149.html

Weaver, WE; Hagans, DK. 1994. Handbook for forest and ranch roads: a guide for planning, designing, constructing, reconstructing, maintaining, and closing wildland roads. Ukiah (CA): Mendocino County Resource Conservation District. 161 p.

Weaver, W; Hagans, D; Weppner, E. 2006. Upslope erosion inventory and sediment control guidance. 1998 revised 3rd ed. Sacramento (CA): California Department of Fish and Game. (California Salmonid Stream Habitat Restoration Manual. Part X.). 108 p.

Wood, SH. 1975. Holocene stratigraphy and chronology of mountain meadows Sierra Nevada California. Vallejo (CA): USDA Forest Service Pacific Southwest Region. (Earth Surface Monograph 4). 180 p.

Xiao, Q; McPherson, G; Simpson, J; Ustin, S. 1998. Rainfall Interception by Sacramento's Urban Forest. Journal of Arboriculture. 24(4):235-244.

Ziemer, RR. 1987. Water yield from forests: an agnostic view: California Watershed Management Conference. In: Callaham, RZ; DeVries, JJ, editors. Proceedings of the California Watershed Management Conference. California Watershed Management Conference; 1986 Nov 18-20; West Sacramento (CA). Berkeley (CA): University of California, Wildland Resources Center. p. 74-78. Available at: http://www.treesearch.fs.fed.us/pubs/8672

Ziemer, RR; Lisle, TE. 1998. Hydrology. In: Naiman, RJ; Bilby, RE, editors. River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. New York: Springer-Verlag. Chapter 3, p. 43-68. Available at: http://www.humboldt.edu/~rrz7001/pubs/Ziemer98a.PDF

Zinke, PJ. 1987. The recovery factor in watershed land use for timber harvest and growth. Impact '87. California Licensed Foresters Association (CLFA) Annual Conference; 1987 Mar 6-7; Sacramento (CA). Sacramento (CA): California Licensed Foresters Association. 7 p.