Water Quality Stressors

The evaluation of potential land use impacts to water quality requires an understanding of the linkages between natural watershed processes and management activities.

Analytically, the evaluation of potential land use impacts to water quality requires an understanding of the linkages between natural watershed processes and management activities. Various models and approaches have been developed to portray possible relationships between natural processes and management activities. For example, in watersheds where sediment is a pollutant, a sediment budget can be constructed to identify the relative magnitude of different sources, both natural and management-related. Another example relates to an expert system model developed by the California Department of Forestry and Fire Protection (CDF) for the North Coast Watershed Assessment Program (NCWAP). This model is referred to as the Ecosystem Management Decision Support system and provides an evaluation of potential sediment production (Figure 16). For more information see Ecosystem Management Decision Support Case Study. This model explicitly states how different features in watersheds are thought to contribute to sediment production. Still another illustration is that a recent study (Benda et al., 2002) used a mass balance approach to account for the input of wood into stream channels. Evaluation and assessment techniques like these can be thought of as an accounting system for watersheds.

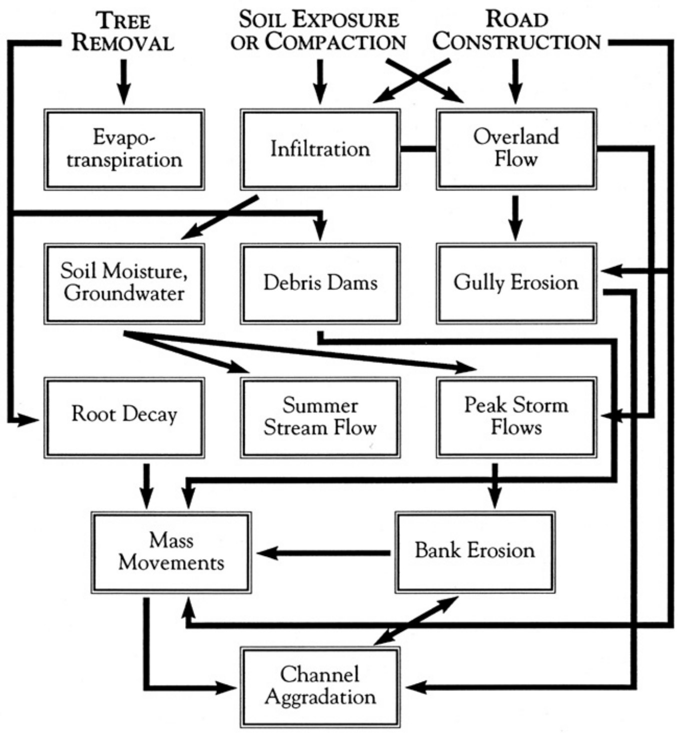

Parlin Creek, Jackson State Demonstration Forest.

The water quality impacts of timber harvesting—including stream sedimentation, lack of instream LWD (an important fish habitat element in many streams), increased water temperature, and hydrologic impacts (higher peak flow and lower low flows)—are related to the effects of vegetation removal, road building, and soil exposure and compaction. Some of these water quality impacts may occur in ranching operations as well, along with the possible addition of nutrients from animal waste. The interrelationship among tree removal, soil impacts, and road construction and their potential effects is depicted in Figure 17. With the possible secondary and indirect effects being so numerous, a lag exists in both space and time between the original action and the present conditions.

Figure 16. Ecosystem Management Decision Support model to evaluate potential sediment production in North Coast watersheds

Source: Keithley and Walker, 2002

Figure 17. Related impacts from timber harvesting on water quality



Source: Mount, 1995

Sediment

Monterey County, California. Photo: Lynn Betts, USDA NRCS.

Through erosion processes, hillslopes produce sediment that is delivered to streams through surface erosion and mass wasting. Sediment is transported from hillslopes to streams through both slow (soil creep) and rapid processes (landslides). The quantity of sediment generated in both undisturbed and managed areas depends largely on the soils and underlying geology. Water facilitates the transport of sediment both by weakening hillslopes and moving material downslope. Watersheds produce sediment largely episodically as the result of high intensity storm events that occur infrequently. Additionally, in areas of intense management, many sediment sources are ongoing and chronic. Once delivered to the stream, the transport of sediment through a stream occurs over time scales from decades to hundreds of years. Smaller particles of sediment are transported downstream as suspended sediment, while larger material is moved along the channel bed (i.e. bedload transport). The amount and timing of sediment stored in stream channels can exert a strong influence on channel morphology.

Forests in a watershed intercept precipitation and promote infiltration of water into the soil. However, management activities that remove forest canopy and disturb the soil profile can accelerate erosion and runoff rates. Early forest management was conducted with little consideration of environmental impacts, and the effects can be long lasting. Hence, the condition of a river reflects both current management practices and the legacy of past management. To better understand the amount and sources of sediment in a watershed, a sediment budget can be constructed. A sediment budget is an accounting system for a watershed, dividing the amount of sediment that a watershed produces amongst the natural and management-related sources. However, the input sources only represents a partial budget. A full watershed budget ($I + \Delta\ S = O$) includes sediment inputs (I), changes in sediment storage (S) within stream channels and the amount of sediment discharged from a watershed (O). The primary mechanisms that represent sediment sources are included in a sediment production model that was developed for North Coast Watersheds with input from a wide range of government and university specialists (Figure 16). The model shows the relationship between natural and management-related sources of sediment. The model evaluates the potential for sediment production to vary with management activities in different landscape positions. The processes represented in a sediment budget are complex and can vary greatly in space and time (MacDonald, 2000). As such, most sediment budgets lack the precision to predict sediment yield with a high degree of accuracy, but can clearly identify the major contributors of sediment. With the understanding of the magnitude of natural and anthropogenic sediment sources that a sediment budget provides, water quality regulators and land managers can better direct their activities to reduce management-related sediment sources that may be contributing to the impairment of water quality.

A sediment budget is an accounting system for a watershed, dividing the amount of sediment that a watershed produces amongst the natural and management-related sources.

It is worth noting that sediment budgets and erosion studies have shown that sediment is not distributed uniformly across a watershed. The most predominant sources often represent a relatively small portion of the watershed. For the Van Duzen River basin, Kelsey (1980) attributed 50 percent of the sediment budget to six percent of the drainage area. Lewis and Rice (1991) reported an average harvest area erosion of 1,100 cubic meters (m^3) per square kilometers (km^2) based on measurement of erosional features. Their study noted that most sediment yield from harvest areas came from critical sites occupying a small portion of the landscape.

Sediment budgets and erosion studies have shown that sediment is not distributed uniformly across a watershed.

Erosion from forest roads can be a persistent source of sediment in a watershed. For example, a sediment budget developed as part of the management plan for the Jackson Demonstration State Forest (JDSF) estimated the average sediment yield for JDSF to be 300 tons/mi^2/year for the period from 1958-1997 (Table 8). Road related surface erosion and land sliding was the dominant source accounting for 74 percent of the sediment budget. Background surface erosion was low, suggesting that in undisturbed forests surface erosion plays a minor role in sediment delivery. A detailed sediment budget for Freshwater Creek produced similar results. From 1988-1997, the average sediment input rate was estimated to be 420 tons/mi^2/year (Table 9). Management activities were shown to be a major source of the sediment budget. Surface erosion from roads was the largest contributor of management related sediment (59 percent), followed by road related landslides (29 percent), and smaller inputs for harvest related landslides and surface erosion. Sediment inputs from natural sources represented more than a third of all sediment inputs over the 10-year period, but were highly variable among sub-basins.

Table 8. Sediment budget for Jackson Demonstration State Forest, 1958-1997

Individual Processes	Process Rates (tons/km2/yr)
Hillslope Erosion	
Shallow Landslides	209 (275 from 1958 – 1978; 137 from 1978 – 1996)
Deep-seated landslides	9
Soil Creep	10
Background hillslope surface erosion	10
Road-related surface erosion	194
Total hillslope erosion	430
Hillslope Sediment Delivery to Channels (Input)	
Total hillslope sediment delivery to channels	280
Change in Storage	
Lower hillslopes and valley flats	150
Channel (LWD sediment storage)	20
Sediment Yield (Output)	
Estimated for HCP/SYP assessment area	300

Source: California Department of Forestry and Fire Protection, 1999

Table 9. Summary of sediment inputs, 1988-1997, for Freshwater Creek, by sub-basin (Total tons over a 10-year period)

Source / Sub-basin	Management Related[1]	Natural Background[2]	Legacy Inputs[3]
Upper Freshwater	19,610	25,470	2,570
S. Fork	9,890	9,610	2,370
Graham Gulch	11,060	12,450	920
Cloney Gulch	16,390	5,020	710
Little Freshwater	32,820	12,950	4,060
McCready Gulch	9,940	1,770	810
Lower Freshwater	7,050	3,330	1,400
School Forest	1,670	510	0
Total	108,430	71,110	12,840
Percent	56%	37%	7%

[1] *Management sources include: road surface erosion, road landslides, deep-seated landslides, shallow landslides, harvest surface erosion, and bank erosion.*
[2] *Natural sources include: deep-seated landslides, shallow landslides, bank erosion, soil creep, streambank slides.*
[3] *Legacy sources include: bank erosion, low order valley fill, scour of tractor fill, and streambank slides.*
Source: Watershed Professionals Network, 2001

The road network is often extensive and difficult to maintain. Recent studies suggest that the connectivity of roads to stream channels increases sediment delivery and affects runoff processes. With forest roads, the highest erosion rates tended to be associated with the initial road construction period overlapping with major storms. However, a high incidence of landslides (mass wasting) is also correlated with steep slopes, unstable soils, and road location and design. Controlling road drainage and avoiding construction of roads on sidecast are shown to prevent fill failures and major debris torrents. Less erosion is observed with improved road design as well as location and roadside erosion control practices. Where forest roads cross streams, a culvert is the typical structure used to pass the stream flow under the road. When such culverts are sized too small, they may impede storm flows and associated debris. If they do, water will back up and may eventually overtop the road and completely erode the road surface and fill. This development results in a large input of sediment to the stream.

Forest roads can be designed to significantly minimize erosion and downstream sedimentation in a cost effective manner. Low maintenance, low impact roads can be constructed on forests and rangelands (Weaver and Hagans, 1994). How road systems are built and managed has changed dramatically in the past decade due to improved awareness of road impacts on watershed health, along with heightened regulatory scrutiny for clean water and endangered aquatic species. National forest managers, for example, are presently conducting a thorough roads analysis to determine the risks and opportunities for each road, especially the effect on water quality (U.S. Forest Service, 1999). The State FPRs for roads have evolved to require increasingly stringent standards for roads associated with timber harvest on non-federal lands. Some low value roads are being "decommissioned," meaning permanently removed and restored. Timberland and ranch managers are learning and applying better practices. Because of all of the above, forest roads today are not all created or managed equally in California, and their impact on water quality varies tremendously.

Riparian forests and large woody debris

Riparian forests are defined as the area of land located immediately adjacent to streams, lakes, or other surface waters, and extending into floodplain and terraces. The spatial extent of riparian areas varies laterally throughout the channel network and is strongly influenced by geomorphology (Naiman et al., 1998). The boundary (e.g., ecotone) of the riparian area and the adjoining uplands is not always well defined, but can exhibit strong differences in microclimate (Brosofske et al., 1997). Riparian areas differ from the uplands because of high levels of soil moisture, frequent flooding, and the unique assemblage of plant and animal communities found there. Riparian vegetation influences stream ecosystems by contributing wood and organic material to streams, providing shade, and regulating microclimates.

Flooding, fire, mass wasting, and disease are all natural disturbance processes that affect vegetation through succession.

Riparian forests develop in response to disturbance. Flooding, fire, mass wasting, and disease are all natural disturbance processes that affect vegetation through succession (Naiman et al., 1998). The relative importance of disturbance processes results in distinct differences in vegetation patterns along low gradient floodplains versus forest conditions along steep confined channels. Forest practices, agriculture, development, and other land use have the potential to affect riparian processes through the following: sedimentation, slope and bank instability, stream temperature, channel structure, floodplain processes, alteration of vegetation, amounts of woody debris, aquatic plant production, terrestrial litter inputs, and invertebrate, fish, and wildlife populations (Gregory et al., 1991).

Through tree mortality and disturbance (e.g., bank erosion and landslides), riparian forests deliver wood to streams. The wood adds structure to the stream, helping in pool formation and providing cover. Although recognized as an important habitat element, the relationship between input rates and management activities is not well understood. Table 10 shows data on LWD "loadings" from Alaska through northern California. These loading data express the volume of wood (m^3) per unit of channel area (square meters). The redwood forests of northern California have been shown to have relatively high loadings (volume of wood per unit area) when compared to forest types in other regions (Table 7)

(Lassettre and Harris, 2001). Compared to the Sierra Nevada, the amount of LWD in North Coast streams is 10 to 20 times higher in unmanaged basins (Lisle, 2002). Some studies have shown differences between the amounts of wood provided by unmanaged forests to that found in second growth forests (Spies et al., 1988; Wooster, 2000). Due to the high variability of LWD in streams, the amount of wood needed has not been clarified.

Compared to the Sierra Nevada, the amount of LWD in North Coast streams is 10 to 20 times higher in unmanaged basins.

Most streams exhibit a high degree of variability in LWD loading among different stream reaches. The variability of wood recruited to stream channels is greatly influenced by both current and past management practices. Logging, salvage operations, and stream clearing all have an impact on the amount of wood being recruited and remaining in stream channels. However, due to the naturally high variability in wood loadings, the relationship between input rates and management activities is not well understood. A common approach is to compare the amount of wood in a managed stream to that found in an unmanaged stream.

As an alternative, recent studies have proposed the use of a wood budget. Similar to a sediment budget, this approach attempts to account for wood in streams by the mechanisms for recruitment—tree mortality, windfall, and bank erosion (Benda et al., 2002).

Table 10. Large woody debris loadings

Location	Forest type	LWD loading	Reference
Alaska	Sitka Spruce, western hemlock	190 m^3/ha	Harmon et al., 1986
Alaska	Sitka spruce, western hemlock, red alder	610 m^3/ha	Robison and Beschta, 1990
British Columbia	Sitka Spruce, Western Hemlock	680 m^3/ha	Harmon et al., 1986
Oregon	Douglas Fir	570 m^3/ha	Harmon et al., 1986
Oregon	Douglas Fir	534 m^3/ha	Spies et al., 1988
Northern California	Douglas Fir	280 m^3/ha	Harmon et al., 1986
Northern California	Coast Redwood	1550 m^3/ha	Harmon et al., 1986
Northern California	Coast Redwood	1810 m^3/ha	Keller and MacDonald, 1983
Northern California	Coast Redwood, Hardwood	279m^3/ha	O'Conner, 2000
Northern California	Coast Redwood	579 m^3/ha	Wooster, 2000
Northern California	Coast Redwood	309 m^3/ha	Wooster, 2000
Northern California, Sierras	Conifer	30 m^3/ha	Berg et al., 1998; Lisle, 2002

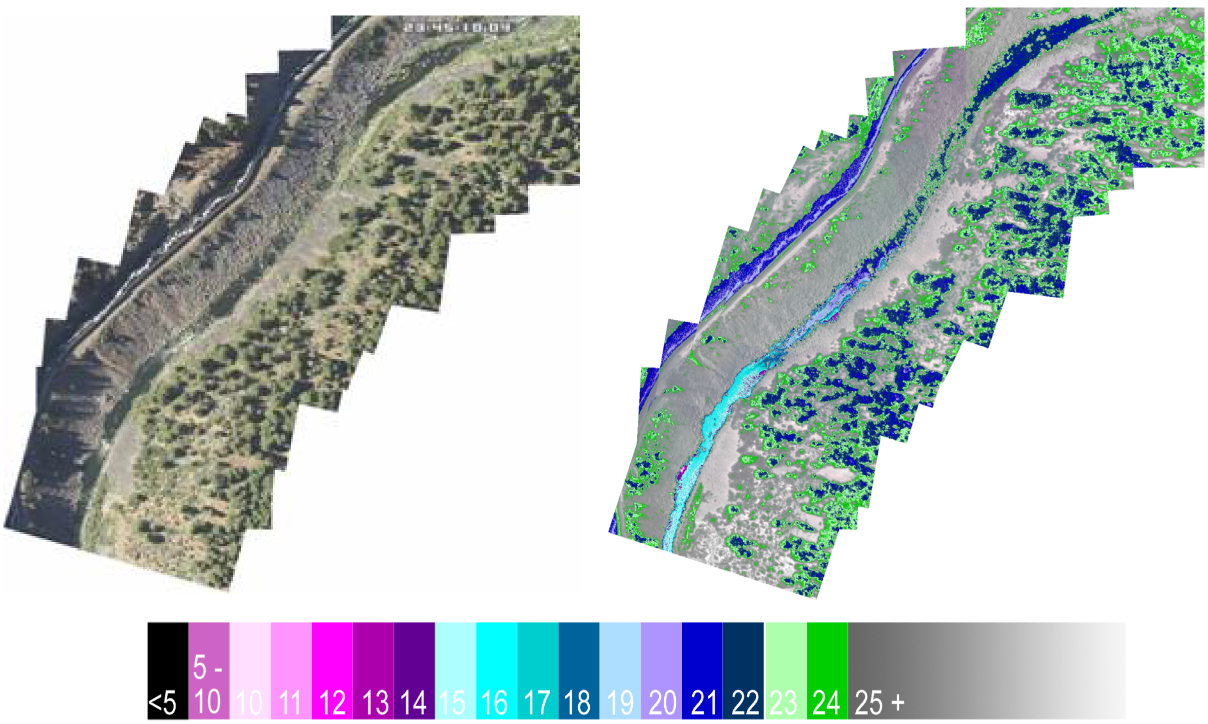
LWD – large woody debris; m^3/ha – cubic meters per hectacre

Source: Modified by FRAP from Lassettre and Harris, 2001

Water temperature

Stream temperature in forested watersheds is a significant water quality parameter that affects both chemical and biological processes in aquatic species. It can greatly influence growth, behavior, timing of life history stages, and survival of salmonids (Beschta et al., 1987). For more information on temperature requirements for salmonids, see the online document KRIS Stream Temperature Review. Physical factors that affect water temperature include air temperature, riparian vegetation, ground water, tributary inflows, air temperature, solar radiation, and water depth (Welch et al., 1998; Sullivan et al., 1990). Water temperature throughout a stream channel is dynamic and can vary dramatically over short distances (Figure 18). Temperature can also vary greatly across the water depth at a given spot. Deep, cool pools can provide important thermal refugia for fish where water temperatures closer to the surface or in shallower areas are sub-optimal or even lethal.

Figure 18. Klamath River variability in stream temperature across a short reach



Paired with an aerial color photo mosaic (left), an aerial thermal infrared image (right) of the Klamath River shows dramatic variability in stream temperature across a short reach—the change is attributed to the presence of cold-water springs.

Source: Watershed Sciences, LLC, 2002

The physical factors that influence stream temperature vary with channel position. Headwater streams are typically steep, narrow, and shallow. They are greatly affected by topography, riparian canopy, and air temperature. With higher order streams, this is not the case. These streams are characterized by lower stream gradients, finer sediment, and wider and deeper channels. As channels widen, topography and riparian vegetation becomes less effective at providing shade (Poole and Berman, 2000).

As channels widen, topography and riparian vegetation becomes less effective at providing shade.

Land management can affect water temperature both directly and indirectly. For example, the storage and release of water from dams and reservoirs can have a direct and immediate impact on water temperatures. Other events in a watershed that are not directly associated with a stream also can indirectly influence stream temperatures. For example, activities or natural events that deliver excessive amounts of sediment into stream channels can aggrade stream beds over time. This process can lead to wider, shallower channels that warm with increased exposure to solar radiation.

There have been very few regional assessments of stream temperatures in California. The Institute for Forest and Watershed Management (formerly Forest Science Project) provided one such study for streams in Northern California (Lewis et al., 2000). See the online document Regional Assessment of Stream Temperatures Across Northern California and Their Relationship to Various Landscape-Level and Site-Specific Attributes for more information. Their study covered the coastal region in northern

California that coincides with the range of Coho salmon. The study used data from over 1,000 sites on predominately private timberlands. Their findings suggest that stream temperature increased with watershed area and distance from the watershed divide. The distance from the watershed divide at which the stream channel becomes too wide for riparian vegetation to provide adequate shading is referred to as a threshold distance (Sullivan et al., 1990). For northern California watersheds, this study found that at 70 meters, canopy closure was minimal and presumably no longer influential in regulating stream temperatures.

Water temperature is of primary concern in North Coast watersheds. Under provisions from the federal CWA, California has listed 14 rivers and streams on the North Coast as impaired for water temperature (Table 11).

Table 11. Temperature impaired waterbodies in California

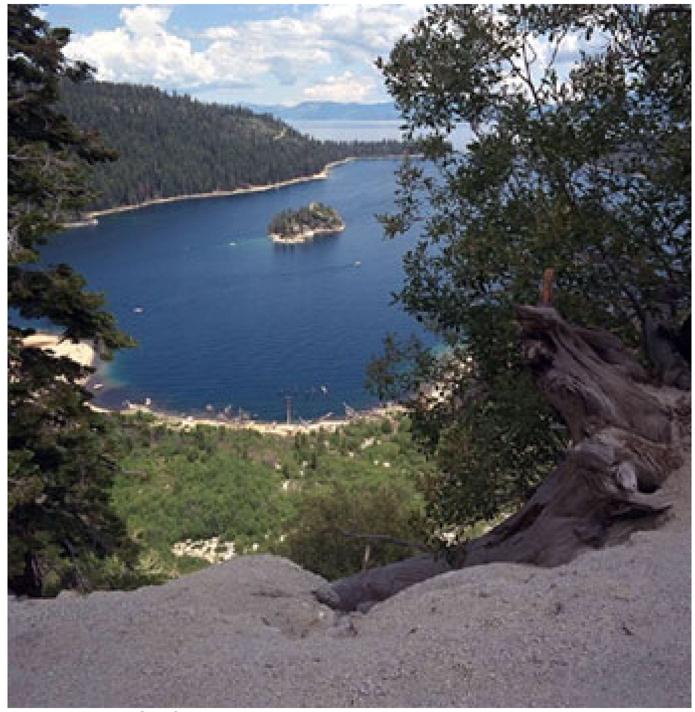
Water body name	Pollutant source
Eel River, Middle Fork	Nonpoint source
Eel River, Middle Main Fork	Nonpoint source
Eel River, North Fork	Nonpoint source
Eel River, South Fork	Nonpoint, erosion/siltation
Eel River, Upper Main Fork	Nonpoint source
Garcia River	Habitat modification, removal of riparian vegetation, streambank modification, and nonpoint source
Mattole River	Silviculture, habitat modification, removal of riparian vegetation, nonpoint source
Navarro River	Agriculture, agricultural return flows, resource extraction, flow regulation, water diversions, habitat modification, removal of riparian vegetation, streambank modification, filling of wetlands, nonpoint source
Scott River	Irrigated crops, pasture land, agricultural return flows, silviculture, water diversions, habitat modification, removal of riparian vegetation, streambank modification, filling of wetlands, nonpoint source
Shasta River	Agricultural water diversion, water diversions, habitat modification, removal of riparian vegetation, filling of wetlands, nonpoint source
Trinity River, South Fork	Riparian grazing, water diversions, habitat modification, removal of riparian vegetation, streambank modification
Pit River	Agriculture, agricultural grazing

Source: SWRCB, 2000b

Effect of forest cover on stream temperatures

Stream shade from riparian canopy cover is not the only factor affecting stream temperatures but is one of the factors that is greatly influenced by management activities. Intuitively, a reduction in canopy cover can lead to an increase in the amount of water surface area that is exposed to direct solar radiation. Detecting the affects from this has met with mixed results. Along the North Fork of Caspar Creek, clearcut harvesting with buffer strips produced only a minor (four degree Fahrenheit) increase in stream temperature (Cafferatta, 1990).

Nutrients


Lake Tahoe, California.

Nutrients are essential to the health and diversity of biota in streams and watersheds. However, excessive amounts of nutrient inputs can lead to eutrophication and ultimately a decline in the biologic communities that a stream supports. Nutrients are chemicals such as carbon, nitrogen, phosphorous, sulfur, calcium, magnesium, potassium, and iron and are essential for growth of living organisms in a watershed. Forested streams are generally considered nutrient poor and are sensitive to changes that can lead to nutrient enrichment (Naiman et al., 1992). Forests regulate the uptake of nitrogen, phosphorus, and sulfur from atmospheric and geologic sources. While forests retain some amounts of nitrogen and phosphorus, nutrients are input to streams through groundwater baseflow, storm flow, canopy throughfall, litterfall, landslides, and bank erosion.

In undisturbed watersheds, nitrogen and phosphorus are considered limiting nutrients (Naiman et al., 1992). Phosphorus is typically in much shorter supply than nitrogen, where nitrogen to phosphorus ratios can easily exceed 20 to one. Land use activities (e.g., changes from forest to agriculture) are typically associated with substantial increases in concentration of nitrogen and phosphorus compounds (Binkley, 2001). Data on undisturbed watersheds (see the Hydrologic Benchmark Network) have recorded low levels of total nitrogen, less that one milligram per liter (mg/L) (Clark et al., 2000). A similar pattern was observed for phosphorus, .022 mg/L and greater than one mg/L respectively. By comparison, data from intensively managed basins typically exceeds one mg/L. A recent study of over 300 streams in small, forested watersheds found that nitrate concentrations averaged 0.31 mg/L (Binkley, 2001).

Land use in a watershed has the potential to increase nutrient inputs dramatically. Timber harvesting, nonpoint source runoff from agriculture, and stormwater runoff from urban areas all provide significant inputs. Natural disturbances such as wildfires are also a source. Management activities can create nutrient changes that are short lived, while other changes have more profound and longer lasting effects. Environmental studies in the Caspar Creek watershed provide insight into the temporal effects of timber harvesting on nutrient losses (Dahlgren, 1998). Increases in stream water nitrate concentrations were detected after clear-cutting. Nitrate concentrations decreased in higher order stream segments. However, the maximum loss of nitrogen (1.8 kilogram nitrogen per one hectare per year) was low and decreased dramatically after three years to less than 0.4 kilograms nitrogen per one hectare per year.

Lake Tahoe provides a good example of the degree to which human activities can dramatically alter the nutrient inputs and nutrient cycles within a basin. The historical clarity of the lake water has diminished over time with increased nutrient loadings from streams, urban runoff, groundwater, and atmospheric deposition. As part of a watershed assessment of the Lake Tahoe Basin, researchers developed a nutrient budget to better understand the magnitude of different sources. The budget allocates the annual inputs of nutrients amongst these sources.

Table 12. Nutrient Budget Lake Tahoe Basin, metric tons

Inputs	Nitrogen - total	Phosphorus - total	Soluable
Atmospheric deposition	233.9 (56%)	12.4 (27%)	5.6
Stream loading	81.6 (20%)	13.3 (29%)	2.4
Direct runoff	41.8 (10%)	15.5 (34%)	5.0
Ground water	60.0 (14%)	4 (9%)	4
Shoreline erosion	0.75 (<1%)	0.45 (1%)	N/A
Total	418.1	45.7	17.0

N/A – not available

Source: Murphy and Knopp, 2000

The nutrient budget for Lake Tahoe highlights the significance that atmospheric deposition can play in terms of nutrient inputs. Studies in southern California forests suggest that atmospheric deposition can create an excess of nitrogen (Fenn et al., 1998). Nitrogen excess can lead to increased soil acidification and aluminum mobility, increased emissions of nitrogenous greenhouse gases from soil, reduced methane consumption in soil, decreased water quality, toxic effects on freshwater biota, and eutrophication of coastal marine waters.

Hydrologic impacts

Intensive land management in forested watersheds has been shown to have hydrologic impacts in a number of ways. Changes have been noted in both the timing and magnitude of peak flows and low flows. A peak flow is the highest in-channel discharge level reached for a specific precipitation or storm event. Increased peak flows are caused by a larger proportion of the water reaching the channel sooner. Jones and Grant (1996) have shown that this phenomenon can be caused by the cumulative effects of timber harvest practices. The four major mechanisms speeding delivery and routing of the storm water discharge are the following: 1) increased snow accumulation and melt; 2) decreased evapotranspiration; 3) decreased channel roughness; and 4) road extension of stream channel network. Mechanisms one and two affect the hillslope water balance and would be expected to increase peak discharge and storm flow volume. Mechanisms three and four affect flow routing and would be expected to speed storm flow, advancing the peak without changing the volume (Morgan and Smith, 1997). In Caspar Creek, an association between timber harvesting and road building on peak flows is not as pronounced (Ziemer, 1998).

Intensive forestland management also can affect the low flows of streams (Euphrat, 1992). Low flows occur between storms. With California's Mediterranean climate (cool, wet winters and hot, dry summers), summertime low flows are typically far below wintertime low flows. The faster runoff rates contributing to the increased peak flows described above also results in less infiltration of water into forest soils and less storage of water in the soils. Water stored in the soil is released more slowly to the stream system, helping to maintain streamflow between precipitation events. With less water stored in the soils for release into the stream between precipitation events, low flows are reduced from what they otherwise would be. These low flows can result in there not being enough water in streams to support aquatic life or to maintain cooler water temperatures important for fish.

Hydrologic impacts from roads involve the increase in runoff from compacted road surfaces and the interception of groundwater by road cuts (Weaver and Hagans, 1994). Roadside ditches tend to concentrate runoff and deliver sediment to adjacent streams. If flood flows cause a stream crossing a culvert to plug, the road fill can be washed out or the stream can be diverted down the road or ditch. Either event typically results in sudden delivery of large sediment pulses to the stream.

Impact of dams on watersheds

California rivers provide water storage, irrigation, flood control, and hydroelectric power for domestic, agricultural and industrial uses. To support these uses, California has constructed a vast network of over 1,400 dams on rivers across the State. The location of dams reflects both the supply and the demand for water. Watersheds in the northern part of State have more rainfall than those in the south, receiving more than 70 percent of California's average annual precipitation.


Trinity Lake, California. Photo: U.S. Fish & Wildlife Service.

Coastal watersheds receive most of their precipitation as rainfall, whereas a significant portion of precipitation in higher elevation Sierra watersheds comes from snowfall. Historically, the largest dams in California have been located to capture snowmelt from the Sierras. With the exception of the Klamath and Trinity, most of the rivers along the North Coast are free flowing. Land use within these watersheds largely dictates how water supply is distributed and used. In the Sierra, many of the rivers have dams that provide water to support agriculture uses in the Central Valley and growing urban population centers in the Bay Area and southern California. The Sacramento and San Joaquin are the largest rivers draining the Sierra. Through a complex network of aqueducts, canals, and reservoirs these rivers provide an average of nearly 16.4 million acre-feet (MAF) annually for urban and agricultural uses (DWR Bulletin160-98). This represents 57 percent of the combined water supply for the Sacramento River (22.4 MAF) and San Joaquin River (6.4 MAF). Statewide, the water demand from agriculture (43 percent) and urban water (11 percent) uses is similar, accounting for over half of the water budget (see Water Supply and Use for a more in-depth discussion).

Dams alter both the magnitude and timing of flows, which in turn influences the natural ability of a river to transport sediment and gravel.

The sophisticated and well-developed water supply system benefits all Californian's by providing water for residential, agriculture, and industrial uses. However, the placement of dams on rivers raises a number of environmental issues that affect the health of California's watersheds. For example, dams obstruct the migration of anadromous fish. Dams in the Central Valley block an estimated 90 percent of the spawning habitat that was historically used by spring-run Chinook salmon and steelhead. In addition, dams alter both the magnitude and timing of flows, which in turn influences the natural ability of a river to transport sediment and gravel. Dams not only trap sediment, but also the regulated flow affects sediment transport and limits the interaction between the river and its floodplain. Floodplains provide temporary storage of water during high flows and provide critical habitat to both fish and wildlife. Changes in flow can also have a dramatic impact on in-stream aquatic habitat as well, reducing spawning gravels on some rivers and significantly altering water temperatures.

Restoring the natural processes on rivers involves difficult choices. Maintaining minimum flows or enhancing peak flows to address environmental uses often means less water for urban and agricultural uses. In recent years, there has been an increased interest in removing dams that are no longer needed. For example, the removal of several small irrigation dams on Butte Creek restored migration access upstream for Chinook salmon and steelhead. An estimated 20,000 spring-run Chinook salmon returned to Butte Creek in 1999 after the restoration project was completed (see Friends of the River: California's State Wide River Conservation Organization).

Urban watershed management

For most people in California, domestic and municipal drinking water comes from surface water runoff on forested and range watersheds.

For most people in California, domestic and municipal drinking water comes from surface water runoff on forested and range watersheds. For example, the City of San Francisco and the East Bay cities primarily import their water from Sierra Nevada reservoirs on the Tuolumne and Mokelumne Rivers whose drainage basins are a mix of public and private forestlands. Similarly, the City of Los Angeles and other southern California cities bring in most of their water supply from wildland sources in the eastern Sierra Nevada (Owens Valley and Mono Basin) via the Los Angeles Aqueduct and from Central Valley basin headwaters via the California Aqueduct. Although the Colorado River Aqueduct imports out-of-State water from the Rocky Mountain and southwest drainage of that river, much of that land is also in forest and rangeland use. Local storage reservoirs in the South Coast region are primarily terminal facilities of the aqueducts and other importing pipelines, with San Diego County also storing local surface water supplies.

Some urban areas are more directly linked to a local water source. The City of Pasadena obtains at least 40 percent of its water supply from the Arroyo Seco Creek watershed on the Angeles National Forest. This watershed is located in its backyard and visible from the freeways and other public spaces. This 32-square-mile upper watershed supports the Raymond Basin aquifer, a 40-square-mile groundwater basin supplying drinking water to Pasadena. Vegetation is composed of big cone spruce-canyon oak forest, southern sycamore-alder riparian woodlands, southern mixed chaparral, and alluvial sage scrub. In the Santa Clara Valley, the City of San Jose, and other South Bay communities use locally developed surface supplies and extensive groundwater recharge sources in addition to imported Central Valley Project


Los Angeles River, City of Los Angeles. Photo courtesy of Erin Klaesius, California Biodiversity Council.

(CVP) and State Water Project (SWP) water. Most communities in the Central Valley, except for Sacramento, rely primarily on groundwater (DWR, 1998).

Table 13 below relates some urban areas to their watershed-of-origin for water supply. Even in highly urbanized areas like the Santa Clara Valley, 50 to 80 percent of the local watersheds contributing runoff to local reservoirs remain in forest and range use (Santa Clara Basin Watershed Management Initiative, 2000).

Table 13. Linking urban water supplies to watersheds-of-origin

Urban area	Water supply watersheds-of-origin
Eureka	Mad River
Santa Rosa	Russian River – Dry Creek Russian River – East Branch Eel River - upper
Sacramento	American River CVP – upper Sacramento
San Francisco	Tuolumne River
Oakland / Berkeley / Walnut Creek / Concord	Mokelumne River
San Jose	Guadalupe River Coyote Creek SWP – Feather River
Los Angeles	Owens Valley Mono Lake SWP – Feather River Colorado River Basin
Pasadena	Arroyo Seco Creek
San Diego	Sweetwater River Otay River SWP – Feather River

CVP –Central Valley Project; SWP – State Water Project

Source: Santa Clara Basin Watershed Management Initiative, 2000

Linking the quality of community and municipal water systems to their watersheds-of-origin is becoming more obvious due to recent legal requirements. In response to the 1996 reauthorization of the federal Safe Drinking Water Act, the California Department of Health Services developed the Drinking Water Source Assessment and Protection Program. Drinking water systems using surface water sources were already required under California law to perform watershed sanitary surveys every five years. Maps will soon be available of each community drinking water system matched up with the estimated 16,000 active surface and ground water drinking sources in California (to be prepared by the University of California, Davis, Information Center for the Environment). Water suppliers are concerned about possible contaminating activities within each source area and protection zone, recognizing that prevention is better and cheaper than expensive monitoring and environmental clean-up. Pristine and well-managed forest and range watersheds obviously have a lower risk of contamination than urban or poorly managed watersheds.

Currently, the main focus of concern over water quality in forests and rangelands has been to stop the decline of fish species (such as anadromous salmon) and to improve aquatic and related species diversity. Concerns over the quantity of water call for increasing supply and storage and for reducing demand, while concerns over the quality of water have constrained the ability to increase supply and have focused on the need for alternative solutions. The need to make accommodations for threatened, endangered, and sensitive species, as well as biodiversity in general, have put additional limitations on the timing and amounts of flows that can be delivered through the current water delivery system. Maintaining minimum instream flow requirements for salmon and steelhead, for example, reduce the amount of water that can be delivered through stream diversions and reservoirs to urban and agricultural water users. Complex flow release schedules from upstream storage facilities are also now required to maintain State mandated water quality requirements in the Bay-Delta estuary. Environmental water requirements, such as through the Central Valley Project Improvement Act, have reduced the yield of the CVP for consumptive users. Attention is being refocused on how watershed management can improve both water quality and supply.