

Managing Forest Roads to Control Cumulative Erosion and Sedimentation Effects¹

William Weaver, Danny Hagans, and Mary Ann Madej²

Detailed watershed studies on the causes and effects of erosion and sedimentation in the 280 mi² Redwood Creek basin have been conducted by the U.S. Geological Survey and the National Park Service since the early 1970's and particularly since the 1978 expansion of Redwood National Park. This latest addition to the park included 36,000 acres of logged and roaded land in the lower Redwood Creek basin.

The purpose of these hydrologic and geomorphic investigations has been to identify sediment sources on private and public lands throughout the watershed, and to differentiate between man-caused and natural erosion. In concert with these investigations, field inspections of over 300 proposed timber harvesting plans have been conducted by Park Service scientists, and recommendations were forwarded to the California Department of Forestry for their consideration in their regulatory role as administrators of the State Forest Practices Act.

Studies culminating within the last several years have revealed a number of persistent impacts that have originated, in large part, from past logging and road building in the watershed (Harden and others 1978; Janda and others 1975; Kelsey and others 1981; Marron and others, in press; Pitlick 1982; Weaver and others, in press). The effects are found on-site at the location of land disturbance, in areas downslope of harvest plan areas and roads, and in far-removed stream channels where the erosional products are deposited (Hagans and others 1986).

Abstract: Recent studies have identified specific road building and abandonment practices on private forest lands in northwestern California as greatly contributing to high erosion rates and sediment yields. Resultant impacts have been found to be additive, to occur essentially instantaneously on large areas, and to be displaced both temporally and spatially from the site of disturbance. Sources of fluvial erosion, a major contributor to total sediment yield, could be significantly diminished by improving road construction practices and employing preventive erosion control measures when abandoning road systems between harvest rotations. Improved road locations could also reduce the contribution of mass soil movement to downstream impacts.

The substantial or potentially substantial adverse effects of land use have been found to be additive, to occur essentially instantaneously on large areas (in response to major storms), and to be displaced both spatially and temporally (often up to a decade or more) from the source and time land use disturbance.

This is the essence of our working definition of cumulative effects, and examples in the Redwood Creek basin are numerous. Although each incremental land use disturbance may have an insignificant or imperceptible effect when viewed either alone or at the time of original land use activity, the impacts become cumulatively significant when seen in aggregate or when multiple erosion sources are triggered simultaneously by a large storm.

An analysis of Redwood Creek erosion and sedimentation data suggests several potentially rewarding and technically attainable approaches to significantly reducing the threat of cumulative on-site and off-site effects. Thus, the objectives of this short paper will be first, to discuss likely scenarios for future erosion problems on 30 mi² of private forest lands upstream from the National Park, based on the identified causes of past erosion, and second, to discuss preventive land use practices which could substantially reduce the threat of significant, cumulative erosion and sedimentation effects.

METHODS

The conclusions presented here draw extensively from data and results previously published which detail elements of the sediment budget for the Redwood Creek basin. Detailed studies of gully erosion on the hillslopes, combined with documentation of channel processes in Redwood Creek and its tributaries, were used to develop a model for the operation of cumulative effects in the watershed (Hagans and others 1986).

¹Presented at the California Watershed Management Conference, November 18-20, 1986, West Sacramento, California.

²Geologists, Redwood National Park, National Park Service, U.S. Department of Interior, Arcata, California.

Weaver and others (in press) documented the causes and effects and quantified the magnitude of fluvial erosion, especially gullying, on forested lands of the 76 mi² lower basin over the last three decades. Kelsey and others (1981) presented the results of detailed landslide mapping and sediment source inventories along Redwood Creek and its major tributaries, and compiled portions of their findings into a sediment budget for the upper watershed.

In more geographically confined studies, Best and others (in press) mapped and developed a sediment budget for the 4.1 mi² Garrett Creek basin, a tributary of Redwood Creek, and Weaver and others (1981) quantified sediment sources from a 1 mi² intensively logged site in the Copper Creek watershed, now within Redwood National Park. Completing the erosional cycle, Pitlick (1982) elaborated on the dynamics of sediment production, transportation, and storage in 16 major tributary basins to Redwood Creek, and Madej (1984) quantified sediment storage and transport in the main channel system from the headwaters to the mouth of Redwood Creek.

Coupled with the findings of these and other studies, field inspections (past timber harvest reviews) and aerial inventories were conducted to determine the "condition" of logging roads within the 30,000-acre Park Protection Zone. Stream crossings were also classified within the 4.1 mi² Garrett Creek basin during detailed field investigations. These data form the basis for an analysis of the future potential for significant, multiple erosion impacts that will likely occur on these forest lands, as well as the methods by which they can be avoided.

RELATIVE IMPORTANCE OF LANDSLIDING AND FLUVIAL EROSION IN THE REDWOOD CREEK BASIN

Measured sediment sources in the lower Redwood Creek basin are nearly equally divided between mass soil movement processes and several types of fluvial erosion, including surface erosion, washed-out stream crossings on logging roads and skid trails, and gully erosion attributable to several causes (table 1).

Table 1--Measured sediment sources in the lower Redwood Creek basin (1954-1980)

Sediment Source	Volume (m ³)	Total Yield (pct)
Gullies	1,157,400	37
Eroded Stream Crossings	225,600	7
Surface Erosion	124,400	4
Streamside Landslides	1,600,000	52
Totals	3,107,400	100

Although it is generally difficult to establish a direct cause-and-effect link between land use and mass erosion, a clear association does exist (Janda and others 1975; Kelsey and others 1981; Pitlick 1982). For example, in Redwood Creek the number and frequency of major streamside landslides in 16 tributary basins is comparable for both logged and unlogged hillslopes (Pitlick 1982). However, slides associated with harvested and roaded slopes were individually much larger and accounted for approximately 80 percent of the total mass erosion.

Similarly, during the winter of 1982-83, 44 debris slides occurred within cutover lands in the lower Redwood Creek basin. Upon inventory, all 44 were found to be directly associated with logging roads and skid trails. Importantly, most of these failures occurred where roads crossed headwater topographic swales on slopes exceeding 30 degrees and were in close proximity to topographic slope-breaks (LaHusen 1984).

While there is a strong association between sediment production caused by landsliding and the occurrence of road building and timber harvesting, it is usually impossible to assign a strict cause-and-effect relationship between landsliding and land use activity. This has made it both scientifically and politically difficult to dictate specific land use regulations for activities in potentially unstable areas, even on steep inner gorge slopes where the risk for potential damage is highest. Unambiguous, authoritative data are usually not available for even the best studied hillsides to accurately predict the effect of individual land use practices.

The ambiguity between cause and effect does not exist for sources of fluvial erosion throughout the Redwood Creek basin. Studies in Redwood Creek and in nearby watersheds such as the Van Duzen (Kelsey 1980) have identified gullying as a major contributor to increased sediment yields since the advent of modern logging and road building over three decades ago (Kelsey and others 1981; Weaver and others, in press). Fluvial erosion accounts for between 40 percent (table 1) and 60 percent (Kelsey and others 1981) of all sediment discharged to Redwood Creek, and its origin is very clearly linked to land use practices.

Most significant fluvial erosion is caused by stream diversions which occur during moderate or extreme winter storms. These diversions occur at stream crossings on inclined or "climbing" logging roads when culvert capacity is exceeded or a culvert plugs. Streamflow is diverted down the road and across adjacent hillslopes or into nearby watercourses. Extensive networks of gullies develop on the hillslopes, and stream channels which carry added water are widened and deepened.

Diverted waters in measured study areas created large, complex gully systems and were responsible for increases in on-site drainage density, sediment production and yield and enlarged stream channel dimensions, as well as numerous off-site effects

associated with stream channel aggradation (Hagans and others 1986). The resulting gully networks, while mostly "invisible" from the active logging road system, delivered large quantities of sediment to streams throughout the basin.

In detailed geomorphic mapping (1:1200 scale) of over 5200 acres of logged and roaded study sites in the middle and lower Redwood Creek basin, gullies caused by stream diversions yielded 150,000 yd³ of sediment, virtually all of which quickly reached the main channel of Redwood Creek. Seventy percent of the 161 logging-road stream crossings in the study area exhibited a high potential for causing stream diversions if the culvert were to plug or be overtopped during large storms.³ In fact, nearly 60 percent of the streams with a high diversion potential had actually been diverted at least once since the stream crossings were built, only to be reconstructed with the same high diversion potential (Hagans and others 1986). These diversions created numerous gully systems.

Storms with a return period of roughly 10 years or greater have triggered the most severe erosional and depositional events in the Redwood Creek basin (Janda and others 1975; Harden and others 1978). Chief among these were storms in 1955, 1964, 1972 and 1975. Gully erosion rates reached their peaks during these extreme events and stream diversions at logging road stream crossings were the leading cause of fluvial sediment production.

NEW AND EXISTING ROAD NETWORKS AS CONTRIBUTORS TO CUMULATIVE EFFECTS

In 1978 Congress established a special "Park Protection Zone" (PPZ) management area consisting of 30,000 acres of private timber land upstream

³The diversion potential of a crossing is a measure of the probability that streamflow would divert down the road, rather than over the fill crossing, if the culvert were to plug or its capacity were exceeded.

Table 2--Status of logging roads in the Park Protection Zone as of August, 1986

Area Description	Status of logging roads in the PPZ			
	Maintained	Drivable but Unmaintained	Abandoned	Total
	(mi)	(mi)	(mi)	(mi)
Garrett Creek & adjacent slopes	4.9	4.9	12.1	21.9
Coyote Creek & adjacent slopes	10.6	8.3	22.0	40.9
Lacks Creek	4.9	19.7	36.0	60.6
Panther Creek & adjacent slopes	17.4	11.7	21.6	50.7
Total PPZ	37.8	44.6	91.7	174.1

from the park (fig. 1, inset), within which National Park Service geologists inspect proposed land use operations. Underlain by Franciscan sedimentary and metamorphic rocks, land and land use within the PPZ are largely representative of the remainder of the Redwood Creek basin.

Most of each of the four major tributary basins in the PPZ had been logged by 1985. These watersheds serve to illustrate how the imprint of past and present land use practices have "primed" the cutover landscape for additional, future erosional events that are likely to lead to substantial on-site and off-site erosion and sedimentation effects.

Most logging roads in the PPZ were constructed between 1950 and 1985. As old growth forests were cleared, unneeded road segments were largely abandoned. By 1985, roughly 78 percent of the 175 mile road network in the PPZ had been effectively abandoned. These roads are classified as either impassable, or lacking any indication of continued maintenance (table 2). Individual basins, such as Lacks Creek, Redwood Creek's second largest tributary, show as much as 92 percent of its road system in an unmaintained or abandoned state.

With land-use related fluvial erosion, principally gullying, contributing to significant on-site, off-site and downstream impacts in Redwood Creek and its tributaries, the status of the logging road network is critically important in determining future environmental effects of both past and current forest land use activities. Unmaintained logging roads are potentially damaging because culverts which are undersized or which plug during winter storms can cause fill crossings to wash out or streams to divert. The resultant environmental effects can be significant and long term.

For example, in the Garrett Creek basin, 43 percent of the 114 logging road stream crossings have a high failure or diversion potential (fig. 1). If old ranch roads near the watershed divide are excluded from the inventory, the number increases to 53 percent. The main line logging road which climbs obliquely across the basin has the highest frequency of crossings with high diversion

GARRETT CREEK WATERSHED

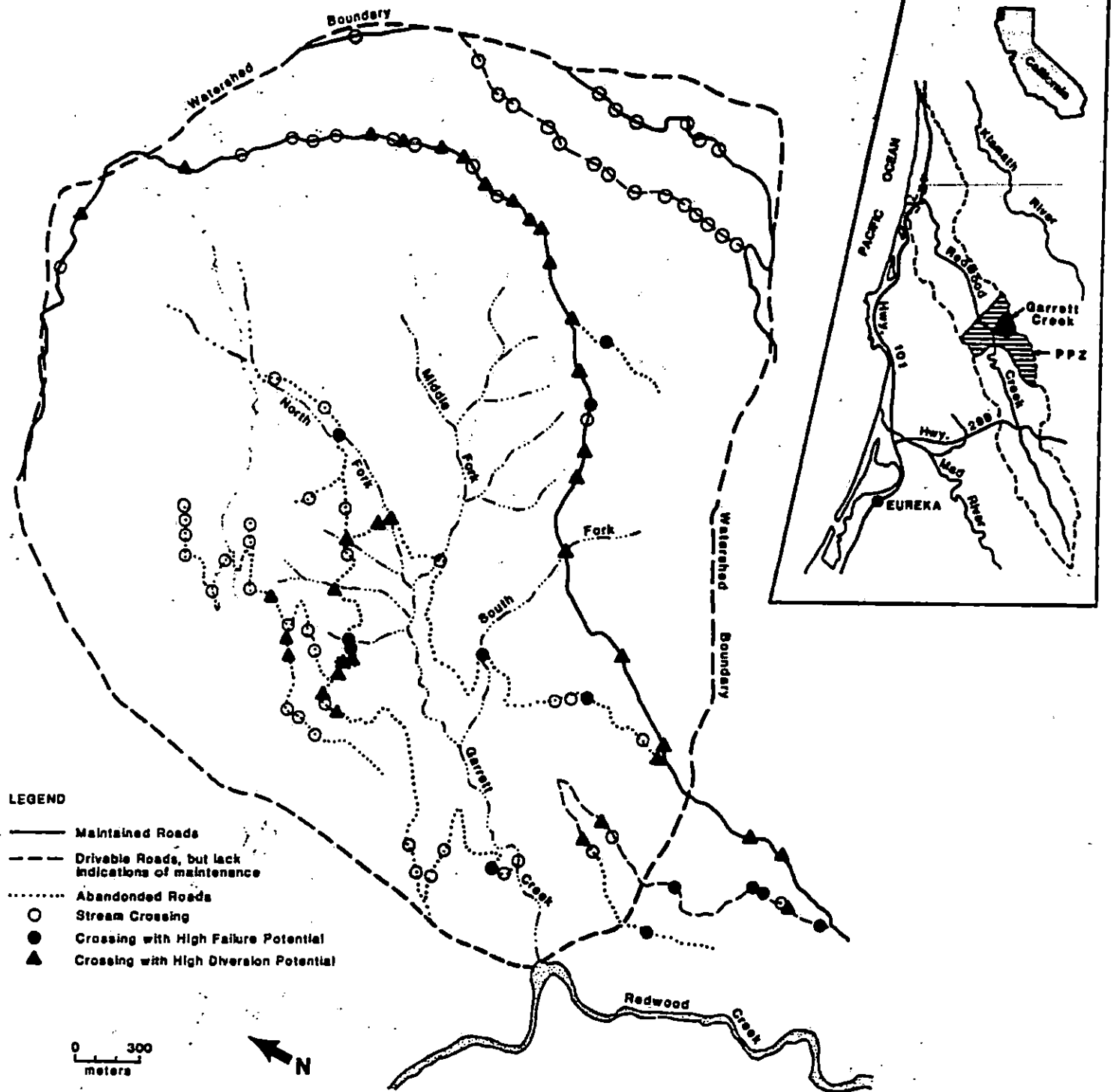


Figure 1--Classification of logging road network and stream crossings in the Garrett Creek watershed.

potentials (65 percent). Of these, 75 percent have diverted at least once in the past. The large amount of fluvial erosion which has occurred in the basin during the last two decades has been mostly caused by stream diversions along this road (Best and others, in press).

The problem of high diversion and high failure potentials at logging road stream crossings is not restricted to Garrett Creek; it is ubiquitous. Of nearly 500 logging road stream crossings inventoried in the middle and lower Redwood Creek basin, including 320 in the PPZ, in excess of 60 percent have a high failure potential; that is, the culvert is undersized for the expected 25-year storm.

In addition, from 45 to 70 percent of the 500 inventoried stream crossings, depending upon the basin, have a high stream-diversion potential (that is, streams will divert out of their channels when the culverts plug or their capacity is exceeded). Many stream crossings have both a high failure potential and a high diversion potential, making them especially likely to cause future erosion and sedimentation problems in the watershed.

Most stream crossings in the Redwood Creek basin were constructed with undersized culverts. Only recently were newly installed culverts required to accommodate 25-year or 50-year return period discharges. While this improvement helps reduce the potential for failure of newly constructed crossings, current forest practice regulations still do not address the serious problems caused by the lack of long term road maintenance, the common practice of road abandonment, and the construction or reconstruction of stream crossings with high diversion potential, whether they be on previously existing or newly built roads.

Ubiquitous stream crossings with high diversion potentials is perhaps the most threatening potential erosion problem in the Redwood Creek basin, and perhaps in other coastal watersheds of northern California. Both their common occurrence and adverse effects have been well documented (Weaver and others, in press; Hagans and others 1986). Unfortunately, the threat of avoidable but still pending cumulative environmental damage triggered by infrequent, high magnitude winter storms is substantially heightened by the practice of abandoning logging roads between harvesting cycles. The high potential for erosion problems is only compounded by the pervasive occurrence of undersized culverts on most forest roads built in the last four decades.

TREATING THE CAUSES OF CUMULATIVE EROSION AND SEDIMENTATION EFFECTS

The Redwood Creek basin is one of the most rapidly eroding large watersheds in northern California. Studies there suggest that a great deal of the documented erosion and sedimentation is the result of specific road-related land use practices. Data clearly indicate that future crossing failures and stream diversions throughout the Redwood Creek basin have the potential for causing substantial additional erosion and sediment production, and additively impacting downslope and downstream aquatic and riparian resources.

However, the same studies also suggest that employing a variety of simple, preventive land management measures could largely eliminate fluvial gully erosion and its long-term effects. Such treatments include (1) conducting long-term (more than 3-years) preventive road maintenance (culvert cleaning, trash rack installation, culvert size upgrading) on all roads--not just active routes--before failures occur, (2) constructing each new logging road stream crossing so that it has no diversion potential, (3) performing minor reconstruction of existing crossings that already have a

high diversion potential to eliminate the chance for future stream diversions; and (4) on roads that are abandoned or effectively abandoned, excavating or "dishing out" crossings that have a high diversion potential, to ensure that streams remain in their natural drainages.

Similarly, the observed associations between land use and landsliding, mentioned only briefly in this paper, also suggest the utility of at least defining a mass erosion hazard rating for lands which fall into susceptible slope and morphology categories. Once identified, foresters could then prescribe and apply special, restrictive practices (especially for road location and construction, and clear-cut harvesting) on steep, potentially unstable streamside slopes. Measures which successfully address the effect of land use on critical channel side slope areas could substantially reduce the increased contribution of man-caused landsliding to sediment yield and its downstream individual and cumulative effects.

None of these preventive techniques is systematically or regularly practiced on private forest lands in the Redwood Creek basin, nor are they specifically required by current California forest practice regulations. In fact, new legislation would probably be needed to extend and expand the regulatory authority of the California Department of Forestry in order to ensure that long-term road maintenance was required and performed. Similar action would be needed to ensure that the thousands of miles of existing road network in environmentally sensitive watersheds would be treated to eliminate the substantial threat of future cumulative effects resulting from stream diversions during major winter storms. Without such work, significant, adverse downstream impacts are unavoidable.

For the last eight years the National Park Service has been conducting an aggressive program to excavate thousands of potentially unstable road and landing fills and stream crossings on unused or unneeded former logging roads in Redwood National Park. This methodology is a constructive alternative to abandonment and has eliminated unused roads as a future erosional threat. Cost and effectiveness data from these and other erosion control procedures employed in the park (Weaver and Sonnevil 1984) can be used to evaluate the feasibility of their broader application to private lands and currently abandoned roads throughout the state.

In addition, a number of stream crossings which exhibit a high diversion potential are currently being reconstructed with no diversion potential on former main line logging roads to determine the practicality, cost and effectiveness of using this procedure in a variety of settings where roads are to be permanently retained. The importance of this latter, fairly inexpensive regrading treatment, and its utility in preventing stream diversions, cannot be overlooked. Most land use related fluvial erosion in the Redwood Creek basin, and its well documented, substantial contribution to cumulative erosion and sedimentation effects, could be effectively eliminated by employing these or similar preventive techniques.

CONCLUSION

In recent years, substantial improvements have been made in road construction practices and regulations for private lands in California. Culverts are now required to accommodate the 50-year discharge. However, while improvements in road building have occurred, many shortcomings inherent in early land use activities still plague current forest practices. For example, landowners are still not required to maintain logging roads beyond the short life of an active timber harvest plan or beyond its physical boundaries.

Our inventories clearly reveal that most roads in the 30,000 acre Park Protection Zone are unmaintained and effectively abandoned. Other road systems throughout the Redwood Creek basin are in a similar state of disrepair. In these areas, most roads will have to be reconstructed across washed out crossings, diverted streams and landslide areas when future access is needed. In the past, these reconstructed crossings have been rebuilt with the same high diversion potentials that previously existed, thus perpetuating the erosional cycle.

Through modifications and improvements in current forest practices, many of the potential future impacts caused by both past and present forest land use can be substantially reduced. Employing specific measures to eliminate severe fluvial erosion, for example, would likely do more to reduce the continued and future threat of substantial on-site, off-site and downstream "cumulative effects" in the Redwood Creek basin than would any other single measure, including the application of broad controls on basin-wide harvesting rates.

Techniques employed to recognize and avoid potentially unstable streamside hillslopes, where landslides are likely to occur and landslide materials have ready access to stream channels, could likewise diminish the equally important contribution from mass movement processes. These specific "best-management" methodologies are perhaps the most straightforward and rewarding of the techniques available for dealing with cumulative or significant environmental effects.

REFERENCES

- Best, D., Hagans, D.K., Kelsey, H.M., Alpert, M. Role of fluvial hillslope erosion and road construction in the sediment budget of Garrett Creek, Humboldt County, California. In: Nolan, K.M., Kelsey, H.M., and Marron, D.C., editors. *Geomorphic processes and aquatic habitat in the Redwood Creek basin, Northwestern California*; U.S. Geol. Survey Prof. Paper 1454; in press.
- Hagans, D.K., Weaver, W.E. and Madej, M.A. Long term on-site and off-site effects of logging and erosion in the Redwood Creek basin, Northern California. In: *Papers presented at the American Geophysical Union meeting on cumulative effects (1985 December)*; NCASI technical bulletin no. 490; 73 p. 1986 May; 38-66.
- Harden, D.R., Janda, R.J., and Nolan, K.M. Mass movement and storms in the drainage basin of Redwood Creek, Humboldt County, California - a progress report. U.S. Geol. Survey Open-file Report 78-486; 1978; 161 p.
- Janda, R.J., Nolan, K.M., Harden, D.R., and Colman, S.M. Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California, as of 1973. U.S. Geol. Survey Open-file Report 75-568; 1975; 266 p.
- Kelsey, H.M. A sediment budget and analysis of geomorphic process in the Van Duzen River basin, north coastal California, 1941-1975. *Geological Society of America Bulletin*, Part II; 91(4); 1980; 1119-1216.
- Kelsey, H.M., Madej, M.A., Pitlick, J., Coghlan, M., Best, D.W., Belding, R., and Stroud, P. Sediment sources and sediment transport in the Redwood Creek basin, a progress report. Redwood National Park Tech. Report 3; National Park Service, Arcata, CA; 1981; 114 p.
- LaHusen, R.G. Characteristics of management related debris flows, northwestern California. In: C.L. O'Loughlin and A.J. Pearce, editors; *Proceedings, Symposium on the effects of forest land use on erosion and slope stability*; International Union of Forestry Research Organizations; 1984; 139-145.
- Madej, M.A. Recent changes in channel-stored sediment, Redwood Creek, California. Redwood National Park Tech. Report 11; National Park Service, Arcata, CA; 1984; 54 p.
- Marron, D.C., Nolan, K.M., and Janda, R.J. Effects of logging and geology on hillslope erosion and deposition by surficial processes in the Redwood Creek Basin, northwestern California. In: Nolan, K.M., Kelsey, H.M., and Marron, D.C., editors. *Geomorphic processes and aquatic habitat in the Redwood Creek basin, Northwestern California*; U.S. Geol. Survey Prof. Paper 1454; in press.
- Pitlick, J. Sediment routing in tributaries of the Redwood Creek basin, northwestern California. Redwood National Park Tech. Report 8; National Park Service, Arcata, CA; 1982; 67 p.
- Weaver, W.E., Choquette, A.V., Hagans, D.K. and Schlosser, J. The effects of intensive forest land use and subsequent landscape rehabilitation on erosion rates and sediment yield in the Copper Creek drainage basin, Redwood National Park. In: *Proceedings, symposium on watershed rehabilitation in Redwood National Park and other coastal areas*; Arcata, CA; 1980; Center for Natural Resources Studies of the John Muir Institute, Berkeley, California; 1981; 341-360.
- Weaver, W.E., Hagans, D.K., and Popenoe, J.H. Magnitude and causes of gully erosion in the lower Redwood Creek drainage basin. In: Nolan, K.M., Kelsey, H.M., and Marron, D.C., editors. *Geomorphic processes and aquatic habitat in the Redwood Creek basin, Northwestern California*; U.S. Geol. Survey Prof. Paper 1454; in press.
- Weaver, W.E. and Sonnevill, R.A. Relative cost-effectiveness of erosion control for forest land rehabilitation, Redwood National Park. In: *Proceedings of Conference XV; Erosion Control... Man and Nature, International Erosion Control Association*, Denver, CO; 1984; 83-115.