John Craig - C

TETRA TECH, INC.

10306 Eaton Place, Suite 340
Fairfax, VA 22030
Telephone (703) 385-6000
FAX (703) 385-6007

Date: January 26, 1998

To: Theresa Wistrom, North Coast Regional Water Quality Control Board
From: John Craig, Tetra Tech, Inc.
Subject: Redwood Creek Review
Copies: Dave Smith, EPA Region 9

Per technical direction received from Dave Smith through Work Assignment 4-120, Contract #68-C3-0303, and 5/28/97 letter from Theresa Wistrom, Tetra Tech reviewed information and data provided for Redwood Creek The purpose of this review was to provide guidance on TMDL development issues in the Redwood Creek basin.

The review of the Redwood Creek information was conducted by Kevin Kratt and John Craig of Tetra Tech. We appreciated the opportunity to review these documents and provide our recommendations for developing a sediment temperature TMDL for Redwood Creek. Although some additional analysis will need to be conducted to develop the TMDL, the amount of data available should be adequate to complete a phased TMDL for sediment. I'm sorry for the long delay in transmitting these comments to you. If you have questions or comments on the attched review, please feel free to contact me at (703) 385-6000. Thanks for the opportunity to review the information and provide our input.

Executive Summary

Literature provided by the North Coast Regional Water Quality Control Board (Regional Board) on the Redwood Creek watershed in northern California was reviewed to determine its adequacy for TMDL development. Although many of the analyses necessary to develop the TMDL have not been conducted, the information available on the Redwood Creek system should be sufficient to develop a phased sediment TMDL. A phased approach to TMDL development is recommended because of the uncertainties associated with the transport and storage of sediment, both upland and in-stream. Under the phased TMDL approach, nonpoint source load allocations are calculated using the best available data and information and recognizing the need for additional data to characterize sources and loadings more accurately. Despite the relative abundance of information on sources and loadings of sediment to Redwood Creek, a number of steps should be considered, including the following:

1) Develop a clear statement of the water quality standards (i.e., designated uses and numeric or narrative criteria) that apply to Redwood Creek, as well as the impairment that led to the need to develop a TMDL. It was not clear from the information reviewed what the focus of the TMDL would be and what indicators would be most appropriate. It is assumed that the TMDL will focus on aquatic habitat and will identify appropriate in-stream indicators. Regardless of the indicator(s) selected, it appears that adequate information is available to make a scientifically defensible selection.

2) Identify one or more site-specific indicators that can be used to quantitatively describe the status of the designated uses of concern. These indicators should provide a connection between in-stream conditions and sediment sources. From the data reviewed, it appears sufficient information is available to select appropriate in-stream indicators. Note that an important component of indicator selection is the inclusion of stakeholder groups in the process. After selecting a suite of indicators, target conditions for the indicators should be established. The development of numeric targets can be accomplished through the use of water quality standards, reference reaches, in-basin monitoring data, literature values, or best professional judgment. Based on the information reviewed, the reference reach approach is recommended for Redwood Creek because of the level of impairment in the watershed and the lack of data representative of pre-impairment conditions. As with indicator selection, stakeholders should be encouraged to participate in the establishing of numeric targets for the indicators.

3) Use the existing sediment budget (Appendix C of the *Redwood Creek Watershed Analysis* [1996]) as an initial estimate of sediment loadings and update it as more recent information becomes available. Identify the problems with using the data in the sediment budget. For example, because it appears that the 1954-1980 data are not indicative of current conditions in the watershed, the TMDL should clearly state that load reductions (or loading targets) are based on these historic conditions. In essence, this means that landowners would get credit for whatever unquantified load reductions have been achieved since 1980. Also, the dates of the sediment budget are not likely to reflect much influence from improved forest practices and the reduction goals are likely to appear correspondingly large.

4) Identify load reduction targets for the various sediment process categories identified in the sediment budget (i.e., roads, gullies, streambank erosion, mass movement). Because of uncertainties associated with the sediment budget, an approach such as the use of reference reaches to identify target sediment yields that will result in attainment of the in-stream numeric targets should be considered. Establish these targets by the erosion processes identified in the sediment budget, and

avoid allocations to actual land management practices since this will only add another layer of uncertainty to the analysis. This approach will still require use of the sediment budget developed for 1954 to 1980. Using the sediment budget, the technology-based controllable loading could be determined for each process and the total loading could be determined assuming the maximum technologically feasible level of control. A problem might arise if significant allocations must be assigned to both forestry and agriculture (i.e., range lands). If so, some thought needs to be given to what constitutes a fair assignment of allocations between these sources, given that agricultural practices might or might not have moved farther toward BMPs by 1980 than forestry.

5) Because the TMDL is going to rely on a set of in-stream indicators as surrogates for a healthy aquatic system, the TMDL should include a plan to develop a monitoring and adaptive management plan to evaluate the effectiveness of the BMPs in meeting the in-stream goals.

6) Lastly, although the development of separate TMDLs for the upper and lower Redwood Creek is proposed, significant coordination will be required. Dividing Redwood Creek into two TMDLs is apparently based on the fact that the lower basin is mostly National Park and the upper basin is mostly private landowners. Obviously, the TMDL for the upper basin will affect the lower basin's TMDL load allocation strategy. In one sense, these should merely be separate load allocation groups and not separate TMDLs. There is, however, no barrier to forming separate but linked TMDLs, insofar as the TMDL is driven by conditions in the lower mainstem.

Despite the concerns expressed above, it is apparent that significant progress has been made toward developing an understanding of sediment processes in the Redwood Creek basin. Note that the ideas presented in this report should not be considered the only viable approaches to TMDL development. Many different approaches could be applied.

Introduction

This report presents the results of a review of information available on the Redwood Creek watershed in northern California to determine its adequacy for developing a sediment TMDL. Recommendations are made regarding the next steps for TMDL development, including the need to fill several potential data gaps and how to avoid certain pitfalls. This review is based on an examination of the documents listed in Appendix A.

Background

The California Regional Water Quality Control Board, North Coast Region, placed Redwood Creek on the 1996 section 303(d) list of waters because of sediment-related impairments. Section 303(d) of the Clean Water Act requires states to develop TMDLs for their waterbodies that are not meeting designated uses under technology-based controls. A TMDL establishes allowable loadings of a pollutant (or other quantifiable parameters) at a level necessary to meet the designated uses of a waterbody. The TMDL process assigns allocations for point sources (wasteload allocation [WLAs]), nonpoint sources (load allocations [LAs]), and a margin of safety (MOS) that are designed to protect the designated uses of the waterbody. A TMDL for Redwood Creek is scheduled to be developed by July 1998 (Wistrom 1997).

The Redwood Creek watershed drains 278 square miles in north coastal California. The upper two-thirds of the watershed is privately owned, whereas the lower third is publicly owned and consists of Redwood National Park. The climate of the Redwood Creek watershed is Mediterranean, with mild, wet winters, and warm, dry summers (Janada et al. 1975). Land disturbance activities, such as timber harvesting and road building, that have occurred in the watershed since the 1950s have affected Redwood Creek by altering the stream's natural course and contributing to sedimentation. Key issues of concern in the watershed related to this sedimentation are the ability of the creek to provide suitable aquatic habitat and the maintenance of the health of streamside redwoods.

Although the information that has been compiled for the Redwood Creek watershed was not collected for the explicit purpose of developing a sediment TMDL, it does contain a great deal of data that pertain to the various components of TMDL development. These components include (1) defining the problem the TMDL is intended to address, (2) setting quantitative targets to measure waterbody health, (3) conducting an analysis of sediment sources, and (4) allocating appropriate controls. This report will discuss the available information in terms of these components.

Problem Definition

To develop a sediment TMDL it is necessary to have a clear understanding of the nature of the impairments, the potential sediment sources, the geographic setting of the watershed, and other related information. A clear definition of the problem will facilitate TMDL development by relating the TMDL back to the original listing decision and helping to focus the implementation of controls. Key questions to address in defining the problem include the following:

- What is the relationship between the activities assumed to be causing the problem and the actual waterbody impairments (i.e., need to assess the cause-effect relationship)?

- What should be the geographic setting of the TMDL (i.e., one TMDL for the entire watershed or several TMDLs for different subwatersheds)?

- What are the temporal issues associated with the TMDL? What are the critical hydrologic conditions that the management actions need to be able to address?

- What are the sources of impairment in the waterbody, and what role do they play in affecting water quality?

- What is the needed level of accuracy for the TMDL? How should a margin of safety be incorporated into the TMDL?

- What are the potential control options?

- What are the potential obstacles to successful TMDL development (i.e., technical, economic, social)?

Because the Redwood Creek watershed has been studied extensively for more than 20 years, a number of documents are available that provide good explanations of the sediment problems in the watershed and the associated impact they have had on channel morphology and aquatic life. Klein and Weaver (1989), for example, document the relationship between excessive sedimentation in the watershed and the resulting impairments in the Redwood Creek estuary (including the impact to rearing habitat for juvenile salmonids). Several sources of information also provide detailed information on the conditions of several subwatersheds in the basin (such as Garrett Creek [Best et al. 1995], Airstrip Creek [Kelsey and Stroud 1981], and the lower Redwood Creek drainage basin [Weaver et al. 1995]). These documents and others also provide excellent background data related to a number of issues that the TMDL will need to address, such as soil types, geology, climate, precipitation patterns, past and present land use activities, location and type of roads, etc. The available information should be more than suitable for purposes of establishing a TMDL problem definition statement.

A preliminary step to the problem definition, however, should clearly identify the reason the waterbody was listed as impaired, especially noting water quality standard violations and/or nonattainment of beneficial uses. The development of a TMDL is predicated on linking existing water quality standards and/or beneficial uses to the problems identified.

It appears from the documents reviewed that the TMDL problem identification statement for Redwood Creek should focus on at least two key issues: (1) protection and restoration of aquatic habitat and (2) preservation of streamside redwoods (from *Redwood Creek Watershed Analysis 1996)*. Depending on the applicable water quality standards for Redwood Creek, these issues may change. Other issues outlined in the *Watershed Analysis* document, such as protection of endangered terrestrial species and sustainable timber production, are probably not best addressed through the TMDL process.

In the problem statement, the relationship between the activities assumed to be causing the problem and the actual waterbody impairments (i.e., need to assess the cause-effect relationship) needs to be clearly made. For example, in Redwood Creek this might mean linking upstream land uses (i.e., logging roads, timber harvest, etc.) to the increased streamflow and sediment loads that threaten alluvial redwood groves. Similarly, the connection between these land use activities and aquatic habitat degradation should be explicitly stated. It is critical in the problem definition to recognize the propensity of the Redwood Creek watershed for 'naturally' high sediment yield, and especially to distinguish how the existing conditions (which are in violation of water quality standards and are caused by the effects of the upstream land use) would differ from natural conditions.

It should also be noted that the general term "sedimentation" covers several types of stressors within the Redwood Creek watershed. First, past sediment loading has apparently led to significant aggradation and accompanying channel instability in the lower watershed. To the extent that aggradation reflects past land use practices, it might not be particularly amenable to TMDL load allocations; instead, in-stream restoration might be an important tool. Second, ongoing bulk sediment loading in certain tributaries is related to landslides and bank failure. These occurrences are influenced by current land use practices, but they might be difficult to evaluate within the context of a TMDL. In addition, fine sediment loading causes substrate embeddedness and poor habitat. Fine sediment can derive both from mass wasting of bulk sediment and from nonpoint runoff processes and is more amenable to traditional TMDL development.

The geographic setting of the TMDL for Redwood Creek also needs to be identified in the problem definition. The setting should consider both the locations of all sources (e.g., logging road crossings at headwater tributaries as well as in-stream sediment from the lower main stem), as well as the locations of problems themselves (e.g., alluvial redwood groves in the park and degraded aquatic habitat throughout the watershed). As mentioned in your letter of May 28, 1997, the watershed is being divided into two segments for TMDL development: that inside the National Park and that outside the park. In theory, a TMDL implementation strategy should achieve water quality standards at all locations within a watershed. This is obviously a tall order for something as poorly quantified and diffusely generated as clean sediment impairment.

It really makes most sense to nest water quality management plans for individual sub-watersheds within the framework of a fairly general basin TMDL. Dividing Redwood Creek into two TMDLs is apparently based on the fact that one part of the watershed is mostly National Park and the other mostly private landowners. In one sense these should merely be separate load allocation groups, and not separate TMDLs. There is, however, no bar to forming separate TMDLs, but these need to be linked, insofar as the TMDL is driven by conditions in the lower mainstem.

For the lower mainstem, a TMDL needs to address all loading sources. Thus, the lower river TMDL needs to have load allocations both for lower watershed sources and for upper watershed sources. A separate upper basin TMDL would have load allocations for upper watershed sources based on upper watershed conditions. Thus, for a two-TMDL split, the logical course of events would be as follows:

- Develop TMDL and load allocations for the lower watershed, considering all sources of sediment load (both lower and upper watershed)
- Develop TMDL and load allocations for the upper watershed, considered separately from the lower.
- For lower watershed sources, the allocations are as determined in the lower watershed TMDL.
- For upper watershed sources, the allocations are determined as the more stringent of allocations from the upper and lower watershed TMDLs.

Remember also that the downstream TMDL presumably also addresses sediment impairment in tributaries, which are independent of upstream conditions.

Finally, the problem definition should address temporal issues associated with the TMDL. This might be the most difficult part of the TMDL process for Redwood Creek because of the current sediment source in the main stem and the future potential for renewed yield from upstream sources. The problem definition requires consideration of all critical hydrologic conditions during which water quality violations and/or non attainment of beneficial uses occur. This should include the potential for high sediment yields and erosion associated with large storm events *and* existing problems caused by sediment wave propagation/movement in the main stem (Madej and Ozaki 1996) associated with the recent lower peak flows. The target values for water quality indicators set out in the next section should reflect this consideration in that they can be attained regardless of future hydrological conditions.

Water Quality Indicators and Target Values

To develop a TMDL it is necessary to establish quantitative measures or indicators that can be used to evaluate the relationship between pollutant sources and their impact on water quality or beneficial uses. Examples of indicators for a sediment TMDL include maximum turbidity or suspended sediment concentrations, geometric mean size of substrate particles, percentage of pool volume occupied by sediments, and percentage of eroding stream banks. Selection of an appropriate indicator or set of indicators should take the following into account:

- The indicator(s) should be sensitive to the beneficial uses of concern.

- The indicator(s) should be sensitive to where and when impacts occur.

- The indicator(s) should take into account practical considerations, such as the ability of control options to affect the value of the indicator, and the cost and feasibility of monitoring that indicator.

For Redwood Creek, the indicator(s) chosen should be related to the problems identified in the previous section. Much of the existing literature for the Redwood Creek watershed will be valuable in selecting indicators. For example, if the problems include threats to streamside redwoods and degradation of aquatic habitat, a suite of indicators like the following could be used for TMDL development for Redwood Creek:

Streamside redwoods:

- Streamflow (Nolan and Janda 1981; Mahacek and Shelton 1987)
- Sediment transport (Kolipinski et al. 1975; Nolan and Janda 1981)
- Channel morphology (e.g.,channel bed elevation, pool/riffle morphology, cross sections, width/depth rations (Madej et al.).

Aquatic habitat:

- Channel substrate (e.g., percent fine sediment [because of the importance of salmonid habitat; see Klein paper]).
- Water temperatures, especially in the main stem (Anderson 1993).
- Riparian vegetation.
- Dissolved oxygen (Bradford and Iwatsubo 1978)
- Suspended sediment and bedload sediment (data are available from several studies, including Madej 1992)
- Streamflow (Nolan and Janda 1981; Mahacek and Shelton 1987)
- Channel morphology, e.g., pool frequency (see Madej et al.).
- Road density, as surrogate for sediment production.
- Avoided tons of erosion from road crossings.
- Number of redds per mile.

It is likely that more than one indicator will be needed for Redwood Creek because of the spatial and temporal complexity of problems that exist in the watershed. Selecting indicators that address these complexities is critical to successfully measuring the impacts of TMDL implementation. For example, choosing indicators for both 'hillslope' and 'in-stream' conditions is important to ensure that the relationship between the sediment sources and habitat function can be monitored and assessed during implementation of the TMDL. In addition, multiple indicators might need to be selected for the different subwatersheds based on the severity of their impairments and physical conditions. Similarly, indicators that account for different temporal factors can be used to measure conditions during both low flow and peak flow situations, since both probably occur during water quality violations in Redwood Creek.

Target values for selected indicators can be based on portions of the watershed (or similar watersheds) that are fully supporting their designated uses (i.e., reference reaches), literature/historical values, and best professional judgment. For example, sediment data are available for Little Lost Man Creek (Pitlick 1993 *in* Madej and Ozaki 1996) that allow comparison of logged portions of the Redwood Creek watershed to this unlogged, 'reference' watershed. The target value for an indicator can also vary spatially and temporally, depending on the location in the watershed and the seasonal hydrologic conditions.

Identification of suitable indicators and target values is probably one key area where additional work will need to be done to develop a TMDL for Redwood Creek. Although much of the available literature documents what has happened in the watershed, there does not appear to be an equivalent amount of work related to identifying "target" conditions. TMDL developers will need to consider the conditions that are desired in the watershed and attempt to select a suite of indicators that describe them.

Source Analysis

The source analysis is a key component of TMDL development. Its purpose is to characterize the types, magnitudes, timings, and locations of loadings to a waterbody. When conducting a source analysis, the focus should be on determining the primary and controllable sources of sediments and estimating their absolute and relative contributions, taking into account spatial and temporal differences in sediment discharge patterns.

For feasibility reasons, TMDLs for sediment often focus on grouping sources by category as opposed to grouping them by actual land areas. For example, sediment sources can be grouped by type (e.g., roads, streams, nonharvested land, harvested land), parcel (e.g., individual ownership), or subbasin (e.g., tributary watershed). The groupings should consider the relative magnitude of sediment loads, potential management options, and the capabilities of the assessment under consideration. Although the selection of indicators discussed above will somewhat influence the grouping of sources in Redwood Creek, it appears that the most logical grouping would be by source category (as opposed to by subbasin or land ownership). This will facilitate the use of existing data (i.e., most of the previous studies are grouped in this manner), as well as the eventual allocation of loads.

Many of the studies that have been conducted for the Redwood Creek watershed provide the type of information necessary to conduct a TMDL source analysis. Erosional sources and a sediment budget have been detailed in the *Redwood Creek Watershed Analysis* (1996), which summarizes much of the past research on sediment in the Redwood Creek watershed. This study identifies the major sources of sediment to Redwood Creek for the period 1954-1980, a period that includes some major hydrologic events. Although much of the budget is empirically derived and estimates are extrapolated to other sub-basins, the budget should be suitable for purposes of developing a phased TMDL. The budget can be used in conjunction with the selected indicators and target values to identify critical subbasins for which more fine-scale loading estimates can be made.

One apparent need for additional information is to update the 1954-80 sediment budget with data from 1981 to the present. One critical finding from the budget is that approximately ½ of the sediment production can be attributed to land use (i.e., roads, surface erosion of bare ground, and gullies caused by stream diversions). To the extent that hydrologic conditions have remained similar to the 1954-1980 period, allocations based on this budget might be reasonable. However, because it appears that the 1954-1980 data are not indicative of current conditions in the watershed, the TMDL should clearly state that load reductions (or loading targets) are based on these historic conditions. In essence, this means that landowners would receive credit for whatever unquantified load reductions have been achieved since 1980. Also, the dates of the sediment budget are not likely to reflect much influence from improved forest practices, and the reduction goals are likely to appear correspondingly large.

Linkage and Load Allocation

Developing a TMDL requires defining the cause-and-effect relationship between the selected indicator(s), the associated numeric targets, and the identified sources. This linkage can be derived from data analysis, empirical methods, best professional judgment, models, and previously documented relationships. The linkage is used in determining what loads or conditions are acceptable to achieve the desired level of water quality and in allocating load reduction strategies to all significant sources.

For a sediment TMDL, the linkage between sources and water quality indicators may be based on an explicit, quantitative accounting of the movement of sediment within the watershed (e.g., a sediment budget) and its impact on measurable indicators; or, it may be based on well-documented qualitative analysis.

Because of uncertainties in the sediment budget, the identification of load reduction targets for the various sediment process categories identified in the sediment budget (i.e., roads, gullies, stream bank erosion, mass movement) might be difficult to accomplish. An alternative to developing load reduction targets is use of the reference reach approach to identify target sediment yields that will result in attainment of the in-stream numeric targets. Using this approach, the targets should be established by the erosion processes identified in the sediment budget and avoid allocations associated with specific land management practices since this will only add another layer of uncertainty to the analysis. This approach will still require use of the sediment budget developed for 1954-1980. Using the sediment budget, the technology-based controllable loading could be determined for each process and the total loading could be determined assuming the maximum technologically feasible level of control. A problem might arise if significant allocations must be assigned to both forestry and agriculture (i.e., range lands). If so, some thought needs to be given to what constitutes a fair assignment of allocations between these sources, given that agricultural practices might or might not have moved farther toward BMPs by 1980 than forestry.

As the load allocations are made, the TMDL developers will also need to account for a margin of safety (MOS). The MOS is a required element of a TMDL and accounts for the uncertainty about the relationship between pollutant loads and the quality of the receiving waterbody. The MOS can be addressed through inclusion of conservative analytical assumptions or methods, or through explicit reservation of available loading to account for uncertainty. The explicit MOS approach, which essentially allocates a portion of the load for this purpose, is usually addressed during the allocation phase. In cases where the TMDL provides the required MOS through implicit analysis assumptions, the allocation section should indicate that this approach obviates the need for an explicit reservation of loading capacity as a MOS. Where an explicit allocation is reserved as a MOS, the analysis should discuss why this reservation is adequate to account for uncertainty present in the TMDL.

Once an appropriate linkage has been established and a decision has been made regarding the MOS, allocation of controls can proceed based on the best professional judgment of those with expertise in the watershed. The following factors should be kept in mind:

- Types of sources and management options
- Equity issues
- Variability in loads and impacts
- Needs for stakeholder involvement and public outreach
- Implementation issues and need to provide reasonable assurances concerning allocations.

Summary

The quality and quantity of work that has already been prepared for the Redwood Creek watershed make development of a sediment TMDL fairly straightforward. The researchers who have been working in the watershed obviously have the best understanding of the physical processes and current condition of the stream and should be relied on as the TMDL is developed. Although some work remains to be completed, resolution of the issues encountered in this watershed will provide important information for those developing TMDLs in similar watersheds.

References

Janda, R.J., K. M. Nolan, D.R. Harden, and S.M. Colman. 1975. Watershed conditions in the drainage basin of Redwood Creek, Humboldt, County, California, as of 1973. U.S. Department of the Interior, Geological Survey.

Reid, L.M., and T. Dunne. 1996. *Rapid Evaluation of Sediment Budgets.* Catena Verla GMBH, Reiskirchen, Germany.

Wistrom, Theresa. 1997. Letter to John Craig, Tetra Tech, Inc. May 28, 1997.

APPENDIX A—LITERATURE REVIEWED

Alternatives for Erosion Control and Disturbed Lands Restoration within Redwood National and State Parks. A summary presented to the California Coastal PIEC/PAC. Ukiah, CA. December 5, 1996.

Best D.W., H. Kelsey, D.K. Hagans, and M. Alpert. *Role of Fluvial Hillslope Erosion and Road Construction in the Sediment Budget of Garrett Creek, Humboldt County, California*. Redwood National Park, Arcata, CA.

Coghlan, M. and M.A. Madej. 1981. Main Channel Response to Increased Sediment Supply, Upper Redwood Creek, California. *EOS* 62(45):856. November 10, 1981.

Hagans, D.K., W.E. Weaver, and M.A. Madej. 1986. *Long-term On-Site and Off-Site Effects of Logging and Erosion in the Redwood Creek Basin, Northern California*. Presented at the AGU meeting on cumulative effects. NCASI technical bulletin No. 490. May 1986.

Hagans, D.K. and W.E. Weaver. 1987. Magnitude, cause and basin response to fluvial erosion, Redwood Creek basin, northern California. *Erosion and Sedimentation in the Pacific Rim* (proceedings of the Corvallis Symposium, August 1987).

Hofstra, T., G. Bundros, and B. Hill. 1997. *Protecting Resources at Redwood National and State Parks Through Cooperation and Understanding*. Paper presented at the 9th Conference on Research and Resource Management in Parks and on Public Lands. The George Wright Society Biennial Conference, March 17-21, 1997, Albuquerque, NM.

Janda, J., K.M. Nolan, D.R. Harden, and S.M. Colman. 1975. *Watershed Conditions in the Drainage Basin of Redwood Creek, Humboldt County, California as of 1973*. USGS Open-file report 75-568. October 1975.

Kelsey, H.M., and P. Stroud. 1981. *Watershed Rehabilitation in the Airstrip Creek Basin*. National Park Service, Redwood National Park, Arcata, CA. February 1981.

Kelsey, H., M.A. Madej, J. Pitlick, M. Coghlan, D. Best, R. Belding, and P. Stroud. 1981. *Sediment Sources and Sediment Transport in the Redwood Creek Basin: A Progress Report*. NPS, RNP, Arcata, CA. May 1981.

Kelsey, H.M., M. Coghlan, J. Pitlick, and D. Best. *Geomorphic Analysis of Streamside Landsliding in the Redwood Creek Basin*. National Park Service Redwood National Park, Arcata, CA.

Klein, R.D. Sediment flux, fine sediment intrusion, and gravel permeability in a coastal stream, northwestern California. *Advances in Hydro-Science and -Engineering, Volume I.*

Klein, R.D. 1987. *Stream Channel Adjustments Following Logging Road Removal in Redwood National Park*. RNP Watershed Rehabilitation Technical Report #23. NPS, RNP, Arcata, CA. December 1987.

Klein, R.D., and W.E. Weaver. 1989. *Hydrologic Restoration of the Redwood Creek Estuary*. Presented at the Society for Ecological Restoration and Management Annual Meeting, January 16-20, 1989, Oakland, CA.

Kveton, K.J., K.A. Considine, E.M. Babcock, R.G. LaHusen, M.S. Seltenrich, and W.E. Weaver. *Comparison of Slope Treatments for Reducing Surface Erosion on Disturbed Sites at Redwood National Park.*

Madej, M.A. 1995. Hillslope-River Interactions. In *Watersheds '94: Respect, Rethink, Restore.* Proceedings of the Fifth Biennial Watershed Management Conference. July 1995.

Madej, M.A. 1992 *Cooperative Erosion Control Efforts Based on Sediment Transport Trends, Redwood Creek, North Coastal California.* Redwood National Park, Arcata, CA.

Madej, M.A., D.K. Hagans, and V. Ozaki. *Aggradation and Degradation in Redwood Creek, Northwestern California, Over Three Time Scales.*

Madej, M.A., and V. Ozaki. 1994. Channel Response to Sediment Wave Propagation and Movement, Redwood Creek, California, USA. *Earth Surface Processes and Landforms* 21:911-927. October 1994.

National Park Service Briefing Paper. March 31, 1997.

Pitlick, J. 1982. *Sediment Routing in Tributaries of the Redwood Creek Basin: Northwestern California.* Redwood National Park, Arcata, CA. October 1982.

Redwood Creek Watershed Analysis. 1996. Division of Resource Management and Science, Redwood National and State Parks, Arcata, CA. December 3, 1996.

Steense, D.L., and T.A. Spreiter. 1992. *Watershed Rehabilitation in Redwood National Park.* Presented at the 1992 National Meeting of the American Society for Surface Mining and Reclamation, Duluth, MN, June 14-18, 1992.

Weaver, W.E., D.K. Hagans, and J.H. Popenoe. 1995 *Magnitude and Causes of Gully Erosion in the Lower Redwood Creek Drainage Basin.* Redwood National Park, Arcata, CA.