Proceedings of the

CALIFORNIA WATERSHED MANAGEMENT CONFERENCE

November 18-20, 1986, West Sacramento, California

WILDLAND RESOURCES CENTER
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA

Report No. 11
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CALIFORNIA WATERSHED MANAGEMENT CONFERENCE

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Contents

Opening Remarks .......................................................... 1
Robert Z. Callaham

The Challenge of Watershed Management .......... 3
Gordon K. Van Vleck

The University of California Relates to California’s Watersheds ................. 7
Lowell N. Lewis

Moving Forward in Watershed Management ...... 11
John Garamendi

Water: California’s Leading Natural Resource .... 13
Zane G. Smith, Jr.

Conference Evaluation and Recommendations ... 16
Roger R. Bay

Best Management Practices for Water Pollution Control

Best Management Practices for Water Pollution Control: A National Perspective .... 19
Frank M. Covington

California’s Program to Control Nonpoint Source Water Pollution .......... 24
Danny Walsh

Water Quality Protection on National Forest Lands in California ...................... 27
Andrew A. Leven, John R. Rector, and Robert D. Doty

Regulating Timber Harvest on Private Land for Water Quality Protection .......... 32
Carlton S. Yee

Livestock Grazing and Water Quality ............. 38
W. James Clawson

Timber Harvesting and Water Quality ............. 43
Arne E. Skaugset III

Monitoring Effectiveness of Best Management Practices on National Forest Lands ...... 48
Christopher M. Knopp, Mark E. Smith, Jerry Barnes, Brent Roath, and Michael J. Furniss

Robert R. Curry

Synthesis and Summary: BMPs ............. 62
Dan Otis

Yields of Water from Managed Watersheds

Vegetation Management for Water Supply Augmentation ........................................ 65
Kenneth M. Turner

Water Yield Opportunities on National Forest Lands in the Pacific Southwest Region .......... 68
John R. Rector and Lee H. MacDonald

Water Yields from Forests: An Agnostic View ........................................ 74
Robert R. Ziener

Water Yields from High-Elevation Basins in California ........................................ 79
Richard Kattelmann and Neil H. Berg

Soil Moisture Budget: An Example of Effects of Timber Harvest and Regrowth .......... 86
Paul Zinke

The Economic Value of Water in National Forest Management ........................................ 89
Jeffrey M. Romm and Amy Ewing with Shou-Jen Yen and Robert Haberman

Summary and Synthesis: Yields of Water ...................... 103
Jeffrey M. Romm

Cumulative Impacts of Development in Watersheds

Cumulative Watershed Effects: A Historical Perspective ........................................ 107
Robert Coats

Analyzing Cumulative Effects in Watersheds: A Legal View ........................................ 112
Theodore A. Cobb

Forest Practice Regulations for Review of Cumulative Effects ........................................ 115
Edward F. Martin

Managing Forest Roads to Control Cumulative Erosion and Sedimentation Effects .......... 119
William Weaver, Danny Hagans, and Mary Ann Madej

A Management Model for Evaluating Cumulative Watershed Effects .......... 125
Donald M. Haskins
Managing Cumulative Effects: An Industry Perspective .............................................. 131
George G. Ice
Myths and Misconceptions about Forest Hydrologic Systems and Cumulative Effects .... 137
R. Dennis Harr
Assessing Effects of Peak Flow Increases on Stream Channels: A Rational Approach .......... 142
Gordon Grant
Summary and Synthesis: Session IV ................................................................. 150
Raymond M. Rice and Neil H. Berg

Voluntary Papers (Abstracts)

Cumulative Contribution of Roadbed Erosion to Spawning-Gravel Abundance in a Mountain Stream ...................................................... 155
Barry Hecht
The 1983 Erosion Event on Tularcitos Creek, Monterey County, California, and Its Aftermath ...................................................... 155
John Williams and Graham Mathews
Managing for Water Yield: The Importance of Timing ........................................ 155
Lee MacDonald
Present Ecological Aspects of Selected Grazed and Ungrazed Stands of Oak Woodland in Central California ........................................ 155
William H. Brooks
Modeled Hydroclimatic Impacts of Timber Management in Redwood Creek Basin .......... 156
Virginia L. Mahacek King and M. L. Shelton
Progress Report on Cumulative Watershed Effects Study: Eldorado National Forest .... 156
Mike Kuehn
Analysis and Rehabilitation of a Watershed on the Hoopa Indian Reservation ............. 156
William Brock

Coordinated Resource Management and Planning: The California Experience ............ 156
Kent A. Smith and Delmer L. Albright
Diffusion Hydrodynamic Model for Floodplain Modeling ....................................... 157
Johannes J. De Vries and T. V. Hromadka

Poster Presentations

Erosion Control Demonstration Project on Red Clover Creek .................................... 159
Lawrence H. Carver
Involving Water Districts in Vegetative Projects to Increase Water Yield .................. 160
Harley H. Davis, Jr.
Small Instream Structure Construction for Meadow Restoration in Clark Canyon, California ................................................................. 161
John W. Key
Results of 1986 Snow Acidity Sampling in California ............................................. 162
Maurice Roos
The Honeydew Slide: Consequences and Management ......................................... 163
David L. Steensen
Estimates of Annual Streamflow from Precipitation and Vegetation Cover Data .......... 164
Kenneth M. Turner
Effects of California Riparian Woodland on Flood Conveyance: Case of the Pajaro River .... 165
Barry Hecht and Mark Woyshner
Carmel River Watershed Management Plan ....................................................... 166
Ken R. Greenwood

Exhibitors

Exhibitors at the Conference ................................................................. 167

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Preface

Watersheds in California, receiving precipitation as snow or rain, funnel water into our streams and groundwater reservoirs. These watersheds, covered by brushfields, grasslands, forests, or barren rock, are managed for multiple uses. Issues and technical problems arise in relation to this management and use of wildland watersheds. The first California Watershed Management Conference was organized to provide a forum for discussion of these issues and problems.

Many agencies of Federal, State, and local government, and many private landowners are concerned about management of watersheds. A proposal to these agencies for a conference on watershed management immediately brought their endorsement and assignment of key people to help with the work to be done. Accordingly, we created a steering group of 16 people, listed on the preceding page.

Conservatively, the steering group planned for 100 to 150 attendees to the Conference. The final count of 292 registrants undoubtedly reflected the importance of the three subject areas chosen for discussion.

In order of consideration, the topics were: best management practices (BMPs), potentials for increasing yields of water from managed watersheds, and cumulative impacts of development in watersheds. Each topic was examined during a half-day symposium.

Information on these topics was presented by 22 invited authors. Their papers represent a unique assemblage of knowledge, viewpoints, and methodology. The authors have had enlightening experiences in research, applications of technology, management of land and resources, and governmental processes. Collectively, they described both the state-of-science and the state-of-practice of BMPs, yields of water, and cumulative impacts.

The Conference also provided opportunities for presentations of voluntary papers and posters. Nine voluntary papers covered a variety of technical topics; abstracts are included in this volume. Eleven poster presentations were viewed and discussed during an evening session. Eight are described in the final section of these Proceedings.

Following the Conference, five technical training courses were presented. These short courses, of either 3 or 6 hours duration, attracted 106 trainees.

To expedite publication of the proceedings, we asked authors to assume full responsibility for delivering manuscripts in photoready format by the time the conference convened. The views expressed in each paper are those of the author(s) and not necessarily those of the sponsoring organizations. Trade names are used solely for necessary information and do not imply endorsement by sponsoring organizations.

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California's watersheds produce the water that gives life to our people, industries, and agriculture. The alpine and coniferous forest zones in our mountains receive the most rainfall and snow, and yield most of our streamflow and groundwater. Lower elevation watersheds, covered with brush and hardwood vegetation, receive and yield relatively less water. Watersheds covered by brush, grasslands, forests, or barren rock produce nearly 95 percent of our water from only 55 percent of the land in the state. Considering the values of water yielded by these lands, it is surprising that more attention has not been given to improving their management as watersheds.

In 1979, a report by the Standing Committee on Research to the State Board of Forestry gave watershed problems highest priority for research. Again, in four workshops conducted during 1985 and 1986 by the Wildland Resources Center of the University of California, watershed problems consistently and persistently ranked highest in priority for research and extension. The identified problems included increasing yields of water; reducing nonpoint pollution; determining cumulative impacts of man's activities within watersheds; managing riparian zones, particularly stream channels and adjacent vegetation; avoiding mass wasting; and preventing or healing soil erosion from steep lands.

These problems provide the basis for employing hundreds of people in California in jobs related to watershed management. They work for the federal government, state agencies, public and private utilities, consulting firms, and private landowners. These workers include the traditional specialists concerned with watersheds, such as hydrologists and soil scientists, but also included in their midst are engineers, foresters, and range managers.

These many and diverse people concerned about watershed management have not previously had opportunities to meet one another and to discuss their common interests related to management of watersheds in California. In response to this need, the Wildland Resources Center and the Water Resources Center, of the University of California, decided to organize a major conference on management of watersheds in California.

Our goal in organizing this conference was to provide a forum for discussing the problems, experiences, and needs for research related to wildland watersheds in California.

We hoped to meet a number of objectives through such a conference. First, we wanted to bring together people of various backgrounds for technical discussions. Second, we wanted to provide summaries of information through invited papers on important topics in watershed management. Third, we wanted to provide training in the use of new techniques through short courses. Fourth, we wanted to enable those who had unique or special experiences to present their findings through voluntary papers and poster presentations. Fifth, we wanted to provide exhibits of new equipment, techniques, and publications related to watershed management. Sixth, we wanted to keep costs for such a conference to a minimum and to pay as we went without recourse to financial sponsors. Seventh, we wanted participants to decide if, when, and how their interests in watershed management in California might be directed and organized in the future.

To achieve these goals and objectives, we asked others to join with us in a steering group to create a conference. Nearly all of the organizations asked to participate named representatives to the steering group. Meeting only six times, for a total of about 16 hours during the past year, the members of the steering group managed to put together this 3-day conference. Of course, individual members of the committee worked long and arduous hours between meetings of the steering group to fulfill the assignments for which they volunteered.

The steering group was comprised of five representatives from the University of California; six representatives from five Federal agencies, in the Departments of Agriculture and Interior; three representatives from State agencies, one each from the Department of Water Resources and Department of Forestry, and one from the Water Resources Con-
trol Board; one from the East Bay Municipal Utility District; and one representative from the Association of Resource Conservation Districts.

Several other people deserve special recognition for their contributions made before, during, and after the Conference. May Huddleston, our editorial consultant, worked with authors of papers and posters to improve the Proceedings. Her services were financed by the Edgebrook Fund through the Department of Forestry and Resource Management of the University of California at Berkeley. Shirley Stuart, Program Assistant in the Wildland Resources Center, was responsible for developing the original mailing lists and for providing liaison between the Centers, our editor, and speakers. The staff of the Water Resources Center, at Davis, has been responsible for registrations and for local arrangements.

Any undertaking as large as this Conference should be evaluated as to its organization, program, and conduct. Six participants have agreed to serve on an evaluation committee. Their charge is to look not only at this Conference, but also at the needs for related conferences in the future and mechanisms to provide continuity between such conferences. The evaluation committee will report at the final session.

During the planning sessions, the steering group realized the need for a simple brochure describing the magnitude and importance of California's watersheds. Cooperative Extension at the University of California was producing a leaflet, just released, entitled "Watersheds and Water Yields." The steering group felt that still another pamphlet was needed to describe the sources of California's water and some of the issues and problems related to managing California's watersheds. Responding to this need, Darwin Briggs and Robert Nuzum, from the steering group, and Raymond Coppock, from Cooperative Extension, produced a brochure that is available for the first time here. All participants are asked to review this brochure and to comment on whether it is needed and should receive wider circulation in its current form.

A special effort was made to arrange for exhibits by organizations having products or services of potential interest to those who manage watersheds. Michael Schaefer, the member of our steering group responsible for exhibits, has arranged for 16 presentations immediately adjacent to the conference hall. These exhibits, available before and after our sessions and during the refreshment breaks provide an excellent way for participants to learn of new activities and technologies. I urge all participants to avail themselves of this opportunity.
The Challenge of Watershed Management

Gordon K. Van Vleck

As a rancher who has managed range and forest lands for more than 40 years, I have learned that watershed management is a simple idea that is often complicated to implement. I have also learned that while just about everyone supports the principle of watershed management, many people disagree about the best ways to go about it. Thus it seems appropriate at the outset of this conference to ask, "Why is this topic important enough to bring us all together to talk about it?"

In the broadest sense, the answer is that sound management of our watersheds is necessary to ensure the continued productivity of our renewable resources--water, forests, fish, wildlife and soils--which are the basis for a strong economy and a healthy environment.

In a narrower context, sound watershed management means

The development and use of our water resources
Sustaining a productive forest products industry
The preservation of habitats for fish and wildlife as well as open spaces for the use and enjoyment of our increasingly urban population

Human activities as well as natural events create special challenges to watershed managers. The list of many activities includes

Wildfires resulting from carelessness or arson
Construction projects such as highways, dams, powerlines, and homebuilding
Resource exploitation ranging from timber harvesting, to mining, hunting and fishing

The list of natural events that impact watershed management includes

Heavy rainfall and floods
Forest fires caused by lightning
Landslides and volcanic activity

To a cattleman, sound watershed management means more grass and fatter animals. But we also recognize other important benefits, including reduction of wildfire hazards, increased streamflows, larger and more diversified wildlife populations, improved fisheries, and opportunities for increased public use and enjoyment of open space.

This conference was planned by representatives of two centers of the University of California, five Federal agencies, three departments of the State Resources Agency and two private organizations. That's an indication of the interest in this subject and of the diverse viewpoints that surround it. But the fact that we are all here today, not only to discuss our own views but to share the experiences of others is an encouraging sign. I also view this meeting as an important step toward creating increased public awareness and understanding of the problems and rewards of comprehensive watershed management programs.

Those of you who have participated in discussions between fishery biologists, foresters, hunters, park rangers and water developers know that we still have a long way to go in developing a unified approach to managing the resources of our watersheds. It's important to realize, however, that we have made substantial progress in recent years.

Four of the major departments of the Resources Agency are involved in watershed management. Each of them approaches the task from a different angle, based on their primary responsibilities. Yet in recent years much has been accomplished in bringing their views and concerns together and in creating a unified approach to managing our watersheds.
I would like to take the rest of my allotted time to describe some of the responsibilities and special concerns of the Departments of Water Resources, Forestry, Fish and Game, and Parks and Recreation.

WATER RESOURCES

The California Water Plan, adopted by the Legislature in 1959, recognizes the importance of watershed management and states that the objectives of the Plan should include

"Reducing silt deposition which impairs or destroys the effectiveness of expensive and irreplaceable reservoirs and clogs stream channels; and

"Increasing watershed yields by improving the regimen and characteristics of runoff and ... by increasing total water production ...."

Today, more than 25 years later, these objectives are still valid guidelines for our Department of Water Resources.

Throughout construction of the State Water Project and in the operation of the Project's reservoirs, canals, pumps, and power facilities, the Department strives to deliver maximum benefits with minimum environmental impact.

Future water development in California will have less impact on watersheds and their resources because of increased environmental awareness on the part of the public as well as among government agencies. In addition, all of the best sites for dams and reservoirs have already been utilized and future projects are not likely to receive the large Federal subsidies that were provided for earlier projects. This doesn't mean that there will not be additional water development in California. It does mean that future development will be based on new strategies which will include offstream storage, conservation, increased ground water management, and use of reclaimed water. While these approaches will help provide additional water supplies for California's growing population, it will become increasingly important to protect existing reservoirs from sedimentation.

Vegetation management can help reduce silt loads as well as provide increased runoff from springs.

FOREST AND RANGE

The Department of Forestry is concerned with production of high quality wood products while maintaining soil stability, water quality, fish and wildlife habitat, and recreation values in our privately owned forest lands.

To help achieve these objectives the Department regulates timber harvesting on private lands through the Forest Practices Act. This Act, the strictest set of timber harvest regulations in the country, provides for interdisciplinary monitoring by other concerned agencies—such as the Departments of Fish and Game and the State Water Resources Control Board—to determine compliance and assess its effectiveness.

Wildfires are a serious problem in California and, as I have already mentioned, they can have disastrous impacts on watersheds. I am sure that most people don't think of firefighting as vegetation management or watershed protection. But controlling these fires and reducing their after-effects certainly is an important watershed management effort. Two or three decades ago, we were more apt to think of this kind of watershed protection in terms of timber resources. Today, as a result of urban encroachment into rural areas a new factor has been added. That factor is protection of human life and property. In 1985 there were more than 10,000 wildfires in the state, burning a total of 595,000 acres. To meet this responsibility, the Department of Forestry maintains one of the largest fire protection forces in the country. It operates 220 wildfire fire stations, 22 lookouts, 8 helicopter units, and 13 bases for air tankers and other aircraft.

While the Department devotes a great deal of time and money to putting out forest fires, it also has a program to start them—but on a small scale. The Vegetative Management Program enables the Department to work with landowners to protect and improve timberland and other watershed values through controlled burning.

These controlled burns reduce wildfire hazards and increase a variety of range and forestland benefits—including increased water yield and improved wildlife habitat. Since 1981, about 160,000 acres have been burned under this program. The Department assumes liability responsibility, and costs are shared between the Department and the landowner. Average cost for a controlled burn is $24 an acre, and the average landowner share—in cash or services—is about one-third of the total cost.

In addition to protecting watershed values from wildfires, the Department also has several programs underway to study soil erosion and cumulative impacts from timber harvesting and other forest uses.

Despite these programs, the Department is confronted with many unknowns—including the lack of an objective measure of the cumulative
impacts of natural and man-caused events in watersheds. We look to scientists and professionals such as you to help establish the standards necessary to evaluate present impacts and to measure the effects of future programs and practices.

FISH AND WILDLIFE

The Department of Fish and Game has a vital interest in watershed management because the vitality of many fish and wildlife populations is directly related to the conditions of watershed habitats. The Department cooperates with other agencies and private landowners to achieve multiple uses that include use of a variety of watershed resources. While this kind of comprehensive planning and management may be more expensive in the short run, in the long term it will return broader and more cost-effective benefits. For example, the preservation of riparian habitats enhances wildlife populations, reduces soil erosion and acts as a filter for sediments that might otherwise enter streambeds, in addition to providing benefits for many species of wildlife. Decreasing erosion and sediment transfer lengthens the life of reservoirs and reduces the need for expensive draining and dredging.

Watershed managers and wildlife biologists agree on the value of chaparral management. Removal or thinning of dense, overage stands of chaparral provides improved wildlife habitat and is an effective means of encouraging plant growth that helps stabilize soils. At Grindstone Creek in Glenn County, the Department and the U.S. Forest Service, through controlled burning, have interspersed thousands of acres of chaparral with grasslands. Deer populations have increased, and livestock grazing conditions have improved significantly.

PARKS AND RECREATION

The Department of Parks and Recreation manages more than a million acres of land in California that contain a full range of watershed problems, including soil erosion, sedimentation, flooding and loss of riparian habitat. At Pescadero Marsh Natural Preserve in San Mateo County, the Department has a complex erosion-sedimentation problem that is difficult to resolve because the Department owns only the lower coastal wetlands. Restoration of the marsh will be impossible unless something can be done about the large sediment loads coming from the upper watershed. The Department has asked the Coastal Conservancy to fund a watershed study which will propose long-term solutions to these problems. In the interim, local landowners and public agencies are working on temporary solutions which include relocation of levees in the wetland to improve water circulation.

At Humboldt State Park, the Department must resolve problems resulting from past disturbances in the upper watershed of Bull Creek where erosion now threatens the world-renowned Rockefeller Forest of coast redwoods. Floods in 1955 and 1964 caused extensive bank erosion and loss of more than 800 old-growth redwoods. The Department has since acquired all of the watershed, and management is now focused on controlling the transfer of sediments in the stream system. Future work will be focused on stabilizing the sediment sources in the upper slopes of the watershed.

SOIL CONSERVATION

Recognizing the need for a comprehensive, long-range approach to meeting the State's soil conservation problems, in 1984 I appointed an advisory committee to work with the Department of Conservation to develop and recommend soil conservation policies and programs. One of the major recommendations of the committee is the designation of a single agency to be responsible on a Statewide basis for all aspects of soil conservation. The committee also recommends that the State's 120 Resource Conservation Districts have a lead role in the implementation of local soil conservation programs.

While reflecting on this new effort to conserve soils, it's appropriate to comment on a program that has been working effectively for the last two decades, and which continues to provide benefits in the management of watersheds. I am referring to the State's Williamson Act.

The Williamson Act enables owners of agricultural lands to pay lower taxes in return for a commitment not to use their lands for development purposes. The Act has long been considered a program for the conservation of prime agricultural lands in or close to urban areas. However, fully two-thirds of the 15 million acres of lands under Williamson Act contracts are nonprime, mainly grazing lands, many of which also have open space and wildlife values. Two years ago I appointed a task force to determine if the Williamson Act was accomplishing its intended purposes and to find out how landowners felt about it. The task force found that the Act has widespread local support and that it still is an effective instrument in preserving agricultural and open space lands in both urban and rural settings.

LOOKING AHEAD

Watershed management is a broad subject that includes forest products, fire protection, fish and wildlife preservation, esthetics, recreation, soil and water conservation, and fire and flood protection. Obviously effective management calls for an interdisciplinary, multiple-agency approach with participation by
landowners, scientists, and the educational community, as well as understanding and support from the public. That's no small task. However, I hope that this and similar meetings will establish the groundwork for effective examination of all aspects of watershed management issues, and thus lead to new programs and policies which will help us achieve the goal we all desire. That goal is the wise use and enhancement of our natural resources for the lasting benefit of all the people of our State.

Thanks for inviting me to join you here today and for this opportunity to share some of my thoughts with you. Best wishes for a successful and productive conference.
I find that many aspects of this Conference are gratifying to me. Naturally I am pleased by the University of California's leading role, through the Wildland Resources Center and the Water Resources Center, in bringing about this conference. I also want to recognize the large number of State and Federal agencies and other organizations that have contributed substantially to planning and presenting this conference.

Personally, I must confess to being somewhat surprised when watershed management turned out to be so important from the viewpoint of managers of forest, grass, and brush-covered lands in California. As Director of the Agricultural Experiment Station, I am repeatedly made aware of the great importance of water—to our agricultural systems, to industrial development, to the well-being of livestock, and to the overall health of our citizenry. Like all laymen, I knew that the water we use originates as runoff from rain and snowmelt, but I had little appreciation of the technological complexities in managing watersheds so as to increase the quantity and enhance the quality of water that flows therefrom.

Believe me, over the last few months I have come to appreciate the serious lack of technology for the management of rural watersheds, and to recognize the need for many professionals to be involved in the management of lands for water production.

As I prepared for this talk today, I turned to UC's Directory to Expertise and Facilities Related to Wildlands. The Directory showed how many people of various disciplines were interested in watersheds. I found 61 members of our academic staff listed. Forty-nine were faculty members working on eight of our nine campuses. Twelve of those listed work within Cooperative Extension. As I expected, hydrologists, engineers, soil scientists, and meteorologists were prominent in the list. Very surprising to me was that one quarter of those listed were faculty members concerned with law, political science, and economics. The broad array of disciplines pointed out to me the multiple dimensions of watershed management problems involving earth scientists, physical scientists, biologists, engineers, and political scientists.

CURRENT EFFORT ON RESEARCH AND EXTENSION

Considering the many staffers at UC interested in watersheds, I anticipated that the University of California and other organizations might be investing substantially in research and extension programs related to watershed management. But I was wrong. A quick survey of all research and extension directed at watersheds revealed that Statewide expenditures amount to only $2.7 million during the current fiscal year. Spreading those funds over 58 million acres of wildland watersheds, we annually spend about 5 cents per acre on watershed research and extension.

This survey also disclosed that watershed research and extension is scattered and piecemeal. More than 60 people work at 36 locations across the state. Their combined efforts add up to an equivalent of 19 full-time scientists and specialists.

The Federal government funds most of the research and monitoring effort. The Forest Service Experiment Station headquartered at Berkeley has four watershed research projects with eight scientists and a budget this year of $1.4 million. The Water Resources Division of Geological Survey has a large cadre of people involved in monitoring the State's water resources.

The California Department of Forestry is spending $300,000 for research and extension related to soil erosion and watersheds and another $380,000 for the soil vegetation survey.

The University of California, by our best estimate, is spending about $635,000 on watershed research and extension during the current year. Within UC's Agricultural Experiment Station there are four projects involving five scientists at a total cost of about $240,000.

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2Acting Vice President, Agriculture and Natural Resources, University of California, Berkeley, Calif.
Another six scientists outside of the Agricultural Experiment Station are estimated to spend about $240,000. Cooperative Extension is spending about $175,000 for work by 18 people at 18 different locations.

The survey also included faculty on all 19 campuses of the California State University system. On 9 campuses 26 people were involved in watershed research with an effort equivalent to about 5.6 scientist years. This work spanned California from Humboldt State University in the north to San Diego State University in the south.

The problems tackled by these scientists and specialists will be entirely familiar to you. Included are water quality and water chemistry, acid deposition, fluvial processes, riparian habitats, soil erosion and slope stability, nonpoint pollution and its abatement, and uses to which land and resources are put.

HIGH PRIORITY PROBLEMS

Remarkable to me is the fact that such watershed problems were voted to be paramount in four workshops to determine priorities for research and extension related to wildlands. Whether we considered forests, rangelands, shrublands, or streambank zones, the needs for research and extension related to watersheds always came out on top. Let me recall for you some of the problems listed as critical or urgent.

The workshop on forestland identified three problems—management of buffer strips, stream channels, and aquatic habitat—as having highest priority. Next in importance were problems related to nonpoint pollution from sedimentation, and cumulative impacts.

The workshop on rangelands put the problems in this descending order of importance: effects of rangeland management on water quality; pathways of sediment transport through watersheds; background levels of sedimentation; landslides in unstable areas; and effects of grazing systems on riparian and aquatic ecosystems.

The workshop on shrublands assigned critical importance to several watershed problems. One of these was methods for predicting yields of water and sediment associated with management of shrublands. Another was how to use prescribed burning to increase yields of water without unacceptable sedimentation and degradation of water quality.

The workshop on management of streambank zones, organized by the University with support from the Pacific Gas and Electric Company, identified urgent problems related to sources of sediments, yields of water, and economics of managing for water, and substantial needs for demonstration projects and educational programs.

These four workshops in a 2-year span of time brought forth overwhelming evidence that California's rural watersheds deserve greatest priority for research and extension programs. But simply listing the problems to be solved was not enough. We needed to know the approximate costs and time required to solve these problems.

HIGH COST OF RESEARCH AND EXTENSION

In 1984, the University's Water Resources Center analyzed the research needed for management of shrubland watersheds. A team of watershed researchers estimated costs to establish paired watersheds at four locations in California. Research to calibrate the watersheds, treat them, and determine effects of treatment would take 8 to 10 years at a requested annual budget of $1.3 million. Even a "bare bones" budget for this minimal research effort would have cost $800,000 per year, or a total of $8 million during 10 years.

Similarly, large costs to solve the highest priority watershed management problems were estimated at the workshops. Here are three examples of annual costs for 10-year programs of research and extension. To address nonpoint pollution and sediment problems in streams would cost $760,000 per year. Research and extension on managing stream channels and aquatic habitats would cost about $510,000 per year. To quantify and develop strategies for managing cumulative impacts of multiple harvests would cost $640,000 per year. To tackle these three problems at the same time would require an annual budget totaling $1.9 million. We should be working on not one but all of these problems, and even more.

In the face of this justified demand for research and extension, our annual budgets for research and extension at the University of California, in the current budgetary climate, will allow for only partial solutions to the most pressing problems.

UC'S INCREASING BUDGETS FOR RESEARCH AND EXTENSION

The University is responding to demands for higher investments in research and extension related to watersheds and other wildland problems. Our Division of Agriculture and Natural Resources was successful in obtaining a budgetary augmentation of $650,000 during the current fiscal year. These funds, together with $350,000 appropriated to the California Department of Forestry, are financing the Integrated Hardwood Range Management Program, which may have some activities related to management of soil and water resources.

Specially relevant to interests and concerns of this conference, I am pleased to report that the University's budget for next year, as
The recent approval by the Regents includes an augmentation of $400,000 in State funds to expand research on:
- management of vegetative bufferstrips
- management of nonpoint pollution in streams
- management of soil erosion from forests and rangelands

The proposed multidisciplinary watershed management program would involve academic staff at several campuses of the University of California, at other universities, and at county offices of extension. Included also might be specialists and consultants in the private sector. Our hope is that the watershed management program would parallel the program of competitive grants and contracts just instigated by the Integrated Hardwood Range Management Program.

Before I leave this budgetary augmentation, let me reemphasize that this is merely a proposal at the present time. It must survive many steps in the appropriation process before funds would be available. Simply put, there may not be room in the budget next year for this urgently needed watershed research item.

THREE AREAS TO IMPROVE COOPERATION AND COORDINATION

Regardless of whether we obtain this augmented funding for research and extension, there are things that we need to do, that we can do, to improve coordination and cooperation in research. Here, I am echoing the remarks made by the University of California's President, David Gardner, at the Centennial Celebration of the State Board of Forestry nearly a year ago. Three areas emphasized in his speech are entirely relevant to our conference here today. We need to:
- work together more closely to identify critical needs
- broaden participation in the research and extension process
- find ways to share the burden of funding

The University of California and California State Universities need to work together more closely with State agencies and public groups to identify the critical needs for research and education. We must target a few critical problems that we will try to solve. We must all accept that some important problems will be left unattended until a later time. Our combined efforts should be directed at identifying and solving those problems that we agree have greatest urgency.

Let me tell you how UC has already moved to broaden participation in the research and extension program. For the first time, and in a major way, the University of California has offered a competitive grants program to specialists at the California State University system, at other universities, and in the private sector. Here, I am talking about the competitive grants and contracts just made from UC's Integrated Hardwood Range Management Program.

The important feature of the program is that only 4 of the 12 projects to be funded by the University will be located on UC's campuses at Davis and Berkeley. Five of the remaining eight projects will be at five different campuses of the California State University system. One will be at Loma Linda University, a private institution. The remaining projects will go to private consulting firms that have special expertise needed to conduct the proposed work. This action establishes an entirely new precedent for the University.

Under this concept of broadening participation in the research and extension process, I want to make another point. In many cases, we have not spent enough on extension. Again, the Integrated Hardwood Range Management Program shows a break with that tradition. More than half of the funds available to the University will expand Cooperative Extension to conduct applied research, demonstrations, and educational programs. A similar expansion of Cooperative Extension's capabilities in the watershed areas has been justified.

Joint funding of the Integrated Hardwood Range Management Program by UC and the California Department of Forestry illustrates the third point made by President Gardner. All of us are obliged to develop new ways of sharing the financial burden of costly new research and extension programs. The University of California cannot and should not be the sole source of funding for this work. Governmental agencies and the private sector all should help to pay for the needed technology. People who make decisions about the budgets of various organizations must plan together and decide how to share the financial burdens of expensive research and extension programs.

We also need to look for new and imaginative ways of financing these programs. In this regard, let me toss out a suggestion that the public utilities concerned about watershed management might find a way of taxing themselves to support needed research and extension. Such a procedure would parallel arrangements under which agricultural commodity groups tax themselves to support needed research and extension. Perhaps those of you who represent public utilities can discuss possibilities of such an arrangement during this conference.

CONCLUSIONS

While thinking about budgetary augmentations for watershed management and preparing for this talk, I have been repeatedly impressed by the magnitude of the social, economic, and technical
problems associated with management of watersheds in California. There seems to be little appreciation of these values and needs by flatlanders, legislators, and many decision-makers. One desirable outcome of this Conference would be deliberate actions to improve the appreciation of the importance of watershed values by these people.

Another need is to impress decision-makers with the serious lack of technology for managing California's watersheds. A Statewide program should be mounted to respond to the need for technology.

Although the University of California's budgetary augmentation will barely scratch the surface of these needs, at least we propose a small step in the right direction. I would challenge others to take parallel action.

Finally, let me reiterate the points made by President Gardner. All who are concerned about California's watersheds should work together closely to identify the critical needs, to share the burdens of funding the programs to resolve them, and to seek new and imaginative ways of financing the needed programs.

We are proud of the steps recently taken by the University of California to broaden participation in the research and development process. The Integrated Hardwood Range Management Program demonstrates our commitment to seek out and fund the best talent to work on critical problems. If our forest and rangeland watershed program is funded, we will be sharing the wealth next summer among the best qualified watershed scientists and specialists.

I have profited substantially from my preparations for delivering this talk to you today. My appreciation for the immensity and technical difficulty of your problems has expanded greatly. I hope that you will profit in equal measure from your participation in the technical sessions to follow. Thank you for giving me this opportunity to describe how the University of California relates to California's watersheds.
It's good to be here today. I'm going to address my subject a bit differently than I'd planned to today and I need your help. I want you to imagine scenes from throughout this great State. Recently I was in the San Benito Mountains along the Central Coast...so picture in your mind the beauty of the quiet coastal wilderness—steep divides, free-flowing streams, underbrush, cypress, and wildlife. Then think about the majestic Sierra—after a forest fire, hillside burned black, vegetation and homes destroyed. Now move south, traveling over the water projects of the Central Valley to the Los Angeles Basin. Here there is an ever-growing population with ever-growing demands on the State's resources. This sprawling metropolis is our clearest reminder that California will be home to some 32 million people by the year 2000. Now think about Proposition 65—approved by a 2-1 margin—and if there is a clear mandate from its passage, it would be that Californians are vitally concerned about water quality.

All these images are very real and very important for all of us. The common link between these images is the need for effective resource management. Some people are offended at the thought of "resource management." They would have you believe that management means an intrusion into places where we ought not to be. That, however, does not reflect the reality of the world in which we live. With increasing demands on our resources we have no alternative but to monitor our land and water use with an eye toward more effective resource management. In the 1980's and forever more—unless we are all to become victims of a thermonuclear war, in which case our entire purpose here today would be meaningless—management simply must come into play when we talk about natural systems. How we interact with natural systems in large measure will determine the quality of life for our children. There is another speech that I have been delivering quite often of late about our current economic situation and the precarious status of this State as we look toward the future, but I will save that for another day.

We live in the midst of a fragile balance of beauty, the pressures of population growth, and increasingly restricted State revenues from which we must address important issues before us. Resource management—management of watersheds—is an important issue, and the fact that there are some three times as many of you attending this conference as we expected speaks to that. Let's ask ourselves in this political and natural world we are living in, what are the objectives of resource management? In so doing, I believe we will also address the feelings of those who question the need for resource management. The answer, at least for my purposes, is simple. Resource management does mean preservation and protection of important natural resources. It also happens to mean cultivation of resources, and it necessarily means nonexploitation of resources.

Management is an absolutely critical facet of maintaining the lifestyle we have come to expect in "the Golden State." How do we develop the State and protect its resources? How do we use water supplies to keep the economy strong? Where do timber harvesting, livestock grazing, water quality, and water conservation fit in our equation of California? These are important questions and I don't pretend to have the answers, but you do. Or you will when this conference is over.

We know that the human interface with our environment exacerbates problems. We also know that by working together we can mitigate environmental damage and we can even solve many of our problems. However, it is very important that policymakers see the relationships in the environmental equation. We must know what is happening to our watersheds and our agricultural lands every bit as much as we need to be aware of what is and isn't selling at the market. Agricultural policy is a good example of what we're doing wrong.

The State Water Project, the Central Valley Project, Federal agriculture policy, all are based on a wrong-headed idea—unlimited demand. California was a net importer of agricultural products last year. The staple crops of the Southern San Joaquin Valley are up against competition from all over the world. Third world

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

2 Senator, State of California, Sacramento.
nations are increasingly self-sufficient in production of staple commodities and their prevailing wage and shipping rates are considerably lower than ours.

Bad policy decisions are based on bad information and good decisions naturally follow from good information. I have not touched much on research, but that is a critical factor in moving forward when it comes to resource management.

I mentioned Proposition 65 earlier, and let me go back to that issue for just a moment. Californians are very concerned about all the extras they are getting in a glass of tap water. I don't want to get into the politics of that initiative, but clearly the management of watersheds, not just in the foothills and the Delta--areas of this State that I represent--but also in urban centers, is important. The interface of humans and their environment is perhaps most immediately felt through the quality of our water supplies. Whether or not we do a good job in protecting water quality is not just an issue to be determined by how close we allow timber harvesting to watersheds, but how we manage land use and development in urban areas.

Let's go back to the images I asked you to draw up in your minds earlier. Remember the mountains of the Central Coast, the Sierra, and of course that ever-growing Los Angeles Basin. It all fits together. That rugged terrain in San Benito County is something most of us don't think about very often, but it is a very special part of this State. Oh, it's not a park or anything like that, but it's part of what is so special about California--untamed wilderness, open space. It can be used for a variety of different purposes, timber and grazing among them, and a place where wild animals roam freely, and a place where one can be alone and think about our past and our future. You can't get that at Yosemite--you're as likely to get caught in a traffic jam there as you are in the L. A. Basin.

I alluded to it earlier and it is a critical issue. While the need to manage our resources is greater than ever, because of the antigovernment, antispending sentiments that began to take hold in the 1970's, it will be increasingly difficult to address these important issues. So your purpose here becomes even more important.

It is my feeling that watershed management should be an important element in the debate about State water policy. Watersheds do not exist in a vacuum and you are well aware of the importance of watershed management in maintaining water quality. However, your role must be to expand awareness of where watershed management fits into policy debate about water and land use. When you finish here do not think that your work is done. I can't overstate how important it is for you to take your knowledge across the river and to the halls of the Capitol.

As I said, the resources from which to address resource management will be increasingly hard to come by. Consider in your solutions then, how we should apportion the costs. Where should research dollars go? Where should they come from? What is the State role in watershed management? Where does local government fit in? These questions are only a beginning. There are undoubtedly others which you should offer and follow up with answers.

Your work is important. Those of you who are here are responsible for land use policy and implementation at Federal, State, and local levels. Share your knowledge with those of us who are supposed to develop policies which will help you do a better job.
Water: California's Leading Natural Resource

Zane G. Smith, Jr.

California has the hardest working water in the nation.

Californians use about 40 million acre-feet of water each year. Some 32 million acre-feet, almost 85 percent of the total, goes to irrigate more than 200 crops that make up California's $30 billion-plus agribusiness, still the largest sector in the State's economy.

Most of the remaining water goes to residential, commercial, and industrial users, supporting 27 million people and the sixth largest economy in the world. And along the way, that water passes through more than 175 hydroelectric plants that produce 8500 megawatts of power for towns, cities, farms, ranches, homes, offices, stores, and factories throughout the State.

California also has the most traveled water in the nation.

Unequal distribution of rainfall due to our wet winters and dry summers forced the State to develop the most extensive system of man-made lakes, reservoirs, aqueducts, siphons, and pumping stations for collecting and distributing water to be found anywhere in the world.

About 75 percent of the water supply originates north of Sacramento and 80 percent of demand for water occurs to the south. To offset this imbalance, six major water projects and countless smaller ones move water north to south, east to west, up and down the State.

Water from the Owens River travels 400 miles through the Los Angeles Aqueduct along the east side of the southern Sierra Nevada and Tehachapi Mountains to storage reservoirs in San Fernando. Water from Oroville Dam flows through the State Water Project as far south as San Diego. Runoff water from Mt. Shasta moves through the Central Valley Project to irrigate wheat, cotton, and other crops in Kern County more than 500 miles away.

WATER SUPPLY IN CALIFORNIA AND THE NATIONAL FOREST ROLE

About 200 million acre-feet of precipitation falls in California each year. Of this amount roughly 130 million acre-feet is lost through evaporation and evapotranspiration. The remaining 70 million acre-feet flows as stream runoff or is absorbed into the soil to recharge ground water reservoirs.

Northern California gets 66 percent of the precipitation and accounts for 40 percent of the runoff water. The Sacramento River Valley system accounts for 31 percent of all runoff, and the San Joaquin for 9 percent. The rest is scattered elsewhere throughout the State.

Usable groundwater reserves statewide amount to an estimated 140 million acre-feet or four times the total surface storage capacity serving the State. Groundwater supplies communities and farms throughout the State and accounts for as much as 50 percent of the irrigation water used in parts of the Central Valley.

National Forests occupy only 20 percent of the land in California but provide about 50 percent of the runoff water. They contain 2,100 of the 3,600 lakes in the State and 13,000 miles of the total 18,000 miles of streams and rivers.

About 85 percent of the snowpack in California, its largest water reservoir, is on National Forest lands, and more than 160 dams that supply 75 percent of the hydroelectric power in California are within National Forests.

National Forests form the watershed of more than 2,400 reservoirs and man-made lakes that supply most major aqueducts in California. For example, the Shasta-Trinity National Forest yields 8.5 million acre-feet of water annually into the Lake Shasta reservoir of the Central Valley Project. The Lassen and Plumas National Forests yield 5.5 million acre-feet of water into the Feather River that flows to the Oroville Reservoir of the State Water Project.

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

2Regional Forester, Pacific Southwest Region, Forest Service, U.S. Department of Agriculture, San Francisco, Calif.
In Southern California, the San Gabriel Mountains in the National Forests produce 40 percent of the water used by Los Angeles each year. The list can be extended to every part of the State.

MANAGEMENT OF NATIONAL FOREST WATER RESOURCES

Although National Forests are commonly associated with timber production and recreation, water has been and remains the primary resource in National Forest management.

This priority was set by the Organic Act of 1897 that established the National Forest System. Water is the first resource mentioned in the Act:

"No national forest shall be established, except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows..."

The Act goes on to state:

"...all waters within the boundaries of national forests may be used for domestic, mining, milling, or irrigation purposes under the laws of the State wherein such national forests are situated..."

These statements pretty well define two themes that have guided management of National Forest water resources to this day:

First, make water available for reasonable and appropriate uses.

Second, cooperate with the State in planning for the protection, use, quality, and development of water supplies.

I believe we have met those commitments.

The Forest Service worked with the State to develop and apply best management practices for maintaining and improving the quality of water resources on the National Forests, and National Forest Land and Resource Management Plans provide for protecting water quality and increasing yields where practical.

CONCERNS FOR THE FUTURE

We have met the requirements for water quality and water yield so far. But what are the major concerns for the future?

Meeting The Demand For More Water

The State's population is expected to increase to more than 35 million by the year 2000, and annual water use is expected to rise to more than 50 million acre-feet.

We cannot substantially increase the available yield to meet the likely increased demand, and further development of existing water resources on both public and private land is becoming very questionable due to special land designations, rising costs, and increasing concern for the cumulative effects of land management activities.

Furthermore, access to a substantial part of surface runoff water is restricted by law. About 25 percent of the total 70 million acre-feet of stream runoff is in the Eel, Klamath, Van Duzen, and other rivers protected from development as State and Federal Wild and Scenic Rivers. It also seems unlikely that large transfers of water from outside the State will occur. The recent loss to Southern California of about 800,000 acre-feet of water from the Colorado River to Arizona suggests outside sources may in fact be reduced.

Consequently, the supply of water in California will remain pretty much at current levels, although some practices, such as vegetation manipulation, snow pack management, and artificial recharge of ground water reservoirs may yield modest increases in supply or delay the timing of flows to make more water available for local use.

For these reasons, the cost, allocation, and use of water will remain controversial in the decades ahead.

Protecting Nonconsumptive Uses of Water

If we attempt to increase use and withdrawals of available runoff and ground water for consumptive uses, we must carefully consider likely effects on nonconsumptive uses of water. Nonconsumptive uses include water for fish habitat, wildlife, recreation, and scenic beauty, and to maintain fragile ecosystems such as riparian areas, wetlands, and marshes. Such uses are of particular concern to those of us who manage public lands for multiple use benefits.

A familiar example of the potential for conflict between consumptive and nonconsumptive uses is the decline of salmon and steelhead trout habitat for spawning. These anadromous fish once migrated from the ocean up coastal rivers throughout California, providing both recreational and commercial fishing. Construction of dams for hydroelectric power and water storage and withdrawals of water for agricultural and urban uses reduced anadromous habitat from 9,000 to 4,500 miles of stream and the annual migration from 1.2 million to 430,000 fish.

Protecting Water Quality

Water supply shaped past development in California, but water quality is likely to be the leading issue shaping future development within the State.
Potential adverse cumulative effects on water quality are expected to determine the extent of allowable development and management in watershed. Concern for cumulative watershed impacts has already begun to affect National Forest management, especially in areas where lands are in mixed ownership and are managed for different resource objectives. A number of timber sales have been held up because management on adjacent lands in other ownerships may have exceeded allowable limits of impacts on the affected watersheds.

The allowable disturbance that can be permitted within a watershed should be shared by all landowners. No one landowner would then be allowed to take so much of the total permitted disturbance as to exclude other landowners from their fair share of management activities.

INTEGRATED SOLUTION TO THE ISSUE OF WATER USE AND MANAGEMENT

Given the challenges facing us, we need an integrated approach to future use and management of water resources. I think such an approach requires four basic elements.

First, we need to find ways to measure and control cumulative impacts on watersheds caused by various developments and uses. Use of best management practices and cooperation between public and private land managers in applying them can contribute to this objective.

Second, we need to encourage wise use and conservation of water resources. Wasted water is our greatest reservoir. During the 1976-78 drought, for example, users reduced consumption by as much as 20 percent in some areas. This indicates the significant contribution water conservation can make to insuring adequate supplies for beneficial uses.

Third, we need a reasonable and acceptable balance of priorities, cost, allocation, and use of water resources to insure fair access to water supplies. We all share the need for an adequate water supply, and we all benefit from the many uses of water throughout the State. Cooperation rather than competition for water will be the most productive approach to solving issues in the future.

And finally, the State Legislature should reassess the policies and regulations that govern distribution and pricing of water and set water quality standards to be maintained. Such revision and updating of water policy should insure consistency and fairness in applying standards on public and private lands. Policy for the use of groundwater resources in the State also is needed.

The Forest Service is ready to work as a partner to develop water policy and to manage National Forest water resources to contribute to the quality of the environment and the future well being of the people of California.

This conference is a step toward the kind of cooperation needed to meet the challenges before us.

Thank you very much.

ACKNOWLEDGEMENTS

I thank Andrew A. Leven and John R. Rector, Forest Service, U. S. Department of Agriculture; California Water Atlas; PSW Regional Guide; State Water Resources Control Board and Department of Water; Resources Statement of Policies and Goals for California Water Management; and numerous magazine and newspaper articles for contributing data.
Conference Evaluation and Recommendations

Roger R. Bay

The Evaluation Committee thanks the many participants for their excellent suggestions and constructive comments concerning the various sessions.

In general, participants' comments on the sessions have been very positive. Such words as "good speakers", "interesting and timely topics", "well organized", and "moved along well" appeared in many of the comments. Further positive comments were "thought provoking", "stimulating", "excellent format". Many people liked hearing about not only what works in the field of watershed management, but also what fails. A number of the speakers were open and frank when discussing their successful and not-so-successful field projects.

We also had a number of good comments about the exhibits. Participants appreciated having exhibits available during the days of the meeting. Exhibitors seemed to appreciate the break-periods when attendees were able to spend time viewing displays and discussing mutual interests.

In general, most people saw this conference as a major opportunity for people with watershed interests to come together and discuss key topics—an opportunity that people with these kinds of interests have not had in California.

SUGGESTIONS FOR IMPROVING FUTURE CONFERENCES

Participants had a number of specific suggestions on individual topics as well as the following general comments for consideration in the future:

2. Director, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California.

Use panels to cover controversial topics: this technique would stimulate both the speakers and the audience for questions and further discussion.

Hold small discussion groups after speakers' presentations to help develop additional points of view and to bring some type of closure to key subjects.

Arrange to allow more discussion and to better focus on issues and their resolution, and obtain some agreement on at least where we want to go.

Obtain better representation from other groups such as fish and wildlife interests, local governmental groups, and other kinds of policy groups.

Focus on only a few issues with in-depth discussions.

Everyone is looking forward to receiving the published Proceedings and urge the Steering Committee to see that the papers are published as soon as possible and, wherever possible, to include illustrations that were discussed by the speakers.

SUBJECTS FOR FUTURE FOCUS

The Evaluation Committee perceived a number of concerns about watershed management in California that the Steering Committee might wish to further consider:

Support is needed by top administrators and state legislators for improving water policy development, and for financial and legislative support of research, extension, and action programs in California.

Opportunities are needed to apply present technology aggressively in watershed management at all levels of management.

Some type of certification or credential program is needed, in the view of some, to assure high quality, professional
judgment in applying watershed management practices.

Further discussions and agreement are needed on best management practices and their field application.

Water yield increases and general water supply improvement are still topics of concern among many people.

Instream flows and management of riparian areas command significant interest.

One or more watershed demonstration areas are needed in California to bring together current knowledge and the management of this important resource on the ground.

SOME GENERAL RECOMMENDATIONS TO THE STEERING COMMITTEE

Although the above discussion contains a number of recommendations and suggestions for future conferences, the Evaluation Committee recommends to the current Steering Committee three general well-supported recommendations:

1. Hold another meeting in approximately two years; build on the interest now stimulated

2. Organize some kind of follow-up, or ongoing, steering or executive committee to be a focus for continuing the interest in California watershed management.

3. Develop a newsletter or other type of communication for those interested in watershed management.

On the basis of the many positive comments from participants, we commend the Steering Committee for organizing and completing a needed, well-run conference.
Best Management Practices for Water Pollution Control: A National Perspective

Frank M. Covington

(presented by Catherine Kuhlman)

Good afternoon. It is a very real pleasure to be with you today. The agencies and organizations represented here have been some of EPA's earliest and most steadfast partners. In many, many ways, your goals exemplify several of our own: Preserving and improving the quality of our environment—and thereby the quality of our lives.

The Environmental Protection Agency has been working towards that goal since its inception 16 years ago. And while we can now anticipate the end of significant conventional pollution from point sources, the end of water pollution is not nearly in sight. More than that, even when we have finished the major task of controlling toxic point sources, to which we are legally committed, the end will still not be in sight.

Over the past decade we have mounted an enormous effort to establish a system of industrial waste and sewage treatment facilities. We have avoided the catastrophe that threatened our waters and revived many lakes and streams that had been thought beyond help. But there is no denying that in recent years the curve of improvement has flattened out. The

Abstract: The purpose of this paper is to discuss the United States Environmental Protection Agency's proposed new policy statement which addresses the relationship between Best Management Practices (BMPs) for the control of nonpoint source (NPS) pollution and Water Quality Standards (WQS). The proposed policy statement basically conveys the message that each State establishes its own public-interest-oriented uses of its receiving waters and water quality standards. Then all sources of pollution, point and nonpoint, have to be managed to achieve or maintain those standards. In the case of nonpoint source pollution this is accomplished through the application of Best Management Practices.

1982 U.S. Fish and Wildlife survey showed, for example, that although 67 percent of the Nation's waters have at least a minimum ability to support sport fish, the situation had not noticeably improved during the previous five years. The 1983 Nonpoint Source Study by the Association of State and Interstate Water Pollution Control Administrators (ASWPCA) showed that in the decade since 1972, of 354,000 stream miles for which there was water-quality information, 13 percent had improved, 3 percent had gotten worse and the rest had remained unchanged.

In 1985, EPA sponsored a similar ASWPCA report titled, America's Clean Water: the State's Nonpoint Source Assessment. The California State Water Resources Control Board (SWRCB) participated in this report, which examined the effects of nonpoint source pollution on impacted waters within the United States—those waterbodies assessed by States to (a) already have impaired designated uses, and (b) be currently threatened by the continuation of nonpoint source pollution. From existing data these affected waters constitute:

- 11 percent of the total 1.8 million miles of rivers and streams;
- 30 percent of the total 39.4 million lake acres;

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

2 Director of the Water Management Division, U.S. Environmental Protection Agency, Region 9, San Francisco, Calif.
° 17 percent of the total 32,000 estuary square miles;

° 30 percent of the total 22,667 miles of ocean coastline.

It does appear that we are making progress against water pollution. With the increase in economic activity and population in those years, this must be considered an impressive accomplishment. However, the Clean Water Act set a deadline of July 1, 1983 for attainment of fishable and swimmable waters. We haven't yet achieved that goal in an unacceptably large proportion of our waterways. And it's becoming ever more clear that much of the reason for this is our failure to adequately control nonpoint source pollution.

So, while we at EPA continue to implement the major point source efforts embodied in our municipal policy and in toxics control requirements, we have only just begun to place increased efforts on nonpoint source controls. The purposes of the management of point sources and nonpoint sources of water pollution are the same: to enable receiving waters to achieve water quality standards. Actually, both sources can carry the same pollutants. They both contribute to the Nation's surface waters and both are part of EPA's continuous, overall water quality assessment process. The major difference is how the pollutants are transported to the receiving waters.

From a water quality standards point of view, there is no difference between the pollution which comes from point sources and which comes from nonpoint sources. It's the quality of the effluent or runoff that impacts the receiving waters that is the real problem. And, you can measure the quality of effluent and runoff against water quality standards.

Standards are the backbone of the basic elements of the water quality management framework established by the Clean Water Act. The Act states, that there shall be clean water, preferably fishable and swimmable; with State-promulgated water quality standards that define the public interest uses of the water. A standard for any waterbody includes designated beneficial uses, criteria that protect those uses and provisions for antidegradation. Each State establishes standards and uses for its receiving waters, and then all sources of pollution have to be managed in order to achieve or maintain those standards and uses for its receiving waters. Then all sources of pollution have to be managed in order to achieve or maintain those standards. In the case of nonpoint sources this is accomplished through the application of nonpoint source controls, including best management practices.

EPA is currently developing guidelines for State Water Quality Management Agencies which will address water quality standards in relation to the control of nonpoint sources of pollution and the relationship between standards and best management practices. Actually, this guidance will update an earlier EPA nonpoint source policy statement, "SAM-32" issued in November, 1978. The new policy will remain completely consistent with the 1978 statement.

The guidance is being prepared through a work group operating under the Federal Interagency Task Force on Nonpoint Sources of Pollution. The group includes all of the Federal agencies that manage public lands, many of the USDA agencies that deal with farmers, as well as special interest groups such as the American Paper Institute, the National Forest Products Association, the Society of American Foresters, and the Fertilizer Institute, to name a few.

Representatives of U.S. Forest Service's Pacific Southwest Region 5 have been active participants in the process. EPA considered their participation to be essential especially since they were key players in recent environmental issues such as the G-O Road litigation and the development of a model working relationship with the California State Water Resources Control Board during the 208 Program on water quality management. The Planning and Management Agency Agreement forged between the Board and the Forest Service's Region 5 have been touted as National models of State-Federal cooperation. The Handbook of Best Management Practices for Water Quality Management Planning has proven to be a necessary tool for environmental protection on National Forest watersheds in California.
During the process of developing the new guidance it is clear that not all of the groups I mentioned were in total agreement with EPA on all of the points covered. I do think it is fair to say that they understand where EPA is coming from as well as the reasons and basis for its policy positions. In the process EPA is listening and learning a great deal from the participants.

Let me now talk a bit of the process of applying NPS controls. In the design of NPS controls and the application of their best management practices, instantaneous achievement of water quality standards is not expected. The guidance suggests an iterative process because of the inherent complexities involved in the management of nonpoint sources and the realization that in some cases the BMPs and other controls might have to be adjusted. If one approach doesn't work, something new will have to be tried. The iterative approach is based on the performance of the chosen BMPs. Does monitoring of the performance of the controls indicate that water quality standards are being achieved or not? The proposed guidance provides that the implementation of BMPs and other NPS controls is presumed to result in compliance with water quality standards unless subsequent evaluations indicate otherwise.

The need for flexibility in NPS management was also recognized in writing the guidance, particularly when working with a largely unpredictable natural environment. Language has been included suggesting the use of measures other than fixed numerical criteria to gauge water quality standards violations and their effects. Narrative criteria, biological assessments, and other on-site evaluations are suggested.

Perhaps gaining a common understanding of the term "feasible" relative to the application of nonpoint source controls in Section 208 of the Clean Water Act was one of the more troublesome things to work out in writing the guidance. The Clean Water Act does use the term "to the extent feasible" in speaking of the application of controls to nonpoint sources. The Act also establishes a mandate for clean water, establishes the swimable and fishable goals for the Nation's waters and provides for the States to set water quality standards.

While EPA accepts the fact that in NPS management certain BMPs could be found to be infeasible in any particular situation for any number of reasons, EPA cannot accept the fact of "infeasibility" to be defensible grounds for persistent violations of water quality standards. The Act does not say that polluted water is to be tolerated if control actions are found to be difficult. The Act does say that impacting waters so that they do not meet State established water quality standards is unlawful under State law. If water quality cannot be assured, where there have been persistent and continued violations, and/or where NPS controls are found to be infeasible, the State may have to impose its regulatory sanctions, including the issuance of orders for cleanup and abatement or, if necessary, orders to cease the activities causing the violations. Such extreme actions are very necessary, but rarely used, being reserved for clear and persistent violations.

The process of managing nonpoint sources of pollution is a complicated one at best. We have been at it for the 14 years since passage of the original Water Pollution Control Amendments of 1972, and we are still on the lower reaches of the learning the curve but, I suggest, gaining needed understanding daily.

Neil Sampson, who is Executive Director of the American Forestry Association, delivered a very thoughtful paper in July of this year, titled: "Nonpoint Pollution -- What Works?" He said three things in that paper that warrant highlighting here:

First, he indicated that nonpoint source pollution problems vary:

... technical solutions are often linked to the specific land and water situations involved and there are many cases where the leadership of a certain individual seemed to be the key to success.
Secondly, he said: "...the more your problems are technical or financial in nature, the more likely you are to find workable solutions."

Finally, he came to what I have come to believe lies at the heart of successful nonpoint source management over the long term:

... If you happen to have a situation where the major roadblock to controlling nonpoint pollution is the need for money to install engineering practices, you have it easy. As much as we grouse about the expense of pollution controls, we find the money for them fairly readily. It is where you have a situation where basic patterns of land use and management must change that you have it difficult. Replacing old social and cultural patterns with new ones is incredibly slow and difficult...

The successes in cleaning up water pollution have, indeed, come where there has been available a combination of engineering technology and money to build sewage treatment plants to manage point sources of pollution. The politically arranged institutions, the cities, counties and sewer districts, were largely in place to utilize the technology and manage the money.

We frequently don't have the same cultural traditions, history or even the widely accepted technology to draw upon in the management of nonpoint sources. Like it or not, as Neil Sampson indicated, we are in the business of "replacing old social and cultural patterns" in the management of nonpoint sources of pollution, seeking changes in basic land management in the interests of clean water.

In recognition of these facts, and the further recognized need for a stronger approach to the control of nonpoint sources, the Congress wrote a new Section 319 into the proposed Clean Water Act legislation, to specifically deal with the management and control of nonpoint sources of pollution. The legislation is part of the Clean Water Act. It passed both houses of Congress only to be vetoed by the President.

If this legislation becomes law during the next Congressional session, the States will have a modest amount of money to address their nonpoint source problems. But, there's more.

New Section 319 speaks forthrightly of using best management practices, "to assist, encourage or require the implementation...thereof." This is a major shift in emphasis for the States. Under the new Section 319 a BMP becomes a State tool in the use of which the State determines how and to what extent it will assist, encourage, or require. To put it differently, the State will determine which BMPs it will assist, which it will encourage and which it will require...and, in each case, how it will go about assisting, encouraging and requiring.

This places the States out in front, pro-actively developing controls and measures to manage nonpoint sources.

As of now, it's anyone's guess as to what the Congress will do about the reauthorization of the CWA, or whether or not the President would even sign a revised bill. I mention the new legislation here only to point up that there is new thinking going into nonpoint source management. Our management ability will continue to grow so as to match the size and the complexity of the problem. We will continue to search for new ways, new techniques, new methods of communication, and yes, some new nonpoint source political science to do this.

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America's clean water.


California's Program to Control Nonpoint Source Water Pollution

Danny Walsh

Thank you very much. I am happy to represent the State Water Resources Control Board and tell you about the Board's nonpoint source control program. When Don Maughan, our Chairman, asked me to speak to you today, I'm sure he realized that in this gathering of mostly Northern Californians, I would be one of the most northern. I am from Eureka. I graduated from Humboldt State, and I share with you the concerns about the present and the future of watershed management in California.

California is a large and complex state—large and complex in terms of its geography, with mountains, valleys, and deserts covering both the highest and lowest points in the contiguous 48 states. It has a large and complex economy, eighth largest in the world. Its population is large and complex; it is the most populous and ethnically diverse state in the country. California is a land of contrasts, from the steep, heavily forested mountains of the North Coast, with abundant rainfall, to the seasonally hot and dry Central Valley, and the deserts which may go years on end without seeing a significant rainfall.

California's size is so great that we who live and work in the northern part of the State sometimes forget that we are outnumbered by those who "stop and go" their way to and from work on Southern California freeways. The Southern California majority of our population usually sees our northern rivers and forests from the family car during a vacation or a long weekend. Despite the distance and the differences between Northern and Southern Californians, all share a common concern about the quality of our State's water and the protection of its beneficial uses.

California has over 1,800 miles of coastline, more than 1,000 rivers and streams, 5,000 lakes, and about 460 ground water basins to protect. Growing population, industry, and agricultural activities make our job of protecting and enhancing the quality of California's water more difficult and increases the competition for available water.

The regulatory control of water quality in California is based on the Porter-Cologne Water Quality Act, passed by the State Legislature in 1969. The Act declares that "all the waters of the State shall be protected for use and enjoyment by the people of the State" and that "the State must be prepared to exercise its full power and jurisdiction to protect the quality of waters in the State from degradation..." Porter-Cologne greatly strengthened the water quality enforcement powers of the nine Regional Boards, originally established in 1949, and the State Board, established in 1967.

The State Board determines budgets and grant outlays, establishes and administers statewide regulations, policies and programs, reviews actions and inactions of the Regional Boards, and approves Regional Plans and Policies. The Regional Boards function as relatively autonomous entities, each formulating regional water quality control plans, known as Basin Plans, as well as directly regulating thousands of waste dischargers. The Regional Board Basin Plans were approved by the State Board and the U.S. Environmental Protection Agency in 1975-76 for all State waters. The Basin Plans are reviewed and revised by the Regional Boards, incorporating appropriate public input, during the Triennial Review Process.

California has made much progress in cleaning up its waters; however, much still remains to be done.

Point source problems have been the primary focus of water quality programs in California over the past 30 years. Progress has been made in cleaning up the most severe point source pollution problems. In fact, pollution control of point sources has been so successful that in the past 10 years nonpoint sources have emerged as the major contributors of pollutants.

Common types of nonpoint source pollutants include silt and sediments, salts, pesticides, toxicants, and nutrients. Silts and sediments, although not sharing the highly toxic nature of many urban and agricultural pollutants, are...
probably the most common watershed pollutants and have the most obvious impacts on streams and rivers. Sedimentation reduces the productivity and esthetic quality of streams and may adversely affect municipal water supplies. Nonpoint source pollution most often comes from road construction, homesite development, urban runoff, logging, grazing, abandoned mine drainage, agricultural drainage, and industrial operations. Due to their nature, nonpoint source problems are difficult to identify and address and more difficult to solve. Nonpoint source problems are widespread and are usually a product of land use activities. Solutions often involve alteration of land use practices. Changing these practices in order to reduce pollutants often requires social, economic, political, and environmental trade-offs. By definition, nonpoint source pollutants do not originate from a point source such as a pipeline discharging to a river, and thus do not lend themselves to easy treatment before entering the environment. This results in a dilemma for the Regional Boards, which commonly control the discharge of pollutants by the issuance of waste discharge requirements or permits.

To address nonpoint source pollution, the Federal Clean Water Act called for the preparation of Areawide Waste Treatment Management Plans or "208 Plans", referring to Section 208 of the Clean Water Act. The 208 Plans involve problem identification and developing Best Management Practices (BMPs) by local, State or Federal agencies. Federal regulations define BMPs as methods, measures or practices selected by an agency to meet its nonpoint source control needs. BMPs include, but are not limited to, structural and nonstructural controls and operation and maintenance procedures. BMPs can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters.

Established State Board policy calls for nonpoint sources to be controlled to the extent practicable. It also states that nonpoint source controls are the responsibility of individuals with land management responsibilities, and Federal, State and local agencies. Local agencies, such as county governments, often develop and implement BMPs involving land use controls through local ordinances and land use permits. Preferably, such controls are to be implemented through land use activity BMPs, but if BMPs fail, then controls may be achieved through waste discharge requirements or other regulatory actions.

Correction of most nonpoint source problems require the use of management and nonstructural techniques rather than technical or structural solutions that might be used on point source problems. A nonpoint source control strategy must overcome three problems.

First, the technical hurdle. Nonpoint pollutants are often difficult to locate and monitor. The source and the observed water quality problem are often hard to correlate because the impacts are usually separated in time and space from the source. Transport mechanisms which link sources and observed impacts (usually through flowing water) are often poorly understood. This also makes it hard to assess the effectiveness of BMPs developed to address the problems.

The second problem is the wide variety of possible control techniques (BMPs) for each type of nonpoint problem and the lack of any organized, established implementation and funding mechanism.

The third problem is that nonpoint sources are not amenable to existing regulatory approaches. Management techniques often involve land use controls which are politically controversial because they sometimes limit the uses of private property. Usually, the local agencies with authority to control land use practices are not primarily involved in protecting water quality.

Typically, point source effluent controls and limitations leave operation methods fairly open. For nonpoint source control, the shift to land use BMPs often defines specific land use operations, and administrators start to invade what tend to be sensitive issues of land use management, rather than simply defining or controlling the water quality resulting from the use. Since operations, rather than their effluent, are being controlled by BMPs, the land manager becomes the focus of the control efforts.

Another significant feature of BMPs is that they are often practices which are new, or at least different, from the present ways of doing things for many land use managers. BMPs may seem to be attractive solutions to nonpoint source problems and may even make common sense, but they still haven't become heavily used since passage of the Clean Water Act over a decade ago. Some of the delay is due to legal and administrative problems, but much of it is due to sociological or economic problems. Sometimes land managers do not realize or may not want to acknowledge that their operations can create nonpoint source problems. They feel problems are occurring because of other operations and not their own. At times, conservation costs associated with BMPs may appear to exceed benefits, especially if all associated benefits are not considered.

Under the authority of Section 208 of the Clean Water Act, the State Board has designated some agencies as water quality management agencies for their respective areas of the State. Some examples are the Association of Bay Area Governments, San Diego Association of Governments, and the Association of Monterey Bay Area Governments. In 1979, the State Board designated the U.S. Forest Service as the water quality management agency for all National Forest Systems lands in California. At the same time, the State Board
certified over 90 Forest Service management practices as BMPs. Other Forest Service management practices needing improvement or development are still in the process of implementation.

In 1981, the State Board entered into a Management Agency Agreement with the U. S. Forest Service. The Agreement calls for the Forest Service to develop and implement additional BMPs, to facilitate early State involvement in project planning and review, and to provide periodic project site review. The general experience of the State and Regional Board staffs indicates that the U. S. Forest Service BMPs, when properly administered, have generally proven to be effective, practical and feasible measures for controlling nonpoint source water pollution.

Any planning effort, in order to be successful, must periodically evaluate what progress has been made and determine what needs to be done to successfully accomplish the objectives and goals that spell success. The State Board is now asking--where are we now and where are we going?

The 208 nonpoint source management planning effort began in California in the mid 1970's, with funding expiring in 1981. Despite the inherent weakness of the 208 program from its failure to provide for the implementation of developed BMPs, there were some major accomplishments under 208. These include sediment control around Newport Bay, effective urban erosion control in the Monterey Bay area, the development of BMPs by the Forest Service, and the initiation of the Tomki Creek watershed restoration project in Mendocino County. In hindsight, however, the 208 program was essentially a learning experience for all agencies involved. The 208 program was a first attempt to deal with a large, complex, and poorly understood problem. The 208 program provided a starting point for nonpoint source management in California. It resulted in improved problem documentation and greater expertise on the part of State and local agency staffs.

In a side note, one 208 project with which many of you are probably familiar is the evaluation and revision of the State Board of Forestry rules as BMPs. This evaluation was begun under the old 208 program. The revised Board of Forestry rules were submitted to the State Board and considered for certification as BMPs at a public hearing in 1984. Certification of the rules is still pending, awaiting the results of the Statewide Forest Practice Rules Assessment Project. The results of the assessment of the Board of Forestry's Forest Practice Rules are scheduled for consideration at a State Board public hearing in March 1987.

The 208 program at the State Board has been replaced by another water quality planning program which is funded under Section 205(j) of the Clean Water Act. The 205(j) program contains improvements over the 208 program, including increased sophistication in selecting, designing, and managing projects, and more direct State control over the program. But, as with the old 208 program, projects are selected by choosing among submitted proposals. We still have not inventoried, evaluated, and prioritized problems statewide to guide funding.

The State Board's current process for allocating resources to study nonpoint source problems thus consist of competitive evaluation of 205(j) proposals and direction of available staff and funds to particular high visibility problems. Allocations reflect the narrow priorities of individual project proponents and the demands of immediate "brush fire" situations.

We need a more systematic approach to nonpoint sources. The State Board is now beginning a project to build at least the foundation of a comprehensive statewide strategy for nonpoint source management. The objective of the project is to initiate a systems-type approach to managing nonpoint source pollution on a statewide level. The project will be somewhat broad-brush, but it will be more detailed and comprehensive than anything available to date. The two-year project will inventory and characterize nonpoint source problems, create a computerized data base, develop a ranking system, identify high priority projects, and recommend general management strategies.

We need greater coordination between the planning, assessment, and implementation activities that the State and Regional Boards and other agencies carry out in attempts to solve nonpoint source problems. Nonpoint source problems are inherently difficult to quantify, but we need to get better numbers to enable us to assess impacts and evaluate progress.

We need to target the serious nonpoint source problems within the context of an overall strategy, based on reliable, unbiased problem assessments. Future projects should incorporate specific water quality goals and post-project evaluation. And finally, in the nonpoint source problem areas where there are overlaps in agency responsibilities, we need to open up communications to develop interagency strategies for targeting and solving problems on a more site-specific watershed basis.

To assess and target nonpoint source problems, to open communications, and to establish greater coordination among concerned agencies are attainable goals for all of us. But it will take all of us, Federal, State, and local agencies and organizations, working more closely, to realize these goals.
Water Quality Protection on National Forest Lands in California

Andrew A. Leven, John R. Rector, Robert D. Doty

The United States Department of Agriculture Forest Service administers approximately 20 million acres of Federal lands (20 percent) in the State of California. Over 72 million acre-feet of surface runoff occurs annually in California. Over half the annual runoff, 37.5 million acre-feet, comes from National Forest Service lands. Clean water from these lands is vital to the state's vast water supply systems, maintaining the productivity of coastal rivers for fisheries, recharging of underground aquifers and numerous sport and recreational instream uses, and use activities on the National Forests have a direct influence on the quality of water used by millions of Californians for their domestic, industrial, recreational, and agricultural purposes.

HISTORICAL DEVELOPMENT OF THE PROCESS

Federal and State Legislation

Federal legislation specific to water quality began in 1956 with the Federal Water Pollution Control Act. The most significant change came with the passage of the Clean Water Act in 1970, in which Congress directed and empowered states to control sources of water pollution. Section 208 of the Act directed that states develop Areawide Waste Treatment Management Plans for water quality control, including the control of nonpoint sources of pollution.

In 1970, the State legislature approved the Porter-Cologne Water Quality Control Act, which gives authority for administration of the Federal Clean Water Act to the State Board and the nine Regional Boards. Thus, the State Board became responsible for development of 208 Areawide Waste Management Plans. This planning effort began in 1973 and dealt mainly with nonpoint sources of pollution.

Abstract: The Federal Water Pollution Control Act, as amended by the Clean Water Act of 1970, directs states to develop Areawide Waste Treatment Management Plans for water quality control, including the control of nonpoint sources of pollution. To carry out the requirements of the Act, in regard to nonpoint sources from forestry activity, the State of California and the USDA Forest Service entered into an agreement to develop a control strategy. This control strategy utilizes best management practices (BMPs) as a mechanism to prevent, mitigate, and/or correct water quality problems. This strategy has evolved into the Forest Service water quality management plan, which encompasses training, development, and refinement of BMPs, a BMP handbook, implementation of BMPs in various management activities, and monitoring of the application of BMPs.

Development of State/Federal Cooperative Relationship

The principal target for nonpoint source planning in California has been sediment. Working with the USDA Forest Service, Resources Conservation Districts, the California Department of Forestry, various local governments and others, the State Board sought to develop best management practices to control erosion and to reduce the effect of sediment and turbidity from controllable activities of man. The goal has been to protect public water supplies and fish and wildlife habitat.

In 1977, under the general authority of Section 208 of the Federal Clean Water Act and the State's Porter-Cologne Act, the Forest Service entered into a cooperative agreement with the State Water Resources Control Board to develop a Water Quality Management Plan for National Forest System lands in California.

Water Quality Assessment

An interdisciplinary team was assembled by the Forest Service to conduct a water quality problem assessment, and to identify the internal agency controls which prevent, mitigate, and/or correct water quality problems. Existing management practices were identified from Forest Service manuals, handbooks, design specifications and guidelines, contract and permit provisions, and policy statements. These practices describe required procedures, methods or techniques, and/or management actions that would abate or mitigate nonpoint source pollution from Forest Service lands. Once it was compiled, the nine Regional
Boards facilitated the review of the Forest Service Water Quality Management Plan through their public hearing process.

Two years of coordinated effort culminated in the identification of 98 management practices. After extensive public and Federal/State agency review, these practices and procedures for control of water quality impacts were certified by the State Board and approved by EPA. Upon certification as best management practices (BMPs) by these two entities, they became the means through which the Forest Service is expected to maintain and improve water quality.

Management Agreement

In March 1981, the Forest Service and the State Water Resources Control Board entered into a Management Agency Agreement (MAA) expressing a desire to achieve several mutual goals. Among these are (1) attaining the goals in the Federal Water Pollution Control Act, (2) minimizing duplication of effort through coordinated pollution control program, (3) implementing Forest Service legislative mandates for multiple purpose management and sustained yield consistent with requirements for environmental protection, and (4) assuring control of nonpoint source water pollution through implementation of best management practices.

The Forest Service agreed to implement best management practices, facilitate early State involvement in project planning, provide periodic project site review, and review the BMPs annually and update them as necessary.

The Forest Service also agreed to schedule improvement of existing management practices and development of new ones that were identified in the 208 planning process.

The State agreed that the Forest Service BMPs did constitute sound water quality protection and were consistent with attainment of River Basin Plan Water Quality objectives and standards; that reasonable implementation of BMPs constitutes compliance with substantive and procedural requirements of State Clean Water law; and that issuance of waste discharge requirements for nonpoint source discharges would be waived by the Regional Boards as long as the Forest Service reasonably implemented BMPs.

FOREST SERVICE WATER QUALITY MANAGEMENT PLAN

The Forest Service Water Quality Management Plan, as published in 1979, documented the completion of the major tasks originally specified by the State/Federal cooperative agreement. The Plan included an assessment of the existing nonpoint pollution problem areas on each of the National Forests, the compilation of the best management practices themselves, and a description of management practices which needed further refinement or development before they could be recommended by the Forest Service to the State Board and EPA as BMPs. The plan initiated programs needed to further develop and refine these practices.

In the Plan, the 98 best management practices are grouped by management activity as follows: (1) Timber, (2) Road and Building Site Construction, (3) Mining, (4) Recreation, (5) Vegetative Manipulation, (6) Forest Suppression and Fuels Management, (7) Watershed Management, and (8) Grazing. A detailed reference section is also included as an appendix to the BMPs. This section is used by forest managers to identify the specific Forest Service documents in which more detailed implementation direction may be found relating to an individual BMP. This appendix is updated semiannually.

Uniqueness and Flexibility of BMPs

The purpose of the BMPs is to enable the Forest Service to protect water quality while meeting other resource goals. The primary pollutants generated by logging, road building, and recreation on Forest Service lands are sediment, elevated temperature, nutrients, and bacteria. These same pollutants occur naturally. Therefore, the actual effects of nonpoint source pollution resulting from land use management activities are often difficult to distinguish from the ambient condition. The magnitude, duration, and severity of the pollution varies as a function of the type of management activity, the timeframe over which the activity occurs, and the physical environment within which the activity takes place. All of these factors vary from National Forest to National Forest, and from site to site throughout the State of California. It follows then, that if the extent and kind of contaminants are variable so also must the control measures vary. No given abatement or mitigation method or technique will best suit all circumstances.

The Forest Service's BMPs are designed to be flexible enough to take into account variable project site conditions and management activities. The site-specific water quality prescriptions, specifications, designs, etc., that affect implementation of the BMPs are developed by professional personnel during project environmental assessments. Interdisciplinary team interaction results in the identification of the water quality protective measures tailored to the specific management activity and site.

BMPs are process oriented in that they initiate planning, field investigation, and coordination activities prior to conducting a project, and describe the evaluation and monitoring to be conducted during and after project.
implementation. BMPs are not intended to be the specific mitigation or corrective measures that are applied on-site to protect water quality. They are the action-initiating mechanisms that result in the corrective or preventive measures being identified for a specific site. The procedure for employing BMPs is closely linked to the Environmental Assessment (EA) conducted to evaluate projects.

**Application of BMPs**

There are four basic phases in the application of BMPs. Phase I is the project feasibility phase. Water quality concerns are identified and appropriate BMPs are selected. Phase II involves field investigation for site-specific conditions that will dictate specific measures for controlling nonpoint pollution. An interdisciplinary team prepares an environmental analysis which serves as a guide for site-specific BMPs that are included in project plans, contract clauses, and so on. In Phase III the BMPs are applied during project operation. Phase IV includes the monitoring and evaluation of the BMP measures.

Regional Water Quality Control Board review is present throughout the four phases of BMP application. The most intensive review is made of environmental analysis and project plans.

Because of the wide variety of activities on National Forest system lands, such as timber harvest, reforestation, road construction, ski slope operations, grazing, electric power lines, control burning, etc., knowledge and commitment for applying BMP to protect water quality varies. Proper application of BMP is, of course, the key to control of nonpoint source water pollution. Monitoring of activities in Phase I and II gives an indication of how well BMPs are being used in the planning process. Visual monitoring is conducted to determine if BMPs were or were not applied during Phase III. Visual observations and water sampling are also conducted to determine the effectiveness of BMPs to prevent nonpoint source water pollution.

Forest monitoring and Regional surveys of BMP application indicate that understanding and acceptance of best management practices is increasing among Region 5 employees. This is resulting in implementation of BMPs and successful protection (or enhancement) of water quality. The forests do an outstanding job of BMP implementation when there is strong citizen interest (herbicide application), strong, well-enforced contract provisions (timber administration); or strong earth scientist participation (watershed restoration).

The key to successful implementation in all areas is well trained personnel.

There are problem areas. To generalize, BMP implementation is weak in reforestation, mining, grazing, and dispersed recreation. Problems develop when project implementors do not, for whatever reason, enforce permit and contract provisions or fail to follow mitigation measures identified in environmental analysis.

A major cause of problems in applying BMP is the transferring of mitigation measures from the planning stage to the project plan and implementation on the ground. The failure to complete this essential step was common to nearly all function areas, but was especially true when planning time frames were long, or project responsibility changed hands. This failure suggests the need for a checklist to track BMPs from recommendation through implementation.

Another shortcoming common to all functional areas was inadequate monitoring. Review of results on the ground is essential to determine whether BMPs prescribed for water quality protection were successful and to make needed improvements. This shortcoming has contributed to reduced budgets and human resources.

**Land Management Planning**

Water quality management is also an integral part of the Region-wide Land and Resource Management Planning effort. The National Environmental Policy Act and the National Forest Management Act guide and direct these planning efforts. Alternatives for land management are not to be formulated if mitigation is unfeasible or if alternatives would knowingly violate laws and regulations. As such, Forest plans have an understood mandate to maintain, and where practical, improve the quality of water. These plans become the mechanism through which the water quality management programs of BMPs is integrated into land management programs. The plans allocate the 20 million acres of National Forest System land to various management activities, and identify the commodity and amenity goods and services that will be produced. From a water quality perspective, the modeling and planning premises are (1) that only land suitable for accommodating disturbance without adverse impacts to water quality is being disturbed, and (2) the intensity, duration, and extent of the disturbance is limited to levels that are consistent with the land's ability to assimilate the disturbance without impacts to water quality. In short, model analysis is conducted in such a manner that linear program constraints applied will control the location, amount, and timing of land use in a manner that will not affect water quality.
IMPLEMENTATION PROGRESS

Training

Since 1982, approximately 1600 Forest Service employees have been trained in the concepts and use of BMPs. A master standardized training program was developed for individual forests to train employees at all organizational levels in water quality management. The program consists of three basic modules—an introductory module for all employees; a legislative-legal module designed for Forest Supervisors, District Rangers, and management staffs to provide information on responsibilities; and a third module for individuals responsible for applying BMPs in everyday resource management projects, such as timber harvesting, road construction, and range management.

Development and Improvement of BMPs

The 1981 Management Agency Agreement called for the Forest Service to improve BMPs for pesticide management by completing a handbook on the aerial application of herbicides; for stabilization of road prisms and soil disposal areas; minimization of sidecasting; closure or obliteration of temporary roads; administering the terms of the US mining laws; and tractor windrowing on the contour. Additional BMPs for cumulative watershed impact was identified as needing to be developed.

Because of the serious concerns over the effect of pesticides in public drinking water supplies, the State and Regional Boards with the Forest Service jointly conducted an intensive monitoring program to reassess the effectiveness of seven pesticide application BMPs. The monitoring program demonstrated that the pesticide application BMP enabled the Forest Service to meet the State Water Quality Standards for pesticides. The pesticide application BMPs were certified in 1983.

The Forest Service completed work on all BMPs scheduled for improvement, except the BMP for tractor windrowing on the contour. The BMPs for stabilizing roads, sidecasting, and closure of temporary roads were certified in 1983. The BMPs for cumulative watershed effects and for administering the terms of the US mining laws are nearing completion. The BMP for tractor windrowing on the contour is in the first stages of development and will probably be completed in 1987.

Watershed Restoration Work

In the past 5 years over $3.3 million dollars have been expended to correct nonpoint source water pollution problems on 6000 acres of deteriorated watershed lands throughout National Forests in California. Approximately $1.4 of the $3.3 were spent in correcting problems in the Lake Tahoe Basin, which has the most active water quality improvement program in the nation. But we have not been able to proceed with correcting water quality problem areas identified during Section 208 planning as rapidly as we would like because of reduced funding. A recent inventory of projects needing attention to comply with environmental laws such as the Resource Conservation and Recovery Act, Comprehensive Environmental Response, Compensation and Liability Act, Clean Water Act, and Federal Insecticide, Fungicide, and Rodenticide Act, indicates that we have approximately 1100 projects requiring an estimated $57 million to correct. Of this amount, $37 million alone is required to correct nonpoint source problems that are resulting from erosion. Some of the more complex and perplexing problem areas are abandoned mine wastes that are contributing both sediment and acid drainage to stream flows.

Monitoring

Monitoring is being conducted on National Forests in California to determine if BMPs are being used in the planning and implementation of projects. Monitoring intensity ranges from review of planning documents and visual observation of projects on the ground, to water sampling in streams near projects. Except for pesticide application projects, most of the monitoring to determine the effectiveness of BMPs has been visual. The Lake Tahoe Basin Management Unit has the most intensive water sampling program in California relative to other National Forests. On the remaining 17 National Forests, the most intensive stream water sampling was related to pesticide application projects.

Regional Boards monitor implementation of project plans through field observations and input from local publics. When implemented activities are inadequate and there is evidence of nonpoint pollution, Regional Boards work with local National Forest offices to design appropriate mitigation measures that can be applied immediately to correct the situation causing nonpoint source pollution.

If performance in implementing mitigation measures is inadequate, that is, it is determined that BMPs are not being reasonably implemented, Regional Boards have the authority to issue Waste Discharge Requirement (WDR).

CONCLUSIONS

The State/Forest Service working relationship concerning water quality management in California is dynamic. Both agencies entered a Management Agency Agreement in 1981 that serves as the foundation for the relationship. The Forest Service's water quality management program has
established the framework for discussion and understanding. At least annually the two agencies meet to discuss program implementation status, discuss areas of mutual concern, resolve issues, and revise-update the MAA. Strengthened communication at the National Forest and State Regional Board level will further strengthen a sound relationship between the forest manager and responsible water quality agency.

Forest Service BMPs, compiled from internal agency direction, have proven to be the practical means for nonpoint pollution control. They reflect many years of Forest Service experience and they are implementable with presently available personnel and equipment. They are compatible with multiple resource management mandates. In employing internal mechanisms to control nonpoint source pollution, water quality management is readily accepted as a familiar means of land management by Forest Service employees as well as contractors and permittees. The effectiveness of the institutional arrangements used to develop and implement BMPs has been proven by subsequent results.

The Forest Service's BMPs will continue to be the standard of performance for Forest Service activities and nonpoint source pollution control. Our objectives for the future are to strengthen the working relationships through continued communication, coordination, and cooperation; to continue to yield water of unimpaired quality while managing the land for multiple uses and sustained yield; and to establish a level of mutual trust that will surpass regulation and enforcement as a means to maintain the quality of surface water in the State. All of the mechanisms are in place to make great strides toward these objectives.
Regulating Timber Harvest on Private Land for Water Quality Protection

Carlton S. Yee

California's forest resources are among the most valuable in the Nation. For 20 years California has ranked as one of the top three States in annual harvested volume of forest products. Over 42 percent of the State, 16.8 million ha (42 million acres) is forest land, an area larger than 30 of the 50 States. The forest lands produce over 70 percent of the annual water yield, on which California's agricultural and urban economies depend. Eight million ha (20 million acres) of this forest land is in private ownership and is subject to regulation by State forest practice rules whenever harvested commercially.

The subject of timber harvesting regulation and its relation to water quality and other environmental concerns has provoked heated political controversy in California for almost two decades. More than the usual animosity between the timber companies and environmentalists, fishing interests, and local communities reflects a basic disagreement about how the State's forests are to be used. Because California probably epitomizes the growing conflict of values at an urban/forest interface (Vaux 1982), California's handling of such political confrontations may inform other States facing this conflict in the future.


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Abstract: California's more than 16,800,000 ha of forest land make it one of America's top timber-producing States. To meet the mandate of the 1972 Federal Water Pollution Control Act, Sec. 208, the State of California, through the California State Board of Forestry and the California State Water Resources Control Board, has had to initiate significant institutional and regulatory changes. Regulation of forest practices in California on private timber lands is a complex process of rule-making, mandatory timber harvest permits prepared by State-licensed professional foresters, interdisciplinary review and approval of timber harvest plans by the State's Department of Forestry, and ongoing enforcement inspections during the operational life of the plan. In addition, the requirement that logging operators in the State be licensed adds leverage for rule compliance during logging.

This paper summarizes the history of the last 8 years involving the California State Board of Forestry and the California State Water Resources Control Board efforts to institute a silvicultural nonpoint-source pollution control program.

HISTORICAL BACKGROUND

The 1972 Federal Water Pollution Control Act (FWPCA) placed responsibility for water pollution control in forest management at the State level, with oversight and national administration by the U.S. Environmental Protection Agency. The FWPCA did not give EPA direct authority over control of pollution from nonpoint sources, but dictated that nonpoint sources of pollution had to meet State-developed water quality standards that were approved by EPA. These became known as Basin Plans (Gefrath 1984).

Although the FWPCA was probably one of the most complicated measures ever passed by Congress, the writers correctly assessed that nonpoint sources had to be treated by modification or elimination of practices that caused pollution. These best management practices (BMPs) were to be favored over "end of pipe" remedies so common to point source treatments. As a result, under Section 208, local governments were required to develop Areawide Waste Treatment Management Plans for both point and nonpoint sources of pollution. Also under this section, the governor of each State could require that agricultural, silvicultural, mining, and related nonpoint source activities become part of a State's control program. If the State assumed control of nonpoint source enforcement, any plan for control must include "...processes to (1) identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution, and (2) set forth procedures and methods (including land use requirements) to control to the extent feasible such sources."
Since FWPCA was passed, two California agencies have had an interest in regulating silviculturally related nonpoint sources, the State Water Resources Control Board and the Board of Forestry. California's 1967 Porter-Cologne Water Quality Control Act designated the Water Resources Control Board as the State's water pollution control agency for all purposes stated in the FWPCA. The Board of Forestry, on the other hand, was the forest practices rulemaking body, directing policy for the State's Department of Forestry, the enforcement agency for forest practice regulation. In 1976, sensing that a battle over regulatory turf would be best avoided, Governor Edmund Brown Jr. assigned the Federal-State coordination and contractual duties to the Water Resources Control Board, but allowed for that agency to subcontract to the Board of Forestry for development of a set of BMPs for silvicultural operations. The interagency agreement called for the Board of Forestry to review and revise rules relating to water courses and erosion control, erosion hazard rating, and silvicultural and cutting methods; to provide for increased public notice of harvesting operations; and to formalize an interdisciplinary review team procedure for timber harvesting permits. It was the State's intent to eventually certify the Board of Forestry as the agency designated to carry out the mandates of Section 208 on private timber lands.

In early 1979, the Board of Forestry set up a committee of its own and Department of Forestry personnel, industry and public agency foresters, other land use specialists, environmental organization representatives, and the general public to study forest practices as they related to water quality. They investigated whether the structure of mandatory timber harvesting permits and licensing professional foresters and loggers, along with an aggressive enforcement program, would provide an adequate framework for a BMP program. They also examined the changes required to correct potential deficiencies. This report was submitted in its final form to the Water Resources Control Board in October 1983. In March 1984, after lengthy hearings and much heated testimony, the Water Resources Control Board granted certification to the Board of Forestry for a limited term, 4 years.

Because the Board of Forestry study presented new rules and procedures, the Water Resources Control Board made certification contingent upon the development of a Monitoring and Assessment Program to evaluate the Board of Forestry program. However, by January, 1985, the 4-year Monitoring and Assessment program was put on hold because the probable cost was projected by the SWRCB to be more than $3,000,000. In its place, a one-year pilot assessment was proposed to determine if sufficient cause existed to go ahead with a full-blown 4-year study as originally specified. A 4-person team comprised of a SWRCB quality engineer, a CDF forester, a California Department of Fish and Game fisheries biologist, and an industry forester developed a study which is to look at 100 timber harvest plans, statewide, and report back to the SWRCB by March of 1987. At this time, a further hearing will be held to determine whether the 4-year study is still warranted or an unlimited certification will be granted.

THE CALIFORNIA PROGRAM—OVERVIEW

The California BMP program for forestry relies on more than just rules, even though the rules are acknowledged by most authorities as the toughest forest practices laws in the United States. California's program is an integrated process including legislation, administrative regulations, licensing of professional foresters and timber operators, and an active enforcement program. California chose an integrated process for three reasons:

1. A Site-Specific Process

Forested terrain in California varies greatly in physical features, site quality, vegetative species, and climatic factors. Ownership objectives and past logging history serve to compound these variations, making it very difficult to set narrowly prescribed standards for performance, like those used in regulating point sources.

Public concerns over timber harvesting are usually greater in more heavily populated forest areas. Considerations such as traffic, noise, and timing of logging become important, in addition to questions of water quality.

In response to the adverse environmental effects of timber harvesting, many mitigation measures are possible. However, practices that work in one place may not work elsewhere, may not be needed, or may even cause damage.

In view of the wide variety of conditions, the Board of Forestry chose to adopt general, flexible rules and then find a process to make them specific. This is an extremely important point and will be elaborated upon later in this paper.

2. A Mixture of Laws

The Board of Forestry operates under the Forest Practices Act, the Professional Foresters Law, the California Environmental Quality Act (CEQA), the Coastal Act (a coastal zoning law), the Wild and Scenic Rivers Act, and a variety of provisions in the State's Fish and Game Code, the Water Code, and the Government Code.

The Professional Foresters Law and a strong new Forest Practices Act went into effect in 1972-73. A court decision in 1975 held that provisions of CEQA applied to timber harvesting. Ultimately the concept of functional equivalency under CEQA was developed. Board of Forestry
rules and procedures were changed and certified as functionally equivalent to the environmental impact review procedures under CEQA for other types of projects. Multidisciplinary review of proposed harvesting operations was included.

Until 1978, the director of the Department of Forestry could require necessary mitigation measures under CEQA even if such measures were not explicitly spelled out in the Forest Practice Rules. However, in 1978, the Legislature mandated that the Board of Forestry set standards limiting the director’s use of discretion in requiring mitigation measures not included in the Forest Practice Rules. This mandate changed the types of general rules that could be used by the Board of Forestry and led to more emphasis on the procedures and the timber harvest plan review process to make the rules specific.

3. A Flexible Policy

California has the strongest law to license and discipline foresters in the United States. Foresters working for both the Department of Forestry and private timber companies and landowners are usually licensed or in training for licensing. Timber operators must also be licensed.

To harvest timber commercially for sale or exchange in California the registered professional forester must prepare a timber harvest plan. This document goes through an interdisciplinary review process and eventually contains specific enforceable conditions to protect the environment. These conditions interpret and make the Forest Practice Rules specific.

The Board of Forestry has adopted the philosophic premise that rules will be written rather generally and be made specific in the timber harvest plan. This is very similar to the practice of the U.S. Forest Service of adopting very general statements in policy and making them specific in technical manuals and handbooks. Recent rulemaking by the Board of Forestry has heavily emphasized the professional judgement of registered professional foresters. Less reliance is placed on prescriptive standards in rules to control loggers and more reliance is placed on the timber harvest plan.

Before harvesting, timber owners must have obtained a timber harvest permit prepared by a registered professional forester and approved by the director of the Department of Forestry. It is mandatory permit, analogous to a building permit, and it is a criminal offense in California to harvest timber commercially without one. Proposed permits are noticed publicly and reviewed by an interdisciplinary review team that may recommend acceptance of the plan with or without modification. It may also recommend rejection if suggested additional mitigation measures meeting the standards set in the rules are not incorporated by the submitting registered professional forester.

The Timber Harvest Plan Process

The complete timber harvest permit process in California is shown in figure 1. The process is broken up into three periods: the filing period; the preharvest inspection period, which is not compulsory where no environmental questions exist; and the review period, when the review team determines if additional mitigation measures are needed.

Note that the time periods listed are maximums. The longest time it would take a timber harvest permit to pass through this process is 35 days. A longer time may be required if the permit submitter and the Department of Forestry agree to an extension, as for lengthy negotiations on mitigation measures. In practice, the average permit is processed in about 20 days, and no less than 10 days, so that public comment can be heard, even on a simple, very remote plan.

For the State as a whole, an average of over 1,400 permits per year has been processed in the recent past. This is down from as high as 1,900 plans during the late 1970's. Review teams work at each of the five Department of Forestry regional offices. However, a great majority of the permits, both in numbers and volume harvested, occur in the northern half of the State.

If a permit is denied by the Department Director, the submitter may appeal to the Board of Forestry. At present, no other party may appeal the issuance or denial of a timber harvest permit.

Enforcement and Review

As previously mentioned, Board of Forestry rules are enforced by the Department of Forestry. The Forest Practice Enforcement Process is shown in figure 2. The Department has many legal enforcement tools as shown in table 1. Obviously, the Department inspectors attempt to use persuasion and less drastic actions to obtain compliance with the rules and conditions in the timber harvest plan, such as warnings, before resorting to judicial and misdemeanor remedies.
As Section 208 anticipated, the Board of Forestry continuously reviews its rules and institutional procedures. Consultation with Federal and other State agencies is mandatory. This is important because no set of rules and procedures is perfect. There must be ways to incorporate improvements, experience, changing technology, and evolving institutional needs.

From the beginning of its involvement with the FWPCA, the Board of Forestry has implied the term "best management practices."
Harvesting Begins With Approved THP

- Inspection by CDF

No Violation Observed
- Inspection Report Sent to Responsible Person

Minor Correctable or Non-correctable Violation Observed
- Inspection Report Sent to Responsible Person; Describes Violation, Corrective Work & Due Date

- Inspection Shows Violation Corrected
  - Inspection Report Sent to Responsible Person Clearing Violation

- Inspection Shows Violation Not Corrected
  - Misdemeanor Action
  - Administrative Action
  - Civil Action

Serious Correctable or Non-correctable Violation Observed
- Inspection Report Sent to Responsible Person; Describes Violation & Due Date

- RPF Disciplinary Action if Serious Unprofessional

- Violation Corrected by Responsible Person
- Violation Not Corrected by Responsible Person

- Violation Corrected by Responsible Party or CDF

Figure 2—California's forest practice enforcement process.

OUTLOOK FOR THE FUTURE

California is one of America's leading timber States. Yet it was probably the last major timber State to develop a 208 plan for managing nonpoint sources of pollution from silvicultural operations. It based its program around a previously developed regulation program rather than around voluntary or educational programs as in other States. As a result, the Board of Forestry estimates that its program increased logging costs by up to $13 per thousand board feet. When compared to stumpage prices ranging from about $100 to $150 per thousand on a statewide average, this is not an inconsequential cost.

The Board has established a system of general water quality and environmental protection, leaving its field personnel considerable flexibility at specific sites. This flexibility and reliance on a process has made California water quality personnel uneasy, especially since their predominant experience is in regulating point sources of pollution. This difference in philosophies was largely responsible for the delay in certifying California's silvicultural BMP program. In fact, the story is not yet complete as the results of the 1-year Monitoring Assessment Program will not be available until after 1987, at the earliest.
Table 1 - Forest Practice Enforcement Actions and Possible Resolutions.

<table>
<thead>
<tr>
<th>Actions available</th>
<th>Possible resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Warnings</td>
<td>Via inspection reports, verbally; and/or administrative letters</td>
</tr>
<tr>
<td>2. Notice of intent to take corrective action</td>
<td>Violation corrected by responsible person; violation corrected by CDF</td>
</tr>
<tr>
<td>3. Stop work orders</td>
<td>Violation corrected - operations continue; agreement entered into for continuance of operations; injunctive process started</td>
</tr>
<tr>
<td>4. Injunctive process</td>
<td>Temporary restraining orders; preliminary injunctions; permanent injunctions; court ordered correction; stipulated agreements</td>
</tr>
<tr>
<td>5. Misdemeanor action</td>
<td>Fine; probation; incarceration; dismissal</td>
</tr>
<tr>
<td>6. Timber operator license action</td>
<td>Warning; suspension; revocation; dismissal</td>
</tr>
<tr>
<td>7. RPF disciplinary actions</td>
<td>Warnings; letters of reprimand, suspension; revocation</td>
</tr>
</tbody>
</table>

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Livestock Grazing and Water Quality

W. James Clawson

A climate of misconceptions surrounds the relation of livestock grazing to water quality. The sanitation engineer, the hydrologist, the range manager, and the land owner look at the problem from the standpoint of their own experience, and have differing definitions and perceptions of it.

There are very differing views as to the severity of the impact of livestock grazing on water quality. From a national perspective, livestock grazing lands, mostly rangelands and pastures, are not identified as a major contributor to water quality problems. It is well documented, however, that there are local or site specific water quality problems (Halbach 1986). A view is also held that on public rangelands non-point source pollution leads to a major problem of sedimentation due to inadequate vegetative cover. The best solution then offered is to reduce grazing to natural levels of erosion (Coggins 1984), but this is interpreted by many to mean no grazing at all.

These representative statements refer to sources of data from which one can select a position to support one's own interest or concern (as is often done in public statements), without differentiating between sets of conditions. With the diversity of ecological systems, it stands to reason that water quality concerns are site-specific and should be evaluated as such. Where then are the real issues and what type of management is "best"?

Watershed concerns have long been a part of range management as identified in national assessments (U.S. Senate Document 199 1936; RFA 1980; and RCA 1980). Within California these concerns are most recently described in the Preliminary Assessment of Forest Resources in California (1979) and the California Soil Conservation Plan (1986).

The relation of grazing and water quality is also very much on the minds of the livestock industry, professional societies, and interest groups. Water quality was the topic selected for the first workshop of the Grazing Land Forum, an attempt to get diverse interests together and define issues more clearly (Grazing Lands Forum 1986).

Watersheds are just one way of classifying land. When considering grazing influences on water quality, we should consider all areas being grazed by livestock: pastures, meadows, riparian areas, and uplands. These lands are important to us in California, both as a base for a large livestock industry and for many other values, including watersheds and account for a third to a half of the State's land area (Clawson and George 1985).

The problems and management approaches are different for different types of vegetation and livestock conditions. Central to the theme, however, is that grazing is an important land use and that other such values, like water quality, must now be a part of land use objectives and subsequent management efforts.

The purpose of this paper is to describe some of the major relationships of livestock grazing and water quality, to present some basic concepts of grazing land management suitable for California, and to encourage communications and understanding leading to more effective cooperative management. More detailed treatment of the topic is found in such publications as "Livestock Grazing Management and Water Quality" (EPA 1979) and "Rangeland Hydrology" (Branson and others 1977).

GRAZING AND WATER QUALITY RELATIONSHIPS

To incorporate water quality concerns into resource management, water quality should be defined as to its source and potential use (Cwanson 1986). This would allow consideration of the uniqueness of each management situation, set appropriate management objectives, the most satisfactory multiple-use, and an adequate monitoring process (to measure progress toward goals and indicate needed management changes).


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Major grazing influences on water quality appear to be related to sedimentation and contamination by nutrients and biological organisms. The actions that occur are altering vegetation and the physical environment of the watershed, plus direct deposits of animal waste into the water course. As these influences are briefly discussed, keep in mind that grazing impacts will be greatly different for the various parts of the watershed—the aquatic system, the riparian area, and the uplands. Sedimentation (and to some extent physical soil alterations and nutrients) is the major concern with the uplands, while all impacts are more critical on the riparian and aquatic systems. Management implications of these relationships will be treated in the next section.

Sedimentation (Erosion)

Erosion is identified as a widespread concern on grazing lands, but assessments of the magnitude of this problem, particularly sedimentation, are questioned because of several factors:

1. The frequent usage of soil movement, erosion, and sedimentation to mean the same thing
2. Extrapolation of site-specific data to large geographic areas
3. Inappropriate use of the Universal Soil Loss Equation on western rangelands
4. Oversitegment of problems when requesting agency program funding
5. The assumption that lower "range condition" always results in increased erosion

As mentioned above, erosion (and sedimentation) are closely associated with the vegetation and physical soil disturbance, which are impacted by grazing. The main factor influencing the erosion status of an area is the degree of soil protection provided by the vegetation present. This is often described by the amount of ground cover and consideration of the soil-holding capacity of the root system. Within the range management profession, the status of vegetation is classically described by a "range condition" rating. This rating is based on an ecological status, the degree to which the vegetation differs from a perceived potential vegetation for that site (Heady 1975; Stoddard and others 1975).

Application of this rating system is being questioned by range scientists and has been troublesome in attempts to evaluate the current status of California's naturalized annual grassland vegetation for many years. The RCA (1980) and RPA (1980) assessments of national rangelands have described over 80 percent of the grasslands in California to be in "fair to poor" condition because they are no longer the perennial grasslands they were before settlement. Poor condition has been associated with increased erosion potential. The extrapolation of this association to California's naturalized annual grasslands has led to broad statements of erosion potential (Sheridan 1981), while in fact the annual grasslands of California have a greater degree of ground cover and annual production than most other grasslands in the United States.

It is well recognized that major shifts in the western range vegetation occurred in the late 19th and early 20th centuries because of improper livestock grazing on the unregulated open ranges, but range scientists generally agree that improved grazing management in the past 50 years has led to significant range improvement and decreased soil erosion (Box 1980). Certainly there are local exceptions to this improvement, particularly where management goals do not include soil protection, where management goals have not been achieved, or where soil and vegetation resources are inadequate.

Physical soil disturbance can also influence erosion. Some of this can be attributed to grazing, but often this influence is more likely to result from other activities either associated with or separate from the actual grazing, such as roads, water developments, and structures.

Estimates of sheet and rill soil erosion from California rangelands amount to 10.2 tons (metric) per hectare (8.2 tons per acre) (RCA 1980). While there might be a question of the absolute value, soil erosion must be a consideration in multiple use management. Fortunately, Swanson (1986) indicates that many studies have shown that livestock grazing at light to moderate levels will not lead to accelerated soil erosion.

Nutrients and Biological Contamination

These two items are considered together since they are usually associated with animal waste. In most water quality situations they are also associated with animal concentration and even more so when the grazing animals are in close proximity to water bodies.

One of the major problems is that water quality discussions often relate livestock waste to humans and their waste rather than recognize the unique differences of metabolic processes and disease organisms of ruminant animals. Another is that animals are a part of the nutrient cycle in grazing systems and while they may concentrate and locate these nutrients in some cases, they also disperse nutrients most of the time and they also can remove nutrients from the system (Ayers 1974).

These examples point to the problem of lack of communications and understanding among professional groups. It is too easy to set up professional cases for arguments, rather than work collectively for the best answers. We do need to recognize the potential for nutrient and biological contamination of water supplies from grazing livestock, but we need to describe the problem in terms of the livestock impact for specific situations, then develop management schemes to minimize these impacts.
In general, the effects of livestock grazing on runoff and stream water quality are minimal and often do not exceed nutrient levels of ungrazed lands (Saxton 1983; Sweeney and Melvin 1985). This is particularly true where livestock are in unconfined pasture situations. Situations deserving the most consideration are where livestock are concentrated in or near streams and lake shores for extended periods of time.

Recognition should be made of the potential effect of fertilizer and pesticides use on water quality. On grazing lands, however, these materials are of less importance than siltation and biological contamination. Rates of material application and surface water movement are usually lower on these lands than on croplands.

GRAZING LAND MANAGEMENT

The management of natural resources and multiple use is complex and needs broad understanding. It could be said that all management practices in the production of grazing livestock have an influence on water quality, since they influence the time and manner of using grazing lands.

The term "best management practices" (BMPs) has a specific meaning in dealing with water quality (Federal Register, Vol. 40, No. 230, Nov. 28, 1975), but is unsuitable for use when dealing with broader management issues. What might be "best" for water quality might not be "best" for another use or value. It is much more appropriate to consider management options and responses to meet a set of defined objectives than to predetermine "best management practices".

Livestock grazing encompasses a variety of animals, physical land forms, types of vegetation, seasons of use, and diseases and nutritional problems. To focus on a reasonable approach, management practices that have the greatest influence on water quality can be grouped as either livestock management or range improvements. The first refers to the opportunities of manipulating the manner in which livestock graze (location and time of grazing) and the type of livestock; while the second refers to resource manipulation, such as reseeding, prescribed burning, and water developments.

BMPs may involve a single practice, but most often will require a combination of practices which are determined for a specific soil, topography, climate, vegetation, and livestock complex. Often there are several technically adequate alternatives that may apply. The recommendation is again made to involve the expertise of interdisciplinary specialists, which also includes the landowner.

California has taken the leadership in establishing residual dry matter (RDM) as a criteria for range utilization that is easily understood and recognized. Clawson and McDougald (1982) have drawn on research data from the U.S. Forest Service (Bentley and Talbot 1951; Hormay and Fausett 1942; and Hormay 1944) and the University of California (Bartolome, and others 1980; Heady 1966, Hooper and Heady 1970) and others (Hedrick 1948) to establish RDM guidelines for range utilization in a majority of California rangelands. The same concepts of residue are gaining favor with range scientists and managers in grasslands other than the annual type associated with 80 percent of California rangelands. After all, it is what's left after use by livestock and all the other creatures that is important for soil and water quality protection.

These guidelines for RDM management are simply stated in visual terms and presented as photo standards from the San Joaquin Experimental Range (Clawson and others 1983). Achieving moderate grazing is the management objective in most situations. This is a condition in which the residue in late summer (late September or early October) has an average height of 1 1/2 to 2 inches of old, dry vegetation which will have a patchy appearance, with little bare soil and small objects showing at a distance of 20 feet or more. It is surprising that these same guidelines fit many of the other grassland types in California. Range utilization need not be couched in the abstract terms of proper use, as has been taught and promoted, but rather measured in what is left. If range use can be simplified to one term, RDM would be that term.

Keep in mind that most livestock grazing management practices are intended to keep the animals in a dispersed grazing situation. This is preferred by the rancher/range manager as well as others. Problems arise where there is concentration of livestock. Most water quality concerns surround concentration of livestock in or near water courses. Our time should then be spent with efforts dealing with those problems and not trying to regulate the situations that don't really cause problems.

The following describes briefly some of the types of management considerations that are available to meet the management objectives of those who are interested in the use and protection of the grazing land resources.

Livestock Management Practices

Management practices to disperse animals or improve the uniformity of forage utilization have been of major interest to range management. These include such practices as fencing, water developments, herding, supplemental feeding and salting locations, and even changes in type of livestock. These practices are often the least costly, but may contrast with the previous livestock use patterns or operational goals of the ranch.
Grazing systems are a popular topic in discussion of proper use of grazing lands. Grazing systems provide opportunities to vary the intensity and season of use. Rather than evaluate differences between such systems as deferred rotation, rest-rotation, and short duration-high intensity. I suggest that appropriate expertise in range management be involved in specific evaluations. The pro’s and con’s of such systems can be argued at length, but in the end it is the specific situation that should dictate what grazing management scheme is suitable.

Riparian area management probably has the greatest impact on water quality. Much is now being written and discussed on this topic. Swanson (1985) has described a number of management considerations for livestock ranchers and range managers. He suggests a number of livestock management alternatives in addition to eliminating grazing. This area of discussion is one of great interest to many concerned with the use of natural resources including wildlife managers, fisheries managers, ranchers, and water quality organizations.

Range Improvements

The other set of management practices available to the range manager are those that change the composition of vegetation in some manner. Most common are range fertilization, range reseeding, prescribed burning, and weed control. These practices tend to be more costly to implement and thus need careful consideration. They may have benefits other than those usually associated with increased livestock performance.

In California the use of fire (or other practices) to reduce the brush for fuel hazard reduction and other values has much support. While there is short-term risk of soil erosion, long-term evaluation should be considered, both in terms of fire hazard and erosion potential. Smaller, more frequent controlled burns have been advocated in lieu of larger uncontrolled wildfire for the health of the brushland resources.

As mentioned before, fertilization and pesticide use may be suitable to increase forage quantity and quality, but most of the time are used in lesser quantities over larger areas and are not a threat to water quality as they are with crops. These too should be evaluated on a case-by-case level.

COOPERATIVE MANAGEMENT

The emphasis throughout this paper is that livestock grazing management along with managing for other values is a complex and site-specific challenge. None of us are equipped to deal with the situations in total, and the science at our disposal doesn't answer all the questions about interactions. A realistic joint effort is needed by the scientist, manager and regulator. Not to be left out is the land owner/manager who often has experienced more fluctuations in the production of the resource than the agency staff who often have the luxury of seeing the situation in a short time frame. Range management in California (as probably in the west generally) is still a consensus reaction rather than one arrived at from a single scientific evaluation.

The interaction of all members of the professional staff in looking at situations realistically and trying to understand each other is a great starting point. Then bringing in others concerned will lead to improved resource management and to meeting more of the desired objectives. Opportunities are available from simple meetings between the animal scientist, the animal health specialist, the sanitation engineer, the hydrologist, and the wildlife/fisheries biologist to the more complex Coordinated Resource Management Planning process. All that is needed is a willingness to get together and make things work.

CONCLUSIONS

In many minds livestock grazing and water quality suggests a conflict—how can these two uses can mutually exist? Well, they can; it only takes a cooperative effort to see that it happens to the advantage of both. To see that it happens takes a good assessment of the watershed in question, a look at multiple alternatives, and then a selection of choices to allow multiple use to occur. The process of arriving at suitable solutions requires that all interested parties become involved and that they all have an equal say in the matter.

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Timber Harvesting and Water Quality

Arne E. Skaugset III

My specific charge for this presentation is to review how well the Forest Practice Rules protect water quality. I am to present from an on-the-ground, private industry, timber harvesting perspective an objective view of the strengths and weaknesses of implementing the Forest Practice Rules as best management practices.

As I perceive it, the Forest Practice Rules process is not a single process. There are two very real and distinctly different parts. First, there are the operational constraints, which are the practices that protect water quality. Practices like waterbarring, downspouts on culverts, buffer strips, and the directional felling of trees away from streams are operational constraints. Second, there are administrative constraints, a time-consuming and expensive but very real part of harvesting timber in California. Such practices as flagging protection zones, flagging trees in protection zones, watershed maps, and review teams are administrative constraints. I shall review these two aspects of the regulatory process separately.

OPERATIONAL STRENGTHS

The greatest strength of the Forest Practice Rules is that they work. They do protect water quality during timber harvesting. When the Rules are critically reviewed with a jaundiced eye toward the protection afforded water quality, there is no doubt that the quality of timber harvesting going on today is a tremendous improvement over that of 15 years ago.

Let's briefly review the BMP recommendations that have come from paired watershed studies and compare these recommendations with the operational constraints in the Forest Practice Rules. For protection from organic debris and logging slash, the rules require buffer strips, directional falling of trees in the buffer strip, and stream cleanup. For stream temperature protection, the rules require shade canopies be left on perennial streams. If stream temperature and logging slash are not a problem, then dissolved oxygen cannot become a problem, because dissolved oxygen is intricately linked with these two parameters. A dissolved nutrient problem can be dismissed out of hand. These are all accepted practices with their roots in paired watershed studies; these practices are proven BMPs, used and accepted in other states' regulatory programs.

Let's briefly review the BMP recommendations that have come from paired watershed studies and compare these recommendations with the operational constraints in the Forest Practice Rules. For protection from organic debris and logging slash, the rules require buffer strips, directional falling of trees in the buffer strip, and stream cleanup. For stream temperature protection, the rules require shade canopies be left on perennial streams. If stream temperature and logging slash are not a problem, then dissolved oxygen cannot become a problem, because dissolved oxygen is intricately linked with these two parameters. A dissolved nutrient problem can be dismissed out of hand. These are all accepted practices with their roots in paired watershed studies; these practices are proven BMPs, used and accepted in other states' regulatory programs.

The single biggest water quality problem to be dealt with is accelerated erosion and sedimentation. This is a much harder subject to cover briefly but I will lump BMPs together and review the subject as quickly as possible. The rules have a special section on roads, which is appropriate because roads have repeatedly been shown to be the most serious erosion problem encountered in logging. In the roads section of the Forest Practice Rules, there is appropriate language for minimizing total road length, constructing minimum-standard single-lane roads, and constructing roads that conform to the terrain. Adequate cross drainage, 50-year design return period for culverts, and waterbarring are among the recommended practices. All of these are tried and true practices that are part of other states' accepted rules. For stream protection the rules embody the concept that the streambed and streambank should not be physically disturbed. The rules require buffer strips, directional falling of timber, yarding logs away from or suspending logs over streams, and stream cleanup. The rules adequately convey the message that during timber harvesting the aerial extent and degree of ground disturbance should be minimized. The rules also require post harvest erosion control activities such as waterbars on skid roads, pulling stream or watercourse crossings.

Abstract: The Forest Practice Regulation process is divided into two parts; operational constraints and administrative constraints. The strengths of the operational constraints, the best management practices, is that they 1) protect water quality during timber harvesting, and 2) have flexible wording to allow site-specific application of general rules. The administrative constraints are a weakness primarily because they imply that woods workers cannot understand the importance of environmental constraints. The forestry profession needs to realize that the woods worker is the solution to continued environmental advances during timber harvesting and develop programs that enhance the environmental awareness, knowledge, and involvement of the woods worker.
putting roads to bed, and grass seeding. These are all proven activities that minimize erosion.

A new area of concern is steepland forest management. Steepland forest management is the intensive management of forests on slopes over 60 to 65 percent. This subject has been addressed by the Forest Practice Rules; some concerns have been expressed and some regulations have been passed without any egregious overregulation. There is appropriate concern for road construction on slopes over 50 percent and only cable harvesting is allowed on slopes over 60 percent. The types of slide-prone terrain have been identified and defined. So far the restraint that has been shown with respect to steepland forest management by addressing concerns and providing some proven rules without overregulating the situation is a strength.

A second very positive strength of the Forest Practice Rules, despite their prescriptive nature, is that they do allow some flexibility in some critical areas of forest management. The argument of flexibility as opposed to numeric standards has been and still is a polemic topic. However, there are situations in forest management where prescriptive rules will not work and a forester has to be allowed the flexibility to apply a rather general BMP to a site-specific situation. This is an important part of Forest Practice Rules and the California rules do incorporate it.

On the other hand, if there is no standard in the technical literature to compare the BMP with and it has flexible wording, what proof is there that the BMP is protecting water quality? The response to that concern will probably be better known when the 208 Evaluation Team presents its final report. But, as a partial response to the concern, at this time, two erosion studies recently completed in the state could be reviewed: Dr. Ray Rice's study of erosion from timber harvesting (1981) and the state's own soil erosion study (WESCO 1983). Both studies reported that the accelerated erosion from the majority of timber harvesting being done is acceptable. The majority of the erosion measured was coming from a minority of the sites. The logging being done today in California uses BMPs that are made up of numeric standards and allowance for flexibility, and on about 90 percent of the sites the accelerating erosion is acceptable. The majority of the timber harvesting being done using BMPs, even those BMPs couched in flexible terms, is acceptable. The BMPs must be working.

OPERATIONAL WEAKNESSES

An operational weakness of the Forest Practice Rules is that there are situations when the prescriptive nature of the rules goes too far. There are situations when the prescriptive standards are associated with ever-increasing logging costs and there is no evidence that the increasing costs are providing a comparable increase in the level of water quality protection. The best example of this is the stream buffer strips. The numeric standards for stream buffer strips are in excess of the recommended standards in the technical literature. These excessive standards are costly in terms of merchantable trees left and increased logging costs, and there is no data or evidence to show that there is an equal added protection to water quality as a result of the increased cost. Stream protection is just one example of excessive prescriptive standards and it is also the best example. There are other excessive prescriptive standards but they will not be detailed at this time.

One additional weakness of the Forest Practice Rules was alluded to when the soil erosion studies were discussed. This weakness is that on some occasions the rules don't work. In Rice (1981) over 90 percent of the measured erosion came from 4 out of 102 plots. For these plots the erosion is most likely unacceptable while for the other 98 plots the erosion was probably acceptable. In the WESCO (1983) study, 77 percent of the measured erosion came from less than 15 percent of the plots. In this study about 85 percent of the time the level of erosion was most likely acceptable and about 15 percent of the time the erosion was probably considered unacceptable. The moral of this story is that perhaps somewhere around 10 percent of the time, something is going wrong and the Forest Practice Rules aren't working adequately.

From my tenure on the Soil Erosion Study Advisory Committee and as a result of a professional acquaintance with Dr. Rice, I know what these individuals consider to be the causes of the unacceptable erosion. One cause is critical or sensitive sites. Some sites are simply more susceptible to management activities than most other sites, and when some disturbance occurs on these sites the result is an unacceptable level of accelerated erosion. The California Department of Forestry is working toward a solution to this problem with the Critical Site Soil Erosion Study. The expressed goal of the study is to be able to predict critical sites before disturbance takes place. The other cause is one I first heard referred to as the blunder factor. This is a name for human error and the fact that loggers are people and things can go wrong in the woods. It is also called operator error. It describes the fact that loggers or equipment operators can make mistakes with no malice or forethought. Culverts can be inadvertently installed in bad locations, waterbars can be constructed in wrong locations, and sometimes fill can be put in places where it shouldn't be. These are things that all loggers or equipment operators are inadvertently capable of and so far an increasingly prescriptive set of Forest Practice Rules hasn't been able to eliminate them.
STRENGTHS AND WEAKNESSES OF ADMINISTRATIVE CONSTRAINTS

I have thought a great deal about the strengths of the administrative constraints of the Forest Practice Rules with regard to protecting water quality. To say that water quality protection results from such practices as flagging protection zones, preharvest inspections, and review teams, means that there is a better end result when these practices are included than if only operational constraints are applied. Admitting this means to me that public agency foresters are better than private or consulting foresters because the former can routinely and consistently perceive mitigation to water quality problems that the latter cannot. I don't believe this is true. In my experience the pool of foresters is all the same. No one group is either better or worse than the other.

I am not saying that there is no benefit in having the administrative constraints. I'm sure there are good bureaucratic reasons for having the administrative constraints. They are probably what allows timber harvesting to take place in California with a minimum amount of rancor. But if all the administrative constraints of the Forest Practice Rules disappeared tomorrow and only the operational constraints existed, or in other words, if private foresters were just held accountable to an acceptable end product, I honestly don't think the quality of the State's water would be affected as a result.

While I don't consider the administrative constraints to be a strength for water quality, I do think that they are a weakness and have the potential to become an even greater weakness. They are a weakness because of the subliminal way they encourage woods workers to be viewed. At the inception of forest practice regulation, the forester was probably not thought of as the problem. When the spotlight was put on water quality, the concern was timber harvesting and the logger was considered the problem. The solution to the problem was perceived to be a prescriptive set of regulations and constant supervision. To date that formula has been pretty successful. Registered Professional Foresters were viewed as the best candidates for being the supervisors. There exists even to this day a disagreement regarding to what degree RPFs are responsible for the actions of the loggers who actually operate the equipment. The subliminal message the Forest Practice Rules convey is that in protecting water quality while harvesting timber, the logger is the problem and he can't be expected to perform correctly without a fairly rigorous amount of supervision from either RPFs or forest practice inspectors.

Why is this a weakness? Consider the blunder factor referred to earlier. Loggers and logging equipment operators, without malice or forethought, can do things that increase the risk of unacceptable changes occurring in water quality. For instance, a grader operator when waterbarring a road or broaching an outside road berm may locate one outfall every mile in a bad location. Or maybe a catskinner on one out of every five landings he constructs may drift a little fill onto a spot that shouldn't have fill on it. Maybe a hooktender on one layout for every other setting will put a tailblock in such a location that unacceptable damage is done to a buffer strip. This type of problem is not going to be solved with more rigorous, prescriptive regulations. A forest practices officer can't supervise everything going on in the woods and neither can the private or consulting RPF. The only real solution to the problem is an increased awareness by the loggers or equipment operators themselves. In other words, for the blunder factor the solution to the problem is the logger, and the rules not only don't help but foster an attitude which directly conflicts with the solution. This I consider to be the major weakness of the administrative constraints in the Forest Practice Rules.

DISCUSSION

I have labeled the administrative constraints of the rules a weakness, and intimated that a new way of working with the woods worker is needed to cope with timber harvesting and water quality related problems that still occur such as the blunder factor. What is that new way of working with the woods workforce? Realizing that the administrative constraints in the rules are not going to be changed and that more rigorous and prescriptive rules are not the answer, what direction do we head?

Let us consider a situation in the woods which parallels Forest Practices Regulations, that is, Safety Regulations. When a safer workplace for woods workers was deemed as desirable goal, the first step was enabling legislation at both the Federal (OSHA) and State (Cal-OSHA) levels. After the enabling legislation came regulations in which for almost every specific work situation a set of safety regulations was prescribed. Yet despite the fact that all the woods workforces in the state operate with essentially the same set of regulations, the incident rates for different companies and work groups varies between 5 and greater than 30 incidents per 200,000 hours worked. What is responsible for this variation in incident rates? In my experience, the outfits with the low incident rates are places where the individual worker is directly involved in the safety process. Safety goals are communicated to the workers, there are safety committees, tailgate sessions, and probably some incentive systems. The individual employee is perceived to be the solution to the problem and he or she is involved, aware, and in communication.

To parallel the safety situation, for the individual logger or equipment operator to become the solution to the blunder factor in the woods, these individuals must be thought of differently.
Instead of simply prescribing tasks, like waterbarring, someone must explain the reasons why the task is being done and the consequences of its not being done right. Woods workers have to become involved in and aware of the environmental and water quality protection business.

Let me give you an example of how it can work. Right after I was hired by Simpson, the logging manager was looking for some work to put in front of the CAT 235 hydraulic excavator. The machine was purchased to end-haul roads but at the time roadwork could not be kept in front of it so work for the machine was being sought. The idea was brought up, and I seconded it, that perhaps the 235 could be used to pull back some of the perched fills on some of the roads and landings in situations that looked precarious and at risk of failure. This idea did not meet with unanimous approval but the logging manager was willing to try it. I was given the job of finding a few suitable locations where the pull-back could be tried. The initial trials were acceptable, given the productivity and quality of the work, so a more widespread program was approved.

One of the first projects to be undertaken was a stretch of road in Terwar Creek which involved pulling back a couple of landings and the road between them. At the same time this pull-back was being done, a competitor of Simpson's had a logging crew at the end of the road and they went in and out on the road every day. Also, at this time the pull-back program still had not won widespread approval. The work was going forward primarily because of the will of the logging manager and there was some opposition to it by both management and hourly woods workers. The pull-back program was considered a waste of time and very expensive eyewash. As the work continued in Terwar Creek it was obvious that it was not going well. The productivity was way down and the quality of the work was not very good. It was just a matter of time before the road foreman would make a serious effort to get this nonsense stopped.

One day when I was out visiting the site, I got to talking with the operator about the quality of the work. I asked about the reach and power of the 235 and he let me get in and gave me a short lesson on how to operate it. During our conversation the operator admitted that one of his big problems concerning this particular job was the ridicule of the logging crew that was going in and out every day. Now this is important stuff. In a town the size of Klamath these men were undoubtedly boyhood friends and were drinking and fishing buddies. They could even have been related to him. So this was ridicule from friends and peers and as a result he didn't feel real good about what he was doing and his work reflected it.

Having nothing to lose, I had the operator get in my pickup and we went on a tour of Terwar Creek. I drove him to an old road that had been built about twenty years ago and had failed repeatedly and then I took him to some newer roads that had tension cracks in them and looked like they were going to fail soon. I then drew him pictures of failures and failure planes and explained factor of safety equations to him and tried to explain that the material he was pulling back was the driving force for failures where the toe of the potential failure was where the potential friction was. Finally we went to some places on Terwar where the consequences of multiple road failures could be viewed, and I tried to explain that to him. After about two hours of this I took him back to where he was working and I left. Right then I didn't feel very confident about the future of the pull-back program.

I didn't get back up to Klamath for about three days, but when I did get up there I went straight out to Terwar Creek to see how the pull-back was going. To my surprise not only was that particular job completed but the high quality work was back and the operator had even gone back and fixed the poor quality work. I found out where he was working and went to talk to him. He was a changed man. He no longer felt bad about what he was doing and he wasn't terribly concerned about being ridiculed. He was really wired. He hadn't just pulled back the areas I had flagged but he had found some areas he thought looked bad along the way and had decided to pull them back, too. Something must have clicked during our discussion because on his own he had gone to the road foreman and suggested that the man working with him on CAT watch take some grass seed and seed the bare pulled-back areas as he went along.

The pull-back program took off after that. Pretty soon almost everyone was looking for areas that they felt needed to be pulled back and the program became widely accepted. The person responsible for the turnaround was the operator of the 235. However, memories being selective and ego needing boosting, I will not shy away from taking some credit for the added involvement and awareness that helped the operator get excited about the project. I have had similar experiences with dozer operators and grader operators but none of the successes were as striking as the one involving the pull-back program.

The pull-back program undoubtedly can be considered a BMP. Yet the success and continuation of the program was decided not by prescriptive regulations and close supervision but by communication, involvement, and awareness. To parallel the safety situation, for the individual logger or equipment operator to become the solution to the blunder factor, these individuals will have to be thought of and treated differently. They will have to become more aware of and more involved in the environmental protection measures that are required. Instead of simply prescribing tasks, like water-barring, administrators should explain the reasons why the task is being done and the consequences of its not being done right. In short, woods workers have to
become involved in and aware of the environmental and water quality protection business.

The current administrative constraints in the rules are not going to be changed, so how does this new mentality get fostered? If the safety situation was duplicated once again, environmental awareness programs would come from the private sector and be planned for individual companies. However, I'm sure there is room for such a program among public sector foresters. I certainly hope if this type of communication, involvement, and awareness ever gets going that it comes from the forestry profession. Most California Department of Forestry forest practice officers are foresters and with the regulatory authority and control the CDF has, I can't see why they shouldn't play a leading role in a program of this type. They have as much to gain as anybody from such a program.

What form should such a program take? I don't know. Find a successful safety program and emulate it. But I can give you an example of a possible form it could take. The CDF is currently making a series of video tapes and slide tapes on erosion control during timber harvesting. The video tapes are being done with the close involvement of the Associated California Loggers. They are intended to be taken to the logger instead of the logger coming to them and they are intended to be upbeat and positive. They show successful erosion control practices and how they are done and they do not dwell on failures. The idea is to show real loggers doing things right to illustrate that it is being done and can be done correctly. I think this type of project is a step in the right direction and I applaud the CDF for it.

SUMMARY AND CONCLUSIONS

I started this paper with a handful of points I wanted to make and I will briefly summarize them now. First of all and most importantly, I want to state that BMPs work. The operational constraints in the Forest Practice Regulations with their combination of prescriptive standards and flexibility provide a framework which results in demonstrated protection for water quality during timber harvesting. Second, there are isolated occurrences and occasions when BMPs fail and a potential by-product of this failure is short-term unacceptable water quality. The failures of the BMPs are preliminarily blamed on critical sites in steepland forest management and human error or the blunder factor. The critical sites are currently a research areas and technical solutions are being sought for this problem in that arena. The administrative constraints of the Forest Practice Rules are a weakness when it comes to protecting water quality primarily because of the way they encourage woods workers to be viewed. To solve the blunder factor a new approach to working with the woods workforce will have to be found. The woods worker has to be viewed as the solution to the problem not the cause and professional foresters have to take the time and trouble to get these people in touch with, aware of, and involved in the water quality and environmental quality business.

REFERENCES


Monitoring Effectiveness of Best Management Practices on National Forest Lands

Christopher M. Knopp, Mark E. Smith, Jerry Barnes, Brent Roath, and Michael J. Furniss

The Pacific Southwest Region of the Forest Service employs Best Management Practices (BMPs) to prevent or limit water quality impacts that can result from forest management. There are 96 general rules and guidelines which require an interdisciplinary team (ID Team) to analyze the effects of a proposed action and prescribe specific mitigation measures to maintain water quality. The prescribed measures or BMPs become a part of the environmental assessment and are translated into contract language that specifies how a project will be accomplished. "Best Management Practices" are actually the series of steps, from general rules and guidelines to on-the-ground results, intended to protect beneficial uses.

The Management Agency Agreement between the Forest Service and the California Water Resources Control Board requires that each project with the potential to affect water quality will implement BMPs to ensure protection of water quality. In turn, the State agrees that implementation of BMPs constitutes compliance with its water quality objectives. The result is less bureaucracy and an emphasis on prevention.

The State's authority to issue Waste Discharge Requirements and impose civil penalties is not diminished by this agreement. BMP monitoring seeks to avoid this by evaluating compliance with and effectiveness of the prescribed measures. Compliance monitoring is performed routinely during project inspection to determine if BMPs are implemented correctly. Effectiveness monitoring is done to determine if a correctly implemented BMP is effective in protecting water quality and beneficial uses. This type of monitoring is costly and time-consuming, and it requires a scientific approach.

PURPOSE AND SCOPE

This paper evaluates the effectiveness of mitigation measures developed for road building and timber harvesting in the Fox Planning Unit of the Six Rivers National Forest with respect to (1) surface erosion, (2) landslide occurrence, and (3) anadromous spawning habitat. The period 1966 to 1975 represents management before BMPs. Only landslide data are available for this time period. The period 1976 to 1985 represents management consistent with current BMP implementation. Although BMPs were not recognized officially until 1981, the mitigation measures developed for the Fox Unit are now routinely applied in planning, road building, and timber harvesting on National Forest lands in Northern California. There are no practical differences between current BMPs and the mitigation measures that resulted from the Fox Unit studies.

This paper examines potential sediment sources, including soil erosion and landsliding, and certain characteristics of the fisheries habitat, which is the primary affected beneficial use. We believe that the various studies and resource monitoring done in the Fox Unit provide relevant data over a sufficient length of time to allow a semi-quantitative evaluation of BMP effectiveness in preventing water quality degradation from National Forest management.
The Smith River basin has the highest rainfall in California. Average annual precipitation in the Fox Unit is 297 cm, and several high intensity storms of long duration occur each year. Precipitation records for the two analysis periods at Gasquet (13 km to the northwest) are compared in figure 1. Total annual rainfall, especially the larger values, was fairly similar (fig. 1A), but the most intense 72-hour storms, which may be more important in triggering or reactivating landslides, occurred predominantly in the period 1966 to 1975 (fig. 1B). The 1964 flood, which preceded most of the federal management in the Fox Unit, had profound effects on landsliding and stream channel morphology. Landsliding and aggradation of trunk stream channels was extensive, and they are still undergoing progressive scour, removal, and sorting of flood debris.

To isolate specific trends in a comparison of management practices between two periods, background rates for the relevant parameters must be identified. Only landslide occurrence could be compared in this manner; background data on soil erosion and spawning habitat are not available. All naturally occurring landslides that were not spatially associated with management activities were classified as background, although some of the management-related landslides also may have resulted primarily from natural factors. Forty-one background landslides were identified in the period 1966 to 1975, compared to 27 background landslides in the period 1976 to 1985.

The extent of management activity was comparable during the two periods. From 1966 to 1975, there were 452 ha of harvest area and 46 km of road construction, compared to 346 ha and 36 km during the period 1976 to 1985.

History of the Fox Unit

An Environmental Statement (ES) for the Fox Planning Unit was issued in 1974, and four timber sales were sold in the unit. The Sierra Club filed suit, charging that the Forest Service had inadequately assessed the effects of timber harvesting and road building on landslides and watershed resources. The Forest Service signed a settlement agreement with the Sierra Club that required an extensive review of conditions in the Fox Unit and a reevaluation of the four timber sales. A team of scientists produced four technical reports (Barnes 1977, Farrington & Savina 1977, Laven & Lehre 1977, Seidelman and others 1977), which included prescriptions for modifying the sales to reduce resource impacts.

Some important findings related to roadbuilding and timber harvesting that resulted from the Fox Unit studies are presented in table 1. Management practices before 1976 are contrasted with subsequent management practices that incorporate mitigation measures developed by the Fox Study Team.
SOIL EROSION

Soil erosion was monitored on four clearcuts between 1978 and 1985. These harvest units are typical of the study area, with slopes ranging from 40 to 70 percent and averaging 60 percent. The units were skidrow yanked, broadcast burned, and planted to Douglas-fir. Monitoring was done to examine the amount and significance of surface erosion following management activities, and was not performed as a research study with statistical control. Monitoring techniques included erosion pin arrays, erosion bridges, metal troughs, sediment traps, and photo points.

Data from erosion pin arrays and erosion bridges on one unit, monitored two years after treatment, showed an average erosion rate of 86 t/ha/yr. Erosion bridge data from another unit, monitored the first, second, and fourth years after treatment, indicated an erosion rate of 65 t/ha the first year, 149 t/ha the second year, and 95 t/ha for the third and fourth years combined.

Sediment traps were constructed at the bottom of the second unit to detect any off-site sediment transport. All stream channels within the monitored portion of the unit showing evidence of annual scour had been excluded from harvest. No material was collected in the sediment traps during the 4-year monitoring period.

Photo points at the erosion bridges recorded rapid growth of hardwood sprouts and planted conifers over the 4-year period. By the fourth year, near-ground vegetative cover was almost complete and ground cover had increased from litter fall and the formation of an erosion pavement. The rapid natural revegetation of the unit and apparent decline in the erosion rate during the third and fourth years suggest that the erosion rate would soon decline to levels similar to uncut forested sites.

Metal troughs were used on two other units to evaluate the size of material moving on the slopes and to look for any trends. It was suspected that ravel of rock fragments was a major factor of soil surface changes noted in the erosion bridge monitoring. These soils typically have 35 to 40 percent rock fragments by volume, or 60 to 65 percent by weight, in the surface horizon. The data indicate that most eroded material consisted of rock fragments coarser than 2mm. The fine soil fraction (<2mm), which is most important for soil productivity, made up a small proportion of all material. One year after clearcutting and burning, rock fragments accounted for 78 percent by weight of all material collected. In the second year, the proportion of rock fragments increased to 91 percent while the total weight of all sizes collected decreased by 65 percent. Visually estimated soil cover increased from 55 to 80 percent over the 2-year period due to revegetation and the formation of an erosion pavement. There was no evidence of off-site transport of eroded soil except at one location in an unbuffered, ephemeral draw. The higher percentage of rock fragments collected in the troughs could have resulted from washing of fine soil particles into voids in the gravelly soil after broadcast burning, or possibly some fine soil was not delivered to the trough because of a poor soil/trough contact. The decrease in the amount of material collected the second year and the increase in soil cover suggest that the erosion rate was declining.

LANDSLIDE OCCURRENCE

Landslides are the major sediment source in the Fox Unit and appear to have the greatest impact on water quality and fisheries habitat. Recent management has attempted to mitigate geologic hazards by modifying road location and design, as well as harvest unit layout. For this report, landslide rates and magnitudes were compared for the decades 1966 to 1975 and 1976 to 1985 to determine if current practices have produced a decline in management-related landsliding.

Landslides were mapped on 1965, 1975, and 1985 airphotos and ranged in size from 0.02 to 8.0 ha (typically 0.1 to 0.8 ha). Using 1965 as the baseline excludes the direct effects of the 1964
flood from the data corresponding to pre-BMP management. Inclusion of 1964 landslides would have biased our conclusions. Comparison of the airphotos revealed 137 new landslides that had occurred during the 20-year period. The following data were recorded for each feature: (1) period of occurrence, (2) spatial association with management, (3) relationship to sensitive geologic terrain, (4) estimated size on a scale of 1 to 5, and (5) estimated delivery potential to major streams on a scale of 0 to 1. A slide adjacent to a main channel was given a delivery potential of 1, while a headwater landslide away from a water course received a rating of 0.2. A relative impact was then assigned to each feature by multiplying size class by delivery potential. The resulting data are not mathematically pure, but they do furnish a consistent and potentially useful approximation of the relative impact of each slide.

The data were filtered to provide comparable samples in the two decades of management. Seventeen slides associated with private logging were...
omitted to restrict the analysis to Forest Service practices. Twenty-five slides that occurred in one period but were associated with roads or cutblocks from the previous period were omitted also. Twenty-two of these delayed effects are associated with roads. A possible explanation is that roadcuts are a relatively permanent disturbance of slope equilibrium. In contrast, the risk of landsliding in cutblocks tends to decline steadily after an initial window of instability related to declining root strength (Ziemer 1981). Another possible factor is road maintenance which, if faulty, can have as severe an effect on slope stability as the original construction.

The remaining 95 landslides were compared graphically in terms of frequency of occurrence and combined relative impacts. Figure 2A shows the number of slides in the two management periods for background, harvest areas, and roads. The frequencies are further subdivided to associated geologic hazards. These were defined as (1) inner gorge--slopes steeper than 65 percent adjacent to a stream channel; (2) other recognizable geologic hazard--toe zone or lateral margin of older landslide outside the inner gorge; and (3) no recognizable geologic hazard. The majority of all background and harvest-related slides are associated with geologically sensitive terrain. The number of harvest-related landslides, as a proportion of the relevant background frequencies, declined by 49 percent between the two periods. The number of road-related failures, as a proportion of background, declined by 85 percent.

A comparison of the relative impact data for the pre-BMP and post-BMP management periods is presented in figure 2B. These periods differ in two ways that must be considered in evaluating the effectiveness of the Fox mitigation measures. The first is the apparent difference in overall landsliding rates between periods; this was accounted for by expressing the management-related impacts as a proportion of the corresponding background impacts. The second involves the different levels of management in the two periods. The 20 percent reduction in harvested area and road construction in the post-BMP period probably resulted from two factors: the decline in timber markets that occurred in the early 1980's, and the application of mitigation measures that restricted the area of management, such as the avoidance of geologically unstable ground and the removal of streamside areas from the normally regulated timber base. Since it was impossible to isolate the impacts associated with just the mitigation measures, the overall reduction in impacts are presented in figure 2B as a range that reflects both factors.

Harvest-related landslide impacts decreased by 52 to 63 percent between the two periods, while road-related impacts decreased by 84 to 88 percent. The lower number in each range assumes that the difference in management resulted only from market demand for timber, while the higher number assumes that the difference in management resulted from more restrictive mitigations.

The number assumes that the difference in management resulted only from market demand for timber, while the higher number assumes that the difference in management resulted from more restrictive mitigations.

ANADROMOUS FISHERIES HABITAT

Spawning Gravel Composition

The potential impacts of management activities on the beneficial uses of the streams within the Fox Unit were evaluated by studying the compositional changes of spawning gravels in steelhead redds. We assume that all sediment generated in the watersheds of Jones and Hurdygurdy Creeks must eventually be transported through the stream systems. Any significant increase in the fine sediment content of the gravels would indicate an increase in mass wasting. Conversely, an absence of increased fine sediment content of gravels over the long term would suggest that logging and road building in the watershed had not significantly increased sediment production.

Fine sediment (<3.3 mm) in spawning gravel is detrimental to salmonid incubation and fry emergence. Data summarized by Reiser and Bjornn (1979) show a negligible decrease in emergence from amounts of fine sediment up to 20 percent, but increasing amounts cause an exponential decrease in emergence. The gravel composition of redds was sampled during the summer following spawning. Fifteen to 30 samples were obtained annually at one to three gravel accumulation sites in each stream. Sampling locations varied, depending on gravel accumulations and fish utilization, but were always within the permanent index reaches, approximately the lower 5 km of each stream.

Since the gravel samples were taken in completed redds, they represent particle sorting accomplished by the female steelhead during redd construction. This is advantageous because an actual parameter controlling emergence has been measured. However, the data may be limited by the fact that the gravel sampler penetrated the substrate to a depth of only 15 cm. According to Everest and others (1981), anadromous salmonid eggs are usually deposited at depths of 20-30 cm.

![Figure 3--Mean fine sediment content (less than 3.3 mm) of steelhead redds in Jones and Hurdygurdy Creeks during post-BMP period from 1976 to 1985. Data for 1977 unavailable.](image-url)
Therefore, the samples reported on here pertain more to the effects of fine sediment on emergence
of steelhead fry than to the effects on incubation, which would occur lower in the redd.

In Hurdygurdy Creek, the amount of fine sediment in the spawning gravels for 1976 to 1985 ranged
from 13.6 to 20.1 percent and averaged 16.3 percent (figure 3). In Jones Creek, it ranged from 13.4 to
23.4 percent with an average of 16.5 percent for the same period. On the basis of Reiser and Bjornn's work, we conclude that the fine sediment content of the monitored spawning gravels in Jones and Hurdygurdy Creeks has been low enough to have had no effect upon emergence of steelhead fry.

Gravel Utilization

The area of spawning gravel utilized by steelhead was assessed annually by observation and areal measurement of individual redds or groups of redds at the end of the spawning season. The annual total area of utilized spawning gravel for Hurdygurdy Creek is shown in figure 5. The data for Jones Creek show a pattern similar to Hurdygurdy Creek. The total gravel area for 1976 to 1985 ranged from 184 to 1,110 m². In 1976, a total of 414 m² of utilized spawning gravel was present at ten permanent reference sites in Hurdygurdy Creek. In 1985, there was 219 m² of gravel at these sites, but there was an additional 891 m² in new locations within the index reach. The high annual variability in the amount of spawning gravel probably results from both recruitment and sorting of channel substrate by seasonal flows of sufficient magnitude and duration to erode existing deposits and transport bedload. These processes appear to reflect episodic sediment transport resulting from channel adjustments to the catastrophic flood of 1964. Because the data are noisy, only very large upstream impacts would be detected by this monitoring. Effects of large landslides or many small failures might be detected if a background trend could be recognized. A generally increasing trend in spawning gravel area is suggested by the data for Hurdygurdy Creek (fig. 4), but we were unable to relate this to specific changes in watershed conditions.

CONCLUSIONS

The soils monitoring data indicate that erosion does occur with current practices of clearcutting and burning, but eroded material does not appear to be transported off-site. The mobile material consists of mostly coarse fragments that are relatively unimportant for soil productivity. The absence of off-site transport probably results from the coarseness of the material and effective buffering of stream channels. After four years, soil movement appears to approach preharvest levels due to soil armouring and prolific revegetation. On the steep slopes characteristic of timber sites on the Six Rivers, preservation of an organic cover after site preparation and before planting helps to maintain site productivity.

Comparison of landslide occurrence between the pre-BMP and post-BMP management periods, as a percentage of corresponding background rates, revealed a dramatic reduction. Landslide frequencies associated with harvest areas and roads were reduced by 49 and 85 percent respectively. Combined relative impacts of landslides associated with harvest areas decreased between 52 and 63 percent, while the impacts associated with roads decreased between 84 and 88 percent. We believe that this can be attributed in part to the effectiveness of the Fox mitigation measures, particularly changes in road location and geometry, as well as reduced intensity of management during the more recent period.

The low percentages of fine sediment in spawning gravels and the lack of any downward trend in the amount of utilized gravels indicate that management during the last decade has not caused erosion or mass wasting of a sufficient magnitude to adversely affect spawning gravels in the main channels downstream from the managed areas. However, the inherent variability of gravel accumulation, combined with the substantial effect that steelhead exert on their habitat, make it unlikely that this type of monitoring would clearly demonstrate adverse watershed impacts.

We conclude that monitoring of BMP effectiveness should focus primarily on direct, on-site impacts. The goal of BMPs is the protection of beneficial uses, but this can best be achieved by controlling sediment production at its source. Monitoring BMP effectiveness only at the point of beneficial use reduces the opportunity to correct problems promptly at their source because of the potentially long delay between on-site impact and off-site water quality or habitat deterioration. Evaluation of a stream's beneficial uses has an intrinsic value, but the most direct and effective way to ensure resource protection is to verify the effectiveness of mitigation measures on-site.
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To address the question of the adequacy of best management practices (BMPs) one must first define "adequacy." This requires some historical perspective on the impetus for development and goals of these water quality protection guidelines. Both State and Federal regulatory and management agencies generally agree that BMPs are designed to substitute for provisions of applicable laws regulating nonpoint source discharges that could enter water or waterways. The Federal Clean Water Act (PL 92-500) and the California Porter-Cologne Act (Div. 7, California Water Code, §13000 ff) both regulate water quality. California's code provides more administrative control of "other than point-source" (hereafter referred to as nonpoint source) discharges than does the Federal code. The Environmental Protection Agency (EPA) certifies that the State of California Water Quality Control Board (SWQCB) is designated as the water quality management agency for the State of California. These requirements thus apply to both State and Federal lands.

Rather than attempt to meet all the exact requirements of State Regional Water Quality Control Boards (RWQCBs) who administer the mandates of the Porter-Cologne Act and Section 208 of the Clean Water Act through regional Basin Plans developed in the late 1970's, State and Federal agencies were encouraged to develop BMPs to help control nonpoint source discharges. The U.S. Forest Service (USFS) was designated by Management Agency Agreement in 1981 as the responsible agency for development and administration of BMPs on Federal forest lands, while local councils of government agencies were charged with development of BMPs for private lands. Nondesignated areas remain under the direct regulatory authority of the RWQCBs. In theory, regulation of BMPs on non-Federal lands is ultimately passed to local or State authorities such as California Department of Forestry (CDF) and county governments. Ultimate regulatory authority remains with the SWQCB until

REGULATORY ENVIRONMENT DEFICIENCIES

Several important conditions for assessment of adequacy of BMPs arise from the various regulatory environments under which they are administered. All potential guidelines submitted by or through the SWQCB must be approved by EPA. Section 208 of the Federal Clean Water Act of 1972, amended in 1977 and 1980, requires states to prepare areawide nonpoint source pollution treatment plans, to be certified by EPA. This certification is mandatory if the State is to maintain its status as the approved water quality management agency. EPA has threatened to revoke this status in some states because of inadequacies or conflicts that have appeared in their regulatory programs. In California, the SWQCB is under continuing pressure from EPA to maintain and upgrade its regulatory program.

BMP guidelines developed by the USFS are in general of a nature that commend approval by the
State and EPA. However, those provided through CDF are sometimes more problematic and have caused SWQCB to approve such regulations marginally, subject to continued monitoring and evaluation of their adequacy. The Federal BMP management guidelines are directly stated and are termed "BMPs" while those of other State agencies are often rather obscurely buried in local grading ordinances or, as for CDF, incorporated into the Forest Practice Rules. The USFS BMPs total 98 different practices divided into eight different resource categories: Timber, Road and Building Site Construction, Mining, Recreation, Vegetative Manipulation, Fire Suppression and Fuels Management, Watershed Management, and Grazing. All but two of the current (1979) Federal BMPs have been approved by the SWQCB and EPA.

In most cases, SWQCB or RWQCBs may review approved BMPs for adequacy and enforcement and may request improvements or revoke approval. However, in the unique case where the SWQCB approves and delegates authority to another State agency, the SWQCB effectively loses control of the implementation process. It is greatly to the advantage of a management agency like the USFS to maintain its certification and authorization to effect BMPs through Management Agency Agreements. Since the State has the authority to assess permit fees and to require procedural and reporting requirements for each proposed action, agencies without full control of their own nonpoint source discharge regulation could be very considerably slowed down by State actions.

Thus, the SWQCB has some considerable continuing control over non-State agencies, but very little over State agencies, once BMPs are fully approved. In the event of noncompliance by State agencies, only action by EPA could force changes; such actions are difficult and most often too late to be very effective in today’s political climate.

Despite the apparent strengths of the SWQCB in its present position, the RWQCBs do not often take a very hard position on BMPs. Their role is seen largely as being advisory and reactive. They cannot generally develop very extensive monitoring programs and are not staffed or funded to conduct much enforcement. Neither do they feel that it is possible to contract outside monitoring to independent third parties such as the University system because funding cannot be developed from applicants under existing agency regulatory structure. Although the RWQCBs can participate in State and Federal timber harvest plan reviews, they must delegate primary authority for implementation of BMPs to the agencies in direct control of the proposed actions. Further, although the SWQCB has some budgetary allowance for monitoring and laboratory contracts, that funding is mainly focused on point-source problems.

Best management practices therefore provide a desirable method of effecting compliance with nonpoint source water quality regulations from the perspective of both the regulators and those being regulated. However, the regulatory environment is not sufficiently tightly structured to permit enforcement or to mandate continued implementation in all instances. It may be assumed that a merely advisory position is better than no input or oversight at all. As an example of the latter, the California Environmental Quality Act requires that all projects address consistency with regional plans as developed by local councils of government such as the Association of Bay Area Governments. These include BMPs developed by those agencies in response to the planning requirements of Section 206, and all water quality directives of the Basin Plans. There is no administrative structure, however, that can effectively oversee this mandate or can review proposed projects for consistency. It most often must be left to nongovernmental third parties, such as citizens’ groups, to bring pressure or blow whistles when noncompliance is noted.

### STRUCTURAL SHORTCOMINGS

A primary shortcoming of BMPs as presently administered is in the enforcement-implementation-monitoring phases. Conceptually, most practices are sound. Implementation strategies, however, often require impractical or impossible oversight and monitoring, for which funding and staff are not available. Both Federal and private land use management guidelines suffer from the same enforcement failures. Particularly critical are the short periods of monitoring or follow-up before an operator is released from further responsibility. Such 3-to-5 year periods do not accommodate the reasonably expectable significant runoff and rainfall events that would test the adequacy of BMP implementation.

Secondary shortcomings include those groups of considerations that focus around cumulative effects of multiple sources of watershed stress. While a BMP may be more than adequate for protection of an otherwise unstrressed watershed system, it may be completely inadequate in a degraded environment where, for example, background sediment yield and spawning redd gravel impaction is great enough to limit reproductive success of a full fish population to only a few usable sites. Here, even the most diligent application of BMPs may not be adequate because of ongoing degradation. For example, previous land management activities may have included road construction triggering slope failure leading to current channel disequilibrium. It may even be that BMPs are...
precisely the wrong approach to stabilization of a damaged system. For example, removal of large woody debris and log jams create the conditions for sudden release of large quantities of sediment, which moves kinematically downstream and causes undercutting of hillslopes and destruction of streambanks. Controlled restraint of sediments through natural or artificial log jams that provide for fish migration without releasing undue sediment may often be a far better management practice for restoration of a damaged watershed.

ANALYSIS OF SPECIFIC BMPs

A considerable BMP review effort is now going on. Paired watershed studies are being made in the State of California's Casper Creek Watershed and in Santa Cruz County, among other sites. The SWQCB has fielded a "208-review team" made up of a member of the SWQCB staff, an industry representative, a CDF representative, and a California Fish and Game representative to review 100 timber harvest plans for specific water quality damage 1 or more winters following completion of the plans. Their work is to be completed in December 1986, with final reports by March, 1987. Research studies by CDF on upland source erosion and Ray Rice and others investigating the association of large-magnitude events and damage will be integrated with other recommendations to try to refine BMPs. One goal will be to see if the BMPs can be modified to better accommodate geomorphically significant runoff and precipitation events. Because the scope of ongoing review activities is large, and because it would be premature to release the results of these studies, the question of the efficacy of BMPs is difficult to answer completely at this present time. Rather than provide a critical review of all BMPs at the present time, it may be more judicious to look carefully at some unpublished preliminary work and raise some generic questions that can be addressed from theory and presently available data.

Most BMPs appear to do the job they are designed for. For example, if implemented, the theory and practice described in Practice 1-18 "Meadow Protection During Timber Harvesting" is perfectly sound. Similarly, the BMPs relating to road construction methods to minimize erosion (Practice 2-9 "Timely Erosion Control Measures on Incomplete Roads and Streamcroasing Projects"; 2-10 "Construction of Stable Embankments"; and 2-11 "Control of Sidecast Material") are not subject to criticism directly. They embody sound theory and engineering practice that cannot be faulted.

Stream Protection Zone BMPs

Other groups of BMPs are founded less clearly in theory and based on inadequate empirical data or upon observations that are not universally applicable. To illustrate a single, but important example of this class of BMPs that are open to improvement, this paper will explore those practices that focus upon the stream and streambank protection zones. The USFS uses a Streamside Management Zone Designation approach (Practice 1-8) that is similar in theory to that of CDF with their Watercourse and Lake Protection Zone (WLPZ) regulations. Streamcourses are protected, in theory, by designating a zone of more restrictive management along the watercourse (see EMP 1.19 "Streamcourse Protection").

These guidelines and regulations are based upon numerous published studies that were initially summarized by the California SWQCB (1973) and by EPA (1973) as the bases for the present law. They are soundly based upon observations that loss of riparian or streamside canopy leads to degradation of fishery habitat through temperature increases and through bank erosion which in turn affect spawning gravel, stream biota and turbidity (Mahoney and Erman, 1984). Numerous other studies have suggested that streamside buffer strips also provide a measure of filtration of downslope sediment transport. The temperature effects and effects of loss of streamside vegetation on detrital and sediment inputs are well documented (Knight and Bottruff, 1984). Some effects of management activities beyond the immediate streambank and riparian zone upon streamflow, overland flow, and sheet erosion can be assessed based upon the clearly demonstrated hydrologic partial contributing area concept (Dunne and Black, 1970a, Hewlett and Nutter, 1970). The ability of streamside vegetation to filter sediment derived upslope above the buffer strip is open to serious question, however, and is not well demonstrated.

Many applications of BMPs to streamside protection seem to be based upon assumptions about filtration. The USFS and CDF practices define management zones on the basis of "slope distances" from the apparent high-water marks of watercourses (Practice 1-19). Use of the slope-distance concept to define stream management zones or WLPZ's implies that a certain width of protected zone is necessary to protect water quality, thus implying a filtering effect of the width of protected soil and vegetation. As pointed out by Erman, Newbold and Roby (1977) in their statewide California study, the diversity of stream macrobenthic communities increase in a linear fashion as the width of the buffer strip increases from 2 m up to nearly 60 m buffer width (op cit, fig. 1, p. 15). Those authors concluded that invertebrate communities were deleteriously affected by logging without buffer strips of at minimum approximately 30 meters, although this width generally exceeds that required under most applications of BMPs. The authors concluded that streams with buffers less than 30 m wide generally show the same aquatic impacts as do streams without buffers.

5 Practices are designated by the USFS Practice number, based upon the current (1979) list. These are not generally the reference numbers of the sections of the Forest Service Manual and Handbook system, which is subject to continued revision, but they are usually cross-referenced.
Thus, inadequate buffer widths, such as those 40-50 ft. equipment exclusion zones suggested in EMP 1-19, are not generally adequate (Erman, et al, op cit, 1977).

Management guidelines generally do not exclude operations within the protected zones, but limit uses of heavy equipment, filling into watercourses, and other logically founded direct erosion preventive measures. These measures prevent erosion within the protected zone only, not above it. Only the filter/sediment-detention concept can be called upon as a rationale for use of streamside protective zones as a mitigation for upslope sediment release.

To explore the effectiveness of EMPs in promoting filtration to trap sediments, studies are underway in several areas of coastal California. Work is in progress. On private lands considerable effort has been expended simply to obtain agreement among responsible agencies on choices of methodologies for assessing the effectiveness of EMPs. Theoretically sound approaches to testing may be procedurally very difficult. Some of these problems can be illustrated by relating the results of a methodologically experimental study in Santa Cruz County (Mendenhall, 1986).

Branciforte Creek Study

A very small subdrainage of approximately 12.4 acres in a 30-acre area of selective cut in second and third growth redwood forest was chosen for monitoring. The watershed is characterized by a small (CDF Class III) ephemeral watercourse with a well-defined channel incised in a gully at its head and an unchannelized portion along its lower course, where it passes through an undisturbed filter strip and enters Branciforte Creek (CDF Class I). The upper slopes were selectively logged between 1943 and 1948 as well as at some undetermined earlier time or times. Selective tractor harvest was conducted on about 9 acres of the watershed in mid-1984 and monitoring was performed during the 1984-85 and 1985-86 winter run-off periods.

The overall erosion hazard rating for the site was extreme under CDF's classification, and because tractor roads crossed the Class III watercourse, there was little doubt that sediment would be generated by the harvest. This was an ideal site to evaluate the effectiveness of the mitigation measures, which in this case were those qualities of the stream management zone EMPs related to filtration. It is well to recognize here that the practices and implementation of EMPs by CDF are not greatly dissimilar to those of the USFS and that conclusions drawn should be applicable with limitations, to other streamside protection zone EMPs.

Each storm period was sampled for hourly precipitation, runoff, and sediment concentration at three sampling stations representing three stream reaches (see fig. 1). Precipitation intensities for the two years of observation were apparently of average to slightly below average frequency-duration-magnitude. Suspended sediment grab samples were analyzed for grain size distribution. These data were compared with similar analyses of source-area soils and with depositional fans and channel deposits within the three reaches. Slopes of the studied channel averaged 35 percent for reach I near the top of the subwatershed and as little as 8 percent in the lower reach. These are shown to scale in figure 1. Total channel length was 1100 ft and total relief was 315 ft.

Results are summarized graphically in figure 1. Sediment flux was measured in two different fashions. Suspended sediment was measured at the three stations by grab samples. Between storm runoff periods net aggradation and degradation of the channel was estimated directly by observation erosional rill volumes and depositional sheet thicknesses. The depositional features extended well beyond the shallow channel of the class III watercourse. Waterborne sediment flux measured above a reach could then be compared with the estimated deposition within the reach to determine what proportion of that sediment was stored within the reach.

Preliminary results indicate that Reach I, just above the buffer strip, trapped about 5 percent of the sediment supplied to it for the winter of 1985-86 (the second winter). Total flux into the reach was 1443 lb (dry weight), with 1366 lb exiting to the buffer strip. These were net figures. Actual deposition within the reach that had been specially prepared to trap sediment by tractor placement of lopped slash was approximately 400 lb, with net erosion within that reach of 319 lb. As would be expected, the size classes of materials tending to remain in the reach were in the medium to fine sand classes. Silt size materials passed through the lower reach as did all fractions coarser than about 0.2 mm, which tended to remain in the rills and channels. Microtopography was important. Through both years of observation, sites with 8 percent slopes or less had net deposition, sites with 9-13 percent gradients had both net deposition in one year and net erosion in the
other and sites above 13 percent slope had net erosion or no change during all observations.

Sediment passing through the buffer and entering Branciforte Creek was not directly measured. However, it can be estimated from the data at sampling point 1. No erosional or depositional modification of the topography occurred within the undisturbed buffer zone or for 44 feet above it, where slopes were form 9 percent to about 30 percent at the Branciforte Creek bank. Yet, approximately 1366 lbs of sediment passed into the buffer strip, primarily in all-size fractions and must have passed on through into Branciforte Creek along the Class III channel system. No depositional fans or net channel aggradation occurred in the buffer strip. Thus the buffer strip itself did not alter sediment flux. The tractor mulching of slash into the channel above the buffer was effective in detaining a small portion of the sediment above the buffer and might thus give a visual impression of effectiveness if observed after storm runoff events.

Hillslope Hydrology and Stream Protection Zones

A primary shortcoming of the watercourse protection BMPs is their insensitivity to geomorphic variation in sediment sources and transportation modes. To effectively establish a protective zone width, one needs to assess the kind of hillslopes that feed sediment to watercourses. In California, there are basically three types of stream zone geometries, each requiring a different management strategy. Yet all are effectively lumped into one set of management guidelines based upon the apparent assumption that all fit the stream and hillslope geometries classically ascribed to the Horton hillslope model (Betson, 1964; Dunne, 1978). This form has traditional hillslopes that are convex at the tops, straight in their middle reaches, and concave upward near the watercourses. As presented to explain surface erosion for protection of water quality (SWRCB, 1973, vol II, fig. 10), this Horton valley slope model assumes that no erosion occurs by overland flow in the upper convex portions of hillslopes, that the middle straighter section is actively eroded by surface flow, and that the lower concave portion along the watercourse is a zone of deposition of sediment. This faulty model has apparently been used to justify stream protection zones and the use of the concave hillslope section to "catch" downslope movement of sediment.

Much work has been done since that of Horton (1933, 1945) to better understand hillslope sediment production, transportation, and hydrology; yet Horton's ideas seem to dominate current management practice. Horton believed that the primary variable in determining storm runoff and sediment yield from slopes was infiltration capacity. Figure 2 (left) illustrates the typical Hortonian model of hillslope overland flow development and sediment production. As can be seen, this model predicts that undisturbed lower slopes adjacent to watercourses, where concave in profile, should be sites of sediment deposition. Field observations by geomorphologists, hydrologists, and foresters in many regions cast doubt on Horton's model. If lower slopes were to be sites of deposition and if hilltops were to be sites of no erosion, then hill profiles should become increasingly concave through time and toe-slopes may become elevated far above the stream courses that control them. Some authors suggested that Horton's runoff theory represented only an end member in a spectrum of responses possible under various levels of soil infiltration capacity (Kirkby and Chorley, 1967; Nutter, 1971).

![Figure 2--Comparison of classic concept of slope development after Horton and California coastal mountain hillslope model.](image)

A second slope form is that with straight midslope sections abruptly meeting alluvial benches that usually occur near the present watercourses. This form of hillslope may genuinely "trap" downslope movement of sediments derived from upslope disturbances and store it at the break in slope until flood stages of the watercourse undercut and transport it. A third common form of hillslopes in California mountain areas subject to tectonic uplift is that characterized by a straight mid-section meeting a steeper inner gorge that directly borders the watercourse. This form of hillslope is one in which sediment, once mobilized upslope, will pass through any sort of vegetative buffer that can reasonably be expected in inner gorges.

Professional opinion is now well focused on a series of conceptually simple slope sediment models based upon wide empirical field evidence (Dunne, 1986; Kirkby, 1986). Basically, depth of slope sheet runoff increases downslope as a function of the square root of the distance from the drainage divide. As vegetation cover increases on a slope, so also does the depth of the runoff, since it increases roughness and detains the overland flow. The time of concentration of runoff in relation to the slope length is critical in the determination of slope shape. For slopes of uniform potential infiltration capacity, slopes assume convex form where rainsplash erosion dominates and overland flow discharge decreases downslope owing to increased net infiltration.
For long-duration rains, as sheetwash becomes critically deep downslope and begins to erode, the moving sheet of water protects the slope from further direct rainsplash erosion. On this slope segment, rills are generated. With even deeper sheetwash near slope bases, flows become channelized. Upper convex slopes are dominated by rainsplash and creep erosional processes, straight slopes represent areas of primarily sheetwash erosion, and concave slopes reflect both sheetflow and rill or gully erosional processes. All of the hillside is erosional and, in an equilibrium situation, the eroded materials must be transported across the slope profile to the controlling watercourse at the base of the slope.

Where inner gorges characterize hillside profiles, as are typical in much of California, mass erosion may dominate the lower slopes. Rill, sheet, and gully erosion also occur in the lower slopes of the "California Model" (fig. 2, right) but the steep inner gorge slopes owe their existence to mass failure susceptibility, active stream downcutting, and the fact that hillside vegetation can permit slope development in a metastable or "oversteepened" condition. Root arching and root cohesion increase the shear strength of inner gorge slopes. As the controlling stream cuts downward into bedrock, inner gorges become progressively oversteepened by removal of more material from their base than is supplied by overland erosional processes. Mass failure tends to readjust the slope profiles to better equalize rates of downslope sediment delivery with the transportational capacity of the stream below it.

Where upper hillslopes are in equilibrium with the controlling stream and a convexo-concave slope profile develops, modification of infiltration capacity through compaction or dilation of surface soils will lead to direct changes in rainfall/runoff ratios and resulting changes in the profile of a stable slope. This generally means increased erosion at some point in the slope profile. Where evapotranspirative moisture demand is changed on a portion of a hillslope, soil moisture levels will change and this will result in changes in infiltration capacity. This also will often lead to changed slope profile stability. Figure 3 illustrates one form of change figuratively shown as a change in groundwater level. In fact, the change is primarily one in the thickness of the unsaturated zone above a hypothetical zone of seasonal saturation. As evapotranspirative demand decreases, pore water pressures increase and the area of the slope subject to saturation during storms or snowmelt increases. This increases the area of the slope that contributes to the storm hydrograph (the variable source area concept) but more importantly increases the area subject to rill, gully, and mass erosion. This occurs as the result of increased infiltration capacity which can result from roading and decreased interception loss with timber removal. This effect is exacerbated by higher antecedent soil moisture levels before a winter storm runoff period begins.

Effective buffer strips in inner gorges are probably not theoretically possible, even if placed well above the break in slope at the top of the gorge. This is because the watercourse has sufficient power to downcut faster than the hillside can backwaste and will take advantage of any slope profile disequilibrium to erode more rapidly. The Horton convexo-concave slope model cannot be called upon to filter sediments, even if the buffer strip is placed well above the transition to concave slopes, and thus above most of the prime timber producing sites. This is because the concave portions of the slope are not sites of deposition, but are sites of transportation of finer grained materials winnowed downslope by surface flow. If they were really acting as effective filters, the slopes would become steeper at the watercourse. Sometimes this does happen because the concave slopes temporarily trap sediments, releasing it during major surface runoff events only and thus effectively regulating rates of sediment yield from hillside slopes. The hillside bounded by alluvial flats may work very effectively for development of buffer strips. Those buffer widths are defined by the edges of the flat surfaces themselves.

![Figure 3](image-url)
size of partial contributing areas and changes in pore-water pressure within the inner gorge slopes.

CONCLUSIONS AND RECOMMENDATIONS

We must conclude that BMPs are not all working as intended if we consider the goal of the management guidelines as meeting the specific legal requirements of the California Porter-Cologne Act and the Federal Clean Water Act with respect to nonpoint discharges. We must also conclude, however, that BMPs are "working" in that they are the only practical and feasible method of nonpoint source water quality protection for land use management activities that can reasonably be expected to protect against future damage. Although deficiencies exist and need to be remedied, the concept is so valuable that it must be maintained.

It is recommended that stream protection BMPs be significantly revised to accommodate current understandings of hillslope hydrology. Further, effective BMP implementation should be better monitored. Since the State Water Quality Control Board does not have a research role or independent research subagency, and since the USFS does not have the manpower to oversee its implementation requirements, EPA or the State Legislature must be made aware of the need for better enforcement and monitoring and must develop funding to protect California's watersheds. While ongoing studies seek to develop much-needed information on BMP effectiveness, too much reliance is still being placed upon third parties to implement the requirements of Federal and State water quality protection laws. Yet the nature of water pollution is that by the time it is recognized, it is generally too late to correct it. Thus, citizens' lawsuits, county government inquiries, and citizens' task forces are not the ideal way to develop quality-focused monitoring efforts. A more effective method would be to establish and fund, through use permit fees and State taxes, a State Water Quality watershed monitoring program of considerably larger scope than is presently contemplated. Use of the State research university system to conduct monitoring cooperatively with extant Federal Forest and Range Experiment Station and research laboratories, could permit refinement of EMPs to truly effective guidelines.

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Synthesis and Summary: BMPs

Dan Otis

The first paper in this session, by Frank Covington of EPA's San Francisco office (presented by Catherine Kuhlman), pointed out that the Clean Water Act set a 1983 deadline for nationwide attainment of fishable and swimmable waters, which in 1986 still has not been achieved. To achieve the goals of the Clean Water Act, EPA plans to exercise efforts on nonpoint source controls, including the use of BMPs.

EPA is currently developing guidelines for State water quality management agencies (such as the State Water Resources Control Board and the USDA Forest Service) which will address the relationship between nonpoint source water quality standards and BMPs.

Ms. Kuhlman ended her presentation by pointing out the difficulties in managing nonpoint source pollution because it often involves replacing old social and cultural patterns, and requires changes in basic land management in the interest of clean water.

The second paper, presented by Danny Walsh, Member of the State Water Resources Control Board, described the regulatory history of water quality control in California, including the State's Porter-Cologne Water Quality Act of 1969, the roles of the State and Regional Boards, and the role of the Federal Clean Water Act in addressing nonpoint source pollution in the State.

Mr. Walsh pointed out that nonpoint source problems are difficult to identify and address, and more difficult to solve. Solutions often involve the alteration of land use practices, and require social, economic, political, and environmental tradeoffs. State Board Policy calls for the control of nonpoint sources through land use activity BMPs, but if BMPs fail, then through waste discharge requirements or other regulatory actions.

Nonpoint source control must overcome three hurdles: technical difficulties in locating, measuring, and monitoring problems; the wide variety of possible BMPs without established implementation mechanisms; and the lack of existing regulatory approaches.

In conclusion, Mr. Walsh noted that the State Board is developing a more systematic approach to nonpoint sources, targeting the most serious problems and developing specific goals for success, with more open communications and greater coordination among concerned agencies.

In his presentation, Bob Doty of the USDA Forest Service in San Francisco spoke of the Management Agency agreement between the Forest Service and the State Water Board, and the Forest Service's Water Quality Management 208 Plan. The Plan calls for the development and refinement of BMPs, a BMP Handbook, training programs, land management planning, watershed restoration work, and monitoring of the Forest Service application of BMPs.

Carl Yee, Member of the California Board of Forestry, reminded us that timber harvesting regulation and its relation to water quality and other environmental concerns has provoked heated political controversy in California for two decades, reflecting basic disagreements between the timber companies, fishing interests, and local communities about how California forests should be used.

Mr. Yee covered the steps leading up to the revision of the Board of Forestry's forest practices related to water quality, and their ultimate submittal to the State Water Board in 1984 for consideration as BMPs. He described the current Forest Practice Rules Assessment Program performing field reviews of 100 timber harvest plans, with an expected completion date of March 1987.

Mr. Yee discussed the Board of Forestry's regulatory program, including rules, legislation, licensing of profession foresters and timber operators, and the Department of Forestry's enforcement program.

James Clawson of the Agronomy Extension at University of California, Davis, noted that different viewpoints give rise to different...
perceptions about the relationship of livestock grazing and water quality.

Grazing impacts on water quality are related to sedimentation and contamination by nutrients and biological organisms. Mr. Clawson stated that it is more appropriate to consider management options which meet a set of defined objectives than to predetermine the "best management practices." He concluded by calling for "consensus management" involving the scientific and management concerns of agencies combined with the experience of the land owner or manager.

Arne Skaugset, currently at Oregon State University, described the Forest Practice Rules process as having two distinct parts, the first being operational constraints to protect water quality, such as buffer strips, water bars, and so on; and the second being administrative constraints such as flagging, THP maps, and Review Teams, which are time consuming and expensive.

Mr. Skaugset stated that the greatest strength of the Forest Practice Rules is that they work some 90 to 95 percent of the time. The reasons for the 5 to 10 percent of failures are critical sites and human error—both unavoidable with or without rules. Mr. Skaugset feels that the administrative aspects of the Rules are a disincentive for water quality protection because of their negative reinforcement of loggers. He proposed that the only real solution to the problem is an increased effort to involve loggers themselves, so that they are aware of the environmental implications of their actions.

Chris Knopp, hydrologist on the Six Rivers National Forest, described a study of soil erosion, landslide occurrence, and anadromous fisheries habitat conducted on that Forest during the past 10 years. Mr. Knopp summarized the study, concluding that

Soil erosion does occur on steep harvested slopes, but material is unlikely to be transported offsite if stream protection measures are adequately implemented.

Avoidance of timber harvest within the inner gorge and better design and location of roads have resulted in a dramatic decrease in frequency and impact of management-related landslides.

Spawning gravel did not show any adverse effects of logging or road building in the study area.

Bob Curry from the Department of Environmental Geology at University of California, Santa Cruz, stated that BMP's are not working as intended under the goals of the Clean Water Act and Porter-Cologne; however, BMPs are working as the only means of protection before damage occurs, and therefore should be maintained. The three aspects of an effective BMP are implementation, enforcement, and monitoring.

Mr. Curry pointed out that traditional BMPs stress the filtration aspects of Stream Protection Zones, and these BMPs are based on the misconception that no erosion occurs on the tops of slopes. He cited a study in the Santa Cruz area that found 80 percent of the soil which eroded into the stream protection zone traveled through the zone and entered the stream.
The planning and implementation of vegetation management projects for water supply must consider not only the quantity salvaged but also whether the water salvaged is usable at the time it is available. The amount salvaged will be largely determined by precipitation and fraction of watershed cleared of shrubs and trees. The increase in usable water supplies will depend on the timing of clearing and the existence of reservoirs or ground water recharge facilities to regulate the salvaged water.

ESTIMATING ANNUAL WATER SALVAGE

The maximum difference between annual precipitation (P) and annual streamflow (Q), that is, the annual loss (Lst), can be approximated in inches (within the range of 5 to 90 in. of precipitation) by the equation $Lst = \frac{(182P - P^2 - 25)}{172}$. The basis for this equation is a study of the precipitation-streamflow relationship for 68 natural watersheds and 6 research watersheds (Turner 1985a). It was also found that, where $P$ is 14 in. or greater, the annual loss due to herbaceous cover ($Lg$) in inches could be approximated by the equation $Lg = 0.362P + 8.35$.

Annual streamflow from mixed cover watersheds is approximately equal to precipitation less the products of the water loss rates for shrubs and trees ($Lst$), herbaceous cover ($Lg$) and barren (Lb) areas; and the respective effective areas of shrubs and trees ($Ast$), herbs ($Ag$) or barrens ($Ab$). That is, $Q = P - (0.362P + 8.35)(1 - C) - C \cdot \frac{(182P - P^2 - 25)}{172}$. This formula is graphically represented in figure 1.

A study of the relation between tree cover (canopy) and evapotranspiration for irrigated orchards and vineyards (MacGillivray 1980) found that the ratio ($R$) of evapotranspiration with fractional tree and vine cover ($C$) to evapotranspiration with full cover is of the form $R = aC^b$, and that $R = 1.0$ at about $C = 0.75$. If it is assumed that (1) $R$ is also the ratio of actual area of shrubs and trees to effective area of same, and (2) the ratio is of the form $R = C^b$, the interpolation may be accomplished with the divisor 0.14. If the foregoing relationships are substituted into the equation $Q = P - (0.362P + 8.35)(1 - C) - 0.14 \cdot \frac{(182P - P^2 - 25)}{172}$, this formula is graphically represented in figure 1. It may be used to estimate annual water salvage, using appropriate values of $C$ to represent pre- and post-project conditions. It should be noted that the streamflow for fractional values of $C$ cannot be less than for $C = 1.0$.

Water can be salvaged by clearing shrubs and trees, but only when the evapotranspiration of shrubs and trees ($Lst$) exceeds that of herbaceous cover ($Lg$). Thus the point of intersection of the two equations at about $P = 14$ inches is the lower limit of precipitation, or threshold, for water salvage.

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

2Watershed Management Specialist, Department of Water Resources, State of California, Sacramento, Calif.
ESTIMATING DEPENDABLE WATER SUPPLIES

Analysis of long-term precipitation records (Goodridge 1985) indicates that extreme drought events, such as those of 1924 or 1976-77, are about 40 percent of normal. Thus, mean annual precipitation of over 35 in. is required to assure that some water will be salvaged by vegetation management under the most severe drought conditions. Precipitation during the drought of 1929-34 was about 70 percent of normal. Some enhancement of dependable water supplies could be expected under these conditions where mean annual precipitation is 20 in. or more. Even where there is no contribution to dependable water supplies, salvaged water may be valuable for ground water recharge or replacement of imported water supplies. Distribution of the area of California with respect to the 14- and 35-inch thresholds is mapped in figure 2.

The importance of timing of salvaged water and the presence of storage facilities has been indicated. Modeling of type conversion experiments and proposed vegetation management schemes has demonstrated that most of the streamflow augmentation occurs during the wet season (CDWR 1983, Troendle and King 1985). For this reason, surface or ground water storage is required to make the salvaged water available for use when it is needed. Proper timing of shrub and tree clearing can also reduce year-to-year streamflow variability.

MANAGING VEGETATION

The balance between shallow-rooted herbaceous cover, and deep-rooted shrubs and trees is determined by both natural events and human intervention. Natural events (fire and pestilence) are random, except that the probability of occurrence increases with age and density of shrub and tree cover. Clearing of shrubs and trees by harvest of forest products, reforestation, range improvement, and construction is related to the business cycle; that is, more area is cleared during periods of prosperity than during hard times. Without coordination, salvaged water may further increase high streamflows and thereby become unusable. Instead, clearing that could be instituted counter to the business cycle through special funding, (reforestation, range improvement, and fuel management), should complement uncontrollable or business-cycle-tied clearing (wildfire, pestilence, logging, construction, etc.) to reduce year-to-year variation in amount of water salvaged.

Managing vegetation for nearly constant hydrologic effect as a surrogate for carryover storage in reservoirs could be accomplished by a series of actions:

- Setting an annual water salvage objective based on watershed cover composition, clearing cycles for different vegetation types, treatable areas of each, and relative precipitation on such areas
- Estimating the amount of water that would be salvaged during the forthcoming year without management intervention, considering antecedent clearing
Determining the shortfall, if any, in achieving the annual objective

- Devising and implementing a plan to make up any shortfall through discretionary vegetation management

Once a vegetation management program is in operation, variation in streamflow might be further reduced by use of streamflow forecasts (California Department of Water Resources, Bulletin 120 series, January through May) to adjust the annual vegetation management plan. The March 1 forecast would be a sufficiently reliable and timely basis for increasing spring and early summer clearing in anticipation of subnormal streamflow. This would reduce the depletion of percolating waters and underground storage and thereby augment summer and fall streamflows.

EVALUATING PROGRAM ACCOMPLISHMENTS

Estimating the yield of a vegetation management program is necessary in order to plan the use of such yield in water utility operations, to demonstrate cost effectiveness, and to evaluate water right and fishery aspects (Turner 1985b). Measurement of such yield by stream gauging is not possible because of lack of unimpaired control, and because potential errors of measurement are of about the same magnitude as the yield. The effect on water supplies must be determined by monthly modeling of pre- and post-project conditions and comparison of the results (CDWR 1983). Since most of the streamflow augmentation occurs during the wet season, loss of water to riparian vegetation or senior diversion rights is unlikely and need not be considered (Turner 1985b).

Augmentation of dependable yield must be evaluated. The firm yield of reservoirs has traditionally been determined by modeling the operation of a surface storage project during a critically dry period to determine how much water could be supplied to customers during the worst drought on record. Such studies have been made without consideration of the condition of the watershed cover; that is, whether it was densely covered with shrubs and trees, or if a substantial portion had been laid bare by logging, wildfire, or other events before or during the critical period. Since the former dense cover is the worst case for water supply, augmentation of dependable yield by vegetation management projects should be measured with respect to 100 percent shrub and tree cover.

Evaluation of average water supply is also appropriate. Nonfirm water supplies from reservoirs may be valuable for production of hydroelectric power, replacement of other high cost water supplies, ground water recharge, or temporary increases in irrigated cropland. Evaluation of a proposed management scheme would consist of a comparison of water supply with and without the effect of the scheme on reservoir inflow.

REFERENCES

Water Yield Opportunities on National Forest Lands in the Pacific Southwest Region

John R. Rector and Lee H. MacDonald

Water has historically been the subject of statutes governing Forest Service management. The Organic Act of 1897, for example, made the first reference to water as a resource on National Forest lands when it cited "...securing conditions of favorable flow..." as one of the principal reasons for establishing National Forests. Water is also cited as one of the "multiple" resources in the landmark Multiple Use Sustained Yield Act of 1960. This Act requires the USDA Forest Service to manage all resources (timber, wildlife, range, etc.) in a harmonious and coordinated manner without detriment to any of them. Water quality and water quantity are both the subject of numerous legislative mandates.

The quantity of water yield from National Forest lands is primarily a function of precipitation and evapotranspiration. Vegetative manipulation activities, such as timber harvesting and/or prescribed burning of brush, will generally decrease evapotranspiration and thereby increase runoff. As a result, many of the normal Forest Service management activities can be expected to increase water yield. As the vegetation grows back to its original size and density, water yields return to their former levels. Similarly, conversion of brush or low-production timber areas to grass will usually increase total runoff. On the other hand, these same management practices constitute a potential threat to water quality, which might manifest itself as increases in turbidity, sediment loads, and stream temperatures, or as a reduction in fish habitat. In practice, Forest Service emphasis has been to minimize the adverse effects of management activities on water quality and aquatic life.

Water yield from National Forest lands is typically regarded as a byproduct of other Forest management activities, and influencing water yield has not been a specific objective of management actions.

In some parts of the State, particularly along the North Coast, the supply of water exceeds demand, and management efforts to increase water yield would be superfluous. On the other hand, water supply is a central concern of most Californians, and continuing population growth suggests that the concern will become increasingly acute. It is, therefore, appropriate to assess water yield augmentation opportunities on National Forest System lands, and determine if managing for water yield is indeed a partial solution to predicted future shortages.

The importance of National Forest lands to the water resource in California is evident in several ways. First, over 77,300 km² (19 million acres) of land, or nearly 20 percent of California, are managed by the Forest Service, U.S. Department of Agriculture. (The 18 National Forests in California constitute Region 5, the Pacific Southwest Region, of the National Forest System.) Second, Forest lands are located in more mesic areas, so the National Forests yield a disproportionately higher percentage of the State's runoff than would be expected by area alone. Similarly, the high evapotranspiration on National Forest lands suggests that they may have the highest potential for increasing water yields. Finally, the spatial distribution of the National Forests suggests that the results of a water yield program would have relevance to the State as a whole.

Though considerable research has been done on water yield augmentation, relatively little of this has been done in California. The applicability of research study methods to National Forest lands is uncertain as the vegetative treatments typically were either more severe or more widespread than most Forest Service management. Consequently, research findings have not been extrapolated to

Abstract: National Forest lands in California produce 47 percent of the State's runoff, but occupy only 20 percent of the total land area. Using results from the ongoing planning process in each National Forest, it is estimated that the maximum possible water yield increase is 1.4 billion m³ (1.1 million acre-ft.). Under the preferred alternatives, total water yield would increase by slightly more than 1 percent (437 million m³ or 354,000 acre-ft.). Uncertainties in estimating and obtaining this projected increase may pose difficulties in formulating and executing any water yield policy.

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actual land management scenarios in order to provide a comprehensive picture of the Region's opportunities to influence water yield. In the absence of such information, it has been impossible to formulate a Region wide policy on water yield management. The planning process established in response to the 1976 National Forest Management Act (NFMA) provided an excellent opportunity to make the first preliminary estimates of current and potential water yields under different management scenarios. Since all 18 National Forests have completed a draft plan, it is now possible to prepare an overall perspective on water yield opportunities in Region 5.

WATER YIELD ASSESSMENT PROCESS

In 1979, water yield was identified by the public as an issue to be addressed in the Region wide resource management plan ("Regional Guide"). Broad alternative water yield management options were assessed and water yield management guidance given to the 18 National Forests. Subsequent Forest planning direction issued in 1982 included more specific water yield assessment requirements. The context of all this planning effort was NFMA, which required each Forest and the Region to develop comprehensive, long-range land and resource management plans. The mechanism employed to facilitate much of this planning was an extensive linear program (FORPLAN). It was used to quantitatively analyze resource outputs--given certain assumptions and constraints--over a time scale of five decades. With regard to water yield, each Forest was required to estimate water yield under current management, maximum potential yield, minimum yield, and the water yield associated with each of the alternative management scenarios presented in the Forest planning process.

These estimates of current and potential water yield did not take into account ongoing weather modification efforts, as the research results on cloud seeding were found to be inconclusive. Snowpack manipulation was not included in the water yield analysis either, as it was believed to influence runoff timing more than runoff quantity. Forest planning projections of changes in water yield were limited to assessing changes resulting from vegetation manipulation and resulting changes in evapotranspiration.

Some Forests projected water yields by incorporating tables of water yield coefficients within the FORPLAN model. Changes in water yield were then compiled internally as the model made land use allocations and applied various vegetative treatments. Other Forests conducted their water yield analysis outside of the FORPLAN model by applying water yield coefficients to related outputs produced by FORPLAN (e.g., acres of wildfire, miles of road construction, acres of prescribed fire, or acres of timber harvest).

It is important to note here that the methodology used to determine water yield varied from Forest to Forest because of differences in climatological, physical, and biological conditions, and data availability. Some Forests developed water yield coefficients for forested catchments based on research results such as Harr in 1976 and Harr and others in 1979. For more xerio or brush-covered sites, results from Hibbert in 1979 and Burgy and others in 1975 were utilized. Other Forests used similar procedures but made adjustments to account for local conditions not considered in the original studies. In some cases, changes in water yield were simulated by running hydro-meteorologic and vegetation data through computer models such as WET (Williams and Daddow 1982) and HYSED (Silvey and Rosgen 1981). This lack of analytical consistency severely limits the comparability of results from individual Forests, but it is not as critical to the following Region wide summary of potential water yield opportunities. The analysis accomplished by each Forest was as rigorous and accurate as possible for this first cycle of NFMA planning. Despite the methodological differences, the data prepared by the individual Forests provides the best means to assess water yield opportunities from National Forest lands in California. The following sections present the combined results of the water yield assessment for all 18 National Forests, and place these in the context of current management.

Current Water Yield from National Forest Lands

So that all water yield projections may be viewed on an equal basis, current water yield was calculated as the average annual runoff obtained by extrapolating current management practices and policies into the future. The combined water yield values from the Forest's "no action" NFMA alternatives were used to establish the current yield for the Region. In practical terms there is little difference between this projected average yield and actual present yield. Using the "no action" alternative, the 77,300 km² of National Forest lands in California are estimated to yield 41 billion m³ (33.4 million acre-ft.) per year, or 47 percent of the State's total average runoff of 87.6 billion m³ (71 million acre-ft.) (California Water Atlas 1979). This is an average of approximately 53 cm of water per year over all the National Forest lands in California.

Even though the National Forests are in the more mesio sites, there is still considerable variation in the average annual water yield. Among the 18 National Forests in California, the Cleveland National Forest, headquartered in San Diego, is at
the low end, yielding an average of 7.0 cm (2.8 in.) of water over its 1700 km² (420,054 acres). At the other extreme is the Six Rivers National Forest, centered in Eureka, which produces an annual average of 165 cm (65 in.) of water over its 3875 km² (957,590 acres).

For the purposes of this paper it is useful to divide the National Forests in California into three basic groups--Northern, Sierran, and Southern. These have some basic hydrologic consistency, and they allow general trends to be presented without the overwhelming detail of all 18 Forests. Although water yield should be analyzed by river basin rather than management units, many of the Forests span several basins. Furthermore, the aggregated nature of the water yield values, which were derived from Forest-wide management treatment and vegetation unit allocations as opposed to treatment per watershed, does not render the values readily separable into yields per drainage basin.

The six Forests in the Northern group are the Klamath, Lassen, Mendocino, Modoc, Shasta-Trinity and Six Rivers. These Forests represent 31,181 km² (7.70 million acres) or 40 percent of the Region's land base, but provide 60 percent of the annual water yield from National Forest land (79 cm or 31 in. per unit area).

The seven Sierran units include six National Forests--Plumas, Tahoe, Eldorado, Stanislaus, Sierra, and Inyo--and the Lake Tahoe Basin Management Unit. These Forests include 36 percent of the land base (27,560 km² or 6.81 million acres) and yield an average of 52 cm (20 in.) of water, or 34 percent of the annual total yield.

The five Forests in the southern group are the Sequoia, Los Padres, San Bernardino, Angeles, and Cuyamaca. While these Forests incorporate 18,590 km² (4.59 million acres) or 24 percent of the land base, they produce an average annual water yield of only 13 cm (5 in.), or 6 percent of the total yield.

It should immediately be recognized that these current National Forest water yield figures are not "natural" or "pristine" yields. Much of the original forest and brush vegetation has been disturbed and manipulated by man. To the extent that the predisturbance vegetation has been replaced by a vegetation type which utilizes less water, or is being harvested on a regular basis, water yields already have increased. On the other hand, fire suppression has allowed tree and shrub species to invade former grasslands and thereby decrease water yield. Since it is unlikely that there will ever be a return to predisturbance vegetative conditions, our baseline is current yield from National Forest System land. Any assessment of potential increases or decreases in runoff must be compared to current management.

**Maximum Water Yield Potential**

To determine the upper bound for water yield, the Forests were directed to formulate and analyze a Maximum Water Yield alternative. This alternative was defined to be physically and technically feasible, but not necessarily operationally possible. In other words, the Maximum Water Yield alternative was not limited by Forest Service policy, budget considerations, spatial feasibility, or program and staffing requirements. The analysis constraints applied were only those representing management requirements beyond the Forest Service's authority to change (e.g., statutes and regulations rather than internal policy and direction) and the minimum constraints necessary to protect the productivity of the land.

The primary treatments applied within the alternative to maximize water yield were the conversion of brush and low-site timber lands to grass, regular and recurring burning or other brush treatments, and intensive timber harvest at minimum rotation ages. These management prescriptions were applied to (a) all of the land base that was capable of sustaining the treatments without impairing the productivity of the land, (b) all land that was administratively available to the Forest (i.e., not withdrawn or under a special designation that would preclude treatment), and (c) all land that was suitable for water yield treatment application (not barren, rock, or water). Whereas this Maximum Water Yield alternative is believed to approximate the upper limit of theoretical water yield potential, it does not pretend to represent optimal multiple-use management.

Frequently the Maximum Water Yield analysis was synonymous with the maximum timber production and maximum range production analyses that were conducted as part of the overall planning effort. Commonly the management prescriptions and treatment schedules associated with maximizing timber and range production are the same activities and schedules which maximize water yield.

A compilation of the Maximum Water Yield analysis indicates that the maximum average annual yield that could be produced from National Forest lands in California is 42.5 billion m³ (34.5 million acre-ft.). This represents an increase over current yield of 1.4 billion m³ (1.12 million acre-ft.) per year, or a 3 percent increase. While this appears to be a substantial increase in volume terms, it represents considerably less than 1 percent of the total...
forests in California and an areal increase of only 1.8 cm (0.7 in.) of runoff from National Forest System lands.

In contrast to the current distribution of runoff from National Forest lands, the theoretical increase of 1.4 billion m$^3$ would be distributed as follows:

1. 19 percent or 256 million m$^3$ (215,500 acre-ft.) from the six Northern Forests; this represents an areal increase of 0.9 cm.
2. 67 percent or 926 million m$^3$ (751,000 acre-ft.) from the seven Sierran Forests--this is 3.4 cm (1.3 in.) per year on an areal basis.
3. 14 percent or 187 million m$^3$ (151,400 acre-ft.) from the five Southern Forests, which is 1.0 cm (0.4 in.) per unit area per year.

This analysis indicates that under the assumptions and constraints described above, the greatest potential to increase water yields is in the Sierran Forests. The Northern group of Forests, although they generally have higher average precipitation and presumably a higher average evapotranspiration, have less potential to increase water yields. This is presumably related to analysis constraints imposed on timber harvest and type conversion and because much of the water yield increase potential has already been realized as a result of past and present management activities. For the 16 National Forests in California, the highest potential increases were estimated to be 5.8 cm (2.3 in.) and 5.4 cm (2.1 in.) per year on the Tahoe and Stanislaus National Forests, respectively. The lowest potential increases were on the Modoc National Forest in northeastern California (0.06 cm or 0.02 in.), and the Inyo National Forest (0.07 cm or 0.03 in.) on the east side of the Sierra Nevada.

The Probable Regional Opportunity

A more realistic view of potential water yield increases from National Forest lands in California can be made by comparing total water yields from the composite of the Forest "preferred" alternatives against current yields. The preferred alternative represents the Forests' land allocations and resource management practices which best respond to public issues, management concerns, and resource capabilities. In preparing this preferred alternative, constraints were added to proxy resolution of issues and to assure that the final plan was physically, technically, and operationally feasible. Since the preferred alternatives represent the most likely scenario of future management, they offer the best estimate of future changes in water yield from the National Forests in California.

Total water yield from National Forest lands under the preferred alternative is estimated at 41.6 billion m$^3$ (33.7 million acre-ft.) per year. This represents an increase of 0.4 billion m$^3$ (354,000 acre-ft.) or 1 percent above current annual yield. On an areal basis this is approximately 0.6 cm for the entire Region. The respective water yield contributions of the Northern, Sierran and Southern portions of the Region yield more closely resemble distributions typical of the maximum water yield alternative than those represented by current yield conditions. The distribution of this projected increase is as follows:

1. 25 percent (111 million m$^3$ or 89,600 acre-ft.) of the increased runoff would come from the six Northern Forests; this represents an areal increase of 0.4 cm per year.
2. 55 percent (242 million m$^3$ or 196,000 acre-ft.) of the increase would come from the seven Sierran Forests; on an areal basis this increase is 0.9 cm per year.
3. 20 percent (85 million m$^3$ or 68,500 acre-ft.) of the increase in water yield would be derived from the five Southern Forests; this is about 0.5 cm per unit area, or about half the yield increase for the Sierran Forests, but slightly more than could be expected from the Northern Forests.

These projected increases in water yield again differ considerably from current yield, but the proportions are roughly comparable to the estimates obtained under the Maximum Water Yield analysis. Hence the Sierran Forests appear to offer the greatest likelihood for increasing water yields. The projected value of 0.9 cm per year is relatively close to the 0.6 cm estimate by Kattelmann and others, (1983) for the Sierra Nevada Mountains. As in the Maximum Water Yield analysis the largest increase--2.4 cm--is expected to come from the Tahoe National Forest. At the opposite extreme, the Lassen National Forest projects a small decrease in water yield under the preferred alternative.

The important role that management constraints play in influencing the planning analysis output becomes clear when comparing the Maximum Water Yield outputs to those of the preferred alternative. For the Maximum Water Yield analysis only minimal constraints were imposed. For the preferred alternative, additional constraints were imposed by the Forests to assure implementability, resource protection, and responsiveness to public concerns. As a result, the water yields under the preferred alternative are only approximately 42 percent of the maximum yield potential in the Northern group of Forests, 26 percent of maximum potential in the Sierran group, and 45 percent in the Southern group. The reduction in potential water yield for the Sierran group of Forests is greater for several reasons. More constraints were
applied to assure implementability and to protect
amenity values (riparian ecosystems, old-growth
habitat, and visual quality). Reductions were
also made in the land base because of special
designations (such as research areas, natural
landmarks, and other special interest areas) and
economic requirements were imposed that precluded
vegetative treatments where they were not cost
effective. (Much of the upper elevation and
east-side lands are believed to fall into this
category.)

Future Options and Opportunities

While the projections made under the preferred
alternative represent the most realistic estimate
for increasing water yield from National Forest
lands in California. A variety of other
considerations must be taken into account before a
water yield policy and management program can be
developed.

First, the predicted increases in water yield
are estimates and by no means assured. In
general, when vegetation density is reduced, or
when deep-rooted species are replaced with
shallow-rooted species, the amount of water
transpired and intercepted by vegetation is less
(Bosch and Hewlett 1982). Providing there is
rainfall in excess of soil moisture storage and
potential evapotranspiration for at least part of
the year, runoff should increase. Experience in
the Southwest suggests that if mean annual
precipitation is not at least 40–45 cm (16–18
in.), there is no increase in water yield (Hibbert
1983). Similarly, in areas with thin soils the
potential for augmenting water yield may be
negligible, as any type of vegetation can fully
exploit the available soil water. In areas with
heavy fog drip, the reduced evapotranspiration
after forest harvest may not compensate for the
reduced fog drip, and water yield can decline
(Harr 1980). For areas outside the coastal fog
belt and the high elevation zones, higher annual
precipitation usually results in higher rates of
evapotranspiration, and thereby higher water yield
increases from timber harvest or type conversion.
Similarly, water yield increases are likely to be
greater on high biomass production sites than on poor
sites.

Estimating potential increases in water yield
is further complicated by factors such as the
intensity and spatial distribution of the
treatments. A selection harvest does not increase
water yield as much as a clearcut, and cut patches
high on a slope will, in all likelihood, have a
smaller hydrologic effect than patches cut near a
stream channel (Anderson and others, 1976).
Paired watershed experiments have also indicated
that forest cover must be reduced by at least 20
percent before a statistically significant water
yield increase can be observed (Bosch and Hewlett
1982). While many of the other site factors might
be expected to average out over the large scale of
the present analysis, little consideration was
taken of the spatial characteristics of the
management plans, and actual water yields could be
significantly less if the treatments are spatially
dispersed.

Another difficulty in managing for water yield
is that we can, given enough information,
reasonably predict an increase in water yields from
National Forest lands in California, but we lack
the ability to verify it. The research results
which provided the coefficients for the estimated
increases in water yield were conducted on small
research watersheds where streamflow can be
measured to within a few percentage points. In
contrast, the accuracy in measuring streamflow on
most gauged watersheds is typically 5 to 10
percent. This implies that even with
implementation of the Maximum Yield alternative on
the highest-yielding National Forest (Tahoe),
increased water yields may be just barely
measurable. That is, since none of the preferred
alternatives will produce yields that even approach
those of the maximum yield alternative, it is not
reasonable to expect that we would be able to
physically measure the projected increases.

Thus the formulation of a Region wide water
yield policy will depend to a large extent on
whether an increase in water yield that may not be
measurable is worth program emphasis and the
establishment of management objectives. Will water
users accept a theoretical increase in water yield
as a basis for National Forest land management?
How will the uncertainty in the water yield
estimates be dealt with?

These are hardly academic questions when one
considers that the average value assigned to water
during the Region 5 planning analysis was $66 per
acre-foot. On this basis, the total value of water
from National Forest lands in California is
approximately $2 billion per year. If we accept
the Minimum Level Management alternative as a
surrogate for pristine conditions, current Forest
Service management in Region 5 is already producing
an additional 330 million m$^3$ (268,000 acre-ft.)
of water worth almost $18 million. Implementing
the preferred alternative on all Forests is
projected to increase water yield by an additional
437 billion m$^3$ (354,000 acre-ft.), which implies
an increased resource value of over $23 million.
Because the Forest Service does not sell water or
obtain royalties for its use, these figures do not
represent hard dollars returned to the taxpayer
through the treasury. They do, however, provide
some insight into the value of the resource and how
this value might influence management decisions.
Again it must be emphasized that these economic values are derived from Regional water yield estimates and an average water value. In fact, as discussed in other papers in these proceedings, the value of water is both spatially and temporally dependent. If there is no storage structure, additional water at the time of peak runoff may have little value, whereas increased yield during the summer or fall may be useful for both hydroelectric and consumptive uses. The yield figures are also predicated on average years, but in drought years the actual water yield will be less, and in wet years water yield is likely to increase. Thus water yield management may need to vary within the Region, or even within a single Forest.

Just as there are economic benefits, however, there are also costs that must be considered. For example, if vegetation conversions are made specifically to increase water yield, the cost of the initial treatment and subsequent maintenance treatments must be considered. If harvest rotation ages are reduced to increase water yield, optimum saleable timber volume may be foregone. Management practices compatible with water yield increases may also incur other than economic costs. A reduction in vegetative diversity, in terms of both age classes and species composition, may adversely affect wildlife and visual quality. Again, those management practices that are most likely to increase water yields are generally those which have the potential to adversely affect water quality. The message for the manager, then, is to pursue water yield programs with guarded optimism.

In conclusion, the data presented indicate that the potential water yield increase from National Forest land is at best a short-term answer with only limited influence on California's water supply challenges. All opportunities for water management must be considered and carefully weighed. Conservation, recycling, and groundwater management can all play a role in helping to meet the supply-demand challenge. While economic considerations can help guide the development of a comprehensive, State-wide, multiple-agency water management program, ultimately the program will be a question of relative values, and hence fall into the social and political arena for evolution.

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Can water yields be increased through management of vegetation? Nearly all studies clearly show that the answer is yes. Will operational programs to increase water yields be successful? History has clearly shown that the answer is no, and there is little reason to believe that future attempts at an operational scale to increase water yields will be successful. This paper will outline some of the reasons for these contentions.

Only since about the turn of this century has serious scientific thought been directed to the influence of forest manipulation on water yield. The first forest watershed study in the U.S. was started at Wagon Wheel Gap, Colorado, in 1909. In the early 1930’s, additional research was started at San Dimas in southern California, Sierra Ancha in Arizona, and Coweeta in North Carolina. By the 1940’s, a body of knowledge was emerging to the effect that cutting forests and subsequent regrowth can have a substantial effect on water yield. This information was translated in the 1950’s into a number of grandiose regional and statewide proposals to increase water yields through vegetation treatments, primarily in water-deficient areas. Few, if any, of those proposals were ever implemented. Unforeseen social and environmental issues began to emerge in the 1960’s. Also, research results from the 150 forested experimental watersheds under study were showing that many of the earlier assumptions were not generally applicable. By 1970, about 2000 papers had been published defining the forest’s influence on water yield, floods, and water quality (Anderson and others 1976).

Bosch and Hewlett (1982) summarized the results of 94 catchment experiments world-wide. They reported that although there was extreme variation in results, in no case was a reduction of vegetation associated with a reduction in water yield, and conversely, in no case was an increase in vegetation associated with an increase in water yield. They concluded that the potential for vegetation treatment to increase water yield was greatest in coniferous forests, less in deciduous hardwoods, and least in brush and grass areas. In addition, yield increases were greatest in high-rainfall areas, and, within a given area, tend to be greater in wet years than in dry years (Ponce and Meiman 1983). There is no potential for increasing water yield in areas having less than about 15 inches of annual precipitation, and marginal potential when precipitation is between 15 and 20 inches (Hibbert 1983; Clary 1975).

OPPORTUNITIES AND PROGRAMS FOR INCREASING WATER YIELD

About 70 percent of California’s water flows from the coniferous forests which occupy about 21 percent of the State’s land area (Colman 1955). Another 13 percent of the water flows from the low elevation woodland-brush-grasslands which occupy about 18 percent of the State’s land area. Thirty percent of the water originates from the nonforest alpine areas which represent 3 percent of the State’s land area. That leaves only 5 percent of the State’s water to come from the remaining 58 percent of the land area. It would appear from these data that there is potential for increasing water yield in California.

The idea of increasing water yields from the State’s most efficient water-producing lands, the high-elevation alpine areas, can be abruptly dismissed. Opportunities for increasing water yields from the alpine zone is limited by both physical and legal constraints (Kattelmann and Berg 1987). Nearly all of the alpine lands in California are in National Parks, wilderness areas, or areas administratively reserved from management. Vegetation is so sparse and the growing season so short that any management for water yield in those small areas where it is permitted would be limited to techniques of managing drifting snow with structures. This is not new. When Colman (1955) proposed a new research program of snowpack management in California in 1955, he stated that there was little opportunity for water yield management in...
the alpine zone.

At the other elevational extreme, the low elevation woodland-brush-grasslands are the places where historically most interest in water yield enhancement has been directed—in California as well as throughout the arid Southwest. In the southern part of California, these lands lie above the water-deficient agricultural and urban areas where the demand for additional supplies, and the cost of obtaining them, is high. Not only is less water available from these lands, but they are also the areas where the size, number, and distribution of storms, and resultant streamflow, is the most variable. In 3 to 5 out of 10 years, streamflow is less than half the normal (Anderson 1963). The occasional wet years are often characterized by large storms that not only recharge the soil and provide between-storm streamflow, but produce floods and accelerated erosion. These storms result in unusable sediment-laden water that threatens life and property.

In areas where annual precipitation is less than about 15 inches, streams are usually ephemeral, and most streamflow is the result of surface runoff during intense short-duration rainfall. Under these conditions, attempts to increase water yield by treating vegetation have been unsuccessful, because soil water recharge is quickly lost to invading pioneer vegetation. A technique known as water harvesting, in which surface runoff is deliberately increased by reducing infiltration, has been applied on a small scale to provide stock water and local irrigation water (Cooley and others 1975). Such treatments may be the only source of water and may be economically justifiable in limited applications. But, on a broad scale, water harvesting would be impractical because of cost, increased erosion potential, and storage capacity required to retain the flash flood produced by the treatment.

In areas where annual precipitation exceeds about 15 inches, numerous plot and small watershed studies throughout California and the Southwest have demonstrated the ability to increase water yield through vegetation manipulation. In the 1950's, a number of large-scale operational projects were planned, and several were actually begun. All of the projects have failed for several reasons. It is instructive to review those reasons to anticipate what the future holds for water yield improvement in the woodland-brush-grassland areas.

Based on a report by Barr (1956a, 1956b), an action program was proposed that was expected to increase water yield by 285,000 acre-feet per year through several forms of vegetation treatment covering over 3 million acres, including the eradication of noncommercial ponderosa pine forests from 200,000 acres (Cortner and Berry 1978). Additional treatments were proposed for spruce-fir, pinyon-juniper, and streambed phreatophytic vegetation types. Later, another project to clear and convert phreatophytes from riparian zones in Arizona projected that water yield could be increased as much as 600,000 acre-feet per year (Fox 1977). Primary supporters of these programs were the Arizona water interests and State and Federal land management agencies. These proposals engendered criticism and were eventually terminated because of overstated program goals, unrealistic and untested assumptions, political problems of accomplishing the treatments, failure to recognize new interest groups, and questions of who pays the costs relative to who receives the benefits.

OBSTACLES TO WATER YIELD INCREASE

The water yield goals of these early action programs were based on averages obtained in controlled experiments on plots or small watersheds. The projected water increase was obtained by multiplying the average increase for each vegetation type by the area and summing. The result was a great overestimation of potential yield increases. Later, more cautious analyses reduced projections because only part of any vegetation type can be treated economically. The economics are related not only to the cost of land treatment, but to the value of the water, both of which change with time and location. Physical conditions such as poor access, steep slopes, and unstable lands reduce treatable areas and lower potential yield increases. And, consideration of other resources and social or political constraints, which in the 1950's were often overlooked, has become a primary limitation to single-purpose land management plans.

Even if the technical, social, and political constraints of increasing water yield are adequately addressed, the extremely complex legal question of who owns the water remains. In most of the areas where increased water is in greatest need, water rights are defined in terms of season, place, point of diversion, type of use, and return flow (Ponce and Meiman 1983). Any actual increased yield varies from year to year and season to season. The technical problem of documenting or proving to the satisfaction of the courts that water yield from any parcel of land has actually been increased is overwhelming. And, unless the landowner can receive a financial benefit to offset the cost, there is no incentive to spend money to increase water yields on private lands.

The logic of managing the woodland-brush-grass areas for increased water yield is to reduce transpiration losses by replacing deep-rooted trees and shrubs with shallow-rooted grasses. Once the grass depletes the shallow soil moisture, much of which would have been lost to surface evaporation anyway, it becomes dormant, whereas the deeper-rooted vegetation has access to a greater and more dependable supply of soil moisture. Unfortunately, most of the chaparral and woodland ecosystems in these areas regenerate

75
quickly from sprouts or seeds if burned or mechanically cleared. Long-term conversion to grass requires that these regenerating shrubs be killed and periodically retreated, otherwise any water yield increases will rapidly decline, disappearing completely within about five years (Hibbert 1983). Nearly all of the attempted conversions from chaparral to grass have required the use of chemical herbicides in both the initial clearing and followup treatment to control regrowth. A typical experience in the Santa Ynez River drainage near Santa Barbara indicated that after two spray treatments only 25 percent of the brush was killed (Hansen 1968). After a third annual treatment, about 75 percent of the brush was killed, except scrub oak, where only 40 percent was killed. Restrictions on herbicide use have eliminated the feasibility of long-term conversion of chaparral to grass (O'Connell 1972; Clary 1975). Even in 1975, then Chief of the Forest Service John McGuire stated that a "major problem concerns the impact of chemical herbicide restrictions on water yield improvement programs," and "attempts to use other means, such as prescribed fire, have not been entirely effective" (McGuire 1975). Today, as we are well aware, the use of herbicides is much more constrained than a decade ago, and it does not appear that the restrictions will be reduced in the immediate future.

There are numerous undesirable side effects of water yield programs that are often overlooked in the zeal to reap the benefits of the action program. Degraded water quality from erosion is one such side effect that is a major constraint on land management practices. The relation between brushfires and erosion is well documented. The erosion rate from hillslopes is related to the erosion potential of the site and to storm severity. The erosion potential on steep slopes is further related to the contribution of roots to soil strength (Ziemer 1981). Removing vegetation or conversion from brush to grass reduces the frequency of deep, woody roots and increases the probability of accelerated mass erosion. Using computer simulations, Rice and others (1982) investigated the potential effect of different prescribed fire regimes on landslide erosion. The model was based on the average conditions in southern California chaparral. They estimated that using prescribed fire on a 15-year treatment interval would result in an increase of about 280 percent in the long-term soil slip erosion rate above the natural rate. The natural wildfire rate in their model was one fire every 32 years. No estimates were made for permanent conversion from chaparral to grass, but assuming that conversion could be physically accomplished, a best guess is that the long-term erosion rate might be increased about 900 percent above the long-term natural rate. In many of the chaparral areas of California, the present costs of keeping sediment out of urban areas are astronomical. The thought that active management of these watersheds for water might increase the sediment volume by a factor of 2 to 9 is unsettling.

The maximum increase in water yield will result from removing vegetation that transpires at the maximum rate and for the maximum duration. The most favorable locations are riparian zones and other areas where vegetation has access to groundwater. Unfortunately, these are precisely the areas where the opportunity for environmental damage is greatest and the management of vegetation is most constrained. The California Forest Practice Rules severely limit the ability to manage riparian zones for increasing water yield. There is a requirement to leave a minimum of 50 percent of the canopy cover within a buffer zone ranging from 50 to 200 feet from the stream, depending on slope. Local restrictions are much greater adjacent to urban areas. Even so, nearly every proposal to harvest timber or otherwise modify vegetation is contested for numerous reasons, whether in riparian zones or on the upper hillslopes.

Outside of the riparian zones, the next preferred locations for vegetation treatment to maximize water yield are areas having deep soil and the greatest soil water storage. These are the areas where tree growth and the value of the land for producing timber on a sustained basis are best. They are also, however, the places where the potential for logging-related mass erosion is greatest (Rice and Pillsbury 1982). Consequently, economic and environmental factors will probably limit the ability of the land manager to clear these commercial timber lands for water production.

If the climax coniferous vegetation in the riparian zone is removed, there should be an increase in water yield. However, as pioneering phreatophytes such as alder and cottonwood invade the area, Harr (1983) found that summer flows declined to levels below that experienced before cutting. He estimates that these lowered summer flows will persist for several decades, until the streamside phreatophytes are again overtopped by the conifers. Also, there is some evidence that young, vigorous forests transpire more water than mature or old-growth stands (Black 1967; Knoerr 1960). If this is true, long-term estimates of water yield increases, even though modest, may be overstated.

Probably, the areas where vegetation treatment for water yield would be least contentious are those where timber site is moderate to low. Unfortunately, such areas usually have shallow soils and/or deficient rainfall and the potential for increasing water yield is small.

CONCLUSIONS

From the foregoing discussion, it is clear that the options of vegetation management specifically for water are limited. A substantial amount of vegetation has been removed from commercial forest areas in the normal process of harvesting timber. In 1970, Rothacher estimated about 6 billion board
feet of timber was being harvested annually from 200,000 acres in the Pacific Northwest, mostly by clearcut logging. The maximum water yield increase from the 94 catchment experiments reported by Bosch and Hewlett (1982) was 26 inches at Coweeta in North Carolina, but comparable increases, up to 24 inches per year, were reported from experimental watersheds in western Oregon. Surely, there should be ample evidence of substantial water yield increases resulting from this intense level of vegetation removal in Oregon and Washington, an area where water yield increases should be most responsive to treatment. Unfortunately, there is no such evidence on a regional scale.

Although it has clearly been shown that vegetation treatments can increase water yield on plots and small experimental watersheds, there is less assurance that such yields can be observed at downstream points of use. First, transmission losses through untreated portions of the routing system may decrease the added water. In arid regions, the added streamflow may encourage the growth of riparian phreatophytes, and if the distance from the treated area to the point of use is substantial, all of the increase may be lost en route. Second, if the treated area is a small proportion of the watershed area above the point of use, the increased flow may not be detectable—even if transmission loss is negligible. This is the issue of scale.

Scale is an important problem in water yield enhancement. When both spatial distribution of the harvest and rotation age are considered, the potential water yield increase on a watershed basis becomes much more modest. Taking information from experimental catchments and land inventories, Harr (1983) estimated that the potential sustained increase in annual water yield related to forest practices in western Washington and western Oregon would be about 2.7 percent, using a 120-year rotation, and 4.7 percent, using a 70-year rotation. Kattelmann and others (1983) made similar estimates for Sierra Nevada watersheds. They estimated that streamflow could be increased 2 to 6 percent, assuming that the National Forest lands were managed almost exclusively for increased water yield while meeting the minimum requirements of applicable laws. If multiple use/sustained yield guidelines are followed, they estimated that water yield can be increased about 1 percent above current levels. These projected yield increases, if they do occur, will probably not be detected. An excellent streamflow record is expected by the U.S. Geological Survey to have an error up to about 5 percent (Rothacher 1970). The projected water yield increases are within this error. Also, this increased yield is not uniformly distributed seasonally or throughout the rotation. Most of the annual increase occurs in the winter high-runoff season and during the wetter years, rather than during the summer season and drought years, when the additional water is needed.

It may be technically, politically, and socially possible to treat small watersheds on a scale of several hundreds of acres for increased water yield, but large-scale projects were not possible even before the present level of land management constraints. And, if an action program is possible, how does one document any increased yield resulting from land treatment? Very few small watersheds in California, except a handful of experimental watersheds, are gaged. For example, within the 1700-square mile Santa Ana River basin, one of the more intensively gaged drainage basins in California, there are 31 stream gaging stations, but only 4 of those gage watersheds having an area of less than 10 square miles. Any water increases resulting from treatment, then, must be estimated by extrapolation of experimental data, or be based on model estimates—both having substantial error. By the time the increased flows combine with unmeasured flows from untreated watersheds, there is virtually no chance of observing or proving that any increase occurred.

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Water Yields from High-Elevation Basins in California

Richard Kattelmann and Neil Berg

High elevation basins in California produce much of the State's water supply. Alpine and subalpine lands provide high quality water to California's three largest municipal supply systems: Los Angeles, San Francisco, and the East Bay. Water for agriculture and hydroelectric power flows dependably from the upper parts of river basins throughout the Sierra Nevada. However, despite the importance of water from the high mountains of California, little information is available on the hydrology of these regions. This paper describes some of the characteristics of water yield from subalpine and alpine lands in the Sierra Nevada region of California and the potential for augmenting it.

BASIN CHARACTERISTICS

Identification of salient attributes of the vegetation, climate, snowpack, and streamflow provide a backdrop for discussion of opportunities for increasing water yields from high elevation watersheds in the Sierra Nevada.

Vegetation

The subalpine forest of the Sierra Nevada is generally considered to begin above 2100-2400 m (6900-7875 ft) in the northern Sierra and above 2500-2900 m (8200-9515 ft) in the south (Storer and Usinger 1963, Rundel and others 1977). The subalpine zone covers approximately 9000-9500 km² (3275-3670 mi²) in the Sierra Nevada. The common conifers include foxtail pine (Pinus balfouriana), limber pine (Pinus flexilis), lodgepole pine (Pinus contorta), mountain hemlock (Tsuga mertensiana), western white pine (Pinus monticola), and whitebark pine (Pinus albicaulis). At its upper limit, the subalpine forest thins out into isolated groups of trees, largely controlled by persistent patches of snow (Major and Taylor 1977). Alternatively, whitebark pine stands may fade into the krummholz form of multistemmed trees of low height.

Treeline is generally around 2800-3000 m (9200-9850 ft) in the northern Sierra Nevada, rising to 3200 m (10500 ft) in Yosemite and 3300 m (10800 ft) at the southern end of the range (Storer and Usinger 1963, Major and Taylor 1977). The boundary between alpine and subalpine vegetation is rarely precise, and the two vegetation types intermingle over a considerable elevation range depending on other site factors. The alpine zone of the Sierra Nevada covers approximately 2000-2500 km² (770-965 mi²). Plants of the alpine zone are low-lying and occupy discontinuous patches of poorly-developed soil.

Areas of alpine and subalpine vegetation occur in other mountain ranges of California besides the Sierra Nevada but are less important in terms of surface water supply to the State as a whole. The area covered by the higher parts of the Klamath Mountains, southern Cascades, and Warner Mountains is relatively small. The high mountains of eastern and southern California receive considerably less precipitation than the Sierra and lose much of it by evaporation. Additionally, the scarcity of basic data in these other ranges concentrated the focus of this paper on the Sierra Nevada.

Climate

The dominant feature of the winter climate of the Sierra Nevada is the moderating influence of the Pacific Ocean. The resultant climate is characterized by high precipitation and air temperatures often above freezing. Snow falling above treeline is probably wetter and less influenced by wind redistribution than at similar
sites in Rocky Mountain alpine zones (Powell 1986).

Given the importance of the snow zone water supply in California, surprisingly little long-term hydrometeorological information exists for the higher reaches of the Sierra Nevada. Two primary long-term data bases are those from the Central Sierra Snow Laboratory (CSSL)—marginally within the subalpine region at 2100 m (6900 ft) elevation—and the snow survey network. Climate and snow cover characteristics at CSSL (39° 19' N., 120° 22' W., 30 km (20 mi) northwest of Lake Tahoe) were summarized by Miller (1955), Smith (1982), and Smith and Berg (1982). At CSSL, the average peak snow depth is 305 cm (120 in) and a snowpack water equivalent of 90 cm (35 in) is generally reached by early April. Total annual snow accumulation at this site is extremely variable, with extremes ranging from 464 cm (183 in, 1977) to 1704 cm (671 in, 1983). The large yearly variability at one point is amplified by latitudinal and topographic effects. The limited available data suggest that precipitation is less in the southern portion of the range than the northern. Maximum mean annual precipitation reaches 230 cm (91 in) at several locations north of Lake Tahoe while 205 cm (81 in) is the maximum at one point south of Lake Tahoe (U.S. Dept. of Interior 1969). A “rain shadow” effect is also evident; mean annual precipitation values drop from 170–190 cm (67–75 in) at the crest of the range to 25–30 cm (10–12 in) about 30 km (20 mi) east of the crest.

Snow Cover

Snow dominates the hydrology of the high Sierra, accumulating for 6 to 7 months of the year and then melting over 3 to 4 months. The snow-free period for higher elevation areas lasts only from July through September. About 24 snow sensors (pressure pillows) have been installed above 2500 m (8200 ft) by the State of California and provide daily telemetered measurements of snow water equivalent. Most of these sensors were installed between 1977 and 1980. Additionally, some 70 snow courses above 2500 m (8200 ft) are measured in early April or at the beginning of each month from February through May. These snow course data allow a long-term look at snow storage over the Sierra Nevada. Simple basin-wide averages of April 1 water equivalent for snow courses above 2500 m (8200 ft) indicate that peak snowpack water equivalent for the high Sierra averages about 75 cm (30 in) to 85 cm (33 in), decreases from north to south, and tends to be lower in east side basins than in west side basins (table 1).

The distribution of snow in the high Sierra is largely a function of the snow trapping efficiency of the terrain. The structure of the subalpine forest also greatly influences the final resting place of the snow below treeline. Wind deposition, scour, and redeposition of snow are

<table>
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<tr>
<th>Basins</th>
<th>Westside Average SHE (cm)</th>
<th>Eastside Average SHE (cm)</th>
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<tbody>
<tr>
<td>Tuolumne</td>
<td>85 [33 in]</td>
<td>Truckee 95 [37 in]</td>
</tr>
<tr>
<td>Merced</td>
<td>105 [41]</td>
<td>Walker 60 [24]</td>
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<tr>
<td>San Joaquin</td>
<td>85 [33]</td>
<td>Mono 75 [30]</td>
</tr>
<tr>
<td>Kings</td>
<td>80 [32]</td>
<td>Owens 45 [18]</td>
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<tr>
<td>Kaweah</td>
<td>90 [35]</td>
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<tr>
<td>Kern</td>
<td>50 [20]</td>
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Table 1—Basinwide average snowpack water equivalent (SWE) on April 1 from snow courses above 2500 m (8200 ft) (through 1982)

The primary mechanisms of snow transport. Large areas scoured free of snow alternate with deep snowdrifts located in terrain depressions. Avalanches also relocate snow from steep slopes to shallow snow courses above 2500 m (8200 ft) reported in table 1. The high spatial variability of the snowpack above treeline makes generalization very difficult. Evaporation and sublimation add another confounding influence. The effect of elevation on precipitation type is unambiguous, however. The freezing level of winter storms in the Sierra tends to fluctuate between 1000 m (3280 ft) and 2500 m (8200 ft). Rain is very infrequent above 2500 m (8200 ft). In years with intense warm storms, the transition from shallow to deep snowpacks may be quite abrupt. The years 1978 and 1986 provide examples of massive snowpacks above 2500–3000 m (8200–9840 ft) and little snow cover below 2100–2500 m (6900–8200 ft), with the exact elevation dependent on latitude. When low-elevation snow cover is minimal, the high-elevation snowpacks assume even greater importance in sustaining summer streamflow.

The Sierra Nevada supports about 60 small glaciers covering a combined area of 13 km² (5 mi²) in well-shaded cirques, with northeastern exposures favorable for snow collection (Hefer 1961). The glaciers have a local moderating influence on streamflow with respect to precipitation. Generally, annual runoff from glacierized basins is much less variable than annual precipitation because of minimal glacier ice melt in high-precipitation years and much glacier ice melt in low-precipitation years (Krimmel and Tangborn 1974). Analysis of data from the Maclure Creek basin below the Maclure Glacier in Yosemite National Park (Dean 1974) showed that the coefficient of variation for
streamflow was only about half of that for precipitation over the same 6-year period.

Snow Evaporation and Sublimation

The windswept slopes of the high Sierra create the potential for evaporative losses from the snowpack (Stewart 1982). When low dew points coincide with high winds, snow evaporation and sublimation may become substantial. The potential for sublimation is greatest when snow is entrained in the air (Schmidt 1972). Several millimeters of water may be lost when dry winds are active soon after snowfall. Evaporation and sublimation directly from the snowpack surface have not been conclusively determined for the alpine zone of the Sierra, but a few measurements suggest evaporation is on the order of 0.5 mm (0.02 in) to 1 mm (0.04 in) per day during clear dry weather and is less or is even offset by condensation at other times (West 1962). More data are needed before conclusive estimates of alpine snow evaporation losses can be made.

Snowmelt

In general, snowmelt from subalpine and alpine lands in the Sierra both begins later and lasts longer than at lower elevations. Residual heat deficit and persistent negative energy balance delay the onset of snowmelt in the high Sierra for 3 to 4 weeks beyond the start of melt in the forest zone below. This spread in melt timing helps to minimize spring flooding. The slowly increasing energy budget and concentration of snow in deep deposits prolongs the snowmelt period well into summer.

The rugged terrain provides shade to much of the snow on both large and small spatial scales. Because of the very low proportion of advected heat in the energy balance at high altitude, differences in snowmelt rate between north and south exposures are probably exaggerated compared to lower elevations. Another important consequence of the local terrain is the rapid acceleration of snowmelt once rocks begin to be exposed. Reradiation from the energy-absorbing rocks melts snow far faster than direct insolation.

Streamflow

Snowmelt runoff dominates the hydrographs of high-elevation Sierra streams. Streamflow from the Sierra Nevada is not quite as concentrated as in the Rockies, where 85 percent of the annual flow may occur between May 1 and July 31, with less than 5 percent in the winter months (Leaf 1975a). California summers are generally characterized as dry, and although summer rainfall amounts are quite variable, rainfall after the end of snowmelt may account for only about 2 percent of annual runoff in the higher basins (Hannaford and Williams 1967). Rainfall during the snowmelt runoff period may contribute a somewhat greater proportion of annual flow than does rainfall in late summer (Hannaford and Williams 1967).

In mountains throughout the world, a continuous increase of streamflow with altitude has been noted and related to increased precipitation, lower temperatures, and lower evaporation at increasing elevations (Dreyer 1982). In the American River basin of northern California, runoff data from 25 subdrainages (Armstrong and Stidd 1967) indicate an increase in streamflow of 3 cm (7.6 in) per 100-m (328 ft) gain in elevation. The high-elevation lands of California, which cover approximately 3 percent of the State, produce about 13 percent of its annual streamflow (Colman 1955). By contrast, nearly 60 percent of Utah's streamflow is generated in the upper Uinta and Wasatch mountains, which account for only 10 percent of that State's land area. While the estimated 90 cm (35 in) of annual runoff (Colman 1955) generated in the alpine Sierra is high by any standard, the more extensive forest zone also provides large runoff quantities and dilutes the importance of runoff from the alpine zone. In Colorado, runoff has been found to increase both annually and in summer with increases in the proportion of the basin in the alpine zone (Martinelli 1965).

The high Sierra should be the most efficient runoff-producing zone in California, converting a greater proportion of precipitation into runoff than any other area of the state. More than 90 percent of the net annual precipitation appears to become runoff in the alpine zone of the Colorado Rockies (Carroll 1976, Leaf 1975b). Alpine basins are generally assumed to be highly efficient in streamflow generation (e.g., U.S. Congress 1983, U.S. Dept. of Interior 1975) because of large areas of bare rocks and talus, thin soils that are well drained, low losses from evapotranspiration, and minimal transmission loss (Johnson and Brown 1979).

Most stream gages are located where rivers leave the mountains, and streamflow at these sites integrates runoff from a wide range of altitude (Dreyer 1982). This situation predominates in the Sierra also, but a few gages are located fairly high in the mountains. A stream gage on the North Fork of the Kings River at 2480 m (8140 ft) is the highest long-term gage on the western slope of the Sierra. This basin of about 100 km² (39 mi²) extends to above 3700 m (12140 ft). More than three-fourths of the basin is in subalpine and alpine vegetation types. Averaging monthly flow records from 1969 through 1981 indicated that 85 percent of the annual flow occurs during the April through July snowmelt runoff period. The long­term annual streamflow averages about 74 cm (29 in) over the basin area. While total precipitation cannot be estimated with precision, snow course data suggest that peak snowpack water equivalent probably averages between 70 cm (28 in) and 90 cm (35 in). This estimate does not include potential moisture losses through snow melt, sublimation, or evaporation. While we can guess
that the runoff efficiency of this basin is between 70 and 80 percent, better estimates will have to await the completion of detailed water balance studies in the high Sierra.

**OPPORTUNITIES FOR INCREASING STREAMFLOW**

Demand for increased water supplies has prompted evaluation of the possibilities for streamflow augmentation throughout the western United States (Ponce 1983). Previous assessments of the potential for greater water yields from the Sierra Nevada have focused on the forest snowpack zone (e.g., Anderson 1963, Kattelmann and others 1983). This vegetation zone would appear to offer greater possibilities for streamflow augmentation than other parts of the Sierra because of its high precipitation in combination with high evapotranspiration losses and the potential for reducing these losses through forest harvesting. Lands above the commercial forest in other States have also been considered for water yield improvement because some increases are technically feasible (Johnson and Brown 1979). Most previous work on alpine water management (e.g., Caine 1982, Martinelli 1975) has concentrated on the Rocky Mountain region because of the great demand for more water in the Colorado River basin. The remainder of this paper examines the technical, administrative, and economic feasibility of application to the Sierra Nevada of some of the techniques suggested for the Rocky Mountains.

**Vegetation Management**

The subalpine forest of the Sierra Nevada could be managed to some extent to increase local water yields. Because of the short growing season, with low temperatures, shallow soils that are well drained, and low-density forests, evapotranspiration losses should be much less than in the red fir-lodgepole pine belt. With relatively low losses, the potential for recovery is small. Stands of trees could possibly be modified to alter shading and snow redistribution by wind. Most stands of subalpine trees are relatively open, however, and changing their characteristics to a more favorable condition would be difficult. The subalpine forest is not currently managed for timber production and access is limited, making future management very costly. Because much of the subalpine zone is highly valued for recreation, there is a potential conflict in management objectives. In the alpine zone, the harsh site conditions do not allow much potential for change in the existing vegetation (Satterlund 1972).

**Snow Management**

Appreciable amounts of moisture may be lost from sublimation during snow transport by wind. On the Wyoming plains, calculations predict complete sublimation of snow grains transported over distances approximating 3 km (1.9 mi) (Tabler 1975). Snow fences constructed to reduce windspeed and thereby induce deposition of snow to the lee of the fence are used extensively and effectively to reduce blowing snow along sections of interstate highway 80 in Wyoming (Tabler and Furnish 1982). Fences have been advocated for water yield increases in alpine sites in Colorado (Martinelli 1975), but suitable sites for fencing may be a limiting factor at alpine areas (Caine 1982).

Preliminary results from experimentation in Wyoming show the potential to improve water yield with snow fences (Tabler and Sturges 1986). Over a 2-year period, streamflow increases averaged 237 percent (28,200 m³ [22.9 acre-ft]) of pretreatment calibration values. The duration of flow was extended 19 and 18 days during 1984 and 1985 respectively. To amortize the initial construction cost of the fence over its anticipated life of 25 years, the value of the increased water would have to equal $0.06721 m⁻³ ($83 per acre-ft). These results are indicative rather than conclusive, and experimentation on larger basins for a longer period of record are needed.

The Wyoming case study shows that fencing can increase streamflow discharge and extend flow under certain conditions. Extensive snow-covered, treeless plains are not available for fence construction in California, and alpine sites are primarily in statutory wilderness areas closed to fencing. In California the optimum sites for fencing are probably treeless ridge crests in the subalpine zone having upwind fetch areas at least several hundred meters in length. Such sites would be relatively accessible and available for management. The land area in this physiographic type is unknown but probably relatively small.

Another alternative for increasing the trapping efficiency of alpine lands is reshaping the terrain with earth-moving equipment (Martinelli 1975). Properly designed depressions could allow the formation of deep deposits of snow in areas currently scoured of snow. While terrain modification for snow management has been used at ski areas, it is unlikely to become widespread because of its high cost, the inaccessibility of potential sites, and environmental disruption (Johnson and Brown 1979). Due to the rugged topography and legal restraints on management, terrain modification for snow management is not feasible in the alpine Sierra.

Deposits of deep snow can also be created by intentional avalanching and production of artificial snow and ice (Martinelli 1975). Both techniques are widely used at ski areas. Artificial release of avalanches with explosives will increase snow depth in the runout zone and increase trapping efficiency in the starting zone. Late season streamflow could be diverted and sprayed into very cold air to create artificial mounds of ice. Compressed air would
need to be introduced at the nozzle to create snow at temperatures closer to 0°C. Although neither of these practices could ever be applied over much area, they could be implemented in a cost-effective manner in basins of up to a few square kilometers in area for specific water yield improvement goals, should the need ever arise.

Snowpack water losses can also be reduced through the application of chemical suppressants (Slaughter 1970). Long-chain alcohols can cover the snow surface as mono-molecular films and effectively prevent transfer of water vapor to the air. They are rendered ineffective, however, when covered by additional snowfall, and they are costly to apply over much area. In view of the uncertainty associated with snowpack evaporation rates, operational application of suppressants has not been judged worthwhile in the Sierra (Baldwin and Smith 1978).

**Weather Modification**

Weather modification for snowpack augmentation has had operational status in California since 1951. As of 1985, 12 cloud seeding projects were being carried out in the State, and most of these were winter snow zone projects (Roos 1986). It is generally assumed that augmentation of the snowpack will result in increased, and possibly delayed, runoff.

Several factors combine to reduce the management potential for weather modification. First, the chances for successful seeding are greatest when cloud systems already exist. Seeding during droughts, when the water arguably is most necessary, will be less effective than seeding during "normal" or "wet" years. Seeding can then be viewed as most effective by increasing opportunities for more flexible reservoir management in keeping reservoir levels high during normal years. Second, the natural variability of the precipitation process is high. It is extremely difficult to isolate the "signal" from the "noise" in identifying a seeding effect. Extensive atmospheric monitoring of hourly precipitation mass by staff of the Sierra Cooperative Pilot Project (SCPP) over the American River basin suggests that hour-to-hour variation approximates 70 percent of the hourly mean. Given that expected augmentation rates approximate 10 percent of the hourly mean, extremely large sample sizes are required to detect a statistically significant augmentation effect (Humphries 1986). To date, statistical validation of an augmentation effect has not been documented in the atmosphere, let alone on the ground, by SCPP investigators.

Extensive SCPP research suggests that both increases and decreases in precipitation can result from dry ice seeding in the central Sierra Nevada. Of 40 seedable days, 5 showed a strong augmentation effect while 2 showed possible decreases (Humphries 1986). Longterm runoff increases of 4 percent are attributed to seeding over the Kings River basin (Roos 1986). Assuming an even lower runoff increase of 2 percent, the cost of additional water from cloud seeding on the Kings is calculated to be $0.00270 m³ ($3.33 per acre-ft) (Roos 1986). The cost-benefit ratio suggested by this value is attractive, but the efficacy of seeding is still not accepted by many proponents.

**Streamflow Forecasting**

Improved stream discharge predictions would allow improved management of California's water resources. Streamflow forecasting across the State as a whole is probably as accurate as anywhere in the western United States. Forecasting error has been estimated at 10 percent, as opposed to 90 percent, for instance, for the lower Colorado basin (Castruccio and others 1981). Errors are most evident during extreme conditions, the very situations most critically in need of accurate forecasts. The accuracy of forecasts from alpine and subalpine zones is essentially unknown, however, because stream gauging information is lacking. The accuracy of the snowmelt component of runoff models or indices takes on a greater importance in the alpine and subalpine than at lower elevations. The snowmelt fraction of total annual surface runoff in the alpine and subalpine probably reaches 90 to 95 percent. The importance of improved snowmelt forecasts for flood and water supply forecasting and hydroelectric power production is obvious. Assuming a 5 percent increase in forecast accuracy over California as a whole, the economic benefit for hydroelectric energy generation was calculated to equal $0.06 per million watt-hour in 1981 (Castruccio and others 1981). Given that almost 20 percent of the State's energy production is hydroelectric, substantial savings would result from even relatively minor forecasting improvements.

**Economics and Legal Constraints**

At present, the demand for water and its consequent price do not appear to be high enough to justify water yield improvement projects in the high Sierra. In view of the considerable uncertainty as to the amount of "new" water generated, and the high cost of treatment in roadless terrain, water yield improvement projects in the subalpine and alpine lands may always remain difficult to justify on economic grounds. Weather modification offers the potential of increased streamflow at relatively low cost, but, again, the amount of water produced is uncertain.

Legal constraints remove most of the high-elevation lands from consideration for ground-based management activities. Less than 20 percent of the subalpine and alpine terrain in the Sierra Nevada is outside of National Parks and statutory wilderness areas. Much of this remainder is administratively reserved from active management. Even in the few areas that could be developed, there are potential conflicts with
other resource values. Water quality and visual concerns further restrict the application of management practices. Thus, the area of high elevation terrain in the Sierra Nevada available for management is extremely limited—perhaps less than a hundred square kilometers of the subalpine zone scattered in the central and northern parts of the range. We are unaware of any part of the alpine Sierra that could currently be managed on the ground for increased water yields.

SUMMARY AND CONCLUSIONS

The high-elevation lands of the Sierra Nevada should be the most efficient producers of runoff in California. We conservatively estimate that at least three-quarters of the precipitation above 2500 m in the Sierra becomes streamflow. This runoff efficiency could be above 90 percent in some areas in some years. Uncertainty in these estimates comes from our inability to adequately measure precipitation and snowpack evaporation. Some small gains in efficiency and delayed yield can theoretically be achieved by concentrating snow in deeper deposits with a small surface area to volume ratio. Legal, economic, and administrative constraints, however, preclude any real consideration of water yield improvement projects in the high Sierra. Limited areas in the subalpine zone, such as high ridges on the western slope, could be managed for additional water if some local project required it. Weather modification offers the only hope for widespread water augmentation from the upper elevation lands, but streamflow increases from cloud seeding still have not been demonstrated conclusively. Improvements in streamflow forecasting may allow better management of existing water resources. Meanwhile, the high Sierra will continue to provide high quality water during California's dry season without any human intervention.

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Soil Moisture Budget: An Example of Effects of Timber Harvest and Regrowth

Paul Zinke

The watershed soil mantle functions as a water storage reservoir. It is charged by inputs from rainfall, snowmelt, interflow, and subsurface aquifers. Following drainage through gravity to soil field capacity losses occur through direct evaporation from the surface, and evapotranspiration use by vegetation. Water yield from a watershed is the residual after evapotranspiration losses, either directly from the soil or by use of stored soil moisture by the vegetation.

MAGNITUDE OF SOIL RESERVOIR

The size of the soil moisture storage reservoir depends upon areal extent or capacity and the intensity or point water storage of the soils. Water storage in this soil water reservoir will vary from place to place. It is the difference between the field capacity of the soil which holds water against drainage by gravity, and the water content of the soil at the permanent wilting point of vegetation.

The ability of the soil to store water depends upon the degree of soil development. Table 1 shows a typical sequence of increasing soil moisture storage with degree of soil development on sandstone. The young Inceptisol, Maymen soil series, has a low storage intensity of 2.3 in., while a well developed Ultisol such as the Sites soil series has a storage intensity of 10.4 in.. Similar soil development sequences occur on each of the soil parent materials typical of our watersheds.

On each watershed, the soil moisture storage capacity will be determined by the proportionate areal extent of soils of varying storage intensities. Soil surveys now cover most of California's watersheds. These have provided us with the data from which soil moisture storage intensities can be calculated.

Abstract: Data are presented on the size of the soil moisture reservoir of forested watersheds in California with rate constants of depletion of this storage through water use of forest and associated vegetation cover conditions. The cumulative effect of 30 years of timber harvest on the water yield and soil moisture storage of the south and middle forks of the Mokelumne river is presented as an example. Soil moisture use by the seral cover conditions that followed logging are evaluated. Highest loss rates of soil moisture occurred under brush, with second-growth and young plantations nearly as much, old growth timber less, and bare soil surfaces least. The cumulative effect was a gain in annual water yield from the 91,739 acre watershed area estimated at 20,000 acre-feet; or 2.6 in. additional yield.

I calculated probability distributions of available soil moisture storage amounts (table 2) in 453 wildland soil profiles analyzed by the California Soil-Vegetation Survey. are shown in table 2. The soil moisture storage varies depending upon stoniness, texture, organic matter, and bulk density of soil. The watershed manager uses

Table 1: Available soil moisture storage in inches of water to one foot depth increments for soils representing a developmental sequence on sedimentary rocks in California. Soils indicated by order, series, and mapping symbol used in Calif. Coop. Soil-Vegetation Survey.

<table>
<thead>
<tr>
<th>Soil Depth</th>
<th>Inceptisol</th>
<th>Inceptisol</th>
<th>Ultisol</th>
<th>Ultisol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.3</td>
<td>0.8</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>2.0</td>
<td>3.8</td>
<td>4.1</td>
</tr>
<tr>
<td>3</td>
<td>rock</td>
<td>3.3</td>
<td>5.7</td>
<td>6.4</td>
</tr>
<tr>
<td>4</td>
<td>rock</td>
<td>5.0</td>
<td>7.5</td>
<td>8.7</td>
</tr>
<tr>
<td>5</td>
<td>rock</td>
<td>6.7</td>
<td>9.3</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Table 2: Probability table of soil moisture storage amounts in inches of available water storage to one foot depth increments for California wildland soils.

<table>
<thead>
<tr>
<th>Cumulative Probability</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>453</td>
<td>421</td>
<td>349</td>
<td>273</td>
<td>201</td>
</tr>
<tr>
<td>Sig Level</td>
<td>0.05</td>
<td>0.02</td>
<td>0.09</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>X²</td>
<td>3.85</td>
<td>5.43</td>
<td>2.79</td>
<td>3.85</td>
<td>4.80</td>
</tr>
<tr>
<td>Arith. mean</td>
<td>1.7</td>
<td>3.3</td>
<td>5.0</td>
<td>6.5</td>
<td>8.3</td>
</tr>
</tbody>
</table>

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

2/ Assoc. Prof. Dept. of Forestry & Resource Management, University of California, Berkeley, California.
table 2 to estimate probable soil moisture storage. If soils are less well-developed, the lower ranges of values should be used; if better developed the upper range of values. Site specific data from soil samples collected from the watershed can be ranked by this table.

VEGETATIVE REGULATION OF SOIL MOISTURE

The soil moisture storage reservoir at field capacity loses water through evaporation from bare soil, and water use by the vegetation cover. An exponential drying function describes the water loss from the soil moisture reservoir under various vegetation conditions as shown in figure 1 (Zinke 1975). The slow drying of the soil kept bare, compared to that with a cover of ponderosa pine is shown by rate constants of -.001 to -.018 respectively. Drying rates tend to be low for grass cover, and high for various woody vegetation cover types. A summer influence of marine air in the coast ranges may override the difference between vegetation types, resulting in low loss rates for all types as found by McColl (1977).

Figure 1: Typical soil moisture drying curves for soils having various vegetation cover types in climates not affected by coastal marine air in California. Soil moisture storage plotted on logarithmic scale. Drying rate constants (k) represent slope of curves. (20" field soil moisture storage $P_{WP} = 6$ in.)

CUMULATIVE LOGGING EFFECT-MOKELUMNE WATERSHED

Blanchard (1962) reported an increase in water yield of the south and middle fork watersheds of the Mokelumne River as cumulative acreage of logging increased during a period from the 1930's to the late 1960's. He derived a trend line based upon an 8-year running average of water yield shown in figure 2. Despite the wide amplitudes of annual yield, there is a general trend which showed a 20,000 acre foot increase in annual yield between 1930 and 1960. An interesting series of high and low extremes about this trend line seems related to the alternate recharge and discharge of aquifer storage associated with the Mehrten Formation.

A cumulative logging and recovery function similar to that developed for effects of fire by Anderson and Trobitz (1949) was used to develop the analysis of expected water yield increase from these Mokelumne River watersheds as shown in table 3. In these calculations it was assumed that for areas of ground made barren, a savings of 8 inches of water would result. The lowered recharge of the soil moisture reservoir needed during the subsequent wet season would result in the increased water yield. The regrowth in vegetation in the seral stages following logging harvest for south and middle forks of the Mokelumne River, California. (Blanchard, 1962)

Figure 2: Cumulative trend of streamflow yield of combined south and middle Forks of the Mokelumne (Blanchard 1962) Units 1,000 acre feet

Table 3. Cumulative timber harvest acres, estimated reduction in evapotranspiration and cumulative recovery of evapotranspiration with seral stages following logging timber harvest for south and middle forks of the Mokelumne River, California. (Blanchard, 1962)

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>CUT, ACRES</th>
<th>PREDICTED RECOVERY OF EVAPOTRANSPIRATION, AC. FT.</th>
<th>LAT.</th>
<th>REDUC.</th>
<th>EVAP.-TRANSPIRATION</th>
<th>AC. FT.</th>
<th>TOTAL</th>
<th>REDUC.</th>
<th>EVAP.-TRANSPIRATION</th>
<th>AC. FT.</th>
<th>TOTAL</th>
<th>REDUC.</th>
<th>EVAP.-TRANSPIRATION</th>
<th>AC. FT.</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1931-35</td>
<td>596</td>
<td>600</td>
<td>60</td>
<td>174</td>
<td>528</td>
<td>330</td>
<td>386</td>
<td>432</td>
<td>446</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39-49</td>
<td>9</td>
<td>380</td>
<td>10</td>
<td>158</td>
<td>360</td>
<td>1,043</td>
<td>1,350</td>
<td>1,980</td>
<td>2,190</td>
<td>2,410</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41-43</td>
<td>7,170</td>
<td>8,500</td>
<td>480</td>
<td>1,246</td>
<td>2,162</td>
<td>340</td>
<td>1,580</td>
<td>2,920</td>
<td>2,990</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>46-50</td>
<td>8,600</td>
<td>10,400</td>
<td>480</td>
<td>1,246</td>
<td>2,920</td>
<td>340</td>
<td>1,580</td>
<td>1,060</td>
<td>2,060</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51-55</td>
<td>7,170</td>
<td>4,800</td>
<td>480</td>
<td>1,246</td>
<td>2,920</td>
<td>340</td>
<td>1,580</td>
<td>1,060</td>
<td>2,060</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>56-60</td>
<td>7,170</td>
<td>4,800</td>
<td>480</td>
<td>1,246</td>
<td>2,920</td>
<td>340</td>
<td>1,580</td>
<td>1,060</td>
<td>2,060</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>61-65</td>
<td>3,140</td>
<td>2,100</td>
<td>480</td>
<td>1,246</td>
<td>2,920</td>
<td>340</td>
<td>1,580</td>
<td>1,060</td>
<td>2,060</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>38,986</td>
<td>60</td>
<td>174</td>
<td>783</td>
<td>3,814</td>
<td>4,676</td>
<td>9,576</td>
<td>10,948</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumul. Reduc. (Col. 3)</td>
<td>1,000</td>
<td>9,000</td>
<td>14,400</td>
<td>19,200</td>
<td>24,000</td>
<td>28,100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Reduc.</td>
<td>360</td>
<td>2,170</td>
<td>2,717</td>
<td>10,386</td>
<td>12,724</td>
<td>14,674</td>
<td>15,132</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
this cumulative logging and recovery analysis, somewhat less than that indicated by trend shown in figure 2.

The recovery formula used was of the form:

\[ \frac{x}{a} = 1 - e^{-kt} \]

where \( a \) is the initial loss of evapotranspiration due to vegetation removal by logging, and \( x \) is the recovery in a given period of years after logging due to vegetation regrowth. Units are in inches. A \( k \) value of .0462 was assumed, giving a recovery of 10% in 2.5 years and 50% recovery in 15 years. Analysis was to the midpoint of each five year period.

### SOIL MOISTURE MONITORING

If the increased yield on the south and middle forks of the Mokelumne watershed was due to reduction of evapotranspiration losses from the soil moisture storage reservoir, this should be detectable by monitoring the soil moisture regime of the various cover conditions associated with the logging operations. To accomplish this, a series of six sites with 35 neutron probe tubes were established to monitor soil moisture storage changes in soils under the various seral vegetation classes associated with the logging. Measurements of soil moisture content at uniform depth increments were made at intervals through each year (1961-63) beginning with full storage conditions in the spring (usually May 1), to full drying potential of the respective cover at the end of the dry season (usually mid-October) each year.

The statistics for total soil moisture storage depletion under the various forest conditions typical of logging and vegetative regrowth are shown in table 4. Bare soil had the least depletion, with the greatest depletion of soil moisture storage occurring under brush and young second-growth and plantations. Old-growth timber was intermediate in amount. The logging of the old-growth forest decreased water loss from the soil moisture reservoir, but second-growth used more water.

There were some anomalous areas having very low soil moisture changes during the drying season, apparently due to subsurface recharge from an aquifer. An example of this occurred in a bare area where the soil being monitored with a 16' deep neutron probe tube actually gained 4.2 in. of moisture storage during the dry season. A soil of similar depth in an adjacent old forest showed a very low actual decline in storage. The actual loss was probably equal to the sum of this low loss plus background recharge from the aquifer. Large proportions of the commercial timber sites are underlain by the Mehrten formation, with alternating strata of volcanic mudflows, breccias, and beds of andesitic tuff and ash. The andesitic tuff beds serve as aquifers which when exposed longitudinally along the watershed surface give rise to soils having high timber site quality (Cohasset, Windy, soil series). Such recharge would tend to make the evapotranspiration loss from the timber approximate the potential evapotranspiration loss, instead of restricting it to actual soil moisture storage amounts.

### CONCLUSIONS

Soil moisture storage and associated deep storage in retentive rocks is a considerable storage reservoir over our watersheds. The management of the vegetative use of water from this soil moisture reservoir offers a considerable potential for increasing the water produced by these watersheds. A consistent increase in water productivity has occurred on the south and middle forks of the Mokelumne River watersheds during 30 years of cumulative logging. There are corresponding decreases in soil moisture loss under conditions of tree harvest from logging on these watersheds. However, the reduction in soil moisture use does not appear to be enough to account for all the increased yield. In addition, the reduction in interception loss associated with the decrease in canopy density is another factor.

### REFERENCES


The Economic Value of Water in National Forest Management

Jeffrey M. Romm and Amy Ewing with Shou-Jen Yen and Robert Haberman

Abstract: This paper identifies the economic values of water in the National Forest System of California and institutional factors that influence their effect on Forest Management. The estimated values of forest water range from 0 to $320 per acre-foot among broad areas of the National Forest System and are highest in the southern and central Sierras and in Southern California. Although relatively uniform water values have been used in Forest plans, growing interdependence among State and Federal resource interests and capacities is raising and diversifying these values. Water supply will consequently emerge as an explicit objective of National Forest management and a dominant objective in some areas.

More than half of California's 200 million acre-feet of precipitation fall on National Forest lands (California Water Atlas 1978). An estimated 47 percent of the State's 71 million acre-feet of runoff originate from them. About 35 percent of the State's precipitation is consumed on and evaporated or transpired from National Forest lands. As a class, forest vegetation appears to be the largest single consumer of water in California. The National Forests together form the largest unit of the State's water storage system. Nevertheless, the National Forests of California have yet to be managed actively for their water values.

Forests can be managed to satisfy water quantity, quality, and storage objectives (e.g., Satterlund 1971, Kattelmann 1982). Vegetation can be converted from high to low water-consuming forms and to forms that protect soils particularly well. Timber harvesting patterns and rotation lengths can be selected to achieve desired effects on water yields, snow and soil moisture storage, and rates of water and sediment release. As early as 1912, the future Sierra forest was protected as a honeycomb cover of small short-rotation clearcuts that would serve State interests in both timber and water production (Kattelmann 1982). Thus far, however, water management in the National Forest System in California has been oriented toward protecting vegetative cover rather than toward managing it for explicit water objectives. Although timber management has affected the State's water regime, its vegetative manipulations have generally not been undertaken to achieve their water supply effects.

California's congressional delegation supported the creation of National Forest reserves in the 1890's primarily because of its interests in enhancing the quality of Sierran watersheds (Wengert, Dyer, and Deutsch 1975). Why has water supply become an incidental objective in National Forest Management? Should it be otherwise? If so, under what conditions?

3Ansley Schiff (1960) analyzes the history of Forest Service commitment to the role of watershed protector rather than to that of water manager. Watershed protection provided a quasi-scientific justification for the establishment of Federal forest reserves in the West and their later acquisition in the East. The justification was codified in the Organic Act of 1897 and the Weeks Act of 1911. In the latter case, the justification was central to a debate about the constitutionality of Federal acquisitions, which depended upon Federal powers to protect navigable streams. Schiff argues that the justification became a professional ideology that prevented scientists in the Forest Service from addressing the realities of forest-water relations. Such an ideology would be enforced by its complement, a timber-primacy orientation. Although the ideology has weakened, the pairing of timber-active and water-passive orientations may still retain its effectiveness. Ironically, the ideology has now passed to interest groups who use it to constrain Forest Service timber management activities.

4The Forest Service estimates that past manipulations of National Forest vegetation have already achieved up to two-thirds of their potential impacts upon water yield in California (Kattelmann 1982, Rector and MacDonald 1987). The question remains as to whether this "background" effect would have greater value if the manipulations causing it had been designed for water rather than land management purposes. A redistribution of background impacts over time and space would be expected to increase the water benefits derived.
This paper explores these questions by considering two possible explanations for the peripheral role of water management in the National Forest System.

(a) The economic value of forest water does not justify the costs of managing for it.

(b) Although the economic value of forest water may justify management for it, institutional factors limit the influence of water value on forest management choices.

This paper reports preliminary findings of our studies of forest water values and the institutions that determine their influence. The first section presents the general distribution of on-site water values in California's National Forests. The second discusses institutional factors that determine the influence of water values on management decisions, how these factors are changing, and what the effects of these changes are likely to be. The final section briefly discusses some management implications of institutional trends and the values of forest water.

THE ECONOMIC VALUE OF NATIONAL FOREST WATER IN CALIFORNIA

What is the actual economic value of water on California's National Forests? Does it justify additional attention to forest water management for augmented yield and storage? If so, where and under what conditions? These questions have practical importance. A 1 or 2 percent increase in water yields would be insignificant if water is valued at $10 per acre-foot. If the value is $100 per acre-foot, such increased yields would be one of the dominant economic products of forest management. If water is withdrawn from marginal uses at $200 per acre-foot, an additional unit could change the management regime for a National Forest.

Forest water has downstream economic value for hydroelectricity generation, for consumptive uses, and for the maintenance of instream conditions. Its value is the economic contribution that one additional unit of water would create if available at a given time and place in the forest. This marginal value depends primarily upon five factors.

1. The location of its source in the forest.
2. The time of its release as runoff.
3. The losses in seepage and evaporation that occur during its flow downstream.
4. The capacity of downstream facilities to capture, transport, and process it for productive use.
5. The economic value of that use.

The value of forest water varies significantly with these conditions.

We mapped all streams that flow out of the National Forest System in California. We mapped all hydroelectric plants (FERC 1981) on these streams, grouped the streams into eighteen hydrologic basins (fig. 1) that the California Department of Water Resources has used for assessing hydroelectric potentials (WIR 1981, MIR 1974), identified the elevation of each plant, and determined the average production of electricity per unit of water that flowed through each of them over the 10-year period of 1975-84 (PG&E, SMUD, BOR unpublished data). We mapped all storage facilities on these streams, determined where the water that was stored in each facility was transported for agricultural use, and estimated the storage and transportation losses in water that would occur (Ewing 1985). In other words, we established a framework for predicting where and how an additional unit of forest water, originating from any point in the National Forest System, would be used in hydrogeneration and agriculture.

It was then possible to place an economic value on that unit at its source.

Valuation Methods

Several assumptions created a conservative bias in the values of forest water that the analysis produced.

1. We assumed that water is allocated to its highest-value consumptive uses in times of scarcity. This means that, for a given supply, water is withdrawn from marginal uses in these times. The value of an additional unit of water is therefore its value in the marginal use. We assumed that the marginal use is always agricultural. Even if an additional unit is used directly for urban purposes, it replaces a unit that would otherwise be withdrawn from the agricultural margin, where the actual increment of value occurs. With the exception of the southern Bay Area, the marginal agricultural use of water throughout California is in irrigated pasture or feedcrop production (Ewing 1985). As National Forest water in some locations is stored and distributed directly for use in urban areas and for high-value agricultural crops, and to the extent that this source is not replaceable in times of scarcity, the assumption may produce an underestimate of the consumptive value.

2. The analysis does not treat the values of instream flow. In effect, it assumes that the value of additional instream flow is zero. The consequent estimates of value would be low in basins where additional water or modified...
Figure 1--The hydroelectric and agricultural basins used in water valuation from National Forests in California.

Figure 2--The relationship between the hydroelectric values of forest water and the elevation of the hydrogeneration plants through which they flow.
timing will increase the value of downstream riparian conditions.

The analysis also contained assumptions that may produce overestimates of value. We assumed that hydroelectric and agricultural uses of water are perfect complements and that the values of water for them could therefore be summed in those basins where both drew upon the same flows. The assumption would lead to an overestimate in basins where one of these uses reduces the water that would otherwise be available for the other.

Value for Hydroelectricity Generation

We estimated the hydrogeneration value of forest water as the cost of fossil fuel that would be avoided if an additional unit of water were available for processing through current hydrogeneration facilities. Our values are average annual marginal values over the 10-year period, 1975-84 (PG&E 1985). The average internalizes fluctuations in fossil fuel prices that occurred over that period. It hides seasonal variations in value, which are significant. Values rise in the summer months and drop rapidly in winter and spring. Our use of average annual marginal values may produce underestimates or overestimates, depending upon the time of year in which an additional unit of forest water would be available for use.

The value of a unit of forest water in hydrogeneration depends upon the number and efficiency of power plants through which it moves. As hydrogeneration does not consume water, a unit of water gains value with each successive plant through which it runs. The total marginal value of a unit of water is the sum of its successive contributions. If processing facilities did not exist on a particular stream, we assumed in our analysis that the capital cost of establishing them would drop the marginal value of water to zero.

The number of generation plants in a basin depends upon the range of elevations through which the basin runs. The relation between total marginal value of a unit of water and the elevation of the highest plant through which it runs has an $R^2$ of 0.70 (fig. 2). Departures from the regressed values increase with elevation because of increasing variation in the number of downstream power plants among different basins. The departures arise primarily because a given elevation in the eastside Sierra basins affords fewer downstream opportunities for power generation than elsewhere in the State.

Consumptive Value


We determined the marginal agricultural uses of water from each basin in the National Forest System. We determined the marginal cost of pumping a unit of water for the marginal use in each recipient area. Assuming that farmers equate their marginal costs and marginal benefits, the marginal pumping cost is the marginal benefit as well. Marginal pumping cost is an observable market measure of water value. We used it because actual water prices are administered rather than market-derived and do not provide a sound measure of economic value; imputed market values depend upon the model producing them and cannot be observed. We deducted transportation and facility costs, as well as estimated transportation losses, to obtain a derived value for water in the basin of its forest origin.

The agricultural value of water varies significantly over the course of a year. We used pumping costs for the late-spring early-summer period, when water takes on value rapidly. The approach would overestimate or underestimate value, depending upon the time of year in which additional forest water would be

The economic value of "riparian condition" can conceivably be estimated by assessing the effects of different conditions on riparian land values. The land market presumably reflects the values of those who place a premium upon access to the nonmonetary benefits that these conditions provide. Land values may provide indicators that are superior to measures intended to monetize these benefits directly.

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6The economic value of "riparian condition" can conceivably be estimated by assessing the effects of different conditions on riparian land values. The land market presumably reflects the values of those who place a premium upon access to the nonmonetary benefits that these conditions provide. Land values may provide indicators that are superior to measures intended to monetize these benefits directly.
available for use. Where transportation and storage facilities do not exist, we assumed that the cost of creating them would reduce the value of forest water to zero. This approach underestimates the value of water that recharges aquifers where they are used.

Total Marginal Value of Forest Water

We obtained total marginal values of forest water by summing the average marginal values per acre-foot for agriculture and hydrogeneration in each basin. We also calculated total marginal values on the basis of the regressed value for hydroelectricity at different elevations in the basin. This was done to introduce the significant elevational effect on values.

Results

Weighting values by the proportion of flows to which they apply, we estimated that the average marginal value of water in the National Forest System of California is $62.53 per acre-foot. Of this amount, the value for hydroelectricity is $61.90 per acre-foot. The value for agriculture is $20.63 per acre-foot. Given the conservative bias in our procedures, these estimates are more likely to err on the low than high side. Nevertheless, the numbers must be interpreted as indicators and with great caution, primarily because they do not yet reflect adequate analysis of relationships between the timing of additional water availability and the values of water at different times of the year.

The variations among values are more interesting than the averages. We determined the distribution of agricultural values of forest water among basins in the National Forest System (fig.3); the distribution of average agricultural and hydrogeneration values by basin (fig.4); the distribution of hydrogeneration values that derived from the regression of all hydrogeneration values against hydroplant elevations (figs.1,5). Finally, we determined the distribution of total values that derived from adding the agricultural value in each basin and the hydroelectric value at different elevations of the basin (fig.6).

Total marginal values vary from 0 to $322 per acre-foot among the area units of the National Forest System that we used; they exceed $400 per acre-foot in specific locations we identified within our area units of analysis. Use of the $62.53 average would bend forest management decisions away from the economically optimal allocation of resources in any one site, drawing insufficient attention to water where its value is high and excessive attention where the value is low.

The Forest Service suggested a regional value of $59 per acre-foot for considerations of water in National Forest plans in California. Eleven of the 17 Forests in the region have used this planning value. They extend from northern Klamath southward to the Los Padres and Sequoia Forests. The use of a relatively uniform planning value distorts management choices in the manner that would occur if our average value were used.

The values of forest water are inversely related to water availability and directly related to the presence of facilities for storage, transportation, and power generation. In general, the values of forest water (fig.5) are low in north coast and low elevation areas of the National Forest System, where they are about half the Forest Service planning value of $59 per acre-foot and around one-third of our NFS average. The values are moderate but below our $82.53 average at middle and upper elevations of the northern interior and middle elevations of the northern westside Sierra, where the Forest Service planning value corresponds roughly with our estimate. Water values are above average at upper elevations of the central Sierra and along the southern coast. They are highest in the southern westside Sierra, where they are at least double the Forest Service planning value.

Discussion

The map of forest water values has strategic use. It allows judgments as to where forest water management is likely to be economic, where it is not, and where it may become so in the foreseeable future. The higher water values in

8Rector and MacDonald (1987) indicate that California's National Forest plans use an average value of $66 per acre-foot. The $66 value is not weighted by the proportion of flows to which each National Forest value applies. It is an average per Forest rather than an average per acre-foot. Thus, it is not directly comparable to the average of $82.53 that our analysis has produced.

9The six Forests that developed their own planning values obtained results that are fairly consistent with those we derived for the areas and conditions:

Six Rivers (north coast): $0;
Lassen (northern interior): $84 red fir, $82 mixed-conifer, $76 lodgepole, $70 ponderosa, and $75 other;
El Dorado (central Sierra): $206.30 red fir, $122.10 mixed conifer, $89.85 hardwood;
Angeles (southern): $112;
San Bernardino (southern): $8.19;
Cleveland (southern): $114 municipal and $13.30 nonmunicipal watersheds.
Figure 3--The agricultural value of National Forest water in California, by basin.

Figure 4--Average hydroelectric value of National Forest water, by elevation class.
Figure 5--Average total agricultural and hydrogeneration value of National Forest water in California, by basin (see Table 1).

Figure 6--Average total value of National Forest water in California, by basin (agriculture) and elevation class (hydrogeneration) (see Table 2).
Table 2--Total average value of National Forest water by basin (agriculture) and elevation (hydrogeneration).

<table>
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<tr>
<th>Basin Area</th>
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Table 2--Total average value of National Forest water by basin (agriculture) and elevation (hydrogeneration) (cont'd).

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Note: Basins, as listed, follow a roughly northwest-to-southeast gradient in California.

¹--Elevation classes:
   class 1: 0-3000 ft.
   class 2: 3001-6000 ft.
   class 3: over 6000 ft.

²--Regression is based on a sample of 111 plants in California.

³--Source: Ewing, 1985
the National Forest System generally occur in upper elevations of the Sierra forests. The higher-elevation zones are remarkably congruent (1) with areas receiving at least 35 inches of average precipitation, i.e., a threshold for potential increases in water yield during drought (Turner 1987), and (2) with forests where vegetative manipulation offers two-thirds of the potential increases the National Forest System could yield, that is, where the scope for water management is greatest (Rector and MacDonald 1987). The Sierra forests appear to offer relatively significant prospects.

The value map also indicates where the payoff to research is likely to be large and small. The values point to specific basins where the payoff to research is predictably large. Mapping the factors that determine economic values, biophysical potentials, and the scope for vegetative manipulation provides a basis for stratifying the National Forest to achieve strategic selection of research sites.

Our values are an initial step in establishing the basis for judging where forest water management is and is not economic. Three additional steps must be taken to firmly establish such a basis.

1. The quantity of water that a given management practice can store or release in different circumstances determines the economic desirability of the practice. The value per unit is insufficient basis alone. Although water values are generally lower in the northern than southern Sierra, for example, a given practice may change water flows sufficiently more in the former than the latter to produce a greater incremental value relative to the cost of the practice. Rector and MacDonald (1987) suggest this possibility.

2. The cost of a practice depends upon the values of other possible management regimes that it preempts. The direct cost of the practice is an insufficient measure alone. If water management practices are at the cost of recreation values, for example, and if these values vary among regions, as they do, then the cost of water management will vary accordingly.

3. The value of forest water is strongly related to the timing of its availability for use. Additional water in seasons of abundance has no value; its value in late summer can be extremely high. Although our results are helpful, they must be augmented by analyses that show (1) how water values vary over the course of a year and (2) when different management practices are likely to release additional water in different conditions. Such analyses will modify the value map and facilitate choices among management practices that augment water yields and/or water storage.

Finally, it should be noted that the reconnaissance scale of our value map hides potentially significant local variations. In this regard, it is particularly important to identify conditions and areas in which unusually high values prevail and economic mismanagement is therefore most likely to occur. As these conditions and areas are more probable in the higher-value classes of our value map, refinement of the map should be biased toward these classes.

WATER VALUES, INSTITUTIONAL ARRANGEMENTS, AND FOREST MANAGEMENT DECISIONS

The economic values of forest water need not affect forest management decisions. Economic values influence forest management choices to the extent that forest owners have reason to consider them. Zinke (1987) describes a case in which a forest management system has achieved proven long-term water yield increases in conditions where the yields have high economic value, but the forest owners have little reason to maintain the system because they do not share in the value they create. This case typifies the common situation in California: landowners and water users are separate groups. The management effects of economic values depend upon how institutions distribute the benefits and costs of forest water management among these groups. The weak development of such institutions in California has meant that landowners have not had reason to make forest management decisions that reflect the value of water to its users.

In 1979, the Forest Service was using $5 per acre-foot as its water value in National Forest planning in California. The figure may have indicated the actual economic value of forest water at the time, the quality of available information, or the absence of institutional exchanges that would have encouraged the Forest Service to register the full value of its water. The Forest Service subsequently raised its planning value to $10, then to $41 and, by 1984, to $59 per acre-foot. It increased the value twelvefold in five years.

Why did the Forest Service planning value for water rise so steeply?

Increasing economic demand for water is one proposed explanation. The explanation suggests that $5 and $59 were realistic estimates in 1979 and 1984 respectively. Empirical evidence does not support it. The acreage in irrigated pasture and feedcrops, the dominant agricultural water consumers, has declined steadily since 1975. The decline in acreage has not been due to rises in energy prices; although agricultural energy costs rose steeply from 1975 to 1980, they have remained fairly steady since that time (Pyle 1983). The value of hydroelectricity has risen and fallen over the same period; adjusting for inflation, the value is lower today than it was in 1979. The decline in acreage has been due primarily to a severe depression in the live-
stock industry. In other words, the marginal value of water in its marginal use has declined rather than increased. Although actual and anticipated economic demand may explain some of the rise in Forest Service planning values for water, it cannot explain a twelvefold increase in those values over a 5-year period.

A second explanation is that the Forest Service has learned much more about the value of forest water than it previously had known. The explanation has empirical support. National Forest planning teams, the team on the El Dorado National Forest in particular, have made significant contributions to the understanding of forest water values. Researchers and water system modellers have advanced understanding of the values of water in its various uses in California and have substantially increased the value estimates, however.

We offer and examine a third explanation that arises from the separateness of land owners and water users. Institutional developments are increasing the extent to which the Forest Service must consider the potential economic gains or losses to water users that may result from its land management decisions. The Forest Service has raised its planning value for water dramatically because the growth of institutional exchange has given it reason to do so.

Interdependence, Exchange, and Value

We suggest that the rise in Forest Service planning values for water indicates the growth of means for improved accommodation between State water and Federal land interests. The State and the National Forests have always been interdependent in economic and ecological terms. Only recently, however, have they begun to gain the parity of authorities and capacities that encourages them to negotiate their mutual interests.

In theory, interdependence is said to be mutually beneficial to the extent that opportunities for negotiation, exchange, and cooperation exist (e.g., Pigou 1920; Coase 1960). Such opportunities arise when the values at stake justify support by the parties involved for the arrangements that allow them to bargain toward mutually acceptable outcomes (Olson 1965; Demsetz 1964). The bargaining process has the effect of forcing each party to internalize the values of the other. In theory, it produces outcomes that are superior for both. And the most desirable collective outcomes arise when there is reasonable parity among the parties involved.

The institutional context of forest water management decisions has changed significantly over the last decade and in ways that would be predicted to increase the value of water that the Forest Service considers in its land management decisions. Specifically, the potential effects of State and Forest Service actions on one another are becoming sufficiently valuable to justify the growth of accommodation. The trend in Forest Service planning values for water, a State interest, is consistent with the outcomes that would be predicted to arise.

The following developments illustrate the scope of change in the institutional context within which forest water values are determined.

1. In U.S. v. New Mexico (1978), the Rio Membres decision, the Supreme Court curtailed the Federal reserved right, which had secured all water the National Forests might need for their purposes, to apply only to Federal uses of water for timber production and the maintenance of water flows. In economic terms, the decision confined Federal "free good" treatment of forest water to only those amounts that would be used for these specified purposes. It placed Forest Service water claims for recreation, habitat maintenance, stock ponds, and the like under State law, where they are or could be subject to competing downstream claims and the economic values attached to them. The decision potentially increased the cost of multiple-use management by placing nontimber uses of the National Forests in economic competition with downstream demands.

2. The Federal Water Quality Act of 1977 established State authority to determine and presumably enforce "best management practices" on National Forest lands for control of nonpoint pollution from timber harvests. They increased potential State authority relative to Federal authority to influence Forest Service land management decisions. The State Water Resources Control Board exercises this authority over National Forest management. Thus, the Board has gained the potential power to both withhold National Forest water from National Forest users, through the Rio Membres decision, and to affect National Forest land management directly. Both increase pressures upon the Forest Service to respond to State values.

3. State water policy has been shifting from an era of major capital subsidy for water supply to a policy of placing the full costs of water upon those who use it. The shift is increasing the "felt" scarcity of water among its users, particularly in agriculture. It is promoting the growth of water trade, which redistributes water toward those who value it most. It is promoting the growth of coordination between State and Federal water authorities; this will tend over time to equalize their currently disparate water pricing policies, presumably at the higher State levels. The shift of policy is also increasing the pressures to develop nonconventional sources of supply. These pressures are manifest in an expanding range of Federal, State, and local trials and investigations. When the California Water Atlas...
was published in 1978, it contained one usual paragraph about the State's watersheds, which are predominantly in the National Forests. A similar treatment today is inconceivable. The National Forest System is becoming an acknowledged part of the State's water system and, however implicitly, is increasingly subject to the values that system contains.

4. Under the National Forest Management Act of 1976, the Forest Service has developed processes for National Forest planning that increase both the Agency's capacity to use economic values in choosing land management regimes and the Agency's accountability to State and local interests. Since 1980, Federal fiscal policies have increased emphasis upon the economics of forest management choices. By assigning budget cuts particularly to water, soil, and range programs in the Forest Service, they have weakened the Agency's capacities to withstand State and local interests in these areas. One predicted effect is to increase pressures on Forest Service planning values for water, particularly where the disparities between economic and planning values are greatest.

5. State capacities to exercise informed influence upon National Forest management have grown markedly in the past decade. The State has developed a forest policy that should eventually increase private production of goods and services that the Federal lands have been providing. The policy includes the establishment of a Timberland Production Zone, which now contains 5.5 million acres of private forestland, the subsidization of nonindustrial forestry investments, the regulation of timber harvests to insure regeneration and sound environmental practices, the expansion of technical services to landowners, and the development of wildland planning and analytic capacities for integrated examination of the relationships among private, State, and Federal objectives, opportunities, and constraints. While the Forest Service budget has been sharply constrained, State resource needs for such activities are rising. The predicted effect of these developments is to increase the extent to which Forest Service planning values match the economic values in the State.

These institutional changes have not necessarily been at Federal expense. A successful State forest policy can expand the Forest Service's scope of managerial discretion by shifting toward private lands the pressures for conflicting services that the agency has had to absorb. In addition, the Forest Service has gained leverage for influence upon the State. It has the capacity to specialize its management efforts in timber production, thereby overcoming Rio Membres limits upon the reserved right by withdrawing services, such as outdoor recreation, wildlife habitat maintenance, range management, and water supply, that the State has itself viewed as relatively unlimited rights. It can pursue timber harvesting policies that complement or contravene the objectives of State forest policy. It can withhold permit approvals in the intensely competitive riparian zone for projects the State may want. In other words, the very changes that have increased potential State influence upon the Forest Service have also increased potential State values for National Forest services that have been provided freely in the past and might now be withdrawn.

We would argue that a changing relationship between the Forest Service and the State is largely responsible for the rises in Forest Service planning values for forest water. If this is so, then future developments in the relationship are likely to determine the value and role of water in National Forest management decisions.

Implications

The institutional changes of the past decade have increased the interdependence between State interests and Federal management authorities for the National Forests (Romm and Fairfax 1985). The continuing disparities between economic and planning values for forest water indicate that the opportunities for mutually beneficial cooperation remain very large. There are obvious tensions and social costs in an area where, for example, the planning and economic values of forest water are $59 and $350 per acre-foot respectively, or in regions like the westside Sierra, where economic values are at least double the planning value. The values at stake are substantial; the motives for cooperation appear to be significant. The values at stake vary greatly among the National Forests and areas within each of them; thus, the motives for diversification of means within the National Forest System appear to be significant as well.

Increased cooperation may take diverse forms. It may include, for example:

(a) liaison mechanisms, as these exist in Forest Service cooperative programs;

(b) cooperative pilot projects, as was once proposed for management of the Lower Feather River Basin;

(c) coordinated plans, programs and budgets, as they occur in fire protection;

(d) State payments for desired National Forest services, as in a developing plan for forest water management in Colorado;

(e) coordinated research and monitoring programs, as is developing in timber management, and

(f) mutually supportive political and administrative stances, as in the public lands states.
The development of such mechanisms would be expected to increase the economic realism of planning values that are applied to forest water in land management decisions. It would also increase the realism of values the State assigns to National Forest services that it has tended to take for granted as unlimited rights. If theory is correct, it would have a positive effect on both State and National public interests by increasing the economic efficiency with which National Forest resources are allocated.

FOREST WATER VALUES AND NATIONAL FOREST MANAGEMENT

Water and timber are joint products of forest management. Timber harvest releases additional water for downstream use until regeneration fully exploits the increment. The loss of the increment occurs in a much shorter time than the normal timber rotation in California. Thus, the economic rotation length for timber is inversely related to the planning value for water and to the value of short- relative to long-rotation wood material. Krutilla, Bowes, and Sherman (1983) have shown that, all else equal, rising water values increase the number and frequency of timber harvests. They also increase the economic viability of harvesting "marginal" timber sites. High water values can justify the harvest of low sites, where wood is a by-product of the water management objective.

With some notable exceptions, water values have not been integrated in the decision frameworks for the National Forest plans of California. As Rector and MacDonald (1987) have shown, the Forests used other criteria to determine their "preferred alternative" and then estimated and valued the prospective increases in water yield that their choice might produce. In some National Forests of the Rockies, high water values were put aside when they were found to "drive" the choice of plan. The choice of an institutionally preferred management regime had the effect of imputing lower values to water than Forest Service analyses had revealed. The common use of a $59 value for water in California's National Forest plans suggests that the value did not derive from planning analyses but was used to make "economic" a set of outcomes that were chosen on other grounds.

California has not had arrangements for determining what additional forest water is worth and what it would cost. This is one reason that water supply objectives have had incidental roles in National Forest management. The steep rise in Forest Service planning values for forest water suggests that value-enhancing arrangements are evolving rapidly. The continuing disparities between planning and economic values indicate that there is still a long way to go. The eventual outcomes for National Forest management are not clear, for the institutional developments that are increasing planning values for water also have the effect of increasing the values to the State of possibly competitive National Forest uses, in recreation for example.

In any event, it seems reasonable to expect that water supply objectives will become increasingly important in National Forest areas where the values of water surpass those for competitive uses. A short-rotation honeycomb pattern will eventually characterize possibly significant portions of the mid- to upper-elevation Sierran conifer zones. Some National Forests in Northern California will become predominantly "water forests" that produce small-dimension timber and diversified wildlife habitats as by-products of the main purpose. And current "water forests" in Southern California are likely to become more actively managed for water supply objectives. There seems reason to assess and develop these prospects strategically in order to prepare for the time they will mature.

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Synthesis and Summary: Yields of Water

Jeffrey M. Romm

FOREST MANAGEMENT FOR WATER YIELD AND STORAGE: DEVELOPING A RESEARCH STRATEGY

Where is forest management for augmented water yield and storage more and less like likely to be sensible? The papers in the water yield session collectively produced a possible answer to this question. Each shaped the map of prospects in its own way. Their complementarity was remarkable, for they were based upon independent work about which there had been virtually no previous communication. Together, they generated a common hypothesis that should strengthen future research strategy.

I will not summarize the session. Rather, I will describe the convergence of its papers toward common conclusions and will discuss what the conclusions offer as a basis for potential research strategy and generalization. Finally, I will propose several means by which the potential might be exploited to increase the utility of water yield research.

Patterns and Research Strategy

Three forms of information were used to diagnose the relative potentials among areas in California for managing forests to augment water yield and storage. Climatic factors were used to indicate the degree of possibility for hydrologic modification in different areas. The degree of land commitments to particular forms of vegetative use was used to identify where managers have more and less scope to manipulate vegetation for water objectives. Economic factors were used to array areas by the relative worth of additional water that vegetative manipulation might produce. The three sets of factors produced maps of relative possibility that were consistent with one another.

1. Climate

Water yield depends upon the difference between precipitation and vegetative water consumption. It increases to the extent that consumption is reduced through vegetative manipulation. The physical scientists in our group generally agreed that manipulating vegetative cover to augment water yields did not deserve consideration in climates with less than 15 inches per year of precipitation. Precipitation of 15-20 inches was considered to be marginal. Average precipitation above 35 inches would probably be necessary if water yields were to be increased in drought years. Ken Turner's paper provides a map of these various precipitation zones.

The vast majority of land in California that receives more than 35 inches of precipitation is in the mid- and upper-elevation ranges of the National Forest System. From a climatic point of view, these are the lands that deserve priority for research on forest water management.

2. Scope for Management

Vegetation can be manipulated to increase water yields to the extent that the opportunities for manipulation have not already been foreclosed. Opportunities have been foreclosed where other vegetative management regimes are already established or where laws limit possible actions and uses.

In discussing the scope for managing vegetation to augment water yields from the National Forest System, John Rector showed that about two-thirds of the potentially attainable increases were in the forests of the Sierra region. Neil Berg indicated that alpine areas could probably not be managed for increased storage because of the Wilderness status and the high financial costs of doing so. Possibilities for managing riparian vegetation and North Coast forests were also discarded because of institutional restrictions upon them.

The scope for forest water management appears to exist primarily in the forests of the Sierra, perhaps particularly in the true fir zone. Paul Zinke showed that durable increases in water yield have been attained within a regime of timber management for mixed-conifer forest in the central Sierra.
3. Economics

The economic desirability of forest water management depends upon the value of its yield relative to its cost. The value of increased water yields depends largely on the capacity of existing downstream facilities to capture them for hydroelectric, agricultural, and urban uses. Values are particularly high ($300–500 per acre-foot) where yields are captured directly for urban use or where they feed chains of downstream hydroelectric power installations. In broad area terms, values are highest in the southern Sierra forests. They are high in the northern Sierra and South Coast forests. They approach zero in the North Coast forests, where water is abundant and facilities for capturing its value are scarce, and at low elevations, where increased yields are generally not capturable. The cost of augmented water yield depends upon the values in other uses that are sacrificed when a forest is managed for water supply, as well as upon the direct investment in vegetative changes. Although the comparative costs of water yield augmentation in different contexts have not been determined, they can be expected to be small, relative to value, in those circumstances where water management complements management for other objectives, such as timber and forage production.

The economics of forest water management focus attention on the Sierran forests and on selected alpine and South Coast areas that would seem inappropriate if assessed on purely physical and technical grounds.

The maps of relative possibility that the authors presented—each from his own perspective—were remarkably congruent with one another. The papers collectively produced a hypothetical answer to the initial question. Forest water management is most likely to be sensible in the Sierra conifer forests and where additional water would be captured for direct urban consumption. It is very unlikely to be so in the North Coast, at lower alpine elevations, and in riparian zones generally. The collective map provides a basis for assessing the relative payoffs to forest water research in different areas.

Research Strategy and Research Utility

The hypothetical answer also affords a basis for assessing and designing strategies for forest water research. Research would presumably be weighted toward conditions in which prospects for its utility are relatively great. It would be stratified in a manner that clarified the conditions in which these prospects are expected to be more and less favorable. Factors of climate, management scope, and economic value would be used to differentiate strata at some useful level of resolution. Research sites would be selected for their representativeness of broadly prevailing conditions and particularly of those conditions in which prospects seem relatively good.

The papers indicated that such strategic distributions of research effort generally have not prevailed. Although the greatest prospects for forest water management appear to exist in the conifer zone of the Sierra, most research, including that which was reported in our session, collectively has focused upon alpine, foothill, riparian, and North Coast possibilities. Research has not been focused upon those conditions in which its results appear most likely to be useful. Perhaps this is why, despite seventy years of watershed research in California, few of its results have been incorporated in the management systems of the National Forests in the State.

Bob Ziemer and John Rector offered an alternative explanation for the lack of influence of water research on National Forest management: forest water management produces too little to be worth the trouble, even in the Sierra zone. Research has not yet substantiated this explanation. Forest water is worth more than $400 and less than $10 per acre-foot in different parts of the Sierra. A minor physical increase in $400 water can have major economic importance. Water yield augmentation complements other management objectives in some parts of the region and conflicts with them in others; additional water will be low-cost in the former and high-cost in the latter, whatever its economic benefits. Research can substantiate or reject the explanation once it has been stratified to take these differences into account.

Zinke, Turner, and I offered a third explanation. Whatever the economic value of increased water flows, forest owners, public and private, receive none of it because of the structure of water rights; they have no incentive to manage their lands for water yield objectives. The institutional conditions of forest water management have enjoyed too little research to establish whether or not this explanation is valid, but Zinke's and my findings seem sufficient to suggest that the issue deserves exploration. Current pilot arrangements between water districts and the Forest Service, changes in State-Federal water relations, and growing regulation of riparian zones provide opportunities to examine the effects of water rights arrangements on forest management for water objectives. Their new patterns of exchange between water users and land owners presumably affect what owners do with their forests. This proposition can be verified or rejected empirically. If it is found to be true, the various modes of exchange offer another basis for discriminating among sites in a strategic design for forest water research.

Forest water research has a history of being very site-specific, single-purpose, and tech-
nical. Such work could produce useful generalizations for policy and management if the research sites were selected in a framework that stratified them according to variables thought to make a difference. Unfortunately, sites have been distributed in an almost random way when assessed with respect to the distribution of variables that appear to affect potential research utility. Given the prevailing structure of forest water research, there is little reason to expect that even its useful results would be recognized as such. The convergence of findings in our water yield session was all the more remarkable in this context.

Toward Future Strategy

Is development of a research strategy worth the effort? This would be an appropriate focus for the next meeting of those who presented papers in our session. Some of the papers suggested the conclusion that would be likely to emerge.

At the present time, there are obvious "hot spots" in the National Forests of California that already deserve management primarily for water supply objectives. These are locations that serve urban populations directly or are responsive to low-cost treatment and are upstream from a chain of hydroelectric facilities that can capture their water yields. Larger areas appear to deserve management for various explicit combinations of water, timber, and forage supply objectives. The value of water is rising more rapidly than that of timber and forage. In our session, some argued that water yield augmentation would increase existing flows by only one or two percent at best and that these magnitudes are minor when compared to "background" flows that current forest management regimes already release. Whether these amounts are minor or not depends upon where and when they are released. A 1 percent increase of $200 water is a large amount. Moreover, the value of "background" flows would increase if the management regimes that produced them were designed explicitly to satisfy water as well as other objectives. A doubling of current "background" values would approach the value of projected future National Forest timber harvests at present prices.

In parts of the Rockies, water values now "carry" timber harvests that would otherwise lack economic justification. Given current trends in California, it seems reasonable to expect that, in 50 years' time, large belts of the National Forests may appropriately be managed on short rotations and in numerous small cuts that are designed to achieve desired quanti-ties, qualities, and timing of water yields. What these management regimes might be and where they are likely to be located are questions that must be considered in a systematic way, even if the need for these regimes is not presently apparent.

Proposals for the Development of Research Strategy

I would put forth two proposals for continuation of what this conference has initiated in the development of research strategy and discussion of its associated policy and management implications.

First, we should establish a California cooperative for forest water research. A cooperative exists for timber management research. A forest water research cooperative would promote continuing synthesis of research findings. It would provide a forum for developing an effective research strategy that is based on a Statewide assessment of prospective returns. It would provide a mechanism for pooling resources to support the strategic research that the State and the Forest Service need to achieve an effective knowledge-base for incorporating water in the management of the National Forests.

The Wildland and Water Resources Centers might jointly sponsor the cooperative, drawing its membership from the Forest Service, public utilities, and State agencies as well as from the research community. The organization would include Forest Service hydrologists and would help mobilize financial support for their activities. They have been doing pioneering work, largely to the benefit of State interests, despite several Federal budgetary slashes and limited opportunities for recognition.

Second, we should identify the numerous localized trials of new institutional arrangements between water users and land owners and should proceed to monitor these trials systematically. The trials are currently encountered only by good fortune, yet they are generating potentially crucial information about mechanisms that will better serve long-term forest and water management interests in the State. In addition to the strategic perspective, such information is the stuff that shapes effective public policy.

The water yield session did not reach these proposals in its course, but its papers managed to carve and shape the problem in a manner that clarified its contours and mapped the relative possibilities on its landscape. There seems reason to pursue these possibilities in a systematic and cooperative way.
The issue of cumulative effects of land use activities in California watersheds has raised considerable controversy over the last decade. This symposium offers a valuable opportunity to step back and put the issue in historical perspective.

Cumulative effects may be classified as two types. Type I effects are simply additive: multiple actions taken in subwatersheds of a river basin (such as road construction, timber harvest, urbanization, grazing, or deforestation) may eventually alter basic hydrologic relationships as measured at the basin outlet, with the basin-wide impact a linear function of the area disturbed, type of disturbance, and site sensitivity. In Type II effects, the downstream effects are greater than the sum of the parts. Multiple actions eventually cause some geomorphic threshold to be exceeded, and changes occur in the system that exceed the incremental additive impacts. Such thresholds require the operation of positive feedback or deviation-amplifying mechanisms.

Positive feedback mechanisms and geomorphic thresholds in alluvial channels, hillslopes, and drainage basins are well known even if they are not fully understood (Bull 1979; Schumm 1973). The interaction between stream channels and hillslopes may also involve positive feedback mechanisms, and these may be influenced by land use activities. Figure 1 shows some of the possible mechanisms involved in "cumulative effects" (Coats and Miller 1981).

Defined this way, "cumulative watershed effects" include all of the downstream or off-site effects of all land use activities. The early literature dealing with the effects of deforestation and fire on streamflow and sedimentation is rich, albeit obscure. Especially in the Mediterranean region, the "cumulative watershed impacts" of poor land use practices were recognized by the early 17th century. Kittredge (1948) in his book Forest Influences reviewed some of the early European writing on the relationship between forests, streamflow, and sedimentation.

Figure 1—The influence of timber harvest activities on hydrologic and erosional processes in a watershed. The (+) or (−) indicates whether an event or activity has a positive or negative effect on the frequency or magnitude of an event downslope or downstream.

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

2 Philip Williams & Associates, San Francisco, Calif.
THE FEDERAL ROLE

In American experience, controversy and concern over the effects of forest clearing on streamflow figured prominently in the movement for the creation of the Forest Reserves, which later became the National Forests. The Organic Act of June 4, 1897 provided that

"no national forest shall be established except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States" (USDA Forest Service 1974).

The 1902 Forest Reserve Manual gave as the two principal reasons for maintaining forests: (1) to furnish timber; (2) to regulate the flow of water (Kittredge 1948).

The early emphasis on the role of forests in regulating streamflow derived in part from a question about the constitutionality of Federal ownership of forest lands, except for protection of navigable streams. As long as the forest reserve advocates could argue that the reserves were needed to protect navigation, the constitutional question did not arise.

From the late 1870's to the early 1940's, foresters (especially in the U.S. Forest Service) argued that forest cover played a major role in ameliorating regional floods in large river basins. Forest clearing was thought to be a major cause of large floods, and the solution, according to the Forest Service, was forest conservation and reforestation. Although the early advocates of forest conservation were no doubt sincere, there was a certain measure of self-interest in their claims. Disastrous floods in the Ohio and Mississippi River Valleys focused public attention on the hydrologic role of forest cover, and provided an opportunity for building support for expansion of the National Forest System and for reforestation programs (Schiff 1982).

Unfortunately, many of the foresters' claims about forests and floods were without strong scientific foundation. This weakness led to criticism from Hiram Chittenden of the Army Corps of Engineers and Willis Moore, Chief of the U.S. Weather Bureau. Moore (1910) asserted that "the runoff of rivers is not materially affected by any other factor than the precipitation." Smith, Chief of the U.S. Geological Survey, stated that "what man does with forests will have little effect on erosion" (Kittredge 1948). As late as 1937, W. G. Hoyt of the Geological Survey wrote:

"It is a sad commentary on a so-called scientific organization like the Forest Service that during its existence it has never published a report on the role played by vegetal cover on the hydrologic cycle which was in accord with well-established hydrologic principles. In the history of that organization the hydraulic engineer or hydrologist engaged on experiments relating to the influence of vegetal cover on streamflow has been conspicuous by his absence."

This controversy had the beneficial effect of leading to actual experimentation and study on the relation between forests and streamflow. In 1910, the Forest Service and the Weather Bureau jointly initiated the world's first paired watershed study at Wagonwheel Gap, Colorado. This study produced useful information, but it was beset by conflict and controversy between the Forest Service and the Weather Bureau, and the Forest Service came close to distorting the results to emphasize the role of forests in preventing floods (Schiff 1982). It was not until the late 1930's, with the establishment of research programs at the San Dimas Experimental Watershed and Coweeta Hydrologic Laboratory, that the Forest Service committed itself to high-quality research in forest hydrology. Since then, work in the H.J. Andrews Experimental Forest, the Alsea River Basin (in Oregon), and Caspar Creek watershed in California have contributed to our understanding of the effects of timber harvest on mass wasting (Swanson and Dyrness 1975; Swanson and Swanson 1976) and streamflow (Harr and others 1975; Harr 1986; Ziemer 1979). These studies, some of them directed specifically at questions of cumulative impacts, are continuing to yield useful information (Grant and others 1984).

Federal involvement in "cumulative impacts" is mandated by the National Environmental Policy Act of 1969 (NEPA) and by the Clean Water Act of 1972. The Regulations for Implementing NEPA define cumulative impacts as

"...the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time."

In its response to Section 208 of the Clean Water Act, Region 5 of the National Forest System identified the need to develop a best management practice (BMP) to address cumulative impacts. In a 1981 Management Agency Agreement between the State Water Resources Control Board and the Forest Service, the latter agreed to develop a methodology for addressing cumulative watershed impacts (USDA Forest Service 1986).

In addition to recent legislation, interest-group pressure and public attention to watershed impacts have also played a role in forcing National Forest management to come to grips with the problem of cumulative effects. In the Six Rivers National Forest, for example, a Sierra Club lawsuit challenged the lack of information on geologic
hazards in the Final Environmental Statement for the Fox Unit Plan. The resulting settlement agreement set in motion detailed site-specific studies on the off-site as well as on-site impacts of the proposed Fox Unit Plan. Geologists who were involved in the Fox study later helped to develop a methodology to incorporate formal consideration of cumulative impacts in timber harvest planning in Region 5 (Seidelman 1981).

THE PRIVATE LOGGING CONTROVERSY

Although the watershed impacts of poor land use practices have been long understood, the term "cumulative impacts" or "cumulative effects" in forest management seems to be of relatively recent origin. Several events have combined to spread the idea among both professionals and laypersons. Tractor logging of expansive tracts of old-growth redwood and Douglas-fir took place in California's North Coastal region during the 1950's and 60's. Much of this logging was done with little regard for problems of soil erosion and mass wasting, fish habitat, or even reforestation. This land treatment, combined with a climatic shift in the early 1950's toward more severe storms (Coghlan 1984) led to widespread stream aggradation and destruction of anadromous fish habitat (Kelsey 1977).

Public concern over these land treatment impacts led ultimately to the case of Bayside Timber Co. v. Board of Supervisors of San Mateo County (1970). In that case, the court held that the 1945 Forest Practice Act was unconstitutional on due process grounds. A new Forest Practice Act emerged in 1973, giving greater regulatory power to a State Board that could not, by statute, have a majority of representatives from the timber industry.

The California Environmental Quality Act (CEQA) of 1970 provides the legal basis for considering "cumulative impacts" at the state level (Coats and Miller 1971). The law requires a finding that a project may have a significant effect on the environment if the possible effects of a project are individually limited but cumulatively considerable..."cumulatively considerable" means that the incremental effects of an individual project are considerable, viewed in connection with the effects of past projects, the effects of other current projects, and the effects of possible future projects.

Court decisions since the passage of CEQA have held that CEQA and the Forest Practice Act must be read as one document. Thus, the concept of "cumulative impacts" has come to be applied in a legal sense to timber harvest on private land in California.

Public and professional concern over the impacts of private logging led ultimately to the adoption of a new Forest Practice Act and a new Board of Forestry. The creation of a new Board of Forestry with real regulatory authority did not, however, put an end to the controversy over watershed impacts of private logging. In 1978, under a mandate from Section 208 of the Clean Water Act, the Board of Forestry began a review of the effectiveness of its rules in protecting water quality. In its report to the State Water Resources Control Board, the Board of Forestry identified cumulative effects as an important problem that needed to be addressed.

THE REDWOOD NATIONAL PARK CONTROVERSY

Shortly after the creation of Redwood National Park in 1968, the Department of the Interior launched a series of studies to assist the Park Service in protecting and managing the Park's resources. The first of these (Stone and others 1969) described "potentially destructive inputs into the Park" and recommended specific restrictions on timber harvest activities within 800 feet of the Park boundary. The Stone Report also recommended a voluntary land management association in the Redwood Creek Basin to encourage stabilization of the actively eroding upper basin areas. The need for additional Federal action was reviewed by an interagency task force under the leadership of Richard C. Curry (1973). That task force recommended efforts to influence land management activities considerably beyond the 800-foot buffer recommended in the Stone report. The task force also recommended that the Park Service, together with the U.S. Geological Survey, initiate studies to describe the physical condition of the Redwood Creek Basin, and to identify processes that were modifying or threatening to modify the ecosystems of Redwood National Park.

The resulting study, under the leadership of Richard Janda at the U.S. Geological Survey, documented the effects of widespread tractor logging of old growth on downstream channel morphology and sediment transport (Janda and others 1975) and on the rainfall-runoff relationship (Lee and others 1975; Bradford and Iwatsubo 1978).

The Geological Survey's study of Redwood Creek Basin coincided with intense public controversy over the question of expanding the Park to protect downstream resources and limiting or modifying timber harvest activities on adjacent land. In Congressional hearings on the bill to expand Redwood National Park, Janda was asked what proportion of a watershed could be safely logged without causing "cumulative impacts" offsite. He replied that 30 percent in a decade might be a reasonable guess for Redwood Creek Basin, but that this should not be taken as a management prescription.

THE ROLE OF THE FORESTRY PROFESSION

In reviewing the recent controversy over cumulative effects, it is instructive to examine the role played by professionals from various disciplines. Foresters in both the public and
private sectors have generally reacted defensively, resisting the notion that cumulative impacts could constitute a serious management problem. Throughout the State's '208' process, for example, industry foresters strongly resisted the notion that off-site water quality impacts of harvest activities were a real problem. The independent consulting foresters were somewhat less antagonistic, but were never able to develop a strong independent position. Ironically, geologists harshly criticized the Forest Service during the 1930's for distorting the importance of forest cover in regulating floods; geologists now seem to be providing leadership on problems of watershed protection. From the late 1870's to the early 1940's, protection of streams and streamflow was at least as important in American forestry as was timber production. Had the "cumulative effects" controversy arisen 50 years ago, foresters would have been at the forefront instead of being dragged along by geologists.

The differences between foresters and their earth science brethren seem paradoxical, since both geology and forestry in the United States share a common intellectual heritage in the rational, technocratic approach to resource management that grew out of the Progressive movement around the turn of the century (Hays 1959). In the Progressive view, professional foresters trained in scientific land management could manage forest lands efficiently to produce goods for economic growth without damaging the resource base. The notion of managing forest lands to reduce cumulative watershed impacts is nothing if not rational and technocratic; with or without harvest scheduling, it presupposes large-scale and long-range planning based on site-specific understanding of geomorphology and hydrology as well as silviculture. Yet today, one can find foresters pushing roads onto unstable terrain (against the advice of their specialists) to gain access to marginal timber-producing sites.

During the 1940's, the forestry profession turned sharply away from a multiple-resource orientation in which watershed protection held an important place, embracing instead a kind of "timber fundamentalism." A few far-sighted foresters argued that forestry should be defined as multiple-use wildland resource management, rather than primarily timber management (Gisborne 1943). Others, under the leadership of Professor H.H. Chapman (1942), argued that forestry education should confine itself principally to timber management. At its 1951 meeting in Biloxi, the Society of American Foresters settled the question decisively in favor of the timber fundamentalists. It was not until 1973, and then only with prodding from the U.S. Office of Education, that the Council of the SAF reversed itself and voted to emphasize multiple-resource management in forestry education (Krutilla 1977).

Why did the forestry profession turn away from its historic commitment to watershed protection and narrow its focus to timber production? I would like to suggest some possible reasons.

Early on, the constitutional question about Federal land ownership for reasons other than to protect navigable streams was resolved. The Weeks Act of 1911 provided for purchase of lands in the East in the watersheds of navigable streams. The Clark-McNary Act of 1924, however, dropped reference to navigable streams, and thus foresters no longer felt compelled to beat the drum of streamflow protection.

Perhaps more important was the sharp rise in the commercial value of timber that began shortly before World War II. That private foresters would concern themselves primarily with timber production is not surprising, but the rising commercial value of forests also affected the Forest Service, in part as a result of historical coincidence. In 1937, a massive blowdown occurred in the pine forests of New England, and the Forest Service took a direct part in the salvage operations. When the war began, the same men went on to the Timber Production War Project. These two projects gave Forest Service personnel direct contact with timber production, and established a relationship between the Forest Service and the industry (Vaux, 1986).

As the commercial value of timber rose, the ideological origins of American forestry provided fertile soil for the growth of timber fundamentalism. The forestry profession in America grew out of the ideology of the Progressive Era, which placed heavy emphasis on economic efficiency and production (Hays 1959). To many foresters of the 1940's and 1950's, timber fundamentalism must have seemed almost preordained.

Today, the commercial value of timber continues to be an important driving force in the Forest Service. Budgets for programs in wildlife, fisheries, and watershed protection are in part tied to the attainment of timber production targets. In order to fund watershed rehabilitation projects, it is now sometimes necessary for a Forest or District to set up a small timber sale in the watershed.

SUMMARY AND CONCLUSIONS

Although the term "cumulative effects" is relatively new, the concept has a long history. In the United States, controversy over the effects of logging and deforestation figured prominently in the establishment of the Forest Reserves, which later became the National Forest System. Foresters played a prominent role in the establishment of the Forest Reserves, arguing forcefully for the reserves in large part on the basis of a supposed relation between forests and regional floods. By the early 1940's, however, the forestry profession abandoned its traditional concern with watershed protection, and embraced "timber fundamentalism." When the "cumulative effects" controversy emerged during the mid-1970's, the leadership role fell primarily to geologists rather than foresters.
In retrospect, it seems that the forestry profession has made two big mistakes with regard to cumulative effects. The first mistake was to base arguments for forest conservation on assumptions about the importance of forests in preventing regional floods. A more telling argument in the long term might have been that forests are important in preventing erosion and sedimentation. The second mistake was to drop its historic concern with watershed protection and adopt a more narrow professional identity concerned primarily with timber production.

If the forestry profession is to assert a strong role in the cumulative effects controversy, it will have to reaffirm its historic concern with watershed and stream protection. Such a reaffirmation must be based not on assumptions and faith, however, but rather on recent high-quality research in forest hydrology and geomorphology, much of which is represented elsewhere in this volume.

Acknowledgements: I thank Henry Vaux for stimulating discussion and helpful suggestions.

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Analyzing Cumulative Effects in Watersheds: A Legal View

Theodore A. Cobb

A little more than twenty years ago Potter Stewart made one of the most often quoted statements ever attributed to a Justice of the United States Supreme Court. He concurred in a decision (Jacobellis v. Ohio) finding a film was not obscene. He said he couldn't really define pornography "but I know it when I see it."

I don't want to stretch the analogy too far but I do believe that the cumulative effects issue has some of the same problems. Foresters in the woods know a cumulative effect when they see one. But a lawyer in the city knows how the courts define cumulative effects and can make a forester look bad in court if the forester's practical knowledge isn't properly translated into the world of environmental impact reports. It's not likely that more than a handful of lawyers will learn about forestry or geology or any of the other field disciplines so I suppose the foresters will have to know a little more about the world and the language of the lawyer.

First, a word of caution. I am going to oversimplify everything. In the few minutes we have here, a detailed explanation won't work. Besides, if you are really staring down the barrel of a lawsuit, you need to get your own attorney working with you from Day One. That last point cannot be emphasized too strongly. Complex lawsuits involving state and federal environmental law must be approached with all "i's" dotted and all "t's" crossed.

Now for the oversimplification. The concept of cumulative effect analysis is child's play. Most of the time you ask yourself just two questions. In the tough cases you ask two more.

1. Is there anything near my proposed project of which I should be aware which will make any environmental effects of my project worse than they would otherwise have been?

2. Are there any future plans for the vicinity of my proposed project which would have these effects?

3. Are the possible effects significant?

4. If they are significant, can they be mitigated so they will cease to be significant?

That's California law. In the Federal system, you need to be concerned with other projects only when they are actually proposed, not those which may fall into some lesser category like "reasonably foreseeable." (Kleppe v. Sierra Club) Otherwise Federal law is pretty much the same.

(The other real difference, the "worst case analysis", was eliminated by the Council of Environmental Quality on May 17, 1986.) That being the case I will discuss California law and those of you from other states can get a glimpse of the future.

The California Environmental Quality Act (CEQA) is found in the Public Resources Code between Section 21000 and 21193. The CEQA Guidelines are written by the Secretary for Resources and are published at Title 14 of the California Administrative Code Sections 15000 through 15387. Basically the law and the rules require all significant environmental effects of a project be discussed and, if possible, mitigated. This is true whether the effects come as a direct result of some aspect of a project or exist only because of additional effects of past, current or future projects beyond the control of the plan proponent.

The case law in California on the issue of cumulative effects is not extensive. Only a handful of courts has devoted any time to discussing the topic. Among the most thorough of the analyses is San Franciscans for Reasonable Growth v. City and County of San Francisco. This case concerned a citizen's protest of a plan to permit construction of several high-rise office buildings in downtown San Francisco. The opponents argued that the environmental impact reports (EIRs) were inadequate because, among
other things, the cumulative effects of these projects in combination with existing and reasonably foreseeable future projects were not adequately addressed.

First, the court held that the CEQA Guidelines must be interpreted broadly "so as to afford the fullest possible protection to the environment within the reasonable scope of their language" (at p. 74). Second, the decision maker "had a duty to use its best efforts to find out and disclose all that it reasonable can." (at p. 74, citing Guidelines, Section 15140(g).) Third, the decision maker was required to disclose and include in its analysis all other projects that are "under review" and are therefore "reasonably foreseeable." (at p. 75.) Fourth, the court limited the information which must be collected, analyzed, and disclosed to that which is "reasonable, feasible and practical to include" (at p. 81).

An earlier and somewhat more general case was Whitman v. Board of Supervisors of Ventura County. There an oil company sought a permit to drill an exploratory well in an area of significant wildlife habitat and extreme fire hazard. The EIR was alleged to be inadequate for several reasons, the most important of which was its cursory consideration of cumulative effects.

The court found that the county's failure to include any reference to existing or planned drilling was fatal to the EIR. In addition, the court was very critical of what little analysis there was of other cumulative effects:

We recognize that the "sufficiency of an EIR is to be reviewed in the light of what is reasonably feasible" and that perfection is not required. [Citations omitted.] On the other hand, the courts have favored specificity and use of detail in EIRs since "a conclusory statement unsupported by empirical or experimental data, scientific authorities, or explanatory information of any kind not only fails to crystalize issues but affords no basis for a comparison of the problems involved in the alternatives." (at p. 411, citing People v. County of Kern and Silva v. Lynn.)

The court suggested three elements integral to a discussion of cumulative effects:

1. a list of projects producing related or cumulative impacts;

2. a brief but understandable summary of the expected environmental impacts to be produced by those projects with specific reference to additional impact information where such information is available; and

3. a reasonable analysis of the combined or cumulative impacts of all the projects. (at p. 409.)

The most recent California case applies the Whitman court's analysis and concludes that the EIR was insufficient. In Citizens to Preserve the Ojai v. Ventura County a group of people argued that the County had not done a thorough job of discussing the air quality effects of an expansion of an Ojai Valley oil refinery. They convinced the court that an EIR must include consideration of air quality impacts of emissions from offshore platforms and the cumulative effects of adding more onshore air pollution. The County had found that the available photochemical models were not capable of quantifying the onshore impact of offshore emissions. Nonetheless, some discussion was required:

Although the County was not required to engage in sheer speculation as to future environmental consequences... [citations omitted], the EIR was required to set forth and explain the basis for any conclusion that analysis of the cumulative impact of offshore emissions was wholly infeasible and speculative. (at p. 430)

In other words it is not enough to shrug your shoulders if you don't know the answer. You must explain why you can't come up with the answer.

I am sure most of you know that timber harvests in California are not burdened by the preparation of an EIR. Section 21080.5 of the Public Resources Code provides that certain regulatory programs may be certified by the Resources Secretary as the "functional equivalent" of an EIR. To qualify a program must have, as one of its principal purposes, the protection of the environment, must use an interdisciplinary review process, and must have rules which require, among other things, that no project will be approved if feasible, less damaging alternatives are found to exist. This applies only if the proposed alternative will result in the significant adverse impact to the environment.

In January of 1976, the Resources Secretary certified the Forest Practice Act and the rules of the Board of Forestry and preparation and approval of timber harvesting plans became the "functional equivalent" of the EIR process. In 1985, the Court of Appeal decided the case of E.P.I.C. v. Johnson. Among the many issues addressed by the court was the failure to consider cumulative effects. The industry defendant argued that it was not required to do so but the court disagreed. In no uncertain terms the court held that exemption from the EIR process did not mean that the substantive requirements of CEQA could be neglected. The California Department of Forestry must now consider cumulative effects before it approves a plan.

What this means, of course, is that professional foresters must consider cumulative effects before they turn in the plan. I know that most
good foresters already do that. Without ever letting the words "cumulative effects" cross their minds, they know what happens when too many roads are built too close together. They know, without consulting their lawyers, that a drainage can be overharvested to the detriment of streams and fish. Just because they can't quantify it doesn't mean they don't know it intuitively.

So what do they do?

First, let me summarize, in a few words, the state of the law of cumulative effects in California.

1. No proposed project can be examined in isolation. It must be considered in the context of other projects that exist or that may well be in existence in the near future. There is no well-defined limit, either in time or in space, to tell you what other projects to consider. However, since only those projects that contribute to significant impacts are relevant, a common sense boundary can be found in most cases.

2. Only those projects and effects which can be reviewed with reasonable effort must be analyzed. This applies both to the number of other projects considered and to the depth of the impact analysis itself. But remember that lack of analysis must be explained.

3. Cumulative effects that are identified are treated precisely the same as non-cumulative effects. Their significance is no more and no less.

Now, some words of advice.

First, DON'T PANIC. No court expects you to do the impossible. (That doesn't mean the court will always be quick to accept your word that it is impossible.) All you have to do is your best. A conscientious attempt to identify contributing causes, an honest effort to calculate or approximate the possible cumulative effects, and a candid explanation of why you can't if you can't is all the judge will look for.

Second, DON'T TAKE SHORTCUTS. If there is one theme which runs through most of the reported cases, it is this: the courts want a genuine effort to comply with the spirit as well as the letter of the law. CEQA is a public disclosure law as much as it is an environmental protection law. Lay out the problem. Lay out the dilemmas. Lay out the possible solutions. If you try to play hide the ball, one of my fellow lawyers will nail you every time.

Third, DON'T TAKE IT PERSONALLY. Lots of people get sued, sometimes because they're bad people, sometimes in spite of the fact that they're not. If you take it personally, you lose your number one asset ... your professionalism. A lawsuit over the adequacy of cumulative impact analysis is not a personal attack; it is a disagreement over fundamental policy issues in which two reasonable people can take opposing views. The neighbors who don't want the trees cut may use the cumulative impacts argument as their best weapon in a battle whose real issue involves two conflicting interpretations of property rights under the Fourteenth Amendment to the Constitution.

Finally, DON'T RELY TOO MUCH ON WHAT I HAVE SAID. The law is constantly evolving. Environmental law is changing faster than most other areas of the profession. What I have said is basically true today and will probably be true tomorrow. But the day after tomorrow ... who knows? If you have a serious question, don't rely on a short talk you heard at some conference way back when. Go pay for a few minutes of your lawyer's time.

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Commercial timber harvesting operations on non-Federal lands in California are subject to both the Z'berg-Nejedly Forest Practice Act (FPA) of 1973 and the California Environmental Quality Act (CEQA). Under the FPA, timber harvesting may normally not begin until a Timber Harvesting Plan (THP), prepared by a Registered Professional Forester (RPF), has been reviewed and approved by the Director of the California Department of Forestry (CDF). The conduct of timber harvesting is subject to the terms of the approved plan and to Forest Practice Rules adopted by the State Board of Forestry.

Under CEQA (Sec. 21080.5) the THP, together with the review and approval process, have been certified as the functional equivalent of normal environmental documentation. Review teams assist the CDF during the review of THPs. Each review team normally includes a CDF representative as chairman, a biologist from the California Department of Fish and Game, and a representative of the Regional Water Quality Control Board. Other agencies may also participate in areas where they have authority. Hydrologists, geologists, and other specialists provide expertise as needed.

Much of the review process has developed out of judicial decisions on the applicability of CEQA. The process has been reinforced by regulations adopted to comply with Section 206 of P.L. 92-500. Perhaps the most pertinent of the court decisions to this panel was E.P.I.C. v. Johnson (170 Cal App. 3d 604) in July 1985. Among other things the court ruled that CDF had not demonstrated adequate assessment of cumulative effects in approving the THP in question.

Soon thereafter the CDF convened a task force chaired by Mr. Ted Cobb, an attorney then employed by CDF, and my colleague on this panel. This task force studied the legal precedents and the procedures for cumulative effect assessment as practiced by a wide array of county planners, private industry, Federal agencies, and environmental consultants. The task force made four recommendations:

1. CDF forest practice staff should use resources available from county planning staffs.
2. The Board of Forestry and the CDF should conduct a study to determine the appropriate geographic and time limits for cumulative impact assessment.
3. Review teams should use a checklist to assist their evaluation of cumulative impacts.
4. The Director should require preparers of THPs to address cumulative impacts.

All but the second of these recommendations have been implemented, and we are working on that one. The Board of Forestry in reviewing these recommendations suggested that the checklist be made available for use by RPFs who prepare THPs. That has been done.

This was not the first time that cumulative effects have been reviewed by the CDF or the Board of Forestry. An earlier Board task force published its report in January 1982, concluding in essence that there are many unknowns and considerable disagreement among experts. They recommended use of on-site best management practices as the most direct method to avoid adverse cumulative effects. They also suggested a requirement to consider adjacent and downstream
channel conditions when reviewing alternatives during plan preparation. The Board has conscientiously followed the first recommendation in adopting its forest practice rules. The Department, with review team assistance, has long addressed adjacent and down-stream channel conditions. Our actions since E.P.I.C. have reinforced that commitment.

With these generalities in mind, I will turn next more specifically to the way the CDF addresses cumulative effects when reviewing individual THPs.

We remind our inspectors that cumulative effects are only one segment of the many possible environmental effects to be considered. Our experience has shown that people tend to examine only water quality impacts and to forget cumulative effects on resources such as wildlife and aesthetics. We point out also that the courts have not required more review effort for cumulative effects than for any individual effect.

We employ the definitions and descriptions of cumulative effects found in the CEQA Guidelines (Secs. 15065, 15130, 15355, 15358, 15382). For the sake of brevity, I will give only the definition for cumulative impacts in those guidelines:

"Cumulative impacts" refer to two or more individual effects which, when considered together, are considerable or which compound or increase other environmental impacts.

(a) The individual effects may be changes resulting from a single project or a number of separate projects.

(b) The cumulative impact from several projects is the change in the environment which results from the incremental impact of the project when added to other closely related past, present, and reasonably foreseeable probable future projects. Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time.

By regulation, the words impact and effect are synonymous.

Activities that we consider as possibly contributing to cumulative effects are those occurring near enough in time and location to the proposed operation to produce significant interaction. Water quality effects are usually limited to the watershed, but concerns such as wildlife, air quality, and vehicular traffic may involve a wider area.

We consider past and future activities within 10 years of the timber operation unless a truly significant event has occurred or will occur earlier or later. We consider more than timber operations. Proximity is relative to the size and intensity of the proposed timber operation and the other pertinent land use activities. It's a judgment call. The Department has found no methodology to identify precisely where cumulative effects might occur or how to measure them. To help solve this dilemma we employ the following procedures:

A. Guide for Evaluating Forest Practice Cumulative Effects

The THP form contains a specific question requiring the RPF preparing the plan to address cumulative effects. Review teams and the Department review the answer provided and make an independent analysis of cumulative effects. In doing so, on each THP, we ask ourselves a 14-part question:

Are significant adverse cumulative effects reasonably expected to occur in or to

1. surface soil erosion
2. mass soil movement
3. soil compaction
4. chemical or biological properties of soil
5. water quality
6. water temperature
7. suspended sediment
8. fish or wildlife or their habitat
9. recreation
10. aesthetics
11. rare, threatened, or endangered species of plants or animals, or their habitats
12. archaeological resources
13. fire hazards
14. vehicular traffic

We consider both harvesting and road construction, as appropriate. This is our so-called 14-point checklist. If we expect significant adverse cumulative effects in any of these items, we must identify the item(s) and describe additional measures needed to mitigate the effects.

The list of 14 items is not thought of as all-inclusive or as 14 separate effects. The list is the starting point for an analysis, not the end in itself. The 14 effects might be at least partially
interrelated with each other. They are not to be addressed simply with a "yes" or "no" individually; the interrelationships might still create a cumulative effect. Best professional judgment is used in making this analysis.

B. Information Needs

The review team and CDF personnel must seek cumulative effect information from each other and from other sources to augment information found in individual THPs.

C. Existing Rules

Review teams and CDF inspectors must consider the Forest Practice Rules. Individual rules or rules acting in combination may already provide adequate mitigation of many potential adverse cumulative effects. For example:

- Except for salvage operations, no harvesting is to be done within watercourse protection zones until a protective canopy has been reestablished.

- The clearcutting regeneration method is limited as to size and adjacency of clearcut areas.

These are just two examples. There are many more.

D. Issues Raised by Public, Review Team and Department

Cumulative effect issues may be raised during THP review by the public and other agencies as well as by the review team and the department. Regardless of source, cumulative effect issues that appear to have significance are discussed with the plan submitter and/or the RPF who submitted the plan. If satisfactory mitigations can be developed, they will be included in the plan. The plan has the force of law.

E. Plan Denial or Referral

If the effects are significant but the plan submitter will accept no satisfactory mitigation, denial of the plan will be considered. A plan, however, may by law be denied only for failure to comply with a Forest Practice Rule. If authority for denial is questionable, two other options exist:

1. Where the rules don't appear to provide adequate protection, and serious, long-term damage may occur, we can refer the issue to the Board for an emergency rule. The Board itself must have authority to adopt the needed rule and be able to show the immediate need to mitigate a real threat to public health and safety. The Office of Administrative Law will overturn a rule for failure to comply with these points.

2. Lacking a case for denial or referral, the Forest Practice Act indicates that we must approve the plan. I doubt seriously that we will ever come to this point, however. The rules confer such broad authority that significant adverse effects will rarely, if ever, fail to be mitigated.

F. Record of Review

We must maintain a record of cumulative effects review for each plan. The review team chairperson must complete a form that includes our 14-point checklist and a series of questions about the probability of the occurrence of cumulative effects. The public may review these records. Moreover, the regulations require us to respond in writing to all significant environmental issues, including cumulative effects issues, raised during plan review. Each response requires an explanation with enough specific information that someone not acquainted with the process can understand how the conclusion was reached. Copies of these response statements are given wide public distribution. From a legal standpoint, the written record is the most critical part of the process. It was our primary failure in E.P.I.C. It is also the most time consuming.

We are convinced that our process works and that we do comply with both the letter and the intent of the law. Others continue to disagree and are trying the issue again in several lawsuits. Clearly the plaintiffs in these cases are attempting to have the courts go beyond anything decided in previous CEQA related cases. Previously, the courts have mainly examined whether procedures required by law have been followed. They have not attempted to substitute their judgment or that of the plaintiffs for the judgment of the Department in matters of discretion. Whether the plaintiffs will be successful, only time will tell.

In the meantime, we're not sleeping on the issue. We are cooperating with the Pacific Southwest Forest and Range Experiment Station in the North Fork Caspar Creek Watershed study, the most ambitious cumulative effects study that we know of. Also, through a contract with the Experiment Station, we are conducting the Critical Sites Soil Erosion Study.
which we believe will yield useful
information to reduce individual impacts
of mass wasting. We encourage sincere
advocates of environmental protection to
assist in finding practical answers to
the very real questions that exist.

We need to know how to estimate
accurately the significance of cumulative
effects before they happen. We need to
know how much watershed or viewshed we
should evaluate. We need to know how far
back or how far ahead in time we should
look. We must then have answers that
recognize the rights of property owners
to a reasonable return on their invest­
ment. Until we have seen good answers to
these questions, and more, we believe our
process will do the job as well as any.

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Managing Forest Roads to Control Cumulative Erosion and Sedimentation Effects

William Weaver, Danny Hagans, and Mary Ann Madej

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 over 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 over 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 of 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).
Weaver and others (in press) documented the causes and effects and quantified the magnitude of fluvial erosion, especially gullying, on forestsed 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.

TABLE I--Measured sediment sources in the lower Redwood Creek basin (1954–1980)

<table>
<thead>
<tr>
<th>Sediment Source</th>
<th>Volume (m³)</th>
<th>Total Yield (pct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eroded Stream Crossings</td>
<td>225,600</td>
<td>7</td>
</tr>
<tr>
<td>Surface Erosion</td>
<td>124,400</td>
<td>4</td>
</tr>
<tr>
<td>Streamside Landslides</td>
<td>1,600,000</td>
<td>52</td>
</tr>
<tr>
<td>Totals</td>
<td>3,107,400</td>
<td>100</td>
</tr>
</tbody>
</table>

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. 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 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

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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

<table>
<thead>
<tr>
<th>Area Description</th>
<th>Maintained (mi)</th>
<th>Drivable but Unmaintained (mi)</th>
<th>Abandoned (mi)</th>
<th>Total (mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garrett Creek &amp; adjacent slopes</td>
<td>4.9</td>
<td>4.9</td>
<td>12.1</td>
<td>21.9</td>
</tr>
<tr>
<td>Coyote Creek &amp; adjacent slopes</td>
<td>10.6</td>
<td>8.3</td>
<td>22.0</td>
<td>40.9</td>
</tr>
<tr>
<td>Lacks Creek</td>
<td>4.9</td>
<td>19.7</td>
<td>36.0</td>
<td>60.6</td>
</tr>
<tr>
<td>Panther Creek &amp; adjacent slopes</td>
<td>17.4</td>
<td>11.7</td>
<td>21.6</td>
<td>50.7</td>
</tr>
<tr>
<td>Total PPZ</td>
<td>37.8</td>
<td>44.6</td>
<td>91.7</td>
<td>174.1</td>
</tr>
</tbody>
</table>
Figure 1--Classification of logging road network and stream crossings in the Garrett Creek watershed.

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; Hagns 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.

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A Management Model for Evaluating Cumulative Watershed Effects

Donald M. Haskins

Efforts have been made over the last decade to understand and predict cumulative watershed effects. Previous thrusts were to adapt existing sediment-routing and water-yield models. Modeling cumulative watershed effects in this manner has suffered from problems inherent to using a methodology for a purpose other than the one for which it was designed. Additionally, the natural variation in processes and their response between different physiographic areas vastly complicates adapting the models.

As an alternative, in 1980 the Shasta-Trinity National Forests designed a model specifically for predicting cumulative watershed effects resulting from timber harvest activities. This model is intended to address both Forest and planning level needs. This paper will address project level application of the model; Forest planning level application parallels it but at a broader scale. The model and its development are described, and examples are given of its application to project level work.

CUMULATIVE WATERSHED EFFECTS ANALYSIS

Assumptions and Plan of the Model

For purposes of this paper, cumulative watershed effects are defined as the additive and/or synergistic effects of land management activities on water quality and beneficial uses, which occur away from the site of primary development, and are transmitted to the fluvial system. They may include, but are not limited to the effects of poor management practices in the past. Typical evidence of cumulative effects are accelerated changes in stream channel stability, including aggradation or degradation of bedload sediments, lateral scour, and inner gorge mass wasting.

Abstract: A model to evaluate the potential of intensive timber management activities to initiate cumulative watershed effects was developed in 1980. The model is based on the assumption that cumulative effects are a function of (1) the amount of sensitive ground and its relative hazard level within a watershed; (2) the type, level, and chronology of management activities within a watershed which can influence peak streamflows, erosion, and sedimentation; and (3) the location of management activities relative to sensitive lands. The Shasta-Trinity model addresses the first two points; the amount of sensitive ground within a watershed is quantified through deriving indices based on the watershed's intrinsic physical characteristics, including surface erodibility, mass wasting potential, slope gradient, and peak streamflow characteristics. The type, level, and chronology of management activities is compiled using the Equivalent Road Area (ERA) accounting system. The third factor is evaluated separately, outside of the model. The concept of the threshold of concern (TOC) links these together by establishing an upper limit of desirable management activity, expressed in terms of an ERA percent, based on a watershed's sensitivity. The TOC represents a point beyond which we believe there to be a significant risk of initiating cumulative effects. Land managers generally attempt to maintain management levels below the TOC; if it is exceeded, special strategies including mitigation and watershed rehabilitation are implemented.

Based on this definition, one of our first assumptions concerns management activities. It is assumed that the type, level and chronology of management activities within a watershed will produce changes in peak streamflow, erosion and sedimentation (Rothacher 1973, Harr and others 1975, Harris 1977, Harr and others 1979, Coats and Miller 1981, Megahan 1983, Lyons and Beschta 1983, Grant and others 1984, and Harr 1986).

Another assumption is that all lands within a watershed will not respond identically to the same management activity. Some areas are inherently more sensitive to management activities than others (Megahan and King 1985). Therefore, the amount of sensitive land and its relative hazard level within a watershed will have an influence on the risk of initiating cumulative watershed effects.

Related to this assumption is the necessary ability to accommodate the diversity typical of different physiographic provinces. The Shasta-Trinity National Forests embrace portions of five physiographic provinces. The eastern portion of the Forest, lying generally within the Modoc Plateau and Cascades, has relatively low channel gradients and side slopes. Geomorphology is controlled by ongoing volcanic processes and Basin Range extensional tectonics. Surface erosion and mass wasting are of minor occurrence and peak streamflows are relatively low per unit
area. In contrast, the central and western portions of the Forest, lying within portions of the Klamath Mountains, Coast Ranges, and Great Valley provinces, have well-incised, steep-gradient, high-relief watersheds. The geomorphology is controlled by mass wasting processes and many of the watersheds are noted for relatively high peak streamflows per unit area. Due to this vast diversity, channel processes and responses vary appreciably.

Finally, it is assumed that the model will utilize data normally available on a National Forest. Soil surveys, documentation of past management activities, and topographic, bedrock and geomorphic mapping are representative of this existing data base.

The model consists of three distinct steps. First, the amount of sensitive ground within a watershed is quantified through deriving indices based on the watershed's intrinsic physical characteristics. Second, the type, intensity, and chronology of management activities is compiled and evaluated using the Equivalent Road Area (ERA) methodology proposed by Seidelman (1981). Third, a threshold of concern (TOC) is defined, based on the relative sensitivity of the watershed, and is defined in ERAs. The existing level of ERA is then compared to the TOC as a means of evaluating the present risk of initiating cumulative effects.

Another important factor, that of the location of the activity relative to sensitive ground, has not been incorporated into this process due to its complexity. It is, however, evaluated separately through determining the sensitive grounds by means of inventories, defining activities judged to be appropriate for those grounds, and mitigating hazards on a site-specific basis by prescribing specific Best Management Practices.

For project level analysis, second and third-order watersheds are delineated ranging in size from 200 to 800 ha (500 to 2,000 acres). It is important to maintain resolution within a watershed by keeping the size to a minimum. If it is too large, the effects of clumping activities into a subwatershed within it will not show up in the analysis; therefore, the ability to evaluate the distribution of activities is lost. At the other extreme, watersheds having areas of less than 100 ha (250 acres) may be overly constrained by the analysis, in addition to being too small to be significant.

Watershed Sensitivity

The sensitivity of a watershed is defined as the combination of intrinsic physical characteristics which result in a relative degree of susceptibility to the occurrence of both on-site and cumulative effects. Factors include, but are not limited to:

1. Mass wasting potential, level, and extent
2. Soil erodibility potential, level, and extent
3. Slope gradient
4. Channel gradient
5. Precipitation
6. Drainage density
7. Elevation
8. Peak streamflow characteristics
9. Relief differences
10. Snow hydrology

From these factors, we selected peak streamflow characteristics, mass wasting potential, soil erodibility potential, and slope gradient as the most significant factors for watersheds on this Forest (table 1). Peak flow is the peak discharge per unit area for an event having a recurrence interval of 25 years (Waananen and Crippen 1977). The calculation includes area, precipitation, and channel gradient. Five classes of peak flows are defined. Mass wasting potential (MWP) is evaluated, based on an integration of geomorphic and bedrock mapping from the Geologic Resource Inventory which yields the inherent relative hazard of mass wasting. Four mass wasting classes are defined. Soil erodibility (ERO) is a factor in the erosion hazard rating in the Soil Resource Inventory, which evaluates a soil's intrinsic erodibility independent of vegetation or manipulation. Three erodibility classes are defined. Finally, slope gradient (SG) is an attribute taken from the Soil Resource Inventory; five classes are defined.

To evaluate the sensitivity of a watershed, the four inventories, each comprised of polygons defining areas of equal character, are overlain. This yields a derivative polygon map where smaller polygons are defined by the same mass wasting hazard, erodibility hazard and slope gradient factors.

According to the class of the factor, the appropriate weighted value is assigned each factor (table 1) and these are multiplied by one another and by the area in the polygon. The values for all polygons are finally summed and the total is then divided by the total area within the watershed to arrive at a "sensitivity value" expressed on an area basis. The equation is

\[ \text{Sum (Poly. area x SL factor x ERO factor x MWP factor)} / \text{Total watershed area} \]

This value is then multiplied by the peak flow factor to yield the sensitivity index. The watershed is determined to be of low, moderate, or high sensitivity according to the following:

<table>
<thead>
<tr>
<th>Sensitivity Index</th>
<th>Sensitivity Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>Low</td>
</tr>
<tr>
<td>15-30</td>
<td>Moderate</td>
</tr>
<tr>
<td>&gt;30</td>
<td>High</td>
</tr>
</tbody>
</table>
Table 1 Watershed sensitivity factors

<table>
<thead>
<tr>
<th>Factor and Classes</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Peak Flow Characteristics</td>
<td></td>
</tr>
<tr>
<td>(l/s)/km² (cfs/Mi²)</td>
<td></td>
</tr>
<tr>
<td>0-275 0-25</td>
<td>1.0</td>
</tr>
<tr>
<td>275-1095 25-100</td>
<td>1.15</td>
</tr>
<tr>
<td>1095-1900 100-175</td>
<td>1.25</td>
</tr>
<tr>
<td>1900-3275 175-300</td>
<td>1.5</td>
</tr>
<tr>
<td>&gt;3275 &gt;300</td>
<td>1.7</td>
</tr>
<tr>
<td>2. Mass Wasting Potential (MWP)</td>
<td></td>
</tr>
<tr>
<td>1. Stable</td>
<td>1</td>
</tr>
<tr>
<td>2. Moderately stable</td>
<td>4</td>
</tr>
<tr>
<td>3. Highly unstable</td>
<td>16</td>
</tr>
<tr>
<td>4. Extremely unstable</td>
<td>64</td>
</tr>
<tr>
<td>3. Soil Erodibility (SE)</td>
<td></td>
</tr>
<tr>
<td>1 Low</td>
<td>1</td>
</tr>
<tr>
<td>2 Moderate</td>
<td>1.35</td>
</tr>
<tr>
<td>3 High-Extreme</td>
<td>1.7</td>
</tr>
<tr>
<td>4. Slope Gradient (SL)</td>
<td></td>
</tr>
<tr>
<td>(percent slope)</td>
<td></td>
</tr>
<tr>
<td>1 0-20</td>
<td>1</td>
</tr>
<tr>
<td>2 20-40</td>
<td>2</td>
</tr>
<tr>
<td>3 40-60</td>
<td>3</td>
</tr>
<tr>
<td>4 60-80</td>
<td>4</td>
</tr>
<tr>
<td>5 &gt;80</td>
<td>5</td>
</tr>
</tbody>
</table>

Watershed sensitivity is a relative difference based on empirical relationships. This required calibrating this portion of the model to determine the weighting of different factors and establishing the range of values defining each sensitivity class. This was performed by studying seven watersheds having quite diverse characteristics and sensitivities. According to the physical characteristics of the watersheds, each was subjectively ranked for sensitivity. Sensitivity factor values were then assigned so that both our biases as to the relative importance of each factor, and the final sensitivity index of each watershed matched our subjective evaluation. Factors derived through this subjective approach were then applied to other watersheds and found to yield similar results. A typical low-gradient, low-hazard watershed yields a sensitivity level of 7 to 10, while steep, high-hazard watersheds have yielded indices ranging from 30 to over 70.

Level of Management Activity

The Equivalent Road Area (ERA) method is an accounting system proposed by Seidelman (1981) as a means of normalizing all forms of management activities which have occurred in different time periods. The common denominator is the disturbed area of any activity related to an area of road. A cross-section of road has a cut, roadbed, and fill slope. Of this, the roadbed and to a lesser extent the fill slope are compacted to the degree that infiltration is drastically reduced. In addition, road cuts often intercept subsurface interflow and carry it off either along an inboard ditch or across to an overside drain. Much of the precipitation and runoff on the road section is artificially channelized and delivered to an organized drainage in a much more efficient manner than in an undisturbed area.

The Equivalent Road Area is therefore used to account for the effects of roads and the skid trails, landings, and cableways within timber harvest units. These compacted surfaces result in reduced infiltration and attendant increased surface runoff and erosion. In addition, these surfaces can concentrate and channelize surface runoff due to their orientation on the slope, thus linking adjacent swales or leading to greatly increased delivery coefficients for storm runoff. Disturbance factors were established which relate to the relative disturbance level within a harvest unit due to both the yarding system and the silvicultural prescription (Steinbrenner and Gessel 1955, Wooldridge 1960, Dyrness 1965, 1967b, Froehlich 1978, and Klock 1985). These values are modified based on field evaluation of the past harvest activity and the influence of site preparation activities (table 2).

Table 2 - Typical disturbance coefficients

<table>
<thead>
<tr>
<th>Logging System</th>
<th>Silviculture</th>
<th>Disturbance Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor</td>
<td>Clearcut</td>
<td>0.2 - 0.35</td>
</tr>
<tr>
<td>Overstory Removal</td>
<td>0.15 - 0.30</td>
<td></td>
</tr>
<tr>
<td>Select</td>
<td>0.1 - 0.2</td>
<td></td>
</tr>
<tr>
<td>Salvage</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Cable</td>
<td>Clearcut</td>
<td>0.15 - 0.25</td>
</tr>
<tr>
<td>Overstory</td>
<td>0.15 - 0.25</td>
<td></td>
</tr>
<tr>
<td>Helicopter</td>
<td>Clearcut</td>
<td>0.1</td>
</tr>
<tr>
<td>Select</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

It is recognized that in harvest units, areas such as skid trails, landings, and cableways revegetate and hydrologically recover over time. Some areas recover much more rapidly than others, due to both climatic and soil factors, and the extent of the initial disturbance. The recovery factor can be estimated based on the level of revegetation in the unit and the extent of surface water runoff down skid trails and cableways. In general, we have found that the majority of harvest-related disturbances recover within 30 years. Roads, on the other hand, don't recover. In fact, as a road gets older, drainage channels are better developed, and even though
vegetation is established on portions of the cuts and fill, the prism remains an efficient conduit. In addition, interflow continues to be intercepted by the road cut.

In order to perform the ERA analysis, we compile a harvest history detailing the yarding system, harvest prescription, and date of harvest. The estimated recovery factor is multiplied by the disturbance factor and by the harvest unit’s area, yielding an ERA value expressed in area. This step is performed for each harvested area and summed. Road lengths are then measured and multiplied by an average prism width to yield a road ERA value. This is added to the harvest ERA data to yield a total ERA for the watershed. In order to be able to compare ERA information between watersheds, we divide the total ERA of a watershed by the area within the watershed to yield a percent ERA. This value represents the existing ERA percent.

Harvest Unit ERA (area) = 
(Recovery factor) x (Disturbance factor) x (Area)

Road ERA (area) =
(Road length) x (Average width)

Total ERA = Sum of all harvest unit and road ERAs

\[
\text{Threshold of Concern} \quad \frac{\text{Total ERA}}{\text{Watershed Area}} = \text{percent ERA}
\]

A key to obtaining accurate results in this portion of the analysis is field verification. Representative harvest units are studied and disturbance and recovery factors assigned which best fit the observations. There is a tremendous variability in both recovery rates and disturbance levels. For this reason, values must be field verified for accuracy.

Thresholds of concern link the sensitivity of a watershed and the level of management activities (ERAs). It is apparent that a watershed having a low sensitivity can withstand a higher level of management activity without incurring impacts than can a high-sensitivity watershed. We have therefore assigned TOC values in percent ERA, to the three sensitivity classes.

Harr and others (1975) noted significant increases in peak streamflows when a watershed had more than 12 percent of its area in roads, skid trails, and landings. Based on this work and observations made on the Shasta-Trinity National Forest, relating accelerated channel degradation to ERA levels, we assigned a 14 percent ERA value to our most sensitive watersheds, 16 percent to moderate, and 18 percent to low sensitivity watersheds. Our posture is to take a conservative approach when evaluating the effects of management activities on peak streamflows, erosion, and sedimentation until more definitive studies are completed.

APPLICATION

Project Design and Alternative Evaluation

It is important to know how cumulative impact analysis can be applied to project level work. To be most effective, a cumulative impact analysis needs to be completed at the same time as other earth science inventories are completed—at the beginning of the project planning period. Just as other inventories are used to prescribe appropriate management practices, cumulative effects analyses are used to identify potentially hazardous subwatersheds, and alternatives can be formulated around threshold of concern constraints.

All alternatives are evaluated for the potential for cumulative effects. This is done by recovering the existing ERAs 5 years from present, to account for the time of anticipated harvesting, and adding to them the additional ERAs which would be generated by roads and harvest units for each of the proposed alternatives. Along with the other earth science analyses of the alternatives, these are used to recommend to the line officer the preferred management alternative and the potential impacts of implementing each.

Mitigation Measures and Rehabilitation

The cumulative effects analysis is also used to initiate special mitigation measures and to prioritize watershed restoration measures for watersheds approaching or exceeding their TOC. Mitigation measures often include increased culvert sizing, rocking of roads adjacent to drainages, increased streamside management zone
width, and modified site preparation practices. Watershed rehabilitation might include ripping and revegetation of unnecessary road segments and landings, stream channel stabilization, and fish habitat improvement.

If the analysis of an alternative indicates that the TOC will be exceeded, and that therefore there is a significant risk of initiating cumulative effects, harvest opportunities may be deferred until the watershed further recovers. In other cases, management within stressed watersheds may be appropriate, since through harvesting and reforesting portions of these understocked stands we will actually accelerate the recovery of past logging practices. Additionally, harvesting allows for the acquisition of watershed restoration funds which can be made available for further restoration work.

**Example**

The Prospect Creek watershed lies in the western portion of the Forest, on the Yolla Bolla Ranger District. It is underlain by the Rattlesnake Creek terrain of the Klamath Mountains, a melange terrain composed of dismembered ophiolitic rocks. It encompasses 3650 ha (9,000 acres) and elevations range from 880 to 1645 m (2900 to 5400 feet). Few active landslides exist in the watershed, and areas of slope instability are generally linked to valley inner gorges.

Prospect Creek was initially logged in the late 1950s. Intensive selection logging was employed and management practices were poor, including skid trails and landings located in draws, and high levels of roading. Clearcut logging commenced in the early 1970s. The result of these activities was severe channel degradation, both on-site and off-site. This includes significant channel degradation and widening.

The Prospect Sale was planned in 1982 for this area, and cumulative watershed effects were a significant management concern. A cumulative watershed effects investigation was completed for the watershed. Eighteen subwatersheds were defined for the project area, ranging in size from 80 to 350 ha (200 to 800 acres). Watershed sensitivity indices range from 9 to 14; therefore all watersheds were considered to be of low sensitivity and were assigned TOCs of 18 percent ERA. An ERA analysis was performed for each of the watersheds, yielding present values ranging from 0 to 27 percent ERA. Seven of the eighteen watersheds were well over their TOC and were severely degraded.

The project interdisciplinary team was directed by the line officer to eliminate consideration of further timber harvest activity within watersheds determined to be over their TOC. However, we proposed harvest in some of the watersheds which presently had low ERA levels for a number of reasons. First, by harvesting timber, watershed restoration funds would be generated. Secondly, reconstruction of the road network for the timber sale would lead to the repair of many chronic sediment sources, and the upgrading of stream crossings. In addition, the timber stands in the area were generally understocked due to the previous harvest activity, and the sites were not hydrologically recovering. We believed that through clearcutting and site preparation, we could actually accelerate the overall recovery of the sites after the initial setback. If harvest activities were deferred for the Prospect Creek area, these opportunities would be missed.

The result of the analysis and accordant project design was that timber harvest activities were used as a tool to collect funds for performing restoration work within the watershed. This included the ripping and revegetation of unnecessary logging roads and skid trails. The timber harvest activity was planned in such a way as to distribute it in watersheds well below their TOC and to locate the harvest units on low-sensitivity lands. The timber harvest objectives were met while important watershed restoration work was performed.

**CONCLUSIONS**

For the past 6 years we have used this methodology to evaluate the potential of proposed silvicultural activities initiating cumulative watershed effects. It is a systematic approach which strives for the dispersal of activities in space and time and limits the magnitude of activities to levels which we believe offer a reasonable degree of safety. These levels are defined by the intrinsic sensitivity of individual watersheds. In addition, the model is used to trigger mitigation measures and to prioritize watershed restoration.

The land managers use it in the alternative selection process to evaluate both the dispersal and level of different timber harvest alternatives and to select an alternative which best protects watershed values while balancing timber outputs. It also is used to compare the tradeoffs between deferring timber management within a stressed watershed and the cost, both in resources and dollars of mitigation required to allow harvesting.
Ongoing work is focusing on many aspects of the model, including the sensitivity index analysis, disturbance coefficients, hydrologic recovery, the impact of site preparation, and methods to monitor for cumulative effects. In addition, it is hoped that researchers will help us better understand the relationship between levels of watershed disturbance and peak streamflows and the importance of increased peak streamflows due to harvest activities in the transient snow zone. It is hoped that this work will add to the accuracy of the model.

Acknowledgments: I wish to thank Jerry DeGraff and John Chatoian for their careful review and suggestions.

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Managing Cumulative Effects: An Industry Perspective

George G. Ice

Cumulative effects are changes resulting from the combined impacts of multiple actions taking place over space and time. Cumulative effects associated with forest management are an ill-defined but essential component in current forest management planning. Forest management is conspicuous among the land-use activities which must account for their cumulative effects on the environment. Such effects can be managed either by separating management activities through scheduling or by minimizing the impact of individual operations through the use of best management practices (BMPs) or forest practice rules. Although scheduling is currently receiving the most attention, site-specific practices may prove the most efficient.

There is ample evidence that carefully designed and managed forest operations can reduce the on-site impacts of forest operations. If on-site changes are minimized through these controls, propagation of effects downstream will not occur. If effects are not translated downstream, there is no opportunity for impacts to interact and cumulative effects can be avoided. Similarly, if impacts can be reduced (both in extent and duration) on-site, cumulative effects resulting from multiple activities can be reduced. This paper reviews the arguments for on-site control of cumulative effects as opposed to scheduling controls. Conditions are identified under which scheduling is more appropriate for achieving water quality goals.

DEFINING CUMULATIVE EFFECTS

Definitions of cumulative effects vary but the key elements are that they result from two or more operations separated by either space or time, and that single-practice effects must have characteristics of persistence in order to become cumulative with other practices (Coats and others 1979, Geppert and others 1984). The origin of cumulative effects concerns for forest management is often tied to language in the Clean Water Act and the National Environmental Policy Act. However, water quality questions related to multiple forest operations were researched long before the term "cumulative effects" became popular. For example, Anderson and Hobba (1959) reported on a study of the accumulated effects of harvesting over a 28-year period on snowmelt and rain-on-snow floods for a 320 mi² drainage.

Managing Cumulative Effects

One of the reasons management of forest operations-related cumulative effects for large basins continues to be an issue is that most forest water quality and stream quality research has been focused on small watershed studies. The choice to research small watersheds was a logical one because (a) desired parameters can be more easily selected and controlled, (b) management activities can be concentrated to detect otherwise small effects, and (c) replications of treatments and the use of control basins are possible. The assumption applied to larger basins has been that if no effect can be detected where a small basin is subjected to complete treatment, it is reasonable to expect that no effect will be detected for large basins subjected to a lesser degree of disturbance. Similarly, any effects observed for small watersheds will be diluted as they are spread throughout a basin over space and time.

There are processes in large watersheds, however, which cannot be simulated using small watershed studies. Transport and storage mechanisms for sediments and initiation of channel bank failures during extreme flows are two examples. This does not mean that small watershed studies are not valuable in addressing cumulative effect. It does mean that we have a better understanding of how to avoid or minimize impacts on a site-specific basis than we do of how to schedule practices to avoid impacts. The concept is still valid that if impacts can be minimized on-site, they will not propagate downstream and interact with other impacts.

This does not mean that scheduling can be com-
pletely abandoned as a method of avoiding cumulative effects. Even though forest practice rules can greatly reduce the impact of forest management on water quality, they cannot completely eliminate short-term impacts. Further, we must recognize that as for any management practice a certain response falldown is associated with operational activities (Strand and Promnitz 1979). This operational falldown is similar to what Rice (1985) refers to as the Murphy's Law of cumulative effects. "Best management practices (BMPs) are obviously neither perfect nor perfectly applied." Therefore, scheduling can be used to separate management accidents or operational performance falldowns that might impact water quality and cause a cumulative effect.

STREAM PARAMETER RESPONSE TO FOREST PRACTICES

Several stream parameters used to evaluate stream quality can accumulate changes as a result of multiple management activities. A technical task force for the State of Oregon recently summarized key stream habitat parameters for aquatic life, including temperature, sediment, dissolved oxygen, discharge, nutrients, and woody debris (Carleson and Wilson 1986).

Temperature

One of the easiest water quality parameters with which to demonstrate cumulative effects is stream temperature. Changes in stream temperature associated with forest management require that estimates be made of the change in the stream energy balance. For small streams with complete near-stream canopy removal, the Brown equation has been widely used to estimate maximum water temperature increases. The simple Brown equation (Brown 1970) is shown below.

\[ T = 0.000267 \times (HA/Q) \]

where \( T \) is the maximum temperature change in degrees F

\( H \) is the maximum solar radiation in BTU/ft\(^2\)-min and is dependent on the date, location, and time of exposure for a unit of water passing through an opening

\( A \) is the surface area of the stream in the clearing in ft\(^2\)

\( Q \) is the discharge in cfs

Knowing the length of tributary exposed to solar radiation due to canopy removal near the stream and also knowing stream characteristics including discharge, width, and time of low flow, maximum tributary temperature changes can be predicted.

Temperature changes in a tributary can be translated into temperature changes in a main stem stream using the mixing ratio (Brown and others 1971). The larger the size of the tributary discharge compared to the main stem, the smaller the temperature change needed to cause an increase in the main stem water temperature. As an example we calculate the temperature increase in two tributaries necessary to increase a hypothetical main stem stream by 1°F (fig. 1):

<table>
<thead>
<tr>
<th>Tributary:</th>
<th>Percent Discharge</th>
<th>Temperature Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tributary One</td>
<td>9</td>
<td>11.0</td>
</tr>
<tr>
<td>Tributary Two</td>
<td>15</td>
<td>6.5</td>
</tr>
</tbody>
</table>

1Tributary discharge as a percent of main stem discharge at the confluence.

2Increase, in degrees F, needed to cause a 1°F increase in the temperature of the main stem.

This type of analysis has been used by Brown and others (1971) to estimate the impact of tributary temperature changes on the temperature of Steamboat Creek in the Oregon Cascades.

An example of a cumulative effects analysis for streamwater would be to consider harvesting simultaneously on the two tributaries to the hypothetical main stem. If clearcutting were conducted on both tributaries such that tributary one was raised in temperature by 11.0°F and tributary two was raised in temperature by 6.5°F, then about a 2°F water temperature increase could occur in the main stem. This 2°F increase could be reduced to 1°F by scheduling so that only one of the operations is allowed until the riparian zone recovers and the harvested stream is again shaded.

This is an example of scheduling to moderate cumulative impacts on the main stem. Instead of this type of scheduling, the approach currently used on most private lands applies stream management zone prescriptions which limit the amount of streamside shade that can be removed. This is a BMP and is incorporated as part of state forest...
practice rules. When shade adjacent to the tributaries is protected, not only can stream temperatures be maintained near the undisturbed level for the main stem but temperatures are also maintained for the individual tributaries.

Dissolved Oxygen

Perhaps nearly as well modeled as temperature is dissolved oxygen (DO). DO has long been used as a measure of stream health, particularly for large streams associated with industrial inputs of organic material (Streeter and Phelps 1925).

Research has shown that logging near a stream can potentially introduce large quantities of fresh slash into the channel. Small debris such as broken bark, twigs, needles, and leaves are available for rapid leaching and utilization by stream microorganisms. The oxygen required for chemical and biological oxidation of this material is referred to as the biochemical oxygen demand or BOD. Large amounts of debris can also dam streams into quiescent pools, reducing reaeration rates and increasing opportunity for water/debris contact.

Conditions that lead to depleted dissolved oxygen are (a) high stream temperatures that reduce oxygen solubility and increase biological breakdown of organic matter, (b) low reaeration rates due to placid flow conditions, (c) low discharge, and (d) large loading of fine organic material that can be quickly leached and consumed by microorganisms (Ice and Brown 1978; Plamondon and others 1982).

Control of dissolved oxygen levels for forest streams is based on on-site practices, however. When fresh slash is kept out of the channel, oxygen levels generally remain near saturation. Reaeration rates are generally high in Western forest streams and loading of fine organic material which can increase oxygen demand in streams is avoided by current forest practice rules (Ice and Brown 1978). Therefore, as long as forest practice rules are adhered to on a site-specific basis, there is little benefit to be derived from a scheduling approach to avoid dissolved oxygen problems.

Sediment

The cumulative effects which have generated the most regulatory and modeling interest involve potential changes to stream channels resulting from multiple forest operations. Channels can either transport or store both inorganic and organic material depending on a balance between the flow regime and input rate of material to be transported. Swanson (1982) has listed several possible mechanisms which could cause channel modification, including increased sediment contributions from mass wasting.

A documented example of a stream system where this type of cumulative channel effect has occurred is the South Fork of the Salmon River in Idaho. Megahan and others (1980) and Cole and Megahan (1980) reported that upslope sources of sediment caused by natural landslides, wildfires, harvest units, and roads resulted in measurable deposition of fine sediments on the streambed and the filling of rearing pools. Control of these sediment sources through watershed rehabilitation has resulted in a reversal of channel degradation.

A number of practices can be used to minimize the amount of sediment produced from an operation and delivered to the stream channel system. Hagens and others (1985) have discussed the importance of road design and location in avoiding channel-system expansion and increases in downstream sediments. Grant (1985) has monitored stream channel widening in the Oregon Cascades and identified pulse inputs associated with landslides as a primary cause of channel alteration. Cole and Megahan (1980) reported on several management practices associated with roads which are designed to reduce the total sediment load to the South Fork of the Salmon River.

For surface erosion the key factors in controlling accelerated levels are to avoid exposing bare mineral soil and to keep equipment away from the channel. Surface erosion involves both detachment and transport. If activities are isolated away from the channel, there is an opportunity for deposition to take place. Fine sediments generally remain in suspension once entrained but coarse sediments can deposit. New management practices to improve trapping efficiencies are now being tested. These include debris piling in buffers (Cook and King 1983).

Mass wasting is one of the pivotal considerations for managing cumulative effects on California watersheds. Scheduling strategies are designed to avoid accumulation of numerous mass wasting events in a watershed. The approach is to limit the amount of "sensitive" site conditions (recently built roads and harvested sites without canopy closure). Landslide inventories indicate that this is a logical approach based on the response of forest land to management impacts over time. A weakness in some of these management formulae is that the extent of disturbance (management threshold) is usually fixed and not subject to either management nor geologic differences in site conditions.

Just like temperature, dissolved oxygen, and surface erosion, mass wasting can be minimized using on-site practices. Confirmation that landsliding associated with forest management and particularly forest roads can be reduced comes from several recent landslide inventories. In one inventory, the fraction of landslides associated with roads had decreased at least partly as a result of improved road location, construction and maintenance (Barnett 1983). A second inventory found roads built on steep, high risk locations had fewer landslides than roads built on moderate slopes. Bourgeois (1978) concluded that this improved performance of roads in steeper locations...
resulted from an awareness of hazardous conditions and the implementation of more cautious road construction techniques.

Discharge

Peak discharge changes associated with forest management are another important consideration for scheduling. Research indicates that for rain-only storms, major peak events are probably not affected by forest management unless there is intensive and extensive compaction and soil disturbance (Ziemer 1981; Harr 1976; Harr and others 1979). Research also indicates that rain-on-snow and snow melt peak flows can be influenced by forest management (Harr and Christner 1982). Site conditions which favor snow accumulation and increased wind velocities (harvested opening) can potentially contribute to increased peak flows. Conversely, practices which tend to return sites to preharvest conditions will reverse impacts. There has been a liberal transposition of results from a few observations of peak discharge changes. The general use of thresholds for management impacts based on peak flow response is not currently justified based on the limited understanding of actual response to stand condition.

Nutrients

Changes in nutrient levels associated with harvesting have been observed. Although potential adverse cumulative impacts related to eutrophication are conceivable, there are few reports of this type of problem associated with current forest practices and levels of management intensities. Future forest management strategies can be expected to focus on keeping nutrients on-site in order to maintain site productivity.

Large Organic Debris

One of the forest-stream issues of the 1980's is large organic debris. There is an increased awareness of the importance of large organic debris in creating stream "structure." "Coarse woody debris is important in forming in-stream pools and in trapping gravels for spawning beds. The debris helps stabilize channels by dissipating energy in a vertical direction...producing a stair-stepped creek channel which is more productive" (Carleson and Wilson 1986). Yet even though this issue is coincident with cumulative effects concerns, the management approaches proposed have focused on how to maintain and supply sufficient woody material on a site-specific basis similar to that used in stream temperature control.

STRATEGIES FOR SCHEDULING MANAGEMENT ACTIVITIES

Most cumulative effects control plans call for dispersing management activities to avoid accumulation and interaction of impacts in a single watershed. While this approach seems initially logical, we must caution about the general application of this strategy without a better understanding of the consequences of widespread application.

Hall (1982) notes that "...periodic flooding and streambed scouring has been suggested as a natural phenomenon in streams essential to the long-term stability of aquatic insect and periphyton populations." Hall further notes that "...floods serve as a reset mechanism in streams, redistributing organic material and making new sites available for colonization by both periphyton and macroinvertebrates." Future research may indicate that chronic low-level disturbance is more harmful to stream productivity than short-term high levels. Some forest stream systems have developed under conditions of infrequent, severe natural disturbances such as wildfire. It may be that clustering rather than dispersal of management will prove to be the optimum strategy for overall long-term watershed health.

CUMMULATIVE EFFECTS MODEL REVIEW

The National Council for Air and Stream Improvement is in the process of assessing a number of cumulative effects models developed to regulate forest management activities. In general, lacking specific measurement data on the effects of most forest practices, hydrologists and modelers have been forced to develop various types of indices based on threshold values of management activities. This has led to the development of equivalency tables covering different forest management activities. Examples of equivalency tables can be found in procedures proposed by Klock (1985), Hanes and others (1981), and Chatoian (1985). This allows various management activities to be evaluated and rescheduled if necessary to prevent cumulative effects from occurring. This approach lends itself to the development of administrative and regulatory procedures which have yet to be evaluated. It is unfortunate that the bulk of commitment has been toward development of the models, with little consideration given to validating whether the models are achieving their management goals.

Referring to the threshold values used to identify cumulative effects, we found that only one out of six models reviewed used a water quality/stream quality threshold-of-impact. In other models, management practices were used as surrogates of impact. These surrogates are often too rigid and do not lend themselves to accounting for improvements in forest management practices.

In addition to these criticisms it should be noted that a number of the models currently being developed or used to assess cumulative effects do incorporate important cumulative effects model elements. Several of the models have proven operationally useful in planning activities. One model used local observations of the activity
level associated with resource damage to estimate the threshold-of-concern. Another model accounts for differing watershed sensitivities. Another has undergone preliminary validation testing.

COSTS ASSOCIATED WITH SCHEDULING CONTROLS

The scheduling approach suggests that control of site-specific practices is inadequate to the control of key water quality and stream quality parameters. However, there is recognition that site-specific management can increase the flexibility of the manager. For example, one cumulative effects procedure proposed for coastal Oregon would allow only 11 percent of a watershed to be harvested in a 10-year period if that land was in non-federal ownership (based on assumptions about the normal level of forest protection) (Bush 1985). Figure 2 shows recent fluctuations in the value of timber sold on westside National Forests in Oregon and Washington. An 11 percent threshold for harvesting would not allow a landowner to respond to favorable market conditions such as experienced during the 1976-1981 period or to local conditions which were favorable for harvesting.

In this area, however, harvesting of up to 30 percent of Forest Service land is considered below the threshold where cumulative effects become damaging. The difference is based on assumed improvements in soil erosion protection by the Forest Service. The point is that a 30 percent harvest rate in 10 years allows for a much greater response to favorable market conditions. In this case, an additional 20 percent of the watershed could be harvested at about $50/MBF compared to $30/MBF. If assumptions about erosion protection are correct, then on-site practices have been substituted for scheduling constraints and this has been accomplished at no additional environmental cost.

Both improved on-site controls and also scheduling constraints will impose additional costs on forest operations. These approaches need to be balanced for the best return on environmental protection expenditures.

CONCLUSIONS

Management practices designed to control impacts on-site have been well studied and have been shown to be effective in minimizing the impacts of forest management on key water quality parameters. Operational falldown from research results suggests that scheduling may be appropriate in some sensitive areas where normal forest practice rules have been shown to not be effective. Both improved on-site practices and also scheduling constraints will have associated costs. It will be necessary to balance these two approaches in order to achieve water and forest management objectives.

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Figure 2--Average values of timber sold on westside Oregon and Washington National Forest (adjusted for 1967 dollars). Data from Jackson (1985).


Myths and Misconceptions about Forest Hydrologic Systems and Cumulative Effects

R. Dennis Harr

Among the various documents that have affected the management of Federal forest lands, perhaps the two most important from the standpoint of forest planning are the National Forest Management Act of 1976 (NFMA) (USDA Forest Service 1979) and the National Environmental Policy Act of 1970 (NEPA) (Council on Environmental Quality 1978). NFMA details how USDA Forest Service is to plan its forest management activities, while NEPA requires environmental assessments or environmental impact statements for planned activities. The current concern over cumulative effects of logging activities can be traced directly to the regulations for implementing NEPA. Watershed specialists on interdisciplinary planning teams have been directed to formulate guidelines, determine thresholds, and construct methodologies that can be used to address cumulative effects of proposed activities on soil and water resources. Specialists from USDA Forest Service and USDI Bureau of Land Management in western Oregon, western Washington, and northern California have been contacting me, and probably other research hydrologists, in search of the elusive thresholds. In my efforts to provide assistance, I have become aware of a number of myths and misconceptions that are circulating freely among watershed specialists and others concerned with forest management as they look for simple, predictive tools. The object of this paper is to discuss several of the myths and misconceptions as I see them.

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SIMPLICITY OF THE HYDROLOGIC SYSTEM

Perhaps the most basic of the erroneous beliefs is the idea that simplicity can be willed on the forest hydrologic system. This belief encourages the implementation of simplistic guidelines, the adoption of arbitrary thresholds of concern, and the search for all-encompassing methodologies to predict consequences of forest activities on water resources. These actions occur sometimes with the blessings of hydrologists or soil scientists but other times over their objections. The belief in simplicity has been nurtured by the rapid increase in the use of computer simulation models in forest planning and the desire to accept the output from such models. Another reason for pursuit of simplicity is the current emphasis on planning called for by NFMA; such planning is often conducted under strict time and budgetary constraints.

I must point out that, on the average, the simplistic methodologies may have resulted in fairly prudent forest management. But rather than being viewed as merely a first attempt at solving a problem, they often seem to inhibit further investigation and development. Also, they tend to lead forest managers and some specialists to believe that hydrologic systems really do function in the manner described by the simplistic methodologies.

I will not cite specific planning documents or conversations to illustrate where the myths and misconceptions have surfaced. Such instances are irrelevant and would only embarrass well-meaning individuals, many of whom have been given impossible tasks. I can assure you that these myths and misconceptions do exist.

SIMPLICITY OF THE HYDROLOGIC SYSTEM

Abstract: Review of forest planning documents and contact with watershed specialists and other forest land managers in the Pacific Northwest has revealed several myths or misconceptions about forest watershed management. These are partly the result of pressures created by the level of planning required by legislation and by the quest for simple procedures to predict cumulative effects of management activities on soil and water resources. Myths and misconceptions discussed include these: (1) simplicity can be willed on the forest hydrologic system, (2) soil compaction of 12 percent of total watershed area constitutes a threshold for detrimental changes in streamflow, (3) desynchronization of flows by logging-induced diversity of snowmelt conditions will always be beneficial to soil and water resources, and (4) wet-mantle runoff is not affected by clearcutting.

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SIMPLICITY OF THE HYDROLOGIC SYSTEM

Perhaps the most basic of the erroneous beliefs is the idea that simplicity can be willed on the forest hydrologic system. This belief encourages the implementation of simplistic guidelines, the adoption of arbitrary thresholds of concern, and the search for all-encompassing methodologies to predict consequences of forest activities on water resources. These actions occur sometimes with the blessings of hydrologists or soil scientists but other times over their objections. The belief in simplicity has been nurtured by the rapid increase in the use of computer simulation models in forest planning and the desire to accept the output from such models. Another reason for pursuit of simplicity is the current emphasis on planning called for by NFMA; such planning is often conducted under strict time and budgetary constraints.

I must point out that, on the average, the simplistic methodologies may have resulted in fairly prudent forest management. But rather than being viewed as merely a first attempt at solving a problem, they often seem to inhibit further investigation and development. Also, they tend to lead forest managers and some specialists to believe that hydrologic systems really do function in the manner described by the simplistic methodologies.

SIMPLICITY OF THE HYDROLOGIC SYSTEM

Abstract: Review of forest planning documents and contact with watershed specialists and other forest land managers in the Pacific Northwest has revealed several myths or misconceptions about forest watershed management. These are partly the result of pressures created by the level of planning required by legislation and by the quest for simple procedures to predict cumulative effects of management activities on soil and water resources. Myths and misconceptions discussed include these: (1) simplicity can be willed on the forest hydrologic system, (2) soil compaction of 12 percent of total watershed area constitutes a threshold for detrimental changes in streamflow, (3) desynchronization of flows by logging-induced diversity of snowmelt conditions will always be beneficial to soil and water resources, and (4) wet-mantle runoff is not affected by clearcutting.

I will not cite specific planning documents or conversations to illustrate where the myths and misconceptions have surfaced. Such instances are irrelevant and would only embarrass well-meaning individuals, many of whom have been given impossible tasks. I can assure you that these myths and misconceptions do exist.
specifying how it will be determined or whether it really exists or can be measured. Similarly, implementing a methodology for estimating cumulative effects of harvest operations on water resources does not mean that such cumulative effects either exist or can be measured.

Watershed management research has discovered general hydrologic principles and basic similarities among various hydrologic systems, but it has also discovered differences among these same systems. The same research results that seem to form the basis for fairly simple views of hydrologic systems also indicate how local site characteristics can interact with basic processes to determine a particular watershed's signature, that is, how it expresses itself in terms of outflows of water, sediment, and nutrients or in terms of landslides, channel morphology, and characteristics of the riparian zone. These different signatures can give insight into how a given set of management activities might affect soil and water resources in a given watershed or along a particularly critical reach of stream. But in our desire to simplify, to create a methodology that will predict consequences of harvest activities everywhere or in the average situation, we usually expend considerable energy creating a methodology that predicts reasonably accurately virtually nowhere. We may implement procedures without providing for testing or monitoring the results to see whether the procedures are, in fact, working. In the process, we may even develop a false sense of security that our methodology can really protect soil and water resources.

THE TWELVE PERCENT COMPACTION THRESHOLD

Numerous plans, guidelines, and environmental impact statements have related the predicted amount of soil compaction to a defined threshold of compaction totalling 12 percent of watershed area. Procedures have been developed to summarize compaction from all activities for the entire watershed, including the proposed activity. These procedures commonly contain a recovery function so that changes in soil compaction over time can be considered more realistically. If the proposed activity does not raise the total area of watershed compaction above 12 percent, the proposed activity is deemed acceptable. The myth or misconception here is that soil compaction covering 12 percent of watershed area is a threshold for detrimental changes in streamflow.

What is this 12 percent figure and how did it achieve its mythical threshold status? Some of the cumulative compaction methodologies cite several of my published papers in referring to the scientific basis for the 12 percent figure, while others refer to undocumented studies. I can critically examine the 12 percent figure attributed to my papers, but I can't say anything about the undocumented studies.

In 1979 I prepared a handout for the Harvest Scheduling Workshop held in Portland, Oregon. I used results of three Oregon studies: the Alsea watershed study in the Coast Range (Harr and others 1975), the Coyote Creek study in the South Umpqua drainage of southwestern Oregon (Harr and others 1979), and the Fox Creek study in the Bull Run watershed near Mount Hood (Harr 1980) to illustrate the magnitude of changes in size of peak flows that are possible after certain logging activities. Earlier, Rothacher (1973) had shown that sizes of peak flows were mostly unchanged after clearcutting without roads or ground-based felling. Size of peak flows may be increased when logging causes soil disturbance.

I plotted the increase in size of peak flow over percent of watershed compacted for eight watersheds, seven of which I used to develop a relationship between flow increase and amount of compaction (fig. 1). Amount of compaction ranged from less than 5 percent to nearly 15 percent of total watershed area, and corresponding flow increases ranged from less than 10 percent to nearly 50 percent. In some watersheds, compaction was determined from postlogging surveys, but in others, compaction was taken as the area in roads (including out and fill surfaces), landings, and skid trails. To determine flow increases, I compared prelogging and postlogging regressions at a flow of 10.9 liters/(sec)(ha) or 100 ft^3/(sec)(mi^2) at the unlogged watershed. This flow rate was selected arbitrarily, but with a return period of 8 to 15 years among the study

![Figure 1](relation_between_amount_of_soil_compaction_associated_with_logging_and_increase_in_size_of_peak_flow_at_flow_of_10.9_liters_per_second_per_ha_at_unlogged_watershed_for_seven_small_watersheds_in_western_Oregon)
areas, it represents a runoff event capable of moving significant amounts of bed materials. Both the Coyote Creek and Alsea watershed studies were hampered by not having relatively large peak flows in both the prelogging and postlogging periods.

There are two major problems with viewing the 12 percent figure as a threshold. First, the relationship shown in figure 1 does not indicate a threshold. Instead, a curvilinear relation between amount of compaction and increased flow is shown. A second and related problem is that the 12 percent figure is arbitrary. Flow changes at lesser amounts of compaction may also cause adverse impacts. According to the simple relationship shown in figure 1, 12 percent compaction corresponds to a 32 percent increase in size of peak flow at the flow of 10.9 liters/(sec)(ha) described above. Are we ready to believe streams can accommodate a 32 percent increase in size of an 8- to 15-year event without adverse effects on the channel? Undoubtedly many streams can, but what about those streams that would be adversely affected by flows that were only 10 to 25 percent higher after logging, flows that correspond to only 5 to 10 percent compaction? Without reference to the stream channels in question, we cannot arbitrarily say nothing will happen until the mythical 12 percent figure is surpassed.

If a threshold is to be used, it must be based on the physical characteristics of the stream in question. Furthermore, the allowable percentage of compaction should be the end product of any methodology to assess cumulative effects of harvest activities on streamflow. A methodology more defensible than one based on an arbitrary compaction threshold should start with the slope, critical particle size, and channel morphology, and based on established hydraulic principles, should determine what percentage of a watershed can be compacted without increasing the erosive power of the stream in the reach of interest. This methodology would still require a relation between logging and flow increase but would not arbitrarily fix amount of compaction at the same level for all streams. Some extremely stable stream systems can accommodate much higher flows without any degradation of the stream channel, and to restrict harvest operations in such watersheds to the same degree as in watersheds where some channel reaches are unstable makes little sense. Another paper at this conference develops such a methodology further (Grant 1987).

DESYNCHRONIZING FLOWS

Another strange belief is that the desynchronization of flows, caused by logging-induced diversity of snowmelt conditions, will be beneficial to soil and water resources. Numerous research results over the past 30 years illustrate how logging can change both snow accumulation and the energy balance of melting snow where net shortwave radiation is the major source of energy for melt (e.g., Halverson and Smith 1974; Troendle 1985). Recently, research has shown differences in snow accumulation and subsequent rate of melt during rainfall when convective transfer of sensible and latent heats are the major source of energy for melt (Harr 1981; Berris 1984).

Although timber removal by logging may desynchronize flows and cause lower peak flows in the parent watershed, it may also synchronize previously unsynchronized flows. Furthermore, whether the resultant desynchronization or synchronization is beneficial or detrimental depends on how flows from various source areas originally combined to produce streamflow in the parent watershed. (Here, flow changes are considered beneficial if the resultant peak flow is lowered or its duration is decreased and detrimental if the resultant peak flow is raised or its duration is increased.)

In figure 2A, streamflows 1 and 2 combine to become streamflow 3 at the mouth of the parent watershed. An analysis of channel conditions and bed materials at the confluence indicates a critical flow at which bed materials start to move. Figure 2B shows what could happen if outflow from subwatershed 1 were to occur earlier as a result of logging-induced changes in that watershed's hydrologic system. Peak streamflow below the confluence (hydrograph 3) would be reduced 8 percent, and flow would no longer reach the critical level. According to the definition given above, such a desynchronization of flows 1 and 2 would be beneficial to stream channel 3 below the confluence. But if logging speeded up runoff from subwatershed 2 rather than subwatershed 1, peak streamflow below the confluence would be increased 14 percent, and duration of flow above the critical flow rate would be increased 35 percent (fig. 2C). These changes would be detrimental according to the definition given earlier.

Both scenarios are plausible, but what I've found puzzling is why, without knowing how flows combine under undisturbed conditions, some people believe that logging will desynchronize flows and such desynchronization will be beneficial to stream channels. These two simplified examples would seem to illustrate clearly that logging may either synchronize or desynchronize flows and that such effects may be beneficial or detrimental to streams. In other cases, changes in volume and timing could offset one another, and the resultant flow from the parent watershed could be unchanged. In large watersheds in western Oregon, analyses of flow changes that coincided with abrupt changes in rates of logging suggest that flows can be increased 22 to 56 percent in large parent watersheds (Christner and Harr 1982). It should be clear that whatever changes do occur as a result of logging cannot automatically be termed beneficial to the stream system any more than they can be automatically considered detrimental. Moreover, because stable stream systems can sometimes accommodate increased peak flows without

139
Figure 2--Effects of flow changes due to logging. A, Hypothetical flow at parent watershed 3, comprised of flows from subwatersheds 1 and 2. B, Hypothetical flow at parent watershed 3 if flow in subwatershed 1 occurs sooner following timber harvest. Peak flow in watershed 3 is reduced 8 percent and does not reach critical level. Dashed lines are the original hydrographs shown in A. C, Hypothetical flow at parent watershed 3 if flow in subwatershed 2 occurs sooner following timber harvest. Peak flow in watershed 3 is 14 percent higher, and duration of flow above the critical level is 35 percent longer than before timber harvest in subwatershed 2. Dashed lines are the original hydrographs shown in A.

channel changes, even higher flows considered detrimental in our simplistic analysis here will not always be detrimental in the real world.

WET-MANTLE RUNOFF AFTER CLEARCUTTING

In the 1970’s, several published papers described the changes in size of peak flows that could follow harvest activities. It has become common knowledge among hydrologists that early autumn peak flows will be higher after logging. Wetter soils that result from drastically reduced evapotranspiration allow watersheds to be more responsive to early fall rains. Because less rainfall is required to recharge soil water storage, more can be translated into streamflow, and this results in more storm runoff and higher peak flows. But fall peaks are characteristically small compared to winter peaks flows that transport most bed materials and reshape channels. Thus, whether or not fall peak flows are higher after logging is considered to be of little geomorphic significance.

A study by Rothacher (1973) showed that winter flows after soil water recharge were relatively unaffected in a clearcut watershed without roads, and a general belief originated that wet-mantle runoff is not affected by clearcutting. Results of the Alsea (Harr and others 1975) and Coyote Creek (Harr and others 1979) studies tended to support this belief; higher winter peak streamflows in those studies appeared to be related instead to amount of watershed compaction.

The belief that wet-mantle runoff is not affected by clearcutting is not entirely erroneous; it may be true in watersheds at lower elevations where snow rarely occurs. Rothacher (1973) seemed to know he had looked at only part of the puzzle when he concluded "...harvesting of timber will result in appreciably increased peak runoff only under unusual circumstances..." such as "...a rain-on-snow event in which large quantities of precipitation coincide with melt of a larger accumulation of snow in logged areas." However, even with that statement, Rothacher still was not seeing the entire picture. Not only did he consider rain-on-snow unusual (which it isn’t), he also didn’t recognize what removing forest vegetation might do to rate of snowmelt during rainfall.

Recent rain-on-snow research has shown that changes in both snow accumulation in the transient snow zone and rate of snowmelt during rainfall can combine to cause more water to enter soil in logged areas than in forests. Often, snow intercepted by the forest canopy melts in the canopy and reaches the forest floor as meltwater or as clumps of wet snow. Where trees have been removed, snow accumulates on the ground where it melts much more slowly and is more likely to be available to melt later during rainfall. Because the convective transfer of latent and sensible heats is commonly greater in logged areas where wind speeds are higher, more energy is available to melt snow in many logged areas. During one accumulation-melt sequence in a plot study in the Oregon Cascades (Berris 1984), snow water equivalent in a clearcut was twice that in the forest. And during rainfall, energy to melt snow during rainfall in the clearcut was 40 percent greater than that in the forest.

SUMMARY

The myths or misconceptions about forest hydrologic systems described above are only four
of those I have encountered while working with forest hydrologists and other forest land managers over the past few years. As conflicts among forest resource uses and among forest interest groups intensify, more procedures and methodologies designed to assist the planning process or to regulate harvesting activities will probably be technically scrutinized more closely. Technical soundness of the procedures and methodologies will become more critical and will depend in part on how free they are from misconceptions and myth. I hope this discussion has helped dispel some misunderstandings about forest hydrologic systems and the cumulative effects of harvest activities.

REFERENCES


Assessing Effects of Peak Flow Increases on Stream Channels: A Rational Approach

Gordon Grant

State and Federal land managers, required by law to consider the cumulative watershed effects (CWE) of forest practices on the environment, find themselves in the unenviable position of having to develop guidelines and procedures to mitigate effects which many researchers are not convinced even exist. In this discussion, CWE are defined according to Swanson (1986) as off-site, downstream changes in hydrology, sediment production, transport, and temporary storage in response to forestry practices conducted within the basin. Most existing State and Federal CWE assessment procedures attempt to mitigate perceived CWE by dispersing planned harvest activities in time and space (Chatoian 1985, Klock 1985, Seidelman 1981, Hanes and others 1981). These methods are essentially accounting procedures, allowing managers to schedule harvest activities so that previously determined limitations on the percent of area harvested or compacted by logging activities and roads are not exceeded.

From a scientific perspective there are serious drawbacks to mitigating potential CWE by scheduling activities so as to limit the amount of basin in harvested condition at any given time. First, there is no good evidence nor generally agreed-upon method for determining what these acreage limitations should be. Harr (1987, these Proceedings) has pointed out some of the problems that arise from use of his study results, which are frequently cited; none of his data suggest the existence of a “threshold.” In this context, threshold is defined as the percent of basin area at which large shifts in system behavior, such as peak flow increases, occur as a result of harvest operations. Rather, limited evidence seems to suggest a curvilinear increase in peak flows with intensity of management operations in the small Oregon basins studied by Harr (1979). In other basins, under different vegetative, climatic, and geomorphic regimes, logging did not result in increased peak flows (Ziemer 1981). Identification of a “threshold of concern” is thus quite arbitrary.

Second, the assumption underlying all models that attempt to mitigate CWE by scheduling is that hydrologic factors, particularly peak flow increases, are the primary cause of downstream effects. Available data on downstream effects of harvest practices on stream channels in the Pacific Northwest suggest that increased sediment delivery (particularly from mass movements) and transport of large woody debris are more important than peak flow increases (Lyons and Beschta 1983, Grant and others 1984, Grant 1986). Hence, CWE models that do not take sediment and wood transport into account are difficult to defend. Furthermore, peak flow is simply a surrogate for stream power, the real flow variable of interest, which is usually not measured.

A third problem with most existing CWE methods is that no allowance is made for the fact that both hydrologic response to forest practices and geomorphic response to changes in hydrology vary widely between basins. Instead, arbitrary thresholds of concern are applied uniformly across the landscape without reference to local site conditions. In doing this, we allow oversimplified computer models to replace reliance on knowledge about the

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


Abstract: Current methods for assessing cumulative watershed effects of forest practices employ arbitrary limits on the percentage of basin drainage area affected within certain time periods. Data to support such limits are sparse, making these management strategies questionable. A more defensible procedure uses the magnitude of flow increases that can be accommodated by downstream channels before channel instability occurs. For a given channel cross-section and particle size distribution of bed material, the effective discharge required to entrain bed material of a particular size can be calculated and referred to a discharge to determine the allowable increase in flow. This, in turn, can be used to set the upper limit on total basin compaction area. An example of this procedure demonstrates that streams with different channel geometries and bed materials have different intrinsic sensitivities to peak flow increases.
Finally, methods for mitigating CWE do not have provisions for monitoring to discover whether in fact the methods are working. Analyzing effectiveness requires that basin response to both mitigated and unmitigated forest practices be monitored. Agreement is needed on the appropriate measures of success in reducing the incremental effects of any one project or the cumulative effects of multiple projects. Given the lack of consensus on useful parameters, current methods are essentially untestable. We thus have no good way of capitalizing on what Swanson (1986) calls the "grand experiment" in land management; we cannot determine whether scheduling and dispersion of activities are effective means of reducing CWE.

Current CWE assessment procedures are thus not grounded in what we know about the physical behavior of drainage basins. If all that is asked of these procedures is that they demonstrate good faith in adhering to the legal requirement that CWE be considered in any proposed action, then perhaps they are adequate. We run the risk, however, that future challenges to these procedures will be made on substantive, as well as procedural, grounds and that assessment methods based on questionable assumptions will be found inadequate.

If, however, our goal is to design CWE assessment procedures that can withstand rigorous technical and legal scrutiny, then we are obliged to develop rational procedures that reflect current understanding of drainage basin processes.

AN ALTERNATIVE STRATEGY FOR CWE ASSESSMENT

A rational CWE assessment procedure should have three qualities: authenticity, verifiability, and flexibility. That is, the underlying assumptions on which a procedure is based should be well-established geomorphic and hydrologic principles or solid empirical evidence. The output of a CWE model should be capable of being tested and validated. And a procedure should explicitly treat the large variability in environmental conditions that we know exist within the forested environment.

CWE assessment cannot be done by a simple cookbook procedure. CWE include a wide range of hydrologic and sedimentation phenomena, linked together by cascading series of causes and effects (Grant and others 1984). For peak flow increases, one of several classes of hypothetical CWE, this chain of causality can be framed as a series of questions (fig. 1). Assessment of the potential peak flow component of CWE alone requires an answer to each question. While the task may seem formidable,
flows required to move different size fractions on the bed can be estimated by steps which will be stated and then described through an application of the technique.

Identifying Bed Stability Index

Recent work on sediment transport in coarse-bedded streams suggests that the channel bed resists scour until a point is reached at which the larger clasts which determine the microtopography of the bed are mobilized (Jackson and Beschta 1982, Reid and Frostick 1984). The stability of the channel can thus be estimated by the threshold of mobility of the larger particles. The size class of this stability index is somewhat arbitrary, although it can be argued that sizes of approximately $d_{75}$ (size class for which 75 percent of the bed particles are finer) and larger provide the framework for the bed around which other clasts are imbricated or clustered. Field observations of incipient motion (the point at which bed particles begin to move) indicate that particle sizes near $d_{74}$ more closely obey experimental relationships between size and threshold shear stress (Reid and Frostick 1984). In addition, the relative roughness of the channel is usually defined with respect to $d_{50}$; once this size particle becomes movable, the local relative roughness is likely to change, which in turn affects all other hydraulic variables. The stability of the channel bed is analyzed here with regard to the flow required to move the $d_{84}$ size fraction.

Locating Cross-Sections for Analysis

Since channels vary in their ability to accommodate peak flow increases, specific cross-sections must be identified according to one or more strategies. First, cross-sections can be located in sensitive reaches, defined as those which have a history of instability or where obvious deleterious effects would attend channel changes. Aerial photographs can be used to identify such reaches (Singh 1981, Grant and others 1984). Second, a subset of channel reaches that are representative of drainage area, geometry, slope, and particle size for a basin as a whole can be used to represent conditions for a given basin. Both of the above strategies call for inventorying channel conditions. The U.S. Forest Service channel inventory procedure developed by Pfankuch (1975) and the technique outlined by Rosgen (1985) are well-suited to this purpose. A third strategy would require sampling a population of streams stratified by geology or geomorphology to develop regional relationships between channel geometry, particle size, and slope for a range of flow conditions (e.g., Emmett 1975) and using these relations to define idealized channel cross-sections for analysis. Of these three strategies, the first is probably the most conservative and hence most appropriate where concern over potential CWE is high.

To determine what flow conditions produce movement of the $d_{74}$ size material, the channel cross-sectional geometry, slope, and bed particle size distribution must be measured. Survey of channel cross-sections and pebble counts (Wolman 1954) at representative or sensitive reaches provides a relatively rapid and inexpensive means of gathering these data. Cross-sections should be located on streams for which long-term discharge records are available, so that a frequency analysis of flows can be made. If this is not possible, regional flood frequency equations can be used (e.g., Dunne and Leopold, 1978, p. 316).

ESTIMATING FLOW CONDITIONS AT INCipient MOTION: AN EXAMPLE FROM WESTERN OREGON

An example of the calculations required for this analysis is available for two streams in the western Cascades of Oregon, French Pete Creek and Breitenbush River drain fifth-order basins of 83 and 66 km$^2$ (32 and 25 mi$^2$), respectively. French Pete Creek is a steep stream (average channel slope = 0.04), with a bed of boulders, and flows through a narrow forested canyon. Breitenbush River is less steep (slope = 0.02), with a bed of cobbles and gravel, and flows through a wide, alluviated floodplain. These differences in channel characteristics are reflected in the cross-sectional shape of the channel (fig. 2) and particle size distribution curves (fig. 3) at representative cross-sections, both located at riffles.

Calculating hydraulic variables

Discharges associated with a range of flows at these cross-sections were computed using hydraulic formulae. Cross-sectional area, perimeter, and average depth for any given stage were calculated by a computer program. Velocity of flow at measured cross-sections was calculated for different stages from resistance equations based on measured values of depth, slope, and particle size. The equations used were specifically developed for application in steep mountain rivers with high relative roughnesses and were those that gave best results when compared with field observations (Thorne and Zevenbergen 1985). Two separate equations were used, depending on whether the relative roughness (ratio of $d_{50}$ to hydraulic radius, $R$) was greater or less than 1.0 (table 1, eq. 1 and 2).

Velocities computed for each stage by this method were then multiplied by cross-sectional area to give discharge. Using these data, an empirical relation between mean depth and discharge was developed for each cross-section (table 1, eq. 3 and 4).
<table>
<thead>
<tr>
<th>EQN. NO.</th>
<th>TYPE</th>
<th>SOURCE</th>
<th>FRENCH PETE (S=0.04)</th>
<th>BREITENBUSH (S=0.02)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) For ( \frac{d_{50}}{R} &lt; 1.0 )</td>
<td>Resistance</td>
<td>Hey (1979)</td>
<td>( U = 5.62 \log \left( \frac{3.2 R^{0.666}}{d_{50} d_{max}^{0.314}} \right) ) (1)</td>
<td>( U_s )</td>
</tr>
<tr>
<td>(2) For ( \frac{d_{50}}{R} \geq 1.0 )</td>
<td>Resistance</td>
<td>Bathurst et al. (1979)</td>
<td>( U = \left( \frac{R}{0.365 d_{50}} \right)^{2.34} \left( \frac{W}{D} \right) \gamma (d_{50}^{0.08}) ) (2)</td>
<td>(U_s)</td>
</tr>
</tbody>
</table>

where \( \lambda_s = 0.039 - 0.139 \log \left( \frac{R}{d_{50}} \right) \) and \( U_s = \sqrt{gRS} \)

| (3),(4) | Stage/discharge | Empirical relation | \( \overline{U} = 0.14 Q^{0.49} \) | \( \overline{U} = 0.10 Q^{0.52} \) |
| (5),(6) | Average depth at incipient motion | Costa (1983) | \( \overline{U} = 0.006 d_s^{0.18} \) | \( \overline{U} = 0.008 d_s^{0.26} \) |
| (7),(8) | Diameter of particle moved at critical discharge \( (d_s) \) | Eqns. 3,4,5,6 | \( d_s = 42.95 Q^{0.60} \) | \( d_s = 21.28 Q^{0.63} \) |

**Table 1:** Hydraulic equations used in calculating flow conditions for bedload movement.

Predicting incipient motion of bed particles in mountain streams is complicated by the coarseness and heterogeneity of the bed material. In this environment, traditional methods of estimating incipient motion, such as the Shields curve (Shields 1936), do not work well because of effects of grain packing and hiding. These effects are noticeably diminished, however, if we consider only the largest particles, since these protrude maximally into the flow (Andrews 1983). Costa (1983) used both theoretical and empirical studies to develop "best-fit" equations relating diameter of largest particles in deposits to flow conditions at incipient motion. Equations developed from Costa's data relating mean flow depth to diameter of largest particle moved (table 5, pg. 994) were used here. Since particle diameter moved is not independent of bed slope, two separate equations were developed for the French Pete and Breitenbush cross-sections for slopes of 0.04 and 0.02, respectively (table 1, eq. 5 and 6).

Empirical relations between discharge and diameter of largest particle moved can be determined from these equations, together with the stage/discharge relations (table 1, eq. 7 and 8) and the results plotted (fig. 4). Implicit in this approach is the assumption that the channel cross-sectional geometry remains constant until scour of the bed occurs. The \( d_{50} \) for each site is shown together with the recurrence interval of the flow required to move this size fraction. Recurrence intervals were computed from regional flood frequency equations developed by Harris and others (1979).

A number of points stand out from this analysis. Differences in channel geometry and slope between the two sites mean that similar flows are not equally effective in transporting bed material. In general, a flow of a given absolute discharge can move bed material approximately two times larger in diameter in French Pete Creek than in Breitenbush River. Most of this difference is due to the steeper gradient of the channel in French Pete; however, the channel shape also plays a role in that the narrow V-shape of the channel in French Pete Creek means that small increases in discharge translate into larger differences in depth than in the wider Breitenbush channel (fig. 2). Since shear stress is proportional to depth, larger-sized particles can be moved in French Pete Creek at the same absolute discharge.
Breitenbush River

French Pete Creek

In a comparison of the potential frequency of bedload transport events between the two sites, however, the higher stream power in French Pete Creek is offset by the smaller caliber of bed material in the Breitenbush. Thus, flows capable of entraining $d_{84}$ occur approximately every 1.4 years in the Breitenbush, whereas a 40-year event is required to move this size fraction in French Pete Creek (fig. 4).

The channel morphologies of these two streams appear to reflect differences in the frequency of movement of coarse bedload. The Breitenbush channel is characterized by wide, unvegetated gravel bars, multiple channels, and few pools, suggesting that the channel bed is frequently reworked. On the other hand, the French Pete channel is characterized by a narrow and well-vegetated floodplain, few exposed bars, a single channel, and well-developed step-pool sequences. The 40-year return period for entrainment of framework cobbles and boulders in French Pete accords well with similar observations by

Hayward (1980), who found step-pool systems such as French Pete to be quite stable, with return periods for entrainment of bed material ranging from 50 to 100 years.

IMPLICATIONS FOR CWE ASSESSMENT

As we have seen, channels of similar size in a similar geologic and climatic setting respond differently to flows of a given magnitude. By implication, channel response to hypothetical peak flow increases can be expected to vary from basin to basin. Using the algorithm relating largest particle size moved to discharge, the increase in particle size moved can be calculated over a range of potential peak flow increases for discharges having 1.25-, 5-, 10-, and 25-year return periods (fig. 5).

If entrainment of the $d_{84}$ size fraction is used as a stability threshold, it is clear that French Pete Creek and Breitenbush River have very different sensitivities to peak flow increases (fig. 5). For example, a 30 percent increase in magnitude of the 1.25 year event is required to reach the $d_{84}$ stability threshold in the Breitenbush River, while a 23 percent increase in magnitude of the 25-year event is required in French Pete Creek. Absolute
Assuming there is a known relation between the percent compaction in a basin and flow increase, curves relating percent increases in peak flow to particle entrainment thresholds for sensitive or representative reaches in a basin could also be used to set basin limits on the percent of allowable compaction. For example, a manager may decide that stability of a channel requires that bed material of the $d_{84}$ size fraction be entrained no more frequently than once in 5 years on average. The curve appropriate for the 5-year event (fig. 5) can be read to find the maximum allowable increase in peak flow so that this threshold is not exceeded. This percent increase in peak flow can, in turn, be used together with a curve such as presented by Harr (1987, these Proceedings) relating percent increase in peak flow to percent area compacted for a specific area, geology, climate, or geomorphology. For this purpose, percent area compacted can be viewed as the dependent variable so that the allowable limits on compaction in a basin so as not to exceed a specific peak flow increase can be determined. The curve relating percent compaction to percent flow increase must be determined for the specific flow frequency in question.

Contrary to existing methods, this procedure uses a true geomorphic threshold (entrainment of bed material) to establish an allowable increase in compaction. Threshold here is a condition for which a small increase in applied stress (discharge) results in a large increase in system response (movement of bedload). Procedures for assessing the degree of compaction associated with various logging activities, as proposed by presently used methods (Chatofian 1985, Klock 1985, Bush 1985) could then be employed to provide options for different logging systems and strategies for achieving compaction limits.

The qualifications essential to use of studies relating compaction to peak flow increases include those discussed by Harr (1987, these Proceedings) and the added caveat that most of these studies were conducted on small basins. Drainage areas of basins used by Harr (1979) to develop his curves were, for the most part, less than 1 km$^2$ (0.4 mi$^2$); similar studies have dealt with basins up to four times larger (Ziemer 1981), and there is only limited evidence of measurable peak flow increases in basins with areas comparable to those discussed here (Christner and Harr 1983). Extrapolation of results to large basins should be done with great caution.
SUMMARY AND CONCLUSIONS

The procedure outlined here addresses only one of the myriad components of CWE. It does, however, provide an alternative to currently used approaches and has the three qualities of a rational CWE assessment method: it is based on currently accepted hydrologic principles, explicitly treats differences between drainage basins, and is testable. Testing could be carried out to determine whether: (1) bed particles do, in fact, move at predicted discharges; (2) predicted peak flow increases do occur for specified limits on compaction; (3) channel changes occur at discharges similar to those required for incipient motion; and (4) channel changes are detrimental to the environmental variables of concern.

To address the problem of CWE, we must break it down into manageable, researchable units. Only by analyzing specific linkages within the CWE chain of causality can we develop a set of strategies by which land managers can identify what and where CWE are likely to be operating in a given basin. Many questions remain as to the specific hydrologic or sedimentation processes at work in CWE, and the range of tolerances of specific processes or landforms to disturbance. Only after these are known can the incremental effects of planned activities be assessed.

REFERENCES


Harr, R. D. Myths and misconceptions about forest hydrologic systems and cumulative effects. In: Proceedings, California Watershed Management Conference; 1986 November 18-20; West Sacramento, CA. 1987, This volume.


Although the title of our plenary session speaks generally of "development", virtually all of our discussion (and that in the other two plenary sessions) dealt with the effect of forest practices. That emphasis is appropriate. Seventy percent of the State's utilizable streamflow comes from commercial forest lands. An additional 25 percent of the State's water comes from--often intermingled--brush, grass, and alpine lands. It is not surprising, therefore, that concerns about cumulative impacts concerns also focus on forested lands, and specifically upon activities relating to the harvesting of timber.

There are at least four separate aspects to the concern over cumulative watershed effects (CWE's). The eight papers in our session did an excellent job of highlighting those aspects and the problems and conflicts related to them. The four aspects, as we see them, are (1) the philosophical basis or rationale for the concern over cumulative impacts, (2) the legal requirements which resulted from legislation addressing CWE's, (3) the procedures which have been developed by the responsible government agencies to address CWE's, and (4) the theoretical or empiric basis for CWE's and various mitigative responses.

Coats sees the history of the current cumulative effects controversy as a chronicle of the forestry profession's fall from grace. Foresters, he claims, have abandoned their historic concern with watershed protection and adopted a more narrow professional identity focused primarily on timber production. We see an alternative reading of the chronicle. We see it as a history of a turf battle between geologists and foresters, and between their respective bureaucracies. In the late 19th century foresters found it comfortable and expedient to wear the white hat of environmental protectors. Geologists were, at that time, mainly the handmaidens of the extractive industries of mining and petroleum. Presumably, their hats were black. Both sides were making unreasonable claims. The Forest Service was claiming that large regional floods could be attributed to poor forest management and the chief of the U.S. Geological Survey was claiming that "what man does with forests will have little effect on erosion."

Following World War II, forestry education and the focus of Forest Service management shifted more to timber production. Coats faults foresters for this. Although his criticism may be justified, in California, the Board of Registration of Geologists and Geophysists has recently taken the Board of Forestry to task for wanting to require Registered Professional Foresters (RPFs) to address geologic concerns. This still smacks of a turf battle to us. Regardless of which of these two different readings of history is more accurate, Coats is quite correct in his contention that the leadership in dealing with problems of watershed protection has shifted from foresters to geologists.

Coats accuses foresters of "timber fundamentalism." We see an opposing "earth-first fundamentalism," which is reluctant to accept any environmental degradation in order to acquire the benefits of forest products. Until these two fundamentalisms are reconciled, and the problem of cumulative watershed effects is approached more scientifically, we see little hope of resolution of the current controversy.

Viewed very broadly, a concern over CWE's seems quite prudent. A watershed-disturbing activity ought not to be undertaken as though it were the only activity occurring in a drainage basin. A prudent land manager should be expected to attempt to appraise how a proposed activity might interact with the present status of a watershed and with changes which might reasonably be expected to occur in the future. This very rational expectation that there be prudent management of natural resources becomes somewhat ambiguous when addressing CWE's. Neither the record of legislative deliberations, the subsequent laws, nor the resulting regulations...
give any clue as to the mechanisms that were expected to be operating or how dealing with them might be different, in any way, from mitigating individual effects. This has left land managers and regulatory agencies in something of a quandary. They are unsure of just what type of performance is expected of them. Perhaps, it has also led interested segments of the general public to expect more environmental protection than forest managers can reasonably achieve.

Four pieces of legislation govern the implementation of concerns over CWE's in the State of California. On the Federal side, there is the National Environmental Policy Act (NEPA) and the Water Pollution Control Act of 1972 (often called PL 92-500). These are the acts to which National Forest managers must respond. The Department of Forestry (CDF) and managers of private land in the State of California must adhere to the California Environmental Quality Act (CEQA), which is an analog of NEPA, and the Z'berg-Nejedly Forest Practice Act of 1973 (PPA).

PL 95-200 is the driving force behind the concerns being addressed by most of the speakers at this conference. It requires the control of nonpoint source pollution and specifically identifies "silviculture" as one of the activities likely to produce such pollution. NEPA and CEQA require the development of Environmental Impact Statements (EIS's) describing the environmental effect of planned projects (a timber harvest plan is the "functional equivalent" of an EIS on private land in California). As Ted Cobb pointed out, the requirements for addressing cumulative effects can appear to be quite simple. They consist of determining (1) whether there are any circumstances that would make the environmental effects of a proposed project worse than would have otherwise been the case; (2) whether the possible effects are significant; and, (3) if significant, whether they can be mitigated. None of the laws require superhuman effort. In fact, they state that responses may be limited to what is reasonable, feasible, or practicable. The laws state that cumulative impacts must be considered. They do not require that consideration conform to any particular mode of analysis. They do require, however, that the nature of the analysis be described and the basis for a particular decision be identified. Court cases suggest that it is expected that decisions will be supported by empirical evidence or scientific theory. Several of the speakers noted that, so far, court challenges relating to cumulative effects have focused on procedural matters: were the points just mentioned adequately addressed? Thus far, no challenges have addressed the scientific justification for procedurally correct decisions. Many of us are concerned that once challenges on procedural grounds are no longer effective, the scientific defensibility of those procedures will become the target of law suits. The recent challenge of the Beetle-Dee sale on the Shasta Trinity National Forest may be the first such challenge.

The Forest Service and the Department of Forestry are the two agencies that have had to develop procedures for dealing with CWE's. Their procedures differ considerably because of the different nature of the two agencies' responsibilities. Neither has been tested in court. Consequently, the robustness of either procedure is in doubt at this time. It is our understanding, however, that the Water Quality Control Board prefers the Forest Service approach, which is a form of timber harvest scheduling.

The Department of Forestry has shied away from that approach--in part because of the problems that implementation would present in watersheds of mixed ownership. Instead, the CDF requires the RPF preparing a timber harvest plan to respond to 14 questions related to cumulative effects. Eight of those questions are related directly or indirectly to CWE's. This procedure has both strengths and weaknesses. The strength of the procedure is that it provides the RPF with an outline for the preparation of as thorough a treatment of CWE's as he deems necessary. Its weakness is that the checklist may engender a perfunctory response on the part of the RPF which will later be deemed to be unreasonably superficial.

The procedures currently in use on the Shasta-Trinity National Forest (as described by Mr. Haskins) are typical of those used on National Forests throughout California. We doubt that they will ever be accused of being perfunctory. We do fear, however, that they foster a mechanistic approach to the problem. As pointed out by Harr and Grant, the problem is not simple or uniform from watershed to watershed. We perceive that Forest Service procedures provide more flexibility than attributed to them by Harr and Grant. Nonetheless, we think that it is dangerous to use a single index, however complex its derivation, as a surrogate for all possible cumulative watershed effects.

Harr identified a central issue concerning management of CWE's when he said that it was a misconception to believe that "simplicity can be willed on the forest hydrologic system." This attitude is symptomatic of some forest managers. While proclaiming their expertise and insisting that deference be given to their judgments, they turn to researchers and ask for simple solutions to their complex problems.

Another important issue is whether we are dealing with additive or synergistic effects. Addressing CWE's through timber harvest scheduling makes the most sense if the effects are synergistic. There is, however, very little research support for synergism. Furthermore, the definition of cumulative impact in the NEPA regulations uses the word added. In their study of the Redwood Creek basin, Weaver and others found the adverse effects of land use to be additive, even in that extremely impacted watershed. A lack of synergism does not mean
that cumulative watershed effects do not occur, but it does make them less likely and, presumably, less severe. Ice gave an additional justification for timber harvest scheduling by saying that it "can be used to separate accidents or operational performance falldowns from accumulating to cause a cumulative effect."

However, we agree with several of the authors who contended that the most effective way to deal with cumulative effects is to mitigate individual on-site effects.

Ice and Grant each present methodologies for dealing with possible cumulative effects. Their methodologies are soundly based on existing knowledge about hydrologic processes. Both procedures seem to us to be eminently defensible, technically and legally. There may be other hydrologic processes about which too little is known to develop a sound way of dealing with them. As Cobb has pointed out, the courts do not require that you engage in sheer speculation, only that you explain why you can't come up with an answer, if that is the case.

The papers in our session discussed CWE's from a number of perspectives. Certainly, there was no unanimity of opinion among the speakers. There are, however, some propositions on which we believe most authors could agree. They are as follows: (1) cumulative watershed effects should be taken seriously, if only to respond to the legal requirements for their consideration; (2) there may be real cumulative watershed effects that are not adequately addressed by merely implementing on-site best management practices; (3) timber harvest scheduling is a weak and simplistic way of addressing CWE's; (4) the most effective way to deal with most CWE's is by vigorous application of on-site Best Management Practices; and (5) ways of dealing with off-site cumulative watershed effects should be based on the individual physical processes involved.
VOLUNTARY PAPERS

(Abstracts)
CUMULATIVE CONTRIBUTION OF ROADBED EROSION TO SPAWNING GRAVELS ABUNDANCE IN A MOUNTAIN STREAM

Barry Hecht (J. H. Kleinfelder & Associates, Walnut Creek, Calif.)

Roadbed subgrade and aggregate compose up to 12 percent of the spawning-sized sediment in the bed of Zayante Creek, Santa Cruz County. This proportion can be established because virtually all subgrade and surfacing rock consists of one of three characteristic crystalline rock types imported into the basin. The percentage of imported aggregate in samples of bed gravels increases downstream in direct proportion to the number of homesites. Unit rates of roadbed erosion may be estimated as 40 to 100 tons per acre of right-of-way or as about one-third ton of total sediment delivery from public roads per home per year. Both values assume imported aggregate is one-fifth of roadway materials delivered to streams. Approximately half of the homesites postdate the opening of a nearby quarry in 1954. Aggregate supply from these new homesites appears to be about twice that of the older homes. Land use in the Zayante basin is typical of "mountain residential" development throughout exurban California. Findings are likely to be broadly applicable to other parts of the State.

THE 1983 EROSION EVENT ON TULARCITOS CREEK, MONTEREY COUNTY, CALIFORNIA, AND ITS AFTERMATH.

John Williams (Philip Williams and Assoc., San Francisco, Calif.) and Graham Mathews (Monterey Peninsula Water Management District, Monterey, Calif.)

Tularcitos Creek drains 145 km² of the dry northeastern edge of the Carmel River basin, in the rainshadow of the Santa Lucia Mountains. In 1983 an estimated 25-year-flow of 12 m³/sec (425 cfs) severely eroded a 1-km reach of the channel that had been denuded of riparian vegetation decades earlier, reportedly by cutting and subsequent cattle grazing. Sand transported by Tularcitos Creek severely damaged steelhead habitat in the Carmel River, and invalidated a major study of fish habitat done in 1982. Seedling and planted willows in the eroded reach apparently prevented additional erosion during 1986, when high flows cleared the channel of the Carmel of sand from the 1983 event.

PRESENT ECOLOGICAL ASPECTS OF SELECTED GRAZED AND UNGRAZED STANDS OF OAK WOODLAND IN CENTRAL CALIFORNIA.

William H. Brooks (USDA, Soil Conservation Service, Davis, Calif.)

Thirty stands representing the blue oak phase of the Digger pine-oak forest vegetation type in central California were analyzed in an effort to quantify some aspects of their present ecology. Stands with a near-100-year history of protection as well as those presently grazed on private rangelands were selected for this study. Sites include foothill areas in the southern Sierra Nevada and the Inner Coast Range. Analyses of data support earlier observations of a general decline in blue oak (Quercus douglasii) reproduction in protected stands. Stands of oak surveyed on private rangeland generally included more trees in the younger age classes. Older trees were found in greater numbers in stands above 1300 meters in elevations where black oak (Quercus kelloggii) becomes an associate in the blue oak phase. Climatic shifts were marked by decreases in late winter and early spring precipitation. Infestations by an acorn weevil (Curculio spp.) were noted.

MANAGING FOR WATER YIELD: THE IMPORTANCE OF TIMING

Lee H MacDonald (Hydrologist, USDA Forest Service PSW Experiment Station, Berkeley, Calif.)

Both vegetation management and weather modification (i.e., cloud-seeding) have been proposed as means of increasing water yield. Research and theory suggest that most of the yield increase from vegetation management will occur during winter runoff and spring snowmelt, with progressively smaller increases in the autumn and summer. In contrast, California's long dry season implies that cloud-seeding, in the Sierra snow zone will not increase runoff much beyond the period of actual snowmelt. A small watershed experiment and a comparison of wet and average years for the South Yuba River provide additional evidence that moderately deeper snowpacks do not increase runoff beyond late July. Data from 12 reservoirs over 1972-86 show that, on the average, significant spills occur in May 18 percent of the time, declining to 10 percent in July. Spills in January-March are slightly more frequent than in May, but are typically due to specific storm events. These averages belie the tremendous variability among reservoirs and years. Overall, perhaps 20 percent of a water yield increase resulting from cloud-seeding may not be utilized for power generation or other end uses. Vegetation management should yield a somewhat higher proportion of usable water as well as increase low flows. Any estimate of water yield benefits must evaluate both runoff timing and the engineering infrastructure of each basin.
MODELED HYDROCLIMATIC IMPACTS OF TIMBER MANAGEMENT IN REDWOOD CREEK BASIN.
Virginia Mahacek King and M. L. Shelton
(Department of Geography, University of California, Davis, Calif.)

Timber harvesting within redwood Creek basin has produced controversial hydrologic and geomorphic consequences affecting resources of Redwood National Park. A climatic water budget model, adapted to the physical and climatic setting of the basin, emphasizes the hydroclimatic effects of land use activities. For the "pre-logging" calibration period, water years 1954-57, simulated runoff is within one percent of gaged flow even though runoff during these years ranges between about 900 and 2000 mm. Comparison of simulated monthly runoff and measured runoff for water years 1958-77, a period of intense logging, demonstrates the nature and magnitude of hydrologic change. Logging has augmented storm season runoff and diminished low flow runoff. These seasonal changes have varied magnitude from year to year, depending on the partitioning of precipitation to surface runoff and groundwater. Modeled runoff indicates that timber management practices initiated basinwide after the establishment of Redwood National Park beneficially altered the precipitation/runoff relationship, and supports rehabilitation projects undertaken within the park.

PROGRESS REPORT ON CUMULATIVE WATERSHED EFFECTS STUDY-ELDORADO NATIONAL FOREST
Mike Kuehn (USDA Forest Service, Eldorado National Forest, Placerville, Calif.)

The California region of the USDA Forest Service is conducting a study of Cumulative Watershed Effects (CWEs). Watershed parameters are being evaluated with the intent of identifying those that contribute to, and/or act as indicators of CWEs. Also, an attempt is made to separate true CWEs from poorly-applied "Best Management Practices" (BMPs). The Eldorado National Forest is concentrating its efforts on surface-erosion dominated sediment regimes. A consolidated regional report should be out by summer 1987. Cursory observations from the Eldorado study and the literature suggest significant variation in the ability of a watershed to absorb BMPs. Therefore, it may be difficult to establish useful Thresholds of Concern for CWEs until a more definitive definition and measuring scheme is devised. I believe that the framework for such a scheme can be created by utilizing runoff lag time, which tends to be the fingerprint of the watershed, and a stream classification system, which will define stability of the streamchannel system.

ANALYSIS AND REHABILITATION OF A WATERSHED ON THE HOOPA INDIAN RESERVATION.
William A. Brock (Hoopa Valley Business Council, Hoopa, Calif.), Paul Routon (rehabilitation consultant)

A watershed management analysis and rehabilitation plan was developed in 1985 for the Supply Creek watershed, a tributary to the Trinity River 16 mi2 in size, located on the Hoopa Valley Indian Reservation, Humboldt County, California. The watershed is forested with conifers and approximately 50 percent of the surface area has been disturbed by development. Mass wasting was found to be the predominant form of severe erosion. Most of the episodes occurred during the flood of December 1964. Review of aerial photographs combined with ground checking confirmed that the majority of mass wasting events were caused by some form of ground disturbance prior to the 1964 flood. Nearly all involved road construction. The problems most frequently encountered were (1) runoff from culverts draining inboard ditches onto slopes inappropriate for surface flow; (2) random breaching of outboard berms by runoff from outsloped roads. Undersized culverts, culverts placed at too gentle an angle, and absence of inlet trash racks were other frequent causes of erosion. Many of these "triggers" that caused major erosion events in 1964 were reconstructed, not remedied.

COORDINATED RESOURCE MANAGEMENT AND PLANNING: THE CALIFORNIA EXPERIENCE.
Kent A. Smith (California Department of Fish and Game, Sacramento, Calif.) and Delmer L. Albright (California Department of Forestry, San Andreas, Calif.)

As land and other natural resources continue to become scarce, cooperative efforts like Coordinated Resource Management and Planning (CRMP) have evolved to effect wise use and simultaneous conservation of our multiple wildland resources. The major emphasis of CRMP is improved land management through cooperation. The process is designed to achieve (1) compatibility between uses being made of renewable natural resources, energy and mineral resources, livestock production, watershed, wildlife habitat, wood products and recreation; and (2) improvement of the resources and their perpetuation in a high quality condition. It embodies the concept that integrating and coordinating resource uses will result in the best use of each acre with the least conflict among users, landowners, and public agencies. California has realized many benefits from CRMP, including the opportunity to manage large blocks of land containing multiple ownerships as single management units and cost effective and efficient land management, benefiting wildland resources.
DIFFUSION HYDRODYNAMIC MODEL FOR FLOODPLAIN MODELING

J. J. DeVries (Water Resources Center, Univ. of Calif., Davis, Calif.) and T. V. Hromadka II (Williamson and Schmid, Irvine, Calif.)

During floods water spills out of stream channels and overflows adjacent floodplains. Most computer models used for floodplain analysis do not accurately model this process since they assume that the flow is one-dimensional, when in actuality the flow is often highly two-dimensional. This paper describes a practical two-dimensional model for the analysis of unsteady flow on floodplains. It is based on the diffusion formulation of the equations governing unsteady flow in open channels and provides a major advance in modeling capabilities over conventional and simpler methods such as the kinematic wave method. The model includes two diffusion-routing submodels: a topographic model of the overland flow processes on the floodplain and a channel routing model which simulates the passage of the flood wave in the stream channels. Because the model flow routing technique is diffusive, backwater and ponding effects are automatically included. The model also simulates hydraulic conditions at junctions, inflow to and outflow from channels, critical depth control points, and stage-discharge controls. An example of the use of the model is included.
POSTER PRESENTATIONS

Red Clover Creek Demonstration Erosion Control Project

Lawrence H. Carver

Project Participants

Soil Conservation Service, California Department of Fish and Game, Pacific Gas and Electric Company, California Department of Forestry, U.S. Forest Service, and Plumas Corporation

Problem Statement

Sedimentation in the upstream areas of the East Branch North Fork Feather River watershed is adversely affecting fisheries, water quality, land values, recreational resources, and downstream hydroelectric projects. Rock Creek Reservoir has accumulated 4.5 million cubic yards of silt over the past 30 years.

Objectives

1) Develop a cooperative, interagency regional erosion control plan for the 1,500 square mile East Branch North Fork Feather River watershed.
2) Develop and implement an erosion control project in a problem area of the watershed to demonstrate various methods of controlling erosion and sediment transport, and determine their cost-effectiveness.

Process

1) Thirteen resource management agencies and private organizations have entered into a Memorandum of Agreement (MOA) to develop and implement a Regional Erosion Control Plan for the watershed. The participants in the MOA are: Agricultural Stabilization and Conservation Service, California Department of Fish and Game, California Department of Forestry, California Department of Transportation, California Regional Water Quality Control Board, U.S. Forest Service, Pacific Gas and Electric Company, Plumas Corporation, Plumas County, Soil Conservation Service, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and American Indian Valley Conservation District.
2) Plumas Corporation prepared a proposal for a demonstration erosion control project on Red Clover Creek. The project was subsequently funded by Pacific Gas and Electric Company and the California Department of Forestry. Design was done by the Soil Conservation Service, California Department of Fish and Game, and the Forest Service. Plumas Corporation administered all phases of the project, including permitting, contracting, and construction.

Design and Implementation

The project involved the construction of four loose rock check dams along a degraded stretch of Red Clover Creek, characterized by vertical cut banks up to 12 feet high. The goal was to reduce sedimentation and to stabilize eroding streambanks in the long-term by reducing water velocity, raising the level of the stream and surrounding water table, and reestablishing riparian vegetation. Construction of the dams took place in fall 1985 and summer 1986. Following completion of construction, a fencing enclosure was installed, with rancher permission, and a revegetation plan implemented. Total cost of the project was $70,000.

Results

The four check dams withstood the February 1986 storm event with only minor damage. No additional bank sloughing has occurred within the project area. Much sediment has already been trapped behind the dams, which should aid in the reestablishment of willows, grasses, and other riparian vegetation. The fishery has expanded from a count of 2 trout in a 5-mile stretch of stream to 16 trout in just one of the reservoirs.

Figure 1--Completed loose-rock check dams on Red Clover Creek (10/86)

Evaluation

A monitoring plan has been implemented to evaluate the effectiveness of the project, including downstream gauging stations, instruments to record changes in the water table, and stream profile surveys. Two to three years of data generation will be required before a true cost/benefit analysis can be made.

The project has received much positive publicity in local and regional newspapers, and has promoted good working relationships among the participating agencies. It is hoped that this is the first step in the development of a cooperative regional erosion control plan for the entire East Branch North Fork Feather River watershed.

1Presented at the California Watershed Management Conference, November 18-20, 1986, West Sacramento, California
Involving Water Districts in Vegetative Projects to Increase Water Yield

Harley H. Davis, Jr.²

BACKGROUND

The direction in the Forest Service land management planning process was to consider vegetative management to increase water yield. On the Sequoia National Forest, located at the southern end of the Sierra Nevada, we evaluated various vegetative types for their potential to increase water yield and found that mixed chaparral brush and commercial timber land had the most potential.

Part of the land management planning process involved contacting the water users downstream to determine the demand for and value of more water. Downstream uses are primarily agricultural in Kern, Tulare and Fresno counties. These counties in the southern Central Valley are the three largest income-producing agricultural counties in the Nation. More agricultural use is predicted so future demand for water is high. Some hydropower use also exists.

Proposals to improve water supply to meet future demand have concentrated on importing more Northern California water, cloud seeding, dam construction, and groundwater recharge. Water is transported through the area by the California Aqueduct, Cross Valley Canal, and the Friant Kern Canal through an elaborate exchange system. However, additional supply of Northern California water is politically questionable. Cloud seeding has been funded for a number of years but can only produce limited increases in water. Dam construction is costly and groundwater recharge is limited by the supply available. Even though enormous amounts of water cannot be produced, increased yields by vegetative treatment could help to meet demand.

Various associations of water agencies (which draw water from the Kern, Tule, Kaweah, and Kings rivers) expressed an interest in cooperating in projects to increase water yield through vegetative treatment. In the Sequoia National Forest land management planning process, more information was considered needed on how much increased water could actually be obtained from vegetative treatment (timber harvesting and brush removal) before large amounts of land could be managed to increase water yield.

PROJECT

A project to prescribe burn chaparral (the Barton's project) in cooperation with the California State Department of Fish and Game was being planned and appeared to be a likely candidate for monitoring increases in water yield. Jack Ass Creek within the project area is readily accessible, contains mostly chaparral brush, and could be treated heavily by fire alone and by using fire and equipment to convert brush to grass. An adjacent watershed, Lockwood Creek, was mostly in wilderness and would make a fairly good control watershed for comparison.

In March 1986, the Kings River Conservation District and Kings River Water Association were approached to fund monitoring water yields from the Jack Ass and Lockwood Creeks with the idea of determining how much water could be produced by chaparral brush treatments. Possible water yields and values were roughed out. The uncertainty of showing the results of water yield increases was presented. Labor, modern equipment, and measurement of water quality were included in the costs. The response was very positive. Funding was approved and the project is in its initial stages.

The ground work has been laid for future efforts. Based on this experience, water districts and land managers (such as the Forest Service in California) can co-operate in projects to increase water from upland watersheds.

¹Presented at the California Watershed Management Conference, November 18-20, 1986, West Sacramento, California
²Hydrologist, Yolla Bolla District, Shasta-Trinity National Forest, Forest Service, U.S. Department of Agriculture, Platina, Calif. (Formerly Hydrologist, Sequoia National Forest.)
Small Instream Structure Construction for Meadow Restoration in Clark Canyon, California

John W. Key

The project area in Clark Canyon Creek covers approximately four stream miles within the East Walker River subbasin, Mono County, California. This perennial stream receives most of its subsurface flow through Clark Canyon. Heavy algal growth has occurred in the meadow sections of the stream due to the elimination of undercut banks, widening of stream beds, and large amounts of nutrients added from livestock grazing and trailing. Naturally occurring erosion in the upper stream reaches contributes a large amount of sediment from the upper watershed to lower riparian areas. As a result, an increase of suspended sediments and turbidity has occurred in the lower stream reaches where a viable population of rainbow trout is found.

Small instream structures have been constructed upstream using inexpensive materials and simple techniques with the following objectives:

1. To stabilize active erosion and gully development (headcutting) resulting both naturally and from heavy livestock use;
2. To restore wet meadow riparian areas to high levels of productivity by trapping sediments and raising the meadow water table;
3. To improve aquatic habitat from poor to good condition by prolonging runoff through in-bank water storage; and
4. To improve wildlife cover and downstream fish habitat.

Several different treatments were constructed to control severe headcut gully development in wet meadow areas. These erosion control structures consisted of a series of small gabion baskets, single fence and double fence rock-check dams, all lined with an erosion control filter fabric (Trevira cloth). These structures were designed to trap sediments using hand labor and inexpensive materials such as woven wire fence and metal fence posts, and are currently being monitored and evaluated as to success or failure to meet project objectives.

General Construction Considerations:

Instream structures constructed in mountain meadows such as Clark Canyon need to be keyed into channel bottoms and banks, and should be able to carry expected peak flows, since poor foundation conditions are generally found in meadow gullies. A series of low structures less than 4 ft high are preferred to a few higher structures. Low structures usually do not wash out, but if they do, less flood damage results; they cost less and are easier to construct. Small instream structures such as check dams or gabion baskets should not be impervious, but semipervious enough to allow water to flow or drain through but not around the structure. Structures should be built on a temporary basis rather than permanent as once a meadow has been reclaimed, the structures are usually no longer needed since proper vegetation management should be able to control the erosion.

Proper spacing between instream structures depends upon the gradient of the gully. The minimum interval used should have the crest of one structure level with the apron of the one above. Structures are more effective and tend to be more stable if they are placed in key locations such as immediately below a junction of two or more gullies, at narrow points of the gully, and at points where the gully is not eroding rapidly.

An adequate spillway that will pass peak flood flows safely over the structure is required. A low center draws the overflow toward the middle of the channel, thus preventing the water from cutting around the structure. An apron below the downstream face of the structure is essential to prevent falling water from undercutting. Fine soil material should be placed against the upstream face to prevent large cracks, piping, or undercutting from occurring.

The use of inexpensive available materials and the wise use of both work force and equipment brings the greatest investment return.

It should be remembered that poorly designed or constructed structures actually may cause a lot more damage than the original problem.

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

Results of 1986 Snow Acidity Sampling in California

Maurice Roos

During 1986 snow surveyors in the California Cooperative Snow Surveys Program field tested the snowpack for acidity while they were doing their regular snowpack depth and water content measurements. The purpose of the special sampling was to provide broad coverage of the snow zone in California to see if there appeared to be a widespread problem of snow acidity or if specific "hot spots" or zones of acidity existed. The field tests of surface snow acidity were made with small litmus paper test kits. About 520 snow course determinations of pH were made from about January 1 through April 1. Field pH values clustered around 5.3, not significantly different from the 5.6 theoretically expected from clean precipitation. Results do not indicate any widespread acidity problem in the California snowpack, at least not in 1986.

REGIONAL BREAKDOWN SNOW ACIDITY SAMPLING RESULTS

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

2 Chief, Flood Hydrology and Water Supply Branch, Division of Flood Management, California Department of Water Resources, Sacramento, California.
The Honeydew Slide: Consequences and Management

David L. Steensen

A large catastrophic landslide, locally known as the Honeydew Slide, has created significant impact in the Mattole Watershed in southern Humboldt County, California. The complex translational/rotational slide, with a disturbed surface of 75 hectares, was initiated in the late March storm of 1983. The landslide toe converted to a massive debris flow delivering 305,000 m$^3$ of mud and rock to the Mattole River channel. There were two direct effects on the river: 1) partial damming of the channel creating a 1.5-km-long lake, and 2) relocation of the channel to the left valley-side causing undercutting that stimulated dormant landslides into activity delivering about 30,000 m$^3$ more material to the channel.

The geologic setting is within the Coastal Belt Franciscan Formation, chiefly thin-bedded marine sedimentary rocks: mudstone, siltstone, shale, and sandstone. The local setting may be characterized as pervasively sheared, folded, and faulted. Management in the 162-hectare basin prior to the slide included clearing and burning the upper basin for increasing livestock pasture in the 1950's, logging the lower basin in the 1960's, and subdividing for homestead plots in the 1970's.

The slide debris, combined with overall aggradation in the Mattole system, has exacerbated the problem of downstream erosion of roads and prime agricultural land. An elevated channel bed upstream of the debris dam has accelerated the incidence of stream-side debris slides.

Feasibility of cost-effective rehabilitation is currently under study. Assessment has been directed at erosion potential in areas likely to see significant post-slide adjustments. Efforts are focused on enhancing natural processes that lead to reduction of the rate sediment is introduced to the active channel. Preliminary results suggest that, on the upper slide mass, stabilization of drainage paths at past or potential diversion points could reduce the amount of material that would be produced by these diversions onto slopes. Relocation of the river-bank edge of the debris fan would allow the channel to occupy a position further from the undercut left bank. With these measures, perhaps up to 10,000 m$^3$ could be saved from entering the active channel.

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

2Graduate Student, Department of Geology, Humboldt State University, Arcata, California, and Geologist, Mattole Restoration Council, Petrolia, California.
Estimates of Annual Streamflow from Precipitation and Vegetation Cover Data

Kenneth M. Turner

Annual streamflow (Q) in inches can be estimated from annual precipitation (P) in inches and fraction of watershed covered with shrubs and trees (C) using the equation

\[ Q = P - (0.362P + 8.35)(1 - C) - 0.85 \left( 182P - P^2 - 25 \right) / 172 \]

that was presented in a companion paper at this conference. This method was tested by comparison of estimated and historical flows of Elder Creek near Paskenta for the period 1948-79. Elder Creek was selected because it has great diversity of cover types and unusually high flow with respect to precipitation, which provided a severe test of the procedure.

Annual precipitation was estimated by adjusting record at a rain gauge near the western watershed divide to represent the whole watershed, using an isohyetal map. Fraction of shrub and tree cover in 1979-81 was determined to be 0.58 by interpretation of aerial photos. A watershed-specific equation, \( Q = 0.00364P + 0.186P^2 - 3.416 \), was derived from the general equation to facilitate estimates of annual streamflow.

It was found in comparing estimated flows with historical flows (fig. 1) that there is a consistent underestimation in wet years that is probably due to declining rain gauge catch with wind velocity. This makes a correlation of historical flow with estimated flow desirable for more reliable extensions of record. It also shows the risk of using this method for ungauged streams.

Significant variation in the precipitation runoff relationship was also found (fig. 2). This indicates the desirability of using determinations of watershed cover (C) for several time periods to increase the reliability of the estimate.

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

2Watershed Management Specialist, Department of Water Resources, State of California, Sacramento, Calif.
Effects of California Riparian Woodland on Flood Conveyance: Case of the Pajaro River

Barry Hecht and Mark Woyshner

Since construction of a major flood-control project in the early 1950's, riparian woodland has become re-established along the lower Pajaro River on elevated floodplain areas within high levees. Local flood-control districts manage the project by clearing fallen trees from the active channel, and occasionally thinning the riparian woodland.

The districts requested a technical assessment of the effects of the riparian woodland on hydraulic roughness and flood conveyance in the river. Following the spring storms of 1983, cross-sections and high-water mark slopes were level-surveyed over a one-kilometer reach of the river, a portion of which was forested, and a portion of which was riprapped. The smallest peak was just above the bank level (estimated discharge of 7400 cfs), and the largest was six feet higher (estimated discharge of about 18000 cfs), approaching the design capacity of the levee system. Mannings roughnesses in the forested and riprapped subreaches were identical for the higher flood crest. Measured roughnesses were lower than most commonly accepted values, probably because most riparian species are not in leaf during the winter flood season.

Level surveys show that the bed of the stream is 3.5 to 5 feet lower than in 1954. The levee system can now convey floodflows of above 27000 cfs, compared with 22000 cfs at the time of construction. Limited 1972 data suggest that most of this adjustment had occurred prior to that date by which time the riparian woodland within the levees was fully established. The greater relative channel depth may be in part related to increased bank strength associated with regrowth of the woodland.

Results suggest that riparian vegetation, as managed in this reach, exerts a hydraulic roughness similar to riprap for flows approaching design capacity. Regrowth of the riparian woodland has occurred contemporaneously with a conveyance, for which it may be in part responsible.

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

2Senior Hydrologist, J. H. Kleinfelder & Associates, Walnut Creek, California; Hydrologist, J. H. Kleinfelder & Associates, Walnut Creek, California.
Carmel River Watershed Management Plan

Ken R. Greenwood

The Carmel River watershed drains 255 square miles in the central coastal region of California, southeast of the Monterey Peninsula. The river is the source of domestic water for over 120,000 users and supports a wild run of steelhead trout. Herein lies a conflict for a limited resource. The Carmel River Watershed Management Plan identifies the resources involved and charts a plan of action to ensure a water supply for the human and fishery populations.

THE PROBLEM

The Carmel River supplies water to a growing human population, as well as a declining steelhead run, a fragile riparian corridor and the wildlife that inhabit it.

Water produced from the Carmel River is supplied to six Peninsula cities and nearby unincorporated areas primarily by the California-American Water Company (Cal-A), a privately owned utility. Annual system production has increased over the years to its present level of approximately 18,000 acre-feet (Figure 1).

Figure 1—California-American Water Company system production, 1940 to present.

The Carmel River once supported a run of steelhead estimated at 12,000 adults. Presently, the run is estimated at 2,000 adults. The decline has been the result of a lack of summer flows to support rearing habitat below the dams, streambank erosion, elevated water temperatures, and poor fish passage facilities over the dams.

The riparian vegetation along the river was severely impacted as a result of the 1976-77 drought event. During following years, miles of bank were left unprotected and tons of sediment were introduced to the river system. Property was lost and fish habitat below the dams was severely degraded.

THE SOLUTION

Given the complex problems that the Carmel River watershed faces, it became apparent that a comprehensive plan is needed to manage and protect these resources. The Monterey Peninsula Water Management District (MPWMD) is currently completing such a plan. Funding for development of the Carmel River Watershed Management Plan has been provided by the California Department of Fish and Game.

IMPLEMENTATION

The MPWMD, in cooperation with state and local agencies, is involved in the following programs that achieve the goals of the plan:

- Irrigation of riparian vegetation within the areas affected by production wells
- Planting of 50,000 feet of willows for bank stabilization
- Enacting ordinances to limit surface-water diversions and protect riparian vegetation
- Developing computer simulation models to assess water supply alternatives
- Funding studies of habitat availability and performance of passage facilities
- Formation of a committee to establish Carmel River lagoon-breaching policy
- Support and promotion of U.S. Forest Service and California Division of Forestry Fuel Management Programs
- Providing erosion control technical assistance to riverfront property owners
- Critiquing county EIRs and land use plans to advance district and watershed management plan goals
- Conducting a research program to establish baseline data and monitor long-term changes
- Promoting water conservation and reclamation to reduce demand

The Plan contains additional program proposals and methods to fund them.

1Presented at the California Watershed Management Conference, November 18-20, 1986, West Sacramento, California.
2Monterey Peninsula Water Management District, Monterey, California.
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