**EBBETTS PASS FOREST WATCH**

Little Hoover Commission

925 L Street, Ste. 805

Sacramento, CA 95814

January 19. 2017

Submitted via email to Krystal.Beckham@lhc.ca.gov

**Dear Commission and Staff Members,**

We recently became aware that the Little Hoover commission is going to examine and make recommendations on forest management issues and have read the documents posted on line and had an initial conversation with staff.

Ebbetts Pass Forest Watch (EPFW) is a Sierra based forest and watershed not for profit organization. We were founded in 2000 and been active in local and statewide forest related issues and have worked closely with other NGOs and with the Board of Forestry, the Resources Agency, Department of Fish and Game and Cal Fire.

We are encouraged that the commission is once again looking at forestry issues, and intends to "look beyond the crisis of dead and dying trees and examine the state's plans for recovery and its strategy to position itself ahead of future crises."

The previous Little Hoover 1994 - "Timber Harvest Plans, A Flawed Effort to Balance Economic and Environmental Needs," was an even-handed and thorough analysis of the timber harvest process, and its recommendations had the potential to bring about meaningful positive change. Unfortunately, 23 years later, none of the substantive, and only a few of the procedural, recommendations have been fulfilled while nearly all the problems delineated in 1994 still remain. Sadly, the many hours of good-faith time and State dollars invested in this project have shown little return, and the environment has been further degraded and mismanaged.

The purpose of this letter is to bring to your attention issues and previous studies that we believe are critical to your ability reach valid conclusions and recommendations. We are

hopeful that we and the other NGO groups that work on forest related issues will have additional opportunities to comment and bring up salient issues and welcome the fact and science based approach shown in other Little Hoover Commission work.

It will be critical for the Commission to examine why it's previous 1994 and other independent panel assessments have largely failed and how those failures have allowed continued ecological deterioration of our forest ecosystems. Because of various failures, our forests have entered into an era of dramatic and fast-moving climate change in an extremely weak and vulnerable condition.

**The future of our forests, water and wildlife, and forest communities and economies will be dire without an enlightened, holistic and science based understanding of what practices will make our <u>forests biodiverse, healthy and resilient and which practices are destroying their resilience.</u>**

> **This is not a time for recommendations based on political or vested interest pressures. Rather, the conclusions and the recommendations must create the best future of our forest related public trust resources for generations to come.**

**We urge the Commission and staff to understand what changes need to occur to ensure we have the highest probability that California will have healthy and resilient forest ecosystems that sequester carbon as well as protect our water (and snowpack) and, wildlife. These same forests of course are critical for local economies and tourism.**

**Business as usual in our forests is not an option**

- California's own climate change reports conclude that we will have more droughts, lower snowpack, hotter and drier conditions and fire, dramatic changes in vegetation, and species will disappear
- Climate change impacts are occurring more rapidly than expected and with severe changes – particularly in the Sierra as seen in recent tree mortality.
- Vast areas of California's private forests have lost biodiversity and resilience due to clearcutting and conversion of biodiverse forests into near monoculture evenaged tree plantations which have high fire risk (see fire attachments), and high stand mortality from beetle when most of the stand of pine is attacked. Wildlife, and watershed health is also adversely impacted.
- Declining forest productivity is already occurring and will continue. The draft of the 2006 California's "Our Changing Climate included the following:
    - "Forestlands cover 45 percent of the state; 35 percent of this is commercial forests such as pine plantations. Recent projections suggest that continued global warming could adversely affect the health and productivity of California's

forests. If average statewide temperatures rise to the medium warming range, the productivity of mixed conifer forests is expected to diminish by as much as 18 percent by the end of the century. Yield reductions from pine plantations are expected to be even more severe, with up to a 30 percent decrease by the end of the century.

- Experts understand that unevenaged biodiverse healthy forests with healthy soils will have the greatest likelihood of survival and adaptation in our climate change environment. These forests will sequester more carbon and produce fewer emissions if unevenaged management logging methods and wise use of controlled burning is used. We need to re-evaluate the impact and sustainability of plantations which have been increasingly replacing forests in California.

**Climate Change - Little Hoover Commission report and recommendations must result in positive results for forest health and resiliency in our future climate change scenarios**

*"According to the California Energy Commission, California lost 30% of its sequestration capacity in the last decade alone. It is clear, therefore, that forests may be sources of carbon dioxide or sinks o carbon dioxide, depending upon how people decide to manage them."*

*Laurie Wayburn, President, Pacific Forest Trust, Presentation to the California Climate Action Registry's Conference May 6, 2003.*

**Resource documents relevant to the Forest Management Study**

In undertaking your work, EPFW would call your attention to some other State-funded documents (all attached) relevant to your undertaking:

- "Final Report: Conclusions and Recommendations for Strengthening the Review and Evaluation of Timber Harvest Plans" Prepared for the California Department of Forestry and Fire Protection [now CALFIRE] by LSA Associates, March 1990
- Our Changing Climate: Assessing the Risks to California." A Summary Report from the California Climate Change Center. 2006. See "Forests and Landscapes" section, pp. 10-11.
- "A Scientific Basis for the Prediction of Cumulative Watershed Effects." The University of California Committee on Cumulative Watershed Effects. June 2001. Particularly note Chapter 1 discussion of inadequacies in the current system of identifying and mitigating cumulative watershed effects.
- Z'berg-Nejedly Forest Practice Act of 1973. Section 4512: Findings and Declarations and Section 4513: Legislative Intent

Also, we attach the following relevant documents:

- Dr. Leslie Reid's letter to Assemblyman Fred Keeley, 24 June 1999 on the ability of the Forest Practice Rules to avoid forestry-related cumulative watershed impacts?
- EPFW document on clearcutting and climate change
- 2 EPFW documents on relationship of fire to clearcutting and plantations
- The Western Mountain Initiative Annual Report for FY 2006. "Response of Western Mountain Ecosystems to Climatic Variability and Change."31 July 2007. Note Sierra study under "Question 2" section.

**Conclusion**

EPFW looks forward to being an active participant in the Little Hoover Commission's current process. It holds promise to address a real and present danger to the state that relies on its forests as the source of a majority of its water and a crucial carbon sink, as well as wildlife habitat and scenic recreational areas.

However, it is crucial that this time the work of the Commission not be in vain. Hopefully, the investigation will stay, as it did in 1994, above political and social pressures, using credible unbiased science and facts to develop recommendations to assure the most healthy, resilient, and bio-diverse forests possible for the future. And this time EPFW hopes that the Commission will boldly develop recommendations that acknowledge that business as usual is still not working and that we need a new way of approaching management of our forests. We hope that this time the Commission will undertake implementation of their recommendations despite political and vested interest pressures.

Susan A. Robinson

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FINAL REPORT

# CONCLUSIONS AND RECOMMENDATIONS FOR STRENGTHENING THE REVIEW AND EVALUATION OF TIMBER HARVEST PLANS

PREPARED FOR

CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE PROTECTION
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March 1990

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## INTRODUCTION AND CONTRACT DESCRIPTION

Since March 1989, LSA Associates, Inc., has been under contract to the California Department of Forestry and Fire Protection to provide consultive services in support of the Forest Practices Program. The purpose of this consulting contract has been to assist the Department in improving the administration of the timber harvest plan (THP) review and decision-making process, with particular focus on strengthening the THP administrative file presented to the courts in the event of litigation. It is generally recognized within the Department that the track record of litigated THPs has not been satisfactory and that weaknesses in the THP file (the written record that documents the decision-making process) have directly contributed to adverse court rulings.

In that most THP litigation in recent years has focused on "old growth/wildlife" issues, the geographic focus of the contract was Region I, the north coast region, headquartered in Santa Rosa. During the course of the contract period, LSA performed in a variety of capacities, each with the dual purpose of:

1. Providing real-time support to regional office and field personnel in the review, evaluation, and processing of selected THPs; and
2. Observing and gathering information on the operation of the Forest Practices Program (i.e., the processing of THPs) in order to formulate recommendations to the Sacramento Office on possible changes or modifications in the program.

For selected THPs, LSA was asked to participate in field inspections and discussions that were often, but not always conducted in the context of a formal pre-harvest inspection (PHI).

For these field inspections, LSA was usually represented by a 2-person team of a licensed forester and professional wildlife biologist. LSA personnel were not formal members of the PHI team. During these field inspections, many fundamental wildlife issues were raised and discussed by the representatives from the California Department of Fish and Game, the plan submitter, the land owner, CDF and its consultants. LSA periodically submitted written or oral reports to CDF Sacramento Office personnel that summarized these field inspections and provided focused recommendations.

Another task performed by LSA during the contract period was support to Region I forest practices personnel in the organization and preparation of official response to environmental comments documents ("ORs"). LSA personnel met with forest practices staff in the Santa Rosa office and offered editorial and technical input on how to best structure and present the CDF's response to key wildlife issues raised on selected THPs.





Memoranda were prepared and submitted to the Sacramento office that detailed our evaluation of selected draft ORs.

## SCOPE AND PURPOSE OF FINAL REPORT

The intent of this report is to convey to CDF a series of conclusions and recommendations prepared by LSA on the basis of nine months' involvement in and observation of the THP review and decision-making process. Our active examination of the process ended in November, 1989. The principal investigator and author of this report is Dr. Robert J. Hrubes. The purpose or motivation behind the recommendations is to improve CDF's overall administration of the forest practices program and, thereby, to improve the Department's likelihood for favorable court judgments in the event of litigation. Many of the conclusions and observations concerning the current state of program administration focus on deficiencies and areas needing improvement, particularly with respect to the consideration of wildlife. This is not meant to be construed as a general indictment of the current situation or an indictment of individuals performing various functions within the program. Rather, they are the result of the basic focus which is on opportunities and means to improve the THP review and decision-making process. The premise motivating this consulting contract is that changes and improvements are needed. To identify and implement these changes, it is first necessary to objectively and dispassionately reveal shortcomings and weaknesses. We offer the following conclusions and recommendations in that context.

## CONCLUSION AND RECOMMENDATIONS

The following comments are organized by subject area components of the THP review and decision process with additional sections of more general focus.

### The Time Frame for THP Review

Depending upon the review actions taken (e.g., pre-harvest inspection), the Rules require that CDF reach a decision for a THP within 35 days. For most THP's, this time frame has proven to be adequate. But for the controversial, 53 o1d-growth" THPs, the time frame set out in the

Rules is almost totally irrelevant. In these cases, the average time required for reaching a decision has been much closer to six months, necessitating multiple time extensions being granted by the plan submitter. Our review of several old-growth THP administrative records revealed that requests for time extensions were made at various times by DFG, CDF, and the plan submitter. While DFG has been responsible for the bulk of extension requests, both CDF and the plan submitter have, at times, needed additional time for their own purposes.



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In our opinion, attempts to impose the 35-day review time frame on these increasingly complex and controversial THPs are pointless and detract from the adequate analysis of substantive issues. And from the standpoint of the CDF as lead agency, it is undesirable to be put in a situation requiring frequent appeals to the plan submitter to grant time extensions. We recommend that CDF work with Board staff on a possible rule change aimed at establishing a two track review process. The recent rule change that added up to 10 days additional review time is clearly inadequate for controversial and/or complex THPs. A more appropriate arrangement would allow CDF to assign selected THPs to a separate time frame that reflects the demands associated with reviewing lengthy documents and the time needed to complete negotiations between the plan submitter and reviewing agencies. In Sierra Club vs. CDF, Judge Ferrogiaro concluded that the present time frame leads to decisions based upon 38sheer ~
The recent rule change notwithstanding, we feel that the Department is still vulnerable to this charge, for a distinct subset of THPs.

Feasibility of Suggested Mitigations

For "old-growth THPs81, conflict and controversy frequently arise when DFG proposes mitigations that their forest practices biologists feel are necessary to adequately reduce adverse wildlife impacts. The plan submitter's response often is that the suggested mitigations are infeasible, either because they are too costly or they will result in unacceptable silvicultural ramifications. The response of some RPFs has also included the assertion that the burden falls on the DFG to prove that the suggested mitigations are, in fact, necessary. The CDF review team chairman generally endorses the plan submitter's response by either forwarding it to DFG without critical evaluation or by opting not to be actively involved in the negotiations/discussions.

In our opinion, the Rules require CDF to more actively and vigorously review and evaluate the feasibility of proposed mitigations. We are not arguing that the industry is necessarily in error in rejecting various mitigations as being infeasible. But we do believe that CDF must critically evaluate such claims in order to reach its own, independent judgement. To accomplish this evaluation, the plan submitter should be asked to provide site specific information as to why the mitigation is felt to be infeasible. In evaluating the feasibility of proposed mitigations, CDF must apply the standards set forth in the Rules (Title 14 CCR, Section 895.1). The Rules' definition clearly states that the mere fact that a mitigation may be costly (e.g., in terms of foregone or delayed revenue) is not a valid basis for judging it infeasible. Information should be

supplied by the plan submitter that enables CDF to reach a judgement with respect to the standards set out in 14 CCR 895.1.

In a fewrecent coast-region THPs, CDF has invoked the concept of uncompensated taking when responding to mitigation suggested by DFG. We caution against the attempted use of this argument in that constitutional standards of taking are complex and generally not adequately understood by CDF review team personnel. If tested in court, CDF

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arguments concerning taking of private property through imposition of mitigations are not likely to be sustained. Again, it appears in these cases that CDF personnel are merely echoing the arguments of the plan submitter, without independent critical evaluation.

In a similar manner the principle or goal of maximum sustained yield has been cited by both plan submitters and CDF in rejecting proposed mitigations. While we agree that the sustainability of yields is a valid consideration in evaluating proposed mitigation, we are concerned with the simplistic manner in which the concept has been invoked. Merely rejecting a proposed mitigation as being Incompatible with maximum sustained yield without any elaboration of the standards associated with the concept is not likely to withstand judicial review. How is “maximum sustained yield" measured? Does any silvicultural prescription that involves the retention of merchantable volume necessarily detract from maximum sustained yield? It is noteworthy that both the environmentalists and the industry are citing the concept of sustained yield as support for their clearly divergent agendas. As a lead agency and a leader in the forestry community, CDF should assume, in cooperation with the Board, the responsibility for developing workable standards for applying the concept of maximum sustained yield to the regulation of private harvests. Failing to take the initiative, it is a safe bet that others will, with unknown but potentially troublesome consequences.

**Significant Environmental Impacts**

Title 14 Section 898 of the California Administrative Code requires the RPF to determine if the proposed operation will have any significant adverse impact on the environment, after considering the rules of the Board and any mitigation measures proposed in the plan. A significant, adverse impact is defined as a substantial, or potentially substantial, adverse change in any of the physical conditions within the affected area including flora and fauna. To date, a THP with a positive determination of significance has been submitted in only the rarest of occasions (well less than .1% of all THPs). We were not able to uncover an instance in which CDF rejected the RPF's judgement. So in effect, the THP has evolved into the functional equivalent of a "mitigated negative declaration", applied categorically.

With respect to possible wildlife impacts, we believe the Department's tacit endorsement of the almost-categorical judgement of non-significance is both practically and factually untenable. While the forest practices rules and additional mitigations included in many THPs do substantially reduce the level of adverse impact, it is clear that the preponderance of professional and scientific biological opinion (including ours) holds that significant impacts on



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some species may still occur. We believe that it will be increasingly difficult for the Department to successfully argue in the official response documents or in court that impacts of some

proposed harvesting operations on some species are not potentially substantial (i.e., significant). The impacts of clearcutting old growth stands on “old growth dependent" species are the obvious case in point. To categorically hold to the position that impacts are not significant, as the Department has essentially done to date, increasingly puts the credibility of the THP review process in jeopardy. Some RPF's have argued, and the CDF has accepted, that for non-listed species, significant impacts occur only if viability of the species is threatened. Relative to definitions of significance in both the forest practice rules and the CEQA guidelines, we find this standard to be overly restrictive and without the support of widespread professional biological opinion.

Where the case-specific facts merit it, we feel that it is necessary for the Department to take issue with the RPF's determination of non-significance. Either by not accepting offending THPs for filing or by returning them unapproved, it is important that the Department take steps to end its tacit endorsement of categorical non-significance. While the motivations or concerns of both the RPF and CDF reviewing staff is understandable, aversion to the possible ramifications is not a defensible justification. And, in fact the long term chances for successfully seeing a THP through the review process and subsequent litigation are quite possibly enhanced by shifting the focus away from the significance issue and on to possible "overriding considerations".

**Analysis of Cumulative Impacts**

Our evaluation of the cumulative impacts analyses that are conducted as part of the THP preparation and review process is influenced by a fundamental premise. In our professional judgement, we believe that significant adverse cumulative impacts on wildlife (and other) resources can occur from a broad range of “development" activities including timber harvesting. We note that the preponderance of professional wildlife management opinion is consistent with our perspective. We further note that in the context of other planning processes such as EIR preparation, that a positive determination of significant cumulative impacts is increasingly common.

In contrast to the status of cumulative impacts analyses in other planning processes, of those that we examined we were not able to identify a THP in which the RPF or review team concluded that a significant cumulative impact on wildlife or their habitat would occur. With respect to other resources, the occurrence of a positive determination was only slightly higher and was generally limited to water quality impacts. So, as with significant on-site impacts, the aggregate implication of the conclusions reached in THPs to date is that there are essentially no cumulative wildlife impacts, and very little other resource





cumulative impacts associated with state and private timber harvests in California. In our judgement, the implied position that the Department has assumed with respect to cumulative impacts lacks credibility and represents a significant weakness in the overall administration of the forest practices program. We believe that responsible agencies (e.g., DFG), the public, and the courts are increasingly focusing on cumulative impacts and that continued adherence to the Department's present position places the viability of the THP process in jeopardy.

Our conclusion is that the present situation results from the inadequate cumulative impact analysis methodology that is currently in place. The RPF is required to answer a single question as to cumulative impacts and to elaborate only when the answer Is ny~5u The CDF,

as leader of the review team, must respond to 15 questions contained in the Forest Practices Cumulative Impacts
Checklist. Answers are in the form of Ny~5/~~fl with a brief (2-3 sentence) elaboration for each. Our review of several recent THPs revealed that the exact wording of answers to the checklist questions is replicated on several review team reports. The use of boilerplate responses projects the undesirable and unfortunately accurate impression that the review team is not affording an adequate level of attention to their cumulative impact assessment responsibilities. For both the RPFs' and review teams' responsibilities, it is apparent that the process suffers from a lack of adequate direction and guidance on how to accomplish a meaningful cumulative impacts analysis. When coupled with the widespread sense within the forestry profession that acknowledging the possibility of a significant impact is tantamount to a kiss of death for the THP, it is not surprising that so few THP preparers and reviewers reach an affirmative conclusion. But even though the present situation is understandable or explainable, it is not acceptable with respect to the Department's desire to improve its performance in the courts.

As evidenced by the rule modifications submitted to the Board during the past year, including proposed cumulative impact assessment methods submitted by the industry, CDF, and CLFA, it is apparent that there is a general recognition within the forestry profession that the process needs to be modified. But based upon our review of these suggested rule packages, we are concerned that the forestry community has not yet fully acknowledged the extent to which substantive changes are required. As the various packages are being reworked for submission, there remain issues that will require careful consideration in upcoming deliberations. Issues that are likely to generate public discussion include:

--Standards for information gathering

The various rule packages continue and codify the standard of "ready availability" which states that the need for information that may be necessary to assess environmental impacts is held subservient to the need to reach a decision within the relatively brief review period.



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In our judgment, this priority imparts an undesirable impression of bias, especially if, in the event that needed information cannot be “readily" obtained, the THP is approved.

--Explanation of checklist responses

These.packages require that only "yes" responses on the checklist be supported with explanation. A more balanced approach would requireexplanation of “no” responses, as well.

-Definition of significance

At least one of the packages would formalize the very restrictive definition of significant impacts to non-listed species as being only those impacts that threaten the viability of the species as a whole. This definition strongly conflicts the CEQA Guidelines. Some components of the reviewing public may see no reason why the THP process, as a certified EIR-equivalent program, should have a different standard for judging significance of impacts than that used for other CEQA documents, especially when the Guidelines are cited elsewhere in the Rules.

--Related actions

None of the packages would require the plan submitter to provide and

consider information on related actions (past, present and reasonably foreseeable) on land under other ownerships. Such information, often critical to an adequate cumulative impacts analysis, must be provided by preparers of CEQA documents, within the standards of practicality and reasonableness (Section 15130 of the Guidelines). We believe that shifting this information-gathering burden onto the already over-burdened CDF Forest Practices Staff is both inappropriate and likely to result in inadequate analysis of long-term issues such as old-growth conversion.

--The need for regulatory relief

An explicit premise of the industry's initial rule package was that environmental considerations required under the forest practices program are excessively burdensome and that regulatory relief is needed. That premise implicitly remains in the current rule package. But as we have discussed in other reports to the Department, our investigations have revealed that the validity of this premise is limited to a relatively select set of circumstances and, accordingly, is an inappropriate basis for program-wide rule changes.



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**The Official Response Document**

With respect to the Department's desire to strengthen the administrative record in support of a THP decision, the official response to significant environment comments (the 380R1u) ~5 perhaps the single most important document. The OR provides the opportunity to present the rationale and factual basis for the THP decision and to establish in the record a written counter-argument to assertions made by reviewing agencies and the general public. In particular, the OR affords CDF the opportunity to demonstrate how it has considered and balanced the "conflict of evidence" in the record. As indicated by recent court cases, the OR is closely scrutinized by reviewing judges and it clearly impacts their rulings (e.g., EPIC vs. Johnson, Galle~os vs. BOF, EPIC vs. MAXXAM). For instance, Judge Buffington in EPIC vs. MAXXAM ruled that insufficiency of the OR "may be grounds to set aside a decision approving the plan".

Standards of adequacy for the OR are not formally established in statute or Departmental policy. But as key element of "certified" (i.e., functionally equivalent) program, we feel that the CEQA guidelines on responsive statements constitute sound direction and effectively reflect the standards that are generally applied by the courts in reviewing the administrative record for a THP.

> "The written response shall describe the disposition of significant environmental issues raised (e.g., revisions to the proposed project to mitigate anticipated impacts or objections). In particular, the major environmental issues raised when the Lead Agency's position is at variance with recommendations and objectives raised in the comments must be addressed in detail giving reasons why specific comments and suggestions were not accepted. There must be good faith and reasoned analysis in responses. Conclusory statements unsupported by factual Information will not suffice." [CEQA Guidelines, 15088(b)]

A review of recent court rulings provides additional guidance or direction that reinforces the relevance of the CEQA guidelines to both the courts, in reviewing THP files, and to the CDF in preparing the ORs. In EPIC vs. MAXXAM, Judge Buffington cited EPIC vs. Johnson as the prime judicial standard and concluded that the OR must set forth a "meaningful, reasoned response" to significant environmental comments. Later in the same ruling, Buffington re-states that obligation of the OR to contain a "reasoned assessment, compiled in a meaningful manner" and that the THP decision should be based or supported by "scientific opinion or reasoned analysis". In Friends of Daughertv Creek vs.---CDF, Judge Cox concluded that the OR should "make meaningful responses to all significant issues raised and the responses will set forth the reasoning of the CDF and the facts relied upon in exercising its discretion". Judge Cox further
ruled that only significant points require a response but that the OR should in





response to non-significant points "state the factual basis upon which the determination of `non-significance' was made".

These cases and others reinforce the judicial posture that if the administrative record clearly sets forth substantial evidence to support CDF's decision and, by doing so, demonstrates that CDF has not prejudicially abused its discretionary authority, then the courts may not substitute its judgment for the Director's. The goal of the OR in combination with the entire administrative record should be to present the requisite supporting evidence and decision making logic so as, to the extent feasible, to pre-empt charges of prejudicial abuse of discretion, and, thereby, to obligate the courts to defer to the professional judgments of the Director and his representatives. In the regulatory climate of increasing judicial activism, this is a difficult task. But by responding to these standards of adequacy, the Department can expect to measurably improve its judicial track record.

Our evaluation of several recent' ORs prepared for THPs in the coast region leads us to the conclusion that additional guidance and assistance is needed for personnel who are preparing ORs. Many ORs do not compare favorably with the standard of presenting a reasoned, meaningful response to environmental comments and of demonstrating the scientific opinion and/or reasoned analysis that supports the THP decision. A more detailed discussion of this conclusion is contained in our August 1, 1989, interim report and we will only briefly repeat them, here. As currently being prepared, ORs clearly do not respond to Judge Cox's ruling that even non-significant environmental comments merit a response as to why CDF judges them to be non-significant. And for significant comments, it is sometimes very difficult to identify in the OR where and how the Department has responded. Current direction to OR preparers is to lump all comments into a synthesized response rather than splitting out and responding to each significant comment, individually. But in applying this direction, the ORs generally fail to present an impression of responsiveness or even acknowledgement that many of the comments have been considered. They leave the department vulnerable to judicial impressions that the Director and/or his representative have prejudicially abused their discretionary authority. The use of "boiler plate" language further erodes the credibility of the OR and lends credence to the impression that the Department has not seriously considered some of the significant points raised by commenters.

In large part, we attribute the shortcomings of the ORs to inadequate numbers of staff committed to their preparation. To prepare an OR that adequately meets the judicial standards of review requires more time and preparation than what is presently available, certainly within the present review time frame. Given the workload of the staff who prepare the ORs, it is unreasonable to expect a significantly greater time commitment per THP. We recommend that CDF place high priority on assigning additional staff to the preparation of OR's and additional clerical support to the technical staff. A cautionary note is that the strength of the OR is inherently limited by the strength of the factual arguments it contains. While the format and structure can be improved, with desirable results, we caution that an extra burden is placed on the OR when the Department takes a position on controversial issues (such as old-growth dependency) that runs counter to accepted scientific and professional opinion. We do not argue that contrary opinions should be summarily avoided or rejected, but there is clearly an elevated need to logically and reasonably set forth





the basis for accepting new or minority opinions over accepted opinion. Recent efforts (e.g., Plan 1-89-230-MEN) represent progress in the right direction. But as indicated by the response of one academic to the OR for plan 230 (letter from Gutierrez), basing a THP decision on minority opinion will continue to be problematic, no matter how it is presented.

**Learning from the Past**

Given the widely accepted judgement that the Department's litigation track record has been less than desirable, it follows that the Department should seek to learn from litigative setbacks and to modify policies and procedures within the Rules, accordingly. To a limited degree, we see that this effort is occurring. This consulting contract, for instance, was awarded partially in response to the Department's desire to identify and learn from current short comings. But in our opinion, a more focussed and formalized effort should be made to analyze the on-going litigation track record.

It is our impression that forest practice personnel are not kept adequately abreast of emerging judicial standards of review for such things as the official response document, feasibility, and significance. We recommend that a position be established, or duties be assigned to a current position, that is responsible for continuously monitoring and analyzing relevant court rulings and regularly disseminating pertinent information to field personnel. A similar function does currently exist, but a more rigorous monitoring of court cases' is needed. Coordination with Board staff is important to assure that the Department continues to operate within the roles and responsibilities defined by the Rules. Where this is not possible, CDF should convey to the Board the need for a change in the Rules.

**CDF Interaction With DFG**

A source of frustration and concern among CDF forest practices personnel has been the growing conflicts with their sister agency personnel in the Department of Fish and Game. DFG

is perceived as an increasingly obstructionist element in the timber harvest review process. Requests from DFG for additional information





and mitigations above and beyond those required in the Rules, and their increasing penchant for filing nonconcurrence positions on oldgrowth THPs have all contributed to the deteriorating state of relations between the two agencies. In response, the CDF (often amplifying the responses of the plan submitter) has requested DFG to justify and substantiate the need for additional information and mitigations. In essence, the position of the industry and some CDF personnel is that the burden falls on DFG to prove that additional information and/or mitigations are needed.

While the Department's frustration is understandable and not without basis we know of no statutory authority by which the burden of proof can be shifted' onto the DFG. The consultation requirements under Section 21080.5(d) of CEQA--which is the basis for DFG involvement in timber harvest review--does not allude to a burden of proof on responsible agencies. On the other hand, we do agree that CDF should expect more that bare requests, unsupported by any explanation or rationale. As lead agency under a certified program, CDF needs to seek means and methods for working productively with responsible agencies such as DFG. Based upon our observations on selected THPs, we feel that this is best achieved through active discussion and negotiation rather than confrontation. Ultimately, the CDF has final responsibility for weighing and balancing the conflict of evidence and opinion with respect to information needs and mitigations. The merits of such requests should be judged, in part, by the degree to which other agencies have helped CDF understand the basis and need for those requests.

We believe that a major reason for COF's frustration with DFG is that DFG is asked to perform two, conflicting roles in the timber harvest review process. On the one hand, CDF has a contract and pays DFG to supply technical wildlife biology expertise to the Department in the overall administration of the forest practices program. This inter-agency arrangement is necessitated by CDF's lack of biological expertise within its forest practices workforce. On the other hand, DFG also functions as a commenting/responsible agency under CEQA. In this role, DFG's primary responsibility is to represent the public interest in maintaining the viability of the state's wildlife populations. In this capacity, DFG cannot be expected to necessarily support CDF in the administration of a program aimed at fostering a maximum sustained yield of forest products.

In that the distinction between these two roles is not clearly understood by many within CDF (and DFG) and because these roles are inherently contradictory, we recommend that CDF no longer contract with DFG for biological expertise. A better arrangement would be for CDF to begin hiring its own staff of field biologists, leaving DFG to perform its public trust function. An additional advantage is that with internal wildlife biology expertise, CDF will be on a more equal footing in debating technical issues with its sister agency. We caution, however, against the simplistic expectation that hiring biologists within CDF will automatically generate the necessary professional opinion to counter the opinions held by DFG. As other forestry agencies such as the USDA Forest Service

have discovered, new professional disciplines within the organization do not always embrace the philosophies and professional values held by foresters.

**Strengthening Public Support**

From our perspective, the pattern of unfavorable court rulings is best viewed as a symptom of an underlying erosion of public support and endorsement of some of the more visible aspects of industrial forestry in California. And because CDF administers the primary law and program that regulates industrial forestry in the State, the Department is also suffering from an eroding support base. While the forestry community may be comforted by interpreting the opposition to the industrial forestry agenda as the agitation of the radical fringe, we cannot endorse that view. In a State with a population of 28 million people, and growing at an increasing rate, it is an unavoidable reality that even the most rural counties are undergoing fundamental changes associated with urbanization; changes that bring an increasingly critical public focus on the actions of the timber industry and the agencies who regulate it. The harsh truth is that the majority of the State's population does not, and increasingly will not, support "business as usual" policies such as the rapid liquidation of the remaining privately held old growth stands and the conversion of sizable portions of the State's timberlands to a wood fiber industry.

As the recent events in Mendocino County associated with the planned relocation of processing capacity to Mexico clearly demonstrate, public concern and opposition is not limited to the major metropolitan areas. Beyond geographic diversity, public concern and opposition is not limited to ug environmental community fl but, rather, includes local labor leaders, some county supervisors,
Congressional delegations, state assembly members, and the natural resources professional and academic community. With respect to "old growth lssues", the forestry community is perilously isolated from the general sentiments and values of the California and national electorate.

More to the point, it is our opinion that the public support for the forest practices program has eroded to a degree that threatens its operational viability. In too many circles, the program and its administration by CDF is perceived as generally failing to adequately regulate the actions of the timber industry. The Board and, to a lesser extent, the COF are perceived as overly sympathetic to the corporate goals behind industrial forestry actions and insensitive to the public resource obligations of industrial land owners. As long as these perceptions persist--or, more accurately, intensify-efforts to improve the litigation track record will experience very limited success, at best.



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In our view, the Department is at a crisis point with respect to the administration of the forest practices program. Bold action aimed at recapturing public support is called for. We believe these actions should be pursued on two related fronts:

establishing a greater degree of independence from the industry it regulates,
asserting a stronger leadership role in forestry matters in California.

Rightly or wrongly, too many peqple perceive COF as not aggressively enforcing the intent of the Forest Practices Act and the requirements of CEQA. While it is vital to maintain a working relationship with the industry, it is equally important to visibly demonstrate to the industry and the public that the statutory obligations of assuring adequate environmental consideration in the management of private forestlands cannot be compromised and that the Department is committed to its regulatory obligations even if it angers the industry. Past CDF actions have failed to demonstrate this. In areas such as the determination of significant impacts, the identification of appropriate mitigations, and currently, the development of a new rule package for wildlife and cumulative impacts, the Department is operating in a manner that fails to establish a public perception of appropriate independence from the industry it regulates.

We are not unaware of the complexities of interactions with the industry and, particularly, the Board. CDF does not make the rules; it is charged with administering them. But as a key agency staking claim to a leadership position in the forestry and wildland management affairs of California, the Department needs to begin taking more independently derived positions that may not march in close step with either the Board or the industry. We believe that the current rulemaking actions afford an excellent opportunity to begin this transitional process. In our opinion, CDF's interests are not adequately served by the present rule proposal. At a minimum, the Department should strongly urge the Board to postpone re-noticing of any new package until the findings and recommendations of the Wildlife Taskforce are released and can be integrated into the proposed rules. Standing by (or, more accurately, trying to modify on the margin) while the industry-backed rules are moved through the rule-making process without the benefit of the Taskforce's input does not advance the Department's public image as a forestry leader and will result in a rule change that will exacerbate its efforts at improving' the administration of the forest practices program and its litigation track record.

# Our Changing Climate

## Assessing the Risks to California

A Summary Report from
the California Climate Change Center

**Because most global warming emissions remain in the atmosphere for decades or centuries, the choices we make today greatly influence the climate our children and grandchildren inherit. The quality of life they experience will depend on if and how rapidly California and the rest of the world reduce these emissions.**

**In California and throughout western North America, signs of a changing climate are evident.** During the last 50 years, winter and spring temperatures have been warmer, spring snow levels in lower- and mid-elevation mountains have dropped, snowpack has been melting one to four weeks earlier, and flowers are blooming one to two weeks earlier.

These regional changes are consistent with global trends. During the past 100 years, average temperatures have risen more than one degree Fahrenheit worldwide. Research indicates that much of this warming is due to human activities, primarily burning fossil fuels and clearing forests, that release carbon dioxide ($CO_2$) and other gases into the atmosphere, trapping in heat that would otherwise escape into space. Once in the atmosphere, these heat-trapping emissions remain there for many years—$CO_2$, for example, lasts about 100 years. As a result, atmospheric concentration of $CO_2$ has increased more than 30 percent above pre-industrial levels. If left unchecked, by the end of the century $CO_2$ concentrations could reach levels three times higher than pre-industrial times, leading to dangerous global warming that threatens our public health, economy, and environment.

The latest projections, based on state-of-the art climate models, indicate that if global heat-trapping emissions proceed at a medium to high rate, temperatures in California are expected to rise 4.7 to 10.5°F by the end of the century. In contrast, a lower emissions rate would keep the projected warming to 3 to 5.6°F. These temperature increases would have widespread consequences including substantial loss of snowpack, increased risk of large wildfires, and reductions in the quality and quantity of certain agricultural products. The state's vital resources and natural landscapes are already under increasing stress due to California's rapidly growing population, which is expected to grow from 35 million today to 55 million by 2050.

This document summarizes the recent findings of the California Climate Change Center's "Climate Scenarios" project, which analyzed a range of impacts that projected rising temperatures would likely have on California. The growing severity of the consequences as temperature rises underscores the importance of reducing emissions to minimize further warming. At the same time, it is essential to identify those consequences that may be unavoidable, for which we will need to develop coping and adaptation strategies.

In 2003, the California Energy Commission's Public Interest Energy Research (PIER) program established the California Climate Change Center to conduct climate change research relevant to the state. This Center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts as well as the efforts designed to reduce emissions.

Executive Order #S-3-05, signed by Governor Arnold Schwarzenegger on June 1, 2005, called for the California Environmental Protection Agency (CalEPA) to prepare biennial science reports on the potential impact of continued global warming on certain sectors of the California economy. CalEPA entrusted PIER and its California Climate Change Center to lead this effort. The "Climate Scenarios" analysis summarized here is the first of these biennial science reports, and is the product of a multi-institution collaboration among the California Air Resources Board, California Department of Water Resources, California Energy Commission, CalEPA, and the Union of Concerned Scientists.

Cover photos: (sunset) Photos.com; (from top to bottom) AP Photo/Paul Sakuma, iStockphoto, IndexStock, Picturequest, iStockphoto. Above: Bureau of Land Management. Background: IndexStock

# California's Future Climate

**California's climate is expected to become considerably warmer during this century.** How much warmer depends on the rate at which human activities, such as the burning of fossil fuels, continue. The projections presented here illustrate the climatic changes that are likely from three different heat-trapping emissions scenarios (see figure below).

## Projected Warming

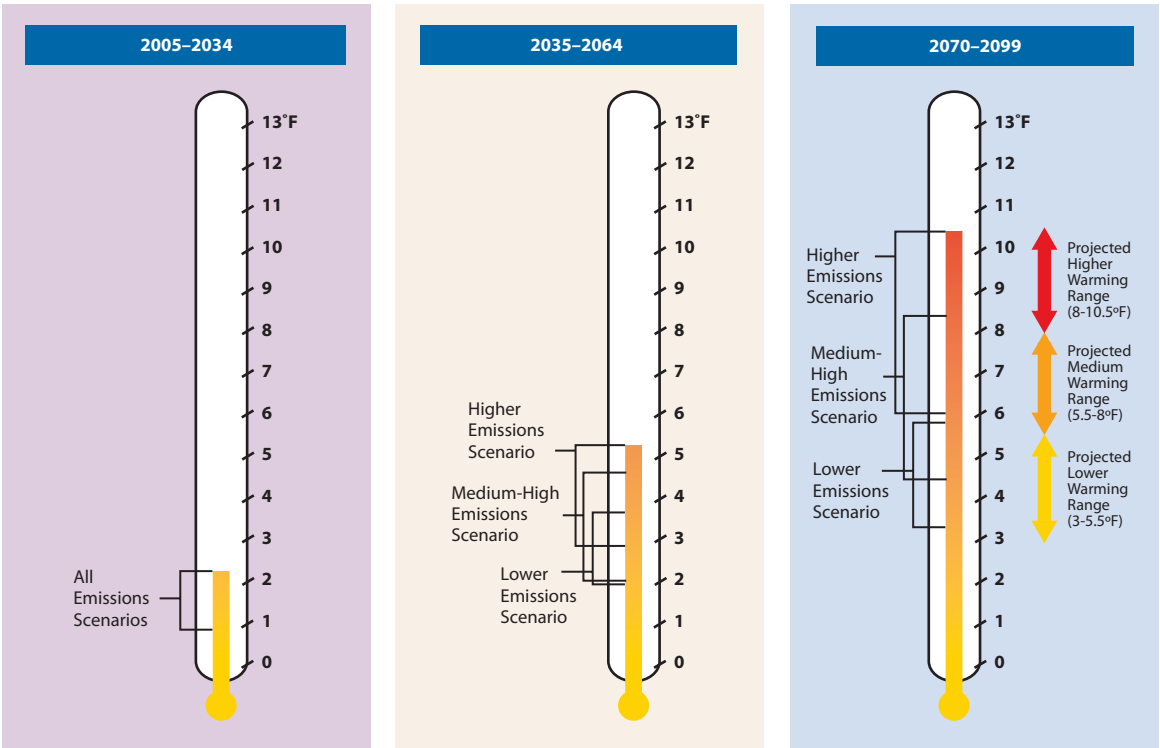
Temperatures are expected to rise substantially in all three emissions scenarios. During the next few decades, the three scenarios project average temperatures to rise between 1 and 2.3°F; however, the projected temperature increases begin to diverge at mid-century so that, by the end of the century, the temperature increases projected in the higher emissions scenario are approximately twice as high as those projected in the lower emissions scenario. Some climate models indicate that warming would be greater in summer than in winter, which would have widespread effects on ecosystem health, agricultural production, water use and availability, and energy demand.

Toward the end of the century, depending on future heat-trapping emissions, statewide average temperatures are expected to rise between 3 and 10.5°F. The analysis presented here examines the future climate under three projected warming ranges:[1]

- **Lower warming range:** projected temperature rises between 3 and 5.5°F
- **Medium warming range:** projected temperature rises between 5.5 and 8°F
- **Higher warming range:** projected temperature rises between 8 and 10.5°F

## Precipitation

On average, the projections show little change in total annual precipitation in California. Furthermore, among several models, precipitation projections do not show a consistent trend during the next century. The Mediterranean seasonal precipitation pattern is expected to continue, with most precipitation falling during winter from North Pacific storms. One of the three climate models projects slightly wetter winters, and another projects slightly drier winters with a 10 to 20 percent decrease in total annual precipitation. However, even modest changes would have a significant impact because California ecosystems are conditioned to historical precipitation levels and water resources are nearly fully utilized.




**California is expected to experience dramatically warmer temperatures during the 21st century. This figure shows projected increases in statewide annual temperatures for three 30-year periods. Ranges for each emissions scenario represent results from state-of-the-art climate models.**

1 These warming ranges are for illustrative purposes only. These ranges were defined in the original Climate Scenarios analysis to capture the full range of projected temperature rise. The exact values for the warming ranges as presented in the original summary report are: lower warming range (3 to 5.4°F); medium warming range (5.5 to 7.9°F); and higher warming range (8 to 10.4°F).

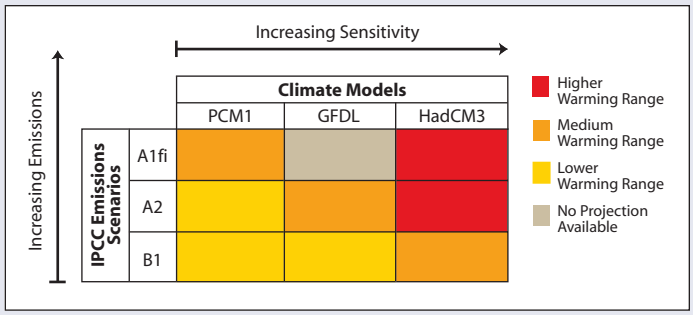
# Projecting Future Climate

How much temperatures rise depends in large part on how much and how quickly heat-trapping emissions accumulate in the atmosphere and how the climate responds to these emissions. The projections presented in this report are based on three different heat-trapping emissions scenarios and three climate models.

## Emissions Scenarios

The three global emissions scenarios used in this analysis were selected from a set of scenarios developed by the Intergovernmental Panel on Climate Change's (IPCC) *Special Report on Emissions Scenarios*, based on different assumptions about population growth and economic development (measured in gross domestic product).

- The **lower emissions scenario (B1)** characterizes a world with high economic growth and a global population that peaks by mid-century and then declines. There is a rapid shift toward less fossil fuel-intensive industries and introduction of clean and resource-efficient technologies. Heat-trapping emissions peak about mid-century and then decline; $CO_2$ concentration approximately doubles, relative to pre-industrial levels, by 2100.
- The **medium-high emissions scenario (A2)** projects continuous population growth and uneven economic and technological growth. The income gap between now-industrialized and developing parts of the world does not narrow. Heat-trapping emissions increase through the 21st century; atmospheric $CO_2$ concentration approximately triples, relative to pre-industrial levels, by 2100.
- The **higher emissions scenario (A1fi)** represents a world with high fossil fuel-intensive economic growth, and a global population that peaks mid-century then declines. New and more efficient technologies are introduced toward the end of the century. Heat-trapping emissions increase through the 21st century; $CO_2$ concentration more than triples, relative to pre-industrial levels, by 2100.



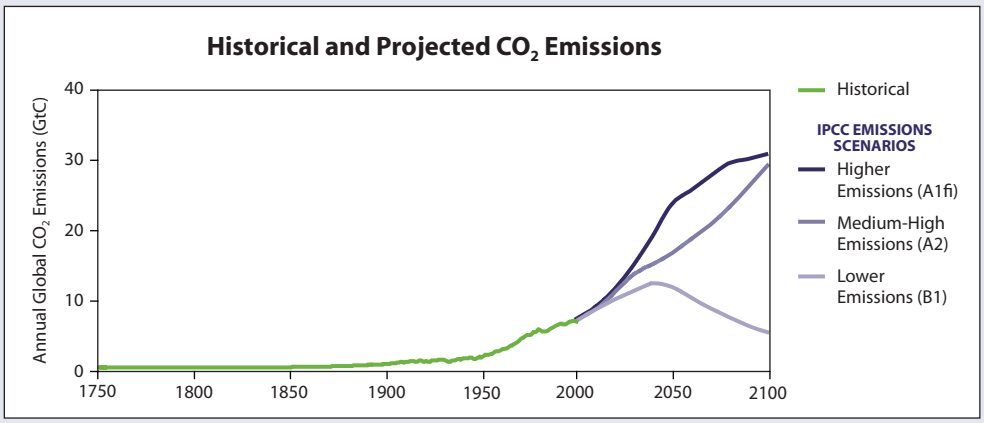

**This matrix shows the temperature increases that result from the three climate models, assuming emission inputs indicated in the IPCC emissions scenarios. The resulting temperatures are grouped into three warming ranges defined in the "Climate Scenarios" analysis.**

## Climate Sensitivity

The three models used in this analysis represent different climate sensitivities, or the extent to which temperatures will rise as a result of increasing atmospheric concentrations of heat-trapping gases. Climate sensitivity depends on Earth's response to certain physical processes, including a number of "feedbacks" that might amplify or lessen warming. For example, as heat-trapping emissions cause temperatures to rise, the atmosphere can hold more water vapor, which traps heat and raises temperatures further—a positive feedback. Clouds created by this water vapor could absorb and re-radiate outgoing infrared radiation from Earth's surface (another positive feedback) or reflect more incoming shortwave radiation from the sun before it reaches Earth's surface (a negative feedback).

Because many of these processes and their feedbacks are not yet fully understood, they are represented somewhat differently in different global climate models. The three global climate models used in this analysis are:

- **National Center for Atmospheric Research Parallel Climate Model (PCM1):** low climate sensitivity
- **Geophysical Fluids Dynamic Laboratory (GFDL) CM2.1:** medium climate sensitivity
- **United Kingdom Met Office Hadley Centre Climate Model, version 3 (HadCM3):** medium-high climate sensitivity




**As this figure shows, $CO_2$ emissions from human activities (such as the burning of fossil fuels) were negligible until around the so-called industrial age starting in the 1850s.**

# Public Health

**Continued global warming will affect Californians' health by exacerbating air pollution, intensifying heat waves, and expanding the range of infectious diseases.** The primary concern is not so much the change in *average* climate but the projected increase in *extreme* conditions, which pose the most serious health risks.

## Poor Air Quality Made Worse

Californians currently experience the worst air quality in the nation, with more than 90 percent of the population living in areas that violate the state's air quality standard for either ground-level ozone or airborne particulate matter. These pollutants can cause or aggravate a wide range of health problems including asthma and other acute respiratory and cardiovascular diseases, and can decrease lung function in children. Combined, ozone and particulate matter contribute to 8,800 deaths and $71 billion in healthcare costs every year. If global background ozone levels increase as projected in some scenarios, it may become impossible to meet local air quality standards.

Higher temperatures are expected to increase the frequency, duration, and intensity of conditions conducive to air pollution formation. For example, if temperatures rise to the medium warming range, there will be 75 to 85 percent more days with weather conducive to ozone formation in Los Angeles and the San Joaquin Valley, relative to today's conditions. This is more than twice the increase expected if temperature rises are kept in the lower warming range.

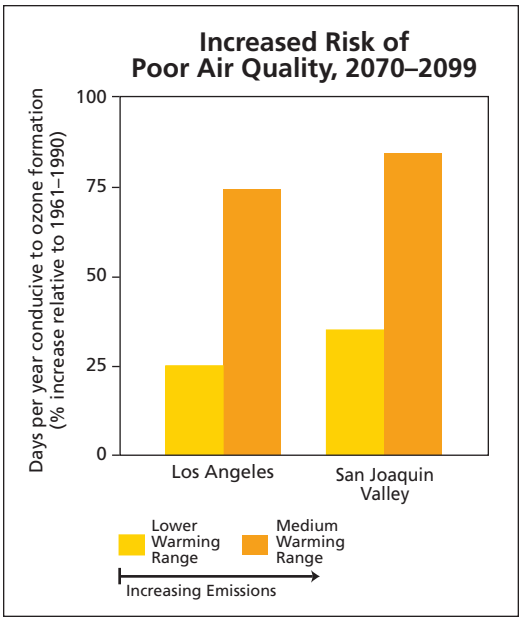
Air quality could be further compromised by increases in wildfires, which emit fine particulate matter that can travel long distances depending on wind conditions. The most recent analysis suggests that if heat-trapping gas emissions are not significantly reduced, large wildfires could become up to 55 percent more frequent toward the end of the century.

## More Severe Heat

By 2100, if temperatures rise to the higher warming range, there could be up to 100 more days per year with temperatures above 90°F in Los Angeles and above 95°F in Sacramento. This is a striking increase over historical patterns (see chart on p. 6), and almost twice the increase projected if temperatures remain within or below the lower warming range.

As temperatures rise, Californians will face greater risk of death from dehydration, heat stroke/exhaustion, heart attack, stroke, and respiratory distress caused by extreme heat. By mid century, extreme heat events in urban centers such as Sacramento, Los Angeles, and San Bernardino could cause two to three times more heat-related deaths than occur today. The members of the population most vulnerable to the effects of extreme heat include people who are already ill; children; the elderly;

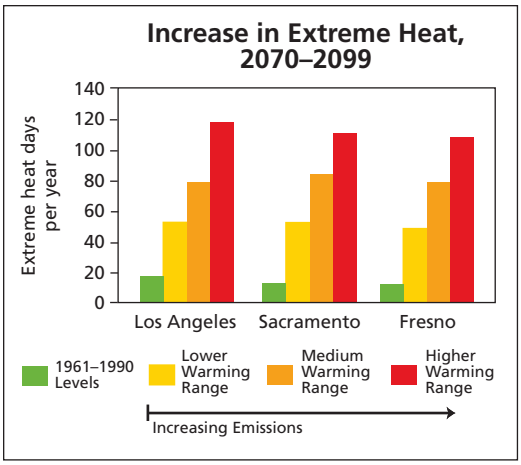
**As temperatures rise, Californians will face greater risk of death from dehydration, heat stroke, heart attack, and other heat-related illnesses.**



**Cars and power plants emit pollutants that contribute to global warming and poor air quality. As temperatures increase, it will be increasingly difficult to meet air quality standards throughout the state.**

and the poor, who may lack access to air conditioning and medical assistance.

More research is needed to better understand the potential effects of higher temperatures and the role that adaptation can play in minimizing these effects. For example, expanding air conditioner use can help people cope with extreme heat; however, it also increases energy consumption, which, using today's fossil fuel-heavy energy sources, would contribute to further global warming and air pollution.



iStockphoto

# Water Resources

**If global warming emissions continue unabated, Sierra Nevada snowpack could decline 70 to 90 percent, with cascading effects on winter recreation, water supply, and natural ecosystems.**

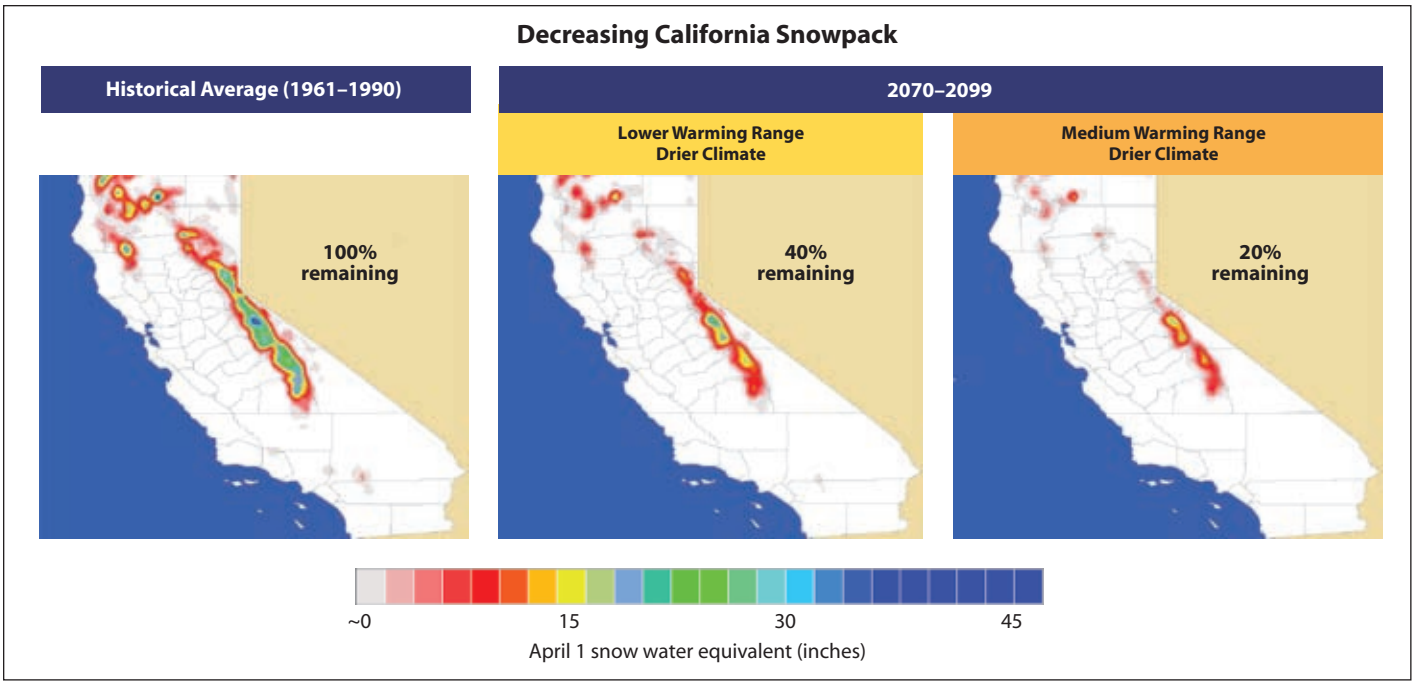
**Most of California's precipitation falls in the northern part of the state during the winter while the greatest demand for water comes from users in the southern part of the state during the spring and summer.** A vast network of man-made reservoirs and aqueducts capture and transport water throughout the state from northern California rivers and the Colorado River. The current distribution system relies on Sierra Nevada mountain snowpack to supply water during the dry spring and summer months. Rising temperatures, potentially compounded by decreases in precipitation, could severely reduce spring snowpack, increasing the risk of summer water shortages.

## Decreasing Sierra Nevada Snowpack

If heat-trapping emissions continue unabated, more precipitation will fall as rain instead of snow, and the snow that does fall will melt earlier, reducing the Sierra Nevada spring snowpack by as much as 70 to 90 percent. How much snowpack will be lost depends in part on future precipitation patterns, the projections for which remain uncertain. However, even under wetter climate projections, the loss of snowpack would pose challenges to water managers, hamper hydropower generation, and nearly eliminate skiing and other snow-related recreational activities. If global warming emissions are significantly curbed and temperature increases are kept in the lower warming range, snowpack losses are expected to be only half as large as those expected if temperatures were to rise to the higher warming range.

## Challenges in Securing Adequate Water Supplies

Continued global warming will increase pressure on California's water resources, which are already over-stretched by the demands of a growing




economy and population. Decreasing snowmelt and spring stream flows coupled with increasing demand for water resulting from both a growing population and hotter climate could lead to increasing water shortages. By the end of the century, if temperatures rise to the medium warming range and precipitation decreases, late spring stream flow could decline by up to 30 percent. Agricultural areas could be hard hit, with California farmers losing as much as 25 percent of the water supply they need.

Water supplies are also at risk from rising sea levels. An influx of saltwater would degrade California's estuaries, wetlands, and groundwater aquifers. In particular, saltwater intrusion would threaten the quality and reliability of the major state fresh water supply that is pumped from the southern edge of the Sacramento/San Joaquin River Delta.

Coping with the most severe consequences of global warming would require major changes in water management and allocation systems. As more winter precipitation falls as rain instead of snow, water managers will have to balance the need to fill constructed reservoirs for water supply and the need to maintain reservoir space for winter flood control. Some additional storage could be developed; however, the economic and environmental costs would be high.

Left: Photodisc. Right: Corbis

**Rising temperatures, potentially exacerbated by decreasing precipitation, could increase the risk of water shortages in urban and agricultural sectors.**

## Potential Reduction in Hydropower

Higher temperatures will likely increase electricity demand due to higher air conditioning use. Even if the population remained unchanged, toward the end of the century annual electricity demand could increase by as much as 20 percent if temperatures rise into the higher warming range. (Implementing aggressive efficiency measures could lower this estimate.)

At the same time, diminished snow melt flowing through dams will decrease the potential for hydropower production, which now comprises about 15 percent of California's in-state electricity production. If temperatures rise to the medium warming range and precipitation decreases by 10 to 20 percent, hydropower production may be reduced by up to 30 percent. However, future precipitation projections are quite uncertain so it is possible that precipitation may increase and expand hydropower generation.

## Loss of Winter Recreation

Continued global warming will have widespread implications for winter tourism. Declines in Sierra Nevada snowpack would lead to later starting and earlier closing dates of the ski season. Toward the end of the century, if temperatures rise to the lower warming range, the ski season at lower and middle elevations could shorten by as much as a month. If temperatures reach the higher warming range and precipitation declines, there might be many years with insufficient snow for skiing and snowboarding.

istockphoto

Stephen McMillan

# Agriculture

**California is home to a $30 billion agriculture industry that employs more than one million workers.** It is the largest and most diverse agriculture industry in the nation, producing more than 300 commodities including half the country's fruits and vegetables. Increased heat-trapping emissions are expected to cause widespread changes to this industry, reducing the quantity and quality of agricultural products statewide.

Although higher carbon dioxide levels can stimulate plant production and increase plant water-use efficiency, California farmers will face greater water demand for crops and a less reliable water supply as temperatures rise. Crop growth and development will change, as will the intensity and frequency of pest and disease outbreaks. Rising temperatures will likely aggravate ozone pollution, which makes plants more susceptible to disease and pests and interferes with plant growth.

To prepare for these changes, and to adapt to changes already under way, major efforts will be needed to move crops to new locations, respond to climate variability, and develop new cultivars and agricultural technologies. With adequate research and advance preparation, some of the consequences could be reduced.

## Increasing Temperature

Plant growth tends to be slow at low temperatures, increasing with rising temperatures up to a threshold. However, faster growth can result in less-than-optimal development for many crops, so rising temperatures are likely to worsen the quantity and quality of yield for a number of California's agricultural products. Crops that are likely to be hard hit include:

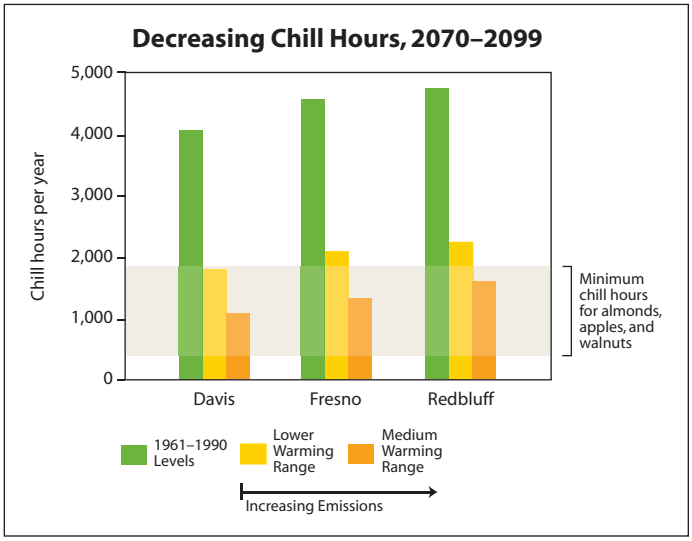
### *Wine Grapes*

California is the nation's largest wine producer and the fourth-largest wine producer worldwide. High-quality wines produced throughout the Napa and Sonoma Valleys and along the northern and central coasts generate $3.2 billion in revenue each year. High temperatures during the growing season can cause premature ripening and reduce grape quality. Temperature increases are expected to have only modest effect on grape quality in most regions over the next few decades. However, toward the end of the century, wine grapes could ripen as much as one to two months earlier, which will affect grape quality in all but the coolest coastal locations (Mendocino and Monterey Counties).

IndexOpen

### *Fruits and Nuts*

Many fruit and nut trees are particularly sensitive to temperature changes because of heat-accumulation limits and chill-hour requirements. Heat accumulation, which refers to the total hours during which temperatures reach between 45 and 95°F, is critical for fruit development. Rising temperatures could increase fruit development rates and decrease fruit size.




For example, peaches and nectarines developed and were harvested early in 2004 because of warm spring temperatures. The fruits were smaller than normal, which placed them in a lower quality category.

A minimum number of chill hours (hours during which temperatures drop below 45°F) is required for proper bud setting; too few hours can cause late or irregular bloom, decreasing fruit quality and subsequent marketable yield. California is currently classified as a moderate to high chill-hour region, but chill hours are diminishing in many areas of the state. If temperatures rise to the medium warming range, the number of chill hours in the entire Central Valley is expected to approach a critical threshold for some fruit trees.

### *Milk*

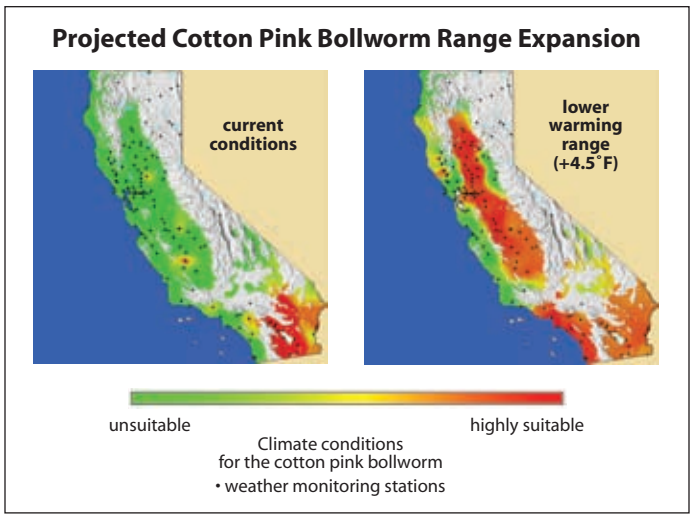
California's $3 billion dairy industry supplies nearly one-fifth of the nation's milk products. High temperatures can stress dairy cows, reducing milk production. Production begins to decline at temperatures as low as 77°F and can drop substantially as temperatures climb above 90°F. Toward the end of the century, if temperatures rise to the higher warming range, milk production is expected to decrease by up to 20 percent. This is more

**Increasing temperatures will likely decrease the quantity and quality of some agricultural commodities, such as certain varieties of fruit trees, wine grapes, and dairy products.**

than twice the reduction expected if temperatures stay within or below the lower warming range.

## Expanding Ranges of Agricultural Weeds

Noxious and invasive weeds currently infest more than 20 million acres of California farmland, costing hundreds of millions of dollars annually in control measures and lost productivity. Continued climate change will likely shift the ranges of existing invasive plants and weeds and alter competition patterns with native plants. Range expansion is expected in many species while range contractions are less likely in rapidly evolving species with significant populations already established. Should range contractions occur, it is likely that new or different weed species will fill the emerging gaps.




## Increasing Threats from Pests and Pathogens

California farmers contend with a wide range of crop-damaging pests and pathogens. Continued climate change is likely to alter the abundance and types of many pests, lengthen pests' breeding season, and increase pathogen growth rates. For example, the pink bollworm, a common pest of cotton crops, is currently a problem only in southern desert valleys because it cannot survive winter frosts elsewhere in the state. However, if winter temperatures rise 3 to 4.5°F, the pink bollworm's range would likely expand northward, which could lead to substantial economic and ecological consequences for the state.

Temperature is not the only climatic influence on pests. For example, some insects are unable to cope in extreme drought, while others cannot survive in extremely wet conditions. Furthermore, while warming speeds up the lifecycles of many insects, suggesting that pest problems could increase, some insects may grow more slowly as elevated $CO_2$ levels decrease the protein content of the leaves on which they feed.

## Multiple and Interacting Stresses

Although the effects on specific crops of individual factors (e.g., temperatures, pests, water supply) are increasingly well understood, trying to quantify interactions among these and other environmental factors is challenging. For example, the quality of certain grape varieties is expected to decline as temperatures rise. But the wine-grape industry also faces increasing risks from pests such as the glassy-winged sharpshooter, which transmits Pierce's disease. In 2002, this bacterial disease caused damage worth $13 million in Riverside County alone. The optimum temperature for growth of Pierce's disease is 82°F, so this disease is currently uncommon in the cooler northern and coastal regions of the state. However, with continued warming, these regions may face increased risk of the glassy-winged sharpshooter feeding on leaves and transmitting Pierce's disease.

U.S. Dept. of Agriculture

**As temperatures rise, the climate is expected to become more favorable for the pink bollworm (above), a major cotton pest in southern California. The pink bollworm's geographic range is limited by winter frosts that kill over-wintering dormant larvae. As temperatures rise, winter frosts will decrease, greatly increasing the winter survival and subsequent spread of the pest throughout the state.**

# Forests and Landscapes

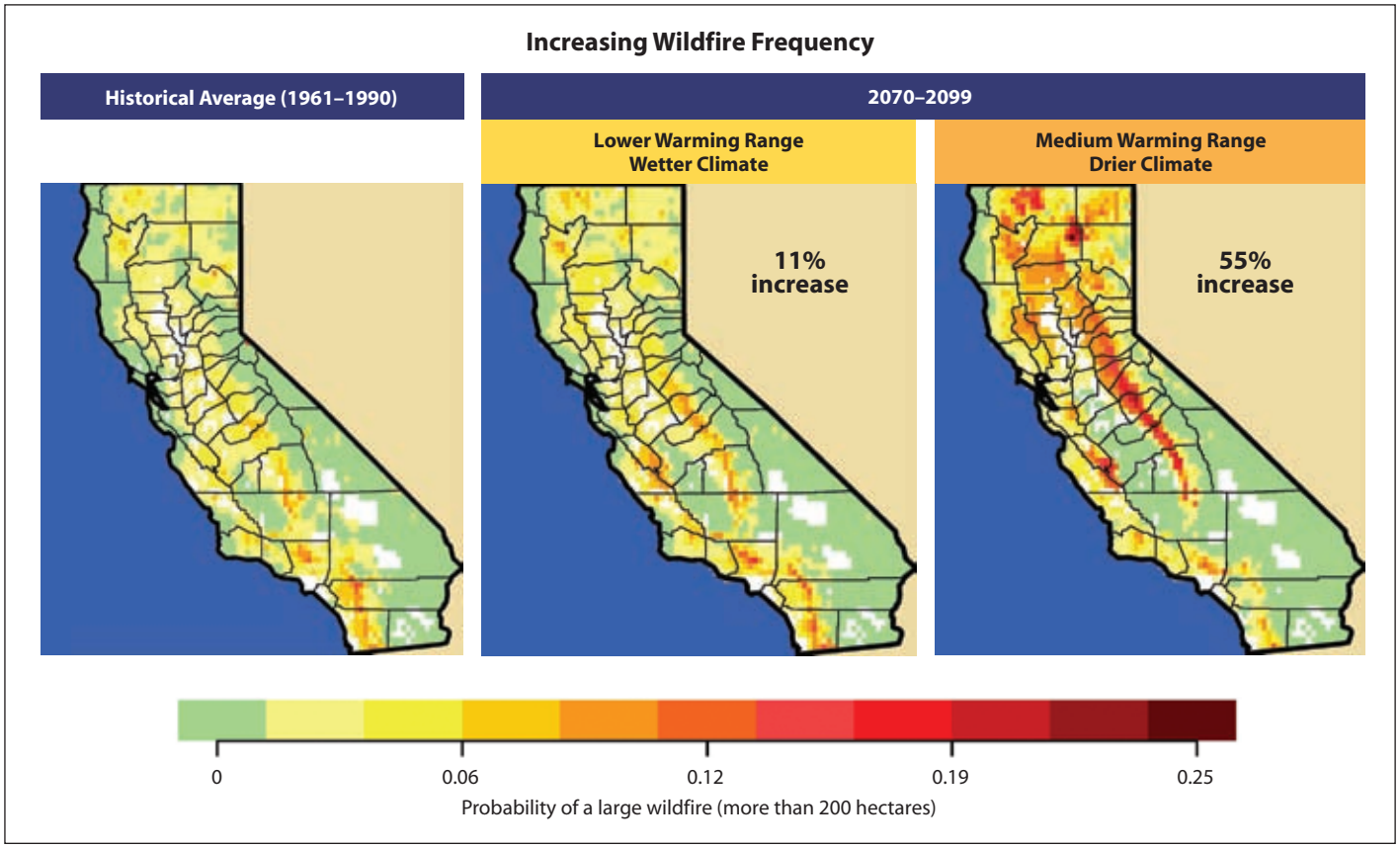
**California is one of the most climatically and biologically diverse areas in the world, supporting thousands of plant and animal species.** The state's burgeoning population and consequent impact on local landscapes is threatening much of this biological wealth. Global warming is expected to intensify this threat by increasing the risk of wildfire and altering the distribution and character of natural vegetation.

Global warming threatens alpine and subalpine ecosystems, which have no place to move as temperatures rise.

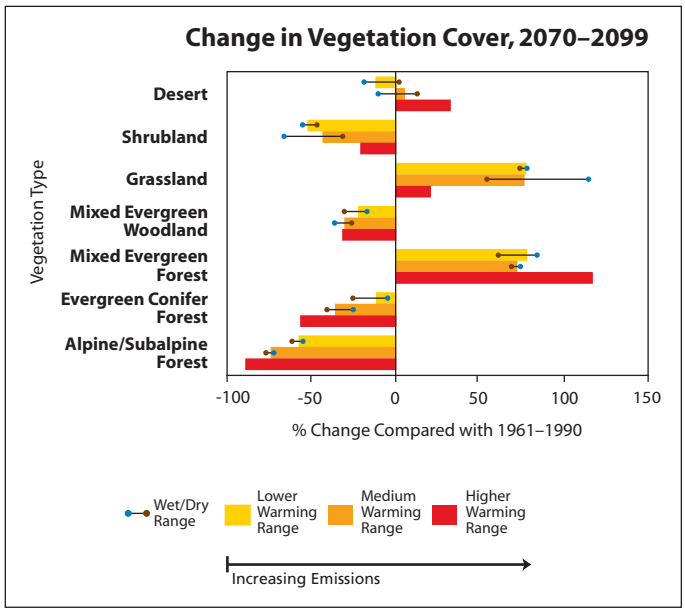
## Increasing Wildfires

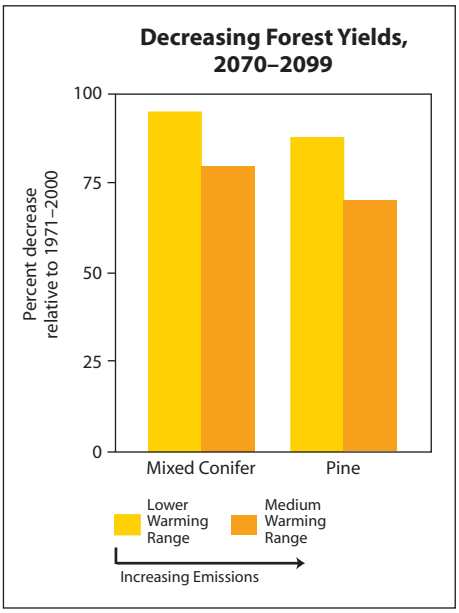
Fire is an important ecosystem disturbance. It promotes vegetation and wildlife diversity, releases nutrients into the soil, and eliminates heavy accumulation of underbrush that can fuel catastrophic fires. However, if temperatures rise into the medium warming range, the risk of large wildfires in California could increase by as much as 55 percent, which is almost twice the increase expected if temperatures stay in the lower warming range.

Because wildfire risk is determined by a combination of factors including precipitation, winds, temperature, and landscape and vegetation conditions, future risks will not be uniform throughout the state. In many regions, wildfire activity will depend critically on future precipitation patterns. For



Vegetation cover over the 21st century will depend on both temperature and precipitation. The lower and medium warming range bars reflect vegetation cover under a wetter climate (blue) and a drier climate (brown) projected in the different climate models. For the higher warming range, only a drier climate was considered.




example, if precipitation increases as temperatures rise, wildfires in the grasslands and chaparral ecosystems of southern California are expected to increase by approximately 30 percent toward the end of the century because more winter rain will stimulate the growth of more plant "fuel" available to burn in the fall. In contrast, a hotter, drier climate could promote up to 90 percent more northern California fires by the end of the century by drying out and increasing the flammability of forest vegetation.

## Shifting Vegetation

Land use and other changes resulting from economic development are altering natural habitats throughout the state. Continued global warming will intensify these pressures on the state's natural ecosystems and biological diversity. For example, in northern California, warmer temperatures are expected to shift dominant forest species from Douglas and White Fir to madrone and oaks. In inland regions, increases in fire frequency are expected to promote expansion of grasslands into current shrub and woodland areas. Alpine and subalpine ecosystems are among the most threatened in the state; plants suited to these regions have limited opportunity to migrate "up slope" and are expected to decline by as much as 60 to 80 percent by the end of the century as a result of increasing temperatures.

## Declining Forest Productivity

Forestlands cover 45 percent of the state; 35 percent of this is commercial forests such as pine plantations. Recent projections suggest that continued global warming could adversely affect the health and productivity of California's forests. If average statewide temperatures rise to the medium warming range, the productivity of mixed conifer forests is expected to diminish by as much as 18 percent by the end of the century. Yield reductions from pine plantations are expected to be even more severe, with up to a 30 percent decrease by the end of the century.

**The risk of large wildfires in California could increase by as much as 55 percent.**

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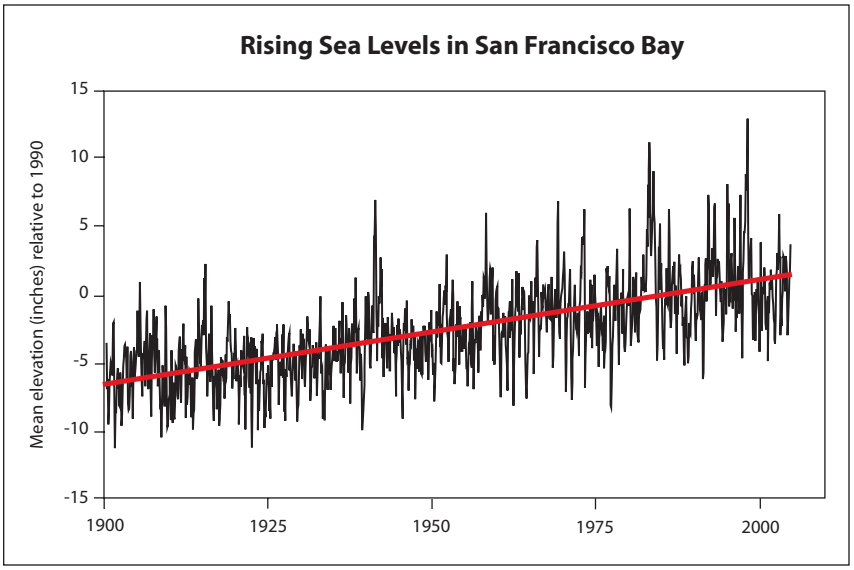
# Rising Sea Levels

**California's 1,100 miles of coastline are a major attraction for tourism, recreation, and other economic activity.** The coast is also home to unique ecosystems that are among the world's most imperiled. As global warming continues, California's coastal regions will be increasingly threatened by rising sea levels, more intense coastal storms, and warmer water temperatures.

During the past century, sea levels along California's coast have risen about seven inches. If heat-trapping emissions continue unabated and temperatures rise into the higher warming range, sea level is expected to rise an additional 22 to 35 inches by the end of the century. Elevations of this magnitude would inundate coastal areas with salt water, accelerate coastal erosion, threaten vital levees and inland water systems, and disrupt wetlands and natural habitats.




## Increasing Coastal Floods

The combination of increasingly severe winter storms, rising mean sea levels, and high tides is expected to cause more frequent and severe flooding, erosion, and damage to coastal structures. Many California coastal areas are at significant risk for flood damage. For example, the city of Santa Cruz is built on the 100-year floodplain and is only 20 feet above sea level. Although levees have been built to contain the 100-year flood, a 12-inch increase in sea levels (projected for the medium warming range of temperatures) would mean storm-surge-induced flood events at the 100-year level would likely occur once every 10 years.

Flooding can create significant damage and enormous financial losses. Despite extensive engineering efforts, major floods have repeatedly breached levees that protect freshwater supplies and islands in the San Francisco Bay Delta as well as fragile marine estuaries and wetlands throughout the

Robert A. Epplett/CA Governor's Office of Emergency Services

**Rising sea levels and more intense storm surges could increase the risk for coastal flooding.**

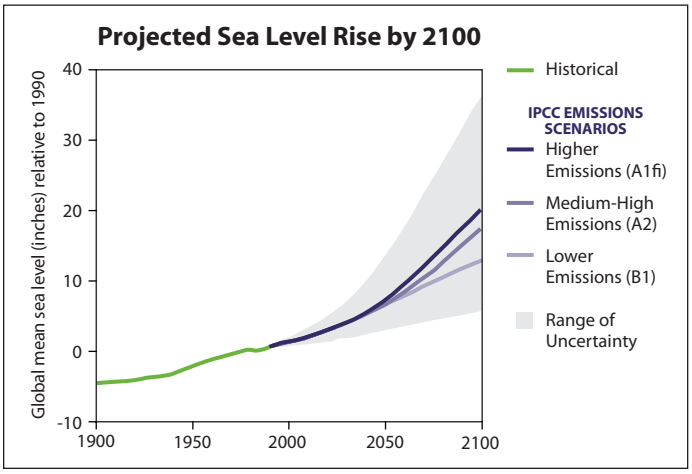
**Sea levels could rise up to three feet by the end of the century, accelerating coastal erosion, threating vital levees, and disrupting wetlands.**

iStockphoto

**Many California beaches are threatened from rising sea levels and increased erosion, an expected consequence of continued global warming.**

state. Continued sea level rise will further increase vulnerability to levee failures. Some of the most extreme flooding during the past few decades has occurred during El Niño winters, when warmer waters fuel more intense storms. During the winters of 1982–1983 and 1997–1998, for example, abnormally high seas and storm surges caused millions of dollars' worth of damage in the San Francisco Bay area. Highways were flooded as six-foot waves crashed over waterfront bulkheads, and valuable coastal real estate was destroyed.

Continued global warming will require major changes in flood management. In many regions such as the Central Valley, where urbanization and limited river channel capacity already exacerbate rising flood risks, flood damage and flood control costs could amount to several billion dollars.




## Shrinking Beaches

Many of California's beaches may shrink in the future because of rising seas and increased erosion from winter storms. Currently, many beaches are protected from erosion through manmade sand replenishment (or "nourishment") programs, which bring in sand from outside sources to replace the diminishing supply of natural sand. In fact, many of the wide sandy beaches in southern California around Santa Monica, Venice, and Newport Beach were created and are maintained entirely by sand nourishment programs. As sea levels rise, increasing volumes of replacement sand will be needed to maintain current beach width and quality. California beach nourishment programs currently cost millions of dollars each year. As global warming continues, the costs of beach nourishment programs will rise, and in some regions beach replenishment may no longer be viable.

## Multiple Causes of Coastal Flooding

Several factors play a role in sea level and coastal flooding, including tides, waves temperature, and storm activity. Sea levels fluctuate daily, monthly, and seasonally; the highest tides occur in winter and in summer, during new and full moons. Sea levels often rise even higher during El Niño winters, when the Eastern Pacific Ocean is warmer than usual and westerly wind patterns are strengthened.

Coastal flooding usually occurs during winter storms, which bring strong winds and high waves. Storm winds tend to raise water levels along the coast and produce high waves at the same time, compounding the risk of damaging waves—a doubling of wave height is equivalent to a four-fold increase in wave energy. When these factors coincide with high tides, the chances for coastal damage are greatly heightened.

As sea levels rise, flood stages in the Sacramento/San Joaquin Delta of the San Francisco Bay estuary may also rise, putting increasing pressure on Delta levees. This threat may be particularly significant because recent estimates indicate the additional force exerted upon the levees is equivalent to the square of the water level rise. Estimates using historical observations and climate model projections suggest that extreme high water levels in the Bay and Delta will increase markedly if sea level rises above its historical rate. These extremes are most likely to occur during storm events, leading to more severe damage from waves and floods.

Top left & right: Photos.com. Bottom: CA Fuel Cell Partnership

**Cleaner energy and vehicle technologies can help California reduce global warming emissions, improve air quality, and protect public health.**

# Managing Global Warming

**Continued global warming will have widespread and significant impacts on the Golden State. Solutions are available today to reduce emissions and minimize these impacts.**

The projections presented in this analysis suggest that many of the most severe consequences that are expected from the medium and higher warming ranges could be avoided if heat-trapping emissions can be reduced to levels that will hold temperature increases at or below the lower warming range (i.e., an increase of no more than 5.5°F). However, even if emissions are substantially reduced, research indicates that some climatic changes are unavoidable. Although not the solution to global warming, plans to cope with these changes are essential.

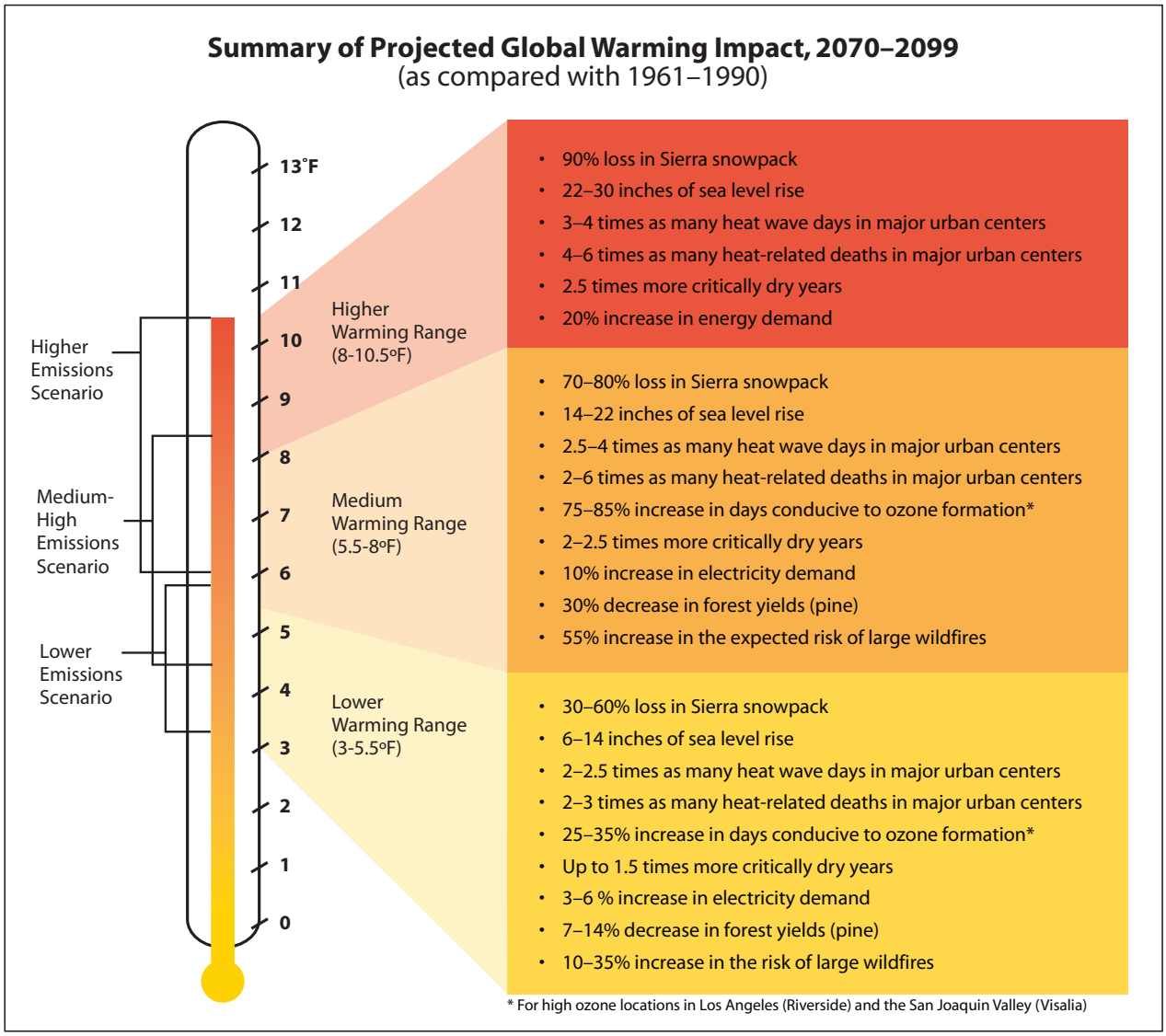
**California's actions can drive global progress to address global warming.**

## Reducing Heat-Trapping Emissions

Reducing heat-trapping emissions is the most important way to slow the rate of global warming. On June 1, 2005, Governor Arnold Schwarzenegger signed an executive order (#S-3-05) that sets goals for significantly lowering the state's share of global warming pollution. The executive order calls for a reduction in heat-trapping emissions to 1990 levels by 2020 and for an 80 percent emissions reduction below 1990 levels by 2050. These emission reduction targets will help stimulate technological innovation needed to help transition to more efficient and renewable transportation and energy systems.

## Coping with Unavoidable Climatic Changes

Because global warming is already upon us, and some amount of additional warming is inevitable, we must prepare for the changes that are already under way.




Preparing for these unavoidable changes will require minimizing further stresses on sensitive ecosystems and implementing management practices that integrate climate risks into long-term planning strategies.

## California's Leadership

California has been a leader in both the science of climate change and in identifying solutions. The California Climate Change Center is one of the first—and perhaps the only—state-sponsored research institution in the nation dedicated to climate change research, and other state agencies such as the Air Resources Board support similar research. Continuing this strong research agenda is critical for developing effective strategies for addressing global warming in California.

The state has also been at the forefront of efforts to reduce heat-trapping emissions, passing precedent-setting policies such as aggressive standards for tailpipe emissions, renewable energy, and energy efficiency. However, existing policies are not likely to be sufficient to meet the ambitious emission reduction goals set by the governor. To meet these ambitious goals California will need to build on its legacy of environmental leadership and develop new strategies and technologies to reduce emissions.

**By reducing heat-trapping emissions, severe consequences can be avoided.**

California alone cannot stabilize the climate. However, the state's actions can drive global progress. If the industrialized world were to follow the emission reduction targets established in California's executive order, and industrializing nations reduced emissions according to the lower emissions path (B1) presented in this analysis, we would be on track to keep temperatures from rising to the medium or higher (and possibly even the lower) warming ranges and thus avoid the most severe consequences of global warming.

**The full text of the Climate Scenarios analysis overview report, and the core scientific papers that comprise this analysis, are online at *www.climatechange.ca.gov*. The scientists that participated in this effort are:**

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# A SCIENTIFIC BASIS FOR THE PREDICTION OF CUMULATIVE WATERSHED EFFECTS

**by**

**The University of California Committee on Cumulative Watershed Effects**

**June 2001**

**University of California Wildland Resource Center Report No. 46**

# A SCIENTIFIC BASIS FOR THE PREDICTION OF CUMULATIVE WATERSHED EFFECTS

**by**

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## Executive Summary

This report proposes an approach for breaking the current logjam in the prediction of Cumulative Watershed Effects resulting from timber harvest in regions such as the coastal redwood region of northern California. We preface the proposal with a review of the nature of Cumulative Watershed Effects (CWEs) of timber harvest and a critique of current methods for assessing them. We propose that responsibility for the assessments be taken out of Timber Harvest Applications and given to a new unit of a State agency, which would make whole-watershed assessments of how land use alters the ***risk*** of damage to ecosystem values. The risk assessments would be made through spatially registered mathematical simulation of watershed processes, using recently developed methods of modeling and spatial data acquisition and processing.

The model-based assessments of risk would then be used by CDF or other agencies in formulating policies for watershed management, considering rates of cutting, locations requiring specific technologies, and the management of risks to particular ecosystem components and functions. The process would involve: multi-stakeholder accord on conceptual models of the target watershed values; agreement about what models need to be implemented and for what purpose; and concurrence on the necessary and appropriate data and predictions for the purpose of decision-making. We also describe how these watershed-scale CWEs could be linked to ongoing efforts in regional-scale assessments, Timber Harvest Plan applications, monitoring, and research.

The basic elements of the procedure in each watershed would be:

1) Identification of stakeholders and their communal conceptual model of system functions under the leadership of the proposed analytical unit.

2) Agreement about the nature of the holistic assessments that need to be made for the purpose of decision-making, and the models to be used for them.

3) Data acquisition using currently available spatial databases, sometimes supplemented by new acquisitions through remote sensing and field surveys.

4) Use of linked models to calculate the effects of particular land-use scenarios on watershed-scale ecosystem functions. The models would assimilate not only the planned, or reasonably foreseeable timber-harvest patterns, but also stochastic patterns of environmental fluctuations, as they are estimated from environmental records or other projections. Running the simulations many times with this range of input data would allow ***calculations of the relative risk*** of water quality deterioration, flooding, habitat degradation, and declines in biotic populations from different management scenarios. The watershed-scale implications of various policies and Best Management Practices could also be assessed. This strategy is called 'gaming' in the following text. Expressing the results in terms of altered risk to resources places them in a form that planners, administrators, economists, lawyers, and the public commonly use in their own decision-making. The models would be implemented as planning models in the manner used to support decision-making in fields such as economic policy, climate and energy policy, risk assessment, or various resource allocations, rather than as models are used in scientific investigations for structuring detailed tests of hypotheses.

The process would involve a wider range of skills and a higher level of training than is currently available to Registered Professional Foresters (RPFs) and the specialists upon whom they currently call. There are advantages to be gained by separating responsibilities according to scale, both spatial and temporal. Thus, CDF or other State agency, could take on responsibility for defining risk of cumulative watershed impacts at the spatial scale of entire watersheds and over the time scale of a

cutting cycle, and the individual RPF could assume responsibility for recognizing local cumulative effects (hillslope-to-small-watershed-scale) and their relation to the larger context, as it is defined by the watershed-scale risk analysis. Related work, currently in place, on region-scale assessments and research would be contracted out to the private sector and academia respectively. Figure 1 outlines the relationships between the modeling and gaming strategy for predicting CWEs and the other decision-support activities that are needed for resource management.

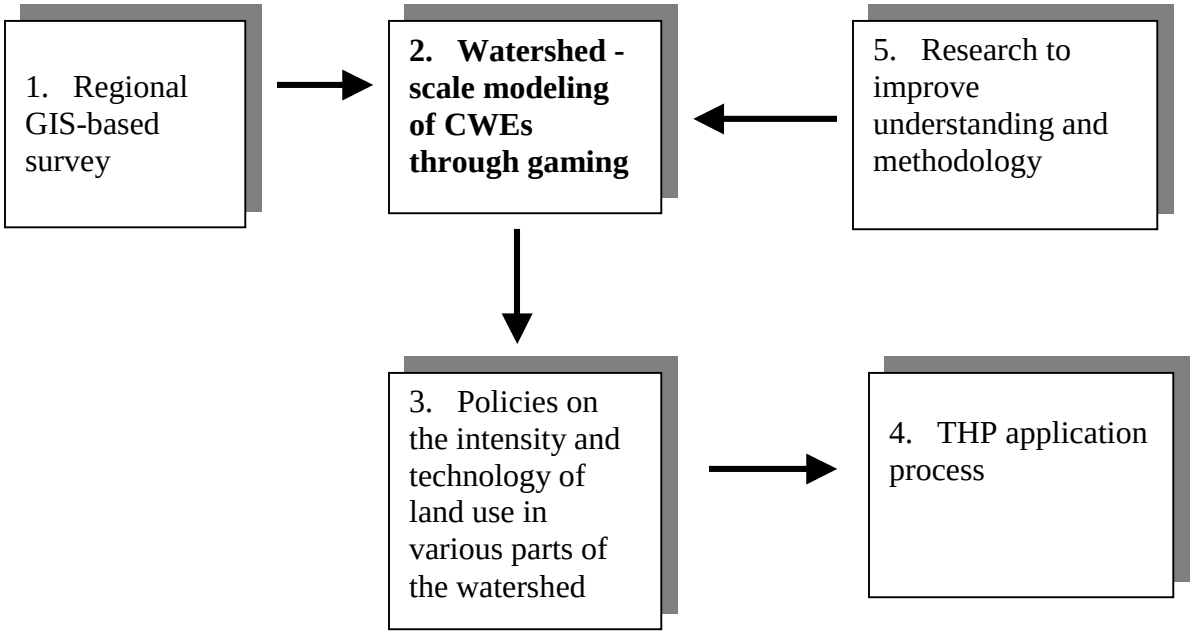


Figure 1: The process-based modeling and gaming strategy (Box 2) described in this report would be conducted simultaneously with other decision-support activities, as outlined in the text. Each activity, except for the policy setting (Box 3), would involve a significant component of fieldwork.

We emphasize that Cumulative Watershed Effects cannot be predicted through the existing parcel-by-parcel analysis for Timber Harvest Plan applications, even if it were based on the best current understanding. Nor can future effects be predicted on the basis of short-term empirical studies of past events, although long-term monitoring of post-project effects would gradually build a database for improving and facilitating modeling efforts. As in many other forms of planning and risk management, it is necessary to base assessments of the uncertain future on our current, communal

understanding of how systems function, and then to fully evaluate uncertainties, which might be reduced through targeted research. However, there is likely to be enough uncertainty about environmental processes for the foreseeable future that judgment and skill will always be at a premium in CWE assessments and in consequent policy formulation. Thus, to implement the proposed gaming strategy for predicting CWEs the State will have to recruit personnel with a type and level of training that is not currently represented among the professionals conducting CWE analyses.

# A SCIENTIFIC BASIS FOR THE RECOGNITION AND PREDICTION OF CUMULATIVE WATERSHED EFFECTS

*"There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things."*

*Niccolo Machiavelli*

## Chapter 1: Statement of the Problem

The non-federal forest lands of California are managed under the guidance and regulation of the State government, which has a policy of managing them for multiple sustainable uses, including timber production, maintenance of water quality, wildlife and fish habitat, and recreation. The State has apparently never explicitly acknowledged the need to protect the runoff regulating functions of forests, but is gradually being forced to confront that function also as human settlements spread into forested lands. Some of these uses are in conflict, and the State has taken on the responsibility for maintaining a balance between the activities so that none precludes or diminishes the others over the long term. Striking such a balance is particularly difficult because much of the land is owned privately, and respect for the rights of individual owners to use and profit from their land is crucially important. Thus, decisions to regulate and balance must be made with care, on the basis of credible and authoritative methods for society to agree on the probable environmental effects of altering the forest ecosystem by one means or another. Of course, credible and authoritative methods are also needed for agreeing on the economic and other policy aspects of altering the forest ecosystem, but those methods are beyond the purview of this committee. The challenge is to facilitate decision-making so that both economic activity and the protection of ecosystem services and values can be made more efficient and secure.

Differences of opinion about the probable nature and extent of land-use effects on biological resources, water quality, and other values stymie many regulatory and planning decisions. An important component of this debate is the concept of *Cumulative Effects*, which, in its simplest form, states that two or more influences of land use, or changes on two or more parcels of land, can interact to produce a magnified effect on the functioning of an ecosystem or other resource, even if each influence alone would have been relatively small or benign. Among the entire set of cumulative effects that have been described, ***Cumulative Watershed Effects*** **(CWEs) are significant, adverse influences on water quality and biological resources that arise from the way watersheds function, and particularly from the ways that disturbances within a watershed can be transmitted and magnified within channels and riparian habitats downstream of disturbed areas.** Many of these CWEs occur at considerable distance downstream from the original site of landscape alteration, and are mixed with other effects that are not driven by land use. The land-use signal may thus be hard to define in quantitative terms. CWEs have been of great concern to resource managers and regulators in forested mountain regions, where the goals of timber harvest may conflict with other social goals for water quality or biodiversity.

Various land-use regulations, including the California Environmental Quality Act Guidelines, require that CWEs be identified. Prominent among the regulated actions is the granting of permits for timber harvest on the basis of a Timber Harvest Plan (THP), submitted by the landowner for each proposed logging operation. The THP must be prepared by a Registered Professional Forester (RPF), and reviewed by a multiagency team with representatives from the Departments of Fish and Game, Forestry and Fire Protection, the Division of Mines and Geology, and the relevant regional water quality board. Public input is invited during a brief period thereafter. Based on all of this input the Director of Forestry makes a decision as to whether the THP conforms to the rules of the Board of Forestry. The Forest Practice Rules of the California Department of Forestry and Fire Protection (CDF) require that for such a

THP to be granted the applicant must specify that the operation will not cause any significant adverse cumulative watershed effects. After that review, the THP may still be granted even though the effects are present.

Regardless of whether any effects are recognized to be "cumulative", the THP must incorporate measures for mitigating damage, offsetting habitat loss, or regenerating forests. The applicant is not required to defend the assessment of CWEs, but is simply asked if he recognizes the possibility of their existence. The preparer is also not required to examine the entire watershed into which the THP site drains, but rather an area of the applicant's choice is selected for comment. No study is required of those selected areas. Furthermore, the applicant may claim that *any* effect that he does recognize will simply be mitigated out of existence by application of a set of engineering or conservation techniques called Best Management Practices that have been reviewed for *on-site* effectiveness by professional foresters.

This state of affairs has come under widespread criticism from a number of quarters. Resource managers and other interest groups concerned with water quality, esthetics, biodiversity, and other ecological values claim that the process allows easy denial of manifest cumulative watershed effects. Landowners and professionals who prepare THPs claim that they have no guidance on how to define CWEs, and that the reception of their plans varies according to which agency or interest group reviews them, causing uncertainty and delay in their operations. Regulators report that they are unable to make defensible judgments of THPs, even when they suspect that environmental damage will result, because they have no guidance or tools for consistent evaluation and no resources with which to make a thorough evaluation. Little or no credence is given to the experience and knowledge of local residents, who are told that, as non-professionals, they are not qualified to render opinions on natural resources.

Reviewers such as the Little Hoover Commission (1994) have repeatedly called for the streamlining of the THP process and the establishment of a true assessment of cumulative watershed effects, but no one has yet described in concrete terms how this might be done. The Commission concluded that the multi-agency review process is "complex, lengthy, and costly, resulting in inconsistency and inequity." Furthermore, in the cover letter to its report the Commission concluded that the process was fundamentally ineffective, and that "the environment is not being protected because of the flawed concept that …ecology can be addressed on a parcel-by-parcel basis." It was pointed out that the State's focus is almost entirely on procedural steps rather than on outcomes, and that there is no mechanism for linking any demonstrated effectiveness of mitigation to future policy directives.

The State's emphasis on process rather than outcome is understandable because there is no generally agreed upon methodology for analyzing or predicting environmental consequences of proposed large-scale land transformations such as timber operations. In particular, no one has yet proposed a convincing method for analyzing or predicting CWEs. The authoritative review of cumulative effects of forest practices in Oregon (Beschta et al. 1995), for example, concluded only with a "conceptual framework" for analyses, and the large-scale analysis of CWEs by a team of consultants to the US Forest Service (Hawkins and Dobrowolski 1994) was essentially a region-wide statistical analysis of watershed conditions.

It is thus not surprising that in all of the years since 1974 in which the State's Timber Harvest Plan documents have required CWE assessments in the coastal redwood region of northern California, only rarely and very recently have any professional preparers of such plans acknowledged that a CWE is likely to occur. Members of this committee have been told explicitly by some RPFs that, in preparing a THP, they would never conclude that a CWE is likely because of the unnecessary regulatory burden that such an admission would bring. Denials of the likelihood of

CWEs are repeated regularly by applicants and reviewers, despite the widespread recognition among environmental scientists that, in the aggregate, timber harvest in coastal California has resulted and continues to result in radical alterations of water quality, habitat conditions, and perhaps flood risk.

A key component missing in previous proposals for addressing CWE is the concept of prediction. The fundamental regulatory purpose of requiring a CWE as part of a forest management decision (THP approval) is to state explicitly what is likely to happen as a consequence of the proposed actions. Not only must the individual THP under consideration be evaluated, in the context of past activities, but it must be linked to probable future activities and conditions. Without a forward-looking, predictive analysis, the inevitable consequence is that each THP will be seen in its own narrow context, and be described as just another small drop in the bucket, with the hard decision about limiting or modifying activities being handed off progressively into a receding future.

Thus, the State needs a method of assessing CWEs that is:

1) predictive;

2) conceptually sound and supported by scientific methods;

3) objective and easily understood;

4) transparent and allowing the participation and contribution of all stakeholders; and

5) designed to be continually improved as new insights, observations, analyses and methodologies become available.

This report proposes an approach to building such a capacity.

## Chapter 2: Responsibilities of the Committee

In view of the lack of an effective method for analyzing and predicting CWEs in timberlands, this University of California committee was asked to address the following questions:

- Is there a scientific basis for the prediction of Cumulative Watershed Effects that is applicable to environmental conditions and land use in the coastal redwood region of northern California?
- If so, what is the basis and how should the analyses and predictions be made?

In Chapter 1, we have reviewed the historical and administrative background of the need for recognizing and predicting CWEs.

Chapter 2 defines the responsibilities of this committee.

Chapter 3 describes the essential features of CWEs, some of the difficulties in defining them, and the interdisciplinary nature of the studies needed to define and predict them.

In Chapter 4, we describe and critique the current process for identifying CWEs in California timberlands.

Chapter 5 presents our fundamental proposal for CWE analysis and prediction. It involves spatially registered mathematical modeling of the *risks* of land-use effects on ecosystem characteristics (habitat, populations, water quality) in an environment that is subject to stochastic fluctuations, economic conditions, or other chosen scenarios. These risks must be predicted in the face of considerable uncertainty about both the future and the watershed characteristics themselves. We make suggestions for how the modeled risk assessments would be designed and conducted by a new unit of a State

agency through a multi-stakeholder process the results of which are accessible to all interested parties. The results would then be used by the State in a transparent process to develop timber-harvest policies for entire watersheds based on the communally recognized risk to certain ecosystem values. Timber Harvest Plans could then emphasize what they can reasonably be expected to address: the local impacts, realistic analyses of the effectiveness of Best Management Practices, and the relationship of the planned harvest to the probable CWEs identified through the holistic watershed-scale modeling exercise.

Chapter 6 outlines impediments that currently stymie the identification and prediction of CWEs in the processing of THPs in the North Coast redwood region of California.

In Chapter 7, we propose some ways of removing these impediments.

Finally, the Appendix is a description of some of the tools (concepts, modeling, database development, fieldwork) for accomplishing these tasks. We expect this toolbox to evolve rapidly, and so we present only examples. The methods we propose are not complete, and in fact should be expected to evolve along with improvements in data acquisition, system understanding, and stakeholder experience with the process.

The report does not include an extensive literature review to establish the existence of cumulative watershed effects. Many authors and committees have compiled and evaluated the scientific literature concerning the effects of land use on water quality and ecological values, both on-site and downstream. The literature is vast, and it credibly documents what the Little Hoover Commission (1994, p. iii) called the "substantial and tangible" impacts of timber operations. Watershed effects that have been shown to result from timber harvest include effects on: sediment, water temperature, in-channel volumes of organic debris, chemical contamination, increases in peak discharges during storm runoff, and reduction of spawning and rearing habitat

for fish (e.g. Beschta et al. 1995). Some of the factors cited by the literature as possible CWE impacts are listed and described in Board Technical Rule Addendum #2 (CDF 2000).

The technical and administrative literature, however, consists of a largely unsorted accumulation of reports on intense, moderate, and smaller effects and their interactions. It does not provide the Board of Forestry or other policy makers with a coherent means of striking a balance between the resources referred to above. The literature documents what researchers have been able to find out so far, but not all of what policy makers need to know. All of the committee members are familiar with this literature, and see little value in repeating its review in the current report. The interested reader can pursue the details of this documentation in, for example, reports by NCASI (1999), Beschta et al. (1995), Reid (1993, pp 91-149), Bunte and MacDonald (1999).

## Chapter 3: Nature of Cumulative Watershed Effects and the Problem of Identification

*"Society can not wait for scientists to understand the world scientifically."*
*J. Ortega y Gasset*

### Context

The nature of cumulative watershed effects has both scientific and institutional aspects. Scientific aspects relate to natural processes over differing spaces and times, how activities affect these processes, and to determining resultant impacts and risks. Institutional elements relate to how activities are evaluated, permitted, and conducted. Inevitably, the institutional aspects involve decisions about how much environmental and other risks are acceptable in a project. Before the institutional evaluation can be made, however, the risks of CWEs need to be identified in some transparent manner.

Both the scientific and institutional aspects of cumulative impacts in California are complex. Scientific understanding is evolving and improving, but will always be imperfect. The institutional aspects, which also evolve, include a set of laws, administrative regulations, court decisions, and attitudes about various resources and the rightful way to use them. Prominent among the relevant laws is the California Environmental Quality Act (CEQA) and its implementing CEQA Guidelines. Under the "functional equivalent" concept, CEQA has been applied to timber operations under the Z'Berg-Nejedly Forest Practice Act. This has created a complicated institutional context for assessment of cumulative effects on private and state forestlands in California. Thus, timber operations are governed by Forest Practice Rules, adopted by the State Board of Forestry and Fire Protection, which combine CEQA terminology, legal structure, and standards of review with general and site-specific operational and procedural rules that govern timber harvest.

In all of this complexity, one rule sets the context for cumulative impact analysis. This rule (14 CCR 897.1(b)(2)(2)) states that "Individual THPs shall be considered in the context of the larger forest and planning watershed in which they are located, so that biological diversity and watershed integrity are maintained within larger planning units, and adverse cumulative impacts, including impacts on the quality and beneficial uses of water are reduced." Other rules do not mention cumulative effects directly, but are intended to avoid such effects by modifying operations or keeping them away from steep slopes, sensitive or erosion-prone areas, and streams.

**Definition**

*Cumulative impacts* are defined in the Board of Forestry Forest Practice Rules (CDF 2000) by reference to the CEQA Guidelines (Section 14 CCR 15355). Paraphrased, they are defined as two or more individual effects, which, when considered together, make a significant (usually adverse) change to some biological population, water quality, or other valued resource, or which compound or increase other environmental effects. The individual effects may be changes resulting from a single project or a number of separate projects. The cumulative impact of a single project is the change in the environment, which results from the incremental impact of that project added to those of "closely related, past, present, and reasonably foreseeable, probable, future projects." Elsewhere, the Forest Practice Rules (14 CCR 912.9, 932.9, 952.9) require answers to the following questions:

1) Does the assessment area of resources that may be affected…contain any past, present, or reasonably foreseeable future projects?

2) Are there any continuing, significant, adverse impacts from past land-use activities that may add to the impacts of the proposed project?

3) Will the proposed project, as presented, in combination with past, present, and reasonably probable future projects…have a reasonable potential to cause or add to significant cumulative impacts in any of the following resource areas; watershed, soil productivity, biological…other?"

The concern, therefore, is with "significant, adverse" environmental impacts of a project. After a cumulative effect has been proven to exist, there is still the requirement to recognize whether it is significantly adverse to some resource.

Cumulative impacts can result from individually minor but collectively significant projects taking place over a period of time. They may occur at a site through repetition of a change caused by successive operations, or through two or more results of an operation, or they may occur at a site remote from the original land transformation and with some time lag. The concern about cumulative effects arises because it is increasingly acknowledged that, when reviewed on one parcel of terrain at a time, land use may appear to have little impact on plant and animal resources. But a multitude of independently reviewed land transformations may have a combined effect, which stresses and eventually destroys a biological population in the long run. More complex aspects of cumulative effects are reviewed by Reid (1993, pp. 31-59), who also provides examples of how CWEs arise.

***Cumulative Watershed Effects*** (CWEs) constitute special kinds of cumulative effects that result from the hydrologic functioning of watersheds. Watersheds are ensembles of hillslopes that interact with the stream channels at their bases and transmit the material and energy fluxes (water, sediment, organic debris, chemicals, and heat) resulting from those interactions downstream along hierarchical networks of channels with relatively numerous small channels draining into a few larger channels. When land use increases the magnitude of any of those fluxes, they accumulate along channel networks, are transmitted downstream, and concentrated in some reaches. Generally speaking, the larger the proportion of the land surface that is disturbed at any

time, and the larger the proportion of the land that is sensitive to severe disturbance, the larger is the downstream impact. These land-surface and channel changes can: increase runoff, degrade water quality, and alter channel and riparian conditions to make them less favorable for a large number of species that are valued by society. The impacts are typically most severe along channels immediately downstream of land surface disturbances and at the junctions of tributaries, where the effects of disturbances on many upstream sites can interact.

Some CWEs are listed in Technical Rule Addendum No. 2 of the Forest Practice Rules (CDF, 2000, p. 34ff). Both on-site and off-site (downstream) interactions of land-use effects are possible, but in addition to spatial interactions (say between nearby watersheds at a tributary junction or between a site and a downstream reach of channel), the Forest Practice Rules mention the potential for interactions between project effects and features or processes triggered by some past or "reasonably foreseeable" future project. Thus, one could imagine a case where the historical cycle of timber harvest emplaced large amounts of sediment along valley floors, and modern, project-related increases in sediment transporting flows (even without large new additions of sediment) might enhance the capacity of streams for conveying that sediment downstream and depositing it in fish habitat or reaches vulnerable to flooding. In other watersheds, past land use may have elevated sediment loads and simplified channel habitat so that even a minor increase in runoff, debris-flow occurrence, or sediment load may be undesirable. Both the spatial and temporal scales of cumulative effects can be large (many kilometers and decades), although it will usually be easier to recognize an interaction over decades in the past than to predict its trajectory accurately over a similar time period in the future.

Technical Rule Addendum No. 2 specifies the factors to be considered and the situations where such impacts are likely to occur. However, the document offers no real methodology guiding the RPF in how to "evaluate watershed impacts" or their

“significance.” Although earlier versions of the document state, “No actual measurements are intended” in evaluating impacts, the 2000 version allows that “Actual measurements may be required if needed to evaluate significant environmental effects.”

The Forest Practices Rules allow account to be taken of the mitigation of project effects by on-site conservation methods, called Best Management Practices (BMPs). As implemented by CDF, the Rules focus mitigations in the plan area (including connected roads and landings). Mitigations may be directly related to the impact of current timber operations, or may treat problems from other sources such as past logging. CDF almost never considers mitigations outside of the plan area.

However, widespread experience in most types of terrain and land uses (forestry, agriculture, urbanization, mining, etc.) has proven that mitigation by on-site BMPs is usually imperfect, and much of the induced perturbation (say of runoff or sediment) “escapes” or “leaks” from the impoundment device or from the surface protection, and accumulates downstream, though at a reduced level. It is because of the limited effectiveness of on-site mitigation that CWEs have been identified widely by environmental scientists.

Watershed impacts that have been shown to result from timber harvest (and other land–cover manipulations) include effects on: sediment, water temperature, in-channel volumes of organic debris, chemical contamination, the amount and physical nature of aquatic habitat, and increases in peak discharges during storm runoff. However, determination of the significance of these effects for some aspect of water quality or biodiversity requires taking into account biological populations, ecological functions, and the role of the above-mentioned physical and chemical characteristics in determining the quality of habitat. Thus, our report is much broader than the treatment of “Cumulative Watershed Effects” in the CDF (1998b) document, which states (p 2, parag. 1) that “CWEs refer to the combined effect of multiple activities involving the

processes of water and sediment transport" and that "CWEs are a sediment routing problem". However, we are not concerned with the broader range of cumulative effects that are not related to watershed functioning, outlined in the California Forest Practice Rules, which include such effects as traffic, visual impacts, and soil productivity.

Although CWEs are currently defined only in terms of adverse impact on some resource, there is no fundamental reason for this. It is also possible to identify and predict positive CWEs resulting from rehabilitation projects. Such accounting would provide opportunities for planning and promoting reconstruction of ecosystems rather than simply identifying potential adverse impacts for purposes of regulation. Thus, if one sees a CWE prediction as a tool not only for constraining timber harvest and other watershed disruptions, but also as a method for evaluating *any* kind of watershed management proposal, then agencies would need a CWE prediction of the positive values of watershed restoration as well. If, for example, it is proposed to de-activate and re-engineer roads, wise decision-making would be served if predictions could be made of the extent to which that strategy, in combination with the other features and activities in the watershed would achieve the intent of preserving or restoring waterways. Of course the two purposes of CWE predictions (reducing the risk of damage and designing rehabilitation) might be required in the same watershed that is undergoing both active timber harvest and rehabilitation such as de-activation of roads, planting and development of riparian zones, loading of large woody debris into channels, etc. Such predictions are likely to be needed in watersheds with a complex mixture of land use, where it is not possible to "get ahead of" some foreseeable wave of change such as a harvest cycle in a mature forest.

At one level, therefore, there appears to be a considerable number of detailed measures with which to define the absence or presence of Cumulative Watershed Effects. Given the widespread nature of the watershed effects of timber harvest listed above in many disturbed landscapes, one would expect frequent identification of

Cumulative Watershed Effects, --- even if the ecological significance of some effects could be debated. In practice, however, virtually no one filing a THP admits to the presence of *any* CWE, and CDF and resource agencies in other states have been unable to promulgate any defensible methodology for defining the presence and source of any CWE, even when they have consulted the scientific community. Thus, there is little effective technical basis for enforcement of available regulations designed to protect aquatic resources. There is an escape from every rule.

**Difficulties of Identifying CWEs**

The recognition of CWEs is not always an easy matter, especially because there is rarely any monitoring or census of conditions before, during, or after a timber harvest project or cycle. Many of the effects referred to are diffuse in space (e.g. shallowing of pools several kilometers downstream of a non-contiguous, multi-owner, asynchronous concentration of harvest activity), and irregular in time (e.g. the triggering of landslides in a rainstorm several years after tree removal, or enhanced turbidity levels during certain flows, but not in others). It is often difficult to prove that such an effect is "significant", even if it is acknowledged to have occurred. Aquatic biologists have so far been unable to compute, or even define consistently, the biological consequences of habitat changes that are below the level of a complete eradication of function (complete filling of rearing pools, smothering of spawning gravels with fine sediment, etc.). This is partly because some habitat-population relationships are hypothesized rather than established, and partly because the effects of any transient perturbation of habitat conditions over a logging cycle interacts with life-history processes and with external factors such as ocean rearing conditions and fishing pressure to obscure links between population dynamics and habitat condition.

The difficulty is enhanced because, almost by definition, particular changes of process intensity or landscape morphology occur as a result of the interaction between the timber operation and large episodic rainstorms, wetter-than-average seasons, or other disturbances. Some people obfuscate this issue and thus misdirect the discussion of CWEs by asking such questions as whether timber harvest *or* large rainstorms cause a habitat change, or a flood, or higher levels of turbidity. If the analysis of the resulting, unwelcome changes is reduced to defining which of these agents is "to blame", it misses the point that a land-cover change and associated infrastructure can often increase the ***risk*** of a landscape's unwelcome response to rainstorms.

Altering the condition of a land surface is (in the game-theoretic sense) a game played in a stochastic environment. A hillslope clear-felled in a run of dry years may subsequently escape any intense rainstorm, allowing the land to recover a resistant tree cover before its stability is again tested by a large storm. A road system may be installed without triggering frequent landsliding, debris flow, or debris torrent during the same relatively dry period. A nearby similar project involving tree removal and road engineering under identical landscape conditions may be initiated during a wet period and suffer much greater impact from landsliding with dramatic downstream effects. These triggering rainstorms remain essentially unpredictable, but we can estimate the *risk* of such erosion events and their downstream consequences. We can also estimate the *increase in risk* of landsliding and habitat damage in the same storm as a result of timber harvest.

Other differences in the response of landscape to timber harvest result from geographical differences in topography and geotechnical properties of the landscape materials. Again, there is usually no mystery about such differences in the eye of the landscape scientist, unless there is undisciplined throwing around of undigested statistics from the literature, as often happens in environmental disputes.

Still other uncertainties and confusion arise through the lack of precise definition of which process or part of a watershed system is causing the recognized or anticipated perturbation. For example, tree removal from a watershed can cause increases in the amount of water available for flood generation. At the same time harvest roads and skid trails can intersect subsurface flow high on hillslopes and convey it quickly into streams. The former change is a transient effect, subject to recovery and to staggering in time across the landscape. The window of vulnerability for such a disturbance to cause flooding is much smaller than in the case of roads and skid trails, which are quasi-permanent features, spreading cumulatively across the landscape and altering its runoff conveyance capacity, typically increasing the drainage density by 20 to 67% (Montgomery 1994). Even when decommissioned as traffic routes, these roads and skid trails intercept drainage, and intensify the evacuation of water from hillslopes. Hillslope runoff theory indicates the sign of this effect, that its magnitude should vary regionally and between rainstorms; and that it should interact with the effects of tree removal on runoff, being largest in absolute terms when tree cover is reduced. Such differences and interactions, although expectable from knowledge of runoff processes, make the quantitative recognition and prediction of this particular CWE difficult in a short field study.

Even with sophisticated statistical studies of multi-decade flow records, controlled for differences in storm size, the effect, though recognizable can be quantified only approximately (Jones and Grant 1996). Yet cautious interpretation of the results in the light of current understanding of runoff processes suggests that the effect of timber harvest on flood runoff may be considerable in some regions. But it is unlikely that the issue will ever be resolved and quantified empirically in the manner of laboratory experiments or agronomic fertility trials (UC Committee on Cumulative Watershed Effects 1999). The general nature, sign, and approximate magnitude of the effect may be established, and the risk of its occurrence estimated quantitatively, but the acceptability of the risk will have to be interpreted in the context of prevailing laws,

policies, and attitudes to the threatened resource. This is the nature of the judgment call that policy makers need to make about the risk of cumulative watershed effects.

Despite the difficulties of identifying CWEs, the field evidence of environmental change in timberlands has led successive groups of scientists (e.g. Beschta et al. 1995; Bunte and MacDonald 1999) to document the widespread occurrence of cumulative watershed effects. Although there is often no steady-state, extant or foreseeable condition against which one can measure or predict in a deterministic, exact way the effects of land management, some changes due to land use are so radical and widespread that they are widely acknowledged, even by land managers as well as resource management scientists. In some cases, there are easily recognized metrics for land-use impact (e.g. the extent of old-growth forest and, by implication, its attendant biota). In other cases (such as turbidity or other measures of streamwater quality) the measures are obvious but the available data are sparse. And in yet other cases it has proven less easy to develop a useful metric (e.g. the grain size and extent of spawning gravels, large woody debris, and other aspects of channel-habitat complexity).

## Interdisciplinary Nature of the CWE Problem

The origin and nature of CWEs require knowledge and skills that are normally the purview of several different branches of science. CDF has thus involved multiple agencies and scientific disciplines in CWE analysis. The complex aspect of CWEs has slowed the development both of consensus about the “significance” of adverse effects and of techniques for their recognition and prediction. The significance of some adverse change in watershed condition is often expressed in the aquatic biology of stream channels or riparian zones. Thus, it is difficult for a physical scientist working alone to establish whether an anticipated increase in streamwater turbidity, for example, is likely to have a significant adverse impact on some ecosystem process. Biologists, on the other

hand, may identify undesirable physical changes in habitat, but have not yet conducted the studies to connect these changes with biological effects, except in extreme cases. Furthermore, they have been reluctant to express anything more precise than general concern about the direction and cumulative nature of ecosystem changes that have occurred simultaneously with a region-wide decline in populations of many birds, fishes, and terrestrial fauna.

Even to understand the original perturbation triggering CWEs involves knowledge from different branches of science and technology. For example, the nature and risk of landsliding are complex biophysical issues. Landslides commonly involve the mechanical failure of unconsolidated earth materials (soil, fractured and weathered rock, or artificially emplaced fill material) reinforced to various degrees by plant roots (Gray and Leiser 1982). Thus, knowledge of force balances and material properties from geomorphology and geotechnical engineering needs to be combined with a quantitative understanding of the nature of plant roots as these vary from one region or substrate to another and through plant succession at a single site. Landslides occur when these materials become weakened as their water content is increased by rainstorms, snow melt, or engineered drainage modifications. Prediction of the increase in soil-water content and pore pressure requires an understanding of hydrologic processes to quantify the role of water input rate, canopy interception, soil hydraulics, hillslope length, gradient, and shape. Insights from silviculturists are crucial because forest covers, which influence root strength, canopy interception of rainfall, and evapotranspiration, varies spatially with climate and substrate conditions and temporally through fire and managed succession. The requirement for extensive road networks and their management requires knowledge of forest engineering. Thus, analysis of the causes and prevention of landslides in forested mountains requires expertise not normally obtained within a single discipline or agency.

The complex requirements of CWE analysis explains the interdisciplinary constitution of this committee, and the range of knowledge that must be organized and made available to RPFs who are responsible for making final determinations of the likelihood and nature of CWEs. Improvements in the analysis and prediction of CWEs is going to require the hiring of people with interdisciplinary training in environmental science at a higher level than is typical among the current cadre of professionals involved in THPs. We know of no licensing procedure or professional examination that currently assures that appropriately trained individuals are analyzing CWEs.

## Chapter 4: Technical Aspects of The Current Process for Assessing CWEs in Timber Harvest Plans and Sustained Yield Plans

"In theory there is no difference between theory and practice. In practice there is."
Yogi Berra

The State requires that all Timber Harvest Plans (THPs) include an analysis of the potential for Cumulative Watershed Effects, and that these Plans be written and reviewed by Registered Professional Foresters (RPFs). The work involves mainly the application of the Forest Practice Rules, which are numerous, but which concentrate on physical conditions of the assessment area, and are not easy to relate to the protection of biological and water resources downstream. The administrative process of reviewing THPs by CDF, other interested agencies, and the public has been described by the Little Hoover Commission (1994, pp. 24-45). After it approves a Plan, CDF takes responsibility for defending it on behalf of the applicant against public criticism, often in court.

Cumulative impacts are currently addressed only on a case-by-case basis in a Timber Harvesting Plan, or by longer-range Sustained Yield Plans (SYP), or for small owners, in Non-industrial Timber Management Plans (NTMP). Seven categories of cumulative impacts are defined (Secs. 912.9, 932.9, 952.9): Watershed, Soil Productivity, Biological, Recreation, Visual, Traffic, and Other. Each category must be checked off in one of three boxes: "Yes, there will remain impacts even after mitigation"; "No, cumulative impacts will not remain even after mitigation"; or "No, no reasonable, potential, cumulative impacts from this project are likely to join with the impacts of any other project (within the same ownership)."

To assist the professional forester in assessing cumulative effects, CDF (1994) provides a set of guidelines, which follow the arrangement and content of the Forest

Practice Rules on cumulative impacts. The guidelines on CWEs lead the applicant through the following ten steps Editorial comments by this committee follow each step.

1) Establish on-site and downstream beneficial uses of water "that you are aware of."

   Comment: *This step does not specify that channels or riparian zones need to be considered, and does not consider hazardous aspects of water such as flooding or the triggering of landslides. How much effort is expected of the applicant in becoming "aware"?*)

2) Describe the watershed assessment area, including the reasons for the selected boundaries. The boundaries are those of 'planning watersheds' defined by CalWater.

   Comment: *Examples we have seen have not included the entire watershed into which a site drains, but include some seemingly arbitrary adjacent drainage areas.*

3) Classify the "condition" of stream-channel segments that lie within the project boundary and have a drainage area of at least 300 acres. Rating classes are 'none', 'slight', 'moderate', and 'severe'. Features to be classified include such examples as: 'gravel embeddedness', 'pool filling', 'scouring', 'canopy reduction', 'recent flooding', and an optional overall 'condition rating'.

   Comment: Little *guidance is given to the forester for making these assessments. Arriving at a single defensible classification based on all of these variables would require a certain sophistication in the fields of fluvial geomorphology and habitat analysis that we have not encountered in our reviews and interviews.*

4) Are you "aware" of any current stream channel conditions outside of the project boundary but within the assessment area that are contributing to a reduction in the beneficial uses of water?"

   Comment: *What is the required level of effort in becoming 'aware'?*

5) Are you "aware" of any current stream channel conditions, outside of the project area but within the assessment area, or any that occur outside of the assessment area, and which are contributing to a reduction in the beneficial uses of water?"

   Comment: *See 4 above.*

6) Have past projects resulted in any of a list of impacts dealing with channel condition, water temperature, and chemical loading of stream water?

   Comment: *The changes in channel morphology and water quality that are suggested would require either some kind of a historical record (photographic or instrumental) or considerable skill in the reconstruction of landscape history from field evidence.*

7) What is the potential ('high', 'moderate', 'low') for the project "as mitigated" to produce certain listed individual effects on channels at or near the project site (such as sediment input, increased water temperature, chemical inputs, increased peak flows, alterations of organic debris loads, future supplies of organic debris).

   Comment: *No methodology is suggested for arriving at such a conclusion.*

8) Given the foregoing, are the identified future projects likely to result in the same set of effects?

Comment: *No indication of how assiduously and specifically the 'future projects" must be identified, but in the THPs that we reviewed there was no treatment of future harvesting and road construction foreseeable in the watershed.*

9) What is the potential for developing adverse cumulative watershed impacts in the assessment area ('high', 'moderate', 'low')?

Comment: *No methodology is suggested for arriving at such a conclusion.*

10) Will the project, "after mitigation", have a reasonable potential to cause or add to significant cumulative impacts to watershed resources? ('yes' or 'no'). Will there be positive effects on watershed condition and existing CWEs?

Comment: *No methodology is suggested for arriving at such a conclusion. The attempt to arrive at a single-word answer, as if a single threshold of concern could be defined that would make the answer for a regulating office, is not realistic.*

Elsewhere, consistent with a CEQA-like framework, the Forest Practice Rules require a determination of whether there are "any continuing, significant, adverse impacts from past land-use activities that may add to the impacts of the proposed project." As mentioned in Chapter 3, the concern is with "*significant, adverse*" environmental impacts of a project. After a cumulative effect on the physical condition of the assessment area has been proven to exist, there is still the requirement to recognize whether that impact is significantly adverse to some resource, such as water quality, biodiversity, or a particular valued species. Yet the only clarification provided in the Forest Practice Rules for defining a significant, adverse impact is: "a substantial, or potentially substantial, adverse change in any of the physical conditions within an area affected by the project." The Rules also state "a social or economic change related to a physical change may be considered in determining whether the physical change is significant." It is not clear how social or economic factors alter the biological

significance of a physical change. They may alter the decision about what weight to give to the adverse impact in view of other social needs, but they do not alter the degree of the adverse impact itself.

The Appendix to Technical Rule Addendum #2 (p. 34, 2000 Rules) provides further definitions and examples of CWEs, and indicates that "actual measurements may be required if needed to evaluate significant environmental effects." However, it offers no real methodology guiding the RPF in how to "evaluate watershed impacts" or their "significance." In almost all cases, no quantitative biological information is required in determining whether the physical change is significant. Thus, although it may be true that "The Timber Harvest Plan process has not proven effective in achieving a sound balance between economic and environmental concerns" (Little Hoover Commission, 1994, p. v), we would add that the guidelines provided to the RPF guarantee that the analysis is inadequate, and this is borne out by the THPs reviewed by us, which have not adequately represented *either* economic or environmental concerns.

A process with such limited guidance is vulnerable to arbitrary interpretations, political forces, enthusiasm for timber harvest or for the implications of species listings, traditional attitudes that have developed within agencies, or traditional competition between agencies for influence. There is obviously a competition among agencies for which of them gets to say what risk to a species is acceptable. Thus, in interviewing technical personnel involved in initiating and reviewing CWE assessments, we found that the outcome, and especially the decision that some impact is 'less-than-significant' depends mainly on the attitude or predisposition of the person doing the 'analysis'.

With such limited guidance, and with the primary goal of the 1973 Forest Practice Act being to allow timber harvest with 'appropriate regulation', it is hardly surprising that neither applicants nor CDF regulators recognize that any significantly adverse, cumulative effects are likely to result from timber harvest. This is particularly

true when all participants, at least publicly, adhere to the belief that, should any adverse impact arise, it can be mitigated out of existence by application of a Best Management Practice. At present, therefore, virtually all rules are written with escape clauses.

We confirmed many of the observations made by CDF (1999) in its review of Cumulative Impacts Analysis. Information provided in individual THPs that we examined was often incomplete or too subjective to assess current resource conditions, lingering cumulative effects, or the potential for additional impacts. The boundaries of the assessment areas are arbitrary, and may be limited to that landowner's property. The burden of proof falls upon the public agencies to establish cumulative effects, and upon plan approval CDF essentially advocates on behalf of the landowner in disputes with other agencies and private stakeholders.

Our reviews of THPs and discussions with CDF officers responsible for reviewing applications indicate that the training of Registered Professional Foresters is not adequate for the legally mandated multidisciplinary assessments of CWEs. The Committee reviewed two summaries of recent THP applications in the redwood region, which suggest that potential environmental effects of proposed harvests are not being recognized by RPFs (Table 1). The "Pape" survey was a random survey of answers to questions on all THPs in the North Coast region submitted in 1998.The "MW" or "Mass Wasting" survey was a random sample of 1998 THPs in Mendocino, Santa Cruz, and Del Norte counties that had been earmarked for additional review by the California Department of Mines and Geology (CDMG). Both surveys asked the question: “Will the proposed project cause or add to significant cumulative watershed effects?” In Table 1.A, the RPFs filling out the applications did recognize that cumulative effects from *past* activities are present in many areas, and it is not surprising that cumulative effects were identified in a higher proportion of the THPs which the CDMG had earmarked for further review (the "MW" survey). There was an absolute degree of confidence by plan applicants (RPFs) that their plans would not add to existing cumulative effects. In both

surveys, not a single plan filed, of the 89 surveyed, identified a single cumulative effect that would add to the existing cumulative effects (Table 1.B).

Table 1. Two Surveys of Timber Harvesting Plans (THPs)

A. Question 2. Are there any continuing, significant adverse impacts from past land-use activities that may add to the impacts of the proposed project?

| Survey | Number Answer YES | Number Answer NO | Percent YES |
|---|---|---|---|
| Pape Survey | 22 | 28 | 44 |
| Mass Wasting Survey | 23 | 16 | 59 |

B. Question 3. Will the proposed project, as presented, in combination with past, present, or reasonably foreseeable, probable future projects cause or add to the significant cumulative watershed effects in any of the following subjects?

| Cumulative Category | Pape Survey | | | Mass Wasting Survey | | |
|---|---|---|---|---|---|---|
| | Yes | No Significant Impacts | No Effect After Mitigation | Yes | No Significant Impacts | No Effect After Mitigation |
| Watershed | 0 | 33 | 17 | 0 | 27 | 12 |
| Soil Productivity | 0 | 23 | 27 | 0 | 20 | 19 |
| Biological | 0 | 29 | 21 | 0 | 23 | 16 |
| Recreational | 0 | 2 | 48 | 0 | 1 | 38 |
| Visual | 0 | 6 | 44 | 0 | 3 | 36 |
| Traffic | 0 | 7 | 43 | 0 | 3 | 36 |
| Other[2] | 0 | 3 | 10 | 0 | 2 | 2 |

Notes: 1. Plans are all 1998 THPs and each was submitted by a Registered Professional Forester. Questions are derived from the cumulative effects analysis contained as part of each THP.

2. 'Other' category has many non-respondents.

The survey suggests that the RPFs acknowledge the existence of *past* cumulative effects but believe *future* cumulative effects from *their* plans are nonexistent. This may be due some of the following possibilities:

- CWEs will, in fact, be mitigated on all of these plans by measures included in the THP (see below for discussion disputing this assumption);

- Additional CWEs may be created, but will not exist as they are defined in the Forest Practice Rules (only within that ownership, based on material in the public record, and/or based on "practicality and reasonableness");

- RPFs are not able to distinguish the additional impact of one plan, so they conclude that any effects of the current THP they are preparing are non-significant;

- RPFs are aware that cumulative effects will occur, and mitigate them to the extent they can, but will not check the box admitting cumulative effects because they believe the THP will not be approved if the YES box is checked.

Our committee did not have sufficient information to conclude which of the above circumstances applied to these THPs, or which was most dominant as a reason for non-identification of cumulative effects.

The Committee also reviewed several ca. 1998 THPs in the Redwood Creek watershed, which is a sediment-impaired watershed listed under Section 303(d) of the Federal Clean Water Act in 1992). None of these plans indicated that there might be cumulative effects resulting from the proposed operations. Obvious major fault zones and unstable areas were not referenced in the THPs; additional harvest plans in the foreseeable future were not referenced, yet were later submitted within less than 9 months on the same ownership; fish ranges were improperly stated in the THP; recent landslides were unreported; recent effects of older land uses (such as recent failures of roads constructed in previous decades) were ignored; and coarse woody debris

deficiencies were largely not addressed. Neither CDF nor CDMG reviewers had challenged these deficiencies. From evidence we have reviewed it appears that as of 1998 CWEs were not being appropriately addressed in these THPs. There appears at a minimum to be a lack of recognition of the existence of cumulative effects, and this may, in part, be a reason why CWEs have not been successfully addressed to date.

Some of the CDF and CDMG officers, who currently sign off on the judgment that no CWE is likely to result from a THP, reported to us that they do so because they have no basis for identifying CWEs since they have no tools for taking a view at a scale greater than a harvest site or a small watershed. The CDF (1994) guidelines certainly confirm this claim, as virtually all of them are concerned with small watersheds, and the resources for a single THP assessment are limited. The process outlined above contains no method for recognizing damage across entire ecosystems or watersheds. For example, with this limitation, a predictable view would be that even if there is an increase in sediment supply to the channel in a third-order watershed, the channel gradient and the high flows expected in that channel are sufficient to transport the sediment 'away' with little or no impact on channel morphology and habitat. In such a view, there is no possibility (and the assessors have no tools) for judging whether any of the increased sediment being washed downstream will travel intermittently along stream channels and spend a considerable amount of time filling fish-rearing pools, or impacting the fine-sediment content of spawning gravels, or increasing turbidity during its transport far downstream, etc.

Another problem is that no standard of proof is required for the assessor to make a determination of whether the effect can be mitigated. For example, CDF field officers reported to us in a meeting that "We have been told that timber harvest does not cause flooding."They had also been told that "a six-inch-thick cover of gravel on a forest road mitigates sediment generation so that the road will no longer be a significant source of sediment", despite published evidence that similar roads elsewhere lose

considerable amounts of sediment. These '"conclusions" are accepted by applicants, reviewers, and their technical advisors with no regard for standards of proof, relevance, or any need to investigate field evidence.

A strong influence in denying the potential for CWEs in individual harvest plans seems to be that an applicant is allowed to state, usually without any burden of quantitative proof, that a deleterious effect of a proposed operation can be "mitigated" (and thus defined not to have an off-site, cumulative effect) if some Best Management Practice (BMP) is prescribed. Apart from the fact that the execution of the BMP is almost never checked in California forestlands, it is the collective judgment of this committee that BMPs do NOT remove off-site impacts. They may reduce them, when the BMPs function well, but they do not remove them, especially when they are tested by severe storms. It is the collective failure of BMPs to mitigate off-site impacts that results in residual, significant cumulative effects. The CWE may be less than in earlier logging cycles, and the timber industry and all citizens can take some comfort from that fact. But CWEs are real and important in many watersheds.

If a significant, adverse cumulative impact is identified in a THP, the Forest Practice Rules (14 CCR 897-898.1) require further discussion of possible mitigation measures to reduce impacts. The Rules (14 CCR 898) say that no THP shall be approved which fails to adopt feasible mitigation measures or alternatives as set out in the rules. Ultimately, if a plan has incorporated all feasible mitigation measures and significant adverse environmental impacts still remain, the Director may approve the plan only if the benefits outweigh unavoidable significant adverse impacts. This is done following a procedure set forth by the Board (14 CCR 898.1 (g) and (h)). The complexity, contentiousness, and delay involved in this process, and the likelihood of a successful appeal by the applicant to the Board of Forestry on the grounds of economic impact, pressures both CDF technical personnel and the applicant to negotiate until the

expected impacts can be declared “mitigated” by some BMP, after which the permit is granted.

Some large landowners are allowed to submit Sustained Yield Plans (SYP) for the purpose of assessing larger-scale watershed effects, both physical and biological. The intent of a SYP is a "maximum sustained yield of high quality timber products" while giving "consideration to environmental and economic values" (Article 6.75, 1091.1 (b) (page 181 of 1998 Forest Practice Rules)). Again, the Rules set the tone of the analysis in that they do not acknowledge from the beginning that it may not be possible to maximize timber and also provide *adequate* protection to other resources. The SYP process is an optional planning process by the landowner, and is intended to address the same issues that a Timber Harvest Plan (THP) would address, but in a more substantive and successful manner. While not substituting for a THP, the SYP, if approved, clears all THPs submitted under the SYP for watershed or fish and wildlife issues for a period of 10 years. SYPs are specifically directed to include a cumulative effects analysis.

The intent of the SYP process is to expand the spatial and temporal framework for THP analysis, and is a step in the right direction. However, it does not, in its current form, solve the cumulative effects problem. Within the section on authority and intent, it states that the SYP shall be guided by "principles of practicality and reasonableness", which are left undefined. A landowner's definition of this may be much broader than that of a resource specialist. This same section recognizes that landowners, and particularly smaller landowners, "may not have nor can reasonably be expected to obtain or project information which otherwise might be helpful." For the redwood region, this language effectively provides an exemption from rigorous cumulative effects analysis across a broad expanse of the land base. The issue of integrating the applicant's ownership into all of the sources contributing to cumulative effects is optional (section 1091.3). There are, in fact, real constraints involved in including other

ownerships, such as lack of data access for the other parcels, insufficient knowledge of projected actions on these other parcels, and legal issues associated with sharing such knowledge (anti-trust legislation in particular). Nevertheless, the current SYP process will generally fall short of the mark in assessing cumulative effects.

We conclude that it is not surprising that the current methods of assessing and predicting CWEs are ineffective. Attempts to define a threshold of "significant", adverse effects –-- though attractive for any agency or individual regulator, who, understandably, doesn't want to make difficult decisions alone -–– are unworkable and too narrow. Secondly, the resources available for a THP are not adequate for the task of conducting a realistic, watershed-scale analysis of long-term, biologically relevant effects. RPFs do not have the training necessary for analyzing CWEs across a spectrum of physical, biological, and biogeochemical disciplines. An individual applicant, and a regulator processing a single application, do not have the time and other resources necessary for a truly cumulative, watershed-scale analysis. This limitation is particularly severe for 'small' landowners (those who own less than 2500 acres of forest land), who own approximately 50% of private forestlands in California (25% of total forest land).

The resulting "postage-stamp", or "parcel-by-parcel", approach, in which only the immediate project area of a single, small timber harvest is ever reviewed. –-- as all other reviewers have said --- does not capture the cumulative influence of multiple harvests over a long period of time in a large, complex watershed. The Little Hoover Commission (1994, p. 55), quoting the State Water Resources Control Board, arrived at the same conclusion, referring to the results as "Inadequate, 'boilerplate' analyses and mitigation measures." Many THP applications are returned by CDF for reasons of incompleteness, but not technical accuracy. Our review of a sample of them suggests that CDF's standards are not high, even though the timber industry complains about the resulting delays. The target time period for processing THPs is 45 days. This might

be a reasonable time for reviewing the physical consequences of a harvest plan for a small area for which well-defined guidelines are available, but is totally inadequate for evaluating the impact of timber harvest on complex watershed-scale ecosystems in the absence of biologically relevant guidelines. Requiring CWE analysis to be conducted in the THP evaluation is intractable.

Another reason for confusion arising in establishing the nature, magnitude and significance of CWEs is that the scientific literature is often vague or does not encompass the particular problem under discussion. In other cases, there is useful literature, but it is not known to agency technical staff, or to the consultants hired to prepare THPs. Where the scientific literature is vague or non-existent, the Board of Forestry relies on professional judgment to fashion solutions. California rulemaking law utilizes a public hearing process and an appointed Board of Forestry to judge the value of science in forestry, and to either implicitly or explicitly set the weighting of risk. Hence the Board rules define limits to silvicultural systems that may include size limits, timing, basal area requirements, leave standards, protection of nest sites, a feathered set of watercourse protection zones that include a later seral component, etc. If there are specific scientific limits (such as a lethal stream temperature for fish or a threshold fine-sediment concentration for spawning beds) RPFs are expected to know this and to apply it in the context of the rules and in protecting beneficial uses of water. If the RPF doesn't know or apply existing knowledge, reviewing agencies have the duty to require additional mitigation.

Such judgments are tenable if the issue is as straightforward as a threshold value of an environmental variable, but this is almost never the case in an ecosystem at landscape scale (What, for example, is the stream temperature in a network of channels with pools, a range of elevation, point sources of ground water inflow, and variations of shade?). So, although the idea of thresholds is attractive to regulators, thresholds are almost never relevant to the diffuse stress placed upon the reproductive success of

groups of organisms in a complex environment when it is drastically altered. This is one reason why so much contentiousness arises when agencies responsible for biodiversity and water quality express their right of review but rely on beliefs in thresholds.

For the foreseeable future there will always be uncertainties about how even established principles from the landscape sciences (ecology, hydrology, biogeochemistry, geomorphology) apply to particular, local cases of landscape change. The same is true for the application of economic principles to the financial affairs of particular countries or firms, but individuals and governments find these principles worthy guides for managing our most prized possession. CWE analysis, like all other human endeavors, will have to be conducted rationally in the face of these uncertainties. Some people will be skillful at this, and will remain well informed as the technology evolves; others will remain confused and be unable to proceed because the scientific literature does not contain the answer to their specific question.

A result of the inability of agencies to establish and agree on the presence and general magnitude of CWEs is that rarely, if ever, in northern California is a case made for limiting timber harvest based on cumulative watershed effects on even the most erosion-prone land. For example, faced with an inability to establish the risk of a significant adverse impact, regulators accept denials of the potential for in-unit landslides, and prescribe Best Management Practices for roads, and then grant the harvest permit. Monitoring has focused on compliance and effectiveness of rules but not on trends. Furthermore, monitoring has concentrated on hillslope activities rather than channel effects. Since there is no long-term, systematic monitoring of the results of timber harvest on landsliding or aquatic habitat, there is no accounting of the consequences of timber harvest when a large storm arrives, and its results are classified by implication as an “act of God.”

Other attempts at addressing CWEs have also been inadequate. The US Forest Service uses an index of land-use intensity, known as the Equivalent Roaded Area,

which is widely viewed as inadequate, and concentrates only on the potential for increases in high streamflows and sediment production without illuminating their significance for biodiversity or water quality. Other agencies have accepted unverified narrative descriptions of potential impacts of timber harvests. The most recent advance in impact assessment is Watershed Analysis, an evolving methodology exemplified by requirements of the Washington Forest Practices Board (1995). In this approach, the analysis is divided into discipline-based modules, and some training and expertise is required for the assessor to be permitted to perform the analysis. The modules include: mass wasting, stream channels, hydrology, surface erosion, and stream habitat. Each analysis is performed and conclusions are drawn separately about causal mechanisms for each module. A synthesis report then summarizes the findings. However, no predictive modeling is included, so cumulative watershed effects of future potential land use are not assessed. The scientists performing the analyses do not propose prescriptions to remedy or avoid problems. Instead, land managers remain responsible for this, and according to Collins and Pess (1996), performance of a Watershed Analysis in Washington led to very little beneficial change in land-use practices. Furthermore, it has been recognized that the analysis did not provide adequate insight about the decline of critical species, and as a consequence of the listing of several fish, the analysis has recently been withdrawn from widespread use in Washington State.

An increasing number of agencies are promoting the construction of sediment budgets (Reid and Dunne 1996) as a means of addressing CWEs, but this methodology addresses only sediment and the physical alteration of habitat conditions and water quality. It does not encompass biological impacts and therefore not the critical test of whether impacts are “significantly adverse.” Thus, a sediment budget approach may contribute to the analysis of CWEs, but it is by no means adequate by itself.

CWE analyses would require the simultaneous evaluation of the effects of many THPs in a large watershed interacting with the specific environmental condition of that

watershed and with the 'legacy' effects of previous timber operations, if they are known to persist in the watershed. These 'legacies' are testament to the long-term and far-reaching effects of (say) sediment that leaves a site or of the slowly reacting changes in forest canopies, root structures, etc., or the effects of quasi-permanent changes to the drainage patterns of hillsides when roads are installed. Whole-watershed, or whole-ecosystem, evaluations are needed. For instance instead of assessing how a single timber harvest will affect a single species, what is needed is a determination of how the balance between different plants and animals of the ecosystem would be altered and would function differently as a result of land-use changes that are being proposed or envisioned over decades and entire watersheds (see later our discussion of appropriate geographic scales to be considered). Key questions are: how can this be done; who will bear the cost; and how big an area should be included in an assessment of CWEs?

This process is too complex and costly to be accomplished by timber operators, even the large ones, and certainly not the small ones who cannot reasonably be expected to contract out for such an expensive service. In addition, the combination of skills required to study CWEs is not easily mobilized. Such training is distinctly lacking in the education of RPFs and most other environmental scientists, especially those with a seniority to be in leadership positions. There is a particular dearth of people trained to be the conceptual leaders of interdisciplinary studies of cumulative effects in particular watersheds. Furthermore, in nearly all cases, large scale, whole-watershed analysis would require even large landowners to perform analyses of lands they do not own and may not get access to review. Complexity, spatial scale, and cost necessitate that CWE analysis be performed by adequately trained specialists in an appropriate state agency.

## Chapter 5: A Scientific Basis for Predicting Cumulative Watershed Effects

*"Major reform is the victim of numerous minor reforms"*
Lord Acton

### Proposal

We propose a radical restructuring of the way that CWEs are analyzed and predicted. We recommend that this burden be removed from landowners and their consultants, who generally have neither the information, nor the resources, nor the training to conduct a basin-wide analysis. Responsibility would be moved to a specialized unit within a major State agency (preferably CDF, but if that becomes impossible, the Resources Agency).

The scientific basis for the CWE analysis would be expressed through spatially registered mathematical models to summarize the best communal understanding of watershed processes. The analysis would use spatial data resources and models that are currently available. Since such models are likely to be improved and new ones developed, the analysis must be allowed to change continually as new insights and tools emerge.

Once a model of one or more watershed processes is constructed and reviewed for its rational basis and congruence with available evidence, it would be used in simulations of stochastic events, such as weather sequences, to calculate the integrated ***risk*** of damage or improvements to resources over likely economic and management scenarios as the watershed is harvested or affected by other land use. The results would be spatially registered, i.e. recorded in map form, to link proposed cause and effect. This process of risk analysis through stochastic simulations of various scenarios will be referred to below as "gaming", and it is a common tool used to assist with other forms

of decision-making. From the spatially registered calculation of risk to resources such as biodiversity, ecosystem functioning, and water quality, resource analysts could distill policies about allowable rates of cutting, differential requirements for BMPs in various parts of a region or watershed, and other guidelines, depending on the risk they are willing to accommodate.

The responsible unit would be staffed with specialists trained in interdisciplinary CWE analysis and prediction, and it would be given the resources necessary to do the job very well. We assume that the lead State agency would collaborate with other State and federal agencies in designing the unit, although the unit should be free of traditional ways of conducting CWE analyses in the various agencies, all of which have proven to be inadequate. In the remainder of this chapter, we describe the strategy and its relationship to other decision-support activities, including the planning of activities on the ground in the form of THPs. The Appendix then presents a sample of the tools available for implementing the model-based strategy in order to illustrate their availability and continuing evolution. The toolbox described in the Appendix is not meant to prescribe which particular models should be chosen by the responsible state unit, whenever the strategy is implemented.

Our proposal for watershed-scale CWE analysis is in line with that of the Little Hoover Commission, which recommended "master plans for watersheds containing productive forests." (p. vi). Our proposal for gaming is in line with the Commission's suggestion (p. vi) for the establishment of "an objective environmental-risk assessment system that would assist in the evaluation of Timber Harvest Plan approvals." The Commission also pointed out that "mutual distrust is the outcome of a process open to interpretation," and that "neither issues nor responsibilities are clearly enough defined to avoid turf battles."

Unfortunately the technical state of the art of environmental prediction is, and for the foreseeable future will be, unable to avoid large uncertainties. Imperfect

knowledge of the local variability of environmental properties and of some system operations, and the indeterminacy of many future influences (biotic, climatic, and economic) will keep the uncertainty high, as is the case with most decision-making challenges. But at least the ground rules for the interpretations of likely events can be formalized through strong conceptual models of the processes involved, consistent ways of evaluating them, and general agreement on letting some authoritative body be responsible for the quantitative evaluation of probable outcomes. That transparent evaluation can then be passed on to a decision-making body for final use.

We also describe how the CWE prediction could fit into broader environmental analyses, conducted for other reasons, and also into the larger social process of reducing disagreement and resolving conflict among disparate stakeholders. We are not experienced in this field and we realize that this process of integration would have to be refined by others. Integration of scientific analyses into community decision-making in the face of uncertainty is an activity that is evolving rapidly, and is needed in natural-resource-rich regions of the western United States. It involves collaborative and learning-based approaches to sustainable development and environment management. We refer to sources of information on these approaches in a later section of this chapter.

## Need for a Risk-based Approach to the Prediction of CWEs

The purpose of predicting relative risks from CWEs and distilling policies from the predictions is to make good decisions about natural resources; not to make some elegant and detailed prediction that would improve landscape science. Society needs a ***reduction of the risk*** of undesired changes in forested watersheds and attendant water and ecosystem resources as a result of land use. Risk can be reduced through avoidance or modification of certain actions (such as deciding not to harvest certain areas or limiting the rate of harvest); through requiring certain actions (BMPs) designed to

reduce the occurrence or intensity of damaging effects; and through restoration measures which improve ecosystem structure and function and consequently their durability under landuse-related stress. Quantitative prediction of the risks of various CWEs can enable a policy of reducing such risks wherever they are deemed unacceptable. The prediction by itself, of course, does not carry out this policy, but allows a balancing of risk and reward under a range of scenarios to facilitate the decision-making.

Some resource managers, environmentalists, and downstream residents seek to constrain the available options of land users by defining the CWE issue in binary terms: "If it can be demonstrated that there *is any* accumulation of negative effects of undefined magnitude, the land use must be stopped for more detailed, possibly prohibitive review." But landowners and supportive agency personnel have found this constraint an easy one to elude, as the current situation illustrates. Risk analysis could provide a more realistic and flexible way of balancing competing claims.

Most questions about CWEs, or about most environmental impacts are posed (but, unfortunately, are also answered) in an illogical way. Members of the committee have frequently been asked, or have read questions such as: "If timber is harvested in this watershed, will it cause landsliding? And will that be significant?" Scientists are often ridiculed when they answer such a question with "It depends." But the appropriate answer really does "depend."

The watershed might be logged intensively during a ten-year period of relatively dry weather with no large rainstorms, and a secondary forest with an adequate root system might be re-established before heavy rains return. Increases in sedimentation of streams due to accelerated landsliding might be small in that case. A nearby, similar watershed might be logged in the succeeding wet period, and suffer heavy damage to stream channels if a particularly large rainstorm causes landslides and debris flows from logged hillslopes and new roads to dump large volumes of sediment into

channels. The sedimentation could eradicate one year's recruitment of salmon fry from many reaches, and make copious amounts of sediment available for degrading spawning redds and rearing pools for several successive year-classes of salmon. In this latter case, those people primarily interested in the fate of salmon would blame the timber harvest, whereas timber interests would blame the rainstorm. There is often no satisfactory answer to the question: "Did the harvest or the rainstorm cause the sedimentation?", and even less of a basis for saying whether the next harvest will cause sedimentation. They both, together, caused the sedimentation, and their concatenation is not a natural event, or an "Act of God." It makes more sense to ask whether the harvest ***increased the risk*** of the slope failures and sedimentation, whether a future harvest will increase such risk, and whether the risk will be larger after harvesting in area A or area B, with technology C or D. The same can be said of flood hazard. Timber companies have often diverted the debate about whether timber harvest aggravates flooding or sedimentation by pointing to the fact that large floods and intensified erosion occur in large rainstorms. They avoid the question of whether logging has increased the risk of flooding of a certain magnitude, or erosion of a certain intensity.

Of course, there are many local examples where forensic analysis can identify that a collapsed logging road or a blocked culvert *was* the cause of destruction of some aquatic resource. There are also a few statistical studies that show increased spatial frequency of landsliding in clearcut and roaded terrain over that in undisturbed terrain. But it is difficult to make quantitative predictions from these studies. At the scale of watersheds, the aggregate effect of these and other perturbations has been difficult to identify, given the usual limited pre-disturbance information, the complexity of watershed conditions and processes, and the difficulty of obtaining adequate information on topography, material properties, and other features needed for a detailed analysis or prediction.

Thus, our ability is limited for *predicting* specific habitat or biotic changes from realistic data resources. Damage is contingent upon the land use, the weather, local variations of geotechnical or biotic conditions, and population dynamics of either valued organisms or their predators. Nevertheless, some changes due to land use are so radical and widespread that they are widely agreed to have occurred, even by land managers as well as resource management scientists.

The concept of risk combines a statement of probability of an event with an identification of its magnitude (its severity or potential improvement). Examples would be: "there is a 0.01 probability of a stand re-setting wildfire occurring in this watershed in any one year", or "there is a 10% chance of the occurrence of 5 channel-intersecting landslides per square kilometer of watershed within 5 years of timber harvest", or "there is a 20% chance that the average annual production of salmon smolts from this watershed will decline below 5000 for the decade following timber harvest." Conscientious analysis of the risk itself then allows (or requires) the responsible decision maker to assess how risk might change with different land uses and what level of risk is acceptable or desirable to society, given the benefits or dangers to be expected. (Again, even the benefits of an investment in rehabilitation can only be estimated in our uncertain world.)

Bloomfield (1985) provides an introduction to the literature on risk analysis, and focuses its concepts on hazard analysis in timber regions. He also elaborates different kinds of risks relevant to decision making in the face of uncertainty: background risk, the incremental risk from a project, and the marginal risk of the cumulative effects of successive projects. He also discusses the need for identifying appropriate physical, biological, and social boundaries of a risk analysis. Such an analysis will not replace judgment, contention, or the taking of ultimate responsibility, but it offers the promise of formalizing them and facilitating action as opposed to the widespread stalemates that currently bedevil resource allocation, conservation, and rehabilitation.

Lee (1993) and Lee and Rieman (1997) have also explored the assessment of risk to salmonid populations at whole-watershed scale by combining models of watershed condition with population viability models in a Bayesian Belief Network. Such decision-support systems explicitly recognize uncertainty in both the reasoning about system operation and the quality of information about system characteristics. Nevertheless, they provide a rational and transparent basis for decision-making and problem solving based on the recognition of risks to resources. Haas et al. (1991) and Olson et al. (1990) discuss other ecological applications of the approach.

## Modeling Basis

We have previously established that CWE analyses and predictions need to be comprehensive in both geographical terms (they should refer to whole watersheds of a significant size, which we will discuss below) and in resource terms (they should describe all major characteristics and values of the landscape). We also proposed that it makes sense only to define CWEs in terms of the risk (probability and magnitude) and the changes of risk that some resource will be damaged or enhanced as a result of management actions. We, and other reviewers, have concluded that the postage-stamp approach of parcel-by-parcel analysis required of THP applications can never address the interactions between many independent land-use actions in diverse terrain and under the influence of an unknown future regime of weather and economics.

It is impossible to analyze and predict the long-term consequences of land use on erosion, sedimentation, ecosystem structure and function, or aquatic habitat through experiments or other empirical approach because to do so would require monitoring large, complex watersheds during land use of varying nature and intensity for many decades of variable weather. Even if the costs of such a strategy could be borne, the results would be available only after much disruption had already occurred. Instead,

the prediction and auditing of interacting events in complex watersheds under uncertain future conditions can only be done through the formal and systematic examination of how risk changes under hypothetical scenarios. This does not mean that empirical studies are not valuable. In fact, such studies are needed to motivate, inform and evaluate hypotheses. Furthermore, monitoring will be required to assess whether prescriptions guided by CWE analysis are effective. But these are activities do not constitute the prediction of CWEs.

In the natural and social sciences, as well as in planning and engineering, the formal term for predicting the consequences of some system change under hypothesized conditions is "***modeling***", and we suggest that it be used as the basis for the analysis and prediction of CWEs in California forestlands. The term 'modeling' describes activities that are linked, but which range from structured, qualitative expressions of how systems work (which we will here call conceptual models) to mathematical descriptions of the various mechanisms comprising the system (which we will call process-based mathematical models). Intermediate levels of complexity are found in statistical models, "rules-based" models, and other labels are used along the continuum.

Models allow us to envision and represent our best communal understanding of how whole, complex systems behave, and then to discuss and analyze the consequences of that behavior in a rational, structured manner. They also allow us to examine how a system will behave under some future condition, if each of its parts interacts in the way we envision in the model. Of course, from time to time we get surprised because the system behaves in an unexpected way, and that is why scientists continually re-evaluate their conceptual and mathematical models by monitoring real systems. The defining characteristic of a scientific approach is the continual re-evaluation of its own prevailing ideas through empirical investigations.

It is unlikely that models of complex interactions at the scale of whole watersheds can be tested in the same manner that models can be tested at laboratory or plot scales. It is also unlikely that data on system characteristics can ever be adequate for accurate, high-resolution predictions. Thus, tests that scientists usually consider necessary for validation of theories are not possible at watershed scale. That is why even watershed hydrology, the most quantitatively developed of the sciences discussed here, does not rest on experimentally validated theories, but rather on a consensus about how watershed hydrology works (see the Appendix). Models used for predictions of CWEs will have to consist of components that have been validated to various degrees through observations and process studies, connected by theoretical reasoning and calibrated against measurements under representative conditions. This is a problem shared with all uses of model-based approaches to decision-making about environmental issues from CWEs up to global warming.

Despite the lack of experimental validation, using models of various kinds is familiar to all of us because we often make decisions about cause and effect, even if we do not think of the activity in the explicit ways summarized in this document. We are also familiar with using models when thinking of risk in our lives. If I wear a seat belt while driving to work, will I decrease my risk of risk of injury? Is my risk of injury greater if I don't wear my seat belt and I drink alcohol immediately before driving? Is the risk to my retirement savings greater if I invest them in real estate or the stock market over a period of three years? Ten years? Should I buy a house close to a nuclear power plant, or a fault zone? Even if people have only sparse empirical information about these matters, the best informed among us make assessments on the basis of a summary of their best estimate of how things work. If we are making sound judgments, we can articulate this conceptual model to others, seek advice for refining it, and defend our decision as being rational. If two people develop different conceptual models, others can judge the basis for those models.

Professionals trained, or at least practiced, in decision-making are even more familiar with formalized ways of using models to structure their thinking about risk. Their methods may range from the conceptual models of decision making in a multi-stakeholder political system, to statistical models used in various environmental sciences, and to more detailed mathematical representations of mechanisms employed by engineers, economists and natural scientists. In particular, risk can be represented, examined, and discussed in each of these models.

Many people, including many resource professionals, express suspicion when the use of models is proposed, even though, at some level they utilize models frequently in their lives and work. It is claimed that models (by which skeptics usually mean mathematical models of processes) can obfuscate, mislead, and give inflated credence to assertions about which there is great uncertainty. Models can only represent the effects of mechanisms that are known about or agreed upon, and the accuracy of their predictions is vulnerable to unanticipated factors. It is also claimed that models are fundamentally anti-democratic because they are not accessible to all interested parties, and often are comprehensible only to the cadre of specialists (often inexperienced in the field aspects of what they are modeling), who can therefore manipulate results to present their masters' preferences in a positive light.

We agree that models can be used imperfectly in all of these ways. However, when they are openly and responsibly used and communicated, models can assure *exactly the opposite results*. At whatever level of elaboration is considered necessary, models can be used to summarize explicitly our communal understanding, or the bases of our disagreement. They can be used to express our communal beliefs about the relations between processes or characteristics, --- even if only the direction of an effect is agreed upon, such as whether the density of primary haul roads can or cannot be confidently related to suspended sediment concentrations in streams on a uniform rock type. Models can be read by anyone with sufficient diligence and training (recruited by

any stakeholder in a debate), whether the ‘reading’ involves examining the existence, direction, and thickness of arrows on a box-and-arrows representation of a conceptual model or the algorithms written in a computer code. Even the most complex mathematical algorithms are explicit, exact, and can be exposed by direct reading or by running of the model with different data inputs. They are by definition, of course, simplified expressions of environmental processes and relationships, and one link in a model or series of linked models may be particularly crude, limiting the applicability of all of the other steps for the needs of policy makers.

Let us specify an example of how mathematical models of watershed effects might be misused to illustrate the point that model-use needs to be managed carefully by a responsible agency. Suppose that we have constructed a model of the loading of large organic debris into channel networks during a timber harvest cycle, and the results are expressed as maps of the number of wood pieces or the volume of wood per unit length of channel. We might even imagine that we have related the number of pieces per unit length to the number or volume of pools per unit length of channel as a measure of aquatic habitat. The developer of the model, or any person experienced in environmental modeling, would understand that predictions made with typical data inputs in a stochastic world would relate to actual field conditions only within quite wide tolerances (i.e. individual estimation errors would be large, even if predicted averages were approximately correct). The model would be useful for making comparisons, for example, between two strategies for gradually building up debris loads and pool occurrence in streams, or for interpreting large differences between pool frequency under various physiographic or management conditions, or for setting a management course that would rehabilitate streams. Such comparisons indicate the relative differences between model outcomes. However, if the same model were used to design a management strategy and to claim (for example) that within a specific time period the woody debris load of a particular channel reach would meet some numerical threshold, an experienced modeler would argue that the model was being used beyond

its capability and was likely to mislead rather than to shed light on the situation. The prediction would be suspect because the propagation of uncertainties from data inputs and spatially variable initial conditions would render the numerical prediction sufficiently unreliable that it should not be compared with a fixed threshold value in order to justify some policy. Of course, as we have argued above, much of this problem would arise because of the inadvisability of depending on threshold values for environmental policy- making, as they are intractably difficult to define with current levels of understanding and biological data.

Apart from our communal, imperfect understanding of landscape mechanisms (which bedevils us when we envision, plan, and debate only in words at least as much as when we use models), the biggest limitation in using models is that once the model is formulated it requires us to specify input values for its variables and parameters. Again, our ignorance is exposed. We are forced to do our best: to measure appropriate values; to transfer values from comparable basins or regions; or to estimate them from some fundamental knowledge of nature (such as knowledge of atmospheric physics). Do we know the magnitude of the largest daily rainstorm likely to occur over Arcata during the planned logging cycle for a nearby basin? Can we estimate the probability of more than 7 inches of rain occurring in a day within that same logging cycle? Can we estimate the reduction in the number of species or individuals if a given acreage of mature forest is removed or regenerated, or if large woody debris is gradually recruited to a stream network and over the long term there is no change in weather, ocean conditions, harvesting or other factors influencing anadromous fish?

An important word in the questions above is “estimate”. No one would claim that we can answer these questions in an exact manner for a complex landscape both because of our own uncertainty about system operation and its large spatial and temporal variation of properties, and because we simply don’t know the future sequence of events that might befall our landscape or ecosystem. But to an extent that is

useful for informed debate and decision-making, the answer to the questions above is "Yes, with various degrees of confidence." The estimates can be made with various degrees of precision, but always in the face of uncertainty about the poorly known existing properties of the system, the course of future events, and their biological consequences. Probably more important than any specific degree of confidence is the facility through modeling (a) to express uncertainty, resulting either from our reducible or irreducible ignorance, and (b) to continuously check and refine our understanding expressed through the models. It is in this sense that modeling is inherently self-critical and democratic, when like other forms of democratic debate it is conducted and communicated in a skillful, responsible, and transparent fashion. The expression of uncertainty does not reflect impotence and confusion. It simply highlights the fundamental fact that, in all of human affairs, decisions must be made in the face of uncertainty, which in this case is definable to some extent.

We trust our lives daily to models of complex engineered systems, operating in uncertain environments. Governments adjust economic policy on the basis of estimates from models of financial and social processes in ways that affect the economic success of competing stakeholders, and timber companies make estimates of market behavior and other business conditions through similar means. In other kinds of land use problems, such as soil erosion and sedimentation in agricultural regions, mathematical models are used for predicting the transfer of soil material, pollutants, and nutrients to waterways under various land-use scenarios and weather patterns in order to decide whether or how soil conservation subsidies should be invested. Models of biological populations are used to evaluate the risk of extinction to highly endangered species. Even in commercial forestlands, decisions concerning safety ranging from the design of flood-conveyance capacities at bridge crossings to the magnitude of insurance premiums are quantified through the use of models. It is curious, therefore, that the debates about CWEs in forested regions have made so little use of the information-organizing power that could derive from well-managed modeling efforts.

We understand, of course, through our own experience in constructing and using models, that they are not perfect instruments, and like the words, tables and graphs that are the currency of most environmental debates and policy decisions, models can be used deliberately or inadvertently in counterproductive ways. Self-delusion is just as common among the users of models as it is among persuasive and committed writers and debaters, and responsible policy makers weigh all of these imperfections. But models can be systematically checked and gradually improved because they are formalized expressions of our collective understanding of the systems we seek to influence. They can also be summarized in simplified terms to make them accessible to all of the participants in a debate; and this simplification can be checked and validated by observers of the more complex level. For example, a hydrologist might use a complex, process-based mathematical model to calculate that, in a basin of a given size, wintertime flood peaks should be expected to increase to some degree because of forest canopy removal and road construction. He could reduce the results to a simpler form for use in a conceptual model for decision-making, and could express and explain the reasons for the results in a manner that could be checked by his professional peers, and then (with greater difficulty) by monitoring or analysis of historical records.

**In summary, we propose that the analysis and prediction of CWEs be conducted through modeling of risks to chosen resources, expressed first of all as communally developed conceptual models, and subsequently in mathematical form.** We do so with the full acknowledgement that models are not the only tools that are needed for reducing uncertainty and guiding policy. In fact, we encourage both modelers and users of their predictions to read the rather harsh criticism of the history of prediction in public policy-making by Sarewitz et al. (2000). The contributors to the volume (few if any being practicing modelers) document many failings of both prediction and the use of predictions in policy-making, but conclude, grudgingly (p. 386), that model-based prediction is necessary, at least as a part of making good

decisions. Even this rather lop-sided review has important lessons about what to avoid in the use of science-based predictions.

## Spatially Registered Simulation Models and Gaming

A CWE prediction needs to have at least the following characteristics:

1) It should establish causal linkages between land use and ecosystem condition (e.g. fish and bird populations or water quality), and should be able to quantify how these ecosystem values will probably respond to future land use or restoration programs.

2) It should be spatially registered. The locations of the disturbance and of potential impacts need to be explicitly defined.

3) It should take account of the fact that the perturbation being considered (timber harvest, road de-activation, loading of LWD into channels, allocation of streamflow withdrawals, etc.) will occur in an environment, which is stochastic. In other words, the perturbation will interact with rainstorms, floods, off-site (even off-continent) ecological conditions, and economic pressures that are essentially unpredictable. Skill in prediction of some of these factors is gradually rising, but it is still so crude that it can largely be discounted for the present purpose. The interactions will occur:

    a. in a landscape which contains a large amount of spatial variability of topographic form and material properties, including transient properties such as evolving tree-root reinforcement of hillside soils, or aquatic primary production, all of which may be sufficiently variable that it is impractical to measure or map them with foreseeable resources in a particular application;

b. in a sequence of weather events (climate) which is essentially unknowable in advance but which drives streamflows, rainstorm and fire occurrence;

c. amid biological perturbations such as disease, ocean-rearing conditions, and in a matrix of nonlinear processes driving population dynamics; and

d. in an economic and political environment that may drive the demand for timber in ways that are difficult to predict far in advance.

4) The prediction should preferably emphasize causal relations based upon an understanding of processes, rather than statistical association alone. A mechanistic expectation (hypothesis) can be developed and agreed upon, even by competing interests, and can be tested and refined through directed research. Even if the precision of predictions made from mechanistic conceptual models is low at a particular time, they are better guides to corporate and public policy than are statistical searches for needles in haystacks of environmental variability. Moreover, approximate predictions that are rationally based on an understanding of processes can often be refined gradually with better data or more realistic representations of the system. Simply agreeing on the expected sign of a change represents an opportunity for making decisions and monitoring responses.

5) Therefore, CWE predictions should be based on sound, broadly agreed-upon conceptual models of how complex watershed systems work. For some decision-making purposes, such as controlling turbidity, it may suffice to construct only a simple conceptual model of the effects of land

use on the budget (sources, generation rate, and transport rate and timing) of fine-grained sediment. For purposes of conserving or rehabilitating aquatic habitat and animal populations, it may be necessary to link physical models of habitat formation (involving the budget of channel-bed sediment and of turbidity-producing fine sediment, interactions of sedimentation with large woody debris or valley confinement, and the control of channel morphology with spawning gravels, pools, shade, and other refuges) and biological models involving habitat quality, spawning success, predation, and growth.

6) These conceptual models should be formalized as mathematical relations and applied to digital representations (computerized maps) of the watershed of interest to predict the location of expected changes, including source areas of material flux or other changes. These latter will often be downstream of the initial alteration, but not always in the case of terrestrial wildlife. The mathematical relations could vary in complexity, such as in the following examples of components of integrated models:

    a. simple, “rules-based” models, such as predictions of the number of salmon fry emerging from spawning grounds as influenced by the percentage of fines in the bed, based on data collected from numerous other watersheds.

    b. mechanistic rules describing the spatial pattern of a process, such as the hillslope locations that are expected to attain a low “factor of safety” with respect to landsliding in rainstorms with some specified probability of occurrence, or the gradients on which sediment coarser than a certain grain size is expected to accumulate for extended periods of time

c. process-based (dynamic) models of large woody debris recruitment from riparian zones and hillslope failure sites

d. dynamic models of wood and sediment supply, downstream transport, and habitat creation

e. spatially distributed, individual-based fish population models.

7) The degree of spatial elaboration (the resolution of the terrain representation to which the model is applied) may vary with the nature of the problem, the decision-making needs, and the resolution of the available data. Applications with differing resolutions may be used in sequence. One might first do a rapid, coarse-grained assessment for the purpose of highlighting the most significant problem watersheds (getting ahead of the problem that land use has already impacted most watersheds of California and decisions about some resources must be made immediately). Later (or more slowly), a more complete and elaborated process model could be applied to a higher-resolution representation of the watershed, including its climate and proposed land use or rehabilitation.

8) The model should be applied to the watershed in a 'gaming' format. That is, the model should be used to calculate scenarios covering the range of conditions that might occur, and the probability of each scenario should be estimated. In this way, the risk to a resource can be defined. Again, a range of approaches could be used, including examples such as:

a. A calculation of the area that might be rendered vulnerable to landsliding in a rainstorm of a chosen probability, with and without timber removal and root death, either with a default assumption of no recent failures evacuating landslide source

areas, or with updated estimates of recent landslides or soil depths (Benda and Dunne, 1997a; Dunne 1998; Dietrich et al. 2001).

b. Linear programming planning models incorporating ecological and economic factors (Olson and Orr 1999)

c. Monte Carlo simulations of sediment and large woody debris supplies to channels under a stochastic climate and fire regime, with various land management scenarios (Benda and Sias 1998).

d. Stochastically driven simulations of populations of the amount and condition of habitat, or animal populations in relation to timber harvest.

9) The models could then be implemented to evaluate the predicted consequences of various land-use scenarios and other events. For example, analysts could examine scenarios such as: total cutting of a watershed in ten years, twenty years, etc. in the face of typical climate variation, including large rainstorms; conversion of timber stands to a more even age; timber harvest with various technologies of road building, maintenance, and use. Of course, the details of watershed response would vary with which parts of the watershed had recently been cut, burned, or roaded when a large storm occurred, which is the essence of acknowledging the stochastic nature of the CWE problem. Spatially registered simulation would allow the analysts a means of calculating risks of localized and widespread effects under a *range* of scenarios. For example, one could calculate the probable watershed-scale effects on sediment production if particular zones were off-limits, or were logged at a slow rate, with or without roads, etc.

10) Although one can imagine a considerable number of options for land management, the number cannot be infinite. The number examined by land managers cannot be very large or else the planning exercise itself would be intractable. In fact, economic planning and GIS-based forest engineering by large landowners already includes methods for quickly recognizing the limited range of tractable options so that their analyses (which are not unlike those envisioned here) can be conducted efficiently. The paper by Olson and Orr (1999) illustrates the feasibility of quite complex modeling of landscape-scale planning of timber harvest to meet certain economic goals while adhering to constraints imposed by ecosystem management goals.

We envision this watershed-scale analysis of cumulative effects as providing guidelines for policy. For example, a possible result might be how the degree and rate of conversion of the age structure of a forest through adherence to riparian-zone rules, clearcutting, seed-tree selection, salvage operations, and various other means of intensifying cutting rates over a ten-year period would *change the risk* of:

- a flood of a given size, or
- a fine-sediment influx raising stream turbidity beyond certain limits, or
- the in-filling of pools in specific reaches of anadromous fish habitat, or
- the expected time series of salmonid production returning to the ocean.

To develop guidelines, a considerable number of weather scenarios, parameter values in models, harvesting strategies, and applications of the Forest Practices Rules would be simulated, utilizing the efficiencies of computer modeling and spatial data handling and presentation with a geographical information system. Out of such scenarios should emerge not only overall guidelines for (say) basin-wide rates of cutting but also

guidelines for avoiding or limiting the rate of harvest on certain portions of the watershed (specific topographic locations, soil types, or rock types), or for leaving buffer strips of various widths in different forest types or channel orders. On the other hand, if such prescriptions were considered intolerable, compensating polices could be searched for through the modeling.

## Implementation

### *Personnel and Other Resources*

We understand that if Cumulative Watershed Effects are to be predicted and the information released by CDF, the activity will almost certainly be managed by a person with the training of a Registered Professional Forester. However, such a qualification by itself is not adequate for the people who would be charged with actually conducting the CWE analysis. Before outlining methodological details, we want to emphasize the critical significance of hiring sufficient qualified personnel for this endeavor and of giving the unit sufficient resources. The activity that we propose is entirely new, and a radical departure from what is being done in this field by any other agency. It would need a high level of training, strategic creativity (Loehle 1996, pp. 9-33), and lucidity among a truly interdisciplinary team, not steeped in the traditions of forest, fish, and wildlife management.

For example, a ‘proof-of-concept’ investment in such a strategy would require at least three Ph.D.-trained analysts and five scientists with Masters–level training from front-rank universities that have already invested in the applied sciences required for CWE analysis (even if the activity is not called by that name in the training.) These sciences would be the ones that we referred to in our description of the interdisciplinary nature of CWEs in Chapter 3. These analysts would have training and experience in model building (not simply the use of off-the-shelf computer packages), as well as experience in field conditions. They would be supported by some field technicians and

several specialists in GIS and the acquisition of spatial data archives including the use of remote sensing, and they would need a significant computing environment. We also believe that inclusion of some analysts with significant management experience could also improve the analysis of CWEs, as well as the chances that model scenarios would be realistic. These experienced managers would also ensure that questions would be addressed and results would be presented in ways that are useful for management and policy.

It is not sufficient to continue current practices of hiring large numbers of entry-level technical personnel with training in a single discipline and with no previous training in the integrative field sciences in which CWEs are well understood. Instead, there is need to hire a relatively small number of leaders with a broad conceptual grasp of the CWE problem, and the leadership skill to forge integrated, multidisciplinary approaches to their prediction and monitoring. Most of these candidates will not be found by traditional civil-service examinations and career tracks, and a concerted, non-standard effort will have to be made to hire talent that is adequate for the task.

*Focal Watersheds*

We propose that CWE analysis and prediction be applied to watersheds with drainage areas in the approximate range 100-200 $km^2$ (40-80 $mi^2$). These watersheds in the hilly-to-mountainous terrain of the western US forest regions typically contain a full range of environments from hillslopes to stream channels with gradients low enough to develop alluvial channel and floodplain morphology and their associated habitat conditions (Montgomery and Buffington 1997), and yet they typically do not incorporate an intractable complexity of land use or environmental conditions. Also, we are advised that such a geographical unit is a useful scale on which to focus for forest land-use planning.

The data requirements for application of CWE models will vary with the complexity of land-use history in the focal watersheds. Those watersheds with strong legacy effects from previous land use would also require a greater investment in documentation to initialize projections of future risk. These are problems of degree rather than fundamental nature, and could be solved with efficient data collection using spatial databases and remote sensing tools that are now familiar to recently trained natural scientists, engineers, and planners. However, the use of the risk evaluations for public policy will have to contend with the implacable fact that any conceivable data collection scheme will leave many important conditions and properties of the watershed and the land-use plan undetermined, and essentially unknowable. The resulting decisions will have to be made in full acknowledgment of those irreducible uncertainties.

There may be other resource management problems for which a coarser-grained view of a larger area may be more appropriate than the watershed-scale approach on which we are concentrating here. Some cumulative effects are more appropriately addressed at the regional or large-river-basin scale, bringing together concerns of the National Marine Fisheries Service (NMFS) about endangered species, the interest of the Environmental Protection Agency (EPA) in Total Maximum Daily Loads, and State regulation of forests and timber harvest.

Choice of the watersheds to be analyzed would be made by CDF and its cooperating agencies through some process for recognizing urgency, vulnerability, and opportunities for rehabilitation. The process could be facilitated through the coarse-grained surveys of watershed conditions that we refer to later in this chapter as regional surveys, which could be aimed at identifying ‘hot spots’ of degradation or of threatened ecosystems in vulnerable locations. However, we envision a time when, through the gradual application of our proposed method, all of the actively logged watersheds of northern California could be documented and subjected to efficient modeling, scenario

building, and policy review. This state-of-affairs would be reached at a time that would depend on the intensity of investment and the rigidity with which the State could maintain a policy of hiring skillful and highly motivated analysts, regardless of whether they have professional degrees in certain fields.

*Stakeholder Identification and Mobilization*

The full complement of stakeholders needs to be involved in defining issues for the new CWE process. In northern California, the obvious agencies to be involved include at least: CDF, California Department of Fish and Game, the State Water Resources Control Board, Regional Water Quality Boards, California Division of Mines and Geology, Dept. of Parks and Recreation, EPA, and other water quality agencies, NMFS, the US Forest Service, the US Fish and Wildlife Service, Native American tribes, and environmental organizations.

However, experience with various forms of watershed analysis, either by individuals or by teams, suggests that it is unwise to make this process a merely technical exercise. The technical exercise in isolation, although accessible and comfortable for scientists, causes unnecessary confusion, suspicion and resentment among non-scientists, including policy specialists, community leaders, corporate officers, labor organizations, economists, lawmakers, and judges. It fails to capture significant concerns and critical knowledge possessed by local inhabitants, landowners, resource management agencies, people who work the resources of interest, professional organizations, and other stakeholders (Roberts 1999; Roberts and Sainty 2000). Thus, when a watershed is chosen for a CWE analysis there should be an effort by the technical analysts to identify and incorporate the concerns and knowledge of all interest groups into setting up the CWE analysis. It would be important not to slow down the analyses with extensive hearings, but recent experience emphasizes that CWE analysis and prediction and the acceptance of its results by various interest groups are social processes, and that fact should be respected from the outset. It requires identification

and consultation of stakeholders through workshops, web-based communication, and other evolving tools.

In this process of consensus building to identify which issues and mechanisms are significant it may be necessary to agree about the kinds of CWE predictions that are required, and what kinds are not required. This step would involve such questions as:

1) What are the critical issues for decision-making in the watershed of interest? Is it necessary to predict probable change in the long-term risk of infrastructure–destroying floods? Or the long-term sediment transporting capacity of fish-bearing stream channels as a result of timber harvest? Or the numbers of individuals in a species (which species?) in the channel network, the most probable number of landslides in a logging cycle, or the acreage of various habitats that would result from a particular land-use policy, or something else?

2) With what levels of precision do these variables need to be predicted?

3) How should prediction fit into the decision-making environment?

The process of sharing understanding and building trust and consensus about watershed functions and values and the factors that influence both lies in the realm of a newly developing social science. This work emphasizes the need for community-based decision-making about what needs to be analyzed, what needs to be predicted, how the analyses and predictions should be made, what needs to be monitored, what kinds of results are needed for the decisions to be made, and how the results are most likely to be utilized for decision-making. Integration of scientific analyses into community decision-making in the face of uncertainty is an activity that is evolving rapidly, and is needed in the resource-rich regions of the western United States. It involves collaborative and learning-based approaches to sustainable development and environmental concerns. It requires the building of ‘social capital’ (Putnam et al. 1994),

which is the institutional and community-based capacity for: managing change; resolving conflict; managing institutional pluralism; enhancing coordination; fostering communication; and ensuring the sharing of data and other information. The social science research underpinning this capacity building is led by institutions such as the World Bank, and several university groups, such as Community and Rural Development Institute at Cornell University (Warner et al. 1997, whose work can be accessed at http://www.card.cornell.edu//publications/cdr/cdr5-2.html), and Massey University, New Zealand (http://nrm.massey.ac.nz/changelinks/).

*Construction of Conceptual Models*

Once the target watershed has been identified and the interest groups have been mobilized, the technical analysis team would lead a wide-ranging debate to identify and to structure prevailing concerns about the watershed and the areas of agreement and disagreement about processes, magnitudes of quantities, vulnerability of components to change, and other issues concerning the functioning of the watershed. The purpose would be to construct conceptual models of the functioning of the watershed as a basis for the CWE analysis, and to ensure that no rational concern on the part of any stakeholder is ignored at the outset. Particular concern should be given to minimizing the 'systemic distortion' that filters unwelcome information or ideas in all organizations and interest groups (Bella 1992).

This part of the process would involve eliciting the insights and experience of local residents in a more structured and less confrontational manner than is the current norm. For example, if residents report that stream turbidity, or overbank deposition, or the depth of pools, or the texture of streambed sediments has changed, and there is some theoretical reason to expect such a change, those anecdotal reports can be used as a basis for hypotheses about magnitude and frequency of the effect, its biological significance, and its cause. If science is to be used in this process of CWE assessment, the *formulation* of a hypothesis does not mean that the hypothesis is *accepted* from the

outset. It is simply a question to be addressed by measurements and calculations. We have observed in the northern California redwoods region that residents have to go to extraordinary lengths simply to get a hearing for their concerns and experiences, and to get their questions investigated. Similar experiences elsewhere have shown that refusal on the part of technical specialists to take the perceptions of local residents seriously can lead to delay, damage and disruption (Harr 1996).

It has to be acknowledged, of course, that not all residents have the same resources of data and mechanistic understanding that can be marshaled by communities of scientists, and thus some perceptions by residents (and scientists) will eventually be refuted. But even if a minority opinion asserts a belief that some issue is significant (e.g. pesticide use or eutrophication), the difference of opinion should not be seen as a conflict delaying the process, but as a hypothesis about which the various parties can agree on a way of studying. If the analysis is agreed upon at the outset, and is followed, there is a greater chance that the study will resolve rather than perpetuate the difference of opinion.

Of course, the CWE team with its technical training, experience in analyzing watershed processes, and its unparalleled access to data resources (which it should have reviewed and presented to the community at this stage) would be in a position to lead the construction of a conceptual model of watershed functioning. The team could thereby assist the parties disputing an issue to structure their debate and the way the issue might be resolved in the CWE analysis itself. Establishing and maintaining the reputation of the team for its technical knowledge, appreciation of the needs of management and policy-making, sound judgment, open-mindedness, and reliability would therefore be crucially important to the gradual extension of such a CWE process throughout the region.

The process of constructing conceptual models should not be seen as a complicated or exclusive process. Conceptual models are simply shorthand descriptions

of the ways people believe a watershed functions, or of the relationships between cause and effect that they believe to exist. The models are often expressed in the form of a cartoon, or a flow diagram consisting of boxes and arrows indicating watershed components and their relationships, often elaborated by means of a short, precise narrative description of the hypothesized components and relationships. The more concrete and precise the conceptual models can be made, the more efficiently can agreement be achieved or critical studies designed.

*Accumulation of databases and choice of models*

As soon as the focal watershed has been identified, the CWE analysis team would be in a position to gather copious amounts of data that already exist about most watersheds in the State. There has been a tremendous growth in the amount and accessibility of such data in the past five years, and these data continue to improve. For example, there is a digital elevation model (DEM, or digital topographic map) of the entire State with elevations averaged over 30m x 30m cells (10m x 10 m cells in many private and some public forest lands). There are land cover maps, and Landsat satellite imagery is routinely accessible for updating changes. Other useful digital maps exist for stream channels, rainfall, soil characteristics, forest roads, and other watershed attributes. Use of digital data products, and the design of CWE predictions with a resolution limited to the quality and resolution of these data products would reduce the problem of gaining access to private land in order to do higher-resolution analyses. The listed data products are publicly available already, and an analysis could be conducted with them, and without field checking, if necessary. However, if a landowner wished to grant access or supply higher-resolution data for his land, the quality of the entire analysis could be improved.

Of course, the most widely available products are imperfect and will need to be improved upon. Examples of methods for such improvements include: projecting low-order stream channels beyond those shown on the US Geological Survey digital map of

channels through analysis of the digital topography, or elaborating rainfall maps through analysis of the sparse network data and topographic information (Rhea 1978; the PRISM project at Oregon State University, http://www.ocs.orst.edu/prism/). Some of these methods are referred to in the 'tool-box' appendix for illustration only, although we cannot give an exhaustive survey of this rapidly evolving field. However, the team would already have most of these archives, or know how to access then quickly, and the team would be familiar with techniques for exploiting the digital records.

The object of the data acquisition would not be to ensure high precision everywhere in an attempt to replicate what could (or has) been recorded on the ground at a particular spot. The data would be utilized in a stochastic analysis of the whole watershed, rather than a site-specific prediction or design, and so its precision at any one location is not as important as its ability to represent the general frequency and approximate spatial pattern of watershed and climatic characteristics. Since the data are going to be used for predictions of what might happen in future, unknowable weather events, defining watershed characteristics with great precision (subject to the important observation below) is not important. Of course, this is also true of data, such as regional flood-frequency curves, that are currently used for site-specific design of systems that are significant for safety and economics.

An important exception to the statement above on the representativeness of data occurs if a data set is *biased* in some way. For example, if the topographic data were too coarse to show hillslope gradients accurately, the user might conclude either that there are no gradients steep enough to cause mass failure, or that there are no convergent portions of the topography that would favor landsliding or gullying. A map of vegetation cover might be too spatially coarse-grained to represent riparian vegetation. Again, however, we are assuming that the State would hire personnel for the team who

would be skilled at evaluating, augmenting, and ordering data resources of the necessary quality.

The team would almost certainly have to order data that are not currently available and would have to do considerable processing and editing of what is supplied. However, the amount and quality of spatially registered environmental data resources continue to improve and to be utilized for quantitative analysis throughout the country. Some of the augmentation may have to be through traditional means. For example, it may be necessary to design rapid field surveys to sample the condition of road surfaces in the watershed (How many of them are surfaced with gravel, according to Best Management Practice rules? What is the probability distribution of gradients for different classes of road?), or the spatial distribution and texture of streambed gravel in channels of various orders. These augmentations would require at least some field surveys, but they could be organized by an experienced team in much shorter time than is currently taken by inexperienced groups that must be trained or must spend time gaining confidence about simple procedures through extensive survey of the literature.

*Application of Models*

We are not proposing the construction of a single large model of everything in the California woods. The best choice of models to apply for predicting CWEs will depend on such matters as: the specific issues identified in the conceptual-model-building phase of the analysis; the paramount issues of concern to the stakeholders; and the continuing evolution of scientific understanding of landscape and ecosystem dynamics and of modeling technology. It will be useful to remember that the purpose of this exercise is to make good decisions about natural resources; not to make some elegant and detailed prediction that would turn our fundamental sciences upside down or contribute to the elaboration of second-order interactions that are scientifically interesting but not yet of proven significance.

It is now widely recognized in environmental modeling that the complexity of the model should be matched to the sophistication of our understanding and data available for calibration or testing of the model. Thus, we expect that care would be taken to use models with only the necessary degree of complexity required to accomplish the decision-making and other management goals. Thus, a good deal of judgment and peer review would have to go into the selection of modeling activities in the first few years of the applications. In the appendix, we suggest a few modeling capabilities that are, or will soon be, tested and generally available. We expect that a team of the quality and experience level we have described above would be able to use off-the-shelf models, and to commission, and even develop their own models. We are not suggesting that the models described in the Appendix of this report should necessarily be the candidates employed in CWE predictions. However, a critical role of the CWE team would be to integrate the results from these or similar models in order to demonstrate the linkages that are currently understood to relate land use and other watershed changes to both 'on-site' and 'downstream' effects in water quality, habitat, and other values.

The team would need to utilize models of the kind we describe in the Appendix in stochastically driven simulations to calculate risk over the entire foreseeable spectrum of rainstorms, floods, fires, timber-harvest scenarios, management practices, and other drivers of watershed response over the spatially diverse, but approximately characterized, terrain. The result would be an integrated calculation of the ***risk*** of various effects such as: reductions in the distribution or quality of certain aquatic or terrestrial habitats; increased frequency of enhanced turbidity; increased frequency or depth of spawning-bed scour; increased risk of local population extinctions or recovery.

The simulations of processes and of management effects that change these risks could then be distilled into general conclusions about what intensities and kinds of timber harvest practices will increase risks to specific biodiversity or water quality

values. In such an analysis, it is not necessary to pinpoint each effect and location with great precision. This has always proven to be impossible anyway, and there is no way to predict the occurrence of damaging rainstorms either in space or in time. The whole-watershed view of the CWE problem requires that broad patterns of risk be computable. This approach does not exclude attempts to identify the location of each potential source of sediment or other contaminant and to implement conservation strategies that might reduce its effect. In fact, the two approaches are complementary, and the latter approach (which is essentially a BMP approach) would be incorporated into the broader CWE simulations.

The predictions of models will not be precise. That could hardly be expected in a stochastic environment. There will always be severe limits on the precision of predictions of water flows and sediment yields because of strong non-linear effects of the initial conditions and because of the difficulty of monitoring those conditions. Nevertheless, the central question of CWE analysis is whether models (or any other method) can provide the community of stakeholders with a vehicle for expressing their communal understanding of watershed-scale interactions and computing their best estimate of the consequences of that belief.

We do not wish to create an impression that all of the modeling tasks are easy. There is a tremendous amount of work to be done just to implement a number of these linked models to predict CWEs for a single watershed. In the appendix, we will also refer to issues for which modeling is still in a crude state, employing statistical and other empirical rules transferred to the site from elsewhere. These are subjects requiring research, and we will point out some of the needs for research. However, it seems the appropriate time for the State to establish a unit to initiate this practice, and to begin to build the skill necessary to serve policy makers. As in the case of weather forecasting, prediction skill will develop gradually in the face of an enormously complex task, if resources are invested generously, but in a rigorous and thoughtful manner.

Realizing that by the time our document is read, the state of the art will have shifted under our feet, in the appendix we will outline some capabilities in the order of a 'logging-cycle' narrative; i.e. roughly in the order in which they occur. The typical sequence of events in timberlands is that trees are harvested completely within a few years through incremental canopy reductions. Terrestrial and riparian habitats are immediately affected. Roads are installed, having both immediate and gradually changing effects on habitat, runoff processes and sediment supplies to channels. Effects of canopy reduction and roads on the water cycle are immediate and then revert gradually (but not entirely) to their original condition; and sediment is transferred downstream along channel networks, spending a considerable amount of time in some portions of the channel network, altering channel and floodplain habitats in some cases. The effects generally spread downstream and then gradually they are cleared from the network, sometimes only after decades of residence. All of these effects can interact with "legacy effects" of earlier timber harvest, but these would best be treated as initial conditions for the modeling exercise. Between periods of intensive tree removal (which may be episodic through a growth cycle, if disease or fire trigger salvage logging), less obvious activities such as spraying, thinning, and road maintenance continue.

Of course, by listing the current capabilities in a disciplinary format, we are undermining the cumulative or synergistic interactions that we are trying to stress in this report. However, we hope that the reader will understand that this sequencing is done for purposes of exposition only, and that the CWE team would link the various components to compute the multifaceted cumulative watershed effects.

## Relationship of Process-based Simulation and Gaming to Other Forms of Watershed Analysis

We have proposed that the responsibilities for predicting CWEs, as a basis for policy making, be separated from those of designing THPs to minimize damage in the light of potential problems identified in the CWE analysis. The process-based modeling approach outlined above, using models detailed in the Appendix, would not proceed in isolation, but would be linked to other analyses for managing CWEs in the context of a broader program of watershed analysis, indicated in Figure 1. We expect that a combination of field investigations and innovative database manipulation would be required in each component. The California Watershed Analysis Program could build on earlier efforts such as the Washington State Forest Practices Board Watershed Analysis procedure, but it would contain improvements that insure that CWEs are addressed quantitatively. Some aspects of such a program are already underway. We are proposing that the various activities be formalized into a program with a long-term plan and adequate resources. The current and required activities and the linkages between them are described below.

1) Because the watershed-scale modeling would initially proceed gradually from watersheds of high and immediate concern, there is a need for an ***extensive, region-wide survey of landscape condition***, which could quickly highlight critical watersheds with combinations of geological substrate, topography, habitat quality, and harvesting intensity that make their ecosystems vulnerable to land-use effects. Methods for doing this are described in a little more detail in the Appendix. California landscapes are diverse and there are large variations in degree of concern about land-use practices and ecosystem state. Therefore, the coarse-grained regional survey would compile information using newly developed tools that can exploit computerized maps of landscape features such a

geology, land gradient, and land cover. The purposes of such a survey would be: (1) to identify spatial and temporal trends in land use and ecosystems, 2) to prioritize drainage basins for application of higher-resolution CWE analyses, 3) to indicate where conservative interim management practices might be needed for some timber harvests until detailed modeling and field work is completed for individual watersheds.

It is expected that this analysis would be completed over approximately a two-year period, but that information could be updated periodically. The process could be contracted out to the private sector. Some of the relevant methods are described in the Appendix. This activity could be pursued immediately, with only a small investment by the State, and more-or-less independently of the establishment of the capability for CWE analysis and prediction.

2) The ***watershed-scale gaming strategy***, which we have emphasized in this report as being necessary for a true CWE prediction, would involve the process-based modeling and risk analysis described above, and would require the highest level of technical expertise and of conceptual leadership, and the highest resolution of data resources. It needs to be conducted by a specialized agency of the State government, since the results would eventually be used by the State for making watershed-scale policies. It is conceivable that specific applications of the general methodology could be contracted out to the private sector, but at present we know of very few firms with the capability for doing such work. Each watershed analysis would begin with the consultative approach, that we described above, to build social capital for facilitating a broadly accepted outcome. The technical analysis would then involve accumulating the necessary databases and models, and using them in the gaming strategy outlined above to simulate the interactions of land-use effects and natural environmental variability.

3) Results of comparing the scenarios could be distilled into a basis for ***watershed-scale policy-making*** about such matters as: the allowable rate of timber harvest, harvest technologies or BMPs to be applied on particularly vulnerable parts of a watershed, expectable time scales of recovery from various adverse impacts, if they should occur. This part of the process, of course, will be in the hands of policy makers rather than scientists, and this is the juncture at which other social and economic factors may be weighed against the level of risk to ecosystems and water quality. The important role for scientists at this stage is to present and explain results of the gaming analysis to policy makers clearly and effectively.

4) When the potential CWEs on a basin's ecosystems have been evaluated, ***THPs would be submitted*** in full knowledge of the best available, communally developed estimate of the risk to resources of various rates and types of timber harvest. At such a juncture, it should not be possible to deny out-of-hand where a potential for CWEs exists, and specifically what it might be. On the other hand, several suspected CWEs might have disappeared from the problem conception developed by the public or some resource agencies. Site-specific prescriptions can still be applied, including extended BMPs such as the use of SHALSTAB (Dietrich et al. 2001) and other spatially explicit models, described in the Appendix. However, the number of THPs might be limited by the policies derived from the gaming and from external influences. It should be remembered, however, that the gaming strategy was focused on the improvement of CWE predictions, rather than on the improvement of THP applications. Many of the deficiencies of THP documented by the Little Hoover Commission (1994, p. 60) and our own Chapter 4 will remain after a true CWE methodology is implemented However, many of the methods described in the Appendix, which can apply to the prescription of site-scale BMPs could be used to improve the THP analysis and to protect ecosystems.

5) From the earliest stages of the CWE gaming analysis, uncertainties would arise about some biophysical mechanisms, relationships, and data sources. Such uncertainties can be gradually reduced through targeted ***research***, although it is unimaginable that they will ever be reduced to a point where decision-making will be straightforward. This will be as true on the biophysical side of the debate as it is on the socioeconomic side. The necessary strategy will always be to formalize the best communal understanding of mechanisms and relationships at the time of each analysis. However, research will be valuable, and it can be contracted out to academic institutions, which could bid competitively in response to well-targeted Requests for Proposals or even more finely prescribed Announcements of Technical Needs.

Without the research program, the current state of methods will persist, and the prediction of some CWEs will remain laborious and uncertain. While we do not mean to suggest that nothing can be done now without research, we need to emphasize that many uncertainties continue to exist, particularly about the relationship of biological productivity and biodiversity to habitat conditions and their spatial and temporal variation. Suggestions for a research program are described briefly in the Appendix.

## Chapter 6: Impediments to the Application of the Proposed Methods for the Recognition, Evaluation and Prediction of CWEs.

Based on our discussions with resource professionals during this study, our reading of the literature, and our personal observations of controversies over resource management in northern California over many years, the committee identified the following principal impediments to recognition and evaluation of long-term cumulative impacts associated with timber harvesting operations. Designing a comprehensive program to analyze, predict, and modulate cumulative watershed effects will require addressing these barriers. The impediments that we found (and have referred to in various places earlier in this report, especially Chapters 4 and 5) are:

1) Legal impediments
   a) Lack of an appropriate legal standard for CWEs analysis
   b) Unclear role of CDF and CDMG in assisting timber production versus enforcing environmental protection
2) Conceptual impediments
   a) Excessive reliance on rule-making rather than problem solving
   b) Reliance on the concept of a threshold of concern
   c) Unquestioning and unverified reliance on mitigation
3) Information and knowledge impediments
   a) Absence of monitoring of habitats, populations, and water quality
   b) Inadequate technical expertise
   c) Lack of scientific knowledge
4) Economic and social impediments
   a) Inadequate funding and time
   b) Adversarial relationship between industry and scientists

The following discussion expands and elaborates on each of these impediments.

## 1) Legal Impediments

### *a) Lack of an appropriate legal standard for CWE analysis*

Timber harvest is regulated under the requirement that Regional Water Quality Boards review and grant waste discharge permits. The California State Water Quality Board can grant waivers to State agencies exempting them from discharge permit requirements. The California Regional Water Quality Control Board for the North Coast Region has granted the California Dept. of Forestry (CDF) such a waiver (see Resolution No. 87-113, dated 24 September 1987). The conditions of this waiver specifically grant an exemption to timber harvests operating under CDF-approved THPs.

The Forest Practice Rules of California require a determination of whether there are "any continuing, significant, adverse impacts from past land-use activities that may add to the impacts of the proposed project". The key words here, "significant" and "adverse" are not defined. This often makes prevention of negative CWEs unenforceable.

### *b) Unclear role of CDF and CDMG in assisting timber production versus enforcing environmental protection*

The current process in which THPs are prepared by industry or private consultants, reviewed by CDF and CDMG personnel, who then, once the THP is accepted, defend the THP against public challenges draws into the question the roles of these agencies. It also places the public at a distinct disadvantage in raising its concerns. As stated above, it may not be possible to *maximize* timber production and provide *adequate* protection of water quality and biodiversity.

## 2) Conceptual impediments

### *c) Excessive reliance on rule-making rather than problem solving*

There is a widely held view that the sheer number of forest practice rules should be sufficient to protect the environment, but the quality and effectiveness of many rules are questionable. Since 1960, there has been an exponential rise in the number of pages in the California Forest Practice Rules. These rules are created largely through reliance on best professional judgment by the Board of Forestry and its advisors, rather than strong empirical studies of effectiveness of the rules. Many of these rules have clauses that permit exceptions to be made. As discussed at length in Chapters 1, 3 and 4, CWE is dealt with through Technical Rule Addendum No.2, which provides no real methodology. It presumes that CWEs can be addressed one THP at a time, which they can not. CDF has issued various reports that offer too narrow a definition (focused on just sediment and water with no linkage to biology). The rule-making approach CDF has used has also left it with little technical basis for enforcement: Timber harvesters can follow these rules and still cause substantial CWEs. Few THP preparers admit to CWEs occurring and in effect, except perhaps in extreme cases, CDF has no procedures to show that CWEs are an issue. Similar comments can be made about Sustained Yield Plans.

More importantly, the rise in the number of rules, which clearly have improved practices relative to the past, has tended to cause many in the State agencies to adopt the view that prevention of negative CWEs can be accomplished just through enforcement of the existing rules. Our discussion above argues strongly against this. Furthermore, many of the Forest Practice Rules, particularly those pertaining to landsliding, road wash, skid trails and non-fish bearing channels are not based on clear scientific evidence and are demonstrably inadequate. Other rules, such as limitations on the size of areas that can be harvested within a short period of time, are easily circumvented. For example, although 15% of the Freshwater Creek watershed was

clearcut under the constraints of even-aged management during the period 1988-1997, another 35% of the watershed was harvested with alternative prescriptions in the same decade (data provided by CDF). The watershed-scale gaming strategy that we propose in this report would allow anticipation of just these sorts of undeclared policies.

### *d) Reliance on the concept of a threshold of concern*

There is a strong tendency to deal with an environmental issue by regulating according to a proposed threshold of concern. As discussed above, this tends to force inappropriate 'yes-or-no' answers to questions about the potential for CWEs. ("Will harvest cause erosion to exceed a threshold of concern?") Typically, the biological significance of such physical thresholds is completely unspecified. A more relevant question to ask about harvest practices is whether they cumulatively increase the *risk* of watershed-scale effects on the quality of habitats or on the extirpation of animal populations.

### *e) Uncritical and unverified reliance on mitigation*

Implicit in many of the actions taken in association with THP approvals is that it is possible to make up for possible consequences of one desired activity (say timber harvesting on steep land) by correcting some problem (say a poorly located, eroding road). It is felt that such "Best Management Practices" can effectively mitigate away possible CWE effects. While there are clear benefits of, say, removing unstable, eroding roads, the notion that such practices coupled with new land-use activities will avoid CWE is unsubstantiated. There has also been a reliance on untested mitigation measures rather than an effort to documenting CWE processes. The resulting belief that BMPs mitigate or prevent potential problems accounts for the proclivity among many THP applicants to assert that no cumulative effects will occur because they will be mitigated out of existence.

### 3) Information and knowledge impediments

#### *a) Absence of monitoring of habitats, populations, and water quality*

It is difficult to believe that habitats and other resources in the coastal redwood region, over which so much controversy exists, are so poorly known. There is almost a complete lack of data on water quality, streamflow, terrestrial biota, aquatic populations, the physical condition of streams, components of the water balance, and the degree to which they are altered by timber harvest in the region. The US Forest Service research effort in the region, while quite valuable, has not documented or investigated widespread environmental conditions or harvest practice, and has yielded few results on mechanisms that can be transferred to other watersheds. At the same time, there is no tradition of well-designed environmental audits of the effects of past projects, so that there can be adaptive learning from past land management. This lack of environmental auditing is a serious impediment to recognition of CWEs and to future attempts to improve CWE prediction through modeling. There is a strong tendency for data to be collected but not analyzed or reported.

#### *b) Inadequate technical expertise*

Most THPs are filed by small landowners with limited financial resources and no ability or authority to enter and conduct studies on adjoining lands. Even large landowners do not file THP applications with an effective and defensible assessment of cumulative watershed effects, and the State does not have regulators trained in the interdisciplinary fashion required to review the analysis and prediction of CWEs. The whole-watershed CWE assessments that we have proposed above will require the State to take over the responsibility for the assessment by establishing a new, adequately supported unit.

The proposed approach to predicting CWEs will require an interdisciplinary team of experts both in predictive modeling and in field analysis. There is little

appropriate expertise in the state agencies to do this work. Among the agency personnel and consultants applying current methodologies, we have not encountered any higher-level training in the processes discussed in this report. Furthermore, the interdisciplinary nature of CWEs, described in Chapter 3, means that very few specialists conducting traditional analyses have developed the conceptual perspective, process-based understanding, or training in methods to conduct a true CWE assessment. The personnel currently in charge of recognizing and regulating CWEs could not provide the conceptual leadership and guidance with methods for CWE prediction described in this report and its 'tool-box' Appendix.

Part of the inability to see relevant watershed processes seems to involve an institutional habit of "defining away" important parts of the problem before any analysis can be done, --- and therefore avoiding the need for any investigation. Bella (1992) referred to this institutional habit of ignoring unwelcome possibilities as "systemic distortion." For example, CDF personnel told us in the field that when they reviewed THPs, they had not investigated the possibility that intensive timber harvest in Freshwater Creek could be exacerbating floods because they had received blanket advice from headquarters that "logging does not cause flooding." Yet, this issue remains under intense discussion among scientists, and there is certainly good reason to take seriously the possibility that there has been *some* increase in flood risk in *some* watersheds. But the field personnel had no advice or resources with which to address the question posed by the THP application form, so they simply discounted the possibility that there could be any such CWE.

Yet another CDF reviewer in the Eureka area told us that he only examined the possibility that a hillslope is vulnerable to post-harvest failure "if the slope is steeper than 60%". Yet a standard slope-stability calculation (Gray and Sotir 1996) would indicate that using reasonable geotechnical properties, diminished tree-root strength, and documented rainfall rates, one can plot the risk of failure on hillslopes of various

steepness and soil thickness. Dietrich et al. (1995) produced digital maps showing that for convergent hillslopes, 60% is excessively optimistic for deep soils in large rainstorms after cutting. Yet again, the analyst simply defined away the possibility of landsliding on almost all cutover slopes, rather than doing the analysis in response to the THP application question. This instance occurred in a watershed in which we were surrounded by copious field evidence that landslides occur, and where landslide maps, constructed by a landowner's consultant had documented frequent in-unit failures as well as numerous road-related failures.

On another field trip, a State employee told us: "I just don't see any evidence of forestry-related sediment sources that would explain the sedimentation in the lower reaches" of a creek that we were examining. Yet, at his feet lay a map on which he had delineated 31 "recent landslides" in a heavily logged tributary, only a few miles upstream of the sediment impacted mainstem channel. Reason would suggest that the employee might at least have developed (and investigated) the hypothesis that the landslides that he had mapped were a sediment source.

In such a climate, it is difficult to see how any useful answer can be given on the THP application form to the questions about whether there is a potential for CWEs. Even at the agency level, some significant attempt needs to be made at educating responsible personnel more broadly about the nature of CWEs before there can be any agency commitment to and investment in integrative, watershed-scale assessments

Some agency personnel also seem unaware of developments in the technical literature, and they have an insular view of what constitutes the best scientific information on a subject, frequently hiring consultants to make quick, "policy-relevant" surveys as a basis for short-term decision-making. These reports, often with major methodological flaws, never undergo peer review in the widely accepted meaning of the term.

Our experience, then, is that consultants and industry employees with inadequate training are collecting and reporting data via the THP process, which is being reviewed by State employees also lacking appropriate expertise. Making matters more difficult, the RPFs we met in the field consistently held the false impression that they had addressed CWE issues by proposing Best Management Practices that would mitigate them out of existence, and that they were committed to never admitting to a CWE on a THP because of the difficulty such an admission created.

#### *b) Lack of scientific knowledge*

The implementation of the proposed modeling approach for predicting CWEs will require a significant increase in our current state of knowledge, particularly of the linkages between physical watershed changes and their biological consequences. In the Appendix of this report, we outline some of the progress that has been made recently in this direction; more is under development. However, there has been little organized effort to direct research towards solving the fundamental problems in CWE analysis and prediction. More directed research will have to be commissioned by the State agency charged with CWE prediction, particularly for northern coastal California where scientific knowledge of forest conditions is woefully inadequate for the management of such a valuable resource. As discussed above, all aspects of CWE prediction needs basic research, from hydrologic processes, sediment production and routing, to ecosystem processes and their dependencies on the physical environment. However, this absence of complete knowledge, should not be perceived as a reason to delay the program of building a predictive CWE modeling approach. There is enough knowledge to get started.

### 4) Economic and social impediments

#### *a) Inadequate funding and time*

Despite the large economic consequences of timber management regulation on both the timber industry and environmental resources, little money is set aside for understanding watershed processes in order to make the costly and environmentally effective decisions. Currently, for example, limited money and inadequate time are being provided to perform court-order TMDL analyses of North Coast watersheds. Consequently, few original data and almost no new understanding are being generated.

While a considerable amount of time is allotted for RPFs to survey THP areas, no time or resources are available to look more broadly. It is generally well beyond individual landowners means, and often beyond the larger timber holders interests, to provide the funding to perform watershed-scale analyses. As discussed above, a centralized effort would remove the financial responsibility for conducting CWE analyses from individual landowners, and should prove cost effective.

### *b) Adversarial relationship between industry and scientists*

The controversies over timber practices in California have led to numerous lawsuits and political battles. The adversarial nature of the legal process has required individuals with relevant expertise to stake out strong positions and to be pitted against each other. Rather than a reliance on gradual learning, sharing of insights, hypothesis testing, informed judgment, true peer review, and expression of appropriate uncertainties, reports are written and testimony given that are little more than opinion pieces, directed at tearing down or building up the limited scraps of relevant data --- and their authors. This adversarial relationship is not productive, and will discourage the involvement of scientists who have the needed expertise, but who also have other options for employment. Which technically trained person with a desire to make a useful contribution to the broad field of sustainable resource management wants to

spend his or her career being attacked, or having the trained skepticism of a scientist misinterpreted as malevolence?

It has been particularly distressing to observe, during our study, the political and social pressures brought to bear on a scientist of high caliber, with almost two decades of experience in the region, who contributed her expertise to the analysis of CWEs at the request of State lawmakers. Her motivations were challenged, she was vilified in the local press, threatened with congressional censure and with legal action by State officials on the grounds that she had not taken a test of professional qualifications that have nothing to do with the subject of timber harvest and surface processes. She is an internationally recognized expert in research on cumulative watershed effects, the author of articles, monographs, and an internationally used textbook on the subject, and a leader in the theory, methodology, and practice of CWE assessments. For agency personnel to suggest that she has no standing in the debate on the effect of timber harvest on surface processes is perverse. It also sends a message to other scientists who might want to contribute high-quality expertise to the management of resources in this region that they would become vulnerable to an ugly process.

The inability of many people in the resource industries and associated State agencies to use skepticism constructively places serious constraints on transparent investigations of issues such as the prediction of cumulative watershed effects. They see all questioning as judgmental, rather than as an approach for improvement of a product, technique, approach, and ultimately of sustainable development of the resource they profess to value.

## Chapter 7: Removing Technical Impediments to the Evaluation and Prediction of Cumulative Watershed Effects.

The following discussion explores possible means for removing the impediments identified in Chapter 6:

### 1) Legal impediments

***Recommendation #1:***

*We propose that responsibility for assessing and predicting CWEs be taken out of Timber Harvest Plan (and Sustained Yield Plan) Applications and given to a new unit of a State agency, which would make whole-watershed assessments of how land use alters the risk of damage to ecosystem values, building on the concepts and methods that we have introduced in this report.*

This change would need the agreement of the California Regional Water Quality Board for the North Coast Region (as the regulating authority) and all concerned parties. CWE analysis as proposed here will require involvement of all stakeholders, and to be successful, agencies involved in the preparation must act independently with the goal of getting the best scientific understanding of watersheds.

### 2) Conceptual impediments

***Recommendation #2:***

*We suggest that the State correctly formulate predictions of how land use affects water quality, biodiversity, and other resources at whole-watershed scale by asking whether land use increases the risk to these resources. This would require abandoning the "threshold of concern" and "everything can be mitigated out of existence" concepts that are implicit in current THP and SYP processes as the primary tool for assessing CWEs.*

THPs and SYPs are useful for the planning individual harvests, but not for the assessment of CWEs. We agree with previous reviewers that the parcel-by-parcel process needs to be replaced with true, watershed-scale assessments, which are beyond the data resources and technical capabilities of even large landowners, and in Chapter 5 and the tool-box appendix we have made some suggestions about how such predictive assessments could be made. The proposed new technical unit would have personnel and data processing resources to conduct watershed-scale gaming simulations of the various interacting processes that affect habitat and animal populations. These simulations would sample the full range of environmental variability that can reasonably be expected to occur in watersheds of the region to answer the question "Will various proposed watershed-scale timber-harvest strategies *increase the risk* of adverse changes in water quality and biological populations?" The risk-based answers to this question could then be used when policies are being formulated for harvest rates, required technologies, BMPs, and the balancing of environmental and socioeconomic goals. Only realistic mitigation practices that are likely to withstand large rainstorms and floods over a logging cycle should be incorporated into model-based assessments of the risk of CWEs.

### 3) Information and knowledge impediments

The formal assessment of cumulative watershed effects, as it should be applied to decision-making, has not been widely taught or applied, particularly in resource-rich regions of the western United States. Though many research scientists understand CWE assessment in principle, practical methods for applications have not been transmitted efficiently to personnel in industry or regulatory agencies, who are presently charged with conducting these analyses. The activity has consequently received little support, so that significant data and time resources are almost never devoted to it. Under the proposal for CWE assessment made in this report, landowners and local offices of CDF

would be relieved of responsibility for true, watershed-scale CWE analysis and prediction. Watershed-scale assessments would require the recruitment of scientists with a high level of training and experience in CWE assessment. However, there would still be a need for improved understanding of watershed processes on the part of agency field personnel, so that THP applications could be developed and reviewed in closer alignment with the policies developed with the CWE analysis.

***Recommendation #3:***

*The State should recruit and train a small group of conceptual leaders and implementers of true, watershed-scale CWE analyses based on a strategy of gaming, new data sources, and computer modeling.*

These people would need PhD- and Masters-level experience with modeling and spatial data handling, and be provided with adequate analytical support facilities, as described in the section on Personnel and Other Resources in Chapter 5. The number of personnel required would depend on the rate at which it was decided to extend watershed-scale assessments through the forested north coast region.

***Recommendation #4:***

*Because California RPFs are licensed to protect the "public interest in the management and treatment of forest resources....and....to enhance the control of air and water pollution...and... the protection of watersheds by flood and soil erosion control..." (PRC 751}, a specialty certificate should be established that requires some specific amount of initial training, continuing education, performance testing, etc. before an RPF may participate in the assessment of watershed effects implicit in a THP application.*

We commonly see individuals with limited training in some specialty conducting field observations outside their skills and experience, and using cookbook methods while missing important problems.

***Recommendation #5:***

*In addition to the CWE specialists and the RPFs trained to reconcile THPs with watershed-scale policies, the State needs to recruit appropriate professionals (working for Industry, State agencies, or other groups) with documented ability and knowledge of management to become involved in CWE analysis.*

***Recommendation #6:***

*In concert with the proposed new CWE technical unit, the State should develop a plan to support scientific research selected on a competitive peer-reviewed basis and directed at well-posed critical problems faced in CWE prediction. In addition, the State should explore ways to support training in appropriate fields so that an elevated level of expertise is available to it in the future.*

***Recommendation #7:***

*Like any other stewards, the various resource management agencies need to collaborate on a plan to monitor the resources, which they have been charged to manage or regulate. To be cost effective and useful, monitoring should be designed to test hypotheses. Data should be reviewed and placed into the public domain.*

**4) Economic and social impediments**

***Recommendation #8:***

*The State should develop a plan, perhaps through new or redirected fees, to obtain permanent funding for both the new CWE technical unit and the scientific research needed to support it.*

***Recommendation #9***

*The State should take a leadership role in supporting public debate about CWEs and should defend the role of its own employees and other citizens in contributing to the debate.*

Disagreement is to be expected, and initial skepticism should not be seen as the final word or an implacable threat on either side of a debate. But attacks against people who offer judgment on matters of their expertise should be denounced.

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## Appendix: The Evolving Toolbox: Illustrations of Modeling Capability

The purpose of this chapter is to indicate that the conceptual and mathematical models required to implement the gaming strategy proposed for CWE prediction are available, or are close to becoming available. In other words, the strategy is feasible, although as with any science-based method, it will evolve as understanding improves. Any decision-making strategy that claims to use scientific understanding will have to absorb that evolutionary feature of science in order to use the science well.

Our description of a number of model capabilities is for the purpose of illustration only. We do not claim that these are the best models; only that we are aware of them at the time of writing. We emphasize that the technology will change as both modeling capabilities and data resources change. But at any time, there will need to be a socially modulated way of expressing the best communal understanding of land-use effects on ecosystem function. In order to build this consensus, models of the type we outline here will need to be implemented, and linked in order to express interdisciplinary effects (such as the influence of accelerated sedimentation on fish habitat and populations). The models will then have to be run in stochastic simulations to calculate the risk of changes in biodiversity, water quality, or other ecosystem values. Thus, surrounding the modeling exercise would be a number of crucial social processes, including: conceptual model development, decisions about the types and resolution of predictions that need to be made, and communication of the results in a form that is useful to policy makers.

As promised in Chapter 5, we will outline some modeling capabilities in the order of a 'logging-cycle' narrative; i.e. roughly in the order in which they occur during and after timber harvest. Typical sequences of events in timberlands include partial canopy reduction over several closely spaced entries (such a shelterwood) or single entries for complete removal (clearcut) or almost complete removal (rehabilitation cut)

of canopy cover. Limits are usually imposed on the sizes of individual clearcuts, but not on the area of operations where partial canopy cover is left. Terrestrial and riparian habitats are immediately affected. Roads are installed, having both immediate and gradually changing effects on habitat, runoff processes and sediment supplies to channels. Effects of canopy reduction and roads on the water cycle are immediate and then they revert gradually (but not entirely) to their original condition. Sediment is released from roads by wash and through collapse, and from some cutover slopes by collapse within a few years of harvest. The finer portion of this sediment washes downstream more or less as it enters the stream, contributing to stream turbidity, and the coarser fraction of the sediment is transferred slowly downstream, spending a considerable amount of time in some portions of the channel network, altering channel and floodplain habitats in some cases. The effects generally spread downstream and then gradually they are cleared from the network, sometimes only after decades of residence. All of these effects can interact with "legacy effects" of earlier timber harvest, but these legacies are best treated as initial conditions for the current modeling exercise. Between periods of intensive tree removal (which may be episodic through a growth cycle, if disease or fire trigger salvage logging), less obvious activities such as spraying, thinning, and road maintenance continue.

## I. Cumulative Effects on Terrestrial Vertebrates

Evaluating cumulative effects on terrestrial biota is extremely challenging due to the great variety of species and their habitat needs and life histories, and the many potential impacts or effects from different landscape modifications. Here we focus on understanding cumulative effects on terrestrial vertebrates or wildlife, which have received the most study and are of the greatest conservation concern. Many of the same processes affect terrestrial invertebrates and other forms of biodiversity, although fewer data exist for other groups.

Examining the cumulative effects of land use decisions on wildlife often takes the form of evaluating the accumulation of the individual impacts of many land use decisions over time and space (Robinson et al. 1985; Theobald et al. 1997). The main impacts on wildlife from resource extraction and development are the loss, degradation and fragmentation of habitat. All wildlife species have particular habitat needs and require specific habitat elements (Morrison et al. 1992), although biologists understand the mechanisms and processes involved in habitat choice only approximately (Cody 1985, Holt et al. 1995). Below we briefly discuss how loss, degradation and fragmentation impact wildlife, and then review approaches that can be used to evaluate cumulative effects.

Habitat loss, degradation and fragmentation are distinct and potentially independent processes, although they often occur in concert. Habitat loss due to direct destruction and conversion of one habitat type into another usually results in the immediate disappearance of a species from a landscape. Wildlife species often require a minimum amount of habitat that depends upon the size of the territory or home range. Minimum area requirements are related to the vagility of the organism and vary by species. Home range size is positively correlated with body size and is larger for carnivores than herbivores (Swihart et al. 1988.). Reduction in habitat area to near or below this minimum size rapidly results in the loss of a species from a landscape.

Habitat degradation results from the loss of key habitat elements or structures that are required to maintain a species. For example, standing dead timber is a key habitat element to sustain woodpeckers, because snags contain high numbers of wood-boring insects that woodpeckers eat. Holes in snags made by excavating woodpeckers also provide cavities for many secondary cavity-nesting birds that are unable to excavate the holes that they need for nests. The slow loss of snags without replacement would result in the loss of woodpeckers, which in turn would reduce other cavity

nesting birds. Habitat degradation is a chronic process that can occur slowly over decades or rapidly over a few years.

The spatial arrangement of habitats can also have an important influence on whether a species or population can be maintained on a landscape. The effects of fragmentation, or the subdivision of remaining habitat into isolated patches, have received considerable attention in recent years (Andren 1994, Fahrig and Merriam 1994, Robinson et al. 1985, Collinge 1996, Zavala and Burkey 1997, Harrison and Bruna 1999, Debinski and Holt 2000). Fragmentation decreases the size of the remaining habitat and increases the ratio of edge to center habitat. Edge effects occur at the junction of two ecosystems or communities. The result is creep of the matrix ecosystem components or environment into the remaining interior habitat. Edge effects may include increased levels of predation due to greater penetration of edge-loving predators (e.g., raccoons, jays and other covids), changes in microhabitat structure extending from the edge into the interior of the fragment (e.g., temperature or wind), and avoidance of edges by interior dwelling species. Fragmentation can also restrict the movements of individuals among patches. Such effects have negative impacts on the natural metapopulation structure of many forms of wildlife, which depend upon recolonization of habitat after local extinction (Hanski 1999). Dispersal often occurs during the juvenile phase of the life cycle in many birds and mammals. In amphibians, however, adults may also make large movements between breeding ponds or streams and adjacent upland habitats. Fragmentation often disrupts these processes because individuals will not move across the matrix that surrounds remaining fragments.

A variety of modeling approaches has been used to evaluate individual and cumulative impacts of landscape change on terrestrial vertebrates. Arguably the most powerful approach is to develop population viability analysis (PVA) models that can be used to evaluate the likelihood of extinction (Boyce 1992, Beissinger and Westphal 1998). PVA models can take a variety of forms, but most usually project the population

for 50, 100 or more years into the future by choosing rates of annual survival and reproduction for all individuals in a population from probability distributions determined by field investigations carried out over a number of years. These stochastic simulation models can be constructed for single populations or for metapopulations that consist of fragmented habitat patches connected by dispersing individuals. The most complex and realistic approaches are spatially explicit, individually based models that use data on land use derived from geographic information systems (GIS) to create a grid-based landscape map of habitat types on which individuals are arrayed and their grid addresses are tracked (Dunning et al. 1995). Rates of reproduction, survival and movement are partly determined by the characteristics of the habitat or grid cell that individuals inhabit. PVA models require large amounts of data to parameterize (Beissinger and Westphal 1998), especially individually based models, and have been developed primarily for a few endangered species such as the spotted owl (Lamberson et al. 1992, 1994) rather than for all species that inhabit a landscape. Although the concept of evaluating cumulative effects by evaluating impacts of land use change on the chances of extinction from a landscape is attractive, such models are beyond the capabilities of most traditional CWE analyses.

If it is not practical to evaluate risk by directly modeling the population trajectories of a wildlife species, it may be more tractable to evaluate impacts to its habitat. Models that track the amount, condition and spatial arrangement of wildlife habitats are well within the capability of the State's ability to conduct a CWE analysis. Such models must first define the types of habitat classes that are important to a species or a set of species, and then determine how the amount and distribution of these habitats would change through time with particular resource extraction and development scenarios. The wildlife component of such models may be directly linked to forest regrowth and hydrological models discussed previously (Olson and Orr 1999).

A starting point for identifying and mapping wildlife habitats in a regional watershed could be the California Wildlife Habitat Relationships (CWHR) system (Mayer and Laundenslayer 1988). The CWHR system relates occurrence of 675 terrestrial wildlife species within the range of the species' known geographic distribution to 59 CWHR habitat classes, which are further subdivided by habitat stages, ages and cover classes, and the occurrence of 124 habitat elements (e.g., snags, logs, vernal pools, etc.). In forested habitats, for example, habitats can be classified using tree species composition, average tree size, tree density, and canopy closure. Habitat classes can be constructed that are used to evaluate the presence or absence of a species on a landscape. Sometimes such models are also used to estimate abundance (Flather and King 1992). Another source of data on the occurrence of vertebrates on landscapes could come from the California GAP analysis program (Davis 1991; Davis et al. 1995, 1998). GAP analyses use land cover maps of actual vegetation to predict distributions of terrestrial organisms, usually vertebrates, based on habitat-relationship models (Scott *et al.* 1993, 1996).

For both the CWHR and GAP approaches, the method for mapping terrestrial vertebrates depends upon creating a habitat-relationship model that links a spatial representation of a species' habitat association(s) to its potential geographic distribution. Such a model is a combination of current range information about a species that is extrapolated to the suitable habitats available within the species' range. The source of available data dictates the scale that is chosen for mapping habitat. CWHR location information is at relatively gross scale, and is available by counties, 1-minute by 1-minute blocks of latitude and longitude, CALWATER 2.0 Hydrological Regions, and CERES Bioregions. The California GAP effort was based on the CWHR database, using maps of relatively low spatial detail (1:100,000-scale) that also only provide an overview of where species are expected to occur.

Developing a base map of habitat or land cover types is the first step of CWHR and GAP Analysis. Relatively low-cost, large-scale, land cover maps can be generated using remote sensing technologies, such as satellite imagery at 30 x 30 m pixel resolution (Sabins 1978). Next, some form of image processing is used to label the raw data and an aggregation algorithm is used to develop a completed map with the specified minimum mapping unit, which can then be quantitatively analyzed (Caicco et al. 1995, Davis et al. 1995). For example, 125 natural communities were generalized into 48 wildlife habitats in California (Davis 1991; Davis et al. 1995, 1998). Finally, each species is linked to land cover types using habitat-relationship models (Scott et al. 1993, 1996;). Briefly, habitat-relationship models are developed by identifying those habitats (i.e., cover types) in which a species might occur (Morrison et al. 1992). Species typically occur in several habitat types, or even all habitat types, within a given area and rarely is a species restricted to only one habitat category. The predicted distribution of a species is all habitats within the known distribution in which it might occur. Additional habitat inputs, such as digital elevation data, location of aquatic habitats, and size and age of habitat polygons, are also used in habitat relationship models to predict species distributions.

Models that use land cover to predict terrestrial species occurrence, however, have a variety of limitations (Catanzaro and Smith 1996, Conroy and Noon 1996, Smith and Catanzaro 1996). Although habitat relationships of animals have long been recognized (Morrison *et al.* 1992), information about specific affinities with particular types of vegetation is limited. Birds are the most widely studied group of terrestrial vertebrates in this respect, but there is surprisingly little information on some relatively common species (e.g., Karl *et al*. 1999).

Statistically methods to assess the accuracy of predicted distributions of animals exist (Fielding and Bell 1997). Tests require an independent data set that was not used for model development. There are four possible outcomes of a model prediction of the

occurrence of wildlife on a landscape: (1) presence of the species is predicted accurately; (2) absence of the species is predicted accurately; (3) presence is predicted, but the species is actually absent (error of commission, false positive, or type I error); and (4) absence is predicted, but the species is actually present (error of omission, false negative, or type II error). Since animals rarely occupy all suitable habitat within their range, CWHR and GAP models typically over-predict species occurrence, leading to a higher rate of commission than omission errors (Smith and Catanzaro 1996).

## II. Cumulative Effects on Riparian Biota

Riparian vegetation plays a significant role in ecosystem function in forests around the world (Harmon et al. 1986), providing shade and coarse woody debris to channels. Bilby and Bisson (1998) review with over 100 citations the major functions of large woody debris (also called large organic debris or coarse woody debris). The material determines channel form, and therefore habitat variety in small streams, facilitates deposition of sediment and fine organic matter that feeds stream invertebrates, helps in formation of pools for fish; and sediment trapped forms substrates for riparian vegetation.

The amount of large woody debris in a stream depends on inputs and outputs. Output of large woody debris depends on removal, transport, fragmentation, and decay rates. Inputs depend on riparian disturbance processes that create treefall within some functional distance from the channel, caused by windthrow, bank cutting, or tree death from insects, disease, fire, or cull timber felled during harvest operations. Because these processes may vary over time, the amount of debris in a stream varies over time. The natural mature forests of the redwood region historically had the highest known amounts of large woody debris in North America for streams with channel widths less than 10m (Bilby and Bisson 1998).

In northern California, large organic debris in streams has generally decreased over the last century due to removal for navigation and misguided efforts to improve fish passage, splash damming, and clearing of riparian trees (Bilby and Bisson 1998). Forest practices regulations in California have focused on shade requirements for stream temperature, rather than other functions of riparian vegetation such as those provided by tree boles. Hardwood trees, even though they reach much smaller size than the conifers, have been deemed equivalent for shade protection to streams. Most harvested terrain, therefore, has significantly smaller loads of woody debris than in prehistoric time, and limited potential to provide significant inputs for long periods into the future. In the Redwood Creek basin east of Eureka, conifer dominance in riparian areas has steadily declined over the last 50 years from about 90% to 20% (G. Bundros, Redwood National Park, unpublished data).

Potentially improved forest practice regulations have been controversial because the same logs important for stream function also have high economic value to landowners. Recent changes in forest practices regulations (1998) specify leaving 25% of existing overstory conifers on class I and II streams in a zone that was changed in width from 100 ft to a slope-dependent variable width between 75 and 150 ft on Class I streams, and from 50 ft to a slope-dependent 50-100 ft on Class II streams. Class III streams remain without tree retention requirements. The baseline for calculating the 25% conifer retention is the density prior to commencement of operations, so if multiple operations are conducted over time (for example, once a decade) the residual from the previous operation is the base for the next. Conceivably, in two operations density can go from 100% to 25% to 6%. The additional requirement for leaving at least two trees 16 inches in diameter and 50 ft tall per acre within 50 ft of the stream is equivalent to 1 tree per 400 feet of stream length, and a basal area less than 1% of the levels in the natural forest. While the current regulations are a qualitative improvement over time, their effectiveness has never been established. As the density and basal area reductions can both exceed 90% of natural forest levels on Class I and II streams, and 100% on Class III

streams, the effectiveness of current regulations for ensuring woody debris recruitment is certainly very low.

There is no scientific answer to the question of how much large woody debris is appropriate in a stream. Rather than defining a minimum acceptable number of logs in streams, most approaches have instead compared large organic debris in unmanaged or natural forests to various proposed scenarios in managed forests. "Natural" levels produced by unmanaged forests have been defined as the "baseline" to compare management alternatives such as variable buffer widths or treatments within buffers. Sources of uncertainty from the regulatory perspective include:

- Natural levels vary in space and time; no single "baseline" for the redwood region exists, any more than for other forests. Natural disturbance affected these levels.
- Current large woody debris loads in streams passing through managed landscapes are usually much lower than the baseline; "good" plans for the future along recently cutover streams may require centuries to restore naturally functioning levels.
- The proportion of the "baseline" that allows natural functioning of wood in streams is unknown, although levels closer to the baseline are "better". Is 95%, 75%, or 50% of the baseline acceptable?

Various streamside management options can be identified, including different widths and different treatments within various parts of the zones. Regulations regarding large woody debris must be a public policy decision on risk. What science can provide is a relative percentage of the "natural" load under these various alternatives. Baseline levels of large woody debris use the natural forest as the comparison condition. Therefore, levels of large woody debris maintained in the natural forest must be estimated. These levels depend on definition of a source area, recruitment rates, and retention of pieces in the stream environment.

The source area is that area adjacent to the stream that can deliver functional wood to the stream. For incised streams, this is usually one site potential tree height slope distance away from each side of the stream (McDade et al. 1990). Source distance may occasionally be greater than one site potential tree length due to the occasional exceptionally tall tree or to downslope movement during the treefall process. A site potential tree length is defined as that height to which mature trees commonly reach in the old growth, or 200-yr-old stage. Recent proposals by Pacific Lumber Company (1998) and the National Marine Fisheries Service (1997) mistakenly define site potential tree height as site index tree height (height of a tree at a specified index age, such as age 100). For redwood, a site index tree height may be 200 ft, for example, but a site potential tree height may be 270 ft tall, with some trees being even taller. Processes such as landsliding may also contribute large woody debris from beyond one site potential tree length.

Treetops do not function as large woody debris because they are smaller than the minimum functional log diameter. They will be transported downstream, and may provide habitat in estuaries, but are not stable in the channel they fall into or in larger channels downstream. Source area should be corrected for treetops depending on the stream channel width. Wide channels can transport larger pieces of wood, so even when input to the channel may be equivalent between narrow and wide channels, the wide channel will retain less of the debris as functional pieces. Thus, in order to contribute stable debris, trees must fall closer to a wider channel. Thus, larger streams, in effect, have narrower source zones. First-order channels can transport little woody debris (Swanson et al. 1982), so small and large woody debris is stable, and smaller material further upslope can contribute to the stable load. Larger channels transport much of the woody debris to even larger channels, so only the larger pieces close to the stream will contribute to stable loads of large woody debris. This is almost exactly opposite of the regulatory approach to stream buffers in western states, which mandate

wider buffers for larger streams with fish, and narrower or no buffers for smaller streams.

In the natural forest, riparian areas were not free of disturbance. Many of the redwood flats and streamside areas have large redwoods or Douglas fir with charcoal on the bark, or fire scars recording repeated fire. Because redwood and larger Douglas fir are very fire-tolerant, they can persist in the presence of these disturbances. Wind is also known to be an important disturbance agent in the natural forest. It is probable that fires and windstorms created periodic "pulses" of large woody debris (Benda and Sias 1998), rather than constant inputs (Kennard et al. 1998, Pacific Lumber 1998, Reid 1998).

Retention of large woody debris is a function of the ability of debris to resist transport, fragmentation, and decay. Quantification of these factors is difficult, although relative comparisons of proposals to the baseline can be made. The natural forest would have had the largest average piece diameter. Piece diameter is directly related to the ability of the piece to remain in a stable location, given a channel width (Bilby and Ward 1989). It is also related to proportion of heartwood that is more decay-resistant than sapwood. For a tree with a 1.5-inch sapwood band, a 20-inch diameter piece has about 72% heartwood, while a 50-inch tree has 88% heartwood, and an 8-ft diameter tree has 94% heartwood. The decay-resistant properties of redwood are world-renowned, and merchantable logs can be recovered decades and perhaps centuries after they have fallen to the ground or into a stream. Larger pieces not only provide more volume to the stream, but a volume that is stable and decays more slowly. Regardless of the decay constant used with negative exponential decay models (Harmon et al. 1986), old-growth forests will produce woody debris with longer retention times simply due to piece diameter. Compared to an old-growth forest with quadratic mean piece diameter of 44 inches (Veirs 1982, Pillers and Stuart 1993), recent riparian management proposals from Pacific Lumber Company (“late seral-high residual prescription”: QMD = 24 inches) have 49-64% of the longevity of the larger material from natural forests.

Creation of some large woody pieces should be an important goal of forest practice regulations where the intention is to restore fully functioning riparian zones with original wood loadings of channels.

Measures to retain shade and cover from riparian vegetation are intended to mitigate harvest effects on stream temperature, direct delivery of sediment to streams, and excess nutrient input (Castelle et al. 1994). California had no provisions to protect streamside zones prior to 1973, when the new Forest Practices Act passed and regulations for stream shading were developed. The initial shading requirements were met by prohibiting broadleaf tree harvest near the stream, and allowed removal of all merchantable conifer trees along Class I, II, and III streams. Harvested trees were to be felled away from stream channels, and slash concentrations were prohibited in the stream channel (Forest Practice Rules, Coast Forest District rules, August 1975). In September 1975, shade restrictions were imposed, so that 50% of the shade canopy present before the operation was required to be retained (however, each entry could remove 50% of what remained after the previous entry). The 1998 Forest Practice Regulations provide limited improvements from a shade perspective. These regulations require 50% shade canopy left on Class I and II streams, but the standard against which this is measured is still the shade canopy present at harvest, not a mature, unharvested forest condition. Repeated entries can degrade the shade canopy considerably, similar to the large woody debris discussed above. Class III streams receive some limited protection in equipment use, with requirements for 50% of the existing cover of understory vegetation to be left.

These requirements are enforceable, but their effectiveness is unknown. Most studies evaluating water temperature effects have evaluated uncut buffers (Lynch et al. 1985, Beschta et al. 1987, Welch et al. 1998) and shown that buffers of 75-100 feet (25-30 m) width are sufficient to maintain water temperatures at pre-logging levels. Avoidance of effects on riparian microclimate (air temperature, wind, solar radiation, relative

humidity) generally requires wider buffers of 100-200 ft (30-60 m) on streams of 6-12 feet width (Brosofske et al. 1997). The effects on water temperature of partially harvested buffers under current California forest practices rules are not known

Many riparian zones have been poorly managed in the past, but it does not follow that passive management may always be the best solution in the restoration of riparian forests. There may be situations where the production of larger material may be stimulated with active management (e.g., Berg 1995), but the objectives for that manipulation must be clear, and the intent should be to produce large conifer stems that will eventually be delivered to stream channels. Thinning within riparian zones must be approached on a site-specific basis. Kennard et al. (1998) predicted the effects of riparian thinning on pool surface areas. Smaller streams increased pool surface area quicker with uncut buffers, while larger streams showed more benefit from thinning. Treatments like low-intensity prescribed fire can be applied in riparian zones (e.g., Agee 1998) for fuel reduction purposes to protect the large tree component, but this will generally be more desirable on inland sites with relatively drier riparian zones, and where harvesting activity (additional disturbance) is absent.

## III. Cumulative Hydrological Effects

The conceptual model of the hydrologic cycle is quite widely agreed upon, especially for natural and managed forest regions (Brooks et al. 1991; Dunne and Leopold 1978), even if some of the quantities are not well defined in areas with few or no local measurements (such as northern California). Process-based mathematical models of the hydrological cycle are also widely developed and are applied in all landscapes for planning and policy making (agricultural lands for agronomy and irrigation scheduling; forests and rangelands for water supply, flood prediction, and land-atmosphere effects on climate). However, such mathematical modeling appears to

be denied to resource managers and policy makers in regions of managed forests. Nevertheless, modeling facilities do exist, and in recent years several spatially explicit hydrologic models have been developed for prediction of the components of the hydrologic cycle, including runoff, from a digital representation of the hillslopes and channels of forested mountainous terrain.

Prediction of the effects of watershed conditions on flow regimes is a traditional activity in hydrology, as one might expect from an engineering-based science activity that has been concerned with problem solving and decision making. The types of models used by engineering hydrologists have often been criticized by some hydrologists who would prefer to see the development of more elegant, flexible, or detailed models. Other hydrologists have criticized these models as being overly complex and difficult to 'parameterize' (parameterization of a model involves estimating coefficients that represent the average behavior of various small-scale mechanisms that are too fine-grained for the model to represent explicitly). These difficulties are real, and so like other complex tools, hydrologic models require skillful use and interpretation. However, during the past decade, watershed models of hydrologic processes have gradually developed to be adequate estimators for (a) design purposes and, (b) more importantly for the present purpose, for illustrating quantitatively our best communal understanding of the interactions among the various components of a complex watershed responding to weather and land use. As such, watershed-scale hydrologic modeling is inherently concerned with cumulative watershed effects.

The hydrologic conditions that are of greatest concern as results of watershed transformations are flood discharges and annual and seasonal water yields. Watershed hydrologic models attempt to quantify these responses by representing how various processes (such as evaporation from the canopy and withdrawal of moisture from the root zone, subsurface percolation, and channel conveyance) are affected by sequences of

weather events (rain, snowmelt, warm air temperatures, etc.) and watershed characteristics such as topography, channel density, and canopy condition. They can explicitly represent the effects of land-use change or other watershed transformation such as fire, agriculture, etc. by incorporating the spatial distribution of canopy change, the locations of roads, the frequency of disturbance and the history of, or proposals for changes in, any of these characteristics. The watershed characteristics are represented by digital maps in a Geographical Information System. Their calculated results refer to points within this map (e.g. predictions of flood peak discharges at particular localities) or to areas (average evaporation rates over patches of vegetation). Thus, such models could be used to answer questions such as: "Given the best current understanding of runoff generation, by how much would a cycle of timber harvest with roads increase the risk of an infrastructure-damaging flood in the settled reach of watershed X?" Or, "How would the probability distribution of sediment transporting floods be altered in spawning reaches of the same watershed?"

Thus, there is no need to discount the risk of changing flood regimes at the outset of a CWE analysis, as is often done by timber companies and other forest managers. The empirical record of floods is too short and uncertain to use for defining the land-use effects on the risk of large, damaging floods (UC Committee on the Prediction of Cumulative Watershed Effects 1999), and the oft-quoted argument that increases in peak flows are small relative to flows from medium to large storm events is a misleading dismissal of the potential for changes in high-flow frequency which might enhance the scour of spawning gravels and large woody debris from channels.

Of course, even when a consensus has been reached, through development of the appropriate conceptual model about how to represent watershed processes, the mathematical modeling still requires the estimation of some parameters in order to predict hydrologic quantities. These parameters can be obtained from local measurements, or they can be transferred from a distant locality at which they have

been evaluated. Both of these activities (which are not mutually exclusive and can be applied in sequence) require skill and experience, but they can be done with a useful degree accuracy for the purposes of CWE prediction. Wigmosta and Burges (1997) demonstrate a commonsense approach to applying models of watershed hydrologic response, employing field mapping, simple monitoring, and the hydrologic model itself.

Moore et al. (1991) reviewed the utility of flow prediction models organized on the basis of a GIS representation of a watershed. The group led by Lettenmaier at the University of Washington developed the Distributed Hydrology-Soil-Vegetation Model, originally to assess the effects of climate on hydrology (Wigmosta et al. 1994) and then to analyze the effects of timber harvest in the Pacific Northwest (Storck et al. 1998; Bowling and Lettenmaier 1997, 2001; Wigmosta and Perkins 2001). The group has demonstrated the feasibility of applying this model to complex basins ranging in drainage area from 5 to 388 $km^2$. The models predict continuous records of streamflow and evaporation from recorded or hypothesized series of meteorological events with one-hour to one-day time steps and mapped watershed characteristics interpolated to square grids of 100 m size or finer. These spatially distributed models of runoff have been made feasible by the widespread availability of digital data on topography, soils, and land cover, much of which is accessible in GIS format (examples are the US Forest Service (1975) Soils Inventory, the STATSGO soils database of the US Department of Agriculture (1994), or data from individual landowners. The spatial databases are available from public sources, but a large landowner with independent resources could offer such information to the CWE team. However, in the absence of cooperation by landowners, there is enough information available from public sources for the team to conduct a credible basin-wide analysis. Even the age and structure of vegetation and the distribution of roads can now be mapped quickly from sequences of Landsat satellite images or with geographical positioning system receivers carried through the basin. Rainfall, the largest term in the water balance, and therefore critically important

for runoff modeling is also becoming better known through improved statistical techniques for extrapolating climatological records over complex terrain. Rhea (1978) used topography to refine distribution of rainfall over a basin interpolated from gauge data, based on an orographic rainfall model. Radar-generated maps of rainstorm characteristics can now be used to generate probability distributions of the characteristics of individual rainstorms.

All runoff models require calibration of some critical parameters at whole-watershed scale, but the techniques for doing this are generally agreed upon, and are the subject of continuing refinement. Once calibrated, the hydrological models can be used for stochastic analyses when driven by probability distributions of rainstorms, melt periods, and antecedent moisture conditions. Each of these data inputs and the mode of analysis could be defined publicly, analyzed independently, and agreed upon before the assessment by all participating interest groups, and thus before the results of the CWE were available.

## IV. Cumulative Effects of Watershed Changes on Sediment Sources

Land use changes affect the sediment supply to streams and sedimentation in channels with implications for aquatic habitat through channel morphology and turbidity. Collapse of soil as landslides and debris flows commonly result from some combination of removal of vegetation canopies and root reinforcement from soil, and reshaping of the land through cutting and filling along roads. Conceptual models of these processes are generally agreed upon throughout the geotechnical and geomorphological scientific communities, despite the resistance of many in the timber harvesting community to acknowledge this consensus. Disturbance of the ground, including bare, compacted road surfaces, also enhances sediment supply to streams. There is a vast literature on this subject (Sidle, Pearce, and O'Loughlin 1985; Reid 1993; Reid and Dunne 1996; MacDonald 2000), and on methods for documenting and computing the sediment supply to streams.

Spatially registered modeling of sediment loading to streams is in its infancy compared to runoff modeling, and requires similar forms of calibration for some planning purposes. Nevertheless, there have been encouraging developments in the past decade that could now be used for CWE prediction in the spirit of our proposal. Again we emphasize that the models would not be able to match short-term measurements (such as single-storm loads or turbidity values), nor meet standards of replication established in the laboratory sciences. Nevertheless, they are, like many other environmental models, useful for obtaining general magnitudes of sediment loads over periods of years, and for estimating risks of extreme loads or consistently high turbidity values under various scenarios of land-use change and weather. Most importantly, models of sediment loading are adequate for representing (a) communal understanding about the interactions between watershed characteristics, meteorological events and forest management that affect the nature, direction, and approximate rates of sediment supply to channels, and (b) how modifications of land use can alter these loads. In other words, they are now comparable in nature to models of soil loss from agricultural fields that are used in agricultural planning, although no systematic comparison has yet been made of the standards of accuracy of the two sets of models.

To be of general practical use, a digital terrain-based sediment yield model should be physically based yet parameter-poor such that it can be calibrated, however crudely, and to some degree validated. The most developed models for predicting land-use effects on sediment sources are those which analyze the threshold of slope stability both along roads and on cutover slopes before and after timber harvest. This activity has a history reaching back to the 1970s (Sidle et al. 1984). These models have recently been implemented in a spatially explicit form, using digital topography (Dietrich et al. 1995). Dietrich et al. (2001) provide a critical review of the accuracy of spatial prediction of landslide zones with SHALSTAB.

Models of the changes in canopy and soil hydrology, and the effects on root reinforcement that accompany timber harvest or fire (Sidle et al. 1985) are difficult to calibrate due to the large number of parameters and the large spatial (and temporal) variation in those parameters. These models are mainly useful for the consensus building about the existence of harvest effects, referred to above. On the other hand, without calibration, it is difficult to model changes in the intensity of landsliding and to convert that intensity into a loading of sediment into channel networks. The simplest approach for shallow landsliding may be to use simple, parameter-poor digital terrain models such as SHALSTAB (Dietrich et al. 1995) or SINMAP (Pack and Tarboton 1997) to identify unstable sites and to measure the landslide potential in watersheds. The landslide potential could then be correlated with the occurrence of documented shallow landslides or the resulting basin sediment yield for specific land-use effects and precipitation extremes. If such a correlation can be established, then it could be used as an estimate of the potential effects of forest practices.

More ambitious attempts at prediction are now incorporating calculations of finite-duration rainstorms into programs such as SHALSTAB to calculate the risk of rainstorms that trigger landsliding episodes of various magnitudes in a watershed. Rather than capturing the absolute magnitude of the landslide-derived sediment flux, such models are more useful for calculating the sign and the probable change in risk to be expected from a change in land cover. However, unless initial data on soil depths in landslide source zones (Dunne 1998), or some other field-based constraint, is entered into the model, most predictions will tend to overestimate the intensity of landsliding (number of slides per storm) because they fail to recognize sites that have been recently evacuated. The problem is being addressed in the generation of models under current development, although it is not yet clear how much initial data inputs (from field inspection or aerial photographic landslide histories) or calibration will be needed to make them sufficiently accurate for watershed planning.

Deep-seated landsliding is more of a challenge to modelers, as frequency of movement can be thousands of years, and destabilization may be driven by stream bank or road cut erosion of the toe, by progressive internal state change, and by hydrologic events that may be influenced by forest practices (via altered water balance or road runoff concentration). The importance of root-strength loss after timber harvest in destabilizing features is much less significant than in the case of shallow landslides. Subtle aspects of fabric and structure of geologic materials can dictate the location of failure surfaces. When deep-seated landslides move, they tend to make large, long-lasting morphologic change in the landscape. Consequently, over geologic time, a large proportion of bedrock types prone to shedding deep-seated landslides will develop topographic signatures of their movement, even if movement frequency is rare. These signatures, which include broad amphitheater valleys, hummocky irregular ground, and low-gradient, poorly dissected surfaces, may be distinct but provide little clues as to future activity. In any particular time period, however, sediment yield from a basin may be dominated by erosion from just a few of the deep-seated landslide features that are active. Some digital terrain-based procedures exist for recognizing areas where deep-seated landslides have occurred and others that might be used for analyzing the risk of future occurrence under altered hydrologic conditions.

Sediment delivery has been estimated from field and aerial photographic surveys of active landslide scars. Because large, deep-seated landslides tend to flow towards rivers for long periods of time, sediment delivery has also been calculated by estimating the mean flow rates towards channels. Similar to the procedure for shallow landslides, a first-cut digital terrain based approach for predicting sediment delivery from deep-seated landslides may rely on empirical studies to determine rates. Digital terrain analysis may then be used to explore correlations between topography, geology and land use and deep-seated landslide sediment loading to channels. Although models are not reliable for predicting absolute magnitudes of this sediment flux, they provide a

basis for analyzing the direction and approximate magnitude of changes that might result from the hydrologic consequences of land use.

In some areas, gullies are an important source of sediment to channels. These features are associated with deep-seated landsliding, with road and skid-trail disturbances, and with channel destabilization. A combination of fieldwork and aerial photography can document erosion and delivery rates and establish causality. Landsliding and gullies related to road failures can be included as part of the digital terrain models of these separate sediment sources. Destabilized channels, in which channel heads advance upstream into stored colluvium and form deep gullies, occur due to a change of hydrology or vegetation resistance. Digital terrain models have shown that such de-stablization is more likely to occur at channel heads that are relatively steep and drain large upslope areas (Dietrich et al. 1995). As for mass wasting, initial estimates of sediment delivery based on digital terrain analysis may have to rely on empirical correlations using well-documented field studies.

Dirt roads (native materials with no crushed rock armor) make up the majority of logging roads in Northern California. Use of these roads in the dry season crushes the roadbed sediment and generates abundant fine sediment (as anyone knows who has driven these roads in the summer). Rain onto these nearly impermeable surfaces washes the fines and commonly the surface wash spills into channels, leading to fine-sediment loading in rivers. The program SEDMODL uses digitized road coverages to estimate flux of sediment to channels (Boise Cascade 1999). SEDMODL is a transformation of the empirical procedure reported in Washington DNR Watershed Analysis Manual.

More work can be done in California to develop a digital terrain-based approach, which is guided by the many empirical studies on road-related sedimentation. Currently we know of no procedure that is based on or supported by quantitative field observations made in California. Yet northern California has more

intensive use of dirt roads than either Washington or Oregon, for example. This region generally has more erodible rock and soil types than regions of the Pacific Northwest. We are less confident in procedures for estimating sediment yield from roads along which mass wasting and wash are not clearly distinguished.

Models of sediment loading to channel networks from timber harvest began with empirically determined associations which could then be used, for example, in projecting the spatial and temporal sediment sources that would result from the diffusion of a road network through a forested mountain watershed (e.g. Reid 1981, pp. 139-143; Reid et al. 1981, p. 58). Mass wasting at that time had to be quantified by empirical means only, but some modeling capability existed for generalizing results from field sampling of sediment loading from road surfaces (Reid and Dunne 1984).

Benda and Dunne (1997a) and Benda et al. (1998) used an empirically based, stochastic approach to modeling the spatial and temporal dynamics of sediment loading from natural forests episodically disturbed by stand resetting fires and rainstorms. The approach has not yet been applied to timber harvest cycles, but there is no reason why this extension cannot be made. Lee Benda and Daniel Miller at the Earth Systems Institute (ESI, http://www.earthsystems.net/) in Seattle have now implemented these concepts in a stochastic model of landslide delivery of sediment to channels based on a digital elevation model, incorporating spatial databases of other watershed characteristics and weather phenomena, in a GIS format. The spatial and temporal patterns of sediment loading are generated in the model when hydrologic calculations indicate that sediment would be transferred to the channel system. The hydrologic and slope-stability calculations in turn are driven by probability distributions of rainstorm and fire characteristics, which encounter a landscape with its own spatial diversity of topographic and geotechnical properties. These properties may themselves evolve through time as fires diminish root strength, and landsliding and debris flows reset the depths of soil and sediment accumulations. The technique yields potential sequences of

sediment fluxes into channel reaches from shallow landsliding and debris flows, including those originating from roads. These computations give an estimate of the pattern of sediment loading to channels integrated over long time scales. However, Dietrich and Casadei have demonstrated that application of a similar model to the prediction of landsliding in a specific rainstorm encounters important discrepancies when compared with mapped landslides, --- probably because some potential landslide source areas with a strong topographic signature had been evacuated of colluvium during a large storm only a few decades earlier. Consideration needs to be given to how models that tend to over-predict landslide occurrence unless updated with soil depth information can be used in establishing a useful signal of watershed vulnerability to mass wasting and sediment loading to channels. More research is necessary on this topic.

It would be straightforward to extend this ESI model to incorporate timber harvest effects, including road surface erosion to compute the risk of various rates of sediment loading. Although not yet published in the peer-reviewed literature, this modeling capability has been checked against the results of field mapping of sediment sources and supplies, and will soon be documented for wider use. The original Benda and Dunne approach is also being extended by Lancaster and Grant as part of the Coastal Landform Analysis and Modeling Study (http://www.fsl.orst.edu/clams/projectf.htm), a joint project of the US Forest Service, Oregon State University, and the Oregon Department of Forestry, which aims to understand patterns and dynamics of ecosystems such as the Oregon Coast Range, and to analyze the aggregate ecological, economic, and social consequences of forest policies of different land owners in the Coast Range.

## V. Sediment Supply and Sediment Routing Along Channel Networks

Predicting sediment transport and deposition along channel networks is in some ways less advanced, but in other ways easier, than the prediction of sediment supplies from hillslopes. As indicated above, the general locations of sediment sources are easy to recognize through field observation or GIS-based modeling (roads, bedrock hollows, tributary junctions, etc.), but the intensity of the supply is a strongly nonlinear function of its driving variables (rainstorm size, gradient, etc.). By contrast, channel sediment transport responds more gradually to its forcing variables and though there are significant complications in applying standard engineering sediment transport functions to forested mountain streams, rates and particle sizes of transported sediment lie within ranges that are easy to document and explain. For example, it is usually straightforward to separate washload, which is quickly transported out of a watershed in suspension, from bed material load, which travels mainly along the channel bed. Conditions of deposition or initial motion are also fairly straightforward to specify and calibrate (Montgomery and Buffington 1998), so that one can fairly accurately predict where sediment of a given particle size is likely to come to rest and alter aquatic habitat.

Benda and Dunne (1997b) extended their modeling of sediment supplies to calculate the routing of washload and bed material down channel networks. The coarse-grained nature of their stochastic transport model emphasized translation of waves or slugs of bed material (hundreds to thousands of meters long) along the network at an average speed scaled approximately by measured values of particle transport and abrasion. This approach has been elaborated recently by Daniel Miller at Earth Systems Institute, Seattle, who uses both simple translation schemes and engineering sediment transport equations combined with probability distributions of streamflow to route sediment along channel networks defined in a digital elevation model.

The state of the art in sediment routing is complicated by the fact that certain untested assumptions about sediment mixing and the textural state of the channel bed

have to be made and the predictions are sensitive to these assumptions. However, the problem is under active research, and in the meantime it is possible to make calculations of the downstream fate of sediment that are consistently related to well-studied controlling factors and are testable. The methods are likely to be in a useful degree of development before any CWE team is staffed and supported. Physically based routing of sediment along channels that contain large woody debris requires keeping track of intermittent storage in and release from log jams, which has so far been a deterrent to this approach and the reason for coarse-grained empirically based predictions in those reaches.

## VI. Modeling Geomorphic Response and the Formation of Aquatic Habitat to Sediment Delivery

Although predictions of sediment migration along channel networks can indicate reaches that are vulnerable to prolonged, intense sedimentation, and the time scales and adjustment mechanisms associated with stochastic delivery of sediment to channels under changing management practices, the prediction of morphological change in aquatic habitat remains difficult, or at least undeveloped.

Digital terrain modeling can again play a central, enabling role in attempts to generalize information on the basin-wide extent of aquatic habitat and its susceptibility to change as a result of changes in sediment supply. Even though under currently available technology, small channels have no physical dimension other than elevation and location in digital elevation models, such data can be used in guiding, interpreting and extrapolating field work and should be used as a foundation for a general model linking ecological and geomorphic processes. River properties, such as their width and depth, the grain size of the bed, the presence or absence of bedrock, the tendency to develop pools, and their susceptibility to influence by LWD, are strongly influenced by

drainage area (a proxy for some geomorphically significant stream discharge) and channel gradient, which are readily determined from digital terrain models. The product of discharge and slope (divided by channel width) is proportional to the stream power per unit area of the bed.

For a given drainage area, bedrock dominated channels tend to occur on steeper slopes. Other channel properties tend to differ in fundamental ways with channel slope (e.g. Montgomery and Buffington 1997; Rosgen 1996). Sediment transport and erosion on channel gradients above about 0.1- 0.2 are probably dominated by periodic debris flows (Sklar and Dietrich 1998). On slopes between about 0.03 and 0.11, channel beds tend to organize into step-pool topography (Grant et al. 1990, Montgomery and Buffington, 1997), and the bed surface grain size in these channels is strongly influenced by large woody debris. Further downstream on slopes of about 0.001 to 0.03, bar-and-pool topography tends to develop and bed grain size may be predictable from estimates of bankfull flow depth and slope. Hence, there is an overall structure to channel properties that emerges from the downstream varying discharge and slope of rivers.

Stochastic inputs of sediment, local flood events, and changes in LWD loading can cause considerable variation about the central tendencies outlined above. At the very least the digital terrain based classification of channel types could serve as an organizing structure for stratified field sampling and for generalizing local measurements across the river network. It is now possible, however, to consider modeling episodic sediment inputs and to examine downstream fate of sediment (Benda and Dunne 1997a,b; Benda and Miller Earth Systems Institute, pers. comm.; Grant, US Forest Service, pers. comm.) by exploiting digital terrain models. Such models would form the foundation for estimating effects of future activities in a watershed on downstream channel conditions. While various university-based research groups are currently exploring aspects of the sediment routing problem, the State could play an important role in providing support to further develop models.

## VII. Cumulative Effects on Aquatic Habitat and Aquatic Biota

Conditions in the channel habitat determine the productivity and diversity of aquatic biota there, with different species and life stages requiring different ranges of conditions. The problem is severely complicated because there are multiple species of concern and because any particular species may have different habitat requirements at various life stages, a fact that underlies the value of whole-basin habitat modeling. Diverse stream habitats are considered vital for the productivity and diversity of aquatic populations, particularly for native species. These populations have evolved to exploit the sometimes highly specific range of conditions. The anadromous species may be affected by external conditions such as temperature and food supplies in the ocean, and access to rivers through altered reaches. However, the fitness of spawning and rearing habitats in low-order streams is a crucial part of sustaining numbers of species and individuals since the size and condition of fish as they leave fresh water affects their success in surviving predation in the ocean and estuaries (Bilton et al. 1982; Holtby et al. 1990; Wedemeyer et al. 1980).

Qualitative expressions of habitat value have so far been at least as useful as quantitative ones, but even the qualitative ones need to be related to watershed conditions, if predictions are to be made of land-use influences. A number of modeling efforts have addressed habitat components as examples of what would be available to answer questions arising in the conceptual modeling phase of a CWE analysis. The examples that we describe concern the dynamics of the channel bed and the survival conditions of salmonid eggs, riparian zone condition, the loading of large woody debris into channels and the resulting amount of pool habitat.

Formal predictive models have not yet been developed for the aquatic populations in the rivers of northern California coast, but certain qualitative

generalizations are possible about the changes to be expected from timber harvest as physical changes occur. The following synthesis is based on the experiences of many researchers familiar with the ecology of streams of northern coastal California. The impacts of timber harvest are likely to vary with location in the channel network. River networks can be divided longitudinally into four ecological zones: upland tributaries, middle reach mainstems, lowland floodplains, and estuaries. Coastal California, with a Mediterranean climate regime, typically has cool, rainy winters (October through March) followed by warm, dry summers (April through September). In stream channels, the summer drought season is more biologically active, and ecological interactions intensify as increasing densities of organisms accumulate in shrinking volumes of inundated habitat. There is considerable year-to-year variation in rainfall regimes, however. Multi-year droughts (with no scouring winter floods), as well as years with floods during the summer season, can both alter the hydrologic regimes experienced by river life.

In the convergent, hierarchical channel systems of watersheds, longitudinal variations in aquatic and riparian habitat support predictable spatial patterns of biota, and also transmit the impacts of land use downstream. Even swales at the heads of channel systems are linked to the channel biota because they provide habitat for moisture-seeking plants (e.g., redwoods, ferns), vertebrates (e.g., terrestrial life stages of salamanders), and invertebrates (e.g., isopods, crickets, millipedes) mobilizing food sources. The upstream limit for production of completely aquatic life begins some distance downstream in the channel system, where surface water is retained long enough for taxa to complete their life cycles. Under forest, the headwater streams (with gradients of 0.01-0.10) are cooled by shading and groundwater discharge. Low light and temperatures maintain conditions crucial for species requiring cool, moist, shaded environments (tailed frogs (Ascaphus truei), torrent salamanders (Rhyacotryton), certain species of diptera, odonates, mayflies, stoneflies and caddisflies, and some juvenile salmonids). Spawnable gravels accumulate where bedload is trapped behind

large woody debris, and predation is limited by the small volume and complexity of the habitat. Logging of headwater stream zones increases both high- and low-flow volumes, and removes shade, some large woody debris, and the source of future wood recruitment, allowing increases of temperature and a gross simplification of both spawning and rearing habitat, as well as diminishing opportunities for animals to disperse to nearby habitats across the cutover slopes. Unfortunately, there is no mechanistic modeling capability available for these processes and their disruption, but there are censuses in sample environments that could be transferred to undisturbed, logged, and recovering channels of various orders. There are large inter-channel variations in habitat conditions because of the disparate histories and high morphological variance between reaches. Attempts to provide integrated assessments of the effects of timber harvest on these habitats and biota appear to founder on this variance. However, if the analysis and questions to be answered relate to whole-basin conditions rather than to individual reaches or harvest plans, there is the potential to make quantitative statements in probabilistic terms that can be integrated over whole watersheds with adequate accuracy for public policy. These surveys need to be collated and extended in some systematic manner, and a CWE team could stimulate such activity on a contract basis.

Drainage areas and discharge increase erratically but in a statistically describable way, along with irregular morphological trends as channel slopes decrease (in the range 0.01-0.001), width-depth ratios increase, channel beds become less rocky and finer textured, and habitats change from cascades and stepped pools to plane bed ("glides") and meandering pools and riffles (Montgomery and Buffington 1998). These are the primary zones of gravel accumulation and water, flowing around channel bends and large woody debris molds these beds into spawning redds, riffles and pool habitat (Chapman 1988). Because the high water discharge forms a wider channel and keeps it free of tall vegetation, the inundated streambed during summer low flow is sunlit, warmer, and more productive than channels upstream. Algal productivity (and to a

lesser extent, terrestrial litter) support a diverse and productive river food web (Vannote et al. 1980) of aquatic insects and crustacea, which feed predatory insects and fish, and in turn feed larger fish and other vertebrate predators. The presence of large woody debris, supplied by mature riparian trees and upstream mass wasting, produces more widespread and deeper pools that provide shelter from high-speed flows, shelter from predators, and cool refuges where groundwater seepage causes the water to stratify. Thus, critical aspects of these reaches are the storage of gravel, a process that is favored by in-channel woody debris, and mature riparian vegetation, which also favors pools as well as shade and food. The reaches are disturbed by floods that scour and displace rock-bound algae and mosses, relatively immobile benthic insects, and young life stages of fish trapped within bed strata that become mobilized, impregnated, or buried with deposited sediment. Nevertheless, scouring floods are ecologically beneficial for at least three reasons. They cleanse and renew spawning gravels for salmonids and other native species such as lamprey; they reset prey guilds in the food web to earlier successional stages that better support the growth of juvenile salmonids and other small predators, and they favor native species over exotic species (bass, sunfish, bullfrogs) that have invaded from more sluggish habitats in midwestern and eastern US rivers and ponds.

Winter floods have these beneficial effects if rivers retain the vegetative and geomorphic structures that prevent spawning gravels from being washed away and pools from becoming shallower, and allow native biota to survive or repopulate after flood disturbances. In middle reaches of river networks, crucial high flow refuges for juvenile salmon and prey that support them are provided by 1) interstitial spaces between cobbles in the bed below the depth of scour (which is often the diameter of the median-sized bed particle); 2) lateral aquatic habitat, which in the incised, canyon-bound rivers common along the tectonically active California coast tend to be restricted (see also discussion below of alluvial flats); 3) undercuts maintained by bank-stabilizing riparian vegetation; and 4) large log jams (although these grow less important, even

under natural conditions, as mainstem channels expand downstream to widths that exceed the lengths of the larger available trees).

In addition to high-flow refuge, vegetational complexity and water-filled spaces in the beds of mainstems offer cover from predators that stabilize predator-prey interactions. Predator populations (juvenile fish that eat insects, larger fish that eat smaller fish and insects, birds and mammals that eat larger fish) benefit in the long term from refuges for their prey. "Living off the interest" (feeding on prey individuals exposed as they move between safe sites) provides a more stable energy supply than "living off the capital" and damaging its regenerative base. In pool-riffle habitats, variation in depth of habitats also provides refuge from predation. Small organisms (insects, juvenile fish) are safe from larger fish in shallow riffles and channel margins. Deep pools, especially those with logjams or boulders, give larger fish refuge from terrestrial predators like wading and diving birds. Deep pools also can stratify thermally, particularly if they are fed by cool groundwater inputs. These habitats can be crucial thermal refuges for large fish that summer in rivers, such as summer-run chinook in the Middle Fork Eel.

Timber harvests on hillslopes draining into middle mainstem reaches will increase fine sediment flux to channels and inputs of solar radiation. Removal of in-channel logs and riparian trees allows scouring of gravels, reduction of pool size, and destabilization of overhanging banks, leading to a simplification of habitat morphology. Pools and water-filled spaces in riverbeds will fill with sediment, reducing or eliminating habitat refuges. The impacts of these changes on biota are non-linear ---- removing the first 20% of the refuges (from predators, high flow, or warm temperatures) will have smaller effects than removing the last 20%. Therefore, the addition of more fine sediment will do much more ecological harm if rivers have legacies of excessive stored fine sediment from previous land use. Mainstem channel reaches with lower gradients, deeper pools, and wider alluvial valley-floor sediment

stores may delay the downstream transport of sediments by decades or centuries after the events that caused them, but eventually these sediments will pass to lowland rivers downstream. Methods for predicting these habitat changes from their fundamental mechanics are not well developed, but local empirical evidence can be extended to yield some credible predictive capability.

In lowland floodplain reaches (slopes < 0.001), the downstream effect of increased sediment flux from land use may have turbidity-related effects on fish feeding in the water column, but they should do little harm to the organisms that are adapted to cope with fine sediments. In the wide floodplain wetlands that once flanked lowland channels, grasses, reeds, and other fast growing wetland plants quickly covered and stabilize the sediments, themselves providing substrates where attached algae (periphyton) can grow if light penetration is sufficient. This food base is important as algal production on the bed and in the water column of lowland rivers is impeded by turbidity (Vannote et al. 1990). If lowland rivers have access to their floodplains, however, (increasingly uncommon in the Northern Hemisphere), aquatic invertebrate and fish production will be well supported by periphyton on floodplain grasses and other macrophytes (Forsberg et al 1993; Sparks et al. 1990; Power et al. 1995). In the Pacific Northwest, lowland rivers were important rearing habitats for cutthroat trout and for coho, pink and chum salmon, but access to these off-channel rearing habitats has been reduced as the channels have been diked and the floodplains developed. The loss of these vast rearing areas has made the small pockets of suitable habitat remaining upstream even more crucial to the persistence of species such as coho.

Estuaries are important rearing areas for sub-adult salmon after they have reached a size that is less vulnerable to the many predators that concentrate in these habitats. Along the northern California Coast, many rivers empty into tidal lagoons that are partially or completely blocked, for various lengths of time from the ocean by sand spits. Birds, various large fish, and marine mammals prey on salmonids in these

habitats. If upstream habitat degradation has left the smolts undersized, or forced them out of freshwater habitats too early, the fish will be much more vulnerable to predators in estuary and open habitats. Many of the estuaries themselves have been degraded by the effects of land use in their watersheds in recent decades (Breitburg 1988, Breitburg et al. 1994, 1997), and these conditions need to be factored into any assessment of the cumulative effect of new logging cycles on anadromous fish. However, again the predictive capability is seriously limited by the lack of population models that contain information on habitat quality.

The lack of predictive population models, even of the coarse-grained, conceptual type employed by Ziemer et al (1991) for spawning gravel availability (though not fish or species numbers) remains a serious limitation for resource managers and policy makers balancing competing demands on forested ecosystems. For the foreseeable future, it is likely that the modeling of CWEs of timber harvest on fish resources will have to rest on predictions about physical habitat change, and either (a) formalized judgments (expert-system advice) about the probable direction and approximate magnitude of changes in aquatic populations resulting from habitat changes; or (b) empirical statistical relationships between organism numbers and habitat variables. In either case, the assessment of risk to populations as a result of land use will need to be made in the face of other influences on the life cycle of each organism. Marshalling the required information and arguments will require significant conceptual leadership. More intensive and structured programs for monitoring organisms will be required.

Most of the attempts at modeling the biological consequences of land use in forests have involved the physical habitat, with the implication being drawn that habitat quality is necessary, if not always sufficient for sustaining the diversity and productivity of certain highly valued species and their food sources. Thus, Ziemer et al. (1991) used stochastic simulations of sediment supply, transport and in-valley storage during hypothetical centuries-long timber harvest cycles in a schematic fifth-order basin

(~40 $mi^2$) with channel characteristics typical of northern coastal California. They calculated random sequences of sediment supply from landslides on logged hillslopes and roads to the channel system. A large portion of this sediment was stored in tributary valleys, as indicated by sediment budget studies in the region. Rates of sediment transport along the network were calculated with an engineering transport equation. Parameters and landscape characteristics used in the model were estimated from basins in northern California or credible analogs. Episodes of sediment deposition and scour occurred in various reaches in response to the time-varying supply and removal rates. Salmon eggs deposited in the channel according to recorded seasonal patterns were subject to scour or smothering by sediment. The model yielded long sequences of egg survival calculations that could be compared between centuries, harvest intensities, different basin characteristics, and other scenarios. In particular, the model allows one to examine the probable long-term effects of logging cycles that could be assessed in any empirical way. The results suggest hypotheses that could motivate searches for field evidence as validation.

A vital element in the quality of aquatic habitat is the geometric complexity and therefore richness of micro-habitats imposed on the channel by the presence of large woody debris that enters from the riparian zone and to a lesser extent from upstream (Bisson et al. 1987). In a rigorous, 8-year field study with a “before-after-control-impact” design Solazzi et al. (2000) showed that increasing winter rearing habitat in two Oregon streams tripled over winter survival of juvenile coho compared to the level in unmodified streams. The supply of woody debris from the riparian zone is strongly affected by the species composition and age structure of the riparian forest. Harvesting mature trees from this zone severely reduces the supply rate of this debris, and most riparian zones in timberlands are now severely depleted. The effects of this reduction on woody debris loads in channels have been aggravated by policies of actively removing wood from channels and by processes of decay and downstream transport of smaller woody fragments. Thus, during the past two decades a considerable amount of

empirical study has been invested in riparian vegetation dynamics and wood supply to channels, and the results are beginning to be formalized and generalized through models that predict wood loading, woody fragment sizes, and resulting areas or volumes of pools, and the expectable evolution of these habitat characteristics under various scenarios of forest succession and management. An important example is the "Riparian-in-a-box" model of Kennard et al. (1998), who developed equations describing tree growth and mortality, supply of wood to the stream as trees fall, and the accumulation, decay, and downstream loss of fragments of various size. Beechie et al. (in press) combined this model with the USDA Forest Service Forest Vegetation Simulator, which calculates riparian stand dynamics and thus wood supply. The combined model is used to predict the load of woody debris of various sizes per unit length of channel. Empirical relationships defined through fieldwork are then used to convert wood loading to the area of pool habitat in each reach as wood load varies through time in response to forest succession and timber harvest.

Benda and Sias (1998) have investigated the origin of spatial and temporal variations in wood loading in natural forests by constructing a stochastic model of five landscape processes that supply wood (from riparian growth and tree fall, bank erosion, mass wasting), decompose it, and transport it downstream or into floodplains. Variations in the average magnitudes and the temporal variability of wood storage in channels thus result from differences in the rates of these processes within and between landscapes. The Earth Systems Institute group in Seattle (http://www.earthsystems.net/) is now constructing DEM-based maps of predicted wood loads for hypothetical environmental histories, based on the slowly accumulating database of field studies referred to above.

These riparian models were constructed for comparison of woody debris delivery and shade provided by different riparian management options. They are useful for comparisons of broad patterns (generally high values under condition A; smaller

values under condition B), but do not accurately determine absolute values that can be reliably compared with field measurements in individual, short reaches. The predicted values can change dramatically with a change in selected treefall or LWD depletion rate, although increasing amounts of field data provide constraints for the reliable values of these controlling parameters.

An example of the emerging capability for modeling habitat influences on animal populations is the Ecosystem Diagnosis and Treatment (EDT) Model, developed by Mobrand Biometrics Inc. for the Columbia River Multispecies Framework (http://www.nwframework.org/index.html). The model computes fish mortalities at each life stage from environmental conditions along the fish's migration pathway through the ocean, harvest, the reaches of a stream network, lakes, dams, and other habitats. In each environment survival is calculated with a Beverton-Holt survival function based on habitat quality ratings. The habitat-survival relationships are currently derived from published scientific literature and expert panels, and are expressed as a set of process-related rules. The model predicts abundance, life-history diversity, productivity, and spatial distributions of fish populations. It represents the interaction of time-varying environmental conditions and the opportunistic nature of each species. Conditions in each stream reach can vary through time in independent or inter-related ways, and the model can assimilate historical conditions, where they are considered relevant in a particular application, and hypothetical future conditions for scenario building or risk analysis. The limitation of the model is its heavy reliance on estimation of many parameters, but it represents a promising way of recording and computing the implications of community knowledge bases, and of estimating the limits of prediction that result from uncertainties in the knowledge base.

The linkage of environmental and population models described here should be based in a digital terrain framework. This will enable spatially explicit analysis, which must lie at the heart of CWE evaluations of THPs. Frameworks for this approach are

already being built by various groups, and CDF and other agencies could take a leadership role in these developments.

## VIII. Cumulative Effects on Water Quality

Predictions of stream water temperature at a basin scale are now possible using widely available, or easily gathered environmental data. An example is the BasinTemp® model developed by Stillwater Sciences (2000), which generates digital maps of reach-scale average water temperatures. The method uses a heat-balance model, incorporating: regional solar radiation; regionalized stream flows; maps of streamside vegetation and its age made from satellite images or aerial photos; a local empirical relationship between channel width and drainage area; and digital topography to define channel networks, elevation ranges, and topographic shading. Although some local temperature measurements are needed for calibration of the model, it can be applied quickly and efficiently to new large basins. Current applications emphasize late-summer conditions, when flows are minimal and temperatures critical for biotic populations, but they could be extended to other seasons wherever necessary. The method allows an analyst to examine the effects of altering stream flows and riparian tree heights over parts of a watershed on the spatial pattern of stream temperature.

Turbidity can be estimated from empirical rating curves relating this parameter to flow for typical landscape and timber harvest patterns, or from sediment budgets calibrated with suspended sediment sampling (Reid and Dunne 1996; Reid et al. 1981; Environmental Protection Agency 1999).

At present, there is no strong capacity for predicting chemical water quality, some aspects of which are of intense concern to downstream residents. Nutrient losses from managed forests during harvest and fertilization have been quantified in some

watershed monitoring studies, and the data have raised concerns about the potential for eutrophication of lowland and estuarine habitats. However, the significance of these effects remains unclear, and the predictive capability, even for the chemical changes themselves, remains empirical and unclear. Prediction of the solute dynamics of stream ecosystems is being developed in pilot projects such as the multi-site collaboration known as Lotic Intersite Nitrogen eXperiment (LINX), a collaborative study of nitrogen cycling in streams involving simulation modeling, field tracer (15N) additions, and inter-site comparison (http://sparc.ecology.uga.edu/webdocs/linx/). The collaboration explicitly uses models from the earliest stages of watershed investigations to assimilate field measurements, including the monitoring of injected tracers, and to plan refinements of empirical investigations. However, in most regions, the best form of prediction still appears to rely on the transfer of empirical results from monitored watersheds in comparable biomes and harvest regimes.

A water quality issue of particular interest to some residents of timber harvest regions is whether pesticides or their degradation products persist for long enough to be transported downstream to recreational or residential reaches. Even Technical Rule Addendum No. 2 of the Forest Practice Rules points out that: “Potential sources of chemical CWEs include run-off from roads treated with oil or other dust-retarding materials, direct application or runoff from pesticide treatments, contamination by equipment fuels and oils, and the introduction of nutrients released during slash burning or wildfire from two or more locations.” It is not clear why the concern should be limited to pesticides or nutrients that might be released from “two or more locations.” This appears to be an example of misdirected complexity that could overlook direct effects of these contaminants originating from a single location.

However, the application of forest herbicides is rarely addressed in THPs. Application rates are not well documented and effects on biota are generally unknown except in laboratory situations. There is a lack of monitoring data, except for the few

studies conducted that have shown little or no evidence of transfer of pesticide residues to aquatic ecosystems or animals. There is also no predictive modeling capability. It is suspected that fat-soluble pesticide constituents may be transferred by runoff from roads that are sealed with oil, but there are few of these in the north coast of California and no experiments have yet been conducted to measure biological responses to this potential source. Even consistent and credible, qualitative predictions of watershed-scale effects of pesticide application await resolution of some of these technical issues, but the CWE modeling efforts of runoff and sediment transfer into aquatic habitat outlined above could provide a framework for field studies that might yield some predictive capability.

## IX. Methods for Regional GIS-based Assessments

The regional GIS-based survey to highlight critical watershed conditions in need of immediate analysis or special conservation programs would compile and (where necessary) generate digital information on the spatial pattern of physical, chemical, biological and socio-economic properties of California landscapes. Digital maps of topography, stream channel networks, lithology, landslides (from CDMG or other sources), roads and skid trail, fish distribution, vegetation cover, and THP submissions can all be combined into a common geographic framework.

Through the use of available software, these digital maps can be overlain efficiently and combined into indices of relative rankings of ecosystem values and risks for individual watersheds. For example, salmonid habitat is limited by bed-material grain size, flow depth and flow velocity to channel slopes generally less than about 8%, and the fish do not use sand bedded channels for spawning, early rearing or overwintering. Channel slopes can be determined from overlays of the channel network on digitized contour lines. Work by Dietrich's group has demonstrated that grain size

can be estimated from these calculated gradients, and potential fish occurrence estimated. Hence from such digital information on river channels, it is possible to generate an approximate map of potential salmonid habitat in all the watersheds of a region.

One common risk to this habitat is excessive sedimentation, which could be indicated by the spatial density of landslide maps that CDMG have already digitized, or by some digital terrain model for slope instability, such as SHALSTAB (Dietrich and Montgomery 1998, Montgomery and Dietrich 1994). Stillwater Sciences (2000) combined channel classification and hazard assessments of erosion potential to generate what was called a Watershed Relative Risk Index to rank watersheds for further analysis (Olson and Orr 1999). Other tools are now available (e.g. SEDMODL, SINMAP, 1998), and there will be further development of digital terrain-based tools that will enable a broad, rapid analysis of land-use and ecosystem risk and status. The State-led program that we are suggesting could exploit and contribute to the development of these tools.

Such regionally applied tools as SHALSTAB and GIS-based channel classification could be used to assign timber harvest specific prescriptions until watershed analysis is done. Channel classification could also assist in delineating river reaches, which would benefit from additions of large woody debris and from downstream elimination of culvert blockage. Rapid field assessment coupled with GIS-based analysis could map river reaches where the greatest benefit of immediate mitigation could be performed. This is a path specifically recommended by the Science Review Panel (p.30, 1999).

## X. Research

There are four general topics that need research: linkage analysis, methods for field quantification, monitoring methods, and quantitative model development. The first, which, as suggested above lies at the heart of CWE analysis, is the quantification of

the linkages between land-use-induced changes and ecosystem response. At present, for example, it is not possible to plot a graph showing quantitatively how a biologically meaningful habitat property in a river varies with changes in sediment loading. Without such a relationship it is not possible to state how much reduction, say, in sediment from landsliding or from road wash is needed to obtain a particular habitat goal. Some recent research comes close to reaching this relationship relating abundance of fines in pools to inferred sediment loading in a watershed. The broad survey by Knopp (1993) focused on identifying response variables to a qualitative measure of timber harvest intensity. The linkage study must be much more quantitative than this survey to be used in management decisions.

There are many hurdles to quantifying biotic response to land use. There are few reaches of river free of anthropogenic disturbance, and none draining large watersheds. The anthropogenic disturbance has a complex history and any particular reach of channel may be on some path of recovery, increasing disturbance, or may be transformed without the possibility of recovery because of its history of use. Most reaches have experienced more than one disturbance. For example, a channel may have experienced splash dam releases in the early part of the century, active wood removal in the 1950-1980 period, and intense skid-trail construction and widespread introduction of first coarse sediment and then chronically fine sediment up to the present. Coarse sediment travels tens of meters to thousands of meters per year, so that in large river systems sediment introduced during peak harvest periods --- typically in the period 1960-1980 --- will still be traveling through the river network (albeit diminished by particle breakdown during transport). Sand and finer sediment tends to travel in suspension and consequently be flushed from gravel-bedded rivers relatively quickly. The presence of excessive fines in a reach suggests contribution from current or recent sources of sediment. While habitat condition relative to biotic potential can be readily quantified, it may be difficult to ascertain which events (and possibly a combination of them) led to the state of the reach. The end result of studies devoted to

linkage quantification should be quantitative relationships that guide modeling of CWEs and the consequent development of policies and prescriptions designed to change flows of sediment, water, wood and possibly nutrients and heat (for water temperature) to restore water quality and ecosystem functioning to conditions that are more desirable to the stakeholder community.

The second need for research is motivated by the standardization of methods with the goals of obtaining: 1) reliable interpretations about causality, 2) data that can be compared and used to test general hypotheses, and 3) measurement sites that can be revisited after prescriptions are implemented to document changes in conditions. The last of these goals would form part of an exercise in adaptive management, wherein policies and prescriptions could be refined as a result of monitoring the response of watersheds to a first, exploratory management strategy. While watershed analyses have been conducted for many years now, it is evident that the three listed goals are rarely met. This is partly due to the lack of clearly stated questions that motivate collection of particular kinds of data. But it is also because there has been no standardization of techniques, which are known to meet the goals given above. Surprisingly, even characteristics as seemingly straightforward as riverbed grain size can be non-trivial to document. It is rarely stated what exactly one expects to interpret from a measurement of grain size, but it is estimated because it is a property of the river. If the bed has a patchy distribution of grain sizes (as is common) what does a single median grain size mean and how should it be measured? Is the surface grain size more important than the subsurface? If the river has a coarse, bouldery bed, partly mantled with patches of gravel, what grain size should be documented? What grain sizes are biologically significant? While some standards could be set already on the basis of current knowledge, others will need to be developed and tested.

The third research topic depends on the success of the first two. There will be pressures to determine if prescriptions that emerge from CWE analysis in a watershed

analysis program lead to improved ecosystem function, Monitoring watershed function can be expensive and a waste of effort unless it is set up to test well-stated, quantitative hypotheses. An example of a poor monitoring plan would be to monitor the suspended sediment in a river draining a large watershed where various kinds of prescriptive measures have been applied in association with ongoing timber harvest. In such a case, it may take decades to detect significant change in suspended sediment load because of annual variability in storm events and landslide occurrence. During that time, an entire suite of changing land-use intensities and forest practices may have affected the watershed, and there is no hope of isolating particular effects or of identifying effective prescriptions. Thus research is needed to design monitoring programs so that reliable methods are used to test well-stated hypotheses. Because this is not widely practiced, hypothesis-based monitoring needs to be treated as experimental until it becomes standardized.

**Z'BERG-NEJEDLY FOREST PRACTICE ACT 213 Division 4, Chapter 8, Public Resources Code**
**Effective January 1, 2007**

**Article 1. General Provisions**

**4511.** This chapter shall be known as the Z'berg-Nejedly Forest Practice Act of 1973.

**4512. Findings and declarations.**

**(a)** The Legislature hereby finds and declares that the forest resources and timberlands of the state are among the most valuable of the natural resources of the state and that there is great concern throughout the state relating to their utilization, restoration, and protection.

**(b)** The Legislature further finds and declares that the forest resources and timberlands of the state furnish high-quality timber, recreational opportunities, and aesthetic enjoyment while providing watershed protection and maintaining fisheries and wildlife.

**(c)** The Legislature thus declares that it is the policy of this state to encourage prudent and responsible forest resource management calculated to serve the public's need for timber and other forest products, while giving consideration to the public's need for watershed protection, fisheries and wildlife, and recreational opportunities alike in this and future generations.

**(d)** It is not the intent of the Legislature by the enactment of this chapter to take private property for public use without payment of just compensation in violation of the California and United States Constitutions.

**4513. Intent of Legislature.** It is the intent of the Legislature to create and maintain an effective and comprehensive system of regulation and use of all timberlands so as to assure that:

**(a)** Where feasible, the productivity of timberlands is restored, enhanced, and maintained.

**(b)** The goal of maximum sustained production of high-quality timber products is achieved while giving consideration to values relating to recreation, watershed, wildlife, range and forage, fisheries, regional economic vitality, employment, and aesthetic enjoyment.

United States Department of Agriculture | Forest Service Pacific Southwest Research Station | Redwood Sciences Laboratory | 1700 Bayview Dr. Arcata CA 95521

24 May 1999

Hon. Fred Keeley
Speaker pro Tem
Assembly of the California Legislature
State Capitol
P.O. Box 942849
Sacramento, CA 94249-0001

Dear Assemblyman Keeley,

Thank you for your interest in the topic of cumulative watershed impacts. I have been working with this issue for more than a decade as a research geologist with the USDA Forest Service. Some of my research has focused specifically on issues relevant to assessment of cumulative impacts on private and state lands in California, and some of this work has been funded by the California Department of Forestry and Fire Protection. I have also worked with Federal agencies in the development of watershed analysis methods in support of the Northwest Forest Plan, and in doing so I have become familiar with logistic, sociological, and institutional problems involved in cumulative impact analysis. Most recently, I have been asked to advise staffs of the EPA, the Water Quality Control Board, and the National Marine Fisheries Service on provisions of particular Timber Harvest Plans, Sustained Yield Plans, and Habitat Conservation Plans as they relate to cumulative watershed impacts.

You asked me the questions, “As currently implemented, are existing California forest practice rules effective in preventing cumulative watershed impacts, including flooding?” and “What kind of measures might improve the effectiveness of forest practices rules for avoiding forestry-related cumulative watershed impacts?” I have enclosed a brief paper written in response to these questions. My discussion here draws heavily on the reviews of THPs and SYPs that I have prepared for state and federal agencies, on my experiences with development of watershed-scale assessment methods, on my own research, on research published by others, and on numerous discussions with state and federal agency personnel.

I hope the enclosed discussion is useful to you, and please let me know if you have any questions.

Sincerely,

Dr. Leslie M. Reid

cc: Dr. Garland Mason, USDA Forest Service

# Forest Practice Rules and cumulative watershed impacts in California

Dr. Leslie M. Reid, USDA Forest Service Pacific Southwest Research Station
Redwood Sciences Laboratory, 1700 Bayview Drive, Arcata CA 95521

## Summary

1. There is nothing mysterious about cumulative impacts. Most environmental impacts are influenced by multiple land-use activities, so most impacts are cumulative impacts. Projects must be evaluated to understand how they will influence existing or potential future impacts, and this is the essence of a cumulative impact assessment. Examination of recently approved THPs and SYPs indicates that plans are being approved that do not contain technically valid cumulative impact assessments.

2. As currently implemented, California Forest Practice rules have not prevented the cumulative watershed impacts that led to the recent listing of multiple northern California streams as impaired by sediment under section 303(d) of the Clean Water Act.

3. Recent studies demonstrate that current Forest Practice rules are not adequate to prevent forestry-related changes to the production and transport of sediment, water, and woody debris in watersheds. Changes in these "watershed products" are the most common causes for downstream cumulative impacts.

   - *As currently implemented, the Rules are not sufficient to restrict excess sediment production from logging-related activities to levels that will not accelerate reservoir sedimentation, increase flooding by channel sedimentation, and degrade water quality. Several studies have shown excessive landsliding rates on recently logged slopes, and recent monitoring indicates that turbidity levels during and after logging can be out of compliance with water quality regulations.*
   - *The Rules are not sufficient to maintain the composition, size, and quantity of in-stream wood necessary to protect channels from increased disruption by debris flows or gullying or to provide adequate habitat for fish and wildlife.*
   - *The Rules are not sufficient to prevent pervasive hydrologic changes due to the maintenance of immature vegetation cover over large portions of watersheds.*

3. A variety of measures could improve the ability of Forest Practice Rules to avoid cumulative watershed impacts. Of these, the most effective might include:

   - *A provision allowing regulation of the rate of logging in a watershed*
   - *Improvement of cumulative impact assessment methods, including a provision for a preliminary watershed assessment to be done by interagency staff. This assessment would identify issues of concern, the impacts affecting them, and the causes of those impacts. The watershed assessment would provide the background information needed to analyze cumulative impacts of future projects anywhere in the watershed and would provide guidance for carrying out such analyses.*
   - *Giving authority to staff of relevant departments (i.e., Water Quality Control Board, Department of Fish and Game, etc.) for decisions falling within the purview of those departments' areas of expertise.*

## Introduction: the nature and cause of cumulative watershed impacts

The concept of "cumulative watershed impacts" is confusing to many because it seems very abstract. However, the word "cumulative" simply indicates that the impact is influenced by multiple activities, as are most environmental impacts. In reality, then, almost all off-site environmental impacts are cumulative impacts. When impacts involve the transport of water, sediment, or woody debris through a watershed, they are referred to as "cumulative watershed impacts." Cumulative watershed impacts are of considerable concern because they are responsible for much of the damage to property and to public-trust resources that occurs away from the site of a land-use activity.

Watershed impacts can accumulate through space, as when sediment from multiple upstream sources begins to fill a reservoir. They can also accumulate through time, as when first-cycle logging depletes streams of large woody debris, allowing mudflows caused by second-cycle logging to travel farther downstream and grow to more destructive sizes. Cumulative impacts can also result when a single resource—a salmon population, for example—is impacted by multiple mechanisms, such as habitat modification, degraded water quality, and construction of dams. In most cases, the severity of an impact increases as its duration increases, so prolonging the duration of an impact is itself a cumulative impact on the affected resources.

An environmental impact cannot be effectively prevented or managed without understanding the variety of influences that contribute to it, and the likely effects of a proposed activity cannot be assessed without understanding existing levels of impact and its causes. The intent of a cumulative impact assessment is to determine how the potential influences of an activity will interact with those of other activities in a watershed. It is not a special kind of assessment; it is simply an environmental impact assessment that places the planned activity in the context of the surrounding activities and existing conditions in the watershed. If the cumulative impact of concern is flooding, for example, a potential project might be evaluated to determine how it will influence storm runoff and downstream sedimentation and to determine whether the resulting changes, *in combination with other past or likely future changes*, will contribute to downstream flood damage. Without a mandate to evaluate cumulative impacts, assessment for such a project would likely conclude that the project, considered in isolation, would have only a small influence on storm runoff and downstream sedimentation. Without a cumulative impact analysis, the project appears to be benign: *by itself*, the project could not cause a flood, even if the combination of similar past projects throughout the watershed has already caused increased flooding, and even if the proposed project would further increase the flood hazard.

Because impacts can accumulate through time and space, they may take a long time to become evident, and they may occur a long distance from the activities that generate them. For example, landslides high in a watershed can introduce gravel into streams, but it may take decades for that gravel to be washed far enough downstream to become a problem at a particular site. By the time the impact becomes evident, it is too late to solve the problem. Land-use management for effective control of cumulative impacts must therefore be proactive: problems must be averted before they become irreversible. Effective oversight of land-use activities therefore requires effective assessment of whether proposed activities will contribute to aggravation of environmental impacts.

## Question: As currently implemented, are existing California forest practice rules effective in preventing cumulative watershed impacts, including flooding?

Several studies carried out recently in northwest California have demonstrated that cumulative watershed impacts have occurred despite the continued implementation of California's Forest Practice Rules. In Bear Creek watershed, for example, a survey of recent landslides showed that rates of

landsliding on areas logged in the previous 15 years is about 9.6 times higher than rates on lands with forests older than 30 years (PWA 1998a, Reid 1998, Reid 1999). As currently implemented, modern forest practice rules thus are unable to prevent nearly a 10-fold increase in landsliding rate in this watershed. Results from nearby watersheds show similar increases by factors of 3 to 13 (PWA 1998b, Michlin 1998, PWA 1999). In each case, such landslides were found to be the major source of sediment in the watersheds.

Additional information suggests that even in the absence of major landsliding, the implementation of current forest practice rules can be associated with increased turbidity levels in streams. Results of a monitoring program in northwest California, for example, suggest that logging and associated road use have resulted in a five-fold increase in turbidity over natural levels at some sites (Reid 1999), thus generating turbidity levels that are out of compliance with objectives of the Basin Plans that had been designed to satisfy requirements of the Clean Water Act. Likely sources for this excess sediment include winter traffic on logging roads, minor landsliding, and destabilization of small channels.

Increased sediment loads are a major influence on downstream cumulative impacts of concern in northwest California and elsewhere. Such impacts include:

- *Harbor sedimentation*
- *Modification of estuary habitat important to chinook salmon*
- *Sedimentation of oyster farms*
- *Reduction of channel conveyance and aggravation of flood hazard*
- *Infilling of channel pool habitat important to coho salmon and steelhead trout*
- *Infilling of reservoirs constructed for flood control, water supply, and power generation*
- *Water quality degradation resulting in constraints on domestic and agricultural use*
- *Water quality degradation resulting in damage to aquatic ecosystems*

Where these or similar problems exist, any additional contribution of sediment above naturally occurring background rates contributes to an already significant cumulative impact. That such cumulative impacts already exist is evident from the recent listing of more than 20 northern California waterways as impaired by excess sediment under section 303 (d) of the Clean Water Act.

Changes in the amount of woody debris in channels also can result in downstream cumulative watershed impacts. Woody debris is a critically important component of streams in forested areas. In the smallest streams, logs act as check-dams that store sediment eroded from hillsides. When landslides occur, the wood catches much of the sediment before it reaches larger channels. Where a landslide triggers a mudflow, abundant woody debris just downstream of the initiation site may halt the debris before it reaches a larger channel. On larger channels, wood also provides an important element in the habitat of aquatic organisms. In addition to creating pool habitat for salmon and trout during the summer, large pieces of wood pond water and create refuges for fish during winter floods. Wood must be of the appropriate distribution of sizes and species if it is to function properly in a stream system. Conifer logs are generally more decay-resistant and so are more effective in channels than riparian hardwoods, and large logs are more effective than small ones. The progressive loss of large pieces of coniferous wood from streams due to continued logging of riparian zones and continued salvage of logs from channels has led to widespread changes in channel form and to impaired aquatic habitat quality.

Current forest practice rules allow these cumulative impacts to increase in severity in part because specified buffer strip widths are too narrow to allow sufficient recruitment of large pieces of wood and because logging is allowed in buffer strips. Further, the lack of any requirement for buffer strips around the smallest, steepest channels will eventually result in the complete loss of full-sized

wood at these locations when the residual old-growth pieces eventually decay. This loss is likely to provoke destabilization of these channels and increase the destructiveness of landslides and mudflows.

A third important mechanism for downstream cumulative watershed impacts is hydrologic alteration. Forests influence runoff by intercepting and evaporating rainfall before it hits the ground, by extracting water from the soil and evaporating it through foliage, and by slowing rates of snow melt. Data from Caspar Creek, California (Ziemer 1998, Reid 1998) show that logging of this second-growth redwood forest has increased flood peaks in completely clearcut watersheds by an average of 27%, and that the effect is proportional to the amount of forest cover removed in the watershed. Work in Oregon suggests that similar effects may occur where removal of forest canopies accelerates snowmelt when warm rain falls onto a snowpack (Harr 1986). Many of the most destructive floods in California have resulted from rain-on-snow events. The presence of roads associated with logging and other activities also affects watershed hydrology by increasing both runoff volume and speed.

In comparison to recently logged land, then, the presence of forest vegetation is expected to decrease overall runoff volumes, decrease average soil moisture levels, and decrease flood peaks in some areas. These conditions are important in controlling the composition and dynamics of downstream aquatic ecosystems. High peak flows and increased runoff volumes increase the depth and duration of scour in stream gravels, thus destroying salmon redds (which are the “nests” that salmon dig in stream channels to protect and nurture their eggs). High peaks and increased runoff also contribute to accelerated bank erosion and pervasive modification of channel forms. Flooding damages downstream properties, lowering property values, and accelerated channel migration provoked by high flows can undermine and destroy structures. The magnitude of the hydrologic changes depends on the proportion of a watershed that is in hydrologically “immature” condition. In timber lands, this proportion is controlled by the rate of cut in the watershed, but there is no provision in the California Forest Practice Rules for regulating the rate of cut or extent of roading in a watershed.

## Examples

The mechanisms of change described above—alterations in the production and transport of sediment, wood, and water—interact to cause downstream cumulative impacts. Such impacts are difficult to comprehend in the absence of concrete examples. For illustration, we will consider three kinds of cumulative watershed impacts of concern in California and elsewhere: reservoir siltation, flooding, and degraded water quality.

In the case of reservoir siltation, the impacts fall on those who depend on the functioning of the reservoir. As reservoir capacity decreases, water available for domestic and agricultural use decreases; the level of protection from flooding decreases; and water available for dry-season power generation decreases. If these functions are to be maintained at levels intended by the original design, new reservoirs would need to be constructed. Accelerated reservoir siltation rates (i.e., rates above those expected when the reservoir was constructed) reflect the combined inputs of sediment from land-use activities throughout the upstream watershed. The cost of accelerated erosion is borne by the taxpayers and utility and irrigation district customers who must pay for increased water treatment costs and for development of new water sources. Currently, Forest Practice Rules are designed to ensure that practices are generally used that are known to be less erosive than others. However, the studies cited above indicate that even the less erosive practices can result in significant sediment inputs. Where any increment of accelerated erosion aggravates an already existing impact, adequate regulation would require that a proposed activity not contribute further to the existing problem. This approach is similar to that being conducted under voluntary agreement in the Mattole watershed. In this area, Timber Harvest Plans (THPs) are intended to be conducted according to a “zero net discharge” strategy: the additional

sediment contributed by a THP is intended to be mitigated by rehabilitation of existing erosion problems so that the net effect of the activity is to promote—or at least not prevent—recovery.

Increased flood hazard can result from upstream land use activities in several ways. Decreased storage potential due to siltation in flood-control reservoirs can increase downstream flood risks; increased upland erosion can cause sedimentation in downstream channels, thereby decreasing flow capacity and increasing flood frequency; and altered hillslope hydrology can generate more runoff in a shorter period and so increase flood flows. Costs of increased flood hazard are borne by those impacted by the flooding, by consumers who depend on goods produced from lands impacted by flooding, and by taxpayers who underwrite federal and state provisions for emergency funding. In the case of altered runoff, the size of the change depends on the proportion of the watershed over which runoff has been altered. Currently, the Forest Practice Rules contain no provision for ensuring that the proportion of a watershed's area that is logged in a given period is low enough to ensure that flood hazard is not significantly increased in areas susceptible to such changes.

Increased stream turbidity increases water treatment costs for domestic use, prevents some agricultural and recreational uses, and decreases habitat quality for aquatic biota. Costs are thus borne by utility and irrigation district customers, downstream water users who must find alternative water sources, and those who depend on aquatic resources for their livelihoods, such as recreational service providers and the fishing industry. Current Forest Practice Rules do not provide for maintenance of buffer zones around Class III channels as "filter strips" to keep surface erosion from reaching channels, and existing provisions for road-surfacing standards and winter road use continue to permit significant erosion from road surfaces. In this case, too, provisions for controlling rate of cut in a watershed may be necessary for reducing chronic turbidity to levels that will not impact beneficial uses of water.

**Question: What kind of measures might improve the effectiveness of forest practices rules for avoiding forestry-related cumulative watershed impacts?**

To identify changes that might be useful for avoiding forestry-related cumulative watershed impacts, it is first necessary to understand what is causing the current problem. Over the past two years I have, at the request of various state and federal agencies, examined two Sustained Yield Plans (SYPs) and portions of six proposed and recently approved THPs. I have also reviewed the California Department of Forestry's official responses to agency comments on several of these plans, I have reviewed numerous supporting documents that provide insight into aspects of the problem, and I have discussed the issues at length with state and federal agency personnel. The material I have reviewed suggests that causes for the problem lie in three general areas. First, in the cases I examined, the standard Forest Practice Rules were not protective enough to avert cumulative impacts. Second, cumulative impact evaluations submitted with the THPs and SYPs I examined did not adequately evaluate the potential cumulative impacts of the plans, so that the standard rules could not be modified effectively to avert cumulative impacts. Third, the expertise available in state and federal agencies did not appear to be appropriately employed during the review process.

Aspects of the first problem have been outlined above in the discussion of cumulative impact mechanisms. If Forest Practice Rules were more capable of preventing accelerated erosion, modifications to woody debris loads, and watershed-scale hydrologic change, cumulative impacts would be less likely, even in the absence of other measures. Appropriate changes might include requirements for:

- *Increased riparian buffer-strip widths*
- *No-cut zones within buffer strips*

- *Buffer strips on small channels*
- *Long-term maintenance commitments for all parts of the road system*
- *Discontinuing use of certain gravel-surfaced roads during periods of wet weather*
- *Regulation of silvicultural methods on slopes susceptible to landsliding even if the slopes do not already show signs of landsliding*

In the case of both sediment production and hydrologic change, some impact from forest land use is inevitable. In these cases, effective management for cumulative impact prevention would require that the intensity of land use in a watershed be maintained below the level at which the resulting impacts are no longer acceptable. Such an approach would require that the Forest Practice Rules include provisions that:

- *Allow regulation of the rate of logging in a watershed*
- *Allow regulation of the density of roads in a watershed*

Without such provisions, standard rules would need to be excessively protective to ensure that incremental additions are not damaging even when use intensities are high. In other words, some accelerated sediment input and hydrologic change is tolerable from individual plans as long as it is possible to ensure that cumulative inputs are below a damaging level. If no such assurance can be made, then the standard for individual plans must be high enough to assure that a damaging level is not attained even at the maximum intensity of activity. It is interesting to note that regulation of cutting rates in watersheds would also lead to a more stable employment base in timber-based communities by reducing the "boom or bust" fluctuations that now impact them, and would contribute to the goal of producing a sustained yield of forest products.

The second problem is that of cumulative impact analysis. Current rules for THPs require that a registered professional forester (RPF) fill out a checklist that discloses whether the RPF expects a plan, when mitigated, to contribute to a significant cumulative impact, and require the RPF to provide a narrative that explains the RPF's opinion. Examination of recently prepared THPs, however, indicates that the analyses do not adequately identify existing impacts in and downstream of the watershed, do not adequately describe the causes of those impacts, and do not adequately evaluate the potential influence of the plan on those impacts and impact mechanisms. In some cases, plans located in watersheds listed as sediment-impaired under section 303(d) of the Clean Water Act do not even indicate that a significant cumulative impact is already present in the watershed. In other cases the plan's influence is severely underestimated, despite clear evidence of significant impacts from previous, nearby plans. The problem here appears to be four-fold: there is little guidance for what constitutes a valid impact assessment; there is a directive that "no actual measurements are intended" for the analysis, thereby making it impossible for effective analysis to be carried out; the areas of expertise required for carrying out valid analyses are not well represented among the RPFs who prepare the analyses or among the California Department of Forestry and Fire Protection (CDF) staff who review those analyses; and there is no established mechanism for learning from the outcomes of past decisions.

To understand the potential solutions to this problem, it is first necessary to understand what would constitute a useful cumulative impact analysis. The objective of such an analysis is quite simple: we want to know whether a plan will make impacts better or worse. The information needed to make such a judgment is also relatively simple: we need to know what the impacts of concern are, how those impacts are generated, and whether the environmental changes caused by the proposed activities will add to the effects of existing impact mechanisms or will diminish those effects.

Clearly, much of the information required for such an analysis consists of background information that will be the same for any plan in a watershed: 1) identification of the impacts of concern and 2) analysis of how those impacts are generated. The only information that is specific to a project is

3) an analysis of how a proposed project will influence impact mechanisms. This distinction suggests that a fundamental change in the existing approach might make cumulative impact analysis both easier and more effective: a preliminary assessment could be carried out in each watershed by those with appropriate expertise to address the first two tasks, and a later analysis to address the third task could be carried out by an RPF as each subsequent plan is proposed. This approach is similar to that already instituted in Washington State for design of "best management practices," although the Washington approach does not incorporate cumulative impact analysis.

The first analysis could be carried out by an interagency, interdisciplinary team. Since many of the areas of expertise most relevant for impact assessment are represented most strongly in departments other than the CDF, and since the results of such assessments would be relevant to many planning and regulatory needs beyond those pertinent to forestry, it would seem that such analyses might best be carried out under the aegis of the California Resources Agency (CRA) itself, rather than by the CDF. The watershed analysis would first identify the issues of concern in the watershed and the mechanisms by which impacts to each issue are likely to occur. Kinds of practices would be identified that have aggravated or ameliorated impacts in the past. Each issue would be evaluated over the temporal and spatial scale relevant to that issue, and the method for evaluation of each issue would be determined by the nature of the issue. Influences of non-forestry land uses would also be evaluated. Measures that would be needed to make such an approach possible include provisions that:

- *A preliminary watershed assessment be done by interagency staff, possibly under the aegis of the California Resources Agency*
- *A document be prepared to provide guidance for watershed assessment*

It is important that each watershed assessment

- *Be carried out by those with expertise in the appropriate disciplines, including geomorphology, hydrology, fisheries biology, and others, as needed*
- *Incorporate analysis of each issue at the appropriate spatial scale for that issue*
- *Incorporate analysis of each issue at the appropriate temporal scale for that issue*
- *Employ appropriate analysis methods for each impact mechanism, including the use of actual measurements where appropriate*
- *Also evaluate the effects of non-forestry land uses in the watershed*

Results of the watershed assessment would then provide both context and guidance for subsequent project-based cumulative impact analyses.

The second stage of cumulative impact analysis would be carried out by RPFs for individual THPs. These analyses would simply show how the proposed plan fits into the context provided by the watershed assessment. For example, if the watershed assessment found that high water temperatures are an issue in downstream reaches and that the current distribution of riparian stand ages is largely responsible for the problem, the analysis for a THP would use methods suggested by the watershed assessment to evaluate how the proposed silvicultural activity would influence riparian cover. Alternatively, if the THP incorporates only those practices determined by the watershed assessment to have no effect on downstream temperatures, no analysis would be needed for that issue. Equivalent approaches would be taken for the other issues determined by the watershed assessment to be of importance in that particular watershed. Such an approach would require a provision that

- *Project-level cumulative impact analyses be guided by the findings of the watershed assessment for the relevant watershed*

Several measures would facilitate such an approach. Currently, some THPs are unnecessarily long (incorporating as many as 600 pages), and some include multiple copies of particular background documents. Copies of THPs can be obtained for review at a price of about 12 cents per page, bringing the total cost for procuring a copy to as much as $70. In addition, there appears to be little linkage between nearby THPs; there is no provision to ensure that measures found necessary for one plan be applied to later, adjacent plans. Benefits arising from outside review of one plan are thus wasted unless the same reviewers make the same effort to make the same comments on each adjacent plan. Further, there is no provision to determine whether the decisions made on a plan turn out to be appropriate, so it is very difficult to improve the decisions being made. These problems could be addressed by provisions that:

- *Electronic copies of THPs and SYPs be made available on an internet web-site. This was done successfully for the recent SYP filed by Pacific Lumber Company.*
- *A library of relevant background materials be established at CDF stations where THP reviews are carried out. Once a document is on file with the station, subsequent plans and comments could incorporate the document into the official record by reference instead of having to provide a copy for each THP. This provision would also make it unnecessary to include a copy of the same watershed assessment for every plan in the watershed.*
- *Any special requirements and concerns identified for past THPs located nearby be described in subsequent THPs*
- *Designated impaired watersheds be recognized to already be undergoing cumulative impact so that the standard for compliance with regulations is necessarily different.*
- *The outcomes of previous decisions be evaluated to determine whether the decisions were appropriate. This might be done by expanding the function of the THP completion inspection to include assessment of particular outcomes identified to have been important. Additional inspections for particular influences could be carried out after large storms.*

Together, these measures would facilitate continuous improvement of decision-making by improving access to outside expertise and by allowing the lessons learned from past plans to be applied to future plans in the area.

The third problem that restricts the ability of the Forest Practice Rules to manage cumulative impacts is the apparent failure of the current system to make adequate use of available expertise. Examination of official responses to comments and to non-lead-agency concerns suggests that sources of information from outside CDF are discounted in the THP approval process: there seems to be a general sense that information contributed concerning likely impacts is to be argued against rather than to be learned from. This problem may well arise from the “cultures” of the agencies involved, wherein some CDF staff members perceive their primary mission to be to facilitate production of maximum sustained yield of high-quality forest products, Water Quality Control Board staff perceive their mission to be protection of water quality, and Department of Fish and Game staff perceive their mission to be maintenance of fish and wildlife populations. Some of these goals conflict with one another.

Decision-making for THPs and SYPs is the responsibility of the CDF, yet the most generally valued and utilized “commodity” produced by California’s forest lands is clean water. The value of this commodity decreases as its quality decreases. The CDF holds most the state’s official expertise in silvicultural issues; the Water Quality Control Board holds much of the expertise in water quality issues; and the Department of Fish and Game holds much of the expertise in fish and wildlife issues. Contention over THP approval generally rests not on the silvicultural aspects of a plan, but on the plan’s influence on public trust resources such as water, fish, and wildlife. Perhaps, then, lead-agency responsibility for

approval of THPs and SYPs lies with the wrong agency. If lead-agency responsibility were shifted to the California Resources Agency itself, the state's technical expertise might be more effectively applied. Such a shift would also free CDF from much of the burden of the "no-win" controversy that currently surrounds the cumulative impacts issue, and would allow department personnel to focus on their other critically important work. Under this framework, staff from the relevant departments would continue to do the preliminary work for which they are currently responsible, but staff from CRA would hold the responsibility for weighing the inputs of the state's technical experts and making the required decisions. Such a change would require that

- *Lead-agency responsibilities for THP and SYP approval be shifted from CDF to CRA*
- *Staff of the relevant departments (i.e., Water Quality Control Board, Department of Fish and Game, etc.) be given authority for decisions falling within the purview of those departments' areas of expertise*

Problems concerning the treatment of outside comments also require consideration in their own right. Examination of the official response to a review of cumulative impact issues in the Pacific Lumber Company HCP/SYP showed that 21% of the responses did not address the issues raised; 9% misrepresented the original comments; and 10% contained technical errors (Reid 1999). Examination of official responses to comments on several THPs showed similar problems: technically valid concerns are being dismissed on technically invalid grounds. Currently, there is no recourse for correcting these errors other than litigation, and the courtroom is not a suitable venue for deciding technical issues. Furthermore, most of these problem could be resolved simply by appeal to an independent authority in the relevant field. This problem could be addressed by

- *Establishment of an independent panel of experts to whom technical disagreements could be referred if the outcome of the decision could have influenced the approval of a plan.*

This provision would increase the level of technical expertise available to support decision making and might diminish the efforts and expense now devoted to litigation.

## Context for this review

Considerable commentary on how Forest Practice Rules might be improved has been provided by others in the past. The Little Hoover Report of 1994, for example, describes the need to better incorporate expertise from other agencies into CDF's decision-making process and also describes the need for watershed-scale evaluations. Even before that, the LSA report of 1990 identified the cumulative impact analysis methodology as inadequate, stating that "there is a general recognition within the forestry profession that the process needs to be modified." The LSA report also notes that "Many ORs [official response to public comments] do not compare favorably with the standard of presenting a reasoned meaningful response to environmental comments and of demonstrating the scientific opinion and/or reasoned analysis that supports the THP decision." Meanwhile, several court cases have demonstrated the need to assess the influence of a plan on downstream cumulative impacts even if those impacts occur outside of a designated watershed assessment area.

Unfortunately, conclusions from these reports and decisions have not been reflected in institutional change. It may be useful to determine why previous findings have not been acted upon. If the reason turns out to be that there is an institutional resistance to change or an institutional denial of the need for change, then the need for a fundamental change in agency responsibilities may be even stronger than suggested above. Experience with a variety of institutions suggests that regulations are

ineffectual if staff of the agency responsible for administering and enforcing those regulations do not believe the regulations are necessary or useful.

There once again is widespread recognition that the state's strategy for management of forestry-related cumulative watershed impacts needs to be modified. Three committees established under the auspices of either the CDF or the Board of Forestry are currently compiling reports dealing with aspects of the problem. It remains to be seen whether these reports will be forgotten as quickly as those prepared by LSA and the Little Hoover Commission, or whether effective changes will be made.

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# Clearcutting and Climate Change

**Clearcutting California's forests is reducing carbon sequestration**

**Clearcutting produces more CO2 emissions than other logging methods**

**Clearcutting is exacerbating the forest effects of climate change**

"According to the California Energy Commission, California lost 30% of its sequestration capacity in the last decade alone. It is clear, therefore, that forests may be sources of carbon dioxide or sinks of carbon dioxide, *depending upon how people decide to manage them*." Laurie Wayburn, President,Pacific Forest Trust, Presentation to the California Climate Action Registry's Conference May 6, 2003.

- **Widespread clearcutting of California forests is causing large scale depletion of California's carbon stores**
- **Clearcutting in California's forests emits more $CO_2$ emissions than responsible harvesting methods such as selection logging; these emissions may exceed carbon storage in plantations for at least twenty years after harvest**
- **Older trees store more $CO_2$ annually than do younger trees in clearcutting plantations**
- **Only about one third of the carbon removed in clearcut logging is "sequestered" in lumber products, and many forest products have limited life spans**
- **Clearcutting exacerbates the three most likely effects of climate change on state forests: lessened snowpack and early run-off, an increase in the number and severity of wildfires, and an increase in forest infestations**
- **A State of California climate change study[1] anticipates decreased timber yields under climate change conditions, with pine plantations suffering the greatest declines**
- **This State-sponsored study concluded that diverse multi-aged forests will fare better under climate change impacts than even-aged tree plantations**

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[1] California Energy Commission. *Climate Change Impact on Forest Resources White Paper*. March 2006. http://www.energy.ca.gov/2005publications/CEC-500-2005-193/CEC-500-2005-193-SF.PDF

**What experts say about the relationship between climate change and clearcut plantations**

"Large amounts of carbon could be released into the atmosphere during transitions from one forest type to another because the rate at which carbon can be lost during times of high forest mortality is greater than the rate at which it can be gained through growth to maturity."

IPCC Working Group II. "Summary for Policymakers:Scientific-Technical Analyses of Impacts, Adaptations and Mitigation of Climate Change." http://www.ipcc.ch/pub/sarsum2.htm

"Some definitions of reforestation include the activity of regeneration after disturbance or harvesting, while disturbance or harvesting are not defined as deforestation. In these circumstances credits could be accounted for the regeneration, without debits for disturbance or harvesting, this would lead to an accounting system where the changes in terrestrial carbon do not reflect the real changes in the atmosphere."

Robert T. Watson, Chair of the IPCC. "A Report on the Key Findings from the IPCC Special Report on Land-Use, Land-Use Change and Forestry." 12th Session of SBSTA, Bonn, Germany. June 13, 2000. http://www.ipcc.ch/press/sp-lulucf.htm

"There is a widespread and misguided belief that logging or clearing mature forests and replacing them with fast-growing younger trees will benefit the climate by sequestering atmospheric CO2. While younger trees grow and sequester carbon quickly, the fate of stored carbon when mature forests are logged must also be considered. When a forest is logged, some of its carbon may be stored for years or decades in wood products. But large quantities of CO2 are also released to the atmosphere - immediately through the disturbance of forest soils, and over time through the decomposition of leaves, branches, and other detritus of timber production. One study found that even when storage of carbon in timber products is considered, the conversion of 5 million hectares of mature forest to plantations in the Pacific Northwest over the last 100 years resulted in a net increase of over 1.5 billion tons of carbon to the atmosphere."

Union of Concerned Scientists. "Recognizing Forests' Role in Climate Change" http://www.ucsusa.org/global_warming/solutions/recognizing-forests-role-in-climate-change.html

"Fluxes of CO2, water vapor, and sensible heat were measured by the eddy covariance method above a young ponderosa pine plantation in the Sierra Nevada Mountains (CA) over two growing seasons....We conclude that the net C[arbon] balance of Mediterranean-climate pine ecosystems is sensitive to extreme events under low soil moisture conditions and could be altered by slight changes in the climate or hydrologic regime."

A.H. Goldstein, N.E. Hultman, J.M. Fracheboud et al. "Effects of climate variability on the carbon dioxide, water, and sensible heat fluxes above a ponderosa pine plantation in the Sierra Nevada (CA)." http://nature.berkeley.edu/~ahg/pubs/Effects.pdf

"Research by CarboEurope, a European program that has pioneered research into the carbon budget, reveals that soils in forests release more carbon than their trees will absorb in the first 10 years. Forest soils and the organic matter within them generally contain three to four times as much carbon as does vegetation on the ground. CarboEurope's researchers contend that, when ground is cleared for forest planting, rotting organic matter in the soil releases a surge of carbon dioxide into the air that will exceed the amount of carbon dioxide absorbed by growing trees for at least the first 10 years of forest growth; only later will the uptake of carbon by the trees begin to offset the release of carbon dioxide from the soil."

Energy Information Administration: "Emissions of Greenhouse Gases in the United States 2003: Land Use Issues." http://www.eia.doe.gov/oiaf/1605/gg04rpt/land.html

Timber harvest, clear cutting in particular, removes more carbon from the forest than any other disturbance (including fire). The result is that harvesting forests generally reduces carbon stores and results in a net release of carbon to the atmosphere."

Mark Harmon, PhD. Professor and Richardson Chair in Forest Science, Oregon State University College of Forestry. Comment letter to the California Air Resources Board. October 2007. http://www.arb.ca.gov/lispub/comm/bccomdisp.php?listname=forestghg07&comment_num=22&virt_num=22

## Clearcutting Increases Fire Risk

**Young trees such as those in new tree plantations contribute to an increased likelihood of severe fire.**

- Young trees are more susceptible to mortality from fires due to lower height and size and thinner bark.
- Younger trees crowns are lower to the ground making them more susceptible to lethal heating by flames of a low height.

(http://www.bof.fire.ca.gov/pdfs/OALEmergencyfinal%206_20_05withOALedits%20.pdf State Board of Forestry and Fire Protection. "Findings Pursuant to Government Code Section 11346.1(b) in Support of Adoption of Emergency Rules to Implement Lake Tahoe Region Exemption Emergency Rule, 2005." Final Version with OAL Edits 6_20_05. Notice Date: June 13, 2005. p. 8)

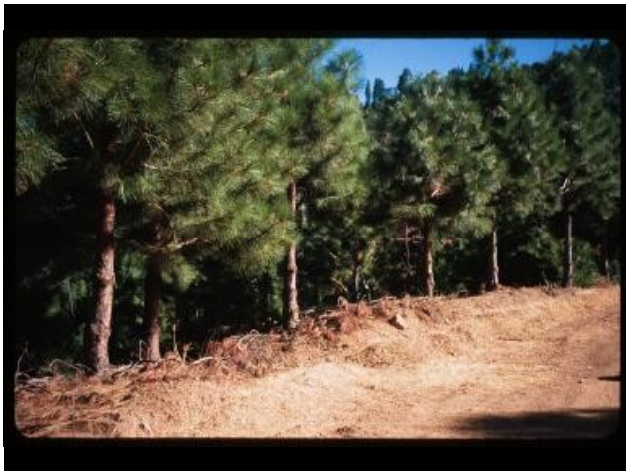
**"A uniform high-density canopy fuel complex could carry crown fire and also trap convective heat and increase crown scorch and mortality."**

- "Uniform fuels in the horizontal and vertical dimensions will support a fire that propagates through the live crowns of the brush and pole sized trees resulting in high levels of mortality and other adverse impacts associated with high intensity wildfire."
- "The overall continuity of surface fuels, the juxtaposition of different fuel types, and the extensive ladder fuels in many of the successfully established plantations create fuel conditions that support large severe fires." ("Turning Plantations into Healthy, Fire Resistant forests: Outlook for the Granite Burn", Dave Sapsis, Fuel and Fire Behavior Specialist; Clay Brandow, Watershed Specialist. Fire and Resource Assessment Program. California Department of Forestry and Fire Protection. 1997)

**Evidence of the increased fire risk of tree plantations was dramatic in the 2002 Umpqua National Forest fire.**

- The Umpqua NF said these "plantations experienced a disproportionately high amount of stand replacement mortality caused by crown fires as compared to older, unmanaged forests." (Over a quarter of the fire area was previously clearcut and converted to tree-plantations). 74% of plantations less than 20 years old were lost.
- Plantations in the Umpqua fire had a tendency to increase the rate of fire spread and increased the overall area of stand-replacement fire effects by spreading to neighboring stands.
- Over 80% of fires in the Umpqua National Forest were healthy, cool under-burns in older forests.
- *The Oregonian* reported September 1, 2002: "The Umpqua National Forest's Tiller fires raced through dense tree plantations with low branches that gave flames a helping hand into the treetops," said Karla Bird, a natural resources staff officer [on the Umpqua National Forest]. In more scattered natural stands, flames kept to the ground, spared many trees and did more good than harm. (http://www.umpqua-watersheds.org/unf/umpqua_fires_02.html)

**“Timber plantations comprised of densely-stocked, even-aged stands of young conifers are extremely flammable and vulnerable to catastrophic fire effects.**



- When plantations burn they normally result in 100% mortality of trees, yet have no native seed sources to naturally regenerate stands Ingalsbee, Timothy Ph.D., “Commercial Logging Does Not ‘Fireproof’ a Forest.” Western Fire Ecology Center. www.fire-ecology.org

**The Darby Fire**
**September 2001**

**Calaveras County**

**Ebbetts Pass Forest Watch**
Post Office Box 2862
Arnold, California 95223
209-795-8260
www.forestwatchers.org

**A sampling of expert opinions about the relationship of fire threat to range-wide clear-cutting:**

From the California Board of Forestry and Fire Protection, discussing the Sierra's Tahoe Basin:
"Extensive harvest in the late 1800s and early 1900s resulted in an overall young forest. There is concern that these changes have contributed to an increased likelihood of severe fire. Younger forests are more susceptible to mortality from fires. This is due to the lower height and size of small trees. Their bark is thinner, and their crowns are lower to the ground, making them more susceptible to lethal heating by flames of a low height. With much of the Basin in a younger state, a large proportion of it could burn severely, with high rates of mortality. These two human activities— creating younger forests by harvesting older trees and suppressing fires that otherwise would have burned off accumulated fuel—have increased the likelihood of severe fire in the Basin."

http://www.bof.fire.ca.gov/pdfs/OALEmergencyfinal%206_20_05withOALedits%20.pdf
State Board of Forestry and Fire Protection. "Findings Pursuant to Government Code Section 11346.1(b) in Support of Adoption of Emergency Rules to Implement Lake Tahoe Region Exemption Emergency Rule, 2005." Final Version with OAL Edits 6_20_05. Notice Date: June 13, 2005. p. 8

"Since European settlement of the United States, fire has been altered substantially by anthropogenic factors acting as root causes of the current fire crisis, including.… increases in fuel accumulation through active creation of dense tree plantations and a buildup of shade-tolerant conifers from fire suppression (Agee 1993; Arno & Allison-Bunnell 2002; Odion et al 2004); ...[and] losses of fire-resilient properties at the stand and landscape levels through the removal of large trees and "legacy" stand components and homogenization of fuels across large landscapes (Lindenmayer & Franklin 2002; Brown et al 2004; Such fundamental changes in fire behavior may be amplified by a predicted incremental lengthening of the fire season and increase in fire intensity in the western United States, exacerbated by global warming (McKenzie et al 2004)."

"Beyond Smoke and Mirrors: A Synthesis of Fire Policy and Science." Dominick A. Dellasalla, Jack E. Williams, Cindy Deacon Williams, and Jerry F. Franklin. *Conservation Biology.* Volume 18, No. 4, August 2004. p. 977

From "Turning Plantations into Healthy, Fire-Resistant Forests: Outlook for the Granite Burn:"
Both fire and competitive stress threaten the development of the plantations into mature forest ecosystems….In some areas, the over story density of pole sized trees compounds the hazard by providing a uniform high-density canopy fuel complex that could not only carry crown fire, but would also trap convective heat and increase crown scorch and mortality….
Silviculturalists from both the federal and private side are concerned about how to handle well-growing plantations of this age. Mike Landram, R5 Regional Silviculturist, defined three pressing problems driving a need for action:

- Where the pine plantations have taken, independent of fuel concerns, the stands are overstocked.
- Competition and beetles, in addition to the creation of continuous crown fuels, constitute considerable threats to the development of these plantations. High tree density tends to increase tree damage through increased crown scorch resulting from limiting the escape of the convective heat rising from the surface fire.
- The USDA Forest Service does not have a sufficient Timber Stand Improvement budget to do much about it. Landrum estimates that at least 300,000 acres within Region 5 need treatment. Many of the private plantations are in a similar situation, and contribute to the landscape level problem.

Sapsis, Dave (Fuel and Fire Behavior Specialist) and Brandow, Clay (Watershed Specialist). "Turning Plantations into Healthy, Fire Resistant Forests: Outlook for the Granite Burn." Fire and Resource Assessment Program; California Department of Forestry and Fire Protection. October 9, 1997.
http://frap.cdf.ca.gov/projects/granite_burn/gb.html

"The removal of large, merchantable trees from forests does not reduce fire risk and may, in fact, increase such risk." (Dept. of Agriculture and Dept. of Interior, Report to the President [September 2000]).

"The Umpqua National Forest's Tiller fires raced through dense tree plantations with low branches that gave flames a helping hand into the treetops. In more scattered natural stands, flames kept to the ground, spared many trees and did more good than harm." Karla Bird, natural resources staff officer

Annual Report for FY 2006

# Response of Western Mountain Ecosystems to Climatic Variability and Change: The Western Mountain Initiative

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# Introduction

The objective of the Western Mountain Initiative (WMI) is to understand and predict the responses – emphasizing sensitivities, thresholds, resistance, and resilience – of Western mountain ecosystems to climatic variability and change.

The rate and magnitude of ecosystem responses to changes in the global atmospheric environment are variable and uncertain, ranging from gradual to abrupt, from moderate to profound. The least understood and least predictable responses are those of greatest importance to policy makers and land managers: responses that are both abrupt and profound. Recent examples of such responses include ongoing drought-induced forest mortality on millions of acres in New Mexico, Arizona, and southern California, and the increasingly large area burned by severe wildfires in the western United States during the past two decades. In both cases, ecosystem thresholds were exceeded relatively quickly, leading to large and often unexpected changes that will have long-term consequences for ecosystem structure, function, and production of goods and services.

In the face of expected climatic change over the next several decades, are significant changes in ecosystem structure and processes likely to become more common? Are these changes predictable? What are the characteristics of ecosystems likely to respond quickly or gradually, profoundly or minimally? How will ecological and economic productivity be affected at various spatial and temporal scales?

Mountain ecosystems of the western United States are ideally suited to address these questions. First, they lend themselves to ecological inquiry because they have: (1) compressed climatic and biogeographic zones containing many ecosystems within relatively small areas; (2) rich paleoecological resources, which record past environmental changes and consequent ecosystem responses; and (3) common ecological drivers, such as snowpack and fire, which facilitate comparisons across ecosystems. Second, because national parks and wilderness of the montane West have experienced minimal human disturbance, effects of environmental changes on ecosystems can be inferred with fewer confounding influences than on intensively managed lands. Third, Western mountain ecosystems are important to society, providing water, wood products, carbon sequestration, biodiversity, and recreational and spiritual opportunities. Finally, more than a decade of USGS research at seven Western mountain parks provides the foundation for broad syntheses of existing knowledge.

For the period 2003-2008, WMI has placed particular emphasis on addressing four key questions regarding Western mountains:

(1) How are climatic variability and change likely to affect disturbance regimes (particularly fire)?
(2) How are changing climate and disturbance regimes likely to affect the composition, structure, and productivity of vegetation (particularly forests)?
(3) How will climatic variability and change affect hydrologic processes in the mountainous West?
(4) Which mountain resources and ecosystems are likely to be most sensitive to future climatic change, and what are possible management responses?

# Overview of Progress and Results

*Question 1: Climate and disturbance regimes*

We conducted a regional-scale analysis of historical fire-climate interactions, using 15 sites from southwestern British Columbia to northeastern Oregon. Synchronous fire years, where more than half the sites recorded wildfires, are strongly associated with extreme drought. Expected associations with multi-year drivers such as ENSO, PDO, and AMO were not evident. This is in marked contrast to historical fire regimes in the Southwest, where ENSO cycles are significantly associated with synchronous fire years. This Northwestern pattern was confirmed by ongoing studies of climate variability and the modern fire record, which show that previous-years' climate is important for predicting wildfire area in the Southwest, but not in northern montane ecosystems. Using mesoscale climate projections, our climate-fire area models, and the BlueSkyEM smoke-modeling framework, we simulated smoke emissions from wildfires across the western United States for a future decade (2045-2054). Results suggest increased smoke emissions and decreased air quality will affect northern mountains (particularly the Northern Rockies) in changing climates of the future.

Based on historical reconstructions and statistical models of 20$^{th}$ century fires, increased fire severity and area burned are expected across the Northwest in response to prolonged and more severe droughts in the 21$^{st}$ century. Forest landscapes across the region may become increasingly vulnerable to synergistic disturbances such as the combination of fires, insect outbreaks, and possible drought-induced mortality such as is already being seen in the Southwest. In the Pacific Northwest, disturbance will almost certainly be the dominant force in ecosystem change, acting over much a shorter time span than changes induced by climate warming alone.

Don McKenzie (WMI) and Craig Allen (WMI) led a workshop devoted to understanding disturbance interactions and synergies in western mountains. Twenty-five leading scientists, both academic and agency-based, from the US and Canada spent 3 days systematically developing a research strategy -- and blueprints for specific models and other tools -- for understanding disturbance interactions in the context of climate change. Additionally, WMI is contributing to several papers for a special section of the *International Journal of Wildland Fire*, on climate-fire interactions.

*Question 2: Climate and vegetation*

Our empirical studies have demonstrated that tree growth in western mountains is predominantly water-limited, except for the wettest sites in the Olympic Mountains. We developed water-balance models for Douglas-fir across the Pacific and Inland Northwest to identify areas with potential significant increases in moisture stress. The ubiquity of these sites portends broad-scale productivity decreases across the Northwest, as warmer temperatures increase moisture stress in trees at all but the highest elevations.

Importantly, we also demonstrated that death rates of trees in California's Sierra Nevada have increased over the last two decades, in parallel with a temperature-driven increase in drought. This represents to world's first demonstration of chronic long-term, temperature-driven changes in death rates in a temperate forest. The findings, published in *Ecology Letters*, suggest that Sierran forests (and by implication, other water-limited forests of the west) are sensitive to temperature-driven drought stress, and may be poised for die-back if future climates continue to feature rising temperatures without compensating increases in precipitation.

Work continued on exploring relationships between tree growth characteristics and probability of mortality – information critical to developing a mechanistic understanding of climatic controls over tree mortality (several manuscripts are in review or in press, and one was published). Working with Dr. Alvaro Duque (Universidad Nacional de Colombia, Medellín), we organized CORFOR – the Cordillera Forest Dynamics Network of long-term forest research plots along the American Cordillera, from Alaska to Tierra del Fuego (http://mri.scnatweb.ch/content/view/88/30/), for exploring effects of global changes on forests.

Last year we demonstrated that at global and regional scales, background rates of tree reproduction and mortality are positively correlated with forest productivity; in 2006 we focused on determining why. In a broad-scale comparison of forests, we demonstrated that climatic conditions favoring rapid tree growth also tend to favor the herbivores, pathogens, and agents of decay that attack trees, with important implications for how forests might respond to otherwise "benign" climatic changes (manuscript in review).

*Question 3: Climate and hydrologic processes*

RHESSys, the Regional Hydro-Ecological Simulation System, was used to simulate vegetation and hydrologic processes in watersheds of Yosemite, North Cascades, Glacier, and Bandolier National Parks, and the Snake River basin of Colorado. This spatial model is being used to explore differences in ecosystem responses across latitudes, maritime versus continental climates, and elevation in the western US. Validation runs for all sites except Bandelier (in progress) show good correspondence between daily to annual simulated results and measured streamflow, snow distribution, and net primary productivity. Next steps are to compare and contrast responses at each of the five watersheds to past climatic events driven by Pacific Decadal Oscillation, Atlantic Multidecadal Oscillation, and El Niño. RHESSys was used to address the responsiveness of transpiration to climate across an elevation gradient in the Merced River Basin of Yosemite National Park. In a paper accepted for publication in *Hydrological Processes* we show that gradients of precipitation and temperature across elevations strongly influence transpiration rates, with precipitation controls on moisture stress strongest at mid elevations, and temperature controls of growing season strongest at high elevations. We have also adapted another hydrological model (DHSVM) for use in coupled modeling of fire and hydrology under both present and future climate, by adding algorithms for fuel-moisture and fire-danger calculations based on fine-scale water balance. The model is currently being tested in the Pacific Northwest and will also be applied across the WMI sites.

The past year additionally saw the successful establishment of an index glacier monitoring program at Glacier National Park that complements glacier monitoring in the North Cascades and Olympic Mountains. The data generated from the Glacier National Park monitoring will directly contribute to the inventory of glaciers in the American West, a WMI effort headed by Andrew Fountain. Additionally, collaboration with Andrew Fountain has produced a complete westwide survey of glaciers, remnant glacial ice, and perennial snowfields. A map product has been made available on the web (http://glaciers.research.pdx.edu/).

John Moody and Deborah Martin (both USGS WRD) have just completed a WMI-supported manuscript on "Synthesis of sediment yields after wildland fire in different rainfall regimes in the western United States," currently being reviewed. Sediment yields

for different rainfall regimes varied over 5 orders of magnitude. The lack of correlation of sediment yields with topographic slope and soil erodibility suggests that sediment availability may be more important than slope or erodibility in determining the sediment yield after wildfire. Additionally, intensive long-term research by WMI at the semiarid Frijolito watershed site in Bandelier National Monument continued to characterize hillslope runoff and erosion processes in response to climate variability at event-scale high-resolution. This work demonstrates watershed responses to multiple disturbances (livestock grazing, fire suppression) and climate (droughts and intense storms) that modulate land cover and thereby watershed processes at multiple spatial scales.

Paleolimnological work coupled with long-term monitoring in the Loch Vale Watershed of Rocky Mountain National Park revealed a complex response of lake diatoms and alpine lichen communities to both changing climate and atmospheric nitrogen deposition. Compound-specific nitrogen, carbon, and hydrogen isotope records from Sky Pond reveal not only a substantial shift in nitrogen cycling in the region, which we knew from previous work, but also enhanced terrestrial lichen productivity and alteration of hydrologic flow patterns due to snow, glacier, and permafrost melt. This WMI-supported manuscript: "Compound-specific stable isotopes of organic compounds from lake sediments track recent environmental changes in an alpine system, Rocky Mountain National Park (United States of America)" is currently in review in *Limnology and Oceanography*. It is the first paper we know of to reveal simultaneous changes in hydrologic, terrestrial and aquatic ecosystems from climate change and nitrogen deposition.

*Question 4: Sensitivities and responses*

All WMI PIs have participated in a national effort, initiated by the Climate Change Science Program (CCSP), to understand responses and potential adaptations of National Parks and other public lands to climate change. WMI PIs and co-authors identified both West-wide and site-specific adaptation strategies by working closely with National Park staff and other land managers. Additionally, WMI PIs are contributing to CCSP's national effort to understand and synthesize information related thresholds of ecological change.

Threshold responses have been identified both within and among WMI regions: (1) massive tree dieback in the Southwest (and similar to events in Mediterranean systems around the world) from a combination of global warming and drought; (2) rates of disappearance of glaciers from western mountains have been quantified, with particularly rapid decreases in the Inland Northwest; and (3) synergistic disturbance pathways ("stress complexes"), leading to rapid change, have been identified for several western ecosystems. These three sets of responses have been documented in internationally attended workshops and conferences, and in peer-reviewed publications.

## Specific Accomplishments and Results

- Jill Baron (WMI) was invited lead author for CCSP Synthesis and Assessment Product 4.4 (SAP 4.4) on *Adaptation Options of National Parks to Climate Change*. Contributing authors include three other WMI scientists: Craig Allen, Don McKenzie, and Nate Stephenson. SAP 4.4 will be presented as a symposium (organized by Baron) at the American Association for the Advancement of Sciences annual meeting in Boston, 2008.

  *Relevance to resource managers*: This chapter is directed towards the needs of National Park Service managers, and provides summary guidance on possible adaptation approaches to climatic change.

  *Cross reference*: This study supports Questions and Products: Q2, P2, P3, P6, P10 and Q3, P2; Table - Feasibility of Milestones, Products and Payoffs.

- Dan Fagre (WMI) is invited lead author for the CCSP Synthesis and Assessment Product on *Thresholds of Ecological Change*. Contributing authors include WMI scientist Craig Allen.

  *Relevance to resource managers*: This chapter directly addresses a pressing concern of National Park Service and other land managers: how to anticipate and cope with increasing uncertainty leading to surprises.

  *Cross reference*: This study supports Questions and Products: Q2, P2, and Q3, P2; Table - Feasibility of Milestones, Products and Payoffs.

- The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT) is a collaborative interagency consortium dedicated to understanding the interactions of climates and ecosystems in western North American mountains (http://www.fs.fed.us/psw/cirmount/). Several WMI principal investigators and collaborators serve on CIRMOUNT's board of directors, and helped organize and sponsor CIRMOUNT's MTNCLIM 2006 conference, dedicated to mountain climate sciences and effects of climate variability on ecosystems, natural resources, and conservation in western North American mountains (http://www.fs.fed.us/psw/mtnclim/). MTNCLIM 2006 included a post-conference workshop for natural-resource managers, with practical suggestions for incorporating climate science information into forest conservation and management. Additionally, WMI investigators contributed to the 2006 publication of CIRMOUNT's *Mapping New Terrain: Climate Change and America's West*, which summarizes climatic change issues in the West and is aimed at informing managers and policy makers.

  *Relevance to resource managers*: The MTNCLIM conferences and *Mapping New Terrain* have proven to be key conduits for summarizing and transferring the latest findings on climatic change and natural resources -- including the findings of WMI-funded research -- to natural resource managers.

*Cross reference*: This supports Questions and Products: Q1, P2; Q2, P2; Q2, P10; and Q3, P2; Table - Feasibility of Milestones, Products and Payoffs.

- Models of fire area burned in response to climate were developed for 16 ecoprovinces across the West for the period 1916-2003. Four different patterns of climatic forcings were found, with implications for the relative contribution of climate and fuels to fire extent. The importance of various drought parameters from current and previous year data varied regionally, with different mechanisms in the Northwest vs. the Southwest.

  *Relevance to resource managers*: By quantifying the relationship of climate to fire, expected fire occurrence in a warmer climate can be inferred, and the relative value of fuel treatments can be incorporated in planning.

  *Cross reference*: This study supports Question and Product: Q2, P2; Table - Feasibility of Milestones, Products and Payoffs.

- Simulations of fire extent under future climate were conducted for the western United States, by integrating mesoscale meteorology, a stochastic fire generator, and vegetation and fuel maps of the West. Results indicate that warmer temperatures will increase fire area, smoke emissions, and regional haze across the northwestern United States. In contrast, in the Southwest, projected increases in precipitation may increase average fuel moisture and actually decrease fire extent.

  *Relevance to resource managers*: This information demonstrates that the interaction of increased fire with air pollution in a warmer climate may result in degradation of air quality, posing major challenges to meeting USEPA regulations for regional haze. This will have major and potentially costly implications for fire management, prescribed burning, and reduction of emissions from non-fire sources.

  *Cross reference*: This study supports Question and Product: Q2, P2 and P10; Table - Feasibility of Milestones, Products and Payoffs.

- Working with WMI collaborator Andrew Fountain at Portland State University, a complete westwide survey of glaciers, remnant glacial ice, and perennial snowfields has been developed from a variety of sources. A map product is available on the web (http://glaciers.research.pdx.edu/). Initial analysis shows the relative rates of glacier recession for each of the WMI areas. Some areas are about 10 years "ahead" of schedule according to predictive models of glacier retreat.

  *Relevance to resource managers*: This effort provides a broader context for managers of protected areas with receding glaciers. For regional policymakers it provides strong indications of potential water supply issues because glaciers are reflecting trends in snowpack.

  *Cross reference*: This activity supports Questions and Products: Q2, P2; Table - Feasibility of Milestones, Products and Payoffs.

- WMI investigators provided several groups of land managers and policy makers with various oral and written state-of-knowledge syntheses on probable consequences of rapid global changes on western mountain ecosystems. Associated publications are in press.

  *Relevance to resource managers*: These syntheses directly provide land managers and policy makers with information needed for adaptation to rapid global changes.

  *Cross reference*: This work supports Questions and Products: Q2, P2, and Q3, P2; Table - Feasibility of Milestones, Products and Payoffs.

- A regional-scale replicated study of the growth response of montane Douglas-fir to climate was completed, with trees sampled from western Washington (maritime climate) to western Montana (continental climate). The predominant finding is that growth is water-limited across the entire region at all elevations. Therefore, increased temperature is expected to cause widespread reductions in growth of Douglas-fir across much of its range.

  *Relevance to resource managers*: Climate-growth relationships across much of the distribution of Douglas-fir will provide the necessary information for predicting (reduced) growth of this commercially and ecologically important species in a warmer climate.

  *Cross reference*: This study supports Question and Product: Q2, P2, P8, and P10; Table - Feasibility of Milestones, Products and Payoffs.

- Forest insect outbreaks are postulated to increase with climatic warming; with prominent insect outbreaks gaining attention in recent years, the topic has been a source of concern for forest managers throughout the West. Using models of vegetation and mountain pine beetle life-cycles, WMI collaborators analyzed spatial patterns of potential outbreaks under both current climatic conditions and future warming scenarios. The area of climatic suitability for outbreaks may in fact decrease with warming, except at the highest elevations (3000-3500 m). As climate warms over the next 100 years, currently suitable habitat will be less conducive to mountain pine beetle, but may provide habitat for other species of beetles now restricted to areas further south. These findings were published in *Journal of Geophysical Research*.

  *Relevance to resource managers*: To plan for adaptation to future climatic changes, forest managers need a range of possible future scenarios, especially regarding pest outbreaks. This work supplies needed scenarios regarding potential outbreaks of the mountain pine beetle.

  *Cross reference*: This study supports Questions and Products: Q2, P2; Q2, P8; Q2, P10; Table - Feasibility of Milestones, Products and Payoffs.

- Don McKenzie (WMI) and Craig Allen (WMI) led a workshop devoted to understanding disturbance interactions and synergies in western mountains. Twenty-five leading scientists, both academic and agency-based, from the US and Canada

spent 3 days systematically developing a research strategy -- and blueprints for specific models and other tools -- for understanding disturbance interactions in the context of climate change (for example, how do fire and insect outbreaks interact to cause rapid ecosystem change in a warmer and drier climate?). A decision-support framework was used that simultaneously produces consensus and represents minority viewpoints. An overview of the results was published in *EOS Transactions*, and a compilation of all results is in preparation, as are four manuscripts, one from each workgroup, destined for publication in peer-reviewed journals.

*Relevance to resource managers*: Managers are profoundly aware of the importance of disturbance interactions within the systems they know best, but often have few or no tools to project ecosystem states into the future, especially in a rapidly changing climate. Products of this workshop will provide those tools.

*Cross-reference*: This study supports Question and Product: Q1, P2; Q2, P2; Q2, P10; and Q3, P2; Table - Feasibility of Milestones, Products and Payoffs.

- The RHESSys model is being used as a synthesis tool for WMI site locations. RHESSys is a simulation model that represents multiple and interacting ecological processes both spatially and temporally. The model simulates water, carbon, and nitrogen fluxes over spatially variable terrain and can simulate these fluxes along with climate patterns within a mountainous environment. Model calibration is now complete for the Upper Merced River basin in Yosemite National Park, CA [Sierra Nevada] the Snake River basin, CO [Central Rocky Mountains], the Lake McDonald basin in Glacier National Park, MT [Northern Rocky Mountains], the Stehekin River basin in North Cascades National Park, WA [Pacific Northwest], and is underway for the Frijoles and Santa Fe River basins of Bandelier National Monument [Southern Rocky Mountains]. The responses of these basins to climate drivers (PDO, AMO, and ENSO) will be compared and contrasted to elucidate broadly how western ecosystems respond to climate extremes, and specifically how each basin responds.

  *Relevance to resource managers:* Both broad-scale and site-specific results will be of interest and use to resource managers for understanding how climate extremes influence hydroecological processes at different elevations across the western US.

  Cross reference: This work supports Questions and Products: Q2, P2, P9, P10; Q3, P2, P3; Table - Feasibility of Milestones, Products and Payoffs.

- Dan Fagre co-edited, with Tony Prato, the book "Sustaining Rocky Mountain Landscapes: Science, Policy, and Management for the Crown of the Continent Ecosystem". The regional ecosystem that is the subject of the book is shared by Canada and the U.S. and the 39 chapter authors reflected the diversity of issues of, and perspectives on, the transboundary area. This book will be highlighted at the world's first International Peace Park Conference to be held in September 2007.

  *Relevance to resource managers*: The book suggests numerous approaches to dealing with complex problems that are exacerbated by climate change. Managers

of mountain protected areas, in particular, will find insights and potential solutions to dealing with both changing natural resources and changing constituencies.

*Cross reference*: This activity supports Questions and Products: Q2, P10, and Q3, P2; Table - Feasibility of Milestones, Products and Payoffs.

- Ortho- and geo-rectified aerial photography taken in 1998 was used to finalize glacier areas from the Northern Rocky Mountains and an analysis of glacier area based on 2005 aerial photography was recently completed. These two inventories are the first complete regional assessments of glaciers in the Northern Rocky Mountains since 1966. Quality control and ground-truthing are being finished in the 2007 field season, however, it is already clear that relative rates of glacier recession are higher in this WMI area than the others. The glacier recession is more advanced than predicted by a geospatial model that indicated that all glaciers would disappear from Glacier National Park by 2030.

  *Relevance to resource managers*: The study makes clear the impact of continued warming on a charismatic resource of mountain protected areas and has direct implications for ecosystem services such as water supplies. Because glacier recession is reflective of broader ecosystem responses to warming, managers need this type of information to reevaluate their goals for maintenance of biodiversity, protecting endangered species, or anticipating different fire regimes.

  *Cross reference*: This activity supports Questions and Products: Q2, P3, and Q2, P1; Table - Feasibility of Milestones, Products and Payoffs.

- A full-service website was produced and launched for the repeat photographs of glaciers at Glacier National Park (http://www.nrmsc.usgs.gov/repeatphoto/index.htm). High-resolution digital files of archival and modern photographs can be downloaded for use on television networks, in magazines, and for use on other websites. Powerpoint slides of paired photographs are available for customer use also. This website has already had thousands of hits from multiple countries and for a huge diversity of uses. It accounts for most of the internet traffic for the Northern Rocky Mountain Science Center.

  *Relevance to resource managers*: The website provides visually compelling evidence of significant changes on western federal lands. These graphic resources are not only used by resource managers but numerous other constituencies as well for educational purposes.

  *Cross reference*: This activity supports Questions and Products: Q2, P10; Table - Feasibility of Milestones, Products and Payoffs.

- Collaborative research by many cooperators continued on the VC-3 deep sediment core collected with initial WMI funding support from the Valles Caldera of New Mexico. The basal sediments found in the core have now been firmly dated to 552,000 years before present. The core is thought to provide a continuous record for about 190,000 years, covering a time period where almost no paleoenvironmental data

exists in western North America, and includes one full glacial – interglacial – glacial set of climatic transitions, as well as major portions of a second interglacial period. Extensive portions of the core exhibit high-resolution laminations, with potential to reconstruct high-resolution (at least decadal to perhaps annual) variations in paleoclimate.

*Relevance to resource managers*: Long-term records of past climatic changes and consequent ecosystem responses are central to building an understanding of possible ecosystem responses to ongoing changes, which in turn is necessary to plan for adaptation.

*Cross reference*: This study supports Question and Product: Q2, P2; Table - Feasibility of Milestones, Products and Payoffs.

- Analysis of long-term forest dynamics data revealed that forest mortality rates have increased in the Sierra Nevada over the last few decades, and that the increase parallels a temperature-driven increase in drought. The finding suggests that these forests (and by implication, other water-limited forests) may be sensitive to temperature-driven drought stress, and may be poised for die-back if future climates continue to feature rising temperatures without compensating increases in precipitation. The results have been published in *Ecology Letters*.

  *Relevance to resource managers*: These findings suggest that ongoing climatic changes may be driving chronic changes in forests that otherwise appear healthy, and that those chronic changes may be a prelude to acute changes, such as sudden forest die-back.

  *Cross reference*: This study supports Questions and Products: Q1, P2, and Q2, P2; Table - Feasibility of Milestones, Products and Payoffs.

- Analysis of lake sediment cores from Rocky Mountain National Park by many cooperators found, in addition to expected changes in lake algal productivity due to atmospheric nitrogen deposition, important changes in terrestrial and aquatic ecosystems due to subtle changes in alpine hydrology due to climate change. Stable isotope analyses are highly suggestive of increasing lichen productivity, as well as melting of permanent snow, ice, and permafrost, along with increased eutrophication. These results are in review in *Limnology and Oceanography*.

  *Relevance to resource managers*: Records of contemporary climatic change coupled with long-term trends of increasing ecosystem responses to atmospheric nitrogen deposition are central to building an understanding of ecosystem responses to ongoing changes, and may complicate the ability of managers to reverse the trends of observed nitrogen deposition effects, now underway through an agreement between the State of Colorado, the EPA, and the National Park Service.

  *Cross reference*: This study supports Question and Product: Q2, P2, P5, P6, P8, P10; Table - Feasibility of Milestones, Products and Payoffs.

- Statistical analyses of long-term records from Loch Vale Watershed using structural equation modeling revealed the importance of climate interactions in controlling watershed nitrate export. Nitrogen biogeochemistry, previously thought to be controlled by inputs of atmospheric nitrogen deposition, are shown to be also strongly controlled by climate through its influences on microbial and plant activity of both alpine and forest ecosystems. This work has been presented at the North American Benthological Society annual meeting, will be presented at the National Atmospheric Deposition Program annual meeting, and is in progress of being written for journal submission.

  *Relevance to resource managers*: Long-term records of ecosystem change in an instrumented alpine-subalpine watershed have been fundamentally important to Rocky Mountain National Park managers for evaluating the threat from atmospheric nitrogen deposition. This work reveals the synergy between air pollution and climate that may complicate the ability of managers to manage air pollution.

  *Cross reference*: This study supports Question and Product: Q2, P2, P5, P6, P10; Table - Feasibility of Milestones, Products and Payoffs.

- Transpiration is an important component of soil water storage and streamflow and is linked with ecosystem productivity, species distribution, and overall ecosystem health. In mountain environments, complex topography creates heterogeneity in the key controls on transpiration. Model results for Yosemite National Park found that elevational differences in vegetation water use and sensitivity to climate were significant and will likely play a key role in controlling the responses and vulnerability of Sierra Nevada ecosystems to climate change. The mixed conifer forests are water-limited on slopes from low- to mid-elevations, but are temperature- limited at high elevations, in contrast to montane Douglas fir forests (described above). A publication from this study is in press in *Hydrological Processes*.

  *Relevance to resource managers:* Plant transpiration is a significant component of the water budget and is a controlling factor of the underlying hydrologic cycle. Understanding how transpiration varies along elevational gradients with variations in climate provides important insight into controls on western water budgets.

  *Cross reference*: The study supports Question and Product Q2, P2, P9, P10; Q3, P2 and P3; Table - Feasibility of Milestones, Products and Payoffs.

- Dan Fagre served on the Montana Governor's Advisory Board for Climate Change and has provided presentations and other information transfer to various boards such as The Nature Conservancy and the National Fish and Wildlife Foundation.

  *Relevance to resource managers*: This accomplishment directly communicates current scientific findings to policymakers and has immediate impacts on resource decisions being made by managers.

*Cross reference*: This activity supports Questions and Products: Q2, P2; Table - Feasibility of Milestones, Products and Payoffs.

- An index glacier monitoring program at Glacier National Park was established that complements glacier monitoring in the North Cascades and Olympic Mountains. The data generated from the Glacier National Park monitoring directly contributes to the inventory of glaciers in the American West, a WMI effort headed by Andrew Fountain (described below). High-resolution snow measurements, ice radar, GPS margin measurements, time-lapse cameras and stream gages provide essential, detailed information for key glaciers such as Grinnell which lost an additional 14 acres in only 2 years from 2004-2006 (about 9% of its remaining area). Collaboration with Dr. Joel Harper, University of Montana, has led to several graduate student projects that will model glacial ice dynamics.

  *Relevance to resource managers*: These studies of individual glaciers are critical to the nested design of glacier monitoring westwide and give managers a specific and tangible link to broader trends. Retreating glaciers are iconic climate change subjects and national parks are looked to for credible information. Information from this study is used by national park interpreters, has been publicized in brochures for park visitors, is the subject of wayside exhibits and is used extensively by TV documentary producers.

  *Cross reference*: This activity supports Questions and Products: Q2, P3, and Q2, P1; Table - Feasibility of Milestones, Products and Payoffs.

- A high-resolution tree-ring based reconstruction of natural avalanche frequency and spatial extent in the SW corner of Glacier National Park was completed during the past year. This reconstruction doubled the known avalanches compiled from historic records and recast the role of avalanches for ecologists and policy makers in a different light. Frequency of avalanches also reflected the Pacific Decadal Oscillation, providing a basis for estimating future avalanche frequency under climate change.

  *Relevance to resource managers*: National Park Service managers are interested in avalanche frequency because of the annual opening of the Going-to-the-Sun Road, concerns about safety for road employees and park visitors, and the central role the Road plays in the regional economy. Avalanche frequency information also is of direct interest to the Burlington Northern railroad and the Montana Highway Department on the southern edge of Glacier National Park.

  *Cross reference*: This activity supports Questions and Products: Q2, P3; Table - Feasibility of Milestones, Products and Payoffs.

# Products

## Data Sets

*Sierra Nevada Forest Demography Database*: Annual census data of tree species from 27 permanent forest research plots in the Sierra Nevada mountains, California. Data set is in progress; data currently span 1982 - 2006.
Location: USGS Western Ecological Research Center, Sequoia and Kings Canyon Field Station, 47050 General Hwy Unit 4, Three Rivers, CA 93271.
Contact: Phillip van Mantgem (pvanmantgem@usgs.gov).
URL: (http://www.werc.usgs.gov/sngc/forest_demography.htm)

*Sierra Nevada Seedling Demography Database*: Annual census data of tree seedlings from 20 long-term forest research plots in the Sierra Nevada mountains, California. Data set is in progress; data currently span 1999 - 2006.
Location: USGS Western Ecological Research Center, Sequoia and Kings Canyon Field Station, 47050 General Hwy Unit 4, Three Rivers, CA 93271.
Contact: Phillip van Mantgem (pvanmantgem@usgs.gov).
URL: (http://www.werc.usgs.gov/sngc/seedling_dynamics.htm)

*Eastern Washington Fire History Database*: Spatially explicit fire-scar records for over 5000 trees in eastern Washington, together with geospatial information, in standard formats (ArcGIS *shapefiles* and MS-Access databases).
Location: College of Forest Resources, University of Washington, Box 352100, Seattle, WA 98195-2100.
Contact: Don McKenzie (dmck@u.washington.edu)
URL: (http://flames.cfr.washington.edu)

*Wildland Fuel Classificaton and Map for the Conterminous United States*: A 1-km GIS layer of 112 categories of wildland fuels, used for coarse-scale modeling of current and future wildland fires.
Location: Pacific Wildland Fire Sciences Lab, US Forest Service, 400 N 34th St #201, Seattle, WA 98103.
Contact: Don McKenzie (dmck@u.washington.edu)
URL: (http://www.fs.fed.us/pnw/fera/local_resources/images/maps/fccs-lower48.zip)

*Long-Term Ecological Research and Monitoring in Loch Vale Watershed, Rocky Mountain National Park:* Meteorology, hydrology, water quality, precipitation chemistry, aquatic and terrestrial species occurrences from 1983-2005 for Loch Vale Watershed.
Location: Natural Resource Ecology Laboratory, Colorado State University, Fort Collins CO 80523-1499.
Contact: Jill Baron (jill_baron@usgs.gov)
URL: (http://www.nrel.colostate.edu/projects/lvws/)

*Climate Data Plotting Page:* Time series of United States climate information at a location or aggregated for an ecoprovince for period of record, in some locations >100 yrs.

Location: Department of Geography, University of Idaho, Moscow, ID 83844-3021
Contact: Jeffrey Hicke, jhicke@uidaho.edu
URL: (http://www.nrel.colostate.edu/~jhicke/climate_data/)

**Oral and Poster Presentations.**

Allen, C. D. 2005. Bark beetles, climate, and regional-scale vegetation dieback in the Southwestern US. Bark beetle symposium. Snowbird, UT.

Allen, C. D. 2005. Climate and land use interactions with vegetation change and disturbance processes in mountain ecosystems of the Southwestern USA. Open Science Conference on Global Change in Mountain Regions. Perth, Scotland.

Allen, C. D. 2005. Cross-scale nonlinearities and interactions among forest dieback, fire, and erosion in northern New Mexico landscapes. Ecological Society of America Annual Meeting. Montreal, Canada.

Allen, C. D. 2005. Fire in the Southwest. Fourth USGS Fire Science Workshop. Tucson, AZ.

Allen, C. D. 2005. Landscape change in mountains of the Southwestern USA: Fire, forest dieback, and erosion. Invited open lecture, University of Alicante. Alicante, Spain.

Allen, C. D. 2005. Water as an ecological factor in the Southwestern USA. Guest lecture, general ecology course, University of Alicante. Alicante, Spain.

Allen, C. D., K. L. Beeley, and B. F. Jacobs. 2005. Long-term ecological monitoring and restoration of piñon-juniper woodlands at Bandelier National Monument, New Mexico, USA. Society for Ecological Restoration International Annual Meeting. Zaragoza, Spain.

Allen, C. D. 2006. Climate-induced forest dieback: An emergent globa and erosion in mountain landscapes of Northern New Mexico. Open lecture, Pajarito Environmental Education Center. Los Alamos, NM.

Allen, C. D. 2006. Disturbance interactions in mountain landscapes of the Southwestern USA: Climate, land use history, forest dieback, fire, and erosion. Open lecture at University of Granada. Granada, Spain.

Allen, C. D. 2006. Ecohydrology of pinyon-juniper woodlands in the Jemez Mountains, New Mexico: Runoff, erosion, and restoration. USFS and Society of American Foresters meeting on Ecology and Management of Pinyon-Juniper Ecosystems. Albuquerque, NM.

Allen, C. D. 2006. Fire, thresholds, and wildland restoration. Invited lecture to University of New Mexico graduate watershed management course. Albuquerque, NM.

Allen, C. D. 2006. Fire-Human interactions as linked cascading events in the Americas. Ecological Society of America international conference "Ecology in an Era of Globalization: Challenges and Opportunities for Environmental Scientists in the Americas". Merida, Mexico.

Allen, C. D. 2006. Global change research in the western U.S.: The Western Mountain Initiative. Guest lecture for graduate global change research course, Environmental Studies Dept., Northern Arizona University, Flagstaff, AZ.

Allen, C. D. 2006. Interactions among climate, dieback, fire, and erosion in forests and woodlands in the Southwest. Presentation to Public Service Company of New Mexico. Albuquerque, NM.

Allen, C. D. 2006. Interactions among climate, land use history, forest dieback, fire, and erosion in mountain landscapes of Northern New Mexico. Distinguished guest speaker series, Forestry Dept., Northern Arizona University. Flagstaff, AZ.

Allen, C. D. 2006. Landscape changes, long-term monitoring, and ecological restoration of pinyon-juniper woodlands at Bandelier National Monument, New Mexico. Lecture to "Interpreting and Measuring Indicators of Rangeland Health", BLM National Training Center Course # 1730-37, Santa Fe, NM.

Allen, C. D., R. S. Anderson, R. B. Jass, J. L. Toney, and C. H. Baisan. 2006. Paired charcoal and tree-ring records of high-frequency Holocene fire from two New Mexico bog sites. Third international fire ecology and management congress. San Diego, CA.

Allen, C.D., 2006, Ecohydrology of pinyon-juniper woodlands in the Jemez Mountains, New Mexico: Runoff, erosion, and restoration. USFS and Society of American Foresters meeting on Ecology and Management of Pinyon-Juniper Ecosystems. Albuquerque, NM.

Allen, C.D. 2006. Disturbance and Climate – Southwestern US and Mediterranean Europe. Western Mountain Initiative PI meeting, Sept. 2006, OR.

Allen, C.D. 2006. Climate-induced forest dieback: An emergent global phenomenon? MTCLIM 2006 meeting. Mt. Hood, OR.

Allen, C.D. Anderson, R.S., Jass, R.B., Toney, J.L., and Baisan, C.H. 2006. Paired Charcoal and Tree-Ring Records of High-Frequency Holocene Fire from Two New Mexico Bog Sites. 3rd International Fire Ecology and Management Congress. San Diego, CA.

Allen, C.D. 2006. Landscape-scale restoration of forest ecosystems (panel presentation). National Conference on Conserving and Restoring Frequent Fire Landscapes of the West: Linking Science, Collaboration and Practice. Flagstaff, AZ.

Allen, C.D. 2006. Ecohydrological Linkages, Multi-scale Processes, Temporal Variability, and Drivers of Change in a Degraded Pinyon-Juniper Watershed: Implications for Erosion Modeling. Invited presentation to session: Improving Integrated Predictions of Soil Erosion. AGU fall meeting. San Francisco, CA.

Allen, C.D. 2006. *Applying historical ecology and long-term research to ecosystem management in northern New Mexico: Reflections of a place-based ecologist.* Invited seminar, Texas A&M University, Department of Rangeland Ecology and Management departmental seminar, College Station, TX.

Allen, C.D. 2006. *Ecohydrology of Pinyon-Juniper Woodlands in the Jemez Mountains, New Mexico: Runoff, Erosion, and Restoration.* Invited seminar, Texas A&M University, Graduate ecohydrology course, College Station, TX.

Allen, C.D. 2006. *Vegetation Change in the Rio Grande Basin.* Invited seminar, Texas A&M University, undergraduate watershed hydrology course, College Station, TX.

Allen, C.D. 2007. *Landscape ecology, disturbance histories, ecohydrological thresholds, and watershed management in northern New Mexico*. Invited seminar, University of New Mexico, "grand finale" 2-hour lecture to spring semester graduate course in watershed management (Prof. William Fleming), Albuquerque, NM.

Allen, C.D. 2007. *Climate change, disturbance interactions, and restoration ecology in the southwestern US.* Invited seminar, University of Granada, Granada, Spain. Departmental seminar, Ecology Department.

Allen, C.D. 2007. Synergistic, threshold, and cumulative effects of disturbances in Western mountain ecosystems. Western Mountain Initiative Workshop: Climate Change and Disturbance Interactions in Western Mountains. Feb., Tucson, AZ.

Allen, C.D., and Castro, J. 2007. Global change, climate-induced forest dieback, and wildland fire risk. 4th International Wildland Fire Conference. May, Sevilla, Spain.

Allen, C. D. and D. D. Breshears. 2006. Climate-induced forest dieback: A global phenomenon. DIRENET annual meeting. Flagstaff, AZ.

Allen, C. D., D. D. Breshears, N. L. Stephenson, and P. J. van Mantgem. 2007. Climate-induced forest dieback as an emergent global phenomenon: overview and synthesis. Introductory symposium talk, *Annual meeting of the Ecological Society of America*, San Jose, California.

Allen, C.D. 2007. Piñon-Juniper Woodland Mortality in the Southwestern USA: Climate-Induced Dieback and Ips Outbreak Interactions. Plenary talk to Workshop on Climate Change, Insects, Pathogen, and Forests, Portland, Oregon.

Baron, J. S. 2005. Consequences of nitrogen deposition in Rocky Mountain National Park - reprise. Colorado Air Quality Control Commission, Denver, CO.

Baron, J. S. 2005. Consequences of nitrogen deposition in Rocky Mountain National Park. Presentation and field trip, Scripps Howard Institute on the Environment, Boulder and Rocky Mountain National Park CO.

Baron, J. S. 2005. Consequences of nitrogen deposition in Rocky Mountain National Park. Colorado Institute for Leadership Training, Fort Collins, CO.

Baron, J. S. 2005. Consequences of nitrogen deposition to Rocky Mountain National Park. Colorado Departments of Environmental Health annual meeting, Aspen, CO.

Baron, J. S. 2005. Environmental consequences of atmospheric nitrogen deposition to Rocky Mountain National Park. Poudre Golden K Kiwanis Club, Fort Collins, CO.

Baron, J. S. 2005. Field trip for air quality managers from Colorado Department of Environmental Health and Environment to Loch Vale Watershed.

Baron, J. S. 2005. Hindcasting nitrogen to determine and ecological critical load. Poster presented at the NADP annual meeting, Jackson, WY.

Baron, J. S. 2005. Led official field trip on Front Range air pollution issues for American Association of Geographers annual meeting in Denver, CO.

Baron, J. S. 2005. Rocky Mountain Environment and Society. NREL Fall seminar.

Baron, J. S. 2006. Mountain Hydrology. Lecture to Colorado State University Watershed hydrology class.

Baron, J. S. 2006. New ecological knowledge? New ecological order? The scope of human activities on Earth. Symposium "New ecological knowledge and practices for society and sustainability," organized as part of the Ecological Society of America (ESA) Conference on "Ecology in an Era of Globalization," Merida, Mexico.

Baron, J. S., C. D. Allen, D. McKenzie, N. L. Stephenson, D. Fagre, D. L. Peterson, J. Hicke, P. G. Van Mantgem, L. Christensen, and C. Tague. 2006. Synthesis activities of the Western Mountain Initiative [Abstract]. MTNCLIM conference, Timberline Lodge, Mt. Hood, OR. September 19-22, 2006.

Baron, J., C. Allen, D. McKenzie, L. Gunderson, E. Fleishman, N. L. Stephenson, L. Meyerson, and J. K. Oropeza. 2007. Adaptation options of national parks to

climate change. *The George Wright Society Biennial Conference on Parks, Protected Areas, and Cultural Sites*. St. Paul, Minnesota.

Baron, J., T.R. Schmidt, and A. Krcmarik. 2007. What is causing the recent increases in $NO_3$ in Loch Vale surface waters? *National Atmospheric Deposition Program* annual meeting, Boulder Colorado.

Baron, J. S., M. D. Hartman, and D. S. Ojima. 2006. Determining critical loads for eutrophication and acidification for alpine ecosystems of the Colorado Rocky Mountains, USA [Abstract]. Proceedings of the Open Science Conference on Global Change in Mountain Regions, Perth, Scotland. In Global Change in Mountain Regions, ed. Martin Price, 131-132. Duncow, UK: Sapiens Publishing.

Baron, J. S., M. Hartman, D. Ojima, B. M. Lafrancois, K. Nydick, H. Rueth, A. Wolfe, and J. Botte. 2005. Nitrogen deposition in the Rocky Mountains: Causes and consequences. Symposium on nitrogen eutrophication in xeric and agricultural systems. Riverside, CA.

Butler, D. R., G. P. Malanson, S. J. Walsh, L. M. Resler, D. B. Fagre, and C. F. Sawyer. 2005. Multi-scale geomorphic impacts and controls on alpine treeline [Poster]. 36th International Binghamton Geomorphology Symposium, University at Buffalo, SUNY, October 7-9, 2005.

Butler, D.R., G.P. Malanson, S.J. Walsh, and D.B. Fagre. 2006. Repeat Photography and the Western Mountain Initiative [poster]. MTNCLIM 2006 conference, Timberline Lodge, Mt. Hood, OR. September 19-22, 2006.

Butler, D.R., G.P. Malanson, S.J. Walsh, and D.B. Fagre. 2006. Repeat Photography and the Western Mountain Initiative [abstract], MTNCLIM 2006 conference, Timberline Lodge, Mt. Hood, OR. September 19-22, 2006.

Christensen, L., J. S. Baron, and C. Tague. 2005. Application of RHESSys model to environmental change in western mountain national parks. American Association of Geographers annual meeting, Denver, CO.

Christensen, L., C. Tague, J. Baron. 2006. Spatiotemporal response of transpiration to climate variation in a snow dominated mountain ecosystem. [Poster]. Ecological Society of America annual meeting, Memphis TN, Aug 6-11.

Christensen, L., C. Tague, J. Baron. 2006. Spatiotemporal response of transpiration to climate variation in a snow dominated mountain ecosystem. [Poster]. CIRMOUNT, MtnClim 2006 Conference, Mt. Hood, OR, September 19-22.

Christensen, L., J. Baron, C. Tague. 2006. Western Mountain Initiative: a network of mountain protected areas for global change research. Rocky Mountain Climate Workshop, Durango CO October 12.

Christensen, L., and C. Tague. 2007. Regional Hydro-Ecological Simulation System: description and application of a mountain hydro-ecological model. Talke presented at IDEAM conference, Medellin, Colombia, February 26-28.

Das, A. J., J. J. Battles, N. L. Stephenson, and P. J. van Mantgem. The effects of demographic processes on the spatial structure of an old-growth forest: the importance of density-dependent mortality. *Annual meeting of the Ecological Society of America*, San Jose, California.

Fagre, D. B. and B. A. Reardon. 2005. Glacier studies in Glacier National Park. Brown bag seminar, Glacier National Park. September 14, 2005. West Glacier, MT.

Fagre, D. B. 2005. Adapting to the reality of climate change at Glacier National Park, Montana, USA. First international conference on impacts of climate change on

high-mountain systems, University of Zurich and Instituto de Hidrologia, Meteorologia y Estudios Ambientales. Bogota, Colombia, November 21-23, 2005.

Fagre, D. B. 2005. Climatic variability drives changes to the U.S. Northern Rocky Mountains. Open science conference: Global change in mountain regions, Perth Scotland, October 2-6, 2005.

Fagre, D. B. 2006. Attended forum "UNESCO-Pro-Natura International Forum on Bio-Carbon Sequestration and Conservation to Combat Climate Change: Promoting Rural Development, Energy Solutions and Biodiversity", UNESCO (United Nations Education, Science, and Cultural Organization) World Headquarters, Paris, France.

Fagre, D.B. 2006. Impacts of declining snow and ice in western U.S. mountains: Progress towards integrated assessments. Western Mountain Initiative Annual Meeting, Skamania, WA, September 16-18, 2006.

Fagre, D.B. 2006, MTNCLIM Conference, Timberline Lodge, Mt. Hood, OR. September 19-22, 2006.

Fagre, D.B., 2005. Climatic Variability Drives Changes to the U.S. Northern Rocky Mountains. Open Science Conference: Global Change in Mountain Regions, Perth Scotland, October 2-6, 2005.

Fagre, D.B. 2006. Climate Change in the Northern Rockies: What Disappearing Glaciers Tell Us About the Future of Water. AWRA (American Water Resources Association), Montana Section 23rd Annual Meeting. KwaTuqNuk Inn, Polson, MT. October 12-13, 2006. Invitied Banquet Speaker

Fagre, D. B. 2006. Glacial Recession: What is Happening to the Glaciers in the Pacific Northwest? Climate Change in the Canadian Columbia Basin: Starting the Dialogue. Columbia Basin Trust, Castlegar, British Columbia, Canada. October 20, 2006.

Fagre, D.B. 2006. Climate Change in Western North America: What Disappearing Glaciers Tell Us about the Future of Water. Connecting Water Resources 2006. Water Management in Canada: Leadership at Every Level. Canadian Water Network, Montreal, Quebec. November 22, 2006. Fagre, D.B. 2006. How Glacier National Park Responds to Climate Change. Glacier Country Avalanche Center, O'Shaunessy Center, Whitefish, Montana. November 18, 2006.

Fagre, D.B. 2006. How Glacier National Park Responds to Climate Change: Cascading Ecological Effects Reflect Rising Temperatures. 2006-2007 Ashland University Environmental Lecture Series: "Environmental Issues in the National Parks". Ashland University, Ashland, Ohio. November 9, 2006.

Fagre, D. B. 2006. Changing climates, changing resources – the future of Glacier National Park. 17th Annual Rocky Mountain State Parks Executive Conference, "State Parks and Tourism – Roles, Relationships and Responsibilities", Glacier National Park, West Glacier, MT.

Fagre, D. B. 2006. Climate change research networks in western mountains: Added value from scaling up our science. USGS Global Change Research Program Strategic Planning Workshop, Denver, CO.

Fagre, D. B. 2006. Climatic change and atmospheric deposition: Global changes to a pristine national park. Western Regional Air Partnership meeting, Glacier National Park, West Glacier, MT. September 13, 2006.

Fagre, D. B. 2006. Glacier National Park and climate change: Past, present and future. Academic awards banquet, Northfield High School, Northfield, Minnesota. Also taped for showing on local Public Broadcasting System TV station.

Fagre, D. B. 2006. How Glacier National Park responds to climate change: Cascading ecological effects reflect changing water balance. Climate change – organizing the science for the American Cordillera (CONCORD), Mendoza, Argentina, April 4-6, 2006.

Fagre, D. B. 2006. How Glacier National Park responds to climate change: Cascading ecological effects reflect changing water balance [Abstract]. Symposium on Climate Change: Organizing the Science in the American Cordillera (CONCORD), Instituto Argentino de Nivologia, Glaciologia y Ciencias Ambientales (IANIGLA), Mendoza, Argentina.

Fagre, D. B. 2006. How Glacier National Park responds to climate change and what it tells us about the future. Community lecture, United Methodist Church, Columbia Falls, MT.

Fagre, D. B. 2006. Changing climates, changing resources – the future of Glacier National Park. 17th Annual Rocky Mountain State Parks Executive Conference, State Parks and Tourism – Roles, Relationships and Responsibilities, Glacier National Park, West Glacier, MT. May 8-11, 2006.

Fagre, D. B. 2006. How Glacier National Park responds to climate change: Past, present and future. Presentation to Glacier Park Associates, Central School Museum, Kalispell, MT.

Fagre, D. B. 2006. Invited and sponsored speaker and panel discussant in water resources and climate change session. All South American countries present except Venezuela and all North American countries present as well as multiple international representatives (e.g. World Bank).

Fagre, D. B. 2006. Workshop participant and consultant for the World Heritage and Climate Change Expert Meeting, World Heritage Center, UNESCO Headquarters, Paris, France, March 2006.

Fagre, D. B. 2006. North-south transect workshop participant, sponsored by Mountain Research Initiative in Bern, Switzerland and Instituto Argentino de Nivologia, Glaciologia y Ciencias Ambientales (IANIGLA), Mendoza, Argentina. Committees are working in hydrology, glaciers, forest dynamics.

Fagre, D. B. 2006. Participated in CONCORD meeting: Climate Change: Organizing the Science in the American Cordillera, Instituto Argentino de Nivologia, Glaciologia y Ciencias Ambientales (IANIGLA), Mendoza, Argentina.

Fagre, D. B. 2006. Rocky Mountain high: Global warming in the west. City club of Boise forum, the Grove hotel, Boise, ID. July 24, 2006.

Fagre, D. B. 2006. Update on glacier and snow research. Western Mountain Initiative annual meeting, Skamania, WA. September 16-18, 2006.

Fagre, D. B. 2006. The effects of climatic change on Glacier National Park: Past, present, and future. Glacier National Park annual interpreter training workshop, Glacier National Park, West Glacier, MT.

Fagre, D.B., N. Stephenson, C. Allen, J. Baron, D. Peterson and D. McKenzie. 2006. Climate Change Research Networks in Western Mountains: Added Value from Scaling Up Our Science. USGS Global Change Research Program Strategic Planning Workshop, Denver, CO. June 26-28, 2006.

Fagre, D. B, K. Holzer, B. Reardon, G. Pederson, and L. McKeon. 2006. Repeat photography [Poster]. Waterton-Glacier science and history day, Waterton Lakes, Alberta, July 27, 2006.

Fagre, D. B, K. Holzer, B. Reardon, G. Pederson, and L. McKeon. 2006. The disappearing glaciers of Glacier National Park, MT [Poster]. Waterton-Glacier science and history day, Waterton Lakes, Alberta, July 27, 2006.

Fagre, D. B., L. M. McKeon, R. Menicke, and B. Reardon. 2006. Geospatial technologies document the disappearing glaciers of Glacier National Park [poster], 26th Annual ESRI International User Conference.

Fagre, D. B., G. T. Pederson, S. T. Gray and L. J. Graumlich. 2006. Teleconnections through space and time: Glaciers, water and the West. Session: Climate variability, natural resources, and societies: Perspectives from the past. 36th AMQUA biennial meeting, Bozeman, MT. August 18-20, 2006.

Fagre, D., G. Pederson, B. Reardon, K. Holzer, and L. McKeon. 2006. Climate change in the northern Rockies. USGS Northern Rocky Mountain Science Center all hands meeting and science review, Bozeman, MT. Feb. 8, 2006.

Fagre, D.B. 2006. Climate Change in the Northern Rockies: What Disappearing Glaciers Tell Us About the Future of Water. 2006-07 Water Faculty Seminar Series, Haub School and Ruckelshaus Institute of Environment and Natural Resources, University of Wyoming, Laramie. November 30, 2006.

Fagre, D.B. 2006. Interview on Wyoming Public Radio, broadcast December 1, 2006.

Fagre, D. B. 2007, Climate Change in Glacier National Park, June 15, 2007, Science and Research Symposium, Lake McDonald Lodge, Glacier National Park, MT.

Fagre, D. B. 2007. *Cascading Climate Change Impacts on the Crown of the Continent Ecosystem*, presented at Spotlight on Science at the US Fish and Wildlife Regional Office in Portland, OR. Spotlight on Science, a cooperative effort between BLM, FWS, USGS, and the USFS, addressed the topic "Effectiveness of Ecological Reserves in the Face of Climate Change" May 3, 2007.

Fagre, D. B. 2007. Panelist and co-presenter at Assoc. of American Geographers annual meeting in San Francisco, CA, April 15-21, 2007.

Fagre, D. B. 2007. Participant in Montana Governor's Science Advisory Committee meeting on Climate Change, Helena, MT, Feb. 8, 2007.

Fagre, D. B. 2007. Presenter in 3-4 communities in British Columbia, sponsored by Columbia Basin Trust and Univ. of British Columbia, Jan 29-31, 2007.

Fagre, D. B. 2007. Presenter to Montana Board of Directors for Nature Conservancy in Whitefish, MT, Jan. 25, 2007.

Fagre, D. B. 2007. Panelist/presenter on climate and global warming at the 23rd Annual Frank Church Conference, Jan. 22, 2007, Boise State University, Boise, ID. Al Gore was keynote speaker.

Fawcett, P. J., J. M. Heikoop, F. Goff, C. D. Allen, R. S. Anderson, L. Donohoo-Hurley, J. W. Geissman, C. Johnson, G. WoldeGabriel, and J. Fessenden-Rahn. 2005. Climate change over a glacial-interglacial cycle from the mid Pleistocene: A Lacustrine record from the Valles Caldera, New Mexico. AGU fall meeting. San Francisco, CA.

Fawcett, P. J., J. M. Heikoop, F. Goff, R. S. Anderson, L. Donohoo-Hurley, J. W. Geissman, C. Johnson, C. D. Allen, G. WoldeGabriel, and J. Fessenden-Rahn. 2006. A mid-Pleistocene glacial-interglacial cycle from the Valles Caldera,

northern New Mexico. New Mexico Geological Society annual meeting. Socorro, NM.
Graumlich, L. J., S. T. Gray, G. T. Pederson, and D. B. Fagre. 2006. Climate change and ecosystem services: Defining the modern currency of Quaternary science. Session: Looking forward from the past: Quaternary sciences and environmental forecasting. 36th AMQUA biennial meeting, Bozeman, MT. August 18-20, 2006.
Gray, S. T., G. T. Pederson, G. T. Betancourt, D. B. Fagre, and L. J. Graumlich. 2006. New approaches for isolating the climate/growth signal of millennial Pinus chronologies from the Northern Rocky Mountains, USA [abstract]. 2005 Meeting of the Association of American Geographer, Chicago, IL.
Gray, S. T., G. T. Pederson, D. B. Fagre, L. J. Graumlich, and J. L. Betancourt. 2005. Disentangling the climate/growth signal of millennial Pinus chronologies from the Northern Rocky Mountains, USA. Eos Trans. AGU, 86(52), Fall Meeting Supplement, Abstract PP11A.
Gray, S. T., G. T. Pederson, and A. G. Bunn. 2007. Hydroclimatic variability in the Upper Colorado River Basin, USA, since 900 AD [abstract]. XVII International Union for Quaternary Research Congress, July 28- Aug. 3, Cairns, Australia.
Gray, S. T., G. T. Pederson, and A. G. Bunn. Millennial-scale reconstructions of regional hydrology from the Upper Colorado River Basin, USA [abstract] In: 2007 Meeting of the Association of American Geographers; April 17-21, San Francisco, CA.
Gwozdz, R., and D. McKenzie. 2007. Modeling spatial variation of forest fuel moisture: integrating effects of terrain and forest structure. Presented at the 2007 meeting of the Ecological Society of America, San Jose, CA.
Harper, J., D. Fagre, and B. Reardon. 2006. The role of ice movement in the response of glaciers to climate change: A focus on Sperry Glacier, Glacier National Park [Poster] Waterton-Glacier science and history day, Waterton Lakes, Alberta, July 27, 2006.
Hartman, M. D. J. S. Baron, and D. S. Ojima. 2005. Calculating pre-measurement atmospheric deposition, stream chemistry, and soil chemistry for an alpine watershed in Rocky Mountain National Park, Colorado. Ecological Society of America annual meeting, Montreal, Canada.
Hartman, M. D., J. S. Baron, and D. S. Ojima. 2005. Calculating pre-measurement atmospheric deposition, stream chemistry, and soil chemistry for an alpine watershed in Rocky Mountain National Park, Colorado. Poster presented at the NADP annual meeting, Jackson, WY.
Hartman, M. D., J. S. Baron, D. S. Ojima, and W. J. Parton. 2005. Modeling the timeline for lake and stream acidification from excess nitrogen deposition for Rocky Mountain National Park. George Wright Society, Philadelphia, PA.
Heikoop, J. M., P. J. Fawcett, F. Goff, R. S. Anderson, L. Donohoo-Hurley, J. W. Geissman, C. Johnson, C. D. Allen, G. WoldeGabriel, and J. Fessenden-Rahn. 2006. A paleoclimate record of two glacial-interglacial cycles from the Valles Caldera, northern New Mexico. Second international conference on global warming and the next ice age. Santa Fe, NM.
Hicke, J. A. 2005. Context, characteristics, and consequences of recent bark beetle outbreaks: Contributions of landscape- to regional-scale analyses. Bark Beetle Symposium. Snowbird, UT.
Hicke, J. A. 2005. Development of a web site for analyzing temperatures in mountain regions over the last 100 years. MTNCLIM 2005 Meeting. Pray, MT.

Hicke, J. A. 2005. Means and trends in solar radiation: Results from two global data sets and effects on estimated net primary production. American Geophysical Union Fall Meeting. San Francisco, CA.

Hicke, J. A. 2006. Bark beetle outbreaks in Colorado and the West. Know your valley lecture series. Vail, CO.

Hicke, J. A. 2006. Bark beetle outbreaks in the West: Impacts on ecosystems and people. Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO.

Hicke, J. A. 2006. North American carbon fluxes in recent decades: Spatiotemporal patterns and drivers of change. University of Idaho, Moscow, ID.

Hicke, J. A., J. A. Logan, and D. S. Ojima. 2006. Insect outbreaks, forests, and climate: Effects on the North American carbon budget. Proceedings of the First Integrated Land Ecosystem-Atmosphere Processes Study Science Conference. Boulder, CO. Edited by A. Reissell and A. Aarflot, Report Series in Aerosol Science 79:194-196.

Hicke, J. A., D. S. Ojima, J. A. Logan, D. Kashian, M. G. Ryan, and W. Romme. 2005. Comparing the impacts of different disturbances of western North American forests on carbon cycling. Seventh International Carbon Dioxide Conference. Broomfield, CO.

Holzer, K. 2005. GLORIA in North America, an alpine ecology monitoring network [Poster]. Ecological Society of America meeting, Memphis, TN.

Holzer, K. 2006. GLORIA in North America, an alpine ecology monitoring network [Poster]. Ecological Society of America meeting, Memphis TN, Aug. 2006.

Ironside, K., and Cobb N., Shaw J.D., Ogle K., Allen, C.D., and Breshears, D.D. 2007. Dieback of Forests and Woodlands Across Elevational Gradients in Response to Global-Change-Type Drought in the Western US, North America. In Organized Oral Session: Climate-Induced Forest Dieback as an Emergent Global Phenomenon: Patterns, Mechanisms, and Projections. Ecological Society of America Annual Meeting. August, San Jose, California.

Lorite, J., Castro, J., Zamora, R., and Allen, C.D. 2007. Salvage logging reduces plant species richness and diversity one year after wildfire. 4th International Wildland Fire Conference. May, Sevilla, Spain.

Malanson, G.P., D.B. Fagre, 2005. Ordination context for GLORIA sites in Glacier National Park, Montana. Open Science Conference: Global Change in Mountain Regions, Perth Scotland, October 2-6, 2005.

Malanson, G. P., P. Bourgeron, A. Bunn, D. R. Butler, L. Daniels, D. Fagre, D. Liptzin, C. I. Millar, D. L. Peterson, L. Resler, W. K. Smith, D. Tomback, S. J. Walsh, and D. Weiss. 2006. Treeline dynamics and climate change [Abstract]. MTNCLIM conference, Timberline Lodge, Mt. Hood, OR, September 19-22, 2006.

McKenzie, D. 2005. A national fuels map for coarse-scale modeling of fire effects. Presented at the BlueSky Annual Meeting, Edmonds, WA.

McKenzie, D. 2006. Implications of wildland fire use for smoke, air quality, and regional haze. Presented at the International Fire Ecology and Management Conference, San Diego, CA.

McKenzie, D. 2006. Scale, air quality, and the Fire Scenario Builder. Presented to the University of Washington CSES Climate Impacts Group, Seattle, WA.

McKenzie, D. 2006. Vegetation, disturbance, and climatic change. Presented at the USFS Region 1 Reforestation and TSI Workshop, Missoula, MT.

McKenzie, D., A. G. Andreu, R. A. Norheim, A. C. Bayard, K. E. Kopper, L. -K. B. Kellogg, C. L. Raymond, and E. Elman. 2005. Landscape mapping of fuels using the FCCS system and remote sensing. Presentation at the EastFire Conference, Fairview Park, VA.

McKenzie, D., L. -K. B. Kellogg, D. A. Falk, C. M. Miller, and A. E. Black. 2006. Scaling laws and fire-size distributions in historical low-severity fire regimes. Geophysical Research Abstracts 8:1607-7962/gra/EGU06-A-01436.

McKenzie, D., L. -K. B. Kellogg, and N. Larkin. 2006. Topographic controls on historical fire sizes in inland forests of the Pacific Northwest, USA. Presented at the International Association of Landscape Ecologists, San Diego, CA.

McKenzie, D., L. -K. B. Kellogg, N. Larkin, D. A. Falk, C. M. Miller, and A. E. Black. 2006. Scaling laws and fire-size distributions in historical low-severity fire regimes. Presented at the European Geosciences Union, Vienna, Austria.

McKenzie, D., S. M. O'Neill, N. Larkin, and R. A. Norheim. 2005. Integrating models to predict the effects of wildfire on air quality in parks and wilderness. Presented at the Open Science Conference on Global Change in Mountain Regions, Perth, Scotland, UK.

McKenzie, D., J. S. Baron, C. D. Allen, N. L. Stephenson, D. Fagre, D. L. Peterson, J. Hicke, J. S. Littell, P. J. van Mantgem, L. Christensen, and C. Tague. 2006. Synthesis activities of the Western Mountain Initiative. *MTNCLIM 2006 Conference*, sponsored by the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT). Mt. Hood, Oregon.

McKenzie, D., S. M. O'Neill, N. Larkin, R. A. Norheim, and J. S. Littell. 2006. Stochastic modeling of fire at daily time steps from mesoscale meteorology. Presented at the International Fire Ecology and Management Conference, San Diego, CA.

McKenzie, D., S. M. O'Neill, N. Larkin, R. A. Norheim, J. S. Littell, and Lara-Karena B. Kellogg. 2007. Stochastic modeling of fire at daily time steps from mesoscale meteorology. Presented to the European Geosciences Union, Vienna, Austria.

McKenzie, D., D. L. Peterson, and J. S. Littell. 2005. Effects of a warmer climate on stress complexes in forest of western North America. EOS Trans. AGU 86(52); Fall Meet. Suppl., Abstract GC32A.

McKenzie, D., D. L. Peterson, and J. S. Littell. 2005. Effects of a warmer climate on stress complexes in forests of western North America. Presented to the American Geophysical Union, San Francisco, CA.

Millar, C.I. and D.B. Fagre. 2005. The North American Gloria Project: A Cirmount Work-group Effort. Open Science Conference: Global Change in Mountain Regions, Perth Scotland, October 2-6, 2005.

Millar, C.I., C. Allen, D.B. Fagre, and G. Greenwood. 2005. Integrating Climate and Ecosystem-Response Sciences in Temperate Western North American Mountains: The Consortium for Integrated Research in Western Mountains (CIRMOUNT) Initiative. Open Science Conference: Global Change in Mountain Regions, Perth Scotland, October 2-6, 2005. [poster]

Ojima, D., D. Schimel, J. Hicke, S. Running, B. Stephens, and T. Hilinski. 2005. Estimation of regional carbon dynamics in complex landscapes of the Colorado Rockies by model-data fusion. Proceedings of the Open Science Conference: Global Change in Mountain Regions. Perth, Scotland.

Pederson, Gregory T., Stephen T. Gray, Daniel B. Fagre, Lisa J. Graumlich 2005. Disentangling the climate/growth signal of millennial *Pinus* chronologies from the

Northern Rocky Mountains, USA. American Geophysical Union Annual Meeting, San Francisco, CA, December, 2005.

Pederson, G. T., S. T. Gray, C. Woodhouse, and T. Kipfer. 2005. The past climate variability and impacts clearinghouse: Linking new users to paleoenvironmental resources. Eos Trans. AGU, 86(52), Fall Meeting Supplement, Abstract PP11A-1432.

Pederson, G. T., B. A. Reardon, D. B. Fagre, and C. J. Caruso. 2006. High-resolution tree-ring based spatial reconstructions of snow avalanche activity in Glacier National Park, Montana, USA [Abstract]. International Snow Science Workshop. Telluride, CO.

Peterson, D. L., D. B. Fagre, D. McKenzie, C. Allen, J. Baron, and N. Stephenson. 2005. Effects of climatic variability and change on forest ecosystems – Empirical evidence from the Western Mountain Initiative network. *Anticipating challenges to western mountain ecosystems: MTNCLIM 2005*, Consortium for Integrated Climate Research in Western Mountains, March 1-4, 2005, Chico Hot Springs, Pray, Montana.

Pederson, G.T., L.J. Graumlich, T. Kipfer, C. J. Caruso, and D.B. Fagre. 2006. 20$^{TH}$ Century Temperature Data Indicate That The "Last Best Place" Is Heating Up. MTNCLIM 2006 conference, Timberline Lodge, Mt. Hood, OR. September 19-22, 2006.

Pederson, G.T., S.T. Gray, D.B. Fagre, L.J. Graumlich. 2006. Climate Change, Glaciers, Water and the West: Lessons from the Past and Relevance to Today's Ecosystem Services. February 22th 2006, Moonlight Basin Ski Resort., Big Sky, MT.

Pederson, G.T., S.T. Gray, D.B. Fagre, L.J. Graumlich. 2006. Climate Change, Glaciers, Water and the West: Lessons from the Past and Relevance to Today's Ecosystem Services. January 24, 2006, Montana Natural Resource Professionals, Bozeman, MT.

Pederson G.T., S.T.Gray, J J. Shanker, D.B. Fagre, and L J. Graumlich. 2007. A novel approach for improving records of long-term, multi-scale snowpack variability in western North America [abstract] In: 2007 Meeting of the Association of American Geographers; April 17-21, San Francisco, CA.

Pederson, G. T., S. T. Gray, J. J. Shinker, D. B. Fagre, and L. J. Graumlich. 2007. A novel tree-ring based approach for reconstructing records of long-term snowpack variability in western North America [abstract]. XVII International Union for Quaternary Research Congress, July 28- Aug. 3, Cairns, Australia.

Prato, T., R. Sugumaran, Dan Fagre, and Ric Hauer. 2005. Assessing Ecological Economic Impacts of Landscape Change in Montana's Flathead County. USDA National Research Initiative Project Director's Meeting, Washington, DC, October 28, 2005.

Prato, T., D. Fagre, Z. Qiu. 2006 Modeling adaptive management of crop production for climate change in a northwestern Montana watershed [Abstract]. MTNCLIM conference, Timberline Lodge, Mt. Hood, OR. September 19-22, 2006.

Reardon, B. A. 2006. Glacier studies in Glacier National Park. Joint Glacier National Park Resources & USGS Brown Bag Seminar, West Glacier, MT. June 13, 2006, West Glacier, Montana.

Reardon, B. A. and M. D. Dundas. 2006. Going-to-the-Sun Road spring avalanche training. Glacier National Park, West Glacier, MT.

Reardon, B. A., D. B. Fagre, C. C. Lundy, and M. D. Dundas. 2006. Glide crack formation and glide slab avalanches, Glacier National Park, USA: A unique hazard and forecasting challenge [abstract]. International Snow Science Workshop. Telluride, CO.

Reardon, B. A., D. B. Fagre, G. T. Pederson, and C. J. Caruso. 2005. Climate influences on large-magnitude natural snow avalanches in John F. Stevens Canyon, Montana [Abstract], Eos Trans. AGU. 8(52). Fall Meeting Supplement, Abstract GC33A-1248.

Reardon, B. A., D. B. Fagre, G. T. Pederson, and C. J. Caruso. 2006. Climate influences on, and interannual variability of, natural avalanches in three paths, Glacier National Park, Montana, USA [Abstract]. MTNCLIM conference, Timberline Lodge, Mt. Hood, OR. Sept. 19-22, 2006.

Schmidt, T.R., A. Krcmarik, and J.S. Baron. 2007. Effects of altered global climate and nitrogen cycles on an alpine watershed, Loch Vale, in Rocky Mountain National Park, CO; use of Path Analysis to elucidate trends in dynamic and hierarchical systems. *North American Benthological Society* annual meeting. Columbia, South Carolina.

Stephenson, N. L. 2005. Biotic consequences of climatic change. Joint USGS - FWS Future Challenges Project, Southwestern Regional Workshop. Sacramento, California.

Stephenson, N. L. 2005. Biotic consequences of climatic change, and some implications for wildlands management. 8th World Wilderness Congress, "Wilderness, Wildlands and People – A Partnership for the Future," Anchorage, Alaska.

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**Other products.**

- Dan Gavin (Univ. of Oregon) completed WMI-funded work on a new software package (CHARSTER) to manage and analyze sedimentary charcoal data. The software, available on the Web (http://geography.uoregon.edu/gavin/software.html), is expected to improve the compatibility of results between researchers, allowing improved data integration between studies and thereby facilitating more extensive geographic syntheses of paleo-fire/climate records.

- WMI and collaborator Andrew Fountain completed a westwide survey of glaciers, remnant glacial ice, and perennial snowfields. A map product has been made available on the web (http://glaciers.research.pdx.edu/).

- A full-service website was produced and launched for the repeat photographs of glaciers at Glacier National Park (http://www.nrmsc.usgs.gov/repeatphoto/index.htm).

**Geospatial Reference.**

| | | |
|---|---|---|
| Northwest corner: | 49.0º N | 124.8 º W |
| Northeast corner: | 49.0º N | 105.3 º W |
| Southwest corner: | 35.7 º N | 124.8 º W |
| Southeast corner: | 35.7 º N | 105.3 º W |

38
26
4
108

4

4
108