Watershed Management Council Networker
Advancing the art and science of watershed management
Summer 2001
Volume 10 No. 1

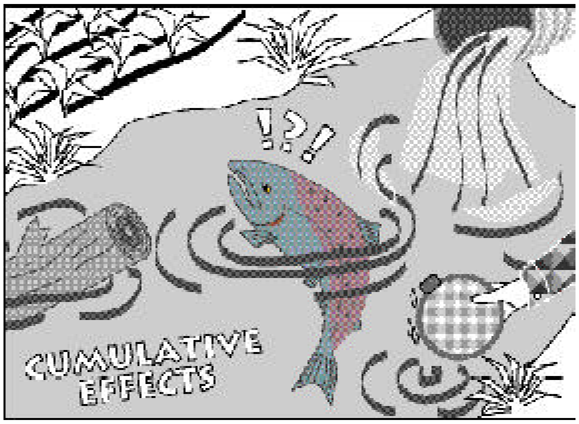
Beyond Arm Waving: Thinking Critically at Large Scales

Lee Benda and Daniel Miller
Earth Systems Institute, Seattle

Abstract

Recent advances in thinking about ecosystem behavior over the past several decades have primarily taken the form of qualitative concepts. Although they represent major innovations in a number of fields, they have also fueled a propensity for arm waving and speculation when it comes to understanding how increasing scale changes our perceptions. Furthermore, this limitation has also encouraged natural resource managers and regulators to default to small scale, reductionist approaches in their fields. The present danger is that scientific myopia in the watershed sciences, focusing on small scales, is creating a number of problems that may weaken the support of policy makers for applying science to environmental questions and undermine the public's belief in the relevance of science in society. To attack the problem of scale, and hence complexity in watershed science, management, and regulation will require developing new interdisciplinary frameworks and theories that address a broad range of scales and scientific uncertainty, and that welcomes new forms of knowledge. In this article, we outline several universal principles that can be used to understand how measurement scale influences our perception of environments. When linked with an understanding of landscape processes, they allow us to predict how unique mixtures of climate, topography, vegetation, channel networks, and basin scale impose first-order constraints on spatial and temporal patterns of environmental variability, at any spatial scale. This form of knowledge is embodied in probability and frequency distributions, and they reveal the consequences of multiple interactions, over multiple scales, within landscapes. We present brief examples of how the behavior of forest ages, landsliding, sedimentation, and large organic debris loading to streams varies according to combinations of space and time scales. Finally, we suggest how this type of understanding might play out in watershed science, resource management, and regulation.

Continues on Page 4



Timber Harvest and Sediment Loads in Nine Northern California Watersheds Based on Recent Total Maximum Daily Load (TMDL) Studies

Sharon H. Kramer, Martin Trso, and Noah Hume
Stillwater Sciences, Arcata

Introduction

This review provides an assessment of sediment source analyses from recently completed Total Maximum Daily Load allocations (TMDLs) in nine northern California watersheds in the range of the coho salmon *(Oncorhynchus kisutch)*. The goal of this review is to address sediment yields associated with forest management activities, particularly after the promulgation of forest practice regulations. Each TMDL provides a sediment source analysis based upon different time frames and source categories. However, this review does not analyze the appropriateness of the methodology used or the results obtained for sediment source assessments in individual TMDLs. A more extensive analysis of the background data used to prepare the TMDLs would be required to verify sediment source categories and to separate out the potential effects of large storm events that vary substantially in magnitude and frequency. Using the published data available from TMDLs, we present a discussion of mechanisms of sediment delivery, sediment source analysis methodology, and a comparison of sediment loadings due to timber harvest, as well as sediment production due to other associated forest management activities and natural sources.

Causal Mechanisms for Sediment Delivery to streams

In steep, dissected and soil-mantled hillslopes of the humid and forested Pacific Northwest region, mass wasting processes (i.e., landslides, creep and biogenic transport) are naturally a dominant erosion process on hillslopes and

Continues on Page 17

WATERSHED MANAGEMENT COUNCIL
NETWORKER
is a publication of the
Watershed Management Council
c/o PSRP
University of California at Davis
One Shields Ave
Davis, CA 95616
http://www.watershed.org

Rick Kattelman, *President*

Chuck Slaughter, *President-Elect*

Jim Bergman, *Secretary*

Terry Kaplan-Henry, *Treasurer*

MEMBERS-AT-LARGE

Robert Coats
John Cobourn
Pete Hawkins
Polly Hays
George Ice
Donna Meyers
Dennis Pendleton

NEWSLETTER AND WEBSITE

Michael Furniss, *Editor and Webmaster*

Kathryn Ronnenberg, *Production*

MEETING DATES

The WMC Board of Directors meets quarterly. All WMC members are welcome to attend.Contact a board member to arrange to attend a meeting or discuss any ideas or issues for the Council.

MEMBERSHIP

Dues are $20 per year. Please use the membership application form on the back page of this issue to join. For inquiries for subscription problems call (510) 273-9066 (WMC's voice mail), or send an email to subscriptions@watershed.org

SUBMISSIONS WELCOME

The WMC Networker welcomes all submissions. All copyrights remain with the authors. Email or disk versions are appreciated. Please keep formatting to a minimum. Mail submissions to President Rick Kattelmann at:

rick@watershed.org

Incoming President's Column

For this first column from the WMC's incoming president for 2001-2002, there are two critical items of business: to encourage every reader's participation in our organization and to thank Sari Sommarstrom and Mike Furniss for their exceptional service to the Watershed Management Council.

First, the encouragement: the Watershed Management Council is a member-based organization. The WMC acts for the benefit of its members and as a vehicle for its members. We formed this outfit back in 1986 to pool our resources in advancing the field of watershed management. The charter members felt that a "Watershed Management Council" could do more than most of us can as individuals. However, as individuals, we need to contribute to the group by sharing our experience and ideas with the watershed management community. The WMC is primarily an educational organization. We try to educate our membership, our colleagues and associates, policy makers, and the public at large about the benefits, potentials, tools, and techniques of watershed management. So far, we've tried to accomplish that mission through the Networker, our web site, our conferences and field trips, our policy forums, and co-sponsorship of events organized by other groups. All these activities (and others we haven't yet explored) require help from the individual members. We need articles for the Networker, we need material for the website, we need speakers for conferences, field trips, and forums, we need organizers for events, and we need fresh ideas for how the Watershed Management Council can serve its members.

Second, the thanks: two of the individual members who have given tremendous help and service to the Watershed Management Council are stepping into less-active roles with the WMC this year. Sari Sommarstrom is now Past-President after a very successful two-year term. Sari has been with the WMC since its beginning, was an active board member, contributed many articles to the Networker and conference proceedings, helped organize at least three WMC conferences, was an outstanding President, and organized the four California Watershed Forums in 1999 and 2000. The Watershed Management Council is most grateful for all of Sari's efforts with the organization and her service to the field of watershed management. Sari will be representing the WMC at the National Watershed Forum to be held this summer.

Thanks, part 2: Mike Furniss is leaving the editorship of the WMC Networker after eleven years. Obviously, we can't thank him enough for creating an excellent publication and continually improving its quality over the years. The high frequency that I see citations to WMC Networker articles in research papers, state-of-the-art summaries, and technical reports is testimony to the quality of our Networker under Mike's leadership and fine-tuning. We've also heard plenty of compliments about the readability and visual appearance of the Networker. Again, Mike has been responsible for the excellent layout and "look" of the publication. All the past issues of the Networker since 1990 are available on the WMC website (www.watershed.org), which Mike has graciously consented to keep maintaining. So, I'd like to extend our deepest appreciation to Mike Furniss for being a fantastic editor and webmaster.

Finally, we are now in need of a Newsletter Editor. Do you have an interest? Do you know someone who might? You don't need to know anything about layout or page design, publishing software or print shops. All that can be contracted for. This is a great opportunity for someone. Mike Furniss told me recently that his entire career changed for the better after he became Editor. Call me if you would like to discuss this.✍

The Watershed Continuum:

Moving Toward Consilience

A cross-disciplinary group is developing a multimedia learning system and courseware development tool to facilitate the discovery of interdisciplinary concepts, novel syntheses, and consilience.

A group of scientists and educators are striving to build an information container that will enable consilience, the "jumping together of knowledge," as recently described and elucidated by E.O. Wilson in his book: Consilience: The Unity of Knowledge.

Working from Corvallis Oregon and Arcata, California, the group is building a

Continues on next page, column 2

Louise Solliday and Coquille Watershed Association Honored in First WMC Awards

The first recipients of the WMC's new leadership awards were announced at our 8th Biennial Conference at Asilomar. Louise Solliday, most recently Watershed Advisor to the Governor of Oregon, received the 2000 John Wesley Powell Award for "An Individual Making an Outstanding Contribution to Watershed Management in the Western United States". The Coquille Watershed Association of Coquille, Oregon received the 2000 Walter C. Loudermilk Award for "An Organization Implementing an Outstanding Watershed Restoration Program".

WMC President Sari Sommarstrom presented the awards, which included a personally engraved plaque and an autographed copy of Dr. Luna Leopold's renowned book, A View of the River. While an award program was suggested in the Council's 1986 by-laws, it took Board Member Robert Coats to officially initiate these two awards last summer. The Council Board is pleased to finally have in place this program for more recognition of individuals and organizations contributing to the field of watershed management in the western states.

Among the nomination letters we received for Louise Solliday was one from Governor John Kitzhaber. We wish to quote a few excerpts from that letter:

"It is with great pleasure that I recommend for the John Wesley Powell Award an individual that has been an outstanding leader in watershed management in Oregon. While thousands of dedicated and talented individuals contribute to watershed restoration, and all of them deserve awards, I would argue that Louise Solliday has provided the essential strategic leadership that has allowed local leadership to flourish."

"Over the last four years, Ms. Solliday has made it her top priority to identify the strategic needs of local watershed restoration efforts, and has worked tirelessly to fill those needs. She recognized that the many volunteers involved in restoring their watersheds need simple tools and 'how to' manuals to apply to their watersheds. Ms. Solliday organized the the development of restoration guidelines and a watershed assessment manual, and worked with the federal agencies to approve these guidelines. Ms. Solliday recognized that if we did not make watershed restoration relatively easy, it would not succeed. Toward this end, she has worked hard to coordinate and streamline federal and state rules governing stream restoration."

"For three years, Ms. Solliday chaired the grant program that Oregon established to fund local watershed restoration efforts. She guided the Watershed Enhancement Board through a transition from a small granting entity to an organization that provides more than $30 million a biennium toward watershed restoration."

"Again, while I believe that thousands of Oregonians are deserving of the John Wesley Powell Award, I am a strong supporter of Ms. Louise Solliday."

Shortly before the WMC conference, Ms. Solliday was promoted to be the Governor's Assistant for Natural Resources.

WMC's first Walter C. Loudermilk Award for an organization was presented to Paul Heikkilla, former Chair, on behalf of the Coquille Watershed Association The group was formed in 1993 by watershed residents who were concerned about aquatic habitat and the watershed as a whole. A watershed assessment and action plan were completed and adopted in 1995, with several subsequent revisions. The Association's list of accomplishments includes a great variety of projects, such as 80 miles of riparian livestock exclusion fencing and tree planting, replacement and/or repair of 22 culverts to improve fish passage, and enhancement or creation of 12 off-channel wetlands. More than 200 private landowners within the Coquille River basin have completed such restoration projects, and 25 more are on a waiting list for future cooperative projects. The group was recognized previously for its outstanding watershed work by the U.S. Forest Service, Bureau of Land Management, and the Oregon Private Industry Council. The Coquille Watershed Association is to be congratulated for its success in involving a diverse array of interests in supporting and implementing watershed management goals.

The Awards Program will be an ongoing activity of the Watershed Management Council. We are seeking a financial sponsor for the awards. Any suggestions in this regard would be appreciated. Members should be thinking about potential nominees for the next pair of awards in 2002. We hope that the WMC awards program will provide greater public visibility for individuals and groups actively "advancing the art and science of watershed management".✍

The Continuum... Continued

product that will help students of all ages perceive connections between myriad knowledge resources that exist, and are now more accessible than ever with electronic communications tools. The team is designing and building a "zooming" user interface, a body of compelling scientific content, organized around a conceptual taxonomy. The Watershed Continuum will contain and deliver courseware that is readily shareable, extensible, friendly, and accessible. An abbreviated version of the current project description follows:

Guiding principles of the Continuum Project

The Continuum Project is about merging experience and practice with immediate access to the wealth of information, expertise and collegiality that has suddenly become available via computing and communications. It is about realizing the potential in information technology to achieve a higher level of understanding, to bridge disciplines once separated by language and proximity, to link ideas and leverage the ability of science to paint a more vivid picture of earth's processes.

The Continuum Project is no more or less about science than it is about philosophy and learning. The key success factor in today's information-rich society—openness—reflects the long-understood truth that collaboration fosters scientific understanding. Our government and social institutions are stronger when there is active participation by an informed citizenry. The Internet is upon us because of open standards for interoperation. The processes of nature are open for all to see, if they will observe. In that spirit, this project embraces open standards for information exchange, and contains resources gleaned from the public domain, or generously donated by authors and speakers. It hopes to foster sharing and dialog across disciplines, so each can learn from and strengthen the others, and move several steps closer to an integrated understanding of how the world works.

While the Continuum Project's initial focus is to provide a

Continues on Page 33

Beyond Arm Waving: Thinking Critically at Large Scales

Continued from Page 1

Introduction

Many environmental issues in the watershed sciences involving forestry, geology, hydrology, fisheries, etc. depend on interactions of numerous landscape processes acting over a large range of spatial and temporal scales. Consequently, scientists and managers have been seeking to understand the role of scale in their respective disciplines for more than two decades (de Boer 1986; Allen and Starr 1982; Folt et al. 1998). For example, recognizing hierarchical time and space domains in surface processes brought issues of scale to the forefront in the science of community and landscape ecology (Wiens 1984; Frissel et al. 1986). Motivated in part by ecologists, watershed scientists also have recognized the need to transfer understanding across spatial and temporal scales in the study of landscapes (Swanson et al. 1988; Benda et al. 1998).

Despite this attention, our understanding of how increasing the dimensional scales of perception would play out in watershed science, management, and regulation is limited. For example, it has proven difficult to extend channel reach-scale measurement and understanding obtained over a period of a few years to larger spatial and temporal scales (i.e., segment to network over decades to centuries) because of un-reconciled stochastic processes and the lack of theory that would allow bridging between data gaps (Benda et al. 1998). As a consequence, most resource managers focus their planning activities at small scales (harvest unit, single rotation) with decision making therefore hinged primarily on market forces and changing environmental regulations. Furthermore, although regulators recognize the need for understanding resource management and impact assessment at large scales, they default to small scale, reductionist approaches, primarily because of the lack of leadership in this area by the scientific community. Nevertheless, this problem is on the radar screen as evidenced by a growing consensus calling for incorporating dynamics or disturbance (i.e., increasing scale) into natural resource science and management (Botkin 1990; Naiman et al. 1992; Reeves et al. 1995; Reid 1998; Dunne 1998; Lackey 1998; Benda et al. 1998; Maurer 1999). In addition, adapting science to questions involving larger space and time scales is becoming a central tenet in new and creative forms of thinking, embodied in systems analysis (Weinberg 1975; Allen and Starr 1982), macro ecology (Mauer 1999), and complexity science (Kellert 1993; Waldrop 1992; McIntrye 1998).

The purpose of this article is to outline highlight several universal principles that address the effects of increasing scale in watersheds or landscapes. Our aim is to equip readers with a handful of tools that should allow them to think critically regarding the role of scale in watershed science, management, and regulation in their home landscapes, in the hope of moving beyond the hand waving stage. In addition, we emphasize how large-scale attributes of landscapes (i.e., mixtures of climate, topography, vegetation, network geometry, and basin scale) impose major constraints on the space and time structure of environmental variability (i.e., the disturbance regime), embodied in forests, erosion, large organic debris, streamflow, channel conditions, and aquatic habitats. Because the study of scale in the watershed sciences is a relatively new and rapidly evolving field, we admit that understanding how increasing scale might play out in natural resource management and regulation (forestry, fisheries, etc.) is at an incubation stage. We leave that topic up to the unbridled imagination of the reader.

Universal Principles of Scale

A Landscape Parameter of Frequency and Probability Distributions

Simply, the system behavior of a landscape can be described as the temporally changing values of an attribute at a single location (forest ages, sedimentation, large woody debris etc.) or the variation in these attributes over many locations in a watershed in a single year (Benda et al. 1998). Hence, the system behavior of landscapes cannot be understood solely with single value parameters. Landscape parameters must be multiple valued to reflect temporal variability and spatial heterogeneity, key aspects to understanding geomorphic and

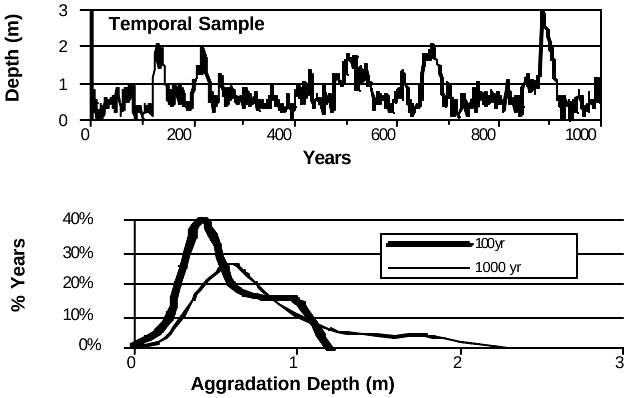


Figure 1. In temporally variable environments, the longer the time of observation, the greater the probability of seeing a large event, here represented with a simulated time series of sediment depth at a channel cross section. Aggradational events create terraces, with the highest terrace recording the rarest events. The frequency of aggradation influences the vegetation communities inhabiting each terrace.

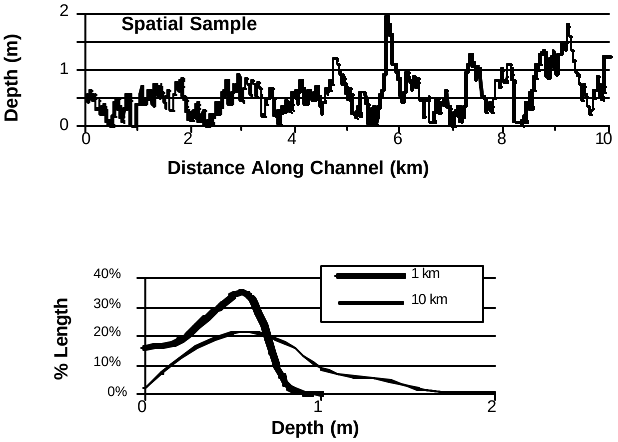


Figure 2. In spatially variable environments, the larger the area observed, the greater is the probable range of observations made, illustrated here with simulated sediment depths along a 10-km channel reach.

ecologic behavior. A distribution of values inexorably arises when attributes are viewed either over long periods or large regions of space; it cannot be inferred from a point observation. In the parlance of the evolving field of complexity science, frequency or probability distributions comprise an emergent property that reveals the consequences of multiple interactions, over multiple scales, within landscapes.

For example, soil depth is a parameter and is used in many applications, such as landslide prediction, groundwater modeling, etc. The distribution of soil depth is, however, a parameter itself because it contains information about the range and frequency of values. Hence, when seeking to understand the role of scale, distributions of parameters (such as soil depth, forest ages, rainfall, etc.) will be integrated into quantitative relationships that predict watershed (system) behavior in the form of other distributions (Benda et al. 1998). For example, the probability distribution of climate coupled with frequency distributions of topographic and vegetative attributes will yield a probability distribution of erosion and sediment flux (Benda and Dunne 1997). Distributions, because they measure temporal variability and spatial heterogeneity, are sensitive to changing scales and they also indicate how measurement scale influences our perception of environments.

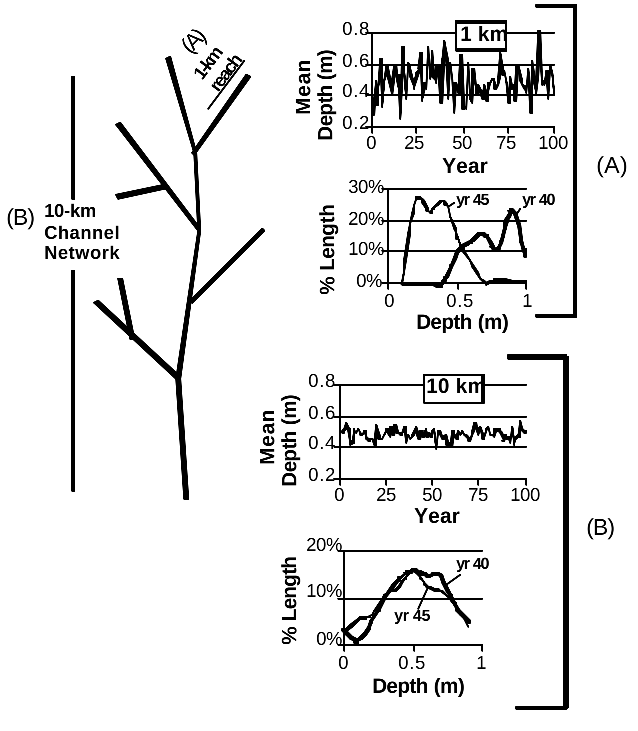


Figure 3. In environments that vary in space and time, the greater the number of elements included in a population, the less variable the distribution over time. Here mean sediment depth over a 1-km length and a 10-km length of channel is compared over a 100-yr time span. Although the range of values sampled over the 10-km length is greater, the difference is the distribution of values, and in the mean value, from year to year, is less.

Relationships Among Distributions, Time, and Space

Most physical and biological landscape processes are strongly dependent on scale. For example, the occurrence of disturbances, such as earthquakes, landslides, fires, storms, floods, etc. is dependent on time scale. These dynamic surface processes contributes to habitat diversity, a multi-valued attribute that depends on spatial scale. Hence, intrinsic relationships between temporal and spatial distributions and scale comprise a fundamental element for understanding how physical and biological processes are interrelated. Five universal scaling relationships are briefly outlined below; some are trivial and this section is meant as a review for many readers.

Scaling in time (disturbance regime at a point). Many stochastic agents, including earthquakes, storms, fires, floods, and erosion, act to create and modify channel and riparian landforms. The time required to observe the full range of events responsible for the full suite of riverine morphologies (e.g., disturbance regime or range of variability) depends on the operative processes. In general, infrequent, but large magnitude events are responsible for large morphologic changes with long legacies, processes located in tails of probability distributions (Dunne 1998). The structure of that temporal variability is increasingly apparent over larger time scales (Figure 1).

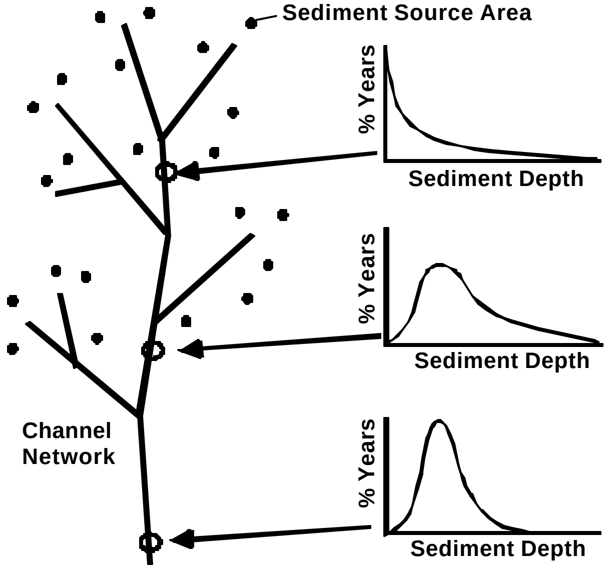


Figure 4. Integration of multiple inputs via routing through a channel network causes the distribution of sediment flux and associated storage to become more symmetrical, with lower variance, downstream.

Scaling in space (many points, diversity at a single time). An observer (human or otherwise) following a stream channel encounters a diversity of attributes (e.g., particle sizes, pool depths, etc.) that originate from temporal variability (Figure 1) and deterministic topographic heterogeneity (i.e., systematic decreases in gradient downstream, for example). The range of that diversity increases with the distance traversed (Figure 2). Thus, the range of habitat types available to an organism increases with increasing scale of movement. Aquatic organisms may have evolved different life history strategies in

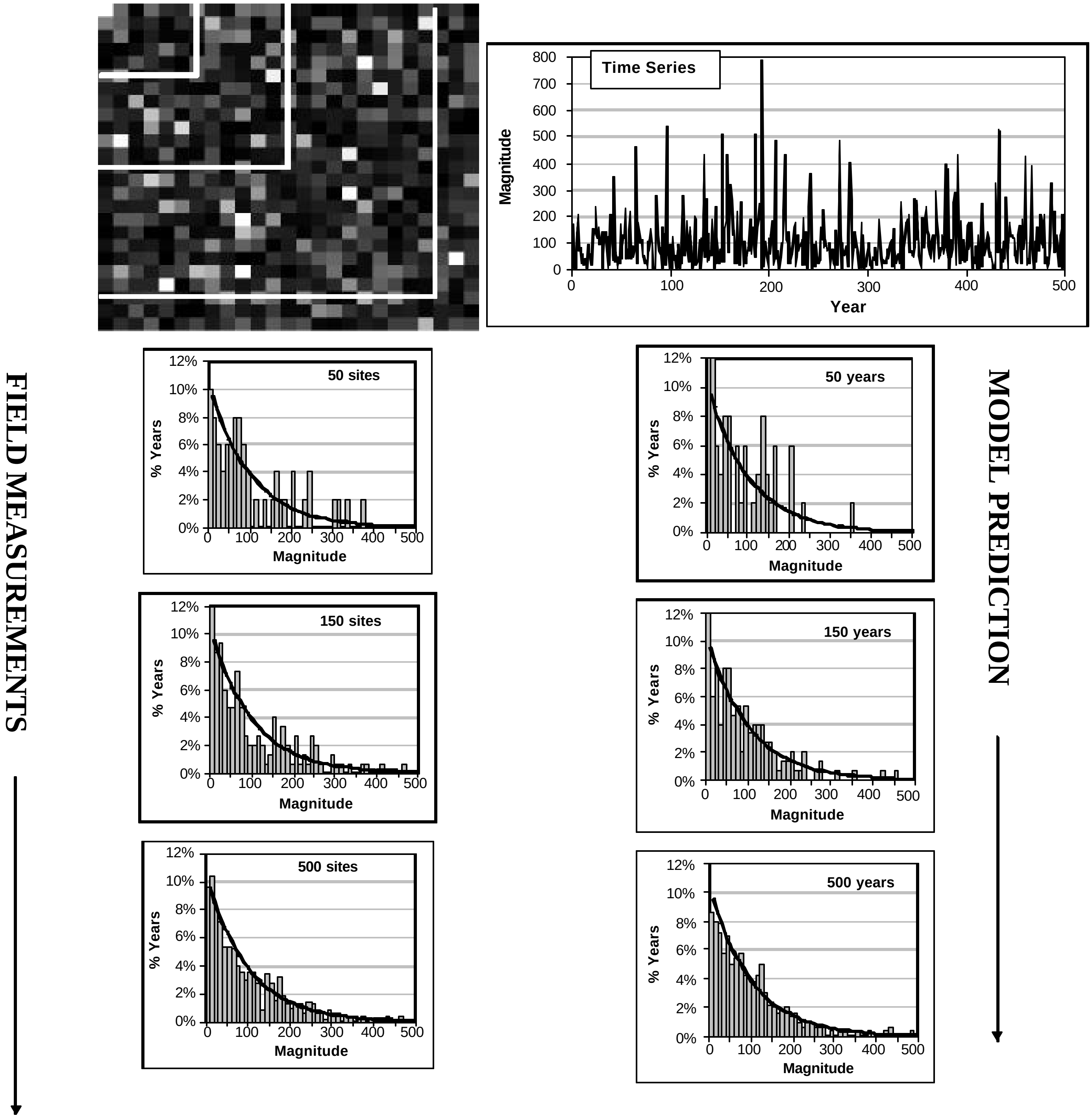


Figure 5. At sufficiently large space and time scales, the frequency distribution of a spatial ensemble of elements (Figure 2) may become statistically similar to a temporal distribution of that attribute at a single location (Figure 1). Similarity between large spatial samples and large temporal samples is referred to as an ergodic relationship (Hann, 1977) and it may be used to infer temporal behavior from a spatial sample. Although complete statistical equivalence is unlikely, location-for-time substitution (Brundsen and Thornes 1978) allows for an understanding of temporal change from only a spatial sample.

response to the spatial and temporal scales of habitat heterogeneity. A similar pattern would be evident with landscape attributes not linked to a channel network, such as forests comprised of different age stands or ages of landslide scars.

Scaling in space and time (many points over time, habitat stability). Stochastic agents of disturbance in combination with time-invariant topographic features (i.e., channel gradients, valley width, etc.) will change the set of attribute values found at any single location over time (Figure 1). However, temporal variability can also be viewed at larger spatial scales, say a population of hillslopes or channel reaches, for example. The third universal relationship between distributions and scale indicates that the extent a population of something changes (i.e., for example channel reaches in terms of the shape of the distribution or of some statistical moment, such as the mean, mode, or variance) is dependent on the size of the population of elements. Holding the mean size of a disturbance, such as a fire or landslide, constant, the probability that the distribution of values will change over any given time increases as the size of the population decreases (Figure 3). This scaling relation is also observed in the temporal variability of the mean value of the attribute under consideration. This is simply a consequence that something (fire, landslide, flood) does not happen at the same intensity (or even occur) every place at once. The statistical stability of a spatial distribution of physical habitats (i.e., resilience to shifts over time) may influence such things as population size, spatial distribution, and dispersal strategies.

Scaling in time modulated by channel networks. Scaling relationships one through three are not only applicable to landscapes or channel networks, they are applicable to any environment, including galaxies or grains of sand on a beach. The fourth universal scaling relationship applies particularly to branching networks, such as a channel system. Over long time periods, a channel network samples from a multitude of individual sources of mass flux (such as sediment and LWD), each with their own probability distribution (Figure 1). The integration of all sampled sources yields a long-term distribution of mass flux through the network that evolves downstream into more symmetrical forms, a demonstration of the central limit theorem (Benda and Dunne 1997; Figure 4). This spatial evolution of the probability of channel and riparian disturbances may impose spatial organization on aquatic and riparian habitats, and on the species that inhabit them.

Similarity Between Space and Time Variability (using field clues). At sufficiently large space and time scales, the frequency distribution of a spatial ensemble of elements (Figure 2) may become statistically similar to a temporal distribution of that attribute at a single location (Figure 1); this potential commensurability is shown in Figure 5. For statistical similarity to hold, all forcing functions must be temporally stationary (over certain intervals). Similarity between large spatial samples and large temporal samples is referred to as an ergodic relationship (Hann 1977) and it may be used to infer temporal behavior from a spatial sample. Although complete statistical equivalence is unlikely, location-for-time substitution (Brundsen and Thornes 1979) allows for an understanding of temporal change from only a spatial sample. This technique is particular useful for evaluating landscape behavior, including model predictions of same that encompass decades to centuries during short human life spans. Next, we examine some of the ramifications of increasing spatial and temporal scale on watershed science, management, and regulation.

Increasing Scale: Implications for Watershed Science

Circumventing Limitations in Understanding: Coarse Graining

Landscape interactions create patterns in the temporal behavior and spatial distribution of watershed attributes that may be discernible only at large temporal and spatial scales (Figures 1 - 4). Because of the absence of long-term data, computational models are needed to identify these patterns and the interactions that created them.

Ideally, large-scale computational models would be built upon physics-based understanding of all relevant interdisciplinary processes. However, there is a growing consensus, that at least in the near future, there will be theoretical and technical impediments to developing large-scale environmental models based on smaller-scale processes (Weinberg 1975; Dooge 1986). To circumvent present limitations, watershed-scale models could be constructed whereby some small-scale processes are ignored, or are subsumed within larger-scale representations of those processes, a strategy commonly applied by physicists and referred to as coarse graining (Gell-Mann 1994). In practice in the watershed sciences, this often requires combining, by means of mathematical synthesis and computer simulation, empirical knowledge with theoretical reasoning available at smaller scales, to produce new understanding at larger scales (Roth et al. 1989; Benda and Dunne 1997). The objective of this approach would not be precise predictions about future states at individual sites, but rather new, testable hypotheses on large-scale interactions of climate, topography, vegetation, and riverine environments. This approach has a history in the study of certain hydrological problems at large scales (Smith and Bretherton 1972; Rodriguez-Iturbe and Valdez 1979).

Coarse-grained modeling is well suited to the use of distributions, and exploring the effects of scale on them (i.e., Figures 1 – 5). System models, by definition, produce synthetic time series of watershed behavior (i.e., forest fires, storms, erosion, channel changes, etc.). In evaluating model predictions over human time frames (i.e., for hypothesis testing or environmental problem solving), the typical absence of long-term data forces us to consider a population of watershed elements sampled over a large spatial area. Here again, point observations are insufficient to reveal system behavior and the distribution parameter in numerical models allow us to link behavior over large time and space scales to field observations made over short times, but large areas.

Although the coarse-grained approach is taken by necessity in the study of complex environmental systems, there is considerable potential for obtaining new insights and understanding. Focusing on small-scale processes often precludes seeing the “big picture”, that is, the emergence of patterns and processes unseen at small scales. Indeed, the description of large-scale patterns of behavior, even in the absence of mechanistic understanding for all of the observed processes, is a hallmark of the study of complex systems (Waldrop 1992; Kellert 1993; Gell-Mann 1994). When applied to landscapes, this approach yields a form of knowledge characterized by: (1) Time, and therefore history; (2) Populations of landscape elements (e.g., forest stands, erosion source areas, channel segments, etc.); (3) Processes and their interactions defined by frequency or probability distributions; and (4) Emergence of processes and patterns at large scales that arise due to the collective behavior of large numbers of processes acting over smaller scales (Benda et al. 1998). Several illustrative examples that examine the effects of increasing scale in the watershed sciences are given below.

Example One: Forest Vegetation

Long-term (decadel to century) sequences of climate (rainstorms, floods, and fires) interacting with topography dictate patterns of vegetation. Distributions of climate, topography, and vegetation are all scale dependent (e.g., Figures 1 and 2).

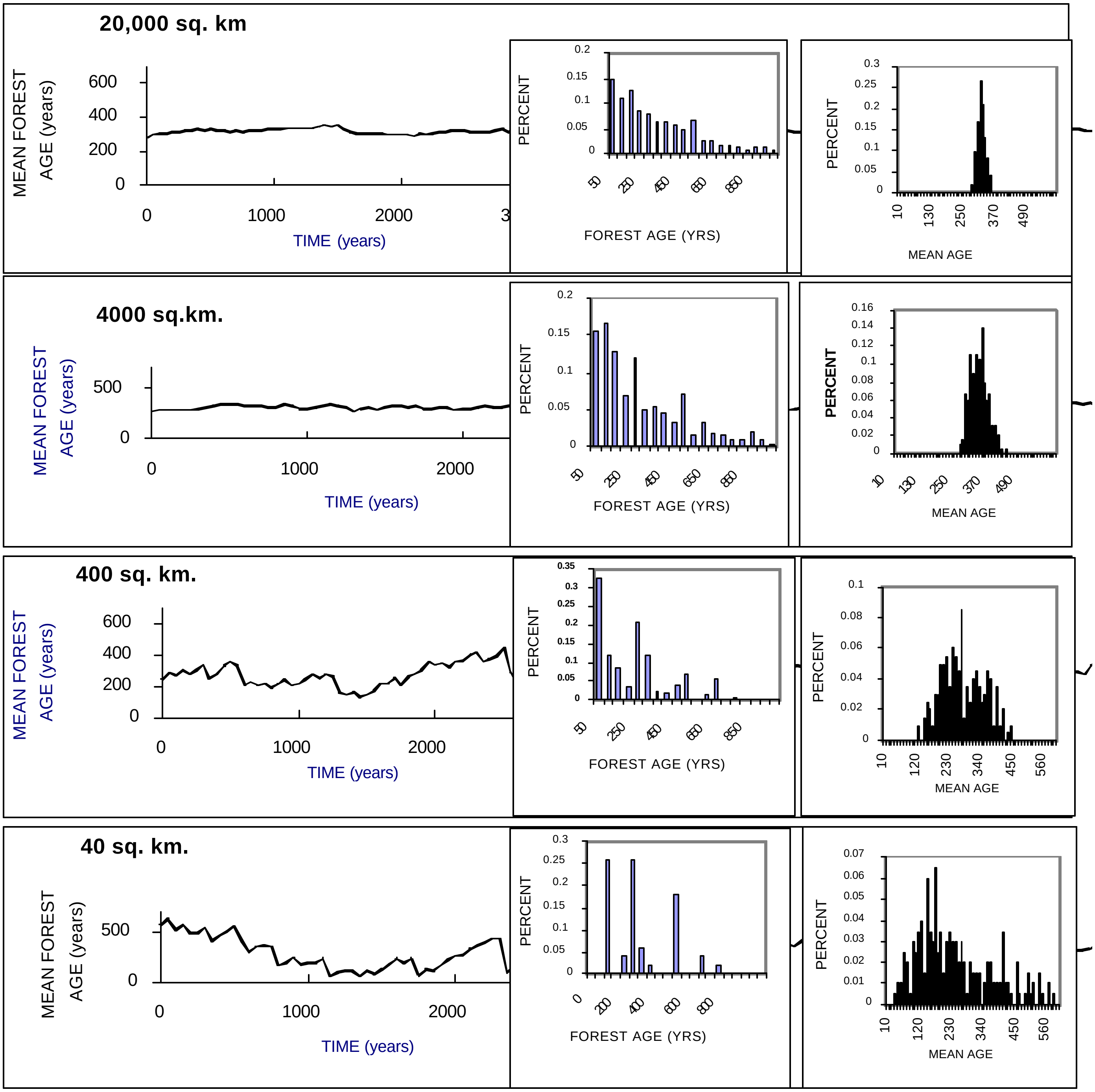
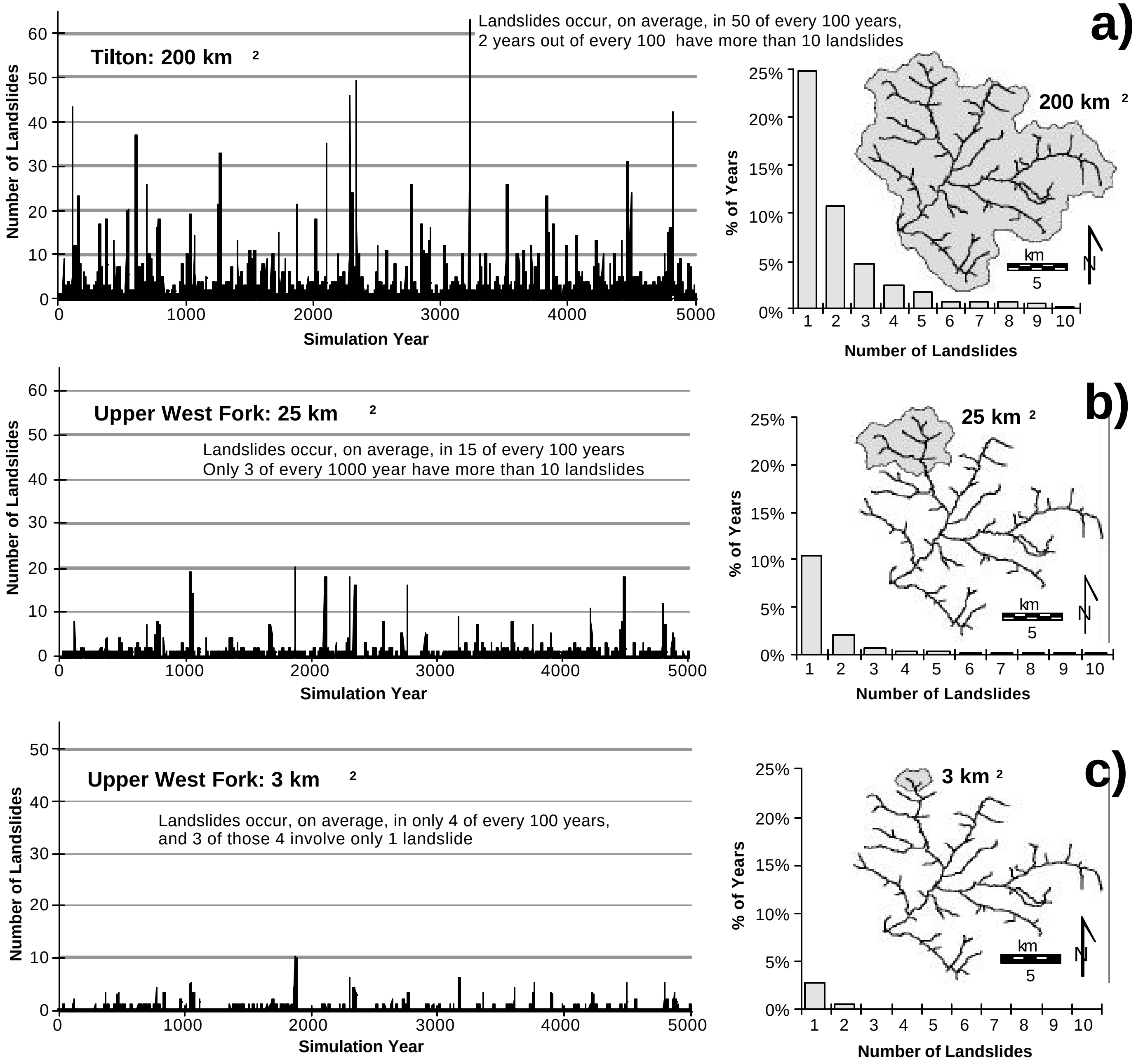


Figure 6. An example of scaling relationships using a forest fires and forest growth. In the Oregon Coast Range, fires occur on average once every 300 years and have sizes ranging from 1 to 1000 km2. (A) A simulated time series of mean forest age over a 2500-year period showing increasing variability with decreasing spatial scale. (B) Forest ages sampled in any one year will be better represented at larger spatial scales. In addition, the spatial distribution of ages at 20,000 km2 should be statistically similar to the long-term probability distribution of ages at any single point in the forest. (C) The decreased variability of mean forest age with increasing spatial scale is represented in the form of a compressed and more symmetrical distribution; a demonstration of the central limit theorem.

In this example, the scale dependency of vegetation is illustrated using a coarse-grained fire model (Benda 1994) in the humid temperate landscape of the Oregon Coast Range (OCR). Forest-replacing wildfires of a range of sizes (~1 – 1000 km2) over the last several millennia occurred at a mean interval of about 300 years, although there was inter-millennial variability (Teensma 1987; Long 1995). In the OCR, probability distributions of forest ages are predicted to be positively skewed and exponentially shaped (Benda, 1994) (Figure 6), similar to fire model predictions in other landscapes (Johnson and Van Wagener 1984). The right skewness arises because of a decreasing probability of developing very old trees in conjunction with an approximately equal susceptibility of fires across all age classes. This forces the highest proportion of trees to occur in the youngest age class and a gradual and systematic decline in areas containing older trees.



Landslides occur, on average, in 50 of every 100 years,
2 years out of every 100 have more than 10 landslides

Landslides occur, on average, in 15 of every 100 years
Only 3 of every 1000 year have more than 10 landslides

Landslides occur, on average, in only 4 of every 100 years,
and 3 of those 4 involve only 1 landslide

Figure 7.The frequency of landsliding within a basin, and the number of landslides occurring over any time, varies systematically with basin size. The 200 km^2 area (a) encompasses thousands of potential landslide sites: within this area landslides are relatively frequent and can occur in relatively large numbers. The 25 km^2 sub basin (b) contains fewer potential landslide sites: landsliding within this area is less frequent with fewer landslides overall. At 3 km^2 (c) landsliding is very infrequent and any episode of landsliding involves only a few sites.

The forest fire example illustrates several of the scaling relationships outlined earlier in this article. Over sufficiently large areas, the spatial distribution of forest ages measured in any year becomes similar to the expected right-skewed probability distribution of ages at a single point in the forest (Figure 6), illustrating the ergodic hypothesis (Figure 5). However, the spatial size of the sample dictates the representation of that probability distribution, illustrating a spatial scaling effect (illustrated in Figure 2). When viewed as a population of forest ages having mean value in each year, the variability of the distribution of means decreases with increasing spatial scale with the distribution increasing in symmetry (Figure 6), demonstrating the central limit theorem (Figure 3). Each of these patterns has geomorphological and ecological ramifications. In addition, the increasing stability of the vegetation age distribution with increasing spatial scale has potential implications for characterizing environmental impacts (discussed later).

Example Two: Erosion by Landsliding

Erosion is dictated, in large part, by climate (i.e., rainstorms), slope steepness, and vegetation. Erosion often depends on a threshold being exceeded, such as in rainfall-triggered landsliding (Caine 1990), or in sheetwash and gullying that is

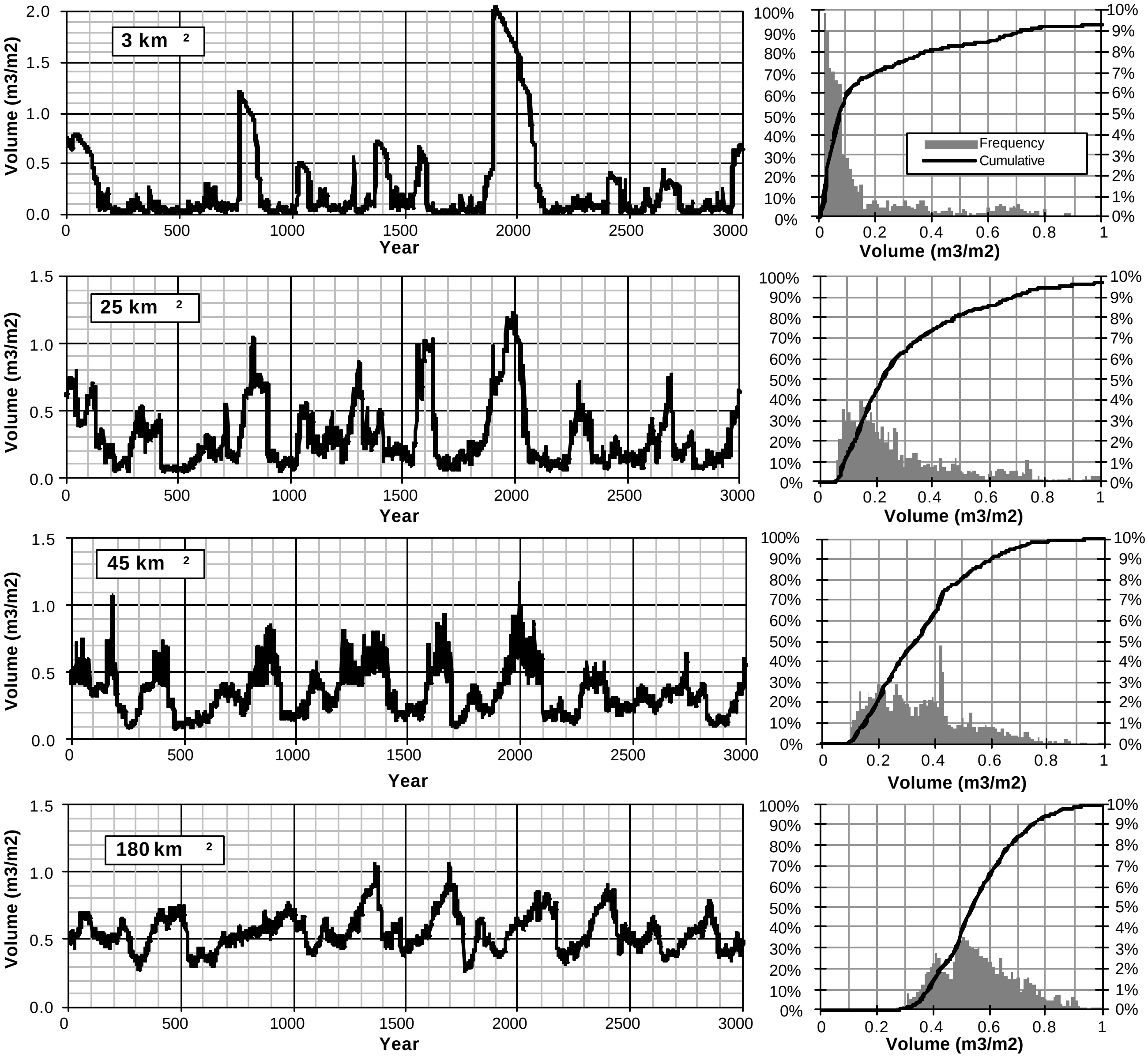


Figure 8. An example of sediment fluctuations vary with spatial scale using computer simulations from southwest Washington. The probability distributions of fluxes evolve downstream to more symmetrical forms, demonstrating the central limit theorem.

dependent on soil hydrophobicity (Heede 1988). Punctuated erosion is ubiquitous in North America, including in the southern coastal chaparral (Rice 1973), Cascade humid mountains (Swanson et al. 1982), Pacific coastal rainforests (Hogan et al. 1995; Benda and Dunne 1997a), Appalachian Mountains (Hack and Goodlett 1960), and in the intermountain and highland arid regions (Wohl and Pearthree 1991; Meyer et al. 1995; Robichaud and Brown 1999).

At the scale of populations of hillslopes over decades to centuries, erosion occurs according to long-term patterns of climate interacting with vegetation and topography. To illustrate this, century-long patterns of erosion were investigated in the OCR using a coarse-grained computational model (Benda and Dunne 1997; Dunne 1998). In the simulation, the temporal and spatial patterns of landsliding and debris flows are predicted to be an outcome of: 1) probability distributions of storm intensity and duration; 2) probability distributions of fire recurrence and size; 3) frequency distributions of topographic and geotechnical properties; 4) deterministic thickening of colluvium in landslide sites; 5) deterministic trajectories of tree rooting strength; and 6) probability functions for sediment transfer from hillslopes to channels. The model predicted that periodic fires and rainstorms triggered spates of landsliding and debris flows every few decades to few centuries, with little erosion at other times and places. Low erosion rates punctuated by high magnitude releases of sediment at the scale of a single hillslope or small basin is expressed by a strongly right-skewed or an exponential probability distribution (Figure 7). Frequency of failures is low in small watersheds because of the low frequency of fires and relatively small number of landslide sites. Landslide frequency and magnitude increases with increasing drainage area because of increasing number of landslide sites and an increasing probability of storms and fires (Figure 7).

Example Three: Channel Sedimentation

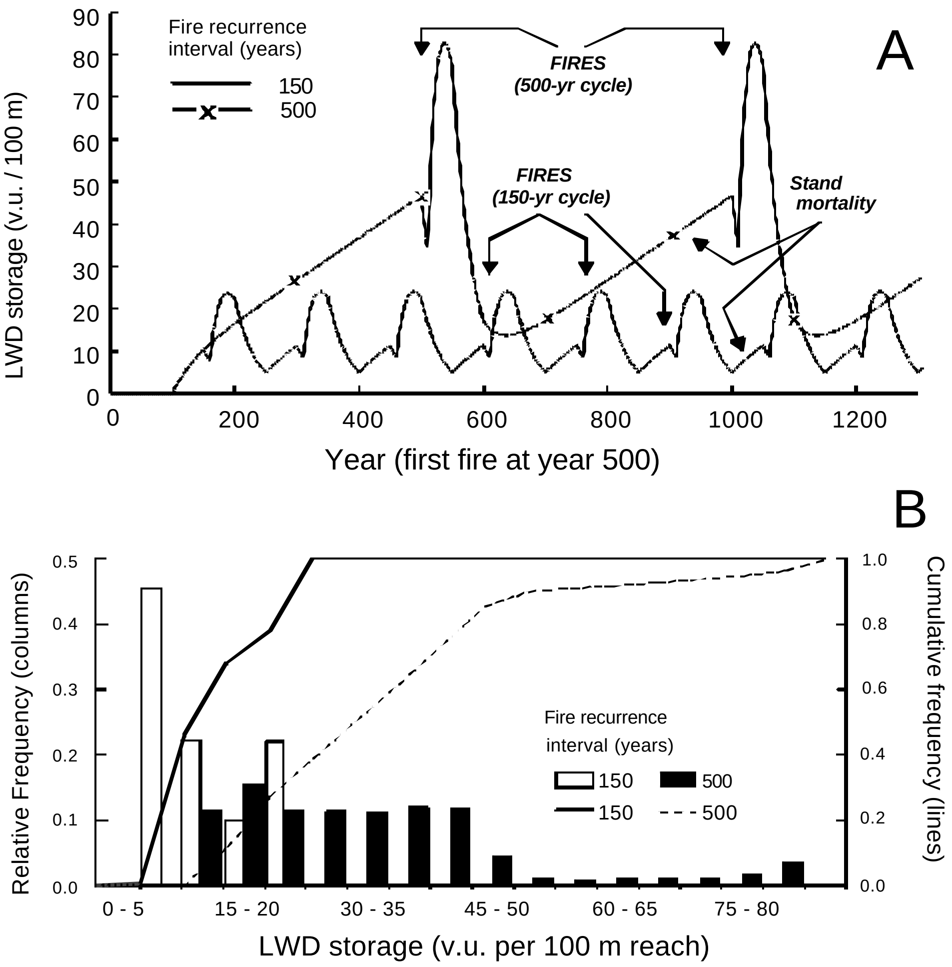


Figure 9. (A) Patterns of wood storage for fire cycles of 150 and 500 years. Gradual increases in storage represent chronic stand mortality. The magnitude of the abrupt pulses of wood storage is governed by the amount of standing biomass (controlled by forest age) and the time interval of the toppling of fire-killed trees (40 years in this example). (B) More frequent fires result in a compressed range of variability and a shift in the distribution towards lower wood volumes (solid bars represent the 500-year cycle). Less frequent fires shift the distribution of LWD volumes towards the right into higher volumes. These patterns indicate the potential for significant differences in LWD storage along climatic gradients in the Pacific Northwest region (east to west and north to south).

Over long periods, channel networks obtain sediment at rates dictated by probability distributions of erosion from individual hillslopes and small tributary basins (e.g., Figure 7). Sediment flux at any point in a channel network represents, therefore, an integrated sample of all upstream sources of supply. Releases of sediment in a basin may be synchronous and correlated in time, such as bank erosion during floods that is likely to occur in smaller watersheds where storm size is equal to or greater than basin size. Asynchronous erosion is likely the rule in basins where threshold-dependent erosion occurs, such as fire-induced surface erosion or storm triggered mass wasting.

A sediment routing model was applied to a mountain landscape in southwest Washington to illustrate the effects of sediment routing on the downstream distribution of sediment flux. The theoretical analysis, required, in addition to probability distributions of erosion (e.g., Figure 7), probability distributions of transport capacities, transport velocities, and particle attrition (Benda and Dunne 1997b). Sediment flux from individual hillslopes and small, low-order basins is predicted to be punctaform and therefore strongly right-skewed, similar to the OCR example (Figure 7). The channel obtains sediment over long periods from such numerous right-skewed distributions in small headwater basins. The accumulation of sediment from the multitude of sediment sources over time causes the flux distribution to evolve into more symmetrical forms, a demonstration of the central limit theorem (Figure 8; also see the more general form in Figure 4). The model also predicts that the magnitude of sediment perturbations decreases downstream in conjunction with a corresponding increase in their number. Increase in perturbation frequency is due to an increasing number and therefore probability of sediment releases downstream. A decrease in magnitude of the perturbation (i.e., difference between minimum and maximum values) is due to several factors, including: 1) particle attrition (breakdown) that increasingly damps sediment signals with distance traveled; 2) a larger and persistent supply and therefore store of gravel; 3) diffusion of discreet sediment pulses due to selective transport and temporary storage in bars; and 4) increasing channel width (Benda and Dunne 1997b).

Episodic introduction of sediment can creates pulses or waves of sediment that migrate thought the network causing changes in channel morphology, including variations in channel bed elevation, sinuosity, substrate sizes, pools, etc. (Gilbert 1917; Madej and Ozake 1996; Benda 1990; Miller and Benda, in press). In addition, fluctuations in sediment supply may also cause changes in sediment storage at a particular location, such as near fans or other low-gradient areas, and these have been referred to as stationary waves (Benda and Dunne 1997b). Migrating or stationary waves create coarse-textured, cut and fill terraces (Nakamura 1986; Roberts and Church 1986; Miller and Benda, in press). Hence, the predicted fluctuations in sediment supply by the model (Figure 8) have morphological consequences to channels and valley floors and therefore on to the biological communities that inhabit those environments.

Example Four: Large Woody Debris

The supply and storage of large woody debris (LWD) in streams is governed by several landscape processes that occur punctuated in time over decades to centuries, including by fires, windstorms, landslides, stand mortality, and floods. A wood budgeting framework (Benda and Sias 1998; in press) was used to evaluate how those landscape processes constrain long-term patterns of wood abundance in streams.

In the example below, the effect of two end member fire regimes on variability in wood loading was examined: a 500-year cycle associated with the wettest forests and a 150-year cycle associated with more mesic areas in the southern and eastern parts of the Pacific Northwest region. To reduce complexity, the analysis of fire kill and subsequent forest growth applied a series of simplifications (refer to Benda and Sias 1998; in press).

The magnitude of wood recruitment associated with chronic stand mortality is significantly higher in the 500-year cycle because the constant rate of stand mortality is applied against the larger standing biomass of older forests (Figure 9). Furthermore, fire pulses of wood are significantly greater in the 500-year fire cycle because of the greater standing biomass associated with longer growth cycles. Hence, longer fire cycles yield longer periods of higher recruitment rates and higher peak recruitment rates post fire. Post-fire toppling of trees in the 500-year cycle, however, accounts for only 15% of the total wood budget (in the absence of other wood recruitment processes). In contrast, drier forests with more frequent fires (e.g., 150 year cycle) have much longer periods of lower wood recruitment and lower maximum post-fire wood pulses (Figure 8). Because the average time between fires in the 150-year cycle is similar to the time when significant conifer mortality occurs in the simulation (100 yrs), the proportion of the total wood supply from post-fire toppling of trees is approximately 50%. Hence, stand-replacing fires in drier forests play a much larger role in wood recruitment compared to fires in wetter forests. Although the range of variability of wood recruitment in the rainforest case is larger, the likelihood of encountering more significant contrasts (i.e., zero to a relatively high volume) is higher in drier forests (Figure 8). Refer to Benda and Sias (1998; in press) for LWD predictions involving bank erosion, landsliding, and fluvial transport.

Potential For Developing New, General Landscape Theories

There is currently a paucity of theory at the spatial and temporal scales relevant to ecosystems in a range of watershed scientific disciplines (i.e., predictive quantitative understanding), including hydrology (Dooge 1986), stream ecology (Fisher 1997), and geomorphology (Benda et al. 1998). Hence, our understanding of disturbance, or landscape dynamics, has remained stalled at the “concept level”, as evidenced by the proliferation of watershed-scale qualitative concepts across the ecological and geomorphological literature, including River Continuum concept (Vannote et al. 1980); Patch Dynamics concept (Townsend 1989), Ecotone concept (Naiman et al. 1988), Flood Pulse concept (Junk et al. 1988), Natural Flow Regime concept (Poff et al. 1989), Habitat Template concept (Townsend and Hildrew 1994), Process Domain concept (Montgomery, 1999), and hierarchical classification of space – time domains (Frissel et al. 1986; Hilborn and Stearns 1992). Although these concepts represent breakthroughs and innovations, they have also promoted the arm waving aspect of scale in the watershed sciences, whether looking over a ridge in the field, or in scientific or policy meetings. It is also the primary reason why natural resource management and regulatory communities prefer more reductionist and small scale approaches in their work.

Any scientific field can encompass a range of different predictive theories that apply to different combinations of space and time scales. Taking geomorphology as an example (see Benda 1999; Figure 1), starting at the largest scales, theories of basin and channel evolution (e.g., Smith and Bretherton 1972; Willgoose et al. 1991) are applicable to watersheds or landscapes over 106 to 108 years. Because of the large time scales involved, they have limited utility for natural resource management and regulation. At smaller scales, there are theories dealing with landsliding (Terzaghi 1950) and sediment transport (duBoys 1879; Parker et al. 1982). At this level, the spatial scale is typically the site or reach, and changes over time intervals of decades to centuries are typically not considered. Theories at this scale are useful to studies of aquatic ecology at the reach or grain scale (bed scour, etc.), and again are of limited utility for understanding, managing, or regu-

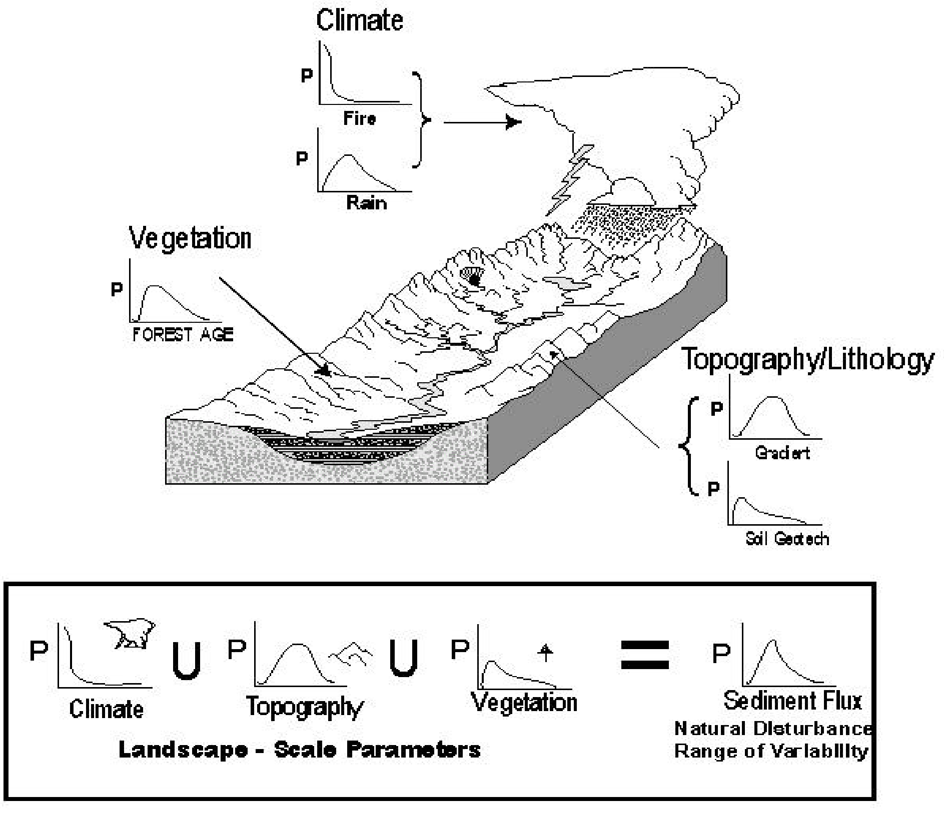


Figure 10. New landscape – scale theories will use distribution parameters of things such as climate, topography, and vegetation, with when integrated will yield probability distributions of output variables, such as erosion and sediment supply (or LWD, see Figure 9).

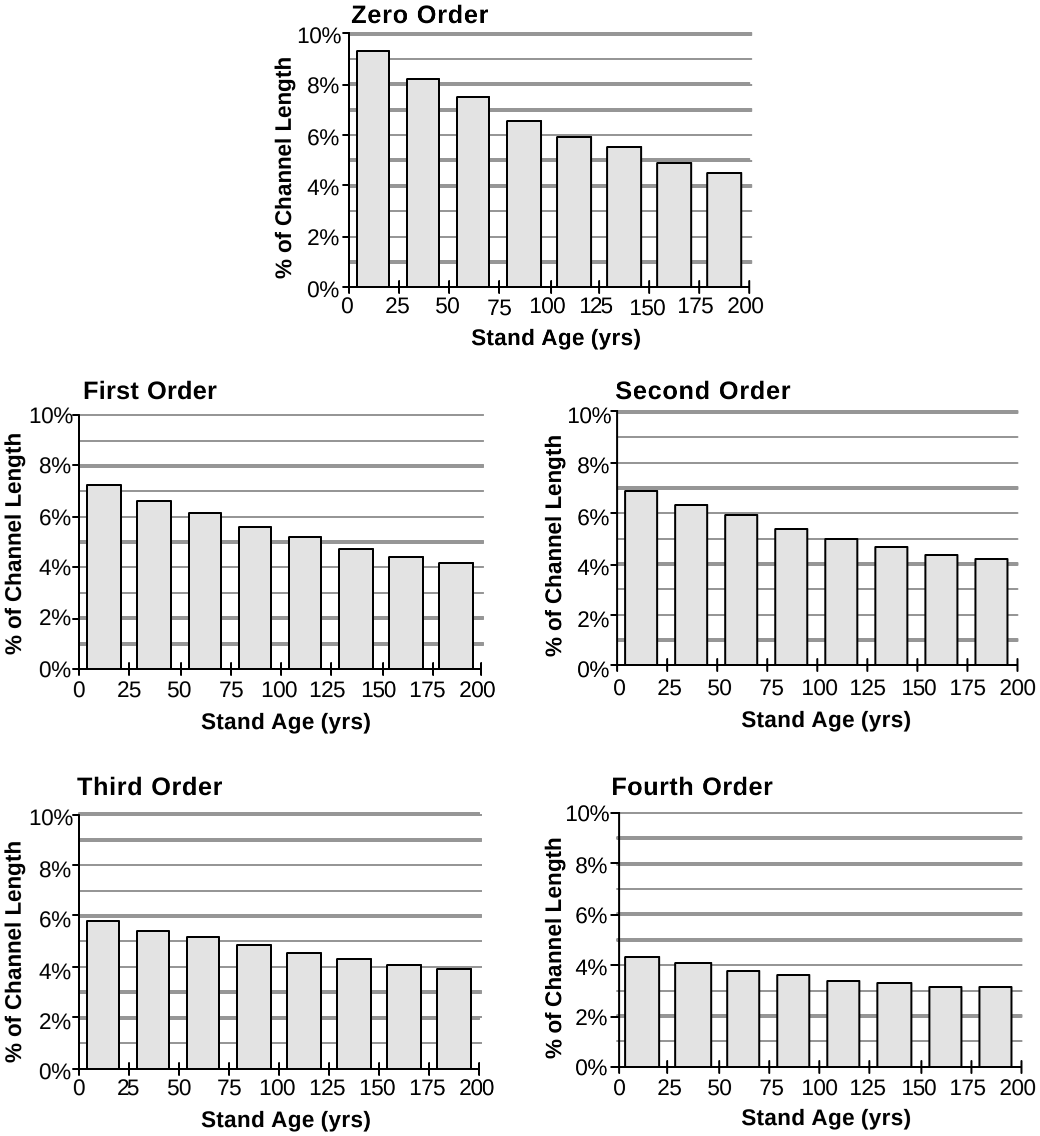


Figure 11. Probability distributions of riparian forest ages, including for landslide sites. The average proportion of channel length with forest stands of a particular age, using 25-year bins up to 200 years (forests greater than 200 years not shown) was tabulated for zero-order (i.e., landslide sites) through fourth order. These predicted histograms indicate, that on average, the proportion of the channel length containing trees less than 100 years old varies from 30% (zero order), 24% (first-order), to 15% (fourth order). The decreasing amount of young trees with increasing stream size is a consequence of the field estimated susceptibility of fires. Fire frequency was the highest on ridges and low-order channels (~175 yrs) and the lowest (~400 yrs) on lower gradient and wide valley floors.

lating watershed behavior at larger scales. Between these two sets of scales is a conspicuous absence of theoretical understanding that addresses the behavior of populations of landscape attributes over periods of decades to centuries. The material presented in this article is designed to eventually fill that theoretical gap.

At the mid level in such a theory hierarchy, knowledge will take the form of relationships among landscape processes (defined as distributions) and distributions of mass fluxes and channel and valley environmental states (Benda et al. 1998). The new class of general landscape theories will be based on process interactions, even if at coarse grain resolution, among climatic, topographic, and vegetative distributions (Figure 10). The resultant shapes of probability distributions of fluxes of sediment, water, or LWD will have consequences for riparian and aquatic ecology (Benda et al. 1998) and therefore resource management and regulation.

Increasing Scale: Implications for Watershed Management

The topic of increasing scale in resource management is virtually unexplored and it will only be briefly touched on here. Recently, forest managers have been promoting the establishment of older forest buffers along rivers and streams to maintain LWD and shade, and for maintaining mature vegetation on landslide prone areas for rooting strength. Often, the management and/or regulatory target is mature or old growth forests at these sites. However, in a naturally dynamic landscape, forest ages would have varied in space and time. The temporal variability in forest cover is illustrated in Figure 6. However, fire regimes are sensitive to topographic position (Benda et al. 1998; Figure 11.5), and hence the proportion of stream channels and landslide sites bordered by mature or old forests would vary with topography.

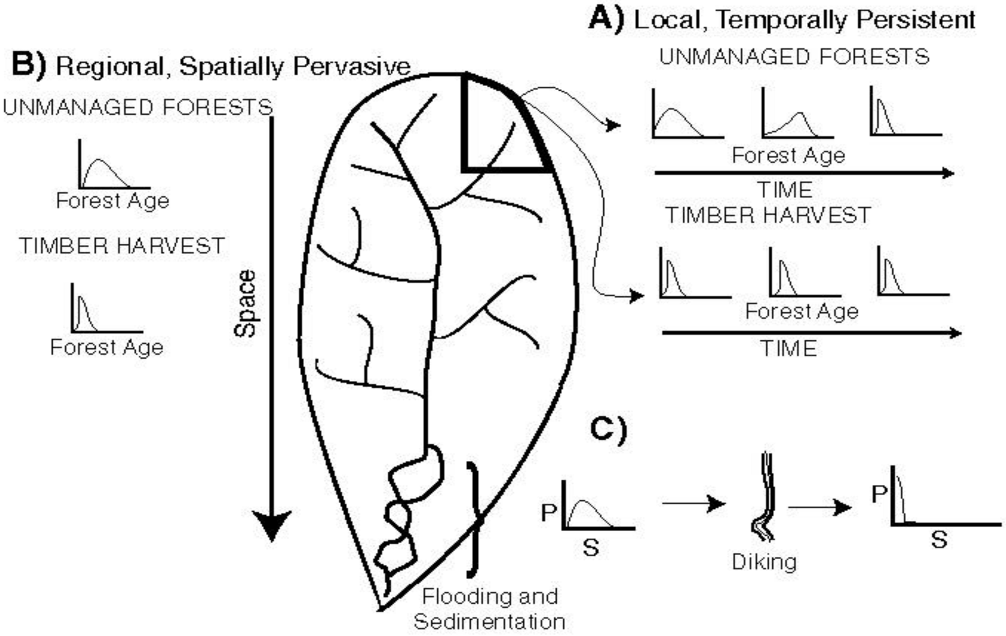


Figure 12. Distributions may offer new avenues for environmental problem solving. Either the degree of shifts in distributions of watershed attributes in space or time might provide insights into environmental problems. (A) Even young vegetation occurred naturally in small areas, temporally persistent timber harvest in upper watersheds can lead to a system being outside its range of natural variability in time. (B) Over short time periods, however, spatially pervasive timber harvest may also cause a system to shift outside its natural range of variability in space. (C) Other forms of land uses, such as dams or diking, will cause significant and persistent shifts in probability distributions of flooding, sedimentation, and floodplain construction. The degree of shifts among the different watershed attributes may offer a means to consider the cumulative effects over space and time.

The variability in forest ages in a 200 km2 watershed located in southwest Washington was investigated using a fire model. Although the long-term probability distribution of forest ages predicted by the model was positively skewed, in accordance with existing theory (Johnson and Van Wagner 1984) and as illustrated in Figure 6(B), distributions of forest ages varied with topographic position or stream size. The distributions for forest ages up to year 200 for a range of channel sizes in western Washington indicated that there was a higher likelihood of younger age classes in landslide prone sites (i.e., zero-order) and in the smallest, steepest streams (Figure 11). An increasing amount of the probability distribution of age classes shifted right into older forests with increasing stream size. This is due to a lower fire frequency in lower gradient and wider valley floors compared to steeper hillslopes and channels. The simulations indicated that natural forests cannot be represented adequately by a specific age class but rather by a distribution of values, the shape of which varies with region and topographic position.

This type of information could conceivably be used to craft future management strategies that mimicked the age distribution of forests along certain topographic positions. For example, the temporal distribution of forest ages at landslide sites shown in Figure 11 could, according to the ergodic hypothesis illustrated in Figure 5, be considered to reflect the spatial distribution of vegetation age classes in any year across a landscape. Figure 11 suggests that approximately 18% of landslide sites in the study area of southwest Washington was covered with young, less than 50 year old vegetation at any point in time. Management strategies focused on landslide reduction might use such information to manage different areas with different timber harvest rotations.

Increasing Scale: Implications for Regulation

Because landscape behavior is complex in space and time, evaluating human impacts to terrestrial and aquatic habitats can pose a difficult problem. The use of distributions outlined in this article may provide fertile ground for developing new risk assessment strategies. First, and most simply, the severity of environmental impacts could be evaluated according to the degree of observed or predicted shifts in frequency or probability distributions in space or time under various land uses. For example, process rates or environmental conditions that fall onto tails of distributions could be considered exceeding the range of variability (e.g., a sediment depth of 1.5 m in channels of 25 km2 or greater in Figure 8). Second, since distributions define probability of event occurrence, probability density functions of certain landscape processes could underpin risk assessment. For example, the chance of encountering 20 landslides in any year at a scale of 25 km2 is less than 1% and such an erosional condition probably requires either widespread fire or wholesale clearcutting (Figure 7). The third, and the most challenging avenue, would involve estimating the level of disturbance (i.e., its regime) that is optimal for certain types of ecosystems and species. These potential techniques would presumably be based on a body of theory applicable at large scales.

To follow up on the first potential option, some environmental systems are so complex that simply knowing whether systems lie inside or outside their range of natural variability might prove useful, particularly in the absence of more detailed understanding. This approach is commensurable with the range-of-variability concept (Landres et al. 1999) and has been applied recently in the global climate change debate (EOS 1999). Because of human civilization, almost no natural systems lie within their pre-human natural range of variability. However, the concept might prove useful in deciphering how far out of whack an environmental system is, or to compare certain types of impact with others (i.e., logging vs. urbanization vs. dams).

The distribution parameter, an index sensitive to changing spatial and temporal scales (e.g., Figures 1 – 4), allows environmental changes to be registered as shifts in distributions. An example of how a forest system might be managed outside its range of natural variability in time is given in Figure 12. In small watersheds (~40 km2), the frequency distribution of forest ages observed at any time is naturally variable because of episodic stand-replacing fires (Figure 6). Although fire is not equivalent to timber harvest, relatively young forests following timber harvest would have had an approximate corollary in post fire forests, with respect to things such as subsequent LWD recruitment and soil rooting strength. In a natural forest, however, the distribution of forest ages would gradually shift towards the older ages over time. If timber harvest were to persist over several rotations, the distributions would persist in the youngest age classes, and therefore reveal management beyond the natural range of variability in time in that limited context.

Figure 12 also illustrates how the natural range of variability can be exceeded in space. At large spatial scales (landscape), the distribution of forest ages is predicted to be significantly more stable over time (Figure 6). If timber harvest occurs over the entire 20,000 km2 OCR over a relatively short period of time (a few years to a few decades), the left-shifted age distribution that would result represents a forest that lies outside it's range of natural variability in space, in any year or short period of time (Figure 10).

The degree of distribution shift might prove useful when prioritizing where to focus limited resources in stemming environmental impacts that originate from a range of land uses. For example, the degree of shift in the age distribution of forests in upland watersheds due to logging could be contrasted with a distribution shift in flooding, sedimentation, and floodplain construction due to diking in the lowlands (Figure 12).

Conclusions

A focus on small scales and a desire for accuracy and predictability in some disciplines has encouraged scientific myopia, with the landscape "big picture" often relegated to arm waving and speculation. This could lead to several problems, some of which are already happening. First, there may be a tendency to over rely on science as the ultimate arbitrator in environmental debates at the wrong scales. This can lead to the creation of unrealistic management and regulatory policies, and the favoring of certain forms of knowledge over other forms, such as promoting quantitative and precise answers at small scales over qualitative and imprecise ones at large scales. Second, science may be used as a smoke screen to justify continuing studies or management actions in the face of little potential for increased understanding using existing theories and technologies at certain scales. Third, science can be used as an unrealistic litmus test, requiring detailed and precise answers to complex questions at small scales when no such answers at that scale will be forthcoming in the near future. Finally, the persistent, ideological, and divisive environmental debates that have arisen in part based on the problems of scale outlined above may undermine the public's belief in science. It may also weaken the support of policy makers for applying science to environmental problems. To attack the problem of scale in watershed science, management, and regulation will require developing new conceptual frameworks and theories that explicitly address interdisciplinary processes, scientific uncertainty, and new forms of knowledge.✍

Earth Systems Institute is a private, non profit think tank located in Seattle WA (www.earthsystems.net)

References

Allen, T.F.H. and T.B. Starr, 1982. Hierarchy: Perspectives for Ecological Complexity. University of Chicago Press, Chicago, 310pp.

Benda, L., 1994. Stochastic geomorphology in a humid mountain landscape. Ph.D. dissertation. Dept. of Geological Sciences, University of Washington, Seattle. 356p.

Benda, L. and T. Dunne, 1997a. Stochastic forcing of sediment supply to the channel network from landsliding and debris flow, Water Resources Research, Vol.. 33, No.12, pp.2849-2863.

Benda, L. and T. Dunne, 1997b. Stochastic forcing of sediment routing and storage in channel networks, Water Resources Research, Vol. 33, No.12, pp. 2865-2880.

Benda, L. and J. Sias, 1998. Wood Budgeting: Landscape Controls on Wood Abundance in Streams. Earth Systems Institute; 70 pp./in press CJFAS

Benda, L., D. Miller, T. Dunne, J. Agee, and G. Reeves, 1998. Dynamic Landscape Systems, Chapter 12 in: River Ecology and Management: Lessons from the Pacific Coastal Ecoregion, Edited by

Naiman, R. and Bilby, R., Springer-Verlag. Pp. 261-288.

Benda, L. (1999) Science VS. Reality: The Scale Crisis in the Watershed Sciences. Proceedings Wildland Hydrology. American Water Resources Association. Bozeman, MT p3-20.

Botkin, D. B., 1990. Discordant Harmonies: A New Ecology for the Twenty-First Century. Oxford University Press, New York. 241pp.

Brunsden, D. and J. B. Thornes (1979). "Landscape sensitivity and change." Transactions, Institute of British Geographers NS 4: 485-515.

Caine, N. 1990. Rainfall intensity – duration control on shallow landslides and debris flows. Geografika Annaler 62A:23-27.

du boys, P. F. D. (1879) 'Etudes du regime et l'action exercee par les eaux sur un lit a fond de graviers indefinement affouliable', Annals des Ponts et Chaussees, Series 5, 18, 141-95.

Dooge, J. C. I., 1986. Looking for hydrologic laws. Water Resources Research 22(9), pp.46S-58S.

Dunne, T., 1998. Critical data requirements for prediction of erosion and sedimentation in mountain drainage basins. Journal of American Water Resources Association, Vol. 34, pp.795-808.

EOS 1999, Transactions, American Geophysical Union, V 80, No 39, September (Position statement on climate change and greenhouse gases).

Fisher, S. G. 1997. Creativity, idea generation, and the functional morphology of streams. J. N. Am. Benthl. Soc. 16(2): 305-318.

Frissell, C. A., W. J. Liss, W. J. Warren, and M. D. Hurley, 1986. A hierarchical framework for stream classification: viewing streams in a watershed context. Environmental Management 10, pp.199-214.

Gell-Man, M., 1994. The Quark and the Jaguar: Adventures in the Simple and Complex, W. H. Freeman and Company, New York. 329pp.

Gilbert, G.K. 1917. Hydraulic mining debris in the Sierra Nevada. U.S. Geological Survey Prof. Paper 105, 154p.

Hack, J.T. and Goodlett, J.C. 1960. Geomorphology and forest ecology of a mountain region in the central Appalachians, Professional Paper 347, U.S. Geological Survey, Reston, Va. 66pp.

Heede, B.H. 1988. Sediment delivery linkages in a chaparrel watershed following wildfire. Environmental Management Vol. 12(3):349-358.

Hogan D.L., S.A. Bird, and M.A. Haussan. 1995. Spatial and temporal evolution of small coastal gravel-bed streams: the influence of forest management on channel morphology and fish habitats. 4th International Workshop on Gravel-bed Rivers, Gold Bar, WA, August 20-26.

Johnson, E. A. and Van Wagner, C. E. 1984. The theory and use of two fire models. Canadian Journal Forest Research. 15:214-220.

Junk, W., Bayley, P. B., and Sparks, R. E. 1989. The flood-pulse concept in river-floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences 106: 110-127.

Kellert, S. H., 1994. In the Wake of Chaos: Unpredictable Order in Dynamical Systems. University of Chicago Press, Chicago, 176pp.

Lackey, R., 1998. Ecosystem Management: Desperately Seeking a Paradigm, in: Journal of Soil and Water Conservation, 53(2), pp.92-94.

Landres, P. B., Morgan, P., and Swanson, F. J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9(4), 1179 – 1188.

Long, C. J., Fire history of the Central Oregon Coast Range, Oregon: 9000 year record from Little Lake, MS thesis, 147 pp; Univ. of Oreg., Eugene.

Maurer, B. A. (1999) Untangling Ecological Complexity. University of Chicago Press, Chicago.

McIntrye, L., 1998. Complexity: A Philosopher's Reflections. Complexity, 3(6), pp.26-32.

Meyer, G. A., Wells, S. G., and Timothy Jull, A. J. 1995. Fire and alluvial chronology in Yellowstone National Park: climatic and intrinsic controls on Holocene geomorphic processes. GSA Bulletin, V.107, No.10, p.1211-1230.

Miller, D. J. and Benda, L. E. in press. Mass Wasting Effects on Channel Morphology: Gate Creek, Oregon. Bulletin of Geological Society of America.

Mongomery, D. R. 1999. Process domains and the river continuum. Journal of the American Water Resources Association, Vol. 35, No. 2, 397 – 410.

Nakamura, R. 1986. Chronological study on the torrential channel bed by the age distribution of deposits, Research Bulletin of the College Experiment Forests, Faculty of Agriculture, Hokkaido University 43: 1-26.

Naiman, R. J., Decamps, H., Pastor, J., and Johnston, C. A. 1988. The potential importance of boundaries to fluvial ecosystems. Journal of the North America Benthological Society 7:289-306.

Naiman, R. J. and Bilby, R. E. 1998. River Ecology and Mangement: Lessons from the Pacific Coastal Ecoregion. Springer-Verlag. 705pp.

Parker, G., Klingeman, P.C., and McLean. 1982 Bedload and size distribution in paved gravel-bed streams. J. Hydraul. Eng., 108: 544-571.

Pickett, S.T.A. and P.S. White, eds. 1985. The ecology of natural disturbance and patch dynamics. Academic Press, New York, New York, USA.

Pickup, G., Higgins, R. J. and Grant, I. 1983. Modelling sediment transport as a moving wave - the transfer and deposition of mining waste. Journal of Hydrology 60:281-301.

Poff, N. L., Allen, J. D., Bain, M. B., Karr, J., Prestegaard, K. L., Richter, B.D., Sparks, R.E., and Stromberg, J.C. 1997. The natural flow regime: A paradigm for river conservation and restoration. Bioscience V.47, No.11, 769-784.

Robichaud, P. R. and Brown, R. E. 1999. What happened after the smoke cleared: Onsite erosion rates after a wildfire in Eastern Oregon. Proceedings, Wildland Hydrology, American Water Resources Association, Ed. D. S. Olsen and J. P. Potyondy. 419-426.

Reeves, G., Benda, L., Burnett, K., Bisson, P., and Sedell, J., 1996. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest, Evolution and the Aquatic System: Defining Unique Units in Population Conservation, Am. Fish. Soc. Symp 17.

Reid, L., 1998. Cumulative watershed effects and watershed analysis. Pacific Coastal Ecoregion, Edited by Naiman, R. and Bilby, R., Springer-Verlag. pp.476-501.

Rice, R.M., 1973. The hydrology of chaparral watersheds. Proc. Symp. Living with chaparral, Sierra Club, Riverside, Calif, pp.27-33.

Rodriguez-Iturbe, I. and J. B. Valdes, 1979. The geomorphic structure of hydrologic response. Water Resources Research 15(6), pp.1409 – 1420.

Roberts, R. G, and M. Church. 1986. The sediment budget in severely disturbed watersheds, Queen Charlotte Ranges, British Columbia. Canadian Journal of Forest Research 16:1092-1106.

Roth, G., F. Siccardi, and R. Rosso, 1989. Hydrodynamic description of the erosional development of drainage patterns, Water Resources Research. 25, pp.319-332.

Smith, T.R., and Bretherton, F. P. 1972. Stability and the conservation of mass in drainage basin evolution. Water Resources Research., 8(6), pp.1506-1529.

Swanson, F.J., R. L. Fredrickson, and F. M. McCorison, 1982. Material transfer in a western Oregon forested watershed, In: R.L. Edmonds (ed.) Analysis of coniferous forest ecosystems in the western

United States, Hutchinson Ross Publishing Co., Stroudsburg, Penn pp.233-266.

Swanson, F.J., Kratz, T.K., Caine, N. and Woodmansee, R. G. 1988. Landform effects on ecosystem patterns and processes. Bioscience 38, pp.92-98.

Swanson, F. J., Lienkaemper, G. W. et al. 1976. History, physical effects, and management implications of large organic debris in western Oregon streams, USDA Forest Service.

Teensma, P.D.A. 1987 Fire history and fire regimes of the central western Cascades of Oregon. Ph.D. Dissertation, University of Oregon. Eugene, Or. 188p.

Terzagi, K. 1950 Mechanism of landslides. In: Paige, S., ed. Application of geology to engineering practice. Berkeley Vol. Geological Society of America 82-123.

Trimble, S. W. 1983. Changes in sediment storage in the Coon Creek basin, Driftless Area, Wisconsin, 1853 to 1975. Science 214:181-183.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing, 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37, pp.130-137.

Waldrop, M. M., 1992. Complexity: The Emerging Science at the Edge of Order and Chaos. Touchstone Books, Simon and Schuster, New York. 380pp.

Weinberg, G. M. 1975. An Introduction to General Systems Thinking, Wiley-Interscience. New York.

Wohl, E.E. and Pearthree, P.P. 1991. Debris flows as geomorphic agents in the Huachuca Mountains of southeastern Arizona, Geomorphology, 4, pp.273-292.

Willgoose, G., Bras, R.L. and Rodriguez-Iturbe, I. 1991. A coupled channel network growth and hillslope evolution model. 1. Theory. Water Resources Research Vol. 2, No.1, pp.1671-1684.

Timber Harvest and Sediment Loads in Nine Northern California Watersheds Based on Recent Total Maximum Daily Load (TMDL) Studies

Continued from Page 1

source of sediment delivered to stream channels (Swanson et al. 1982; Dietrich et al. 1986; Dietrich et al. 1998; Roering et al. 1999). It is generally hypothesized that long-term sediment production rates in this region are geologically controlled by rates of tectonic uplift, which influences topography and certain mechanical properties of the bedrock, and therefore its sensitivity to land use (Ahnert 1970; Summerfield and Hulton 1994; Leeder 1991).

Shallow landslides occur in shallow soils and are typically driven by transient elevated pore pressures in the soil subsurface resulting from intense precipitation during a storm event (Campbell 1975; Reneau and Dietrich 1987). Since pore pressures are drainage area-dependent, convergent areas on hillslopes are more likely to experience soil saturation conditions and reduced shear strength, and thus have higher probability of generating a shallow landslide under natural conditions (Wilson and Dietrich 1987; Dietrich et al. 1992, 1993; Montgomery and Dietrich 1994; Tucker and Bras 1998). Substantial natural landsliding has been triggered during several large storms during the recent past (e.g., 1964, 1973, 1975, 1986, 1992, and 1997). However, it should be noted that any changes to hillslope hydrology, such as increased inputs of rainfall and runoff in the shallow subsurface due to forest management practices, generally results in increased frequency of occurrence of shallow landsliding, which leads to accelerated sediment loading to stream channels, alteration of channel morphology, and degradation of stream habitat (Sidle et al. 1985; Sidle 1992; Dietrich et al. 1993; Montgomery et al.1998, 2000).

Because few North Coast watersheds within the range of the coho salmon have been entirely unimpacted by past logging activities, there have been very few publications accurately associating specific forest practices with sediment delivery. This stems from the difficulty in finding undisturbed reference sites, the long recurrence interval for naturally induced large scale mass wasting events, and the decades-long residence time of in-channel sediment storage required for delivered stream sediment to move through the system (Dietrich and Dunne 1978; Madej 1995).

Harvest-related “in-unit” erosion generally takes the following forms: 1) accelerated shallow landsliding due to loss of root strength, increase in ground moisture, and lower attentuation of rainfall inputs (Wilson and Dietrich 1987; Dietrich et al. 1992; Montgomery and Dietrich 1994; Keppeler and Brown 1998; Montgomery et al. 2000); 2) destabilized deep seated landsliding due to increased ground moisture and loss of landslide toe support (Swanson et al. 1987; Miller 1995); and 3) increased overland flow (surface) erosion due to ground disturbance by forest management. In the Pacific Northwest, the majority of

Table 1: Summary of TMDL sediment source analyses for nine watersheds within the range of the coho salmon (Oncorhynchus kisutch) in northern California. Data reported reflect fraction of total sediment loading by land use association for periods indicated.

TMDL Sediment Source Analysis	Years of Study	Harvest-Related[2]	Other Forest Management Related[3]	Natural[4]
Garcia River[1]	1952-1997	12%	77%	12%
Grouse Creek Watershed of SF Trinity	1976-1989	41%	40%	19%
Navarro River	1975-1998	5%	34%	61%
Noyo River	1979-1999	5%	39%	56%
Redwood Creek	1954-1980	17%	44%	40%
South Fork Eel River	1981-1996	19%	27%	54%
South Fork Trinity River	1975-1990	8%	35%	58%
Ten Mile River	1979-1999	24%	41%	36%
Van Duzen River[1]	1955-1999	18%	10%	72%

Notes:

1. Timber harvest and road building contributions are assumed to have changed before and after the Z’Berg Nejedley Forest Practice Act of 1973.

2. Sources include hillslope mass wasting and “in-unit” surface erosion.

3. Sources include road- and skid-related surface erosion and mass wasting.

4. Sources include mass wasting, surface erosion and creep.

sediment budgets in managed watersheds are dominated by road-related sediment inputs. While road-related erosion is not treated as a timber harvest-related source in this review, in practice it should be treated as "harvest-related" since the majority of these roads support timber-harvesting activities and were built for the purposes of timber hauling.

Methods and Uncertainty.

In general, sediment source analyses used in TMDLs progress from estimates of actual or potential loading from hillslopes and banks to receiving waters, estimates of in-stream storage and transport of sediment, to estimates of the net sediment discharge (or yield) from drainage basins (e.g. Reid and Dunne 1996; USEPA 1999a). The techniques generally use aerial photo analysis of mass wasting and surface erosion features, GIS–DTM (Geographic Information System–Digital Terrain Model) analyses, and limited ground surveys of geology and landslide characteristics and in-stream measures of sediment storage and transport. Although geology and topography are variable across small (100 km2) watersheds within the range of the coho salmon, stratification of the landscape sediment supply by geomorphic terrains could be expected to yield similar rates of production due to similarities in geology and topography. These geomorphic terrains are generally defined by geology, tectonics, topography, geomorphology, soils, vegetation and precipitation. Further stratification within geomorphic terrains by land use can be reasonably assumed to reveal differences in sediment production by comparing areas with and without particular human activities.

Although the degree of uncertainty greatly depends upon the methodology used, the range of uncertainty in sediment source analyses is generally on the order of 40–50% (Raines and Kelsey 1991; Stillwater Sciences 1999). Methodological constraints (e.g. estimates of landslide frequency, areal extent, depth, age, bulk density, estimates of landslide delivery ratio, and natural temporal variability in erosion-triggering storm events) suggest that this uncertainty may be too high to reliably detect differences between land uses or recent changes in land use practice such as those introduced in 1973 under the Z'Berg Nejedley Forest Practice Act (FPA) of 1973 (CCR 14 Chapters 4 and 4.5).

Approach

Despite the limitations described above, the approved methodology for TMDLs (USEPA 1999a) has been used to develop sediment source analyses for several watersheds within the range of the coho salmon in northern California and can also be used to assess the relative impacts of timber harvesting activities on sediment loading in stream channels. In order to make rational comparisons between the published TMDLs, three factors need to be addressed. First, sediment yield data in many publications encompass long periods during which forest practices changed. Where possible, we selected sediment source data that were provided for the post-1973 FPA period to more accurately reflect current forest practices. Second, land use aggregations differ among published TMDLs. For example, road-related mass wasting is aggregated within timber harvest-related sediment production in some studies and is a separate sediment source in others. Third, the difference in periodicity of triggering storms during the time frames used to assess sediment sources in individual TMDLs was not addressed. Note that this analysis uses only existing

Table 2: Human and natural sediment contributions to total sediment loading within the range of the coho salmon (Oncorhynchus kisutch) in northern California for all TMDLs and those TMDLs with information available after the 1973 Forest Practice Act.

	Harvest-Related[1]	**Other Forest Management Related[2]**	**Natural[3]**
Sediment Sources from All TMDL Data Presented in Table 1 (n=9)			
Mean	17%	38%	45%
Minimum	5%	4%	12%
Maximum	41%	77%	72%
Standard Error	4%	6%	7%
Post-Forest Practice Act Sediment Sources from Finalized TMDLs[4] (n=4)			
Mean	18%	35%	47%
Minimum	5%	27%	19%
Maximum	41%	40%	58%
Standard Error	9%	3%	11%

Notes: 1. Sources include hillslope mass wasting and "in-unit" surface erosion; 2. Sources include road- and skid-related surface erosion and mass wasting; 3. Sources include mass wasting, surface erosion and creep; 4. Of the nine TMDLs that have been finalized, only four provide post-Forest Practice Act sediment source assessments. Data include Grouse Creek Watershed of SF Trinity, Noyo River, South Fork Eel River, and South Fork Trinity River.

results of sediment source analyses for the total period of record. Where possible, we have separated results to show sediment source contributions since the passage of the 1973 FPA. Although a more thorough meta-analysis of the background data of currently published TMDLs is not possible without considerable effort, we provide both total estimates of natural vs. human-related sediment loading to stream channels as well as a timber harvest-related estimate only.

Results

Based upon our initial review of the sediment source analyses reported here, two analyses indicate a reduction in total sediment loading after the FPA of 1973. For the

Table 3. Sediment yields for all terrain types in nine northern California watersheds.

TMDL Sediment Source Analysis	Geologic Unit Types	Period of Analysis	Area (km^2)	Total Mean Annual Sediment Yield ($tons/km^2$-yr)	Mean Annual Sediment Yield Associated with Timber Harvest and Roads(2) ($tons/km^2$-yr)	Ratio of Anthropogenic to Total Sediment
Garcia River(1)	Coastal Belt Franciscan Complex; Tertiary to Cretaceous marine sedimentary rocks	1952-1997	296	533	469	88
Grouse Creek Watershed of SF Trinity	Eastern Belt Franciscan Complex; pre-Cretaceous metasedimentary rocks	1976-1989	147	249(3)	201	81
Navarro River	Coastal Belt Franciscan Complex; Tertiary to Cretaceous marine sedimentary rocks	1975-1998	816	745	290	39
Noyo River	Coastal Belt Franciscan Complex; Tertiary to Cretaceous marine sedimentary rocks	1979-1999	293	258	114	44
Redwood Creek(1)	Central Belt Franciscan Complex; metasedimentary rocks	1954-1997	738	1,834	1,105	60
South Fork Eel River	Coastal and Central Belt Franciscan Complex; Tertiary to Cretaceous marine sedimentary rocks	1981-1996	1,784	704	326	46
South Fork Trinity River	Eastern Belt Franciscan Complex; metamorphic and metasedimentary rocks	1975-1990	2,414	194	82	42
Ten Mile River	Coastal Belt Franciscan Complex; Tertiary to Cretaceous marine sedimentary rocks	1979-1999	311	303	195	64
Van Duzen River(1)	Central and Eastern Belt Franciscan Complex; Tertiary marine sedimentary rocks	1955-1999	1,115	700(4)	196(4)	28

Notes: 1) Timber harvest and road building contributions are assumed to have changed before and after the Z'Berg Nejedley Forest Practice Act of 1973; 2) Sources include hillslope mass wasting, skid trail surface erosion, and road-related surface erosion; 3) Excludes stream bank erosion due to data uncertainty; 4) Estimated by assuming bulk density of 1.8 $tons/m^3$.

period of 1954–1980, the Redwood National and State Parks (1997) estimated a total sediment load in the Redwood Creek basin of 1,883 tons/km^2-yr, whereas this rate dropped to 1,070 tons/km^2-yr for the period 1981–1997 (USEPA 1998c). In the South Fork of the Trinity River, Raines (1998) estimated that the 1944–1975 sediment production rate (432 tons/km^2-yr), fell to 194 tons/km^2-yr for the period 1976–1990. These correspond to a 57% and 45% decline in total sediment production rates, respectively, indicating that the pre- and post-FPA production are substantially different. However, a simple comparison such as this does not account for potential differences in the frequency and magnitude of large storms that serve as triggering events for sediment delivery. Regardless, it is on this basis that we attempted to include as much post-FPA data as possible to better assess the current effects of timber harvesting within the range of the coho salmon. Table 1 presents the proportion of the total sediment loads in nine North Coast basins that may be attributed to timber harvesting, other human-causes such as road building, and natural sources. Table 2 provides the range of data associated with human-related activities and natural sources for the period before and after the 1973 FPA. Table 3 provides information on sediment yields for each basin. The results are discussed for each basin below.

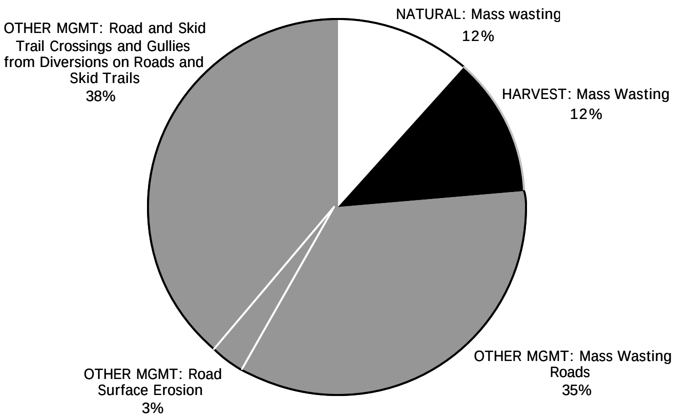


Figure 1: Sediment Contributions to the Garcia River (1952-1997) Source: Pacific Watershed Associates 1997

Garcia River The Garcia River TMDL includes the years 1952–1997 (USEPA 1998a). For the entire period of record, Pacific Watershed Associates (1997) estimated an average sediment production rate of 533 tons/km^2-yr within the Garcia River basin (Table 3). Road building activities dominate the sediment budget for the period of record (Figure 1). Grouping the source analysis data by natural and human caused processes results in an anthropogenic association of 89% of all sediment production within the basin. Approximately 12% of this total is directly attributed to timber harvest-related activities (Table 1).

Grouse Creek sub-Watershed of SF Trinity The sediment budget for the Grouse Creek sub-watershed within the South Fork Trinity River (Raines 1998) was developed for the Six Rivers National Forest. It covers a period from 1960–1989 and represents the only portion of the South Fork Basin where a detailed sediment budget was completed (USEPA 1998b). For the entire period of record, Raines (1991) estimated an average sediment production

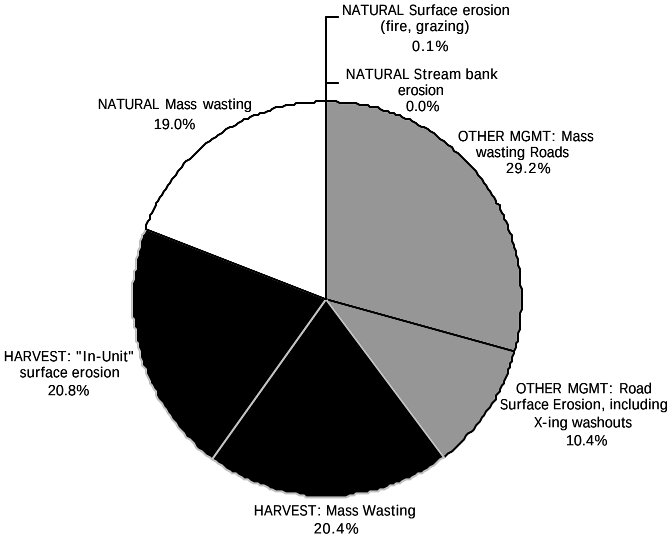


Figure 2: Sediment Contributions to the Grouse Creek Sub-Watershed of the South Fork Trinity River (1976-1989) Source: Raines 1998

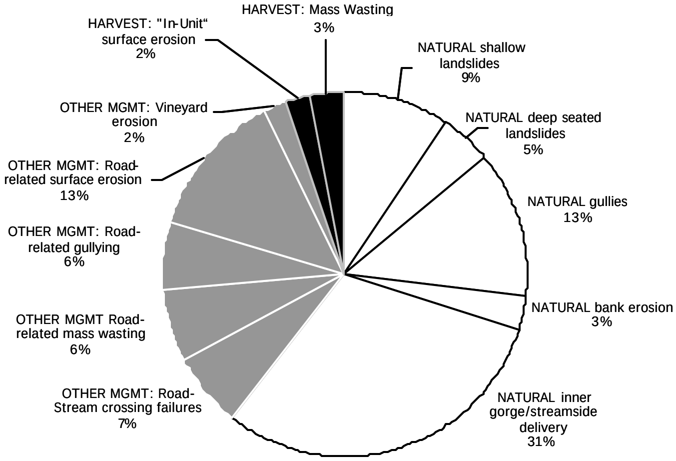


Figure 3: Sediment Contributions to the Navarro River (1975-1998). Source: Navarro River TMDL (USEPA 2000a)

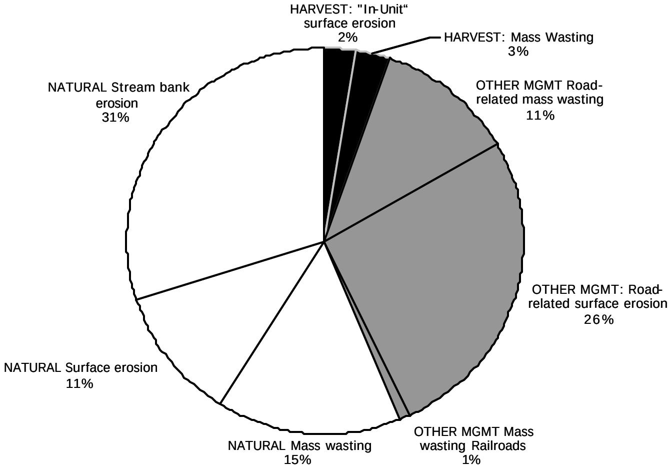


Figure 4: Sediment Contributions to the Noyo River (1979-1999). Source: Mathews and Associates 1999

rate of 1,750 tons/km^2-yr within the Grouse Creek watershed. Grouping the source analysis data by natural and human caused processes results in an anthropogenic association of 50% of all sediment production within the basin (Raines 1991). For the years 1976–1989 (post-FPA), Raines (1998) assumed negligible natural stream bank erosion, resulting in approximately 81% of the total average sediment yield (249 ton/km^2-yr) being related to all human causes combined (Table 3). Approximately 41% of this total may be directly attributed to timber harvest-related activities in this relatively small (147 km^2) sub-basin (Figure 2, Table 1).

Navarro River Although the public review draft of the Navarro River TMDL (USEPA 2000a) does not provide citations for its sediment source analysis, the sediment source analysis provided focused upon rates of sediment yield that have occurred in the recent past (i.e., past twenty years). For the estimated time period of this analysis (1975–1998), 61% of the sediment loading is attributed to natural sources (Figure 3). Total sediment load was 745 tons/km^2-yr (Table 3), of which 34% may be attributed to other forest management activities (Figure 3), and only 5% may be directly attributed to timber harvest-related activities in this 816 km^2 basin (Table 1).

Noyo River In the extensive sediment source analysis for the Noyo River TMDL (USEPA 1999b), Matthews & Associates (1999) evaluated landsliding throughout the watershed using 1:24,000 scale aerial photographs for the years: 1942, 1952, 1957, 1963, 1965, 1978, 1988, 1996, and 1999. The 1942 aerial photos were assumed to give a snapshot of landscape events occurring over a 10-year period (i.e., back to 1933). The sediment yields for 1933–1957 in the Noyo River watershed (85 tons/km^2-yr) captures a period of low intensity logging between old growth harvest (ca 1900) and second growth harvest (post 1950s). For the recent period of this analysis (1979–1999), approximately 44% of the total sediment loading may be attributed to all human-related activities combined (Figure 4). Total sediment load in the recent past was 258 tons/km^2-yr (Table 3), of which only 5% may be directly attributed to timber harvest-related activities in this 293 km^2 basin (Table 1).

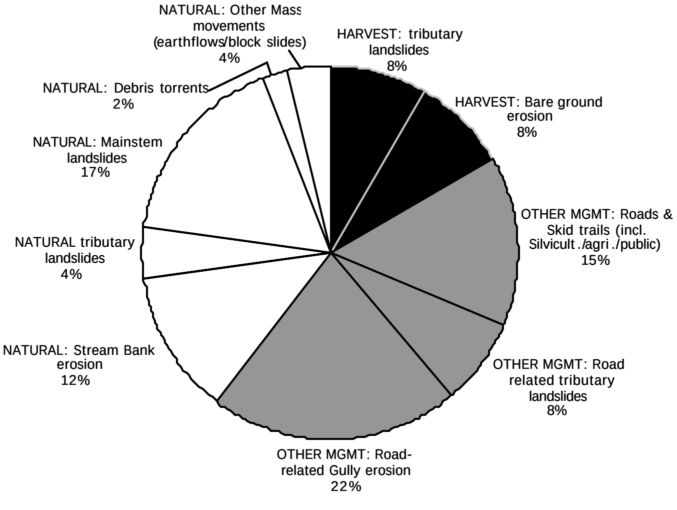


Figure 5: Sediment Contributions to the Redwood Creek (1954-1997). Source: Redwood Creek TMDL (USEPA 1998c; Redwood National and State Parks 1997)

Redwood Creek Although several sediment source analyses were used in the Redwood Creek TMDL (USEPA 1998c), detailed information required to separate sediment sources by process and causality was unavailable for the pre- and post-FPA periods. For the entire period of record (1954–1997), the Redwood Creek Watershed Analysis estimates a load of 1,834 tons/km^2-yr and also separates the sediment yields by process (Redwood National and State Parks, 1997) (Table 3). Approximately 61% of the total sediment load during this period may be attributed to all human-related activities combined (Figure 5). Seventeen percent of the total sediment load may be attributed to timber harvest-related activities in this 738 km^2 basin (Table 1).

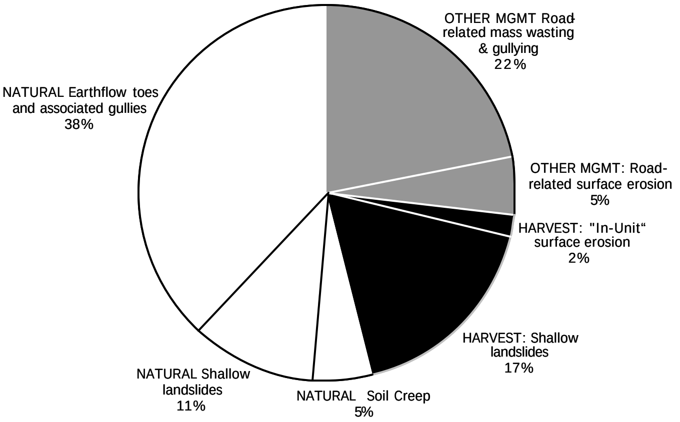


Figure 6: Sediment Contributions to the South Fork Eel River (1981-1996). Source: Stillwater Sciences 1999

South Fork Eel River The sediment source analysis (Stillwater Sciences 1999, USEPA 1999d) combined several methods to generate estimates of sediment in the South Fork Eel Basin. Earlier studies were summarized and detailed photo analysis and fieldwork were conducted in the intensive study areas (ISAs) representative of various

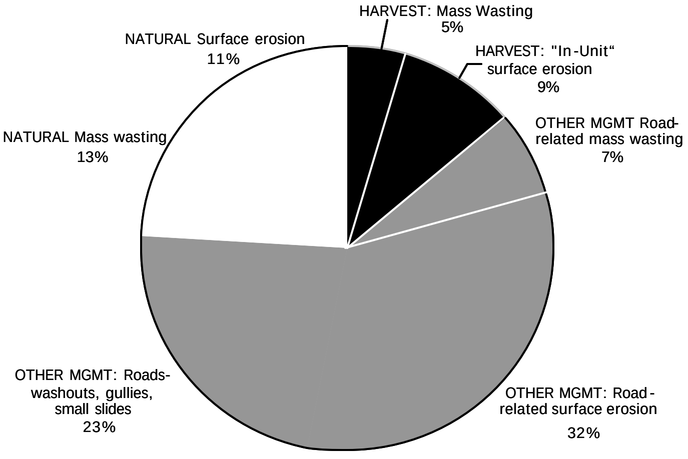


Figure 7: Sediment Contributions to the South Fork Trinity River (1975-1990). Source: South Fork Trinity TMDL (USEPA 1998b, Raines 1991)

geomorphic terrains. Existing data was supplemented by several modeling techniques, and GIS data analysis was used to extrapolate results from the ISAs into the entire basin. A major focus of the sediment source analysis was to better characterize the proportion of human-induced sediment. The USDA (1970) estimated a total sediment production of 1,951 tons/km^2-yr, with approximately 20% of the total from human-related activities from the period 1942–1965. For the most recent time period (1981–1996), Stillwater Sciences (1999) estimated a basinwide rate of sediment production of 704 tons/km^2/year with approximately 46% of the total sediment load attributable to land use activities (Table 3, Figure 6). Nineteen percent of the total sediment load may be attributed to timber harvest-related activities in this 1,784 km^2 basin (Table 1).

South Fork Trinity River The sediment source analysis for the South Fork Trinity Basin TMDL (USEPA 1998b) provided detailed sediment budgets for all sub-basins. Raines (1998) estimated that for the 1944–1990 period, total sediment production was 407 tons/km^2-yr with 9% of this total contributed by timber harvest related activities. Over 86% of all sediment produced by landsliding was found to be concentrated in areas of geologic instability and logging and during major storms. Sixty-three percent of all sediment production between 1944 and 1990 was generated from 1961 to 1975, a period that included four major storm events, the completion of 74% of basin logging activity and 80 percent of road building from 1960–1989. For the most recent time period (1976–1990), approximately 43% of the total sediment load may be attributed to all human-related activities combined (Figure 7). Total sediment production for this period was 194 tons/km^2-yr of which 8% of the total sediment load may be attributed to timber harvest-related activities in this 2,414 km^2 basin (Tables 1 and 3).

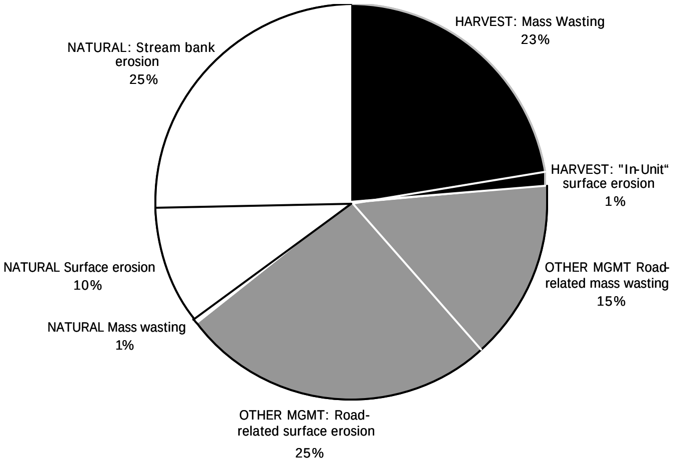


Figure 8: Sediment Contributions to the Ten Mile River (1979-1999). Source: Draft Ten Mile River TMDL (USEPA 2000b, Mathews and Associates 2000).

Ten Mile River The public review draft of the Ten Mile River TMDL (USEPA 2000b) compiled sediment source data from a variety of sources including analyses conducted in adjacent basins (Mathews & Associates 2000). For the period of this analysis (1979–1999), approximately 65% of the total sediment load may be attributed to all human-related activities combined (Figure 8). Total sediment production was 303 tons/km^2-yr of which 24% may be attributed to timber harvest-related activities in this 311 km^2 basin (Tables 1 and 3).

Van Duzen River The Van Duzen River TMDL (USEPA 1999c) covers a period from 1955–1999. The sediment yield rates were based on a study of the upper 60% of the watershed conducted by Kelsey (1977) using aerial photos and a stratified random sampling scheme for field validation (Pacific Watershed Associates 1999). For the entire period of record, approximately 28% of the total sediment load may be attributed to all human-related activities combined (Figure 9). Total sediment production was 700 tons/km^2-yr of which 18% may be attributed to harvest-related activities in this 1,115 km^2 basin (Tables 1 and 3).

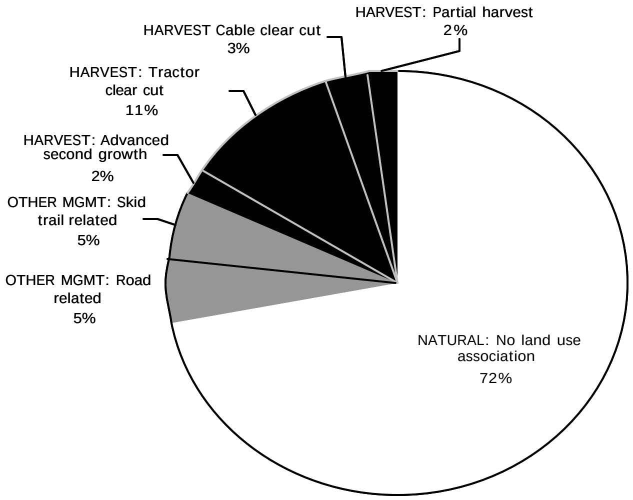


Figure 9: Sediment Contributions to the Van Duzen River (1955-1999). Source: Van Duzen River TMDL (USEPA 1999c)

Discussion and Conclusions

The sediment source assessments used in the nine TMDLs reviewed in this paper were conducted by many different analysts using methods that provided estimated sediment yields with a high degree of uncertainty. Even so, based upon the available data from the TMDLs reviewed here, the total average sediment yields for the entire period of record and the more recent (post-FPA) period show that harvest related sources in logged areas (“in-units”) are between 17% and 18% of the total sediment production. Since the passage of the 1973 FPA the total sediment loading resulting from all human-related activities (harvest- and road-related) decreased by only 2% (55% vs. 53% for the post-FPA period) with a small increase in natural contributions (45% vs. 47% for the post-FPA period). It should be noted that the harvest-related proportion varies (S.E. 4% vs. 9% for the post-FPA period) across watersheds and by individual sediment source analysis.

Although the approach used in setting sediment-based TMDLs assumes that there is some threshold level of increase above natural sediment delivery that will not adversely affect salmon, it is not clear what this threshold is (i.e., it is not clear what levels of human-related sediment loadings can be tolerated by coho salmon). Despite the similarity in the ratio of anthropogenic to natural sediment contributions under differing periods of analysis, the total and harvest-related unit area sediment yields do appear to have substantially decreased in the last 25 years since the passage of the FPA. Roads and skid trails continue to contribute about 35% of the total sediment loading, or two-thirds of all human-related sediment loading, for both periods of analysis, suggesting that no substantial change in road-related sediment inputs has occurred despite improved forest practices. Considering effects of improved forest practices on hillslope stability and erosion, it is plausible that road-related mass wasting and surface erosion under current conditions are legacy effects of old roads. However, the published sediment source analyses, including this review analysis, cannot distinguish whether post-FPA road-related sediment delivery originated from older roads or roads constructed under FPA.

Recommendations

Considering the extraordinary time and effort devoted by the authors of the nine TMDLs reviewed here, a more consistent approach to future sediment source analyses will allow cross-basin comparisons between individual analyses (e.g., the range of the coho) to answer regional scale questions. In order to better discriminate between individual sediment source contributions in future TMDLs, we recommend the following:

- Stratify assessments by geomorphic terrains or geologic unit type and type of land-use.
- Bracket aerial photo analysis and sediment source estimates using multiple time periods, with each period encompassing the smallest geomorphologically meaningful time unit possible and with consideration given to natural variation among years in the magnitude and frequency of larger erosion-triggering storms.
- Determine annual sediment yields by geomorphic process type (e.g., structural landslides, shallow landslides, earthflows, soil creep, road-related surface erosion and mass wasting, and fluvial erosion on hillslopes including sheetwash, rilling, and gullying).
- Determine annual sediment yields by management practice (e.g., skid and road-related surface erosion, road-related landsliding, timber harvest-related landsliding and surface erosion, vineyard and grazing-related surface erosion).
- Future sediment budgets should focus on improving estimates of sediment delivery ratios (ie., proportion of sediment produced on hillslopes to that delivered to stream channel), as well as documenting changes in mean annual sediment yield.
- Future sediment source analyses should distinguish between mass wasting and surface erosion associated with roads built under the 1973 FPA vs. older roads that had no such controls.
- Lastly, future TMDL sediment source analyses should consider separating out estimates of coarse vs. fine sediment loading, especially for road-related sources of sediment, since the biological effects of sediment on salmon vary with sediment particle size.

Acknowledgements

We would like to thank Bruce Orr and Frank Ligon from Stillwater Sciences, Mike Furniss from the Forest Service Pacific Northwest Research Station, and Bill Dietrich from U.C. Berkeley for their input and review. Steve Kramer, Angela Percival, Whitney Sparks, and Jay Stallman provided technical support.

References

Ahnert, F. 1970. Functional relationships between denudation, relief, and uplift in large mid-latitude drainage basins. American Journal of Science 268: 243-263.

Campbell, R.H. 1975. Soil slips, debris flows, and rainstorms in the Santa Monica Mountains and vicinity, southern California. U. S. Geological Survey, Washington, D. C. Professional Paper No. 851.

Dietrich, W.E. and T. Dunne. 1978. Sediment budget for a small catchment in mountainous terrain. Zeitschrift fuer Geomorphologie N. F. 29:191-206.

Dietrich, W.E., C.J. Wilson and S.L. Reneau. 1986. Hollows, colluvium and landslides in soil-mantled landscapes, in: Hillslope Processes, Sixteenth Annual Geomorphology Symposium, A. Abrahams (ed.), Allen and Unwin, Ltd., p. 361-388.

Dietrich, W.E., C.J. Wilson, D.R. Montgomery, J. McKean, and R. Bauer. 1992. Erosion thresholds and land surface morphology, Geology 20:675-679.

Dietrich, W.E., C.J. Wilson, D.R. Montgomery, and J. McKean. 1993. Analysis of erosion thresholds, channel networks and landscape morphology using a digital terrain model, J. Geology 101(2):161-180.

Dietrich, W. E., R. Real de Asua, J. Coyle, B. K. Orr, and M. Trso. 1998. A validation study of the shallow slope stability model, SHALSTAB, in forested lands of northern California. Prepared for Louisiana-Pacific Corporation by Department of Geology and Geophysics, University of California, Berkeley and Stillwater Ecosystem, Watershed & Riverine Sciences, Berkeley, California. 29 June 1998.

Kelsey, H.M. 1977. Landsliding, channel changes, sediment yield and land use in the Van Duzen River basin, north coastal California, 1941-1975. Ph. D. Thesis. University of California, Santa Cruz. 370 p.

Keppeler, E. T. and D. Brown. 1998. Subsurface drainage processes and management impacts. Conference on Logging second-growth coastal watersheds: The Caspar Creek story. Mendocino Community College, Ukiah, California. California Department of Forestry and Fire Protection, USDA Forest Service, and University of California Cooperative Extension. 11 pages.

Leeder, M.R. 1991. Denudation, vertical crustal movements, and sedimentary basin infill. Geol. Rundsch. 80:441-458.

Madej, M. A. 1995. Changes in channel-stored sediment, Redwood Creek, northwestern California, 1947 to 1980. In Geomorphic processes and aquatic habitat in the Redwood Creek basin, northwestern California. Edited by K. M. Nolan, H. M. Kelsey, and D. C. Marron. U. S. Geological Survey Professional Paper 1454. Washington, D. C.

Matthews & Associates. 1999. Sediment source analysis and preliminary sediment budget for the Noyo River. Weaverville, CA. (Contract 68-C7-0018. Work Assignment #0-18.). Prepared for Tetra Tech, Inc. Fairfax, VA. May 1999.

Matthews & Associates. 2000. Sediment Source Analysis and Preliminary Sediment Budget for the Ten Mile River, Mendocino County, Ca. Prepared for Tetra Tech, Inc.

Miller, D. J. 1995. Coupling GIS with physical models to assess deep-seated landslide hazards. Environmental and Engineering Geoscience 1(3):263-276.

Montgomery, D. R. and W.E. Dietrich. 1994. A physically-based model for topographic control on shallow landsliding. Water Resources Research 30(4):1153-1171.

Montgomery, D. R., W. E. Dietrich, and K. Sullivan. 1998. The role of GIS in watershed analysis. Pages 241-261 in S. N. Lane, K. S. Richards and J. H. Chandler, editors. Landform monitoring, modelling and analysis. John Wiley & Sons, New York.

Montgomery, D.R., K.M. Schmidt, H.M. Greenberg and W.E. Dietrich. 2000. Forest clearing and regional landsliding. Geology 28:311-214.

Pacific Watershed Associates. 1997. Sediment production and delivery in the Garcia River watershed, Mendocino County, California: an analysis of existing published and unpublished data, Prepared for Tetra Tech, Inc. and the U.S. Environmental Protection Agency.

Pacific Watershed Associates. 1999. Sediment source investigation for the Van Duzen River watershed. An aerial photo analysis and field inventory of erosion and sediment delivery in the 429 mi2 Van Duzen River Basin, Humboldt County, California. Prepared for Tetra Tech, Inc. and the U.S. Environmental Protection Agency.

Raines, M. A. and H.M. Kelsey. 1991. Sediment budget for the Grouse Creek basin, Humboldt County, California. Western Washington University Department of Geology, in cooperation with Six Rivers

National Forest and the Bureau for Faculty Research, Western Washington University, Bellingham WA. February. 110 pages.

Raines, M. 1998. South Fork Trinity River sediment source analysis, Draft. Tetra Tech, Inc. October 1998.

Redwood National and State Parks. 1997. Draft Redwood Creek Watershed Analysis, 81. p (March 1997).

Reid, L.M., and T. Dunne. 1996. Rapid evaluation of sediment budgets. Catena Verlag, Reiskirchen, Germany.

Reneau, S. L. and W. E. Dietrich. 1987. Size and location of colluvial landslides in a steep forested landscape. Conference on Erosion and sedimentation in the Pacific Rim. Edited by R. L. Beschta, T. Blinn, G. E. Grant, F. J. Swanson, and G. G. Ice. IAHS Publication No. 165. International Association of Hydrological Scientists, Corvallis, Oregon.

Roering, J. J., J. W. Kirchner, W. E. Dietrich. 1999. Evidence for nonlinear, diffusive sediment transport on hillslopes and implications for landscape morphology. Water Resources Research 35(3):853-870.

Sidle, R.C., A.J. Pearce, C.L. O'Loughlin. 1985. Hillslope stability and land use, American Geophysical Union, Water Resources Monograph 11, 140 p.

Sidle, R. C. 1992. A theoretical model of the effect of timber harvesting on slope stability. Water Resources Research. 28:1897-1910.

Stillwater Sciences. 1999. South Fork Eel TMDL: Sediment Source Analysis, Final Report. Prepared for Tetra Tech, Inc. Fairfax, VA. 3 August 1999.

Summerfield, M. A., and N. J. Hulton. 1994. Natural controls of fluvial denudation rates in major world drainage basins. Journal of Geophysical Research 99(7): 13,871-13,883.

Swanson, F. J. and R. L. Fredriksen. 1982. Sediment routing and budgets: implications for judging impacts of forestry practices. Workshop on sediment budgets and routing in forested drainage basins: proceedings. Edited by: F. J. Swanson, R. J. Janda, T. Dunne, and D. N. Swanston. General Technical Report PNW-141. U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Swanson, F. J., L. E. Benda, S. H. Duncan, G. E. Grant, W. F. Megahan, L. M. Reid, and R. R. Ziemer. 1987. Mass failures and other processes of sediment production in Pacific Northwest forest landscapes. Contribution No. 57 in Streamside management: forestry and fishery interactions. Edited by Salo, E. O. and T. W. Cundy. College of Forest Resources, University of Washington, Seattle.

Tucker, G.E. and R. L. Bras. 1998. Hillslope processes, drainage density, and landscape morphology. Water Resources Research. 34(10):2751-2764.

USDA 1970. Water, land, and related resources—north coastal area of California and portions of southern Oregon. Appendix 1. Sediment yield and land treatment: Eel and Mad River basins. Prepared by the USDA River Basin Planning Staff in cooperation with California Department of Water Resources. June 1970.

USEPA. 1998a. Garcia River Sediment Total Maximum Daily Load. U.S. Environmental Protection Agency, Region IX, San Francisco, CA..

USEPA. 1998b. South Fork Trinity River and Hayfork Creek Sediment Total Maximum Daily Loads. U.S. Environmental Protection Agency, Region IX, San Francisco, CA.

USEPA. 1998c. Total Maximum Daily Load for Sediment Redwood Creek, California. U.S. Environmental Protection Agency, Region IX, San Francisco, CA. 30 December 1998.

USEPA. 1999a. Protocol for Developing Sediment TMDLs. EPA 841-B-99-004. Office of Water (4503F), United States Environmental Protection Agency, Washington D.C. 132 pages.

USEPA. 1999b. Noyo River Total Maximum Daily Load for Sediment. U.S. Environmental Protection Agency, Region IX, San Francisco, CA.

USEPA. 1999c. Van Duzen River and Yager Creek Total Maximum Daily Load for Sediment. U.S. Environmental Protection Agency, Region IX, San Francisco, CA.

USEPA. 1999d. South Fork Eel River Total Maximum Daily Loads for Sediment and Temperature. Environmental Protection Agency, Region IX, San Francisco, CA. December 1999.

USEPA. 2000a. Navarro River Total Maximum Daily Loads for Temperature and Sediment. Public Review Draft. U.S. Environmental Protection Agency, Region IX, San Francisco, CA. September 2000.

USEPA. 2000b. Ten Mile River Total Maximum Daily Load for Sediment. Public Review Draft. U.S. Environmental Protection Agency, Region IX, San Francisco, CA.

Wilson, C. J. and W.E. Dietrich. 1987. The contribution of bedrock groundwater flow to storm runoff and high pore pressure development in hollows. Conference on Erosion and sedimentation in the Pacific Rim. Edited by R. L. Beschta, T. Blinn, G. E. Grant, F. J. Swanson,

Cumulative Watershed Effects: Then and Now[1]

Leslie M. Reid

Pacific Southwest Reseach Station, Arcata

Abstract

Cumulative effects are the combined effects of multiple activities, and watershed effects are those which involve processes of water transport. Almost all impacts are influenced by multiple activities, so almost all impacts must be evaluated as cumulative impacts rather than as individual impacts. Existing definitions suggest that to be significant, an impact must be reasonably expected to have occurred or to occur in the future, and it must be of societally validated concern to someone or influence their activities or options. Past approaches to evaluating and managing cumulative watershed impacts have not yet proved successful for averting these impacts, so interest has grown in how to regulate land-use activities to reverse existing impacts. Approaches being discussed include requirements for "zero net increase" of sediment, linkage of planned activities to mitigation of existing problems, use of more protective best management practices, and adoption of thresholds for either land-use intensity or impact level. Different kinds of cumulative impacts require different kinds of approaches for management. Efforts are underway to determine how best to evaluate the potential for cumulative impacts, and thus to provide a tool for preventing future impacts and for determining which management approaches are appropriate for each issue in an area. Future impact analysis methods probably will be based on strategies for watershed analysis. Analysis would need to consider areas large enough for the most important impacts to be evident; to evaluate time scales long enough for the potential for impact accumulation to be identified; and to be interdisciplinary enough that interactions among diverse impact mechanisms can be understood.

Introduction

Ten years ago, cumulative impacts were a major focus of controversy and discussion. Today they still are, although the term "effects" has generally replaced "impacts," in part to acknowledge the fact that not all cumulative changes are undesirable. However, because the changes most relevant to the issue are the undesirable ones, "cumulative effect" is usually further modified to "adverse cumulative effect."

The good news from the past 10 years' record is that it was not just the name that changed. Most of the topics of discourse have also shifted (Table 1), and this shift in focus is evidence of some progress in understanding. The bad news is that progress was too little to have prevented the cumulative impacts that occurred over the past 10 years. This paper first reviews the questions that have been resolved in order to provide a historical context for the problem, then uses examples from Caspar Creek and New Zealand to examine the issues surrounding questions yet to be answered.

Then: What Is a Cumulative Impact?

The definition of cumulative impacts should have been a trivial problem because a legal definition already existed.

Table 1—Commonly asked questions concerning cumulative impacts in 1988 (then) and 1998 (now).

Then:	**Now:**
What is a cumulative impact?	What is a "significant" adverse cumulative effect?
Do cumulative impacts exist?	How can regulation reverse adverse cumulative effects?
How can cumulative impacts be avoided?	How can adverse cumulative effects be avoided?

According to the Council on Environmental Quality (CEQ Guidelines, 40 CFR 1508.7, issued 23 April 1971),

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

This definition presented a problem, though. It seemed to include everything, and a definition of a subcategory is not particularly useful if it includes everything. A lot of effort thus went into trying to identify impacts that were modified because of interactions with other impacts. In particular, the search was on for "synergistic impacts," in which the impact from a combination of activities is greater than the sum of the impacts of the activities acting alone.

In the long run, though, the legal definition held: "cumulative impacts" are generally accepted to include all impacts that are influenced by multiple activities or causes. In essence, the definition did not define a new type of impact. Instead, it expanded the context in which the significance of any impact must be evaluated. Before, regulations could be written to allow an activity to occur as long as the impacting party took the best economically feasible measures to reduce impacts. If the portion of the impact attributable to a particular activity was not independently damaging, that activity was not accountable. Now, however, the best economically feasible measures are no longer sufficient if the impact still occurs. The activities that together produce the impact are responsible for that impact, even if each activity is individually responsible for only a small portion of the impact.

A cumulative watershed impact is a cumulative impact that influences or is influenced by the flow of water through a watershed. Most impacts that occur away from the site of the triggering land-use activity are cumulative watershed impacts, because something must be transported from the activity site to the impact site if the impact is to occur, and water is one of the most common transport media. Changes in the water-related transport of sediment, woody debris, chemicals, heat, flora, or fauna can result in off-site cumulative watershed impacts.

Then: Do Cumulative Impacts Actually Occur?

The fact that the CEQ definition of cumulative impacts prevailed made the second question trivial: almost all impacts are the product of multiple influences and activities and are, therefore, cumulative impacts. The answer is a resounding "yes."

Then: How Can Cumulative Impacts Be Avoided?

Because the National Environmental Policy Act of 1969 specified that cumulative effects must be considered in evaluations of environmental impact for federal projects and permits, methods for regulating cumulative effects had to be established even before those effects were well understood. Similar legislation soon followed in some states, and private landowners and state regulatory agencies also found themselves in need of approaches for addressing cumulative impacts. As a result, a rich variety of methods to evaluate and regulate cumulative effects was developed. The three primary strategies were the use of mechanistic models, indices of activity levels, and analysis.

Mechanistic models were developed for settings where concern focused on a particular kind of impact. On National Forests in central Idaho, for example, downstream impacts of logging on salmonids were assumed to arise primarily because of deposition of fine sediments in stream gravels. Abundant data allowed relationships to be identified between logging-related activities and sedimentation (Cline and others 1981) and between sedimentation and salmonid response (Stowell and others 1983). Logging was then distributed to maintain low sedimentation rates. Unfortunately, this approach does not address the other kinds of impacts that might occur, and it relies heavily on a good understanding of the locale-specific relationships between activity and impact. It cannot be applied to other areas in the absence of lengthy monitoring programs.

National Forests in California initially used a mechanistic model that related road area to altered peak flows, but the model was soon found to be based on invalid assumptions. At that point, "equivalent road acres" (ERAs) began to be used simply as an index of management intensity instead of as a mechanistic driving variable. All logging-related activities were assigned values according to their estimated level of impact relative to that of a road, and these values were summed for a watershed (USDA Forest Service 1988). Further activities were deferred if the sum was over the threshold considered acceptable. Three problems are evident with this method: the method has not been formally tested, different kinds of impacts would have different thresholds, and recovery is evaluated according to the rate of recovery of the assumed driving variables (e.g., forest cover) rather than to that of the impact (e.g., channel aggradation). Cumulative impacts thus can occur even when the index is maintained at an "acceptable" value (Reid 1993).

The third approach, locale-specific analysis, was the method adopted by the California Department of Forestry for use on state and private lands (CDF 1998). This approach is potentially capable of addressing the full range of cumulative impacts that might be important in an area. A standardized impact evaluation procedure could not be developed because of the wide variety of issues that might need to be assessed, so analysis methods were left to the professional judgment of those preparing timber harvest plans. Unfortunately, oversight turned out to be a problem. Plans were approved even though they included cumulative impact analyses that were clearly in error. In one case, for example, the report stated that the planned logging would indeed introduce sediment to streams, but that downstream riparian vegetation would filter out all the sediment before it did any damage. Were this actually true, virtually no stream would carry suspended sediment. In any case, even though timber harvest plans prepared for private lands in California since 1985 contain statements attesting that the plans will not result in increased levels of significant cumulative impacts, obvious cumulative impacts have accrued from carrying out those plans. Bear Creek in northwest California, for example, sustained 2 to 3 meters of aggradation after the 1996-1997 storms, and 85 percent of the sediment originated from the 37 percent of the watershed area that had been logged on privately owned land during the previous 15 years (Pacific Watershed Associates 1998).

EPA's recent listing of 20 north coast rivers as "impaired waterways" because of excessive sediment loads, altered temperature regimes, or other pervasive impacts suggests that whatever the methods used to prevent and reverse cumulative impacts on public and private lands in northwest California, they have not been successful. At this point, then, we have a better understanding of what cumulative impacts are and how they are expressed, but we as yet have no workable approach for avoiding or managing them.

The Interim: Examples

One of the reasons that the topics of discourse have changed over the past 10 years is that a wider range of examples has been studied. As more is learned about how particular cumulative impacts develop and are expressed, it becomes more possible to predict and manage future impacts. Two examples serve here to display complementary approaches to the study of cumulative impacts and to provide a context for discussion of the remaining questions.

Studying Cumulative Impacts at Caspar Creek

Cumulative impacts result from the accumulation of multiple individual changes. One approach to the study of cumulative impacts, therefore, is to study the variety of changes caused by a land-use activity in an area and evaluate how those changes interact. This approach is essential for developing an understanding of the changes that can generate cumulative impacts, and thus for understanding the potential mechanisms of impact. The long-term, detailed hydrological studies carried out before and after selective logging of a second-growth redwood forest in the 4-km^2 South Fork Caspar Creek watershed and clearcut logging in 5-km^2 North Fork Caspar Creek watershed provide the kinds of information needed for this approach. Other papers in these proceedings describe the variety of studies carried out in the area, and here the results of those studies are reviewed as they relate to cumulative impacts.

Results of the South Fork study suggest that 65-percent selective logging, tractor yarding, and associated road management more than doubled the sediment yield from the catchment (Lewis, these proceedings), while peak flows showed a statistically significant increase only for small storms near the beginning of the storm season (Ziemer, these proceedings). Sediment effects had returned to background levels within 8 years of the end of logging; while minor hydrologic effects persisted for at least 12 years (Thomas 1990). Road construction and logging within riparian zones has helped to perpetuate low levels of woody debris loading in the South Fork that originally resulted from the first cycle of logging and from later clearing of in-stream debris. An initial pulse of blowdown is likely to have occurred soon after the second-cycle logging, but the resulting woody debris is now decaying. Today's near-channel stands contain a high proportion of young trees and alders, so debris loadings are likely to continue to decrease in the future until riparian stands are old enough to contribute wood. Results of the South Fork study reflect roading, logging, and yarding methods used before forest practice rules were implemented.

Local cumulative impacts from two cycles of logging along the South Fork are expressed primarily in the altered channel form caused by loss of woody debris and the presence of a main haul road adjacent to the channel. But for the presence of the South Fork weir pond, which trapped most of the sediment load, downstream cumulative impacts could have resulted from the increased sediment load in combination with similar increases from surrounding catchments. Although the initial increase in sediment load had recovered in 8 years, estimates of the time over which sediment impacts could accumulate downstream of analogous watersheds without weirs would require information about the residence time of sediment at sites of concern downstream. Recent observations suggest that the 25-year-old logging is now contributing a second pulse of sediment as abandoned roads begin to fail (Cafferata and Spittler, these proceedings), so the overall impact of logging in the South Fork may prove to be greater than previously thought.

The North Fork studies focus on the effects of clearcut logging, largely in the absence of near-stream roads. The primary study was designed to test for the presence of synergistic cumulative impacts on suspended sediment load and storm flows. Nested watersheds were monitored before and after logging to determine whether the magnitude of hydrologic and sediment transport changes increased, decreased, or remained constant downstream. Results showed that the short-term effects on sediment load and runoff increased approximately in proportion to the area logged above each gauging station, thus suggesting that the effect is additive for the range of storms sampled. Long-term effects continue to be studied.

Results also show an 89 percent increase in sediment load after logging of 50 percent of the watershed (Lewis, these proceedings). Peak flows greater than 4 L s-1 ha-1, which on average occur less than twice a year, increased by 35 percent in completely clearcut tributary watersheds, although there was no statistically significant change in peak flow at the downstream-most gauging station (Ziemer, these proceedings). Observations in the North Fork watershed suggest that much of the increased sediment may come from stream-bank erosion, headward extension of unbuffered low-order streams, and accelerated wind-throw along buffered streams (Lewis, these proceedings). Channel disruption is likely to be caused, in part, by increased storm-flow volumes. Increased sediment appeared at the North Fork weir as suspended load, while bedload transport rates did not change significantly. It is likely that the influx of new woody debris caused by accelerated blowdown near clearcut margins provided storage opportunities for increased inputs of coarse sediment (Lisle and Napolitano, these proceedings), thereby offsetting the potential for downstream cumulative impacts associated with coarse sediment. However, accelerated blow-down immediately after logging and selective cutting of buffer strips may have partially depleted the source material for future woody debris inputs (Reid and Hilton, these proceedings). Bedload sediment yields may

Table 2—Comparison of settings for the South Fork Eel River Basin and the Waipaoa River Basin.

Characteristic	South Fork Eel River Basin[1]	Waipaoa River Basin
Area (km^2)	1,760	2,100
Latitude	39°30'N to 40°20'N	38°10'S to 38°50'S
Bedrock	Intensely sheared late Mesozoic sediments and volcanics; Tertiary sedimentary rocks	Intensely sheared late Mesozoic sediments and volcanics; Tertiary sedimentary rocks
Rainfall (mm/yr)	1,500 to 2,900	900 to 3,000
Maximum elevation (m)	1,290	970
Uplift rate (mm/yr)	0 to 4	0 to 3
Sediment yield (t/km^2-yr)	5,000	7,500
Original vegetation	Redwood, Douglas fir, hardwood, grassland	Podocarp conifers, southern beech hardwoods, bracken scrub
Current vegetation	same	grassland; some reforestation of Monterey pines
Current land use	Logging, ranching	Sheep farming

[1] *information primarily from Scott and Buer (1983)*

increase if future rates of debris-dam decay and failure become higher than future rates of debris infall.

But the North Fork of Caspar Creek drains a relatively small watershed. It is one-tenth the size of Freshwater Creek watershed; one-hundredth the size of Redwood Creek watershed; one-thousandth the size of the Trinity River watershed. In these three cases, the cumulative impacts of most concern occurred on the main-stem channels; impacts were not identified as a major issue on channels the size of Caspar Creek. Thus, though studies on the scale of those carried out at Caspar Creek are critical for identifying and understanding the mechanisms by which impacts are generated, they can rarely be used to explore how the impacts of most concern are expressed because these watersheds are too small to include the sites where those impacts occur. Far downstream from a watershed the size of Caspar Creek, doubling of suspended sediment loads might prove to be a severe impact on water supplies, reservoir longevity, or estuary biota.

In addition, the 36-year-long record from Caspar Creek is short relative to the time over which many impacts are expressed. The in-channel impacts resulting from modification of riparian forest stands will not be evident until residual wood has decayed and the remaining riparian stands have regrown and equilibrated with the riparian management regime. Establishment of the eventual impact level may thus require several hundred years.

Studying Cumulative Impacts in the Waipaoa Watershed

A second approach to cumulative impact research is to work backwards from an impact that has already occurred to determine what happened and why. This approach requires very different research methods than those used at Caspar Creek because the large spatial scales at which cumulative impacts become important prevent acquisition of detailed information from throughout the area. In addition, time scales over which impacts have occurred are often very long, so an understanding of existing impacts must be based on after-the-fact detective work rather than on real-time monitoring. A short-term study carried out in the 2200-km^2 Waipaoa River catchment in New Zealand provides an example of a large-scale approach to the study of cumulative impacts.

A central focus of the Waipaoa study was to identify the long-term effects of altered forest cover in a setting with similar rock type, tectonic activity, topography, original vegetation type, and climate as northwest California (Table 2). The major difference between the two areas is that forest was converted to pasture in New Zealand, while in California the forests are periodically regrown. The strategy used for the study was similar to that of pharmaceutical experiments: to identify possible effects of low dosages, administer high doses and observe the extreme effects. Results, of course, may depend on the intensity of the activity and so may not be directly transferable. However, results from such a study do give a very good idea of the kinds of changes that might happen, thus defining early-warning signs to be alert for in less-intensively managed systems.

The impact of concern in the Waipaoa case was flooding: residents of downstream towns were tired of being flooded, and they wanted to know how to decrease the flood hazard through watershed restoration. The activities that triggered the impacts occurred a century ago. Between 1870 and 1900, beech-podocarp forests were converted to pasture by burning, and gullies and landslides began to form on the pastures within a few years. Sediment eroded from these sources began accumulating in downstream channels, eventually decreasing channel capacity enough that sheep farms in the valley began to flood with every moderate storm. Most of the farms had been moved to higher ground by about 1920. Today, the terraces they originally occupied are themselves at the level of the channel bed, and 30 m of aggradation have been documented at one site (Allsop 1973). By the mid-1930's, aggradation had reached the Whatatutu town-site 20 km downstream, forcing the entire town to be moved onto a terrace 60 m above its original location.

Meanwhile, levees were being constructed farther downstream, and high-value infrastructure and land-use activities began to accumulate on the newly "protected" lowlands. At about the same time as levees were constructed, the frequency of severe flooding, as identified from descriptions in the local newspaper, increased. Climatic records show no synchronous change in rainfall patterns.

The hydrologic and geomorphic changes that brought about the Waipaoa's problems are of the same kinds measured 10,000 km away in Caspar Creek: runoff and erosion rates increased with the removal of the forest cover. However, the primary reason for increased flood frequencies was not the direct effects of hydrologic change, but the indirect effects (fig. 1). Had peak-flow increases due to altered evapotranspiration and interception loss after deforestation been the primary cause of flooding, increased downstream flood frequencies would have dated from the 1880's, not from the 1910's. The presence of gullies in forested land down-slope of grasslands instead suggests that the major impact of locally increased peak-flows was the destabilization of low-order channels, which then led to downstream channel aggradation, decreased channel capacity, and flooding. At the same time, loss of root cohesion contributed to hillslope destabilization and further accelerated aggradation. The levees themselves probably aggravated the impact nearby by reducing the volume of flood flow that could be temporarily stored, and the significance of the impact was increased by the increased presence of vulnerable infrastructure.

The impacts experienced in the Waipaoa catchment demonstrate a variety of cumulative effects. First, deforestation occurred over a wide-enough area that enough sediment could accumulate to cause a problem. Second, deforestation persisted, allowing impacts to accumulate through time. Third, the sediment derived from gully erosion (caused primarily by increased local peak flows) combined with lesser amounts contributed by landslides (triggered primarily by decreased root cohesion). Fourth, flood damage was increased by the combined effects of decreased channel capacity, increased runoff, the presence of ill-placed levees, and the increased presence of structures that could be damaged by flooding (fig. 1).

The Waipaoa example also illustrates the time-lags inherent nisms, some level of impact was inevitable.

But how much of the Waipaoa story can be used to understand impacts in California? In California, although road-related effects persist throughout the cutting cycle, hillslopes experience the effects of deforestation only for a short time during each cycle, so only a portion of the land surface is vulnerable to excessive damage from large storms at any given time (Ziemer and others 1991). Average erosion and runoff rates are increased, but not by as much as in the Waipaoa watershed; and partial recovery is possible between impact cycles. If, as expected, similar trends of change (e.g., increased erosion and runoff) predispose similar landscapes to similar trends of response, then the Waipaoa watershed provides an indication

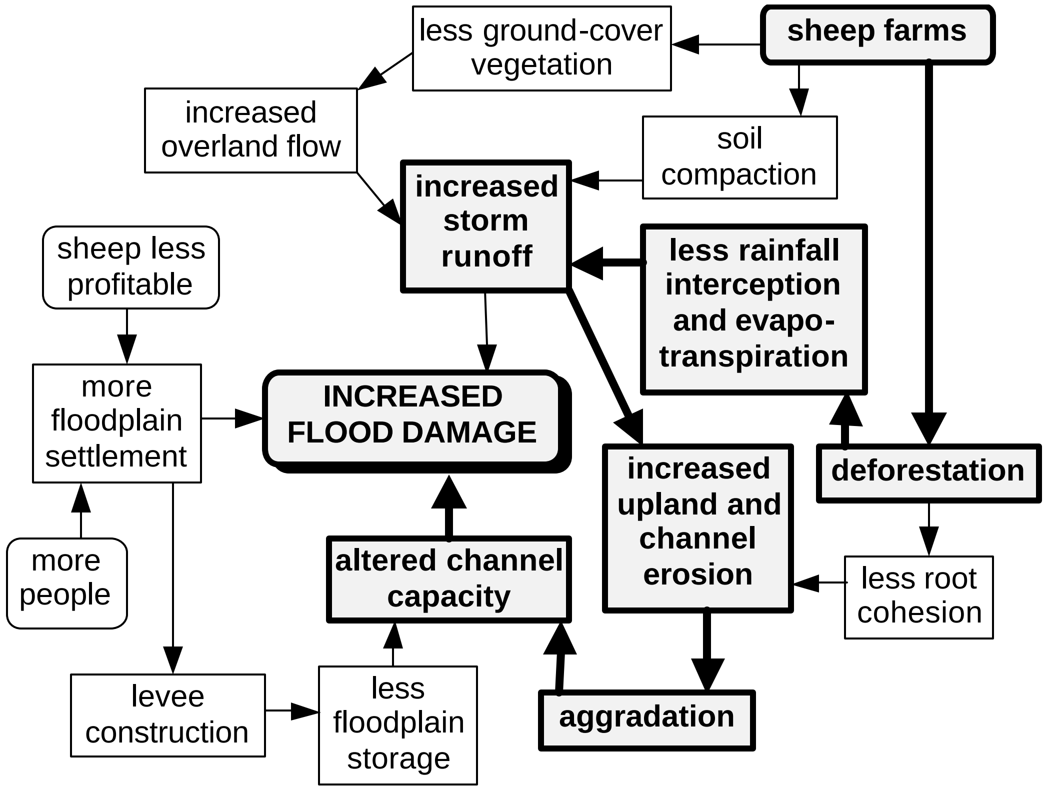


Figure 1—Factors influencing changes in flood hazard in the Waipaoa River basin, North Island, New Zealand. Bold lines and shaded boxes indicate the likely primary mechanism of influence.

of the kinds of responses that northwest California watersheds might more gradually undergo. The first response: increased landsliding and gullying. The second: pervasive channel aggradation. Both kinds of responses are already evident at sites in northwest California where the rate of temporary deforestation has been particularly high (Madej and Ozaki 1996, Pacific Watershed Associates 1998), suggesting that response mechanisms similar to those of the Waipaoa are underway. However, it is not yet known what the eventual magnitude of the responses might be.

Now: What Is a "Significant" Adverse Cumulative Effect?

The key to the definition now lies in the word "significant," and "significant" is one of those words that has a different definition for every person who uses it. Two general categories of definition are particularly meaningful in this context, however. To a scientist, a "significant" change is one that can be demonstrated with a specified level of certainty. For example, if data show that there is only a probability of 0.13 that a measured 1 percent increase in sediment load would appear by chance, then that change is statistically significant at the 87 percent confidence level, irrespective of whether a 1 percent change makes a difference to anything that anyone cares about.

The second category of definition concentrates on the nature of the interaction: if someone cares about a change or if the change affects their activities or options, it is "significant" or "meaningful" to them. This definition does not require that the change be definable statistically. An unprecedented activity might be expected on the basis of inference to cause significant changes even before actual changes are statistically demonstrable. Or to put it another way, if cause-and-effect relationships are correctly understood, one does not necessarily have to wait for an experiment to be performed to know what the results are likely to be and to plan accordingly.

In the context of cumulative effects, elements of both facets of the definition are obviously important. According to the Guidelines for Implementation of the California Environmental Quality Act (14 CCR 15064, filed 13 July 1983, amended 27 May 1997),

(g) The decision as to whether a project may have one or more significant effects shall be based on substantial evidence in the record of the lead agency...Substantial evidence shall include facts, reasonable assumptions predicated upon facts, and expert opinion supported by facts.

(h) ...If there is disagreement among expert opinion supported by facts over the significance of an effect on the environment, the Lead Agency shall treat the effect as significant...

In addition, the following section (14 CCR 15065, filed 13 July 1983, amended 27 May 1997) describes mandatory findings of significance. Situations in which "a lead agency shall find that a project may have a significant effect on the environment" include those in which

(a) The project has the potential to substantially degrade the quality of the environment, ...[or]...reduce the number or restrict the range of an endangered, rare or threatened species.

(d) The environmental effects of a project will cause substantial adverse effects on human beings, either directly or indirectly.

"Substantial" in these cases appears to mean "of real worth, value, or effect." Together, these sections establish the relevance of both facets of the definition: in essence, a change is significant if it is reasonably expected to have occurred or to occur in the future, and if it is of societally validated concern to someone or affects their activities or options. "Someone" in this case can also refer to society in general: the existence of legislation concerning clean water, endangered species, and environmental quality demonstrates that impacts involving these issues are of recognized concern to many people. The Environmental Protection Agency's listing of waterways as impaired under section 303(d) of the Clean Water Act would thus constitute documentation that a significant cumulative impact has already occurred.

An approach to the definition of "significance" that has been widely attempted is the identification of thresholds above which changes are considered to be of concern. Basin plans developed under the Clean Water Act, for example, generally adopt an objective of limiting turbidity increases to within 20 percent of background levels. Using this approach, any study that shows a statistically significant increase in the level of turbidity rating curves of more than 20 percent with respect to that measured in control watersheds would document the existence of a significant cumulative impact. Such a record would show the change to be both statistically meaningful and meaningful from the point of view of what our society cares about.

Thresholds, however, are difficult to define. The ideal threshold would be an easily recognized value separating significant and insignificant effects. In most cases, though, there is no inherent point above which change is no longer benign. Instead, levels of impact form a continuum that is influenced by levels of triggering activities, incidence of triggering events such as storms, levels of sensitivity to changes, and prior conditions in an area. In the case of turbidity, for example, experiments have been carried out to define levels above which animals die; death is a recognizable threshold in system response. However, chronic impacts are experienced by the same species at levels several orders of magnitude below these lethal concentrations (Lloyd 1987), and there is likely to be an incremental decrease in long-term fitness and survival with each increment of increased turbidity. In many cases, the full implications of such impacts may be expressed only in the face of an uncommon event, such as a drought or a local outbreak of disease. Any effort to define a meaningful threshold in such a situation would be defeated by the lack of information concerning the long-term effects of low levels of exposure.

If a threshold cannot be defined objectively on the basis of system behavior or impact response, the threshold would need to be identified on the basis of subjective considerations. Definition of subjective thresholds is a political decision requiring value-laden weighting of the interests of those producing the impacts and those experiencing the impacts.

It is important to note that an activity is partially responsible for a significant cumulative impact if it contributes an incremental addition to an already significant cumulative impact. For example, if enough excess sediment has already been added to a channel system to cause a significant impact, then any further addition of sediment also constitutes a significant cumulative impact.

Now: How Can Regulation Reverse Adverse Cumulative Effects?

In California's north coast watersheds, the prevalence of streams listed as impaired under section 303(d) of the Clean Water Act demonstrates that significant cumulative impacts are widespread in the area. Forest management, grazing, and other activities continue in these watersheds, so the focus of concern now is on how to regulate management of these lands in such a way as to reverse the impacts. Current regulatory strategies largely reflect the strategies for assessing cumulative impacts that were in place 10 years ago, and the need for changing these regulatory strategies is now apparent. Approaches to regulation that are being discussed include attainment of "zero net increase" in sediment, offsetting of impacts by mitigation, adoption of more stringent standards for specific land-use activities, and use of threshold-based methods.

The "zero-net-increase" approach is based on an assumption that no harm is done if an activity does not increase the overall level of impact in an area. This is the approach instituted to regulate sediment input in Grass Valley Creek in the Trinity Basin, where erosion rates are to be held at or below the levels present in 1986 (Komar 1992). Unfortunately, this approach cannot be used to reverse the trend of impacts already occurring because the existing trend of impact was created by the levels of sediment input present in 1986. To reverse impacts, inputs would need to be decreased to below the levels of input that originally caused the problem.

"Zero-net increase" requirements are often linked to mitigation plans, whereby expected increases in sediment production due to a planned project are to be offset by measures instituted to curtail erosion from other sources. Some such plans even provide for net decreases in sediment production in a watershed. Unfortunately, this approach also falls short of reversing existing impacts because mitigation measures usually are designed to repair the unforeseen problems caused by past activities. It is reasonable to assume that the present plans will also result in a full complement of unforeseen problems, but the possibility of mistakes is generally not accounted for when likely input rates from the planned activities are calculated. Later, when the unforeseen impacts become obvious, repair of the new problems would be used as mitigation for future projects. To ensure that such a system does more than perpetuate the existing problems, it would be necessary to require that all future impacts from a plan (and its associated roads) are repaired as part of the plan, not as mitigation measures to offset the impacts of future plans.

In addition, offsetting mitigation activities are usually accounted for as though the predicted impacts were certain to occur if those activities are not carried out. In reality, there is only a small chance that any given site will fail in a 5-year period. Appropriate mitigation would thus require that considerably more sites be repaired than are ordinarily allowed for in mitigation-based plans. Furthermore, mitigation at one site does not necessarily offset the kind of impacts that will accrue from a planned project. If the project is located where impacts from a given sediment input might be particularly severe, offsetting measures in a less-sensitive area would not be equivalent. Similarly, mitigation of one kind of source does not cancel the impact of another kind of source. Mitigation capable of offsetting the impacts from construction of a new road would need to include obliteration of an equal length of old road to offset hydrologic changes, as well as measures to offset short-term sediment inputs from construction and obliteration and long-term inputs from future road use.

The timing of the resulting changes may also negate the effectiveness of mitigation measures. If a project adds to current sediment loads in a sediment-impaired waterway, while the mitigation work is designed to decrease sediment loads at some time in the future (when the repaired sites would otherwise have failed), the plan is still contributing to a significant cumulative impact, irrespective of the offsetting mitigation activities. In other words, if a watershed is already experiencing a significant sediment problem, it makes little sense to use an as-yet-unfulfilled expectation of future improvement as an excuse to make the situation worse in the short term. It would thus be necessary to carry out mitigation activities well in advance of the activities which they are designed to offset so that impact levels are demonstrably decreasing by the time the unavoidable new impacts are generated.

The third approach to managing existing impacts is the adoption of more stringent standards that are based on the needs of the impacted resources. Attempts to avert cumulative impacts through the implementation of "best management practices" (BMPs) have failed in the past in part because they were based strongly on the economic needs of the impacting land uses and thus did not fully reflect the possibility that significant adverse cumulative effects might accrue even from reduced levels of impact. A new approach to BMPs has recently appeared in the form of standards and guidelines for designing and managing riparian reserves on federal lands affected by the Northwest Forest Plan (USDA and USDI 1994). Guidelines for the design of riparian reserves are based on studies that describe the distance from a forest edge over which the microclimatic and physical effects of the edge are evident, and have a principal goal of producing riparian buffer strips capable of adequately shielding the aquatic system—and particularly anadromous salmonids—from the effects of upslope activities. Any land-use activities to be carried out within the reserves must be shown not to incur impacts on the aquatic system. Even with this level of protection, the Northwest Forest Plan is careful to point out that riparian reserves and their accompanying standards and guidelines are not in themselves sufficient to reverse the trend of aquatic habitat degradation. These measures are expected to be effective only in combination with (1) watershed analysis to identify the causes of problems, (2) restoration programs to reverse those causes and speed recovery, and (3) careful protection of key watersheds to ensure that watershed-scale refugia are present. The Northwest Forest Plan thus recognizes that BMPs alone are not sufficient, although they can be an important component of a broader, landscape-scale approach to recovery from impacts.

The final approach is the use of thresholds. Threshold-based methods would allow for altering land-use prescriptions once a threshold of concern has been surpassed. This, in essence, is the approach used on National Forests in California: if the index of land-use intensity rises above a defined threshold value, further activities are deferred until the value for the watershed is once again below threshold. Such an approach would be workable if there is a sound basis for identifying appropriate levels of land-use intensity. This basis would need to account for the occurrence of large storms because actual impact levels rarely can be identified in the absence of a triggering event. The approach would also need to include provisions for frequent review so that plans could be modified

Table 3—Potential effectiveness of various strategies for managing specific cumulative impacts.

Cumulative Impact	Zero-net-increase	Off-setting mitigations	Impact-based Best Management Practices	Impact Threshold	Activity Thresholds
Caspar Creek sediment yield increase from hydrologic change	no	no	no	no	**YES**
Caspar Creek channel change from altered wood regime	no	no	**YES**	no	no
Waipaoa flooding from channel aggradation	no	no	no	no	**YES**

if unforeseen impacts occur.

Thresholds are more commonly considered from the point of view of the impacted resource. In this case, activities are curtailed if the level of impact rises above a predetermined value. This approach has limited utility if the intent is to reverse existing or prevent future cumulative impacts because most responses of interest lag behind the land-use activities that generate them. If the threshold is defined according to system response, the trend of change may be irreversible by the time the threshold is surpassed. In the Waipaoa case, for example, if a threshold were defined according to a level of aggradation at a downstream site, the system would have already changed irreversibly by the time the effect was visible. The intolerable rate of aggradation that Whatatutu experienced in the mid-1930's was caused by deforestation 50 years earlier. Similarly, the current pulse of aggradation near the mouth of Redwood Creek was triggered by a major storm that occurred more than 30 years ago (Madej and Ozaki 1996). In contrast, turbidity responds quickly to sediment inputs, but recognition of whether increases in turbidity are above a threshold level requires a sequence of measurements over time to identify the relation between turbidity and discharge, and it requires comparison to similar measurements from an undisturbed or less-disturbed watershed to establish the threshold relationship.

The potential effectiveness of the strategies described above can be assessed by evaluating their likely utility for addressing particular impacts (table 3). In North Fork Caspar Creek, for example, suspended sediment load nearly doubled after clearcutting, with the change largely attributable to increased sediment transport in the smallest tributaries because of increased runoff and peakflows. Strategies of zero-net-increase and offsetting mitigations would not have prevented the change because the effect was an indirect result of the volume of canopy removed; hydrologic change is not readily mitigable. BMPs would not have worked because the problem was caused by the loss of canopy, not by how the trees were removed. Impacts were evident only after logging was completed, so impact-based thresholds would not have been passed until after the change was irreversible. Only activity-based thresholds would have been effective in this case: because hydrologic change is roughly proportional to the area logged, the magnitude of hydrologic change could have been managed by regulating the amount of land logged.

A second long-term cumulative impact at Caspar Creek is the change in channel form that is likely to result from past, present, and future modifications of near-stream forest stands. In this case, a zero-net-change strategy would not have worked because the characteristics for which change is of concern—debris loading in the channel—will be changing to an unknown extent over the next decades and centuries in indirect response to the land-use activities. Off-setting mitigations would most likely take the form of artificially adding wood, but such a short-term remedy is not a valid solution to a problem that may persist for centuries. In this case, BMPs, in the form of riparian buffer strips designed to maintain appropriate debris infall rates, would have been effective. Impact thresholds would not have prevented impacts, as the nature of the impact will not be fully evident for decades or centuries. Activity thresholds also would not be effective, because the recovery rate of the impact is an order of magnitude longer than the likely cutting cycle.

The Waipaoa problem would also be poorly served by most of the available strategies. Once underway, impacts in the Waipaoa watershed could not have been reversed through adoption of zero-net-increase rules because the importance of earlier impacts was growing exponentially as existing sources enlarged. Similarly, mitigation measures to repair existing problems would not have been successful: the only effective mitigation would have been to reforest an equivalent portion of the landscape, thus defeating the purpose of the vegetation conversion. BMPs would not have been effective, because how the watershed was deforested made no difference to the severity of the impact. Thresholds defined on the basis of impact also would have been useless because the trend of change was effectively irreversible by the time the impacts were visible downstream. Thresholds of land-use intensity, however, might have been effective had they been instituted in time. If only a portion of the watershed had been deforested, hydrologic change might have been kept at a low enough level that gullies would not have formed. The only potentially effective approach in this case thus would have been one that required an understanding of how the impacts were likely to come about. De facto institution of land-use-intensity thresholds is the approach that has now been adopted in the Waipaoa basin to reduce existing cumulative impacts. The New Zealand government bought the major problem areas and reforested them in the 1960's and 1970's. Over the past 30 years the rate of sediment input has decreased significantly, and excess sediment is beginning to move out of upstream channels.

It is evident that no one strategy can be used effectively to manage all kinds of cumulative impacts. To select an appropriate management strategy, it is necessary to determine the cause, symptoms, and persistence of the impacts of concern. Once these characteristics are understood, each available strategy can be evaluated to determine whether it will have the desired effect.

Now: How Can Adverse Cumulative Effects Be Avoided?

The first problem in planning land use to avoid cumulative effects is to identify the cumulative effects that might occur from a proposed activity. A variety of methods for doing so have been developed over the past 10 years, and the most widely adopted of these are methods of watershed analysis. Washington State has developed and implemented a procedure to design management practices to fit conditions within specific watersheds (WFPB 1995), with the intent of holding future impacts to low levels. A procedure has also been developed for evaluating existing and potential environmental impacts on federal lands in the Pacific Northwest (Regional Ecosystem Office 1995). Both methods have strengths and weaknesses.

The Washington approach describes detailed methods for evaluating processes such as landsliding and road-surface erosion and provides for participation of a variety of interest groups in the analysis procedure. Because the approach was developed through consensus among diverse groups, it is widely accepted. However, methods have not been adequately tested, and the approach is designed to consider only issues related to anadromous fish and water quality. In general, only those impacts which are already evident in the watershed are used as a basis for invoking prescriptions more rigorous than standard practices. No evaluation need be done of the potential effects of future activities in the watershed; it is assumed that the activities will not produce significant impacts if the prescribed practices are followed. The method does not evaluate the cumulative impacts that might result from implementation of the prescribed practices and does not provide for evaluating the potential of future activities to contribute to significant cumulative impacts. Collins and Pess (1997a, 1997b) provide a comprehensive review of the approach.

The Federal interagency watershed analysis method, in contrast, was intended simply to provide an interdisciplinary background understanding of the mechanisms for existing and potential impacts in a watershed. The Federal approach recognizes that which activities are appropriate in the future will depend on watershed conditions present in the future, so that cumulative effects analyses would still need to be carried out for future activities. Although the analyses were intended to be carried out with close interdisciplinary cooperation, analyses have tended to be prepared as a series of mono-disciplinary chapters.

Both procedures suffer from a tendency to focus exclusively on areas upstream of the major impacts of concern. The potential for cumulative effects cannot be evaluated if the broader context for the impacts is not examined. To do so, an area large enough to display those impacts must be examined. Because of California's topography and geography, the most important areas for impact are at the mouths of the river basins: that is where most people live, where they obtain their water, where all anadromous fish must pass if they are to make their way upstream, and where the major transportation routes cross. These are also sites where sediment is likely to accumulate. The Washington method considers watersheds smaller than 200 km^2, and the Federal Interagency method evaluates watersheds of 50 to 500 km^2; neither method consistently includes the downstream areas of most concern.

In addition, a broad enough time scale must be evaluated if the potential for accumulation of impacts is to be recognized. In the Waipaoa case, for example, impacts were relatively minor during the years immediately following deforestation; aggradation was not evident until after a major storm had occurred. In the South Fork of Caspar Creek, the influences of logging on sediment yield and runoff were thought to have largely disappeared within a decade. However, during the 1997-98 winter, three decades after road construction, destabilization of old roads has led to an increase in landslide frequency (Cafferata and Spittler, these proceedings). It is possible that a major sediment-related impact from the past land-use activities is yet to come. In any case, the success of a land-use activity in avoiding impacts is not fully tested until the occurrence of a very wet winter, a major storm, a protracted drought, and other rare—but expected—events.

Of particular concern in the evaluation of future impacts is the potential for interactions between different mechanisms of change. In the Waipaoa case, for example, hydrologic changes contributed to a severe increase in flood hazard less because of their direct influence on downstream peak-flow discharges than because they accelerated erosion, thus leading to aggradation and decreased channel capacity. In retrospect such a change is clearly visible; in prospect, it would be difficult to anticipate. In other cases, unrelated changes combine to aggravate a particular impact. Over-winter survival of coho salmon may be decreased by simplification of in-stream habitat due to increased sediment loading at the same time that access to downstream off-channel refuges is blocked by construction of floodplain roads and levees. The overall effect might be a severe decrease in out-migrants, whereas if only one of the impacts had occurred, populations might have partially compensated for the change by using the remaining habitat option more heavily. In both of these cases, the implications of changes might best be recognized by evaluating impacts from the point of view of the impacted resource rather than from the point of view of the impacting land use. Such an approach allows consideration of the variety of influences present throughout the time frame and area important to the impacted entity. Analysis would then automatically consider interactions between the activity of interest and other influences, rather than focusing implicitly on the direct influence of the activity in question.

The overall importance of an environmental change can be interpreted only relative to an unchanged state. In areas as pervasively altered as northwest California and New Zealand, examples of unchanged sites are few. Three strategies can be used to estimate levels of change in such a situation. First, original conditions can be inferred from the nature of existing conditions and influences. No road-related sediment sources would have been present under natural conditions, for example, and the influence of modified riparian stand composition on woody debris inputs can be readily estimated. Second, less disturbed sites can be compared with more disturbed sites to identify the trend of change, even if the end point of "undisturbed" is not present. Third, information from analogous undisturbed sites elsewhere can often be used to provide an estimate of undisturbed conditions if it can be shown that those sites are similar enough to the area in question to be reasonable analogs.

Once existing impacts are recognized and their causal mechanisms understood, the potential influence of planned activities can be inferred from an understanding of how those activities might influence the causal mechanisms.

Neither of the widely used watershed analysis methods provides an adequate assessment of likely cumulative effects of planned projects, and neither makes consistent use of a variety of methods that might be used to do so. However, both approaches are instructive in their call for interdisciplinary analysis and their recognition that process interactions must be evaluated over large areas if their significance is to be understood. At this point it should be possible to learn enough from the record of completed analyses to design a watershed analysis approach that will provide the kinds of information necessary to evaluate cumulative impacts, and thus to understand specific systems well enough to plan land-use activities to prevent future impacts.

Conclusions

Understanding of cumulative watershed impacts has increased greatly in the past 10 years, but the remaining problems are difficult ones. Existing impacts must be evaluated so that causal mechanisms are understood well enough that they can be reversed, and regulatory strategies must be modified to facilitate the recovery of damaged systems. Methods implemented to date have fallen short of this goal, but growing concern over existing cumulative impacts suggests that changes will need to be made soon.

References

Allsop, F. 1973. The story of Mangatu. Wellington, New Zealand: Government Printer.

CDF [California Department of Forestry and Fire Protection]. 1998. Forest practice rules. Sacramento, CA: California Department of Forestry and Fire Protection.

Cline, R.; Cole, G.; Megahan, W.; Patten, R.; Potyondy, J. 1981. Guide for predicting sediment yields from forested watersheds. [Missoula?, MT]: Northern Region and Intermountain Region, Forest Service, U.S. Department of Agriculture.

Collins, Brian D.; Pess, George R. 1997a. Evaluation of forest practices prescriptions from Washington's watershed analysis program. Journal of the American Water Resources Association 33(5): 969-996.

Collins, Brian D.; Pess, George R. 1997b. Critique of Washington's watershed analysis program. Journal of the American Water Resources Association 33(5): 997-1010.

Komar, James. 1992. Zero net increase: a new goal in timberland management on granitic soils. In: Sommarstrom, Sari, editor. Proceedings of the conference on decomposed granitic soils: problems and solutions; October 21-23, 1992; Redding, CA. Davis, CA: University Extension, University of California; 84-91.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. North American Journal of Fisheries Management 7(1): 34-45.

Madej, M.A.; Ozaki, V. 1996. Channel response to sediment wave propagation and movement, Redwood Creek, California, USA. Earth Surface Processes and Landforms 21: 911-927.

Pacific Watershed Associates. 1998. Sediment source investigation and sediment reduction plan for the Bear Creek watershed, Humboldt County, California. Report prepared for the Pacific Lumber Company, Scotia, California.

Regional Ecosystem Office. 1995. Ecosystem analysis at the watershed scale, version 2.2. Portland, OR: Regional Ecosystem Office. US Government Printing Office 1995-689-120/21215 Region no. 10.

Reid, L.M. 1993. Research and cumulative watershed effects. Gen. Tech. Rep. PSW-GTR-141. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.

Scott, Ralph G.; Buer, Koll Y. 1983. South Fork Eel Watershed Erosion Investigation. California Department of Water Resources, Northern District.

Stowell, R.; Espinosa, A.; Bjornn, T.C.; Platts, W.S.; Burns, D.C.; Irving, J.S. 1983. Guide to predicting salmonid response to sediment yields in Idaho Batholith watersheds. [Missoula?, MT]: Northern Region and Intermountain Region, Forest Service, U.S. Department of Agriculture.

Thomas, Robert B. 1990. Problems in determining the return of a watershed to pretreatment conditions: techniques applied to a study at Caspar Creek, California. Water Resources Research 26(9): 2079-2087.

USDA and USDI [United States Department of Agriculture and United States Department of the Interior]. 1994. Record of Decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl; Standards and Guidelines for management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. U.S. Government Printing Office 1994 - 589-111/00001 Region no. 10.

USDA Forest Service [U.S. Department of Agriculture, Forest Service]. 1988. Cumulative off-site watershed effects analysis. Forest Service Handbook 2509.22. Soil and water conservation handbook. San Francisco, CA: Region 5, Forest Service, U.S. Department of Agriculture.

Washington Forest Practices Board. 1995. Standard methodology for conducting watershed analysis under Chapter 222-22 WAC. Version 3.0. Olympia, WA: Forest Practices Division, Department of Natural Resources.

Ziemer, R.R.; Lewis, J.; Rice, R.M.; Lisle, T.E. 1991. Modeling the cumulative watershed effects of forest management strategies. Journal of Environmental Quality 20(1): 36-42.

[1] *Originally published in: Ziemer, Robert R., technical coordinator. 1998. Proceedings of the conference on coastal watersheds: the Caspar Creek Story; 6 May 1998; Gen. Tech. Rep. PSW-GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 149 p .http://www.psw.fs.fed.us/Tech_Pub/Documents/gtr-168/gtr168-toc.html*

The Continuum...Continued from Page 3

collaborative learning system on the dynamics, ecology and human interaction with watersheds, the underlying framework for organizing the ideas, resources and people involved transcends the subject matter. Rather than confine knowledge and learning about watersheds within boundaries, this project provides open doorways to link in new information and learner/experts.

What is the opportunity?

A decade ago, if somebody talked about "hyperlinking toward consilience," few listeners would have had a clue what it was about. Common experience since the advent of television in the 1950s and the World Wide Web since 1994 has reinforced a collective notion that instant, graphically realistic information about any subject can be made available, and that it might be possible to tie it all together to make sense; moving toward consilience. The soil has been prepared for the Continuum Project.

Electronic documents and other digital educational materials need to be organized by context. A rich array of resources about watershed ecology and management, including people with great wisdom and knowledge, is available freely in the world, poised to be made available via computers and the Internet. Texts and research that has lain dormant for decades can be displayed on a screen at the press of a button. Digital video can take us places and show us things with a level of realism and detail that, while not quite the same as a rainy-day climb into the canopy of an old-growth forest, is more comfortable and probably more accessible. But this mass of material is organized in chunks, rather than as a whole. The work of reconciling the knowledge and efforts of multiple disciplines remains to be done. The map of key concepts in the realm of the watershed needs to be overlaid on the knowledge base.

New multimedia technologies make content more accessible. The advent of broadband communications, digital video and streaming content mean that the richness and absolute volume of information that can be shared is far greater than ever before. An expert explanation on video, coupled with supporting scientific papers, rich sources of data collected over time, and opportunities for interactive dialog can all be co-located in the same virtual space, linked by place and conceptual context.

New content organization and delivery systems are available. Standards are maturing for structuring information resources and human interactions so they may be cataloged, searched, and shared, even though the individual components and participants are in many different locations.

Continues on Page 38

Cumulative Watershed Effects: Status, Gaps and Needs

September 7-8, 2000, Sacramento

On September 7 and 8, 2000 over 150 people gathered in Sacramento to discuss cumulative watershed effects (CWE) at a conference entitled Cumulative Watershed Effects: Status, Gaps and Needs. Specifics on the agenda and "proceedings" from the conference and the conference organizing group are available at http://www.cnr.berkeley.edu/forestry/watershed.html. This article summarizes aspects of the conference.

The stated goal of the conference was to—
- Further the dialogue on developing better ways to assess and manage Cumulative Watershed Effects, especially in forested, mixed-ownership watersheds in California

Conference objectives included—
- Summarize current issues and information on CWE assessment and management
- Exchange perspectives on CWE assessment and management, and identify similarities and differences among philosophies and approaches to CWE assessment
- Identify logical next steps for advancing CWE assessment and management

Desired outcomes were—
- Post-conference proceedings including Resource Guide
- Agreement among participants on next steps (e.g., form a working group to continue the dialogue by addressing specific policy and technical issues)
- Agreement on conceptual framework on assessing CWE

Was the conference goal achieved? In a word, yes. This conference re-affirmed the continuing diversity of opinions on CWE assessment and offered promise for improved approaches to address the topic. However, no silver bullets for managing CWE were identified.

Achievement of the objectives and desired outcomes was less easy to assess. A variety of presentations were made on relevant topics by academics, agency and industry representatives, and the public. This was not a "how to" meeting, rather the focus was on steps to take to address CWE. "Conceptual frameworks" and multiple-step procedures were described as guidance for CWE assessment. These frameworks differed in detail but participants affirmed the general utility of a conceptual framework, coupled with a toolbox of techniques to address more specific CWE issues.

A variety of "next steps" were proposed. Partly because the conference was not aimed at tools and techniques, participants advocated discussion of specific assessment methods. Requests in this area included:
- "Workshop discussing technical approaches to quantify different types of uncertainty in watershed analysis and CWE."
- "... how to predict CE's and more importantly to predict thresholds of concern."
- "What about tackling some of the basic and fundamental measurements we need to do CWEs? Gauging stations, sediment measurements ..."
- "How do we do watershed analysis/CWE analysis in real on-the-ground items?"

Other requests were:
- "...[to] develop a multi-disciplinary team to develop a CWE process and conduct pilot."
- "... to talk more openly about the ETHICS. Less about technical aspects."
- "... address CWE analysis in urban and mixed-land use watersheds."
- " ... provide some kind of funding for technical assistance for residence or stakeholders in watershed analysis ..."

Since the conference the organizing group continues to meet and has morphed into an informal action committee. This group is exploring options to formalize an interagency work group to tackle next steps, including the possible sponsorship of a pilot demonstration project for interagency CWE assessment. Notes from meetings of that group will be available on an expanded version of the "conference" website.

Specific products from the conference include a Resource Guide incorporating a listing of relevant web sites, an extensive bibliography, and a networking list of participants, their contact information and their area of CWE interest and expertise. Abstracts and/or multi-page texts are given for most presentations. This conference was unusual in capturing the real-time essence of the meeting through artwork. Words and ideas were visually encapsulated providing focus and a level playing field for all participants. The artwork on the web site replicates the real-time proceedings.

CWE Issues

Discussions identified a broad range of related issues that together add complexity (what's new?) to assessment of CWE. These issues include:
- Relationship between CWE assessment and other analyses (e.g., watershed, roads, watershed condition)
- Multi-scale considerations, in both time and space
- Data inadequacies—variability, accuracy, areal coverage (or the flip-side: too much data)
- Interpretation inadequacies
- Who does the analysis (e.g., is the small landowner the appropriate entity to conduct a CWE assessment?)
- Collaboration/stakeholder involvement
- Decision making and uncertainty
- Conflicting beneficial uses
- Onsite/offsite recovery rates
- Uncertainty re past disturbances and routing of watershed products
- (In)adequacy of BMPs

Many of these issues were concretely described in a panel discussion on Freshwater Creek. In particular uncertainties about determining the true implications of an action, especially in light of potential legacy effects from previous actions, were questioned.

Conceptual Framework

One approach for dealing with many of these issues is to systematically follow an agreed-upon sequence of steps for CWE assessment. One candidate sequence was offered by Lee MacDonald. This "conceptual framework" is similar to others proposed for related assessments and includes scoping, analysis and management phases in an iterative processes that feeds back to earlier steps (as needed).

The scoping phase should—

- Identify issues and resources of primary concern
- Define the temporal and spatial scale for the assessment
- Identify the relative magnitude of risk to each resource
- Select the appropriate level of effort for the assessment

The analysis phase should—

- Identify key cause-and-effect mechanisms
- Estimate the range of natural variability and relative condition for the resource(s) of concern
- Identify past, present, and future activities
- Evaluate the relative impact of past, present and expected future activities
- Evaluate the validity and sensitivity of the predicted CE

The management phase should—

- Identify possibilities for modification, mitigation, planning and restoration
- Identify key data gaps and monitoring needs

Going in the Right Direction

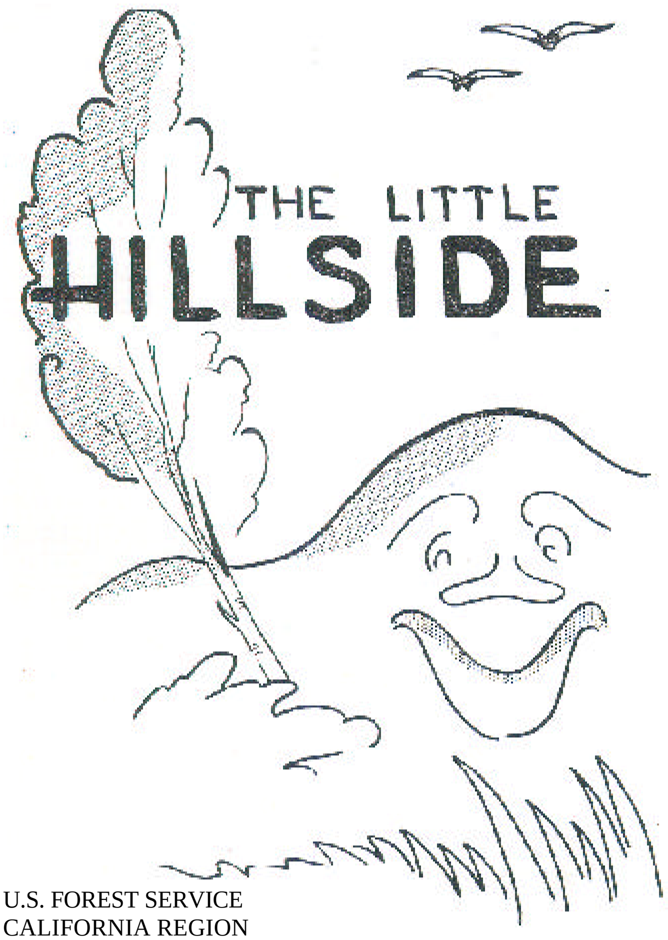
Our institutions are accelerating efforts to address watershed-scale issues. Watershed information systems are now beginning to appear and the state is funding the establishment of a data clearinghouse for the north coast. Analytical tools that combine in a single system data collected from a myriad of sources are coming on line and offer the promise for assessment of disparate conditions. Dramatic funding increases at the state level are evident in increased staffing of Regional Boards and for landowner incentives. Regulatory gaps are being filled and local solutions are occurring. “All-party monitoring” and other collaborative approaches can be mechanisms for successfully incorporating diverse perspectives and assuring that local projects will be responsive to concerns of diverse stakeholders.

In summary, in the 30 years since NEPA and CEQA were crafted, we have figured out when cumulative impacts assessments are required, and have established procedures for review with a paperwork trail to satisfy legal requirements in the record of decision. But we are still searching for appropriate analysis methods to measure and predict cumulative impacts. This doesn’t mean that we haven’t tried. CWE and watershed analyses are not panaceas; science and policy are iterative processes that have advanced since NEPA and CEQA were enacted.

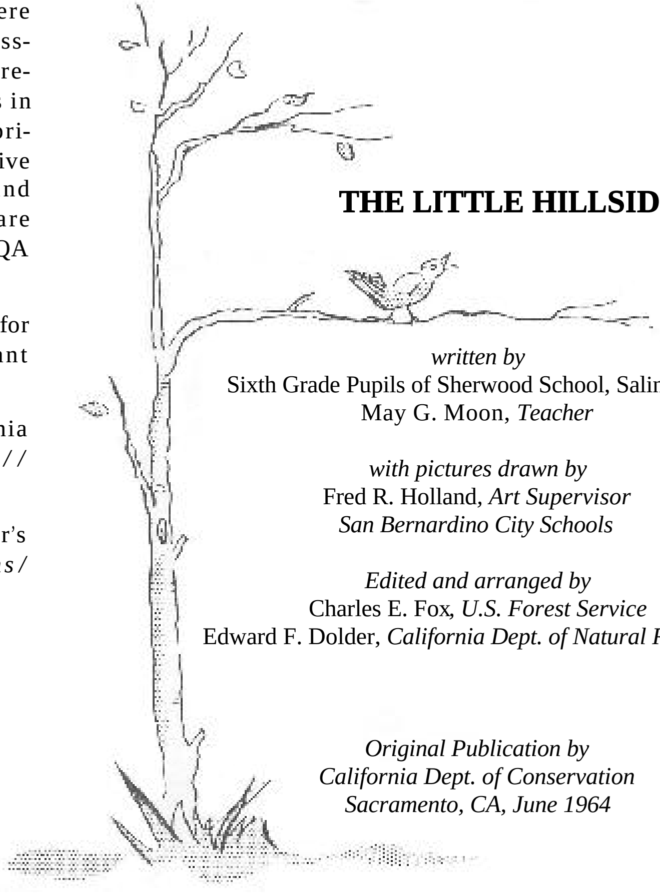
The conference website is the place to go to fill in the flesh for the topics only touched on in this summary. Two other relevant documents are the 1999 publications—

- “Report of the Scientific Review Panel on California Forest Practice Rules and Salmonid Habitat”: *http://www.ceres.ca.gov/cra/download_srp.html*, and
- “Cumulative Impacts Analysis - A Report of CDF Director’s THP Task Force”: *http:frap.cdf.ca.gov/publications/cumin.pdf*

> "A nation deprived of its liberty may win it; a nation divided may reunite; but a nation whose natural resources are destroyed must inevitably pay the penalty of poverty, degradation and decay."
>
> - Gifford Pinchot



U.S. FOREST SERVICE
CALIFORNIA REGION
in cooperation with
CALIFORNIA DEPARTMENT OF CONSERVATION



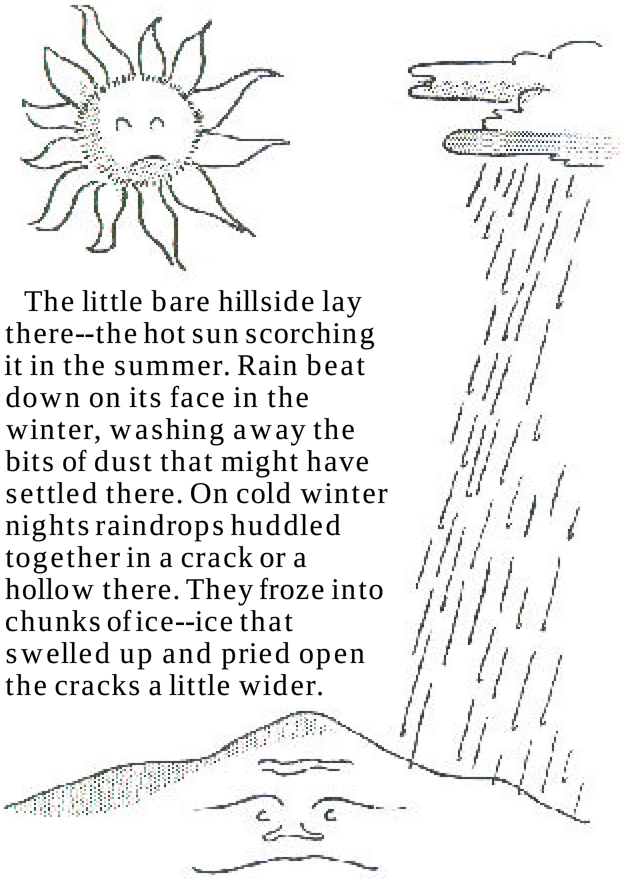
THE LITTLE HILLSIDE

written by
Sixth Grade Pupils of Sherwood School, Salinas, CA
May G. Moon, *Teacher*

with pictures drawn by
Fred R. Holland, *Art Supervisor*
San Bernardino City Schools

Edited and arranged by
Charles E. Fox, *U.S. Forest Service*
Edward F. Dolder, *California Dept. of Natural Resources*

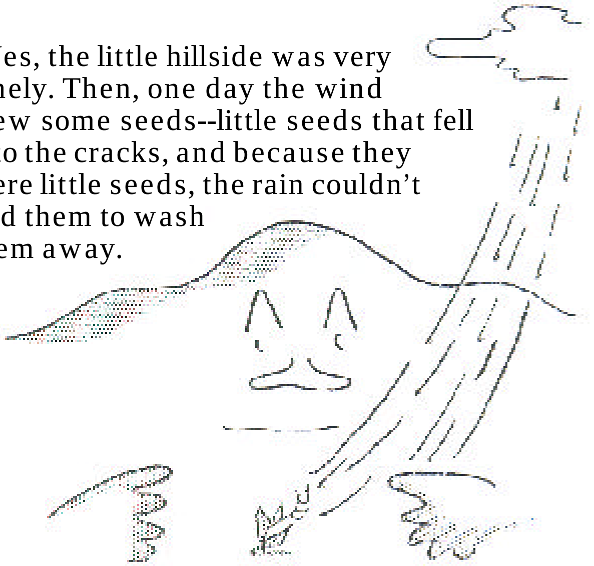
Original Publication by
California Dept. of Conservation
Sacramento, CA, June 1964



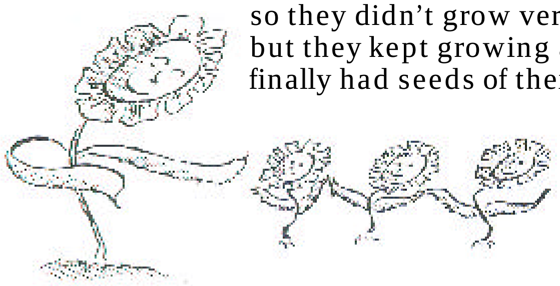
The little bare hillside lay there--the hot sun scorching it in the summer. Rain beat down on its face in the winter, washing away the bits of dust that might have settled there. On cold winter nights raindrops huddled together in a crack or a hollow there. They froze into chunks of ice--ice that swelled up and pried open the cracks a little wider.

It was a lonely little hillside--no grass, no flowers, no trees. You see, there was no soil--no soil to hold the seeds, no soil for their roots, and no soil to hold water for plants to drink!

Yes, the little hillside was very lonely. Then, one day the wind blew some seeds--little seeds that fell into the cracks, and because they were little seeds, the rain couldn't find them to wash them away.



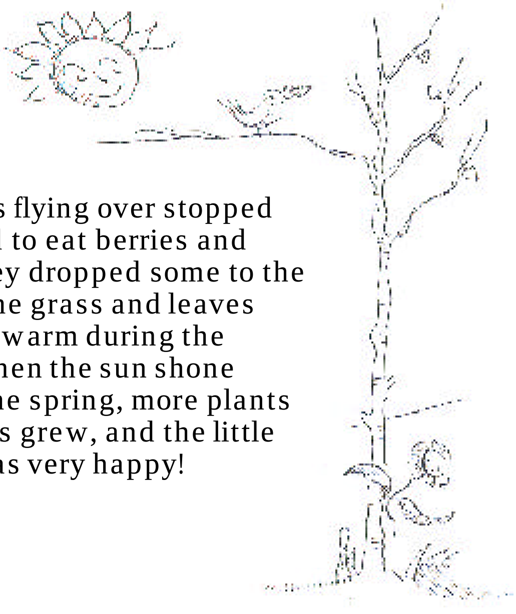
When the warm rains came in the spring, the little seeds grew into plants. The plants didn't have much food and they didn't have much water, so they didn't grow very big, but they kept growing and finally had seeds of their own.



When winter came and the plants went to sleep, the mother plants made a bed for the baby seeds and held them close. When the rains came, the stems and leaves and roots of the baby plants, even though they were small, held a little of the rain. Then, when they had more food and water, they grew larger and had more baby seeds. Every year they grew larger and stronger, and their roots went down farther.

One day the wind brought some cottonwood seeds flying over the hills. Because the plants had made a good place for seeds to rest, the cottonwood seeds stopped and decided to stay.

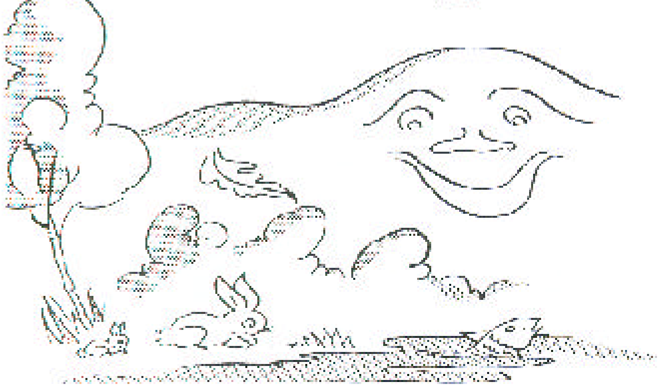
The next year, little cottonwood trees started growing. The little hillside felt much better now. It was not lonely any more.



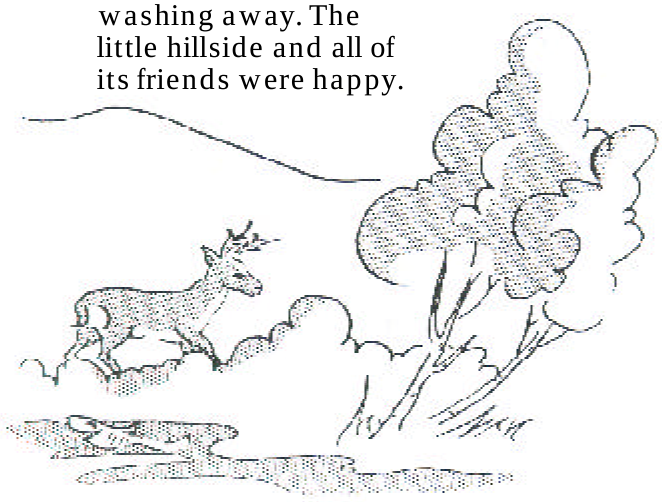
The birds flying over stopped to rest and to eat berries and seeds. They dropped some to the ground. The grass and leaves held them warm during the winter. When the sun shone warm in the spring, more plants and berries grew, and the little hillside was very happy!

The stems and leaves and roots of the plants held the rain. The rain stayed on the hillside instead of flowing away. All summer a little stream of water trickled down the hillside giving a drink to the thirsty grass and flowers and trees when the sun was hot.

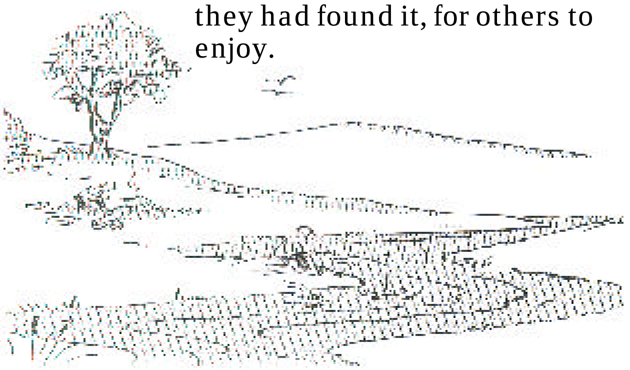
The birds told the animals about the lovely hillside and the cool stream and the pleasant shade. Many animals came to see--mother deer with their baby fawns, little squirrels and rabbits, and animals that dug homes in the soil and stored their food. Fish came to live in the cool stream.



The leaves fell and they made more rich soil. Roots held the soil and kept it from washing away. The little hillside and all of its friends were happy.

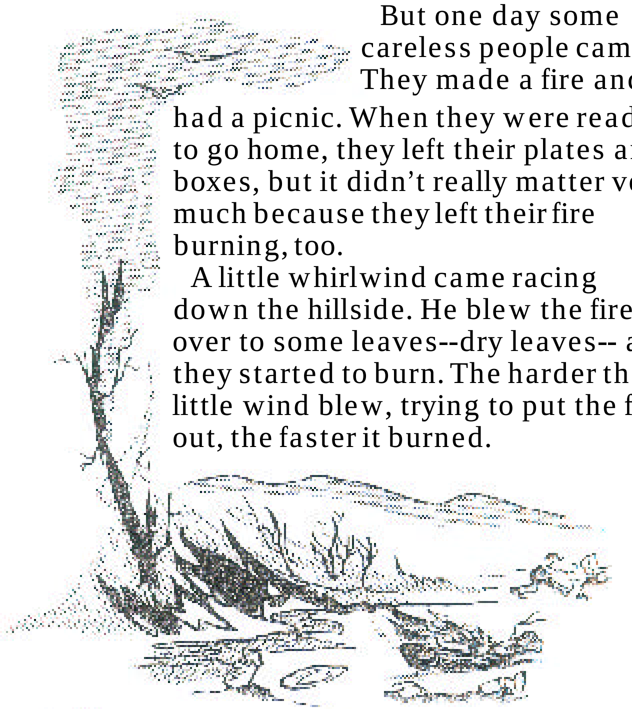


Then people found the little valley by the little hillside, with the flowers and the stream and the fish and the deer. Most of the people were very thoughtful. They enjoyed the shade and the flowers and the cool water. They ate their lunches on the green grass beside the cool stream. They picked up their trash and papers and left the little valley as clean as they had found it, for others to enjoy.



But one day some careless people came. They made a fire and had a picnic. When they were ready to go home, they left their plates and boxes, but it didn't really matter very much because they left their fire burning, too.

A little whirlwind came racing down the hillside. He blew the fire over to some leaves--dry leaves-- and they started to burn. The harder the little wind blew, trying to put the fire out, the faster it burned.

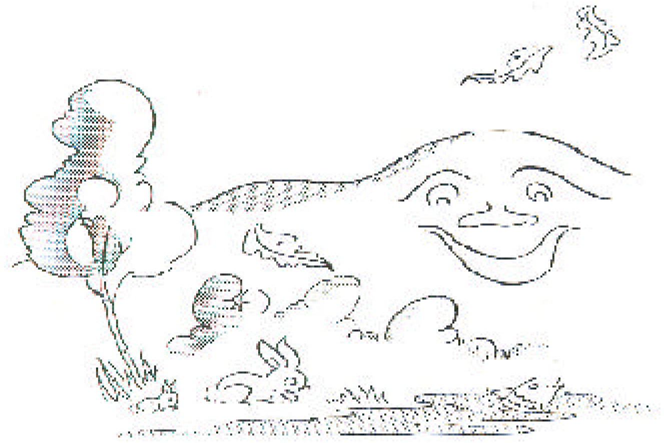


The next day the little hillside was very sad. The trees were gone, the grass and the flowers were gone. All of the birds and animals were gone. The little hillside knew the sun would beat down hot in the summer.

One day some boys and girls saw

the little hillside. They told their teacher how bare and unhappy it looked. The teacher decided to do something. She ordered little trees from the California State Forester in Sacramento. She bought some grass seed. Each pupil brought ten cents to pay for the trees and the seed.

They decided to plant the trees in late autumn.



Then the winter rains would help them grow. So one day they all went out to the little hillside. They planted the trees and sowed the grass. How happy this made the little hillside! The boys and girls were happy, too. They had planted a forest. It would grow, and after many years, other boys and girls would hold picnics there.

The Continuum...Continued from Page 33

What problem do we intend to solve?

The tendency of the physical and social sciences and the humanities to break knowledge into its component parts, and to focus intently in areas of specialization, has led to tremendous advances in understanding – of parts, at the expense of the whole. The essential problem the Continuum Project addresses is the subject of the ancient Parable of the Blind Men and the Elephant... each “saw” the elephant based on their limited experiences. To understand watersheds and to better understand the different perspectives on their management, we need to connect knowledge across disciplines.

Professionals need incentives to continue learning, to broaden their knowledge continually, and to provide leadership in forming a better collective understanding of watersheds.

Whether it is due to lack of time or competition for attention, most people don’t read much. Most professionals engaged in watershed management can’t keep up with the volume of available research and literature. A method for rapidly and effectively disseminating information among professionals is needed that is engaging enough to attract a larger percentage of the audience than printed materials do now.

Society now expects Land management policy decisions to be effectively informed by applicable scientific findings; and that land managers will take scientific approaches to the complex decisions they make and implement. To be more effective in this, experts are needed to filter and synthesize the large body of literature available; selecting, adapting, and interpreting it for land managers.

How do we intend to solve it?

By mapping key concepts in watershed ecology, and linking them within and across the disciplines they involve, the Continuum Project provides a visually exciting, multiple-entry resource for professional development. It is comfortable for self-paced learners, and provides a resource for teachers developing structured, outcome-based instruction.

Just as modern maps are continually evolving documents with multiple layers, the “mapping” of concepts, vocabularies and the relationships between things in the Continuum Project is open and changeable. The overall “ontology,” or concept structure, for the project incorporates existing taxonomies and thesauri, using new standards such as the Resource Description Framework and other metadata standards to make resources sharable, and new tools such as Protégé for collectively developing ontologies.

The concept map underlying the Continuum Project is visually represented in several ways. A two-dimensional landscape navigable by the user offers “points of interest” linked to multimedia and interactive resources, overlaid on geographic maps of real watersheds. Similarly, a two-dimensional map of concepts allows users to explore related ideas and resources.

Each of these interfaces to the Continuum content allows the user to “zoom” into selected subsets of information resources, which may be perceived as organized collections or as guided pathways (courses) to learning. At each point of interest the user may zoom in to explore greater detail, or zoom out to see a broader view.

The “zooming” approach to navigation departs from the more restrictive but generally familiar “desktop” metaphor that combines pull-down menus, buttons and windows. Instead it provides a surrogate for the “real world,” by structuring information spatially, showing greater detail as a user zooms “closer” to an object, and giving greater perspective (but less detail) as the user zooms farther away. In addition, the zooming user interface (ZUI) reduces the individual steps a user must take to reach an objective, providing a simpler, friendlier navigation system.

Using the geographic landscape view, a user may “zoom” across a watershed, and might take a prearranged tour. Starting in the headwaters, the tour takes a step-by-step walk through the channel continuum, all the way to the confluence of the channel with a major waterbody. This tour is repeated at a number of different sites to show the diversity of channel processes and morphologies in different settings, and with differing degrees and histories of land management practices.

This interactive visual tour of stream channels helps to demonstrate the broad natural variability of stream channels along the river continuum (headwaters to mouth of a stream system). An improved understanding of the evolution of channel form and processes from the headwaters to the mouth of the river will be extremely valuable to managers and regulators working on stream buffer-strip designs and riparian management prescriptions.

A textual search capability allows a familiar research method for users who have specific objectives and are less inclined to use the zooming interface.

Resources contributed to the Continuum Project are cataloged using state-of-the-art standards for content-description and content-sharing via the Internet. The first version of the Continuum (on CD-ROM) is a visual jumping-off point for links to data and resources that adhere to these same open standards.✍

The Continuum core team is currently: Andy Alm, Thomas Dunklin, Michael Furniss, Jeff Guntle, Shaun McFarland, Riley Quarles, Michael Penney, Terry Roelofs, Bill Trush, and Judy Wartella. Funding is provided by USDA-Forest Service and the California Department of Forestry and Fire Protection. If you would like to participate or learn more, contact Michael Furniss at:

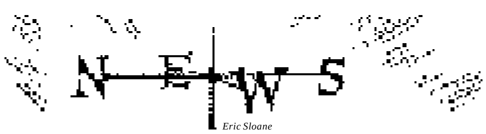
Tributaries

by Clay Brandow
tributaries@yahoo.com

Tributaries, formerly Name Stream and Tributaries, is a column dedicated to covering events and accomplishments in the lives of individuals working in watershed. Keeping up with your fellow watersheders is not only fun, but it is also an important part of networking.

This time I'd like to take a moment to reflect on watershed networking and the origins of the Watershed Management Council. Email and the Internet are such important tools for most us these days; it's hard to remember what life was like a couple decades ago, before instant, convenient messaging and information on demand from thousands of sources. Back then, isolation, both geographic and professional, was a problem for many watershed professionals and advocates.

In the 1970's many entities and agencies had added a few folks in fields related to watershed management, but their own management was still dominated by one or two professions. A lot of agencies that had added watershed professionals weren't sure what to do these odd-ducks. That put many of us in the awkward, sometimes frustrating, sometimes lonely, position being both watershed practitioners and sole watershed advocates. In those early years, my own way of dealing with these feelings of isolation and frustration was through writing long letters to a few longtime friends and mentors, in longhand no less. I told you it was a long time ago.



Then came the earliest forms of email. My first exposure to it was in the form of the Forest Service's Data General (DG) system about 1985. The frequency of my communication with friends and mentors within the Forest Service increased dramatically. This helped more. But, still my view of the watershed world was limited.

Then shortly thereafter the first conference of what later became Watershed Management Council (WMC) was held in November 1986. Volume 1, number 1 of the Watershed Management Council Newsletter (now known as the Watershed Networker) was published in November 1987. The WMC Bylaws were adopted in August 1988. The advent of WMC immediately widened my perspective, exposing me and other members to people we would never have met, ideas we would not have encountered, and career opportunities we might not have considered. And within a very short time, these new people, ideas and opportunities were made more accessible via the Internet. First, through universal email, not bounded by agency or entity. Second, through the World Wide Web.

As WMC grows and the membership diversifies, the promise of new people to meet, new ideas to consider, and new places to practice the art and science of watershed management continues and builds. At a WMC conference or field meeting, you can meet:

- A private consultant from Washington State
- A community organizer form Oregon
- A watershed professor form Colorado
- An extension specialist from Nevada
- A municipal watershed manager from northern California
- A county watershed planner from southern California
- A federal land manager from New Mexico
- A researcher form Idaho
- A lobbyist from Washington, D.C.
- Land owners and managers,
- Advocates and interested citizens
- Professionals and technicians
- And, a myriad of other folks from a variety places all interested in watershed management.

Here is the bottom line. Even in this highly networked world we now live in, WMC can help you expand your personal watershed network, and help you be more successful and happier at what you do best to promote the art and science of watershed management. If you are not a member yet, please join. If you are a WMC member please consider becoming more active in the organization.

And remember, if you've reached a watershed in your career or have an interesting tidbit of watershed news, let your colleagues know about it. Drop a line to Tributaries, c/o Clay Brandow, 1528 Brown Drive, Davis, CA 95616, or call me at (916) 653-0719. Internet email is best. Email me at: clay_brandow@fire.ca.gov or tributariesyahoo.com

Cumulative Watershed Effects

MEMBERSHIP ENROLLMENT

Name ______________________________________

Address ____________________________________

State ______________________________________

Affliation

Phone No.

e-mail

☐ **$20 Regular Member** ☐ **$10 Student**
☐ **$50 Institutional** ☐ **$250 Donor**
☐ **$30 Outside the U.S.**
☐ **_____ Years @ $______/year = $_____________**

Membership dues are for 1 year. Non-profit institutional members receive 5 copies of each newsletter. The WMC is a non-profit organization. All members receive subscriptions to WMC publications, discounts on conference fees, and full voting rights. Mail this form with your check to:

WATERSHED MANAGEMENT COUNCIL
c/o PSRP
University of California at Davis
One Shields Ave
Davis, CA 95616

Inside...

“Of all celestial bodies within reach or view...the most wonderful and marvelous and mysterious is turning out to be our own planet earth. It is the strangest of all places, and there is everything in the world to learn about it. It can keep us awake and jubilant with questions for millennia ahead, if we can learn not to meddle and not to destroy.”

-Lewis Thomas, *Late Night Thoughts on Listening to Mahler’s Ninth.* 1984

WATERSHED MANAGEMENT COUNCIL
c/o PSRP
University of California at Davis
One Shields Ave
Davis, CA 95616

Non-Profit Org.
US Postage PAID
Davis, CA
Permit No. 174

Address Correction Requested