Cumulative Watershed Effects: Caspar Creek and Beyond[1]

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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.*

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. 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,

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?*

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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 blow-down 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 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 2205-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 altered 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

***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	2,205
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^{-1})	5,000	7,500
Original vegetation	Redwood, Douglas-fir, hardwood, grassland	Podocarp conifers, southern beech hardwoods, bracken scrub
Current vegetation	Redwood, Douglas-fir, hardwood, grassland	Grassland; some reforestation of Monterey pines
Current land use	Logging, ranching	Sheep farming

[1] Information primarily from Scott and Buer (1983)

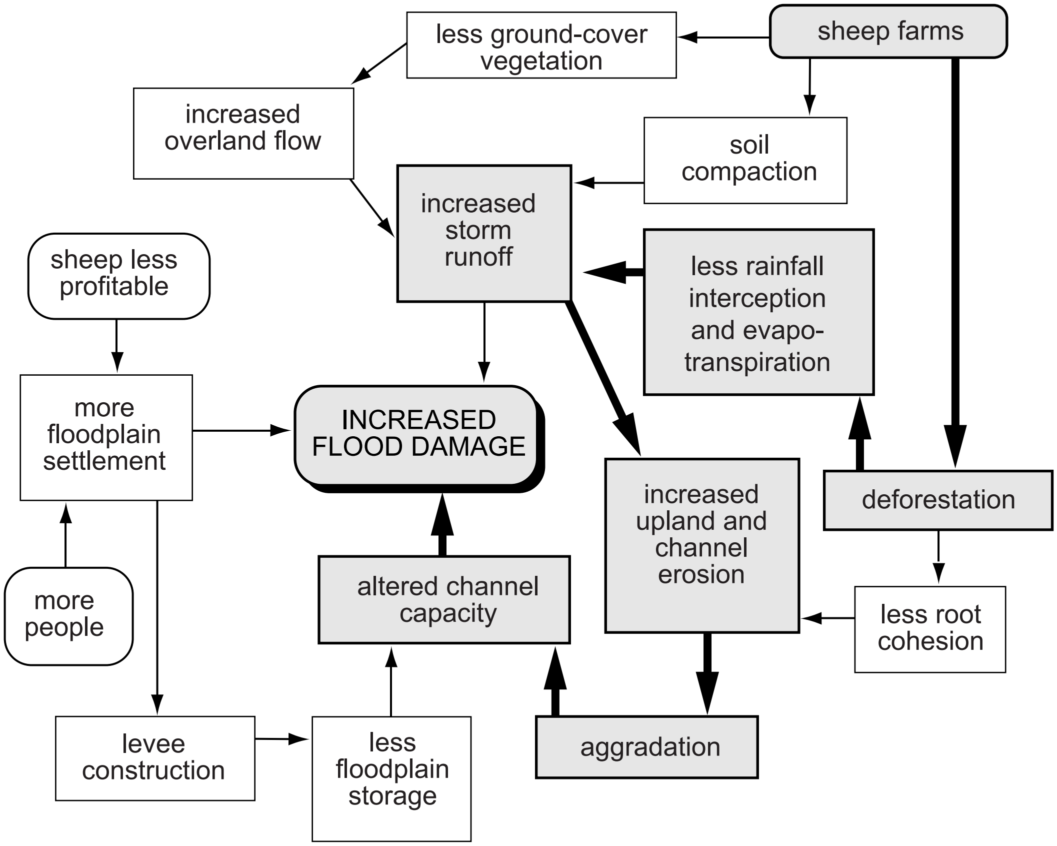

Figure 1—Factors influencing changes in flood hazard in the Waipaoa River basin, North Island, New Zealand. Bold lines and shaded boxes indicate the likely primary mechanism of influence.

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 downslope 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 in the expression of impacts over large areas. Deforestation began in the 1870's, but the first serious impacts were not experienced until about 1900. Although deforestation had approached its maximum extent by 1920, impacts were still accumulating; Whatatutu was not relocated until 15 years later. A large portion of the most severely affected area began to be reforested by 1970, yet downstream aggradation continues a quarter of a century later. Once the hillslope conditions had been altered enough to initiate the chain of impact mechanisms, 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 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 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 partly 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

***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 thresholds	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**

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.

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.

Several requirements for successful cumulative effects analysis are already evident from observations of existing cumulative impacts. First, 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.

Second, 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. Analysis must depend heavily on the recognition and understanding of likely trends of change, and of the likely influences of episodic events on those trends.

Third, the potential for interactions between different mechanisms of change is of particular concern. 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 coho production, 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.

Fourth, the overall importance of an environmental change can be fully 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.

Each of these problems is eminently solvable in any area, but solution requires expertise. Not only must the level of understanding within each disciplinary area be high enough to allow inference and creative problem-solving, but the interdisciplinary communication skills of each participant must be well-enough developed to allow the high level of interdisciplinary cooperation that is necessary to solve what is an inherently interdisciplinary problem.

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 the growing level of concern over existing cumulative impacts suggests that an opportunity is at hand to make useful changes in approach. Results from Caspar Creek and the Waipaoa River illustrate that no single method for controlling cumulative impacts is applicable to every kind of impact. Whatever approaches are adopted for controlling cumulative impacts in an area need to be founded on an understanding the impact mechanisms present in that area.

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. 1995-689-120/21215 Region no. 10. US Government Printing Office.

Reid, Leslie 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**. Northern District: California Department of Water Resources.

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**. 1994 - 589-111/00001 Region no. 10. U.S. Government Printing Office.

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.

WFPB [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.