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Cumulative Watershed Effects and Watershed Analysis

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Overview

• Cumulative watershed effects are environmental changes that are affected by more than one land-use activity and that are influenced by processes involving the generation or transport of water. Almost all environmental changes are cumulative effects, and almost all land-use activities contribute to cumulative effects.

• An understanding of cumulative watershed effects is necessary if land-use activities and restoration projects are to be designed that accomplish their intended objectives. Cumulative effects first must be evaluated to decide what actions are appropriate. The likely direct and indirect effects of the planned actions must then be assessed.

• Technical issues that complicate analysis of cumulative effects include the large spatial and temporal scales involved, the wide variety of processes and interactions that influence cumulative effects, and the lengthy lag-times that often separate a land-use activity and the landscape's response to that activity.

• Analysis strategies contain implicit assumptions about the role of humans on the landscape, the limits of responsibility, and how the natural world functions. Controversy over methods often revolves around philosophical differences concerning these assumptions.

• Cumulative effects analysis requires a nontraditional approach to information: patterns are usually more important than details; an interdisciplinary focus is more useful than multiple monodisciplinary foci; and a large area is more than the sum of its parts, so it must be evaluated as a unit.

• Ad hoc methods for evaluating cumulative effects are well developed and have been widely used for nearly a century. An ad hoc method is designed to address a particular kind of problem in a particular place and often cannot be applied elsewhere without modification.

• Standardized analysis methods were developed in the 1970s and 1980s to fulfill requirements of the National Environmental Policy Act, but most of these methods lack technical credibility or are limited in the kinds of problems they can address or the areas in which they can be applied. Examples include use of index values, mechanistic models, and checklists for applying expert judgment.

• More recently, methods of watershed analysis were developed to provide the background information needed for evaluating cumulative effects.

• The watershed analysis method employed in Washington state uses an understanding of past environmental changes to develop prescriptions for land-use practices, but it does not assess the likely cumulative effects of future activities.

• The ecosystem analysis method used on federal lands in much of the Pacific Northwest provides background information about ecosystem and landscape interactions that can be used for later cumulative effects assessment. when projects are being planned.

Introduction

In 1969 the US. Congress formally recognized that even if each land-use project is allowed to produce only a small environmental impact, enough small impacts can accumulate to have a large effect. This realization took the form of a requirement of the National Environmental Policy Act (NEPA) that the cumulative impacts of proposed actions be evaluated. The Council on Environmental Quality (CEQ) defined a *cumulative impact* (or *cumulative effect*) as:

"the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." (CEQ Guidelines, 40CFR 1508.7, issued 23 April 1971)

In practice, virtually every environmental impact is influenced by multiple land-use activities and is, therefore, a cumulative impact. Similarly, almost any change caused by a land-use activity contributes to a cumulative impact because it affects something that is also affected by other land-use changes. A cumulative impact thus is not a new type of impact. but is a new way of looking at the impacts that people have always confronted.

The CEQ definition is important because it implies that the severity of an impact must be judged from the point of view of the impacted party. Before this, the potential impact of a project could be evaluated in isolation. If a project was not going to produce very much sediment, for example, it probably was not going to have much of an impact. But now the context for the project would need to be examined. Even if a project did not itself produce enough sediment to fill in a reservoir, the incremental effect of the project could be significant if previous activities had already imperiled the reservoir. Or if the project was only one of a series of such projects, then its incremental addition could increase the severity of the projects' combined impact. In short, if the reservoir was filling in, then an impact was occurring, and any contribution to that impact would increase the severity of the impact.

A cumulative watershed effect is a special type of cumulative effect that is influenced by processes that involve the generation or transport of water. Clogging of spawning gravels by sediment from eroding road surfaces is considered a cumulative watershed impact, as is decreased woody debris in streams caused by upstream changes in forest composition. In each case, the change is influenced by water flowing through a watershed.

Cumulative effects are often perceived as a hazy concept that is important only because the law requires that they be analyzed before land-use plans are accepted. However, a basic understanding of cumulative effects is useful for many applications and is particularly necessary for designing projects or land-use strategies that are sustainable through time.

As an example, consider the problems described in Box 19.1. The first of these represents a relatively low-budget restoration effort on a local scale, while the second involves the design of a multimillion dollar program to be administered over a large region. Despite the difference in spatial and economic scales, the same kinds of information are needed to address both of these problems:

a. What areas are important for fish, and why?
b. Where has habitat been impaired?
c. What aspects of the habitat have changed?
d. What caused those changes?
e. What is the relative importance of the various habitat changes to fish?
f. What is the present trend of changes in the system?
g. Which changes are reversible?
h. What is the expected effectiveness of potential remedies?
i. What are the effects of those remedies on other land uses and ecosystem components?
j. What are the relative costs of the potential remedies over the long term?

Answers to these questions will provide most of the information needed for a decision about what actions in what areas will have the biggest return for the least effort. In both cases it is necessary to know what conditions were like in

Box 19.1. What Would You Do?

Problem l: You are the biologist responsible for deciding how to spend the $5,000 raised to improve anadromous fish habitat in the 250-km^2 Wilrick Creek system. What do you need to know to make the best deci-sions? List the types of information you would need.

Problem 2: You are the biologist responsible for deciding how to spend $2,200,100 earmarked by your agency for enhancing anadromous fish habitat in western Oregon. What do you need to know to make the best decisions? Again, list the information needed.

the past (*a*, *b*, *c*), how they have changed (*b, c, d*, *e*), and what they will be like in the future (*f, g, h, i, j*). These are the same questions that must be answered to evaluate cumulative effects. For both of the problems represented by Box 19.1, cumulative watershed effects need to be evaluated twice: once to determine what needs to be done and once to identify the effects of a proposed solution.

Now consider the projects described in Box 19.2. In each of these cases, project outcomes did not meet project objectives–something went wrong. These examples are typical of the kinds of misjudgments that result when people fail to look beyond the symptoms of a problem to evaluate its broader context. In Case 1, the resource specialists knew that they had a big problem – fish were dying - and they had a good supply of dynamite on hand for solving fish-habitat problems. They simply were not aware that the waterfall had its own constituency of interest groups; they had been trapped by monodisciplinary assumptions and failed to consider the broader context for their

Box 19.2. Less-Than-Perfect Projects

Case 1: Fisheries biologists were about to dynamite a small cascade on a popular recreation river to decrease fishing pressure on migrating steelhead: fish would hold for awhile in the plungepool, thus increasing their vulnerability to anglers. The popular tourist vista and major draw for whitewater recreationists was spared because kayakers heard of the plans and protested.

Case 2: Thousands of dollars were spent to build structures on a floodplain to promote deposition and thus initiate revegetation of the floodplain. Because the structures were built in the path of a migrating meander, they were washed away during the first flood.

Case 3: Tens of thousands of dollars were spent to plant young alders across the face of an immense landslide to protect downstream salmon habitat. The slide failed again during the next storm, removing the alders.

Case 4: Hundreds of thousands of dollars have gone into carrying out detailed habitat inventories of stream channels in an area. After nearly a decade of inventory work, the first examination of the accumulating data showed that most of the variables being measured were not correlated with habitat use.

Case 5: Millions of dollars were spent to obliterate roads in the lower third of a watershed to prevent further aggradation of the channel. However, most of the sediment contributing to aggradation comes from upstream of the treated area.

proposed solution. Question *i* of the list (*What effect will those remedies have* on *other land uses* and *ecosystem components?*) had been overlooked.

Case 2 is more sophisticated. The vegetation experts saw the link between the physical process of deposition and their goal of revegetation, but their analysis was limited to conditions at the site of interest. They did not consider the broader spatial or temporal context for those conditions and so did not recognize the inevitability of the meander's migration. Questions *f* and *h* (*What* is *the present trend of changes? What is the expected effectiveness of remedies?*) had been ignored.

Case 3 introduces an additional facet of the context problem. Here, an ineffectual solution to the landslide problem was instituted, ignoring questions *f, g,* and *h* (*What is the present trend of changes? Which changes are reversible? What is the expected effectiveness of remedies?*). In addition, sediment was assumed to be a big problem because the landslide scar was large and visible. The actual importance of this sediment source, relative to others in the system, was not addressed before the solution was implemented. Question *e* (*What is the relative importance of the various changes?*) had been neglected.

The inventory in Case 4 was an attempt to provide information that specialists would need to restore fish habitat. Unfortunately, design of a reasonable inventory was impossible under the circumstances. Not enough was known about what variables were important in the area (questions *a* and *e: What areas are important for fish, and why? What is the relative importance of the various habitat changes to fish?*) and geomorphologists had not been consulted about what patterns and scales of variability to expect (questions *c, d,* and *f*: *What aspects of the habitat have changed? What caused those changes? What is the present trend of changes* in *the system?*). The mistake was not recognized sooner because the success of the project was measured by the length of channel inventoried rather than by the knowledge gained, so there was little motivation to turn numbers into knowledge. No one had been given the responsibility for looking at the results.

In Case 5, evaluation of the causes for change (question *d*) would have revealed that much of the source for the aggradation problem was upstream, and evaluation of question *h* (*What is the expected effectiveness of remedies?*) would have shown that the proposed solution would have little effect on the problem.

Each of these five efforts suffered from inattention to the context of the identified problem. Context also has been overlooked where restoration projects are designed to enhance summer habitat but the major constraint to fish survival is degraded winter habitat (Nickelson et al. 1992), where habitat improvement structures are built that cannot survive typical winter flows (Frissell and Nawa 1992), and when limited restoration money is spent to make small improvements in a few large sediment sources rather than to ensure that a thousand small sediment sources do not become large sources. These examples all involve aquatic habitat restoration, but parallels can be found in any aspect of wildland resource management.

Each of the projects described in Box 19.2 was designed to redress a cumulative watershed impact, but none of the projects incorporated an adequate analysis of the problem. Had these problems been evaluated to understand how the original impacts occurred and to identify the watershed-scale context for the impacts, most of these failures could have been avoided. Thus, an understanding of cumulative effects is important not just because it is an administrative requirement, but because it is essential for designing successful projects.

Problems in the Evaluation of Cumulative Watershed Effects

The concept behind cumulative watershed effects is a simple one: environmental impacts are influenced by multiple factors. However, this simple concept makes the evaluation of potential land-use impacts a difficult task. Not only is the problem technically difficult, but it is further complicated by lack of a common understanding of philosophical aspects of the problem and by analytical constraints imposed by societal value systems.

Technical Issues

Much of the difficulty of cumulative effects analysis arises from the large number of diverse biological and physical processes that influence most land-use impacts. Interactions between processes make it possible for impacts to accumulate through both space and time, they ensure that no single field of expertise can adequately address the cumulative effects problem. and they introduce time lags in the expression of impacts.

Consider the example described in Sidebar 19.3. In this case, increased stream temperature was identified as it cumulative watershed impact in the Pilot Creek watershed of northwestern California (USDA Forest Service 1994). Changes in riparian vegetation, channel form, and hydrologic regime arc all suspected of contributing to the impact, but the relative importance of these changes is unknown.

Land-use activities influencing the temperature regime in Pilot Creek include logging, roadbuilding, and fire control. These activities have occurred for a long time in many parts of the watershed and have contributed to environmental changes that accumulated through time. Stream temperatures probably changed as vegetation began to change in the 1850s, and further temperature changes accompanied riparian logging a hundred years later and

Box 19.3. Causes for Increased Temperatures in Pilot Creek

Pilot Creek drains an 80-km^2 watershed in the Coast Ranges of northwestern California. The stream has provided good trout fishing in the past, but recent surveys suggest that summer water temperatures along the main channel are higher than they would be under natural conditions. Evaluation of past and present conditions in the watershed disclosed several kinds of changes likely to have influenced water temperatures and identified potential causes for those changes (USDA Forest Service 1994):

1. Riparian forest cover has decreased (increasing solar heating)
   - Debris flows originating in logged areas destroyed vegetation.
   - Aggrading and widening channels destroyed vegetation.
   - The 1964 flood destroyed vegetation.
   - Logging along the main channel removed the original forest cover.
   - 7% of the watershed burned in 1987.
   - A possible decrease in summer flows may have stressed riparian vegetation.
2. The channel has aggraded and widened (making more water surface available to be heated)
   - Debris flows contributed sediment.
   - The 1964 storm produced sediment.
   - Long-term sources such as road surfaces and earthflows contribute sediment.
   - Reduced root cohesion in logged riparian areas accelerated bank erosion.
3. Summer flows may be lower than in the past (allowing the entire water column to warm more quickly)
   - Recently there have been more than 5 years of drought.
   - Reduction of fire frequency (since the end of burning by Native Americans in about 1850) has allowed conifers to encroach on grasslands, increasing summer evapotranspiration.
   - Aggradation in the channel forces part of the flow underground.
   - Broader channels increase rates of evaporation.
   - Decreased riparian cover increases evaporation.

upslope logging even more recently. But effects also accumulated through space. Upslope logging, the vegetation change, and logging of downstream riparian zones occurred in different parts of the watershed, yet they all affected temperatures in the same downstream channels.

Not only were several different activities involved, but multiple mechanisms for change were important: temperatures were affected by changes in hydrology, sedimentation, and vegetation. In addition, each of these mechanisms influenced the others. A change in erosion rate, for example, led to channel aggradation, which decreased surface flows by creating a porous substrate. Aggradation also contributed to the destruction of riparian vegetation. Because of the variety of these interacting changes, no single expert was capable of evaluating the issue. It took a fisheries biologist to recognize that temperature changes were important in the watershed; an anthropologist to identify long-term changes in fish abundance; an archeologist to recognize that vegetation had changed; a plant ecologist and a soil scientist to identify the extent of the vegetation change; and a geologist to evaluate changes in erosion rates and channel form.

Even with progressive changes occurring on the hillslopes, Pilot Creek did not change much until the floods of 1955 and 1964. The cumulative impacts of a hundred years of changing land use became visible only after two major storms had occurred. The storms would have happened in any case, but the changes wrought by the storms under disturbed conditions were very different from those that would have appeared under natural conditions. Indeed, large storms of the late 1800s, although similar in character, resulted in much less dramatic changes in the region (Harden 1995). A recent drought provides a similar example. Channel widening had reduced the water depth in the Mad River downstream of Pilot Creek, but normal water years still provided deep enough flow for chinook salmon (*Oncorhynchus tshawytscha*) to migrate upstream. During the drought, however, fish were blocked by shallow reaches (Ken Gallagher, Mad River Hatchery, Arcata, California, personal communication). The original channel form would have provided sufficient flow depth to allow passage even during droughts. Altered conditions that were tolerable during normal years thus were intolerable during the drought, and it became clear that conditions must be maintained at a level that provides a margin of safety even under the most severe stresses.

Time lags occur in the expression of cumulative watershed effects even when a large-magnitude event is not needed to disclose those effects. For example, logging-related landslides might not occur until several years after logging, when roots are sufficiently rotted to destabilize the slope (Sidle 1985). Even then, it takes a long time for gravel to be transported down a channel, so sediment from the slides might not accumulate at sites downstream until decades later (Madej and Ozaki 1996).

These characteristics of cumulative watershed effects mean that analysts must evaluate much larger spatial and temporal scales than they have been accustomed to in the past. Impact analysis must take into account the influence of rare events, which are difficult to observe and may not even have occurred during the period of record for an area. Analysis also must be interdisciplinary. Each of these requirements represents an excursion into the least-understood aspects of the natural sciences.

Philosophical Issues

Three other problems confronting cumulative effects analysts are more philosophical in nature: the standard of comparison appropriate for assessing the importance of an environmental change is rarely evident; there is no inherent limit to the distance downstream over which impacts might occur; and there can be no generalizable measure of impact severity. These problems touch upon deeply held beliefs about the role of humans on the landscape, the limits of responsibility, and how the natural world functions.

Cumulative impact assessments are intended to evaluate environmental change, but change can only be recognized and measured in relation to an unchanged condition. Thus, the "natural" condition of a watershed often needs to be defined. Non-Native Americans usually consider the conditions that met the European explorers to be "natural." However, a sophisticated program of land management that included the extensive use of fire predated European exploration (Lewis 1993). In the case of Pilot Creek. the pre-Euro-American vegetation and hydrologic regimes (and their resulting influences on aquatic habitat) reflected centuries of intentional burning by Native Americans. Thus, "natural" is an ambiguous term–does it include some land-use effects but not others? Throughout this paper the term "natural" refers to the conditions under which the native flora and fauna were evolving at the time of European contact.

The need to identify natural conditions is particularly strong when a cumulative effects analysis is used to identify goals for restoration projects or for sustainable wildland management. Such coals are often designed using the concept of "natural range of variability" (Fullmer 1994). With this approach, the range of conditions that occurred naturally (the maximum and minimum channel widths, for example) are adopted as the bounds for acceptable conditions. The underlying idea is attractive: try to make future conditions look like conditions of the past. However, in most areas past conditions are not well enough known to define maximum and minimum values for most variables. Further, a system can become incapable of supporting its natural ecosystem even when conditions remain within the specified bounds. The Mississippi River flood of 1993 was well within the natural range of variability for that system, for example, but a yearly recurrence of such flows would create riparian and aquatic ecosystems very different from those encountered by European explorers. Thus, what is required as a goal is not simply that conditions remain within a tolerable range, but that the system reassume the temporal and spatial distribution of conditions that originally sustained it (Bisson et al. 1997, Frissell et al. 1997). A distribution, of course, is even more difficult to define than a range.

In other cases, restoration and wildland management goals are defined according to the perceived needs of target species, such as anadromous fish. For example, riparian man. agement objectives defined for federal lands in the Pacific Northwest east of the Cascades (USDA and USDI 1994a) comprise a list of acceptable threshold values for six physical channel variables, including pool frequency and width-to-depth-ratio. However, real streams in natural settings do not adhere to averages, and reaches that are themselves inhospitable to salmonids may contribute to the maintenance of salmonid populations downstream (G. Reeves, USDA Forest Service, Corvallis, Oregon, personal communication). Similarly, landslides that seem to devastate channels over the short term may be the mechanism by which long-term habitat quality is maintained (Reeves et al. 1995).

Furthermore, adoption of channel design specifications for the benefit of a desired species may harm other components of the aquatic ecosystem. Although silty streambeds are considered to salmonids, for example, pacific lamprey (*Lampetra tridentata*) require fine-grained substrates for rearing (Moyle 1976). Similarly, modification of channels to suit the presumed needs of steelhead (*Oncorhynchus mykiss*) can reduce habitat quality for the foothill yellow-legged frog (*Rana boylii;* Fuller and Lind 1992). If all streams were "restored" to conform to the USDA and USDI (1994a) specifications, the biological integrity of the overall aquatic ecosystem thus would be compromised. In addition, such targets rarely reflect the range of conditions actually provided by natural habitats. For example, the USDA and USDI (1994a) riparian management objectives specify that width-to-depth ratios of less than 10 are desired for all channels, even though these values are not characteristic of many natural channels important to salmonids, as demonstrated by Rosgen's generalized descriptions of stream types (Rosgen 1994).

Recently, however, restoration and management goals have occasionally been defined using a more realistic and tractable approach. If land is managed to re-create the distribution of processes (such as landsliding or treefall) that was present naturally, then the processes themselves will reestablish the temporal and spatial array of natural conditions (such as turbidity or woody-debris loads). Managing for processes is easier and likely to be more successful than managing for conditions because processes are more directly influenced by land-use activities than are the conditions which those processes control. In other words, if reestablishment of natural channel conditions is desired, then the system can be managed to ensure that the processes that affect channel conditions–the production and transport of water, sediment, and organic material-are not altered by management activities. This is the rationale used in the Northwest Forest Plan for the establishment of buffer zones along stream channels (FEMAT 1993, USDA and USDI 1994b). Working against this approach is the tendency to redefine goals to make oversight easier: it is hard to tell from inspections if processes are being maintained appropriately, while it is easy to determine if the width-to-depth ratio is less than 10.

The second philosophical problem is that the potential for accumulating impacts does not end at the mouth of a watershed. In the case of the Pilot Creek watershed, few people have heard of the place, and environmental changes there would go largely unnoticed. However, the intakes that supply Mad River water to most Humboldt County residents are located 50km downstream from the mouth of Pilot Creek. What happens in Pilot Creek takes on regional importance because of its downstream effect on 80,000 people. The fact that the perceived significance of a change depends on its context implies that there is no inherent limit to the distance downstream over which potential impacts must be considered. Does this mean that an impact analysis for a 40-ha timber sale on Mount Shasta should evaluate its potential effects on shrimp in San Francisco Bay, 400km downstream? The San Francisco Bay shrimp industry might still exist if such broad-scale connections had been considered in the past.

The third philosophical problem is that there can be no generally applicable measure of impact severity. Temperatures in Pilot Creek have probably increased, and anadromous salmonids are stressed by high temperatures (Bjornn and Reiser 1991). Therefore, according to traditional reasoning, increased temperatures in Pilot Creek are bad. But did the temperature changes in Pilot Creek actually have a negative effect on salmonid populations? Or were they small enough to be irrelevant? Or did they increase primary productivity to a point that benefited the overall system? Or did they merely compensate for earlier cooling due to reduced area of grasslands? The importance of an environmental change can be interpreted only by examining the influences of that change in the particular context in which it occurred. The same magnitude of change may prove beneficial in one setting and harmful in another.

These philosophical issues strongly influence the strategies used for cumulative effects analysis. Any framework for analysis must incorporate approaches for defining reference conditions, identifying the area over which impacts may be relevant, and evaluating the actual importance of changes. Once the approaches are selected, they become fundamental building blocks of the analysis method and cannot be altered without modifying the entire analysis strategy. But because selection of these approaches is based on the formulator's world view, these decisions often become magnets for controversy among those with differing world views. Unlike technical problems, philosophical problems cannot be resolved by amassing facts; they must be addressed by reconciling or selecting among different people's views of the world.

Sociocultural Issues

Efforts to analyze cumulative watershed effects are also complicated by the expectations and traditions of the Euro-American sociocultural system. Because of the extraordinary variety of processes and interactions that can influence an environmental impact, evaluation of cumulative watershed effects requires a different analytical approach than that ordinarily taught to specialists. The education of a specialist in Western society is usually a rigorous journey toward an increased knowledge of detail in an increasingly restricted field of study. Specialists tend to focus on cataloging details rather than on integrating them into a broader understanding of large systems, and they often assume that it is someone else's responsibility to do the integration once the "specialized" work has been completed. Understanding cumulative watershed effects requires an entirely different approach.

First. the cumulative effects analyst must place higher importance on the understanding of general patterns than on the collection of precise data. At the scale of 500-km^2 watersheds, collection of detailed information is often counterproductive. For example, the anomalous relationship between soil and vegetation maps for the Pilot Creek watershed was understood only after distracting details were removed (Figure 19.1): the halos of forested grassland soils around the shrinking remnants of grassland record the earlier extent of the grassland.

Second, the analyst must strive for understanding of interactions between components of the environment rather than for detailed understanding of isolated components. Cumulative effects result from interactions between environmental changes; they cannot be understood without understanding those interactions, and an understanding of the interactions cannot be gained simply by understanding the components in isolation. Because Western science has traditionally focused on the central subject areas of defined disciplines rather than on their boundaries, it is difficult for specialists to realize that an interdisciplinary

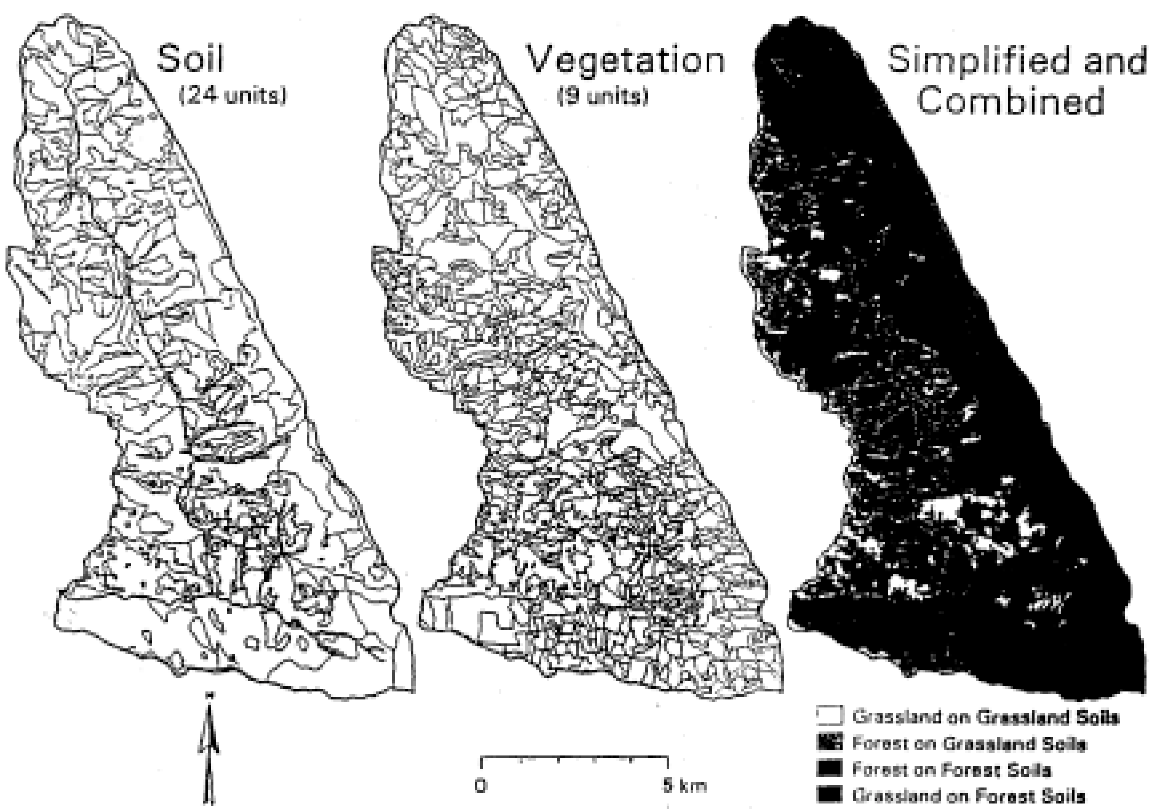

FIGURE 19.1. Soil, vegetation, and combined maps for the Pilot Creek watershed. Twenty-four soil units and nine vegetation units are outlined on the soil and vegetation maps, respectively. These sets of units were each reduced to two general categories (forest and grassland soils for the soil map; forest and grassland for the vegetation map) and superimposed to reveal the pattern of forest encroachment shown on the combined map.

understanding cannot be derived from a detailed understanding of each individual component (Holling 1993). Consider, though, that demarcations between disciplines are cultural artifacts; a different cultural outlook could easily define the interactions as the core areas of disciplines. If "*B*" is the problem, it makes little sense to limit one's attention to "*A*" and "*C*"

Third, the analyst must address each potential impact at the scale required by that impact. In particular, an understanding of small watersheds cannot be scaled up to explain the behavior of a large watershed. For example, a climatic regime characterized by intense, localized thunderstorms produces rare but large changes in the channel that drains any particular small watershed. In a large channel that drains a thousand of these tributary watersheds, the same pattern of storms produces frequent, low-magnitude changes. Science in the past has concentrated on the workings of small watersheds because that is the scale most tractable for experimental watershed studies. The result is a tendency for analysts to divide a large watershed into subareas of a familiar size and to evaluate those, thus ignoring the problems introduced by the larger scale. Unfortunately, it is at the larger, more poorly understood scales that cumulative watershed effects affect most people.

Finally, because so many influences and interactions are involved in the expression of an environmental impact, an understanding of cumulative watershed effects is most often based on qualitative descriptions and order-of-magnitude estimates. The problem cannot be reduced to the deterministic stimulus-and-response models beloved by Western science, and even stochastically based models are limited in their applicability. This must be viewed not as an affliction to be cured, but as an indication that different approaches are necessary when addressing problems whose very nature arises from their complexity. Uncertainty is inherent in the field of cumulative watershed effects.

The conflict between traditional scientific values and the needs of cumulative effects analysis is particularly evident in the treatment of measurement precision: the level of precision necessary to understand cumulative effects is often lower than that considered acceptable by traditional science. For example, knowing exactly how much sediment is eroded from a road contributes little to an understanding a watershed's cumulative impacts. Instead, what is relevant is knowing whether roads in the watershed produce a lot more sediment than grazing, whether a particular kind of road produces a lot more sediment than other kinds of roads, or whether sediment is even a problem in the area.

Because the skills and approach needed for cumulative effects analysis are not those fostered by traditional approaches to science, many would-be analysts find it difficult to forgo their accustomed approaches and adopt those most useful for the problem. Any task becomes difficult if one is equipped with the wrong tools.

The Ad Hoc Approach to Cumulative Effects Evaluation

Despite the complexity of the problem. the questions that must be answered during an evaluation of cumulative effects–what was the past like, how did changes occur, and what will the future be like–are questions that need to be answered for many applications, whether or not the words "cumulative effects" are used. Not surprisingly, they are questions that have been answered routinely for decades.

Until requirements for cumulative effects evaluations were mandated by NEPA, most evaluations of environmental change focused on specific problems in specific areas. Usually, the approach used was ad hoc: people provided an answer relevant to a particular problem using whatever techniques were best suited to that problem. One of the best examples of an ad hoc cumulative effects assessment was carried out more than 80 years ago by G.K. Gilbert (Box 19.4; Gilbert 1917).

Ad hoc methods have been applied to many problems that involve off-site cumulative watershed effects: Will changes caused by Hurricane Iniki aggravate future floods? Can Castleford's water supply be increased by

Box 19.4. G.K. Gilbert and the Fate of San Francisco Bay

Hydraulic mining in the Sierra Nevada had introduced vast volumes of sediment into California rivers, and officials in San Francisco worried that the sediment would eventually shut down the Port of San Francisco. They asked Grove Karl Gilbert to figure out when and by how much the Port would be affected.

Gilbert's first step was to identify the possible mechanisms for damage. Preliminary calculations quickly allowed him to discard all mechanisms except shoaling of the bay-mouth bar because of decreased tidal flow as mining-related sediments aggrade in other parts of San Francisco Bay.

Gilbert then identified the questions that needed to be answered to solve the problem: How much of the excess sediment contrib.-uted by mining will reach the bay? When will it arrive? How much of an effect will it have on tidal flow? How much of an effect will other future activities, such as marsh reclamation, have on tidal flow? How much will a decrease in tidal flow reduce the transport capacity of currents across the bay-mouth bar? Reconnaissance-level field work provided the information he needed to compare the volume of mining sediment to background sediment input rates; channel cross-sections disclosed the location of stored and mobile sediment and its rate of transport to the bay; and hydraulic calculations allowed estimation of sediment transport by tidal currents given various scenarios of sedimentation and coastal development.

From this information, Gilbert concluded that the effects of mining-related sedimentation would be small compared to the effects from development of tidal marshes. The CEQ's definition of cumulative impacts is foreshadowed by Gilbert's description: "Every acre of reclaimed tide marsh implies a fractional reduction of the tidal current in the Golden Gate. For any individual acre the fraction is minute, but the acres of tide marsh are many, and if all shall be reclaimed the effect at the Golden Gate will not be minute" (Gilbert 1917).

Clear-cutting the reservoir's catchment? Why are wells in West Valley drying up? How should the $5,000 raised to improve fish habitat in Wilrick Creek be spent? Each of these problems concerns a specific environmental change in a specific area, and the intent of each inquiry is well defined. The methods used vary with every application because the methods selected are those best suited to the particular questions asked.

The most important phase of an ad hoc cumulative effects analysis is usually the initial step of identifying the question to be answered. The analyst usually must delve into the motivations of those desiring the analysis to determine exactly how the results are intended to be used. With this information, the analyst can select the appropriate scope and level of precision needed for the results. Sometimes only qualitative information is needed, and order-of-magnitude or relative values are sufficient to solve many problems. For example, an analysis of the potential effects of a hurricane on future flooding required only order-of-magnitude estimates of hurricane-related erosion to identify areas where channel aggradation could become a problem (Reid and Smith 1992). Where erosion from the storm was an order of magnitude less than the average annual erosion rate, potential aggradation could be ignored (Table 19.1).

Because ad hoc analysis of cumulative environmental changes is usually done on a small scale, investigators from few disciplines are usually involved, so the full scope of a problem may not be immediately evident. Thus, a second step in solving ad hoc problems is to identify the variety of factors that may influence the problem. Without this effort, proposed solutions often fail to meet their objectives. For example, fisheries biologists asked to restore fish habitat in a watershed generally inventory in-stream conditions and modify the unsatisfactory reaches. Solutions often improve local conditions until the underlying problems reappear to destroy the modifications (Frissell and Nawa 1992). Given the same problem, geomorphologists and hydrologists usually identify the underlying causes for change, such as an increase in landslide frequency, and then design solutions that reverse those causes, such as improving road drainage structures or removing roads (Spreiter et al. 1996). These solutions lead to permanent habitat recovery over the long term, but the fish may already be extinct by the time they take effect. What is needed is a melding of the two viewpoints, combined with input from other disciplines that provide insight into riparian vegetation changes, fire frequencies, and so on.

The third step is usually one of triage. Just enough information is gathered to determine which influences are small, and can be ignored; which are big, and thus require little precision in their evaluation; and which must be examined in more detail to determine their importance.

Once the major foci of the investigation have been identified, the problem can be simplified by making generalizations about the area to be examined. Subareas that are internally uniform are identified, and each is characterized or evaluated as a whole. Common criteria for stratification include climate, geology, topography, and vegetation, though others have been used for specific applications. Using this approach, stream-temperature regimes or habitat use might be described for forested granite watersheds, forested basalt watersheds, and chaparral granite watersheds. An investigation designed to address a different problem in the same area is likely to find a different classification more useful; it might distinguish between lands above and below the transitional snow line, for example, or among small, medium, and large channels.

The remainder of the investigation usually focuses on answering the three major questions

TABLE 19.1. An order-of-magnitude sediment budget for sediment contributed by Hurricane Iniki to watersheds and hydrologic zones on the island of Kauai, Hawaii.

	Increased sediment input from hurricane			
Watershed or zone	Sheet erosion	Landslides	Uprooting	Total
1. Wainiha	+ +	+ + +	+	+ + +
2. Lumaliai	+ +	+ + +	+	+ + +
3. Waioli	-	-	+	+
4. Hanalei	-	-	+	+
5. Kahhiwai	-	-	+	+
6. Kilauea	-	-	+	+
7. Anahola	-	+	+	+ +
8. Kapaa	-	+	+	+
9. Wailua	-	+	+	+ +
10. Hanamaulu	-	-	+	+
11. Huleia	-	-	+	+
12. Waikomo	-	-	+	+
13. Lawai	-	-	+	+
14. Wahiawa	-	-	+	+
15. Hanapepe	+ +	+ +	+	+ +
16. Canyon zone	-	-	+	+
17. Waimea	+	+ +	+	+ +
18. Na Pali zone	+ +	+ +	+	+ +

Expected annual sediment inputs are on the order of 1,000t-km^{2}-yr^{-1} (- = <1 t km^{-2}-yr^{-1}; + = 1-10t-km^{-2}-yr^{-1}; ++ = 10-100t-km^{-2}-yr^{-1}; +++ = 100-1,000t-km^{-2}-yr^{-1}).
Adapted from Reid and Smith (1992).

for each land class: what did the past look like? how did changes occur? and what will the future look like? Depending on the type of information available, different approaches might be taken. Investigators usually use some combination of direct observation of processes. evidence of past process activity, historical records, information from analogous sites. modeling, and reasoning from a basic understanding of the biological, physical, and socioeconomic processes that affect the issue. Monitoring usually requires an intractably long duration to produce interpretable results and so is rarely useful during analysis. After the analysis is complete, however, monitoring is often used to evaluate the effectiveness of whatever solutions are implemented (Chapter 18).

If there are good records of past conditions, then past and present can be compared to define the changes. Aerial photographs and early maps provide the best record of the past in many remote areas, and sequences of images can document changes in channel form and reveal associations between channel changes and land-use activities (Ryan and Grant 1991). Interviews with long-term residents often provide useful information about past biological and physical conditions. If records do not exist, past conditions can often be deduced from an understanding of the mechanisms by which changes occur. The history of land use is first examined to identify direct changes to topography, vegetation, hydrology, fauna, and soils. An understanding of physical and biological processes is then used to infer how these direct changes (e.g. altered forest composition on hillslopes) influenced the conditions of interest (e.g. the size, amount, and stability of large woody debris in the main channel).

Downstream impacts usually involve changes in the transport of water or sediment through channels,, so methods for describing such changes are useful. Sediment and water budgets describe the inputs, storage, and outflows of sediment or water in a system and are widely used for such applications. The precision, scope, and focus of such budgets are readily modified to suit the needs of each application (Reid and Dunne 1996).

Future conditions are controlled by three types of influences. First, the future will reflect trends set by past arid present conditions. and some future conditions can be estimated by extrapolating these trends. Second, "time bombs" set by past. changes will appear suddenly when conditions are appropriate. If logging roads were designed to withstand 25-year-recurrence-interval storms, for example, an unprecedented level of damage is likely the first time a larger storm occurs. Third, the future will reflect the results of, future activities, and these usually must be inferred from socioeconomic projections of changing land-use patterns.

Because each ad hoc application is different, no analytical technique is applicable to all investigations. However, one problem is shared by most: some essential information is usually missing. For example, it might be necessary to know an erosion rate where no measurements exist. In such cases, a best estimate for the missing value often is made using information from similar areas, and the potential significance of an error is evaluated by calculating the effects of particular levels of over- and underestimation. Results also might be presented as a range between maximum and minimum likely values estimated using information from elsewhere.

Standardized Methods of Cumulative Effects Analysis

In 1969 the primary reason for evaluating cumulative watershed effects changed: NEPA now required environmental impact evaluations before federal land-use plans or permits would be approved. Most earlier evaluations needed to consider only a particular kind of impact in a limited area, but now the potential for all types of impacts had to be evaluated over large areas administered by the Forest Service and Bureau of Land Management. State legislation soon followed, and states now had to oversee thousands of private analyses. The ad hoc approach no longer was feasible because each evaluation would require too much expert review to assure the validity of

TABLE 19.2. Extent to which standardized cumulative effects evaluation methods provide the characteristics desired of such methods.

	Cumulative effects evaluation method					
Goal	Ad hoc	ERA	Fish-sediment model	CDF	TFW	Interagency
Administrative preferences						
Consistent set of methods used	no	yes	yes	yes	yes*	no
Results in a number or yes/no	yes*	yes	yes	yes	no	no
Completed in less than a month	yes*	yes	yes	yes	no	no
Can be done by non-experts	no	yes	yes	yes	no	no
Compliance judged by procedure	no	yes	yes	no	no	no
Reproducible results	yes*	yes	yes	no	yes	yes*
Accepted by peers	yes*	no	yes	no	yes	yes*
Can be used anywhere	yes	no**	no	yes	no	yes
Antidote to litigation	yes	yes	yes	no	yes	***
Technical requirements						
Methods tested and validated	yes*	no	no	no	***	***
Evaluates any impact	yes	no	no	yes	no	yes
Evaluates any mechanism	yes	no	rto	yes	no	yes
Evaluates temporal accumulations	yes	no	yes	yes	yes	yes
Evaluates spatial accumulations	yes	yes	yes	yes	yes	yes
Evaluates distant off-site impacts	yes	no	no	no	no**	yes
Based on valid assumptions	yes*	no	yes*	yes*	yes*	yes.
Best available methods allowed	yes	no	yes	yes*	yes	yes

* Varies with the application.
** Has the potential but not as generally applied.
*** Is being or will soon be tested.

analysis techniques. Oversight had not been a problem before because most analyses directly benefited those who paid for the work. Now, however, analyses were done primarily to suit the needs of a third party: the regulatory agencies.

With the change in the scope and intent of analysis came a change in what a desirable analysis method should be like. Impact analysis had to be consistently applicable to facilitate administrative oversight; it had to produce numerical or yes-or-no results to allow consistent decision making; and it had to be accomplishable over a short period. Methods had to be tightly constrained and consistent so they could be carried out by nonexperts. The validity of an analysis had to be judged on procedural grounds: analyses would be accepted if they were carried out according to the agreed-on recipe. Whoever carried out the method in a particular area would have to arrive at the same answer as anyone else.

On this basis, states and land-management agencies began developing their own official procedures for cumulative effects analysis. The approaches adopted range from calculating indices of land-use intensity to using data-intensive mechanistic models: and from following a "cookbook" that requires no expertise to using professional judgment to fill out a check-list. Three examples illustrate the variety of approaches taken and the short-comings entailed by each (Table 19.2).

An Index Approach: Equivalent Roaded Acres

The method designed for National Forests in California is based on an assumption that the potential for cumulative watershed effects increases with land-use intensity in a watershed (USDA Forest Service 1988). Analysts inventory the areas affected by past activities and apply coefficients to adjust the effects of each activity to the same scale and to adjust for the extent of recovery. The scores for each activity are then summed to calculate the total score for a watershed, and this total is compared to the "threshold of concern." In watersheds where scores approach the threshold, further analysis identifies the condition of the watershed, and projects might be planned to decrease the score (e.g., road removal), or projects might be deferred until natural recovery has lowered the score to an allowable level. The intensity of all activities is described in terms of the area of road surface that would provide the same effect, the "equivalent roaded acre" (ERA). Most watersheds analyzed are smaller than 200 km^2.

Administratively, the ERA method is convenient and useful. Coefficients for defining the "road-likeness" of an activity and for describing the rate at which an activity site recovers can be defined for large areas, and subsequent analyses require little fieldwork. Little expertise is required to tally road lengths and logged areas; the method produces a numerical score that can be compared directly to the threshold of concern; and the procedure is fast, reproducible, documented, and relatively consistent.

Unfortunately, the method contains flaws that undermine its technical adequacy. For example, coefficients for recovery refer to recovery at the site of land use but not to recovery from the off-site impacts of that activity. Thus, a logged area is considered recovered when it is revegetated, even though sediment from logging-related landslides may still be present in downstream channels. All else being equal, calculation of ERAs would show that subsequent logging on the site would have no potential cumulative impact, yet the resulting influx of sediment would add to that already stored in the system and so would create a cumulative impact.

In addition, because only one set of coefficients is used to describe each activity, the method implicitly assumes either that only one mechanism for impact is possible in an area or that some composite variable is meaningful. However, a tractor-logged slope might be very much like a road in terms of sediment production but very different in terms of hydrologic change. If both hydrologic and sediment impacts are of concern, then two different sets of coefficients should be used to compare roads and logging. A third problem is that the scope of concern is limited to the watershed being managed, so an analysis for Pilot Creek would calculate ERAs only for the Pilot Creek watershed. Such an analysis could not evaluate Pilot Creek's contribution to impacts on the municipal water supply downstream. Thus the method is inherently incapable of evaluating the downstream cumulative watershed effects that are of most concern to most people.

Other problems arise from the manner in which the ERA method is applied. For example, the procedure requires calibration of many coefficients for each area, and such calibration ordinarily would be based on a lot of monitoring data for each activity. Monitoring is expensive and time consuming, however, so the necessary coefficients are usually estimated using professional judgment. This approach might not present a problem if the results of activities were then monitored to test the predictions, or if the entire program were tested by statistical comparisons between prediction and reality, but no such monitoring has been carried out.

Furthermore, those applying the method rarely specify the impact mechanisms important in the area of application. Instead of identifying hydrologic change, for example, as the major mechanism and using a measure of hydrologic change to define coefficients, most analysts estimate coefficients using a visual estimate of channel disturbance. The variety of mechanisms and activities that influence channel form makes an algebraic solution for coefficients impossible, even if conditions were to be carefully monitored. Further, even if coefficients could be defined, they would be relevant only for the smallest watersheds. Large watersheds require a different set of coefficients than small watersheds because large channels respond differently than small ones, but too many activities have already occurred in large watersheds to allow coefficients to be back-calculated.

These considerations suggest that the apparent simplicity of the index approach is deceptive. To use such an approach appropriately requires that different indices be defined for different areas to account for differences in impacts, impact mechanisms, and recovery trajectories. Appropriate use also requires a tremendous monitoring effort both to calibrate the method for the variety of conditions present and to test the validity of the results.

A Mechanistic Impact Model: The Fish-Sediment Model

In central Idaho, the U.S. Forest Service took a different approach to evaluating cumulative effects. Here, decades of collaborative efforts between researchers and resource specialists had provided data that defined relationships between particular land-use activities and rates of in-stream sedimentation (Cline et al. 1981), and between in-stream sedimentation and salmonid populations (Stowell et al. 1983). When the need for a cumulative effects method arose, the necessary information was on hand to construct a model that could be applied directly to the cumulative impact of most concern in the area: the impact of sediment on salmonids.

The resulting Fish-Sediment Model first calculates the sediment input expected from a planned landuse activity using calibrated coefficients that vary with locale and kind of activity. The effects of coexisting and prior activities are also calculated, and the results for previous activities are modified according to the expected recovery rate of the downstream channel. Results then allow an estimate of future channel conditions, from which the expected level of impact to fish can be calculated. Because the model takes into account the recovery rate of the impact instead of that of the driving variables, it allows evaluation of temporal accumulations of impact. Analysis focuses on changes to moderate-sized, low-gradient, alluvial channels.

Like the ERA approach, the Fish-Sediment Model is administratively convenient. Methods are standardized; results provide a numerical prediction of impact; the required level of expertise is not high; most work can be done in an office once the coefficients are calibrated; and given the same information, all users will produce the same answer.

Unlike the ERA approach, the; Fish-Sediment method is based on a wealth of data that demonstrates the connection between specific land-use activities and a specific impact. Thus, the method is widely accepted as the best method available for predicting embeddedness of spawning gravel in steep granitic terrain of the northern Rocky Mountains where logging, roads, and fire are the major influences. However, the method cannot be applied to other areas where other impact mechanisms apply, other impacts are important, or the necessary data are missing. The method also cannot be used in channels larger than those for which it was calibrated, and this restriction limits the spatial scope of analyses. A similar approach could be developed for other impacts in other areas, but development would require the same painstaking accumulation of data that was needed to construct the model for central Idaho.

Professional Judgment: The California Checklist

The California Department of Forestry and Fire Protection (CDF) has a very different role than the U.S. Forest Service. The CDF manages little land, so it rarely has to evaluate cumulative effects. Instead, like similar resource agencies in other states, the CDF is primarily a regulatory agency with responsibilities for designing regulations for activities related to logging on private lands, reviewing applications for land-use plans, and inspecting activities for compliance with regulations. The CDF thus was responsible for designing a cumulative effects evaluation method for use by private timberland owners in California.

The CDF method (CDF 1998) consists of a checklist that leads the user through an evaluation of the impacts that may be important in an area and of the influences that may contribute to those impacts. The user is responsible for selecting appropriate methods to address each point. The report consists of yes-or-no answers to questions, about whether cumulative impacts are present in the area and whether the proposed project is likely to cause or add to significant cumulative impacts, accompanied by a narrative explanation of the answers. The report is sent to the state for approval as part of a timber harvest plan. State agencies that regulate or manage resources that might be affected by the timber harvest review the plan and decide: whether it is adequate. Analyses usually consider impacts within an area Analyses approximately 10 to 40 km^2, but a larger area may be evaluated if the analyst considers it necessary.

The CDF method has the advantage of being flexible. The method permits evaluation of whatever impacts are important in each area, and it allows consideration of the temporal and spatial scales that are relevant to those impacts. It also allows use of any analytical techniques that are applicable to the identified problems. This method also has several administrative advantages: it can be used consistently throughout the state, it provides a yes-or-no answer, it can be completed quickly, and it requires little specialized expertise beyond that of a state-certified professional forester. The analysis is considered adequate if the report seems reasonable to the reviewers.

From the point of view of the regulatory agencies, however, the method has the weakness that review must be based on the content of the narrative report rather than on whether the procedure was followed. This requirement places heavy responsibility on reviewers to detect faulty reasoning and inadequate methods, but examination of approved reports shows that reviewers have overlooked some fundamental errors. One report explained that the presence of riparian vegetation downstream meant that all logging-related sediment would be filtered out before it could contribute to a cumulative impact, though such reasoning would lead to the obviously absurd conclusion that no channel with riparian vegetation carries suspended sediment. Another report limited its scope to the project area, arguing that impacts would not occur downstream if they did not appear at the site of the activity. This argument obviously conflicts with the definition of cumulative watershed effects, yet it was not challenged in review.

The CDF method could be effective because of its flexibility, but its credibility depends on the diligence and expertise of those reviewing each report. Heavy reliance on expert oversight is necessary for methods based on professional judgment.

Administrative Convenience Versus Technical Adequacy

The three standardized analysis methods described above differ in their strengths and weaknesses (Table 19.2), but together they reveal a pattern that is shared by a variety of other institutionally based methods (Reid 1993). First, each standardized method is convenient from the point of view of the intitutions responsible for the analyses. In contrast, the ad hoc approach would be difficult to carry out in an institutional setting because it depends on expertise both for analysis and oversight. Administrative convenience is important for institutional methods because whatever method is adopted must be accomplishable.

Second, the most technically credible methods are those based on considerable amounts of data and having the most restricted areas of applicability. Both the Fish-Sediment Model and individual ad hoc analyses are restricted in scope because the methods used are designed for a particular kind of problem in a particular place.

Third, a lack of technical validity has not stopped methods from being used, indicating that the utility of an analysis is not necessarily based on its results. Standardized analysis methods did not exist until regulatory mandates made them necessary. If the regulators accept the results of an analysis, the analysis has fulfilled its primary objective; the *results* of the analysis do not aid the institutions in accomplishing their goals as much as the *completion* of an acceptable analysis does. The institutions' ideal method thus is one that is easy to carry out and is acceptable to the regulatory agencies. More credible methods would have required too much expertise, too much data, and too much time.

The people who designed the first generation of cumulative effects methods were not blind to the need for scientific validity, but they were also very aware of the constraints imposed by their institutional contexts. Until pressure on the institutions increased to the point that the institutions allowed those contexts to be broadened, the first-generation methods were the best possible. It was largely through examining the successes and shortcomings of these early analysis efforts that a new approach to the evaluation of cumulative effects could be designed.

Watershed Analysis

The credibility of the standardized methods began to waiver under public scrutiny. A panel of experts criticized the ERA approach for not addressing cumulative effects directly; the Fish-Sediment Model could not be applied to other regions because it does not consider the variety of impacts and mechanisms important elsewhere; and the CDF checklist did not protect approved logging plans from lawsuits concerning impacts downstream of the mandated assessment area. In each case, the validity or applicability of the method was challenged. Meanwhile, an entirely different approach to impact evaluation was being designed in Washington State: *watershed analysis.*

Watershed analysis is not a stand-alone method for evaluating the cumulative effects of a proposed project. Instead, it is a formalization of the procedure used by ad hoc cumulative impact evaluations to develop the locale-specific understanding necessary to evaluate project impacts in the future. The Washington method combines this background analysis with a procedure for using the results to plan land-use activities that are intended to avoid cumulative impacts.

Limited Assessment With Prescriptions-Timber/Fish/Wildlife Watershed Analysis

Under the threat of increased litigation in the late 1980s, an agreement was crafted to protect public resources while allowing logging to continue on private and state lands in Washington State. This effort was known as the Timber/Fish/Wildlife Agreement, or TFW. Fundamental to the: agreement was the realization that any evaluation procedure had to produce credible results, because people could not be persuaded to modify their land-use activities unless they knew that the reasons for doing so were valid. People would once again be analyzing cumulative effects for their own benefit, so validity was again an important goal. But the motivations once again had changed. Validity was important not because a mistake costs money, as was the case with the ad hoc analyses, but because the foundation of the agreement would collapse if results were not valid. None of the participants wanted to embark on the cycle of litigation that the agreement was designed to avoid.

The method that TFW developed consists of two parts-resource assessment and management prescription-that together are referred to as watershed analysis. The resource assessment describes fisheries impacts, their causes, and land-use activities influencing those impacts in different parts of a 40- to 200-km^2 watershed. Assessment teams usually include a fisheries biologist, a hydrologist, a riparian ecologist, and experts on landslides, surface erosion, and capital improvements. Other specialists may be brought in to work on questions that the assessment team cannot answer. All those interested in the watershed may participate, but reports are prepared by certified analysts who have received official-training in the procedure.

A manual (Washington Forest Practices Board 1995) provides recommended methods for carrying out analyses, but assessment teams may use other methods if they are appropriate for the problems encountered. The manual includes modules that describe how to evaluate landslides, surface erosion, hydrologic change, riparian function, channel function, fish habitat, and public works. Each module was designed to suit the conditions and impact mechanisms commonly found in Washington, and each is directed toward evaluating impacts on anadro mous fish and capital improvements. Results from the assessment modules provide the information needed to answer a series of "synthesis questions," which explore the mechanisms of impact, and to identify areas sensitive to particular kinds of change.

The resource assessment provides the objective information needed for the second, more subjective phase of the TFW method, in which management practices are prescribed by a "field managers team" composed of foresters, engineers, fisheries specialists. and hydrologists. Prescriptions arc made for lands of all ownerships within the watershed. so small landowners in the area need not invest their own time or resources in environmental planning. Activities are not proscribed, bill prescriptions for particular areas may define widths of riparian buffers, types of unstable ground that must be protected, specifications for road construction and maintenance, and similar requirements. Participation in the program is voluntary, but the motivation to participate is strong because adherence to the prescriptions absolves landowners of the need for further environmental evaluations. Prescriptions are reviewed by relevant state agencies and by all interested parties, and the long-term effects of implemented prescriptions are intended to be monitored.

The TFW method does not fit the profile of the administrative ideal established for earlier cumulative effects methods (Table 19.2) because it achieves the same ends in a very different way. By design, the method is acceptable to all, and each analysis is carefully scrutinized by the disparate groups that participate in it.

A weakness of the approach is its focus on impacts to aquatic habitat. Even the original intent to include analysis of wildlife needs (the W in TFW) was postponed when participants realized that achieving consensus on fisheries issues was a big enough challenge (Dr. Kate Sullivan, Weyerheauser Co., personal communication). The method also suffers from a reliance on untested analytical techniques. Procedures for calculating road-surface erosion, peak-flow changes from clear-cutting, and sediment yields from undisturbed watersheds have not yet been demonstrated to provide valid results. Revisions of the manual are planned and future versions are likely to correct some of these problems.

The TFW approach does not evaluate cumulative effects in the traditional sense; it does not describe the likely cumulative impacts of a particular project or land-use strategy. Instead, the approach uses an understanding of past cumulative effects to produce a set of land-use prescriptions. Because the impacts of those prescriptions are not themselves evaluated, analyses may overlook potential future cumulative impacts. for example, if the road density in a watershed is low and has not caused an identified impact, then prescriptions for future roads do not necessarily consider the impacts from increased road density.

Broad Assessment Without Prescriptions–Interagency Ecosystem Analysis

Following President William Clinton's "Timber Summit" of 1993, federal agencies worked together to design an approach to federal land management in the Pacific Northwest that would ensure the sustainability of natural ecosystems and rural economies and would satisfy requirements for lifting a federal court injunction on logging of federal lands in the area (FEMAT 1993). Under the resulting Northwest Forest Plan (USDA and USDI 1994b), large tracts of federal land would be set aside as forest reserves, and land-use activities in other areas would be tailored to suit the needs and capabilities of those areas. Central to the strategy was the use of watershed analysis to identify constraints and opportunities in each area. Watershed analysis originally had been intended to focus on aquatic ecosystems, but its role was quickly expanded to include analysis of terrestrial ecosystems and human communities, and the procedure was renamed "ecosystem analysis at the watershed scale" (REO 1995a). Ecosystem analysis was intended to be part of larger-scale analysis efforts that considered entire river basins and the region as a whole (FEMAT 1993).

Interagency ecosystem analysis is designed to produce integrated descriptions of the influence of physical, biological, and socioeconomic processes on environmental impacts in watersheds of 50 to 500km^2. Watersheds were selected as the analysis unit to facilitate evaluation of impacts on the aquatic and riparian environment and because they are readily identifiable features. Other issues are not as conveniently evaluated on a watershed basis, but it was realized that a fundamental knowledge of processes can be applied to understand landscape patterns within any arbitrary set of boundaries. In effect, each issue is to be evaluated using information from whatever scales are relevant to that issue, but the implications of the results are to be highlighted for the watershed in question.

The primary task of ecosystem analysis is to reorganize existing information so that the connections between different components of the system become evident and the relevant interdisciplinary context for each issue can be examined (USDA and USDI 1994b); these connections are to be understood before management actions are planned. In particular, analysis is intended to

- Identify what issues in the watershed are important to what constituencies.
- Facilitate interagency communication
- Identify physical, biological, and socioeconomic interactions in tile watershed.
- Understand the watershed's role in a larger spatial context.
- Identify information that will be needed in the future for making management decisions.
- Explain to the public how the ecosystem and landscape function in the watershed.

Originally, analysis was not expected to provide prescriptions or recommendations for land-use activities, as these would require subjective weighting of conflicting values and desires. Instead, analysis was to provide an objective basis of understanding and cooperation that would contribute to any future land-use decisions. However, agency land managers later modified the procedure to include limited recommendations.

Analysis teams usually consist of federal fisheries biologists, wildlife biologists, hydrologists, and specialists in social sciences, vegetation, and earth sciences. Because of the variety of issues and landscapes that ecosystem analysis must address, no method is applicable everywhere, so particular techniques are not specified. Instead, the analysis manual (REO 1995a) describes a six-step strategy for analysis (Table 19.3). A supplement to the manual provides examples of techniques that might be useful in different areas (REO 1995b).

TABLE: 19.3. Steps of federal interagency ecosystem analysis at the watershed scale.

1. Characterize [lie watershed and show its relation to the larger area.
2. Identify issues of concern and the questions that will need to be answered.
3. Describe existing conditions.
4. Describe the conditions that existed before Euro American disturbances.
5. Describe how the changes in condition have come about.
6. Recommend management strategies and identify information needs and monitoring goals.

REO (1995a).

An on-going review of completed analyses (Reid, unpublished data) indicates that many are approaching the primary goal for analysis: the resource specialists preparing the analyses are becoming more familiar with issues, processes, and interactions in the landscapes they help manage. The level of understanding produced by many of the analyses could have prevented failure in the cases described by Box 19.2. However, many of the reports provide data compendia rather than integrated analyses, and inconsistencies between adjacent chapters are common. Such problems could be remedied by providing training in analysis strategies, putting more effort into interdisciplinary analysis, and soliciting outside technical review.

Interagency ecosystem analysis does not produce a traditional cumulative impact report, but it provides the background information needed by later cumulative effects evaluations. Ecosystem analysis describes the kinds of impacts likely to be important for particular land uses and ecosystem components in different parts of the watershed. Later. project-level impact evaluations identify the changes likely from a proposed project and interpret them in light of the ecosystem analysis results. Most of the work necessary for a cumulative impact assessment thus is done by ecosystem analysis, and project-level impact evaluations need only describe the effects of the proposed project in the context of the larger watershed, basin, and region.

Contrasting Goals and Methods

The TFW and interagency analysis methods share the underlying philosophy that effective management decisions require an understanding of how a system works, but the two approaches differ markedly in procedure and scope. Examination of the reasons for these differences illustrates the importance of carefully defining objectives before selecting strategies or methods.

The most fundamental difference between the two methods is in the application of results. The two-part TFW procedure is designed to produce a prescription for management practices, while interagency analyses are, for the most part, limited to providing the objective information upon which later prescriptions can be based. This limited application for interagency analyses was adopted because of the realization. that any prescription requires subjective consideration of divergent desires and is thus a political decision subject to the decision-making procedures set forth by NEPA. In contrast, the TFW approach can make subjective decisions because the differing political interests have already agreed that consensus is less painful than litigation.

Other differences arise because federal land managers have more options than are usually available to a consortium of private interests. On federal lands, activities can be scheduled over decades on large tracts of the landscape, and particular areas can be designated for particular uses or values. The greater flexibility in land-use options on federal lands means that there is less need for up-front comprehensive prescriptions. Instead, prescriptions are made when a project is planned so that they reflect the condition of the watershed at that time.

In addition, federal management is directed toward a variety of resources, whereas past industrial management tended to focus on a single resource. On federal lands, the project in question might be timber harvest, construction of a campground, or any of a number of other activities. Appropriate prescriptions differ according to the kind of activity, the nature of surrounding activities, and the condition of the ecosystem at the time, so comprehensive prescriptions would be difficult to design before activities are proposed. Results of interagency ecosystem analysis thus provide the background of understanding necessary to better carry out all aspects of land management rather than focusing on prescriptions for a particular land use.

The wide range of issues that federal land managers must consider is also reflected in the broader scope of the interagency approach, and the diverse character of federal lands ensures that no single set of recommended techniques would be appropriate everywhere. In contrast, TFW's limited focus on impacts to anadromous salmonids and capital improvements in Washington State allowed specification of analysis techniques that are well suited to those issues in that area.

Because of their differing contexts, the TFW analysis approach would not suit the needs of federal land managers, just as the interagency approach would not be appropriate for TFW. In essence, watershed analysis is not a solution, but a tool that can come in many different shapes and sizes. Which shape and size is most useful–or whether any version is useful–depends on the type of problem being addressed and the objectives of those addressing it.

Administrative Convenience Versus Technical Adequacy, Revisited

Watershed analysis is a modification of ad hoc environmental impact analysis to fit the needs of an institutional setting. Problems with existing implementations of watershed analysis reflect the compromises necessary when the context for an approach changes. The attributes required to make the approach valid can retrict the method's ability to satisfy administrative needs, and vice versa (Table 19.2). For example, to ensure credibility, the interagency analysis method requires a higher level of expertise than federal agencies would have desired; to ensure feasibility, many analyses lack participation by certain kinds of experts (e.g., sociologists and geomorphologists) not available in those institutions. In the case of TFW, a full solution would require analysis of wildlife issues, but this aspect of the problem was postponed to ensure feasibility.

Each of the potential applications identified for watershed analysis results (Table 19.4) carries a different level of difficulty, uncertainty, political significance, and subjectivity, so each requires a different level of oversight and review. Applications which involve technically difficult problems or which have inherently uncertain results require technical review to establish the credibility of the analysis, while those intended merely to compile information need less oversight.

Applications having high levels of political or economic significance must also be examined to identify analyst biases and implicit philosophical assumptions. "Political significance" is used here in a very broad sense to indicate situations in which a particular group might benefit from a particular result. Thus, identification of a specific inventory need has political significance because it might mean that funding is taken from one group of specialists in an agency or corporation and given to another.

Applications that involve subjectivity require even more careful review. Subjectivity is introduced when applications require value judgments, and any choice between options that carry different levels of benefit or damage to different interests requires a value judgment. Such judgments are necessary for many applications and are the fundamental purpose for land management planning, but there is often a temptation to ensure that a particular outcome prevails when stakes are high (Bella 1997). It is in this situation that the design and implementation of an unbiased procedure for review and oversight become especially important. Not only must investigator biases be understood and the technical foundation for a decision be examined, but the rationale for the value-based decisions must be carefully scrutinized. Watershed analysis procedures that are restricted to objective outcomes thus require less review and oversight and are less likely to be controversial than those which produce recommendations or prescriptions for land management. The TFW approach succeeds in producing widely accepted land-use prescriptions because its

TABLE 19.4. Potential applications for watershed analysis and the extent to which each application is characterized by various attributes.

	Attributes of application					Are analysis results applied in this way?	
Potential application	Difficulty	Uncertainty	Political significance	Subjectivity	Need for review	TFW	Interagency
Identify available information	l	l	l	l	l	yes	yes
Compile relevant information	l	l	l	l	l	yes	yes
Identify inventory needs	m	l	m	l	m	no	varies
Identify monitoring needs	m	l	m	l	m	yes	yes
Describe past conditions	m	m	m	l	m	yes	yes
Understand existing impacts	m	m	m	l	m	yes	yes
Predict future conditions	h	m	h	l	h	no	varies
Identify effects of activity type	m	m	h	l	h	yes	yes
Identify effects of planned activity	m	in	h	l	h	no	no
Identify desired conditions	vh	m	vh	h	vh	no	varies
Recommend suitable activities	m	m	h	h	h	no	yes
Design land-use prescriptions	vh	m	vh	vh	vh	yes	no

The final two columns indicate whether the application is included in the Timber/Fish/Wildlife (TFW) and Interagency Ecosystem Analysis approaches (l = low, m = medium, h - high, vh = very high).

implementation is overseen by the full range of concerned interest groups.

Tomorrow's Analyses

The TFW and federal interagency approaches to watershed analysis are the best developed and most widely implemented at this point, but both have flaws. Neither represents a final stage in the development of methods for evaluating cumulative effects. and both will contribute to further development of analysis strategies and tactics as they themselves are further revised.

Efforts to improve cumulative impact analysis methods are currently progressing in two complementary directions. First, the need continues for ad hoc evaluations, and analysis techniques are continually being developed to support such efforts. Second, the drive toward development of a formal procedure for screening impacts over large areas also continues. Idaho has developed a general method for watershed analysis (Idaho Department of Lands 1995, California and Oregon are considering methods, and there is interest in developing an analysis strategy for use on federal lands throughout the United States.

Any effort to design a new general method for cumulative impact analysis will require making preliminary decisions about the intended use of the results, the range of topics to be considered, the spatial scale of analysis, and the level of oversight and review to be sought. Of these, a very specific definition of the intent and goals of analysis is most important because it strongly influences the remaining decisions. Any general method must be capable of considering the variety of impacts that people are likely to care about, and it must do so in a useful and credible way (Table 19.5). Unless the administrative unit over which analyses are to be carried out is small and uniform, these requirements imply that a single set of recommended methods is untenable. The landscape is too diverse for a single set of techniques to be relevant, useful, and valid everywhere.

TABLE 19.5. Desired characteristics of a generally applicable watershed analysis method.

1. Fits the particular needs of the agency or organization instituting it.
2. Evaluates any potentially important impacts.
3. Evaluates impacts at any point downstream.
4. Evaluates impacts accumulating through both time and space.
5. Evaluates the influence of any expected kind of land-use activity.
6. Evaluates any lands within the analysis area.
7. Uses the best available analysis methods for each aspect of the analysis.
8. Incorporates new information as understanding grows.
9. Can be done for a reasonable cost over a reasonable length of time.
10. Produces a readable and useable product.
11. Is credible and widely accepted.

Ad hoc and standardized analysis methods are independent of one another, although particular techniques developed for one might be applicable to the other. What is shared by both kinds of analysis is a philosophy that calls upon impact analysts to look at the world from a point of view in which

- General patterns are more important than details.
- Qualitative understanding is more important than precise numbers.
- Change is more important than stasis, which has never existed.
- Understanding of process and interaction is more important than description of condition.
- The issue defines the inquiry.
- Extreme conditions are usually more important than average conditions.
- Uncertainty is certain.

Development of this mindset is the biggest problem confronting effective analysis. Those who wish to evaluate cumulative impacts must be capable of departing from their accustomed ways of approaching a problem. In particular, analysts must be able to work in an interdisciplinary format; they must be able to see connections and patterns across very large areas; and they must be flexible enough to step away from a limited set of standardized procedures.

These traits can be encouraged through careful design of an analysis strategy to focus on problems or issues rather than on disciplines, to address types of sites rather than specific sites, and to specify that the team as a whole plans and prioritizes tasks rather than leaving the responsibility to individual members (Reid 1996).

Development of the necessary skills could also be encouraged by changes in educational curricula. Students who have participated on problem-oriented interdisciplinary teams are better able to recognize and solve interdisciplinary problems and to communicate effectively with those in other fields.

Changes are also needed in institutional infrastructures. Institutional budgets are too often designated by discipline, so that an increase in the wildlife budget implies a decrease in the hydrology budget. This framework creates competition among disciplines rather than promoting the cooperation that is increasingly needed. Reorganization of work groups by problem (e.g., "the cumulative effects unit'") rather than by discipline (e.g., "the fisheries unit") would facilitate communication and understanding between disciplines.

Meanwhile, some fundamental research questions have been left largely unanswered. Relatively little is known about problems that sit on the boundaries between disciplines, and methods for aggregating the results of small-scale studies to address large-scale questions are poorly developed. There is a strong need for studies of all types that focus on understanding patterns and processes over large areas or long time scales.

Over the past several decades, the scale and complexity of questions that natural resource specialists are being asked to address has grown considerably. This trend can be seen as intimidating, and those who prefer designing precise answers to well-defined, well-controlled questions arc not confident working in this setting. On the other hand, those who are intrigued by complex systems, who enjoy finding creative solutions to unprecedented problems, and who see beauty in the connections between disparate influences are finding today's challenges to be the most rewarding of their careers.

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