# 4

# DETERMINING THE ENVIRONMENTAL CONSEQUENCES OF CUMULATIVE EFFECTS

**PRINCIPLES**

- Address additive, countervailing, and synergistic effects.
- Look beyond the life of the action.
- Address the sustainability of resources, ecosystems, and human communities.

The diversity of proposed federal actions and the environments in which they occur make it difficult to develop or recommend a single method or approach to cumulative effects analysis. In this chapter, we attempt to provide insight into and general guidelines for performing analyses needed to determine the environmental consequences of cumulative effects. We assume the analysis has already been scoped, including stipulating geographic and time boundaries (see Chapter 2), and that appropriate data have been gathered for the resources, ecosystems, and human communities of concern (see Chapter 3). Reference is made, when appropriate, to specific cumulative effects analysis methods described in Chapter 5 and Appendix A.

The analyst must ensure that the resources identified during scoping encompass all those needed for an analysis of cumulative effects. The analyst must also ensure that the relevant past, present, and reasonably foreseeable future actions have been identified. As an iterative process, cumulative effects analysis often identifies additional resources or actions involved in cumulative effects during the analysis phase. In addition to confirming the resources and actions to be considered, the analyst should complete the following specific steps to determine the environmental consequences of the cumulative effects:

**Step 8** Identify the important cause-and-effect relationships between human activities and resources, ecosystems, and human communities.

**Step 9** Determine the magnitude and significance of cumulative effects.

**Step 10** Modify or add alternatives to avoid, minimize, or mitigate significant cumulative effects.

**Step 11** Monitor the cumulative effects of the selected alternative and adapt management.

## CONFIRMING THE RESOURCES AND ACTIONS TO BE INCLUDED IN THE CUMULATIVE EFFECTS ANALYSIS

Even though scoping has identified likely important cumulative effects, the analyst should include other important cumulative effects that arise from more detailed consideration of environmental consequences. In addition, as the proposed action is modified or other alternatives are developed (usually to avoid or minimize adverse effects), additional or different cumulative effects issues may arise. Specifically, the proposed action and reasonable alternatives (including the no-action alternative) could affect different resources and could affect them in different ways. For instance, hydroelectric facilities primarily affect aquatic resources by blocking fish migration routes, altering thermal regimes, and eroding stream channels as releases fluctuate. Reasonable alternatives for proposed hydroelectric facilities often include various types of power generating facilities that affect the environment in different ways. For example, the effects of coal-fired electric plants are most often related to coal-mining activities, the release of heated water to nearby water bodies in the cooling process, and the release of a variety of pollutants (including greenhouse gases) to the air during combustion. Nuclear plants also release heated water but they release radioactive materials to the air instead of greenhouse gases. Other past, present, or future actions also should be included in the analysis if evaluation of the cause-and-effect relationships identifies additional stresses affecting resources, ecosystems, and human communities of concern.

## IDENTIFYING AND DESCRIBING CAUSE-AND-EFFECT RELATIONSHIPS FOR RESOURCES, ECOSYSTEMS, AND HUMAN COMMUNITIES

In preparing any assessment, the analyst should gather information about the cause-and-effect relationships between stresses and resources. The relationship between the percent of fine sediment in a stream bed and the emergence of salmon fry (Figure 4-1) is an example of a model of cause and effect that can be useful for identifying the cumulative effects on a selected resource. Such a model describes the response of the resource to a change in its environment. To determine the consequences of the proposed action on the resource, the analyst must determine which cumulative environmental changes (e.g., higher sediment load) will result from the proposed action and other actions.

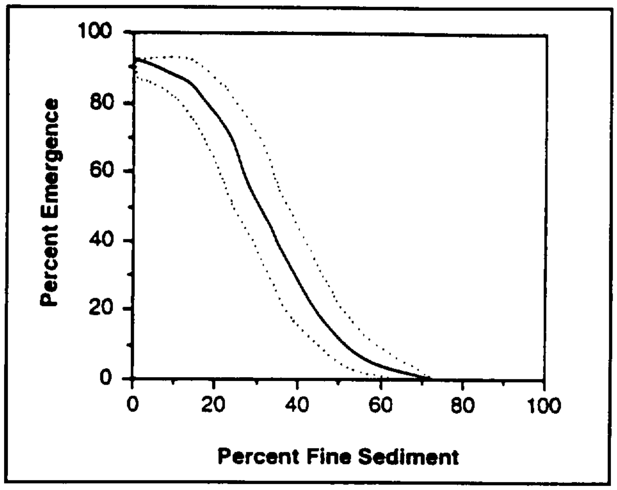


Figure 4-1. Empirical cause and effect relationship between emergence of salmon fry and percent of fine sediment in the stream bottom (Stowell et al. 1983)

### Determining the Environmental Changes that Affect Resources

Using information gathered to describe the affected environment, the factors that affect resources (i.e., the causes in the cause-and-effect relationships) can be identified and a conceptual model of cause and effect developed. Networks and system diagrams are the preferred methods of conceptualizing cause-and-effect relationships (see Appendix A). The analyst can develop this model without knowing precisely how the resource responds to environmental change (i.e., the mechanism of the cause-and-effect relationship). If all pathways are identified, the model will be quite complex (Figure 4-2). Such a complex model can seldom be fully analyzed because sufficient data usually are not available to quantify each pathway. Because of this, the model should be simplified to include only important relationships that can be supported by information (Figure 4-3).

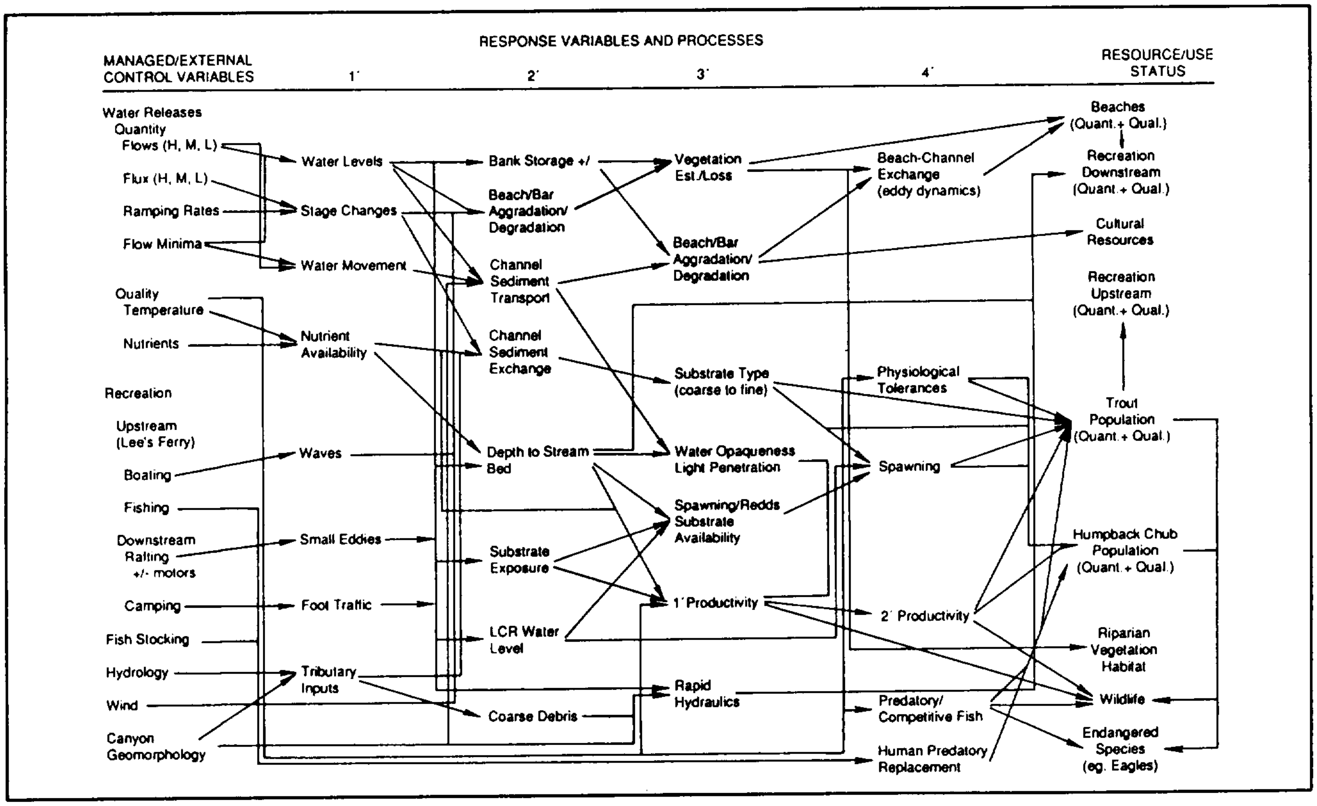


Figure 4-2. Example of a complex model of cause and effect

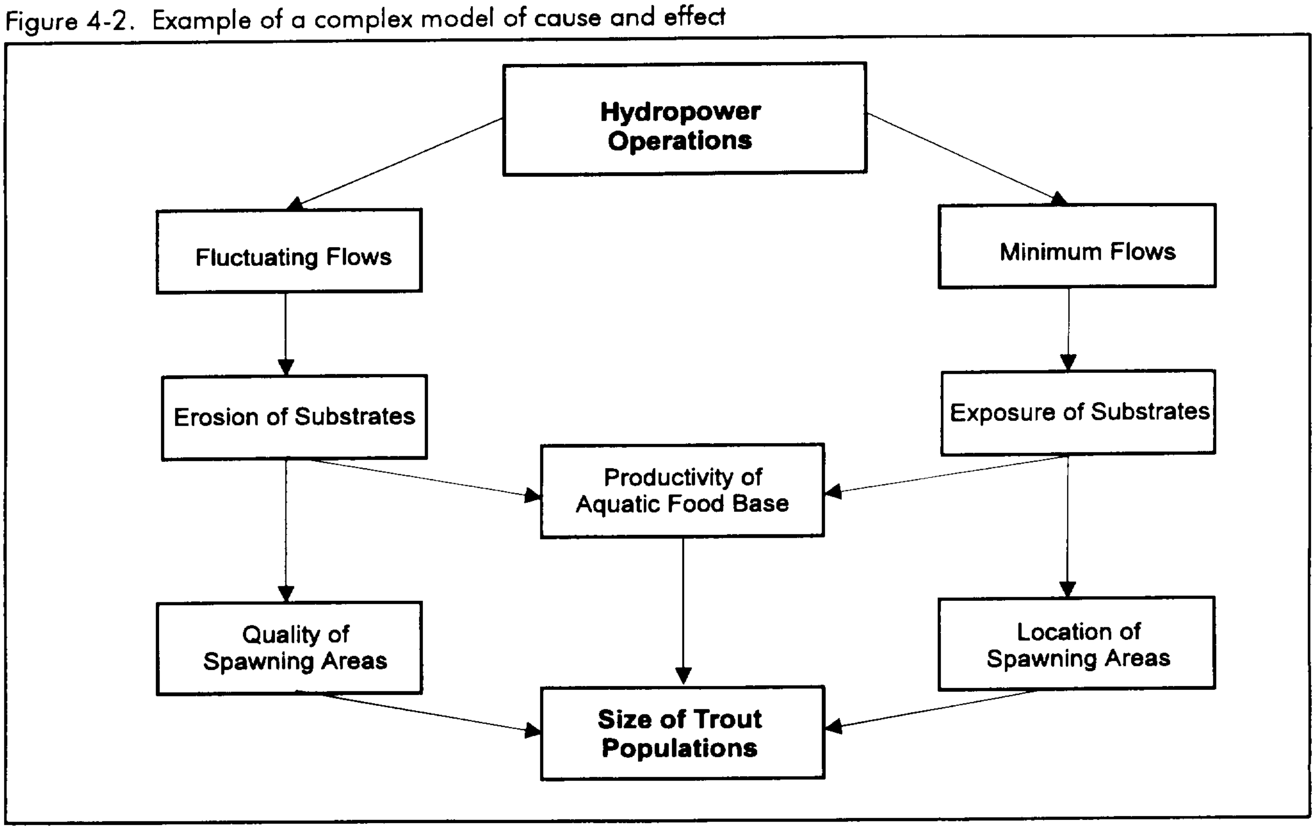


Figure 4-3. Example of a simplied model of cause and effect

The cause-and-effect model can aid in the identification of past, present, and future actions that should be considered in the analysis. In the example shown in Figure 4-3, the analyst should determine if there are other projects in the area that would affect any of the cause-and-effect pathways. The cause-and-effect model for the cumulative effects analysis will often include pathways that would not be needed for a project-specific analysis. Thus, as in defining boundaries, analyzing the consequences of cumulative effects requires broader thinking about the interactions among the activities and resources that affect environmental change.

### Determining the Response of the Resource to Environmental Change

Once all of the important cause-and-effect pathways are identified, the analyst should determine how the resource responds to environmental change (i.e., what the effect is). The cause-and-effect relationships for each resource are used to determine the magnitude of the cumulative effect resulting from all actions included in the analysis.

Cause-and-effect relationships can be simple or complex. The magnitude of an effect on a species may depend simply on the amount of habitat that is disturbed. Similarly, effects on archaeological sites may be quantified by enumerating the sites that are disturbed. Other responses may be more complex. The example shown in Figure 4-1 demonstrated that the successful hatching of salmon eggs depends on the percentage of fine particles in the stream bottom in a complex but predictable fashion. Socioeconomic models can be applied in a similar way to determine the effects of changes in immigration and emigration rates on the financial condition of a human community.

A wide variety of cause-and-effect evaluation techniques have been described in the literature (see Chapter 5). Techniques for evaluating ecological resources include the set of Habitat Suitability Index Models (HSI; Schamberger et al. 1982; Hayes 1989) developed by the U.S. Fish and Wildlife Service for its Habitat Evaluation Procedures (HEP; U.S. Fish and Wildlife Service 1980). These models use cause-and-effect relationships for several key environmental variables to determine the suitability of different habitats for a variety of species. The change in number of habitat units (i.e., the ability of an area to support a species) as a result of multiple actions is a useful measure of cumulative effects. Species habitat models also drive the Habitat Evaluation System of the U.S. Army Corps of Engineers (1980). For wetland habitat designations, the Wetland Evaluation Technique is often used (Adamus et al. 1987). Other methods for linking measures of environmental change to effects on resources include developing relationships between loss in wetland area and functions such as flood storage, water quality, and life support (Preston and Bedford 1988; Leibowitz et al. 1992) and linking hydrology first to vegetation and then to wildlife habitat (Nestler 1992).

Nonlinear cause-and-effect relationships among several environmental changes pose an additional challenge for the analyst. A common example is the synergistic effect on fish populations that results from the combination of direct mortality losses to hydropower turbines and increased predation losses that occur as predators are attracted to dead and stunned fish. The analyst may also have to predict additional fish mortality from disease as a result of reductions in immune responses caused by toxic contamination. A third example of a common cumulative cause-and-effect problem is the combined effect on dissolved oxygen levels of excessive algal growth resulting from both increased nutrient loading and higher temperatures.

One of the most useful approaches for determining the likely response of the resource, ecosystem, and human community to environmental change is to evaluate the historical effects of activities similar to those under consideration. In the case of road construction through a forest, the effects of similar past actions such as the construction of pipelines and power lines may provide a basis for predicting the likely effects of the proposed road construction. The residual effects of constructing and operating these linear facilities include fragmentation of forest tracts and the creation of homogeneous vegetation in the rights-of-way. Trends analysis (see Appendix A) can be used to model the effects of linear facilities over time and extrapolate the effects of a road construction project into the future.

If cause-and-effect relationships cannot be quantified, or if quantification is not needed to adequately characterize the consequences of each alternative, qualitative evaluation procedures can be used. The analyst may categorize the magnitude of effects into a set number of classes (e.g., high, medium, or low) or provide a descriptive narrative of the types of effects that may occur. Often, the analyst will be limited to qualitative evaluations of effects because cause-and-effect relationships are poorly understood or because few site-specific data are available. Even when the analyst cannot quantify cumulative effects, a useful comparison of relative effects can enable a decisionmaker to choose among alternatives.

## DETERMINING THE MAGNITUDE AND SIGNIFICANCE OF CUMULATIVE EFFECTS

The analyst's primary goal is to determine the magnitude and significance of the environmental consequences of the proposed action in the context of the cumulative effects of other past, present, and future actions. To accomplish this, the analyst must use a conceptual model of the important resources, actions, and their cause-and-effect relationships. The critical element in this conceptual model is defining an appropriate baseline or threshold condition of the resource, ecosystem, and human community beyond which adverse or beneficial change would cause significant degradation or enhancement of the resource, respectively.

The concept of a baseline against which to compare predictions of the effects of the proposed action and reasonable alternatives is critical to the NEPA process. The no-action alternative is an effective construct for this purpose, but its characterization is often inadequate for analyzing cumulative effects. Much of the environment has been greatly modified by human activities, and most resources, ecosystems, and human communities are in the process of change as a result of cumulative effects. The analyst must determine the realistic potential for the resource to sustain itself in the future and whether the proposed action will affect this potential; therefore, the baseline condition of the resource of concern should include a description of how conditions have changed over time and how they are likely to change in the future without the proposed action.

The potential for a resource, ecosystem, and human community to sustain its structure and function depends on its resistance to stress and its ability to recover (i.e., its resilience). Determining whether the condition of the resource is within the range of natural variability or is vulnerable to rapid degradation is frequently problematic. Ideally, the analyst can identify a threshold beyond which change in the resource condition is detrimental. More often, the analyst must review the history of that resource and evaluate whether past degradation may place it near such a threshold. For example, the loss of 50% of historical wetlands within a watershed may indicate that further losses would significantly affect the capacity of the watershed to withstand floods. It is often the case that when a large proportion of a resource is lost, the system nears collapse as the surviving portion is pressed into service to perform more functions.

The baseline condition should also include other present (ongoing) actions. For example, the National Ambient Air Quality Standards (NAAQS) inventory represents the universe of present actions used in air quality analyses to determine whether new emission sources will exceed air quality standards. The NAAQS inventory includes all existing emission sources, sources with Prevention of Significant Deterioration (PSD) permits that have not yet begun to operate, and applicants for whom a PSD permit has not yet been issued. The NAAQS analysis requires explicitly modeling all existing nearby sources (as far away as 50 kilometers) be for air quality effects. In the analysis of the cause-and-effect relationships related to the anticipated impacts, each source represents a cause, and their combined emissions create an effect on air quality, the significance of which can be determined by comparing the concentration of pollutants emitted to threshold concentrations specified in the NAAQS. The NAAQS thresholds are concentrations known to cause significant human health or other environmental effects.

The historical context and full suite of ongoing actions are not only critical for evaluating cumulative effects, but also for developing potential restoration as well. The first step in developing a river restoration plan is to understand how past actions (e.g., contributions of contaminants to the watershed) have contributed to the current condition of the water body. The historical trends in resource condition and its current potential for sustained structure and function are an essential frame of reference for developing mitigation and enhancement measures.

### Determining Magnitude

Initially, the analyst will usually determine the separate effects of past actions, present actions, the proposed action (and reasonable alternatives), and other future actions. Once each group of effects is determined, cumulative effects can be calculated. The cumulative effects on a specific resource, however, will not necessarily be the sum of the effects of all actions. Knowing how a particular resource responds to environmental change (i.e., the cause-and-effect relationship) is essential for determining the cumulative effect of multiple actions. Will the effects of two or more actions be additive, i.e., if one project would result in the death of 25% of a trout population (within a given level of uncertainty) and another the death of 10% of the trout, would the two projects together result in the loss of 35% of the trout? Although this is sometimes the case, there are often instances where the cause-and-effect relationship is more complex, i.e., the cumulative effect of two projects may be greater than the sum of the effects of each (in the trout example, more than 35% of the trout would die) or less than their sum (less than 35% of the trout would die). In some cases, the resource may better withstand additional adverse effects as stress increases, while in others, the resource may crash once a threshold is reached.

Once effects are identified using one of the methodologies described in Chapter 5, a table can be used to itemize effects into categories of past, present, proposed, and future actions. Tables 4-1, 4-2, and 4-3 show how these tables can be constructed using the results from different types of analyses. Regardless of the degree of quantification used, such tables are useful tools for putting the effects of the proposed action and alternatives into proper context. Table 4-1 illustrates the net cumulative effects of combining fish population increases from the proposed action with population losses from past and future actions. The table could be expanded to include the countervailing effect of sulfate aerosols on global warming (because they compensate for greenhouse gases) at the same time they are degrading ambient air quality. A series of such tables (one for each alternative) enables the analyst to compare alternatives meaningfully.

**Table 4-1. Example table using quantitative description of effects (within a given level of uncertainty) on various resources**

| Resource | Past Actions | Present Actions | Proposed Action | Future Actions | Cumulative Effect |
|---|---|---|---|---|---|
| Air Quality | No effect on $SO_2$ | 20% increase in $SO_2$ | 10% increase in $SO_2$ | 5% increase in $SO_2$ | 35% increase in $SO_2$ |
| Fish | 50% of 1950 population lost | 2% of fish population lost | 5% increase in fish population | 1% of fish population lost | 48% of 1950 fish population lost |
| Wetlands | 78% of presettlement wetlands lost | 1% of existing wetlands lost annually for 5 years | 0.5% of existing wetlands lost | 1.5% of existing wetlands lost annually for 10 years | 95% of presettlement wetlands lost in10 years |

The separation of effects into those attributable to the proposed action or a reasonable alternative versus those attributable to past and future actions also allows the analyst to determine the incremental contribution of each alternative. Situations can arise where an incremental effect that exceeds the threshold of concern for cumulative effects results, not from the proposed action, but from reasonably foreseeable but still uncertain future actions. Although this situation is generally unexplored, the decisionmaker is faced with determining whether to forgo or modify the proposed action to permit other future actions. Identifying incremental effects, therefore, is an important part of informing the decisionmaker.

Most cumulative effects analyses will identify varying levels of beneficial and adverse effects depending on the resource and the individual action. Aquatic species will experience entirely different effects from terrestrial ones. A warm water fishery (e.g., largemouth bass) may benefit from a change that is detrimental to a cold water fishery (e.g., trout), and effects that are beneficial to the well being of a human community (e.g., provision of social services) may be detrimental to natural systems (e.g., wetlands lost during construction of a hospital). Because of this mixture of beneficial and adverse effects, the decisionmaker is often hard pressed to determine which alternative is environmentally preferred. To overcome this problem, indices of overall cumulative effect can be developed. Some of the matrix methods used in cumulative effects analysis were developed specifically to address this need. These methods use unitless measures of effect (e.g., scales or ranks) to get around the problem of combining results from a variety of resources.

Presentation of overall cumulative effects can be controversial. Intentional or unintentional manipulation of assumptions can dramatically alter the results of aggregated indices (Bisset 1983), and experience indicates that complex quantitative methods for evaluating cumulative effects make it more difficult for the public to understand and accept the results. Effects on resources are usually presented separately, and professional judgment is used in determining the reasonable alternative with the greatest net positive cumulative effect. The U.S. EPA has developed guidelines for addressing specific kinds of risks (including cancer risks and the risks posed by chemical mixtures) and for comparing disparate kinds of risks (U.S. EPA 1993).

| Table 4-2. Example table using qualitative description of effects on various resources, with impact ranks assigned a value from 1 to 5 (least to greatest) | | | | | |
|---|---|---|---|---|---|
| **Resource** | **Past Actions** | **Present Actions** | **Proposed Action** | **Future Actions** | **Cumulative Effect** |
| Air Quality | 1 | 2 | 1 | 1 | 2 |
| Fish | 3 | 2 | 1 | 1 | 4 |
| Wetlands | 4 | 1 | 1 | 1 | 4 |

| Table 4-3. Example table using narrative description of effects on various resources | | | | | |
|---|---|---|---|---|---|
| **Resource** | **Past Actions** | **Present Actions** | **Proposed Action** | **Future Actions** | **Cumulative Effect** |
| Air Quality | Impacts dissipated | Noticeable deterioration in visibility during summer, but standards met | Visibility affected during operations, but standards met | Increase in auto emissions expected | Standards possibly violated |
| Fish | Decrease in numbers and species diversity | Occasional documented fish kills | Increase in number of fish kills | Loss of cold-water species due to change in temperature | Significant decline in numbers and species diversity |
| Wetlands | Large reduction in acreage of wetlands | Loss of small amount of wetland annually | Disturbance of a 5 acre wetland | Continued loss of wetlands | Significant cumulative loss of wetlands |

### Determining Significance

The significance of effects should be determined based on context and intensity. In its implementing regulations for NEPA, CEQ states that "the significance of an action must be analyzed in several contexts such as society as a whole (human, national), the affected region, the affected interests, and the locality" (40 CFR § 1508.27). Significance may vary with the setting of the proposed action.

Intensity refers to the severity of effect (40 CFR § 1508.27). Factors that have been used to define the intensity of effects include the magnitude, geographic extent, duration, and frequency of the effects. As discussed above, the **magnitude** of an effect reflects relative size or amount of an effect. **Geographic extent** considers how widespread the effect might be. **Duration and frequency** refers to whether the effect is a one-time event, intermittent, or chronic. Where a quantitative evaluation is possible, specific criteria for significance should be explicitly identified and described. These criteria should reflect the resilience of the resource, ecosystem, and human community to the effects that are likely to occur.

Thresholds and criteria (i.e., levels of acceptable change) used to determine the significance of effects will vary depending on the type of resource being analyzed, the condition of the resource, and the importance of the resource as an issue (as identified through scoping). Criteria can be quantitative units of measure such as those used to determine threshold values in economic impact modeling, or qualitative units of measure such as the perceptions of visitors to a recreational area. No matter how the criteria are derived, they should be directly related to the relevant cause-and-effect relationships. The criteria used, including quantitative thresholds if appropriate, should be clearly stated in the assessment document.

Determinations of significance in an EA or an EIS are the focus of analysis because they lead to additional (more costly) analysis or to inclusion of additional mitigation (or a detailed justification for not implementing mitigation). The significance of adverse cumulative effects is a sensitive issue because the means to modify contributing actions are often outside the purview of the proponent agency. Currently, agencies are attempting to deal with this difficult issue by improving their analysis of historical trends in resource and ecosystem condition. Even where cumulative effects are not deemed to be significant, better characterization of historical changes in the resource can lead to improved designs for resource enhancement. Where projected adverse effects remain highly uncertain, agencies can implement adaptive management—flexible project implementation that increases or decreases mitigation based on monitoring results.

## AVOIDING, MINIMIZING, AND MITIGATING SIGNIFICANT CUMULATIVE EFFECTS

If it is determined that significant cumulative effects would occur as a result of a proposed action, the project proponent should avoid, minimize, or mitigate adverse effects by modifying or adding alternatives. The proponent should not overlook opportunities to enhance resources when adverse cumulative effects are not significant. The separation of responsibilities for actions contributing to cumulative effects makes designing appropriate mitigation especially difficult. In the case of the Lackawanna Industrial Highway, the Federal Highway Administration and Pennsylvania Department of Transportation sponsored development of a comprehensive plan for the valley that provides a mechanism for ensuring that secondary development accompanying construction of the highway would protect valued resources, ecosystems, and human communities (see box).

By analyzing the cause-and-effect relationships resulting in cumulative effects, strategies to mitigate effects or enhance resources can be developed. For each resource, ecosystem, and human community of concern, the key to developing constructive mitigation strategies is determining which of the cause-and-effect pathways results in the greatest effect. Mitigation and enhancement strategies that focus on those pathways will be the most effective for reducing cumulative effects.

It is sometimes more cost-effective to mitigate significant effects after they occur. This might involve containing and cleaning up a spill, or restoring a wetland after it has been degraded. In most cases, however, avoidance or minimization are more effective than remediating unwanted effects. For example, attempting to remove contaminants from air or water is much less effective than preventing pollution discharges into an airshed or watershed. Although such preventative approaches can be the most (or only) effective means of controlling cumulative effects, they may require extensive coordination at the regional or national scale (e.g., federal pollution control statutes).

## Mitigating the Secondary and Cumulative Effects of the Lackawanna Valley Industrial Highway

Cumulative effects analysis conducted as part of the EIS for construction of a 16-mile-long, multi-lane, limited access highway in the Lackawanna Valley of Pennsylvania predicted substantial secondary environmental consequences from the expected (and desired) economic development in the valley. Specifically, additional industrial, commercial, and housing development would accompany the economic activity, producing higher demands on the valley's circulation system as well as on central water and sewer services and on other types of community services as well. To ensure that the development occurring as a result of the highway's construction would take place in an environmentally-sensitive manner, the Lackawanna Valley Corridor Plan was developed. This plan was a cooperative study sponsored by the Federal Highway Administration, Pennsylvania Department of Transportation, Pennsylvania Department of Community Affairs, and Lackawanna County through the Lackawanna County Regional Planning Commission (1996). The study produced an overall framework for the future development of the valley, including a Land Use Plan and a Circulation Plan, and a series of land development regulations that may be implemented by valley municipalities to ensure that new development protects community values and environmental resources. By undertaking the Lackawanna Valley Corridor Plan as part of the environmental decisionmaking process for the Lackawanna Valley Industrial Highway, the responsible federal and state agencies provided a concrete mechanism to avoid, minimize, and mitigate potentially adverse cumulative effects from secondary actions beyond their direct control.

## ADDRESSING UNCERTAINTY THROUGH MONITORING AND ADAPTIVE MANAGEMENT

The complexity of cumulative effects problems ensures that even rigorous analyses will contain substantial uncertainties about predicted environmental consequences (Carpenter 1995a). Risk assessment methods offer effective ways of presenting the uncertainties to decisionmakers (Carpenter 1995b), and increased scientific knowledge and improved analytical capabilities using modern computers and GIS can help reduce this uncertainty. Nonetheless, both researchers and practitioners generally agree that monitoring is critical to assess the accuracy of predictions of effects and ensure the success of mitigations (Canter 1993). Monitoring provides the means to identify the need for modifying (increasing or decreasing) mitigation, and adaptive management provides the flexible program for achieving these changes. An efficient, cost-effective approach to adaptive management is to sequentially implement mitigation measures so that the measures can be changed as needed (Carpenter 1995c).

It is important to remember that the goal of the NEPA process is to reduce adverse environmental effects (or maximize the net beneficial effect), including cumulative effects. Cumulative effects analysis, therefore, should be an iterative process in which consequences are assessed repeatedly following incorporation of avoidance, minimization, and mitigation measures into the alternatives. In this way, monitoring is the last step in determining the cumulative effects that ultimately result from the action. Important components of a monitoring program for assessing cumulative effects include the following:

- measurable indicators of the magnitude and direction of ecological and social change,
- appropriate timeframe,

- appropriate spatial scale,
- means of assessing causality,
- means of measuring mitigation efficacy, and
- provisions for adaptive management.

## ENVIRONMENTAL CONSEQUENCES SUMMARY

Although cumulative effects analysis is similar in many ways to the analysis of project-specific effects, there are key differences. To determine the environmental, social, and economic consequences of cumulative effects, the analyst should

- Select the resources, ecosystems, and human communities considered in the project-specific analysis to be those that could be affected cumulatively.
- Identify the important cause-and-effect relationships between human activities and resources of concern using a network or systems diagram that focuses on the important cumulative effects pathways.
- Adjust the geographic and time boundaries of the analysis based on cumulative cause-and-effect relationships.
- Incorporate additional past, present, and reasonably foreseeable actions into the analysis as indicated by the cumulative cause-and-effect relationships.
- Determine the magnitude and significance of cumulative effects based on context and intensity and present tables comparing the effects of the proposed action and alternatives to facilitate decisionmaking.
- Modify or add alternatives to avoid, minimize, or mitigate cumulative effects based on the cause-and-effect pathways that contribute most to the cumulative effect on a resource.
- Determine cumulative effects of the selected alternative with mitigation and enhancement measures.
- Explicitly address uncertainty in communicating predictions to decisionmakers and the public, and reduce uncertainty as much as possible through monitoring and adaptive management.

Determining the environmental consequences entails describing the cause-and-effect relationships producing cumulative effects and summarizing the total effect of each alternative. These activities require developing a cumulative effects analysis methodology (Chapter 5) from available methods, techniques, and tools of analysis (Appendix A).