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METHODS, TECHNIQUES, AND TOOLS FOR ANALYZING CUMULATIVE EFFECTS

Analyzing cumulative effects under NEPA is conceptually straightforward but practically difficult. Fortunately, the methods, techniques, and tools available for environmental impact assessment can be used in cumulative effects analysis. These methods are valuable in all phases of analysis and can be used to develop the conceptual framework for evaluating the cumulative environmental consequences, designing appropriate mitigations or enhancements, and presenting the results to the decisionmaker.

This chapter introduces the reader to the literature on cumulative effects analysis and discusses the incorporation of individual methods into an analytical methodology. Appendix A provides summaries of 11 methods for analyzing cumulative effects. The research and environmental impact assessment communities continue to make important contributions to the field. In addition to methods developed explicitly for environmental impact assessment, valuable new approaches to solving cumulative effects problems are being put forth by practitioners of ecological risk assessment (Suter 1993; U.S. EPA 1992; U.S. EPA 1996), regional risk assessment (Hunsaker et al. 1990), and environmental planning (Williamson 1993; Vestal et al. 1995). Analysts should use this chapter and Appendix A as a starting point for further research into methods, techniques, and tools that can be applied to their projects.

LITERATURE ON CUMULATIVE EFFECTS ANALYSIS METHODS

Several authors have reviewed the wide variety of methods for analyzing cumulative effects that have been developed over the last 25 years (see Horak et al. 1983; Witmer et al. 1985; Granholm et al. 1987; Lane and Wallace 1988; Williamson and Hamilton 1989; Irwin and Rodes 1992; Leibowitz et al. 1992; Hochberg et al. 1993; Burris 1994; Canter and Kamath 1995; Cooper 1995; Vestal et al. 1995). In a review of 90 individual methods, Granholm et al. (1987) determined that none of even the 12 most promising methods met all of the criteria for cumulative effects analysis. Most of the methods were good at describing or defining the problem, but they were poor at quantifying cumulative effects. No one method was deemed appropriate for all types or all phases of cumulative effects analysis. In general, these authors grouped existing cumulative effects analysis methods into the following categories:

- those that describe or model the cause-and-effect relationships of interest, often through matrices or flow diagrams (see Bain et al. 1986; Armour and Williamson 1988; Emery 1986; Patterson and Whillans 1984);

- those that analyze the trends in effects or resource change over time (see Contant and Ortolano 1985; Gosselink et al. 1990); and
- those that overlay landscape features to identify areas of sensitivity, value, or past losses (see McHarg 1969; Bastedo et al. 1984; Radbruch-Hall et al. 1987; Canters et al. 1991).

These methods address important aspects of considering multiple actions and multiple effects on resources of concern, but they do not constitute a complete approach to cumulative effects analysis. General analytical frameworks for analysis have been developed for the U.S. Army Corp of Engineers (Stakhiv 1991), U.S. Fish and Wildlife Service (Horak et al. 1983), Department of Energy (Stull et al. 1987), U.S. Environmental Protection Agency (Bedford and Preston 1988), and the Canadian Government (Lane and Wallace 1988). In addition, the U.S. EPA and the National Oceanic and Atmospheric Administration have developed two specific approaches to address the problems of cumulative wetlands loss (Leibowitz et al. 1992; Vestal et al. 1995).

These methods usually take one of two basic approaches to addressing cumulative effects (Spaling and Smit 1993; Canter 1994):

- **Impact assessment approach,** which analytically evaluates the cumulative effects of combined actions relative to thresholds of concern for resources or ecosystems.
- **Planning approach,** which optimizes the allocation of cumulative stresses on the resources or ecosystems within a region.

The first approach views cumulative effects analysis as an extension of environmental impact assessment (e.g., Bronson et al. 1991; Conover et al. 1985); the second approach regards cumulative effects analysis as a correlate of regional or comprehensive planning (e.g., Bardecki 1990; Hubbard 1990; Stakhiv 1988; 1991). Although the impact assessment approach more closely parallels current NEPA practice, an optimizing approach based on a community-derived vision of future conditions may be preferable in the absence of reliable thresholds for the resources, ecosystems, and human communities of concern. In fact, the planning approach to cumulative effects analysis is becoming more common within agencies and intergovernmental bodies as they embrace the principles of ecosystem management (IEMTF 1995) and sustainable development. These two approaches are complementary and together constitute a more complete cumulative effects analysis methodology, one that satisfies the NEPA mandate to merge environmental impact assessment with the planning process.

IMPLEMENTING A CUMULATIVE EFFECTS ANALYSIS METHODOLOGY

Although the NEPA practitioner must draw from the available methods, techniques, and tools it is important to understand that a study-specific methodology is necessary. Designing a study-specific methodology entails using a variety of methods to develop a conceptual framework for the analysis. The conceptual framework should constitute a general causal model of cumulative effects that incorporates information on the causes, processes, and effects involved. A set of primary methods can be used to describe the cumulative effects study in terms of multiple causation, interactive processes, and temporally and spatially variable effects.

The **primary methods** for developing the conceptual causal model for a cumulative effects study are

1. **Questionnaires, interviews, and panels** to gather information about the wide range of actions and effects needed for a cumulative effects analysis.

2. **Checklists** to identify potential cumulative effects by reviewing important human activities and potentially affected resources.

3 **Matrices** to determine the cumulative effects on resources, ecosystems, and human communities by combining individual effects from different actions.

4 **Networks and system diagrams** to trace the multiple, subsidiary effects of various actions that accumulate upon resources, ecosystems, and human communities.

5 **Modeling** to quantify the cause-and-effect relationships leading to cumulative effects.

6 **Trends analysis** to assess the status of resources, ecosystems, and human communities over time and identify cumulative effects problems, establish appropriate environmental baselines, or project future cumulative effects.

7 **Overlay mapping and GIS** to incorporate locational information into cumulative effects analysis and help set the boundaries of the analysis, analyze landscape parameters, and identify areas where effects will be the greatest.

After developing the conceptual framework, the analyst must choose a method to determine and evaluate the cumulative effects of project actions. This method must provide a procedure for aggregating information across multiple resources and projects in order to draw conclusions or recommendations. The simplest method is the comparison of project (or program) alternatives qualitatively or quantitatively in tabular form.

Tables and matrices use columns and rows to organize effects and link activities (or alternatives) with resources, ecosystems, and human communities of concern. The relative effects of various activities can be determined by comparing the values in the cells of a table. The attributes of each cell can be descriptive or numerical. Tables are commonly used to present proposed actions and reasonable alternatives (including no-action) and their respective effects on resources of concern. Tables can be used to organize the full range of environmental, economic, and social effects. Depending on how the table is constructed, a cell may represent a combination of activities and, therefore, be cumulative, or it may include a separate column for cumulative effects.

Cumulative effects are increasingly appearing as a separate column in EISs. In the case of the cumulative mining effects in the Yukon-Charley Rivers National Preserve, Alaska (National Park Service 1990), the estimated effect of the proposed mining actions on each resource (e.g., riparian wildlife habitat) was evaluated both as a direct effect and as a cumulative effect in combination with past mining losses. Quantitative short-term and long-term effects (in acres) were calculated (Table 5-1). In the case of the Pacific yew (U.S. Forest Service 1993), the potential direct, indirect, and cumulative effects on the genetic resource of the Pacific yew were summarized qualitatively (e.g., risk of genetic erosion at edge of range; Table 5-2).

Some tables are designed explicitly to aggregate effects across resources (including weighting different effects). Grand indices that combine effects include the Environmental Evaluation System (Dee et al. 1973) and ecological rating systems for wildlife habitat and other natural areas (e.g., Helliwell 1969, 1973). Such approaches have been relatively unsuccessful because intentional or unintentional manipulation of assumptions can dramatically alter the results of aggregated indices (Bisset 1983), and because complex quantitative methods for evaluating cumulative effects make it more difficult for the public to understand and accept the results. Westman (1985) concluded that aggregation and weighting of effects should be rejected in favor of providing information in a qualitative, disaggregated form. Although it may not be possible to combine highly disparate resource effects, different resource effects that cumulatively affect interconnected systems must be addressed in combination. In any case, greater efforts need to be made to present the full suite of adverse and beneficial effects to the decisionmaker so that comparisons are clear and understandable.

Study Area Drainage	**Habitat (acres)**		**Long-Term Impacts (acres)**			**Short-Term Impacts (acres)**	
	Premining	**Existing (% Premining)**	**Past Mining Loss**	**Alternative A Loss**	**Cumulative Loss**	**Alternative A Loss**	**Cumulative Loss**
Wood chopper	1,227	1,101(89.7)	126	30	156	26	182
Coal	2,081	1,376 (66.1)	705	20	725	14	739
Sam	1,158	1,148 (99.1)	10	20	30	11	41
TOTAL	4,446	3,615 (81.2)	841	70	911	51	962
Fourth of July	833	777 (93.3)	56	20	76	16	92
GRAND TOTAL	5,299	4,402 (83.1)	897	90	987	67	1,054

Table 5-1. Cumulative effects of mining on riparian habitat in Yukon-Charley National Preserve, Alaska (National Park Service 1990)

Table 5-2. Cumulative effects on the genetic resources of the Pacific yew (U.S. Forest Service 1993)

Alternative	**Direct Effects on Existing Levels of Genetic Variation**	**Indirect Effects on Levels of Genetic Variation in Future Generations**	**Cumulative Effects**
A	Risk of losing small populations at edge of range, thereby reducing existing levels.	Risk of losing small populations at edge of range, thereby reducing future levels.	Risk of genetic erosion at edge of range.
B	None.	None.	Would negate risk to small populations and halt genetic erosion.
C	Risk of slightly reducing levels within population for some populations. No effect on overall variation.	Risk of slightly reducing some populations. No effect on overall variation or values.	Would enhance gene variation.
D	Within population levels could be reduced more than in Alt. C. No effect on overall genetic variation.	Could be reduced more than in Alt. C. for some populations. No overall effect.	Same as Alt. C.
F	Within population levels could be reduced more than in Alt. D. Overall levels of variation would be reduced slightly.	Could be reduced more than in Alt D. Potential significant reduction in adaptability of some populations and some reduction in values.	Same as Alt. C.
G 1	Same as Alt. D.	Same as Alt. D.	Same as Alt. C
G 2	Same as Alt. D.	Same as Alt. D.	Gene conservation would not be well served because of fewer reserves.

Although tables and matrices are the most common method for evaluating the cumulative effect of alternatives, map overlays and modeling can be used to summarize and evaluate cumulative effects.

In general, the standard environmental impact assessment methods described above can be combined effectively to address cumulative effects (Figure 5-1). Two aspects of cumulative effects analysis, however, warrant special analysis methods: (1) the need to address resource sustainability, and (2) the need to focus on integrated ecosystems and human communities. By definition, cumulative effects analysis involves comparing the combined effect with the capacity of the resource, ecosystem, and human community to withstand stress. **Carrying capacity analysis** has been applied to a wide range of resources to address cumulative effects. Cumulative effects are a more complex problem for whole ecosystems, because ecosystems are subject to the widest possible range of direct and indirect effects. Analyzing the cumulative effects on ecosystems requires a better understanding of the interworkings of ecological systems and a more holistic perspective. Specifically, **ecosystem analysis** entails new indicators of ecological conditions including landscape-scale measures. In addition to these two special methods, analyzing cumulative effects on human communities requires specific **economic impact analysis** and **social impact analysis methods.**

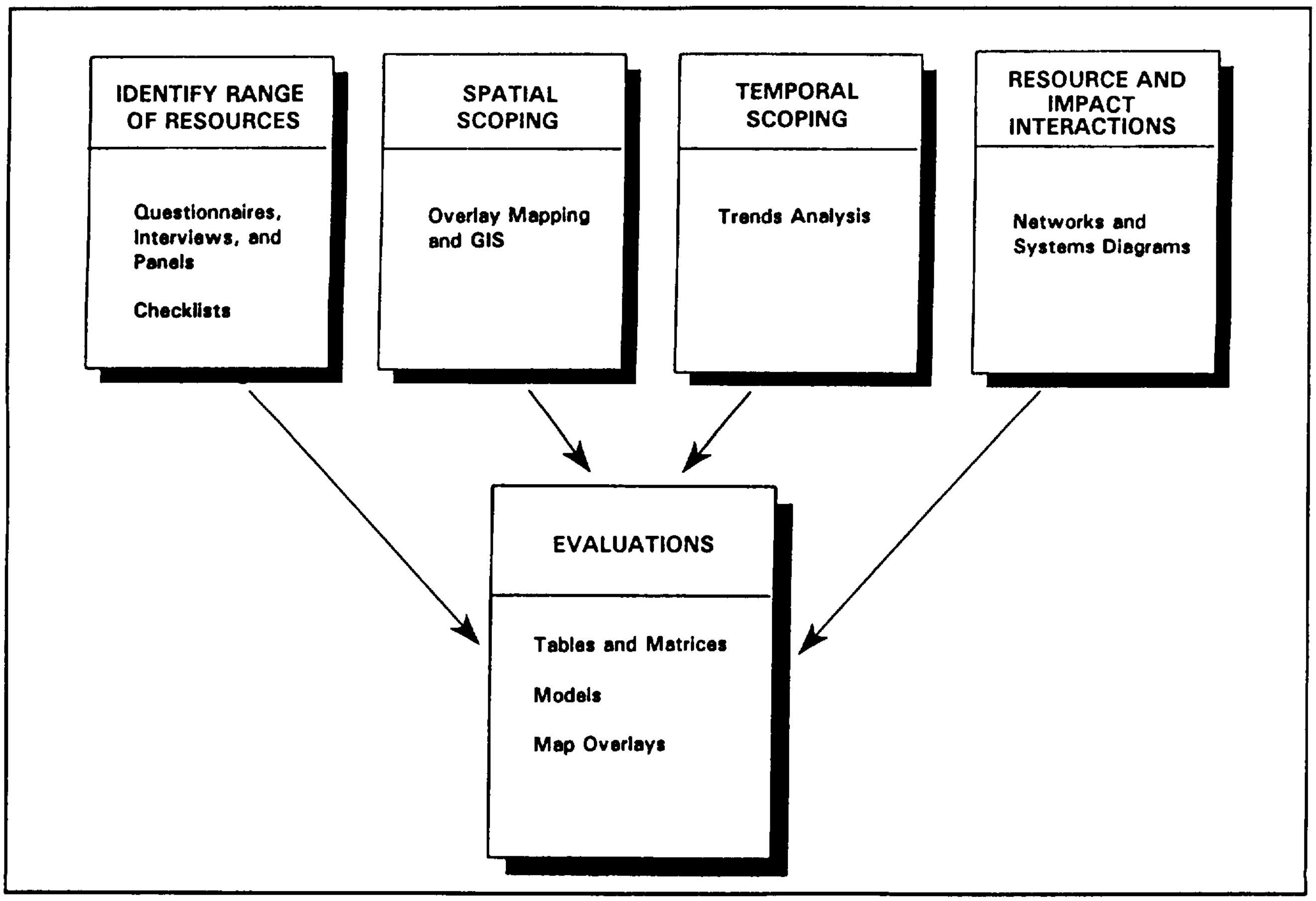

Figure 5-1. Conceptual model for combining primary methods into a cumulative effects analysis

In addition to the primary and special methods discussed above, there are several **tools** that can be used to conduct or illustrate cumulative effects analysis. The most important are modern computers with capabilities for storing, manipulating, and displaying large amounts of data. Although simple tables, graphs, and hand-drawn maps are adequate for many analyses, powerful computers can facilitate the use of multidimensional matrices and sophisticated models that require solving complex equations or conducting simulations. General tools for illustrating cumulative effects include dose-response curves, cumulative frequency distributions, maps, and videography. Video simulation, wherein an existing site is captured through imagery and electronically altered to show how the site will look after a proposed action is implemented, is a promising new technology for analyzing effects and communicating them to the public (Marlatt et al. 1993).

Most importantly, **geographic information systems (GIS)** can manipulate and display the location-specific data needed for cumulative effects analysis. GIS can be used to manage large data sets, overlay data and analyze development and natural resource patterns, analyze trends, use mathematical models of effect with locational data, perform habitat analysis, perform aesthetic analysis, and improve public consultation (Eedy 1995). GIS can incorporate a statistically reliable locational component into virtually any cumulative effects analysis. Unlike manual mapping systems, the scale can be adjusted and the data layers easily updated. Once a GIS has been developed, it can drastically reduce the effort needed to analyze the effects of future projects, i.e., each new development proposal can be readily overlain on existing data layers to evaluate cumulative effects (Johnston et al. 1988).

Effective use of the increased analytical and presentation capabilities of computers and GIS requires large amounts of data. Fortunately, available **remote sensing** technologies can provide locational information at varying levels of resolution for virtually all parts of the United States. Remote sensing applications (both photographic and satellite imagery) can help the analyst reveal the past status of environmental resources or ecological processes, determine existing environmental conditions, and quantitatively or qualitatively assess possible future trends in the environment. Although remote sensing is a relatively recent technological development, aerial photography available for most areas of the United States since the 1930s or 1940s, and space-based photographs and satellite imagery have been collected since the 1960s. For example, aerial photography from 1960, 1981, and 1990 (Figure 5-2) show change in the condition of small mountainous tributary streams to the North Fork Hoh River in the Olympic Peninsula. The photo taken in 1960 shows undisturbed old growth Sitka spruce-hemlock forest. The photos of the same location taken in 1981 and 1990 show extensive timber harvest and soil erosion. Each patch of harvested timber was approved under individual logging permits over a 30-year period. As a result of the cumulative timber harvest, the area has experienced severe landsliding and erosion, causing sedimentation in salmon spawning and rearing areas in the Hoh River and in lower portions of the tributary streams.

The combination of remote sensing and GIS has facilitated the development of a suite of landscape-scale indicators of ecosystem status that hold promise for quantifying ecological variables and improving the measurement of cumulative effects (Hunsaker and Carpenter 1990; Noss 1990; O'Neill et al. 1988, 1994).

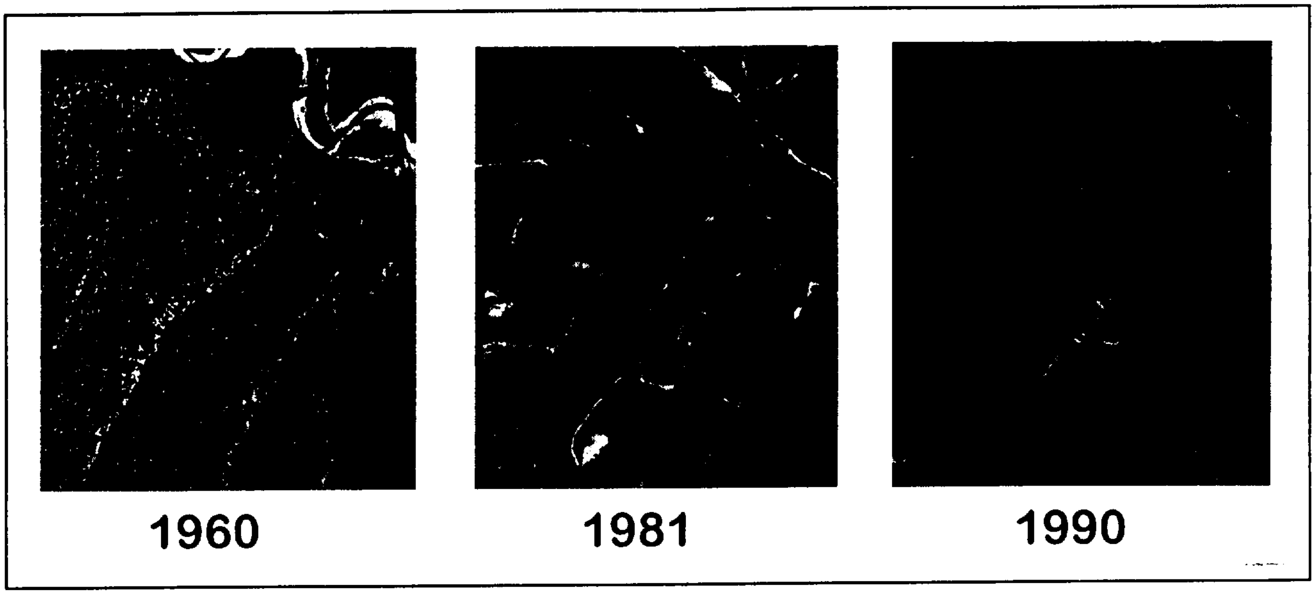

Figure 5-2. Deteriorating trend in watershed condition of the North Fork Hoh River, Washington as illustrated by a time-series of aerial photographs depicting cumulative loss of forest from individual timber sales (Dave Somers, The Tulalip Tribes, personal communication)

Table 5-3 summarizes the 11 important cumulative effects analysis methods discussed above. Appendix A provides standardized descriptions of these methods. Many cumulative effects analysis methods can be adapted for environmental or social impact assessment; the basic analytical frameworks and mathematical operations are often applicable to both social and environmental variables. Each of the 11 methods represents a general category that may contain more specific methods. When and where each method is appropriate for cumulative effects analysis depends on the following criteria:

1 Whether the method can assess

- effects of same and different nature
- temporal change
- spatial characteristics
- structural/functional relationships
- physical/biological/human interactions
- additive and synergistic interactions
- delayed effects
- persistence of impacts

2 Whether the method can

- quantify effects
- synthesize effects
- suggest alternatives
- serve as a planning or decision-making tool
- link with other methods, and

3 Whether the method is

- validated
- flexible
- reliable and repeatable.

Table 5-3. Primary and special methods for analyzing cumulative effects			
Primary Methods	**Description**	**Strengths**	**Weaknesses**
1. **Questionnaires, Interviews, and Panels**	Questionnaires, interviews, and panels are useful for gathering the wide range of information on multiple actions and resources needed to address cumulative effects. Brainstorming sessions, interviews with knowledgeable individuals, and group consensus building activities can help identify the important cumulative effects issues in the region.	▪ Flexible ▪ Can deal with subjective information	▪ Cannot quantify ▪ Comparison of alternatives is subjective
2. **Checklists**	Checklists help identify potential cumulative effects by providing a list of common or likely effects and juxtaposing multiple actions and resources; - potentially dangerous for the analyst that uses them as a shortcut to thorough scoping and conceptualization of cumulative effects problems.	▪ Systematic ▪ Concise	▪ Can be inflexible ▪ Do not address interactions or cause-effect relationships
3. **Matrices**	Matrices use the familiar tabular format to organize and quantify the interactions between human activities and resources of concern. Once even relatively complex numerical data are obtained, matrices are well-suited to combining the values in individual cells of the matrix (through matrix algebra) to evaluate the cumulative effects of multiple actions on individual resources, ecosystems, and human communities.	▪ Comprehensive presentation ▪ Comparison of alternatives ▪ Address multiple projects	▪ Do not address space or time ▪ Can be cumbersome ▪ Do not address cause-effect relationships
4. **Networks and System Diagrams**	Networks and system diagrams are an excellent method for delineating the cause-and-effect relationships resulting in cumulative effects; they allow the user to analyze the multiple, subsidiary effects of various actions and trace indirect effects to resources that accumulate from direct effects on other resources.	▪ Facilitate conceptualization ▪ Address cause-effect relationships ▪ Identify indirect effects	▪ No likelihood for secondary effects ▪ Problem of comparable units ▪ Do not address space or time
5. **Modeling**	Modeling is a powerful technique for quantifying the cause-and-effect relationships leading to cumulative effects, can take the form of mathematical equations describing cumulative processes such as soil erosion, or may constitute an expert system that computes the effect of various project scenarios based on a program of logical decisions.	▪ Can give unequivocal results ▪ Addresses cause-effect relationships ▪ Quantification ▪ Can integrate time and space	▪ Need a lot of data ▪ Can be expensive ▪ Intractable with many interactions
6. **Trends Analysis**	Trends analysis assesses the status of a resource, ecosystem, and human community over time and usually results in a graphical projection of past or future conditions. Changes in the occurrence or intensity of stressors over the same time period can also be determined. Trends can help the analyst identify cumulative effects problems, establish appropriate environmental baselines, or project future cumulative effects.	▪ Addresses accumulation over time ▪ Problem identification ▪ Baseline determination	▪ Need a lot of data in relevant system ▪ Extrapolation of system thresholds is still largely subjective
7. **Overlay Mapping and GIS**	Overlay mapping and geographic information systems (GIS) incorporate locational information into cumulative effects analysis and help set the boundaries of the analysis, analyze landscape parameters, and identify areas where effects will be the greatest. Map overlays can be based on either the accumulation of stresses in certain areas or on the suitability of each land unit for development.	▪ Addresses spatial pattern and proximity of effects ▪ Effective visual presentation ▪ Can optimize development options	▪ Limited to effects based on location ▪ Do not explicitly address indirect effects ▪ Difficult to address magnitude of effects

Table 5-3. Continued			
Special Methods	**Description**	**Strengths**	**Weaknesses**
8. Carrying Capacity Analysis	Carrying capacity analysis identifies thresholds (as constraints on development) and provides mechanisms to monitor the incremental use of unused capacity. Carrying capacity in the ecological context is defined as the threshold of stress below which populations and ecosystem functions can be sustained. In the social context, the carrying capacity of a region is measured by the level of services (including ecological services) desired by the populace.	▪ True measure of cumulative effects against threshold ▪ Addresses effects in system context ▪ Addresses time factors	▪ Rarely can measure capacity directly ▪ May be multiple thresholds ▪ Requisite regional data are often absent
9. Ecosystem Analysis	Ecosystem analysis explicitly addresses biodiversity and ecosystem sustainability. The ecosystem approach uses natural boundaries (such as watersheds and ecoregions) and applies new ecological indicators (such as indices of biotic integrity and landscape pattern). Ecosystem analysis entails the broad regional perspective and holistic thinking that are required for successful cumulative effects analysis.	▪ Uses regional scale and full range of components and interactions ▪ Addresses space and time ▪ Addresses ecosystem sustainability	▪ Limited to natural systems ▪ Often requires species surrogates for system ▪ Data intensive ▪ Landscape indicators still under development
10. Economic Impact Analysis	Economic impact analysis is an important component of analyzing cumulative effects because the economic well-being of a local community depends on many different actions. The three primary steps in conducting an economic impact analysis are (1) establishing the region of influence, (2) modeling the economic effects, and (3) determining the significance of the effects. Economic models play an important role in these impact assessments and range from simple to sophisticated.	▪ Addresses economic issues ▪ Models provide definitive, quantified results	▪ Utility and accuracy of results dependent on data quality and model assumptions ▪ Usually do not address nonmarket values
11. Social Impact Analysis	Social impact analysis addresses cumulative effects related to the sustainability of human communities by (1) focusing on key social variables such as population characteristics, community and institutional structures, political and social resources, individual and family changes, and community resources; and (2) projecting future effects using social analysis techniques such as linear trend projections, population multiplier methods, scenarios, expert testimony, and simulation modeling.	▪ Addresses social issues ▪ Models provide definitive, quantified results	▪ Utility and accuracy of results dependent on data quality and model assumptions ▪ Social values are highly variable