CHARACTERISTICS OF EFFECTIVE CEA METHODS

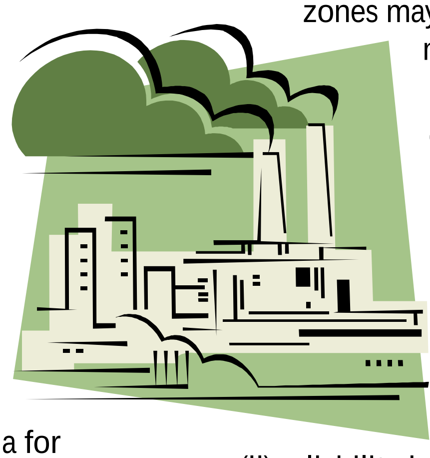
Conceptually, cumulative effects assessment (CEA) is very appealing. However, the selection of a method for conducting a CEA can be quite difficult, in part for the obvious reason that determining and quantifying cumulative impacts can be challenging at best and sometimes not possible. In general, CEA methods should exhibit the following desirable characteristics:

- Some representation of interaction
- Incorporation of impacts as they occur over space
- Incorporation of impacts as they occur over time
- The ability to trace impacts through from first-order, direct impacts to second, third, and fourth-order indirect impacts.

Further, the Council on Environmental Quality (CEQ) in the United States has identified the following criteria for consideration in selecting a CEA method:

- Whether the method can be used to assess effects of the same and different nature, temporal change, spatial characteristics, structural/functional relationships, physical/biological/human interactions, additive and synergistic interactions, delayed effects, and persistence of impacts
- Whether the method can be used to quantify effects, synthesize effects, suggest alternatives, serve as a planning or decision-making tool, and link with other methods
- Whether the method is validated, flexible, reliable, and repeatable.

Additional criteria for CEA methods may be required for specific studies. For example, methods may be needed for specific types of proposed projects or activities, such as fossil-fueled power plants or transportation systems. Various environmental media such as air, surface water, soil, or ground water may also require specific CEA criteria. The cumulative effects of land uses or ecological areas, such as urban areas, upland forests, wetlands, or coastal zones may require unique CEA methodologies.



COMPARATIVE REVIEW OF CEA METHODS

A sound CEA method needs to fulfill two objectives: (i) identification of cumulative effects; and (ii) reliability in the prediction of such effects. In this context, prediction refers to the quantification of cumulative effects. If quantitative predictions are not achievable, qualitative (i.e., descriptive) predictions of cumulative effects can instead be used.

Identification methods can be useful in scoping, establishing spatial and temporal boundaries, selecting physical-chemical, ecological or socio-economic indicators of cumulative effects, determining what features to address in preparing a description of environmental baseline conditions, and in communicating CEA results. Prediction methods are fundamental to delineating actual cumulative effects and to determining the significance of such effects in relation to thresholds and carrying capacities. The results from using these two types of methods can be incorporated within the decision making phase of the environmental impact assessment (EIA) process. This phase may incorporate multi-criteria decision making methods, with one of the decision factors being the cumulative effects of the proposed action when considered in relation to other past, present, and reasonably foreseeable future actions (RFFA) in the study area.

A frequent rationale used to explain the lack of attention to CEA is the absence of appropriate methodologies. This viewpoint is somewhat in error, as existing EIA methods can be modified and applied to address cumulative impact concerns. Table 1 identifies the strengths and weaknesses of nine types of methods that are widely discussed in the EIA literature and which have been applied in actual practice to date. Additional assessment methods which could potentially be applied in analyzing cumulative effects are examined in Table 2.

Careful examination of the methods listed in Tables 1 and 2 reveals some similarities based on the terms used in Table 2 (e.g., matrices, networks and system diagrams, modeling, overlay mapping and GIS, and ecosystem analysis). Unique methods include expert opinion, programming models and process guidelines. Additional methods include questionnaires, interviews, checklists, trend analysis, carrying capacity analysis, economic impact analysis, and social impact analysis.

Finally, modifications of EIA methods have been used in CEA. Some examples include matrix methods, causal analysis, and adaptive management. Matrix methods have been developed to calculate cumulative effects as the sum of all project-specific effects adjusted for interactions among projects in the study area. Causal analysis involves statistical analysis wherein cumulative effects are traced back to specific activities and then reconfigured into a cause-effect network. Such networks can provide the basis for the development of effects hypotheses and appropriate quantitative models. The adaptive environmental assessment and management (AEAM) method was developed for EIA, and with the use of focused workshops and simulation modeling, the concepts can be extended to CEA.

In summary, the following general observations can be made regarding CEA methods:

- Although recent comparative reviews of available assessment methods have tended to focus on the most widely-applied methods, any of the assessment methods currently used in EIA can be modified or adapted for use in CEA.
- The EIA literature has tended to focus on CEA methods related to the biophysical environment, with more limited attention given to methods related to cumulative effects on the socio-economic environment. This narrow perspective probably reflects the state-of-practice of CEA, and the interests of the authors and funding agencies for the comparative studies.

Table 1 Summary of methods for addressing cumulative impacts

GEOGRAPHIC INFORMATION SYSTEMS (GIS) *Spatial analysis with the help of digital mapping*	**Strength**: powerful and useful tool for carrying out spatial analysis of cumulative environmental change; applicable to mapping sources of cumulative environmental change and cumulative effects, with limited application for the analysis of pathways of cumulative change. **Weakness**: data requirements and variation in availability of data among different locales; inability to incorporate processes of accumulation.
NETWORK ANALYSIS *Loop analysis is a qualitative, network technique that is based on feedback relationships*	**Strength**: scores positive on most criteria; recommended for analysis of cumulative effects. **Weakness**: its application in CEA remains largely untested.
BIOGEOGRAPHIC ANALYSIS *Example: Landscape analysis*	Landscape analysis emphasizes the spatial pattern of ecological components and processes within a defined land unit, usually a watershed or other naturally bounded region. Specific indicators that relate to structural and functional attributes at the landscape level are used to measure cumulative environmental change. For example, cumulative effects in hardwood forests: three indices for structural aspects (forest loss, forest contiguity, forest pattern), five indices for functional aspects (change in stream discharge, change in water residence time, trends in stream nutrient concentration, nutrient loading rates, native biotic diversity). **Strength and weaknesses**: see GIS.
INTERACTIVE MATRICES *Example: Argonne multiple matrix*	The Argonne multiple matrix was developed to analyze the additive and interactive effects of various configurations of multiple projects. The total cumulative effect of any configuration is assumed to be the sum of project specific effects adjusted for interactions among projects and their effects. Expert opinion is used to establish three types of data: scores that define the level of effect of each project on selected environmental components, weighting coefficients that reflect the relative value of each component, and interaction coefficients that measure the effect of each pair of projects on each component. These data sets are entered into matrices that are manipulated to calculate a total score indicating the cumulative effect for each project configuration. **Strength**: consideration of the cumulative effect of multiple sources of environmental change. **Weakness**: cumulative effects are not differentiated by type, and parameter values rely extensively on expert judgment.
ECOLOGICAL MODELING *Example: Computer modeling of ecosystems*	**Strength**: theoretically, method scores very positively on a number of criteria. Weakness: application is dependent on reliable data, model validation and resources (e.g., time, money, expertise). Models usually analyze the effect of multiple sources on only one environmental component. They are only applicable to environmental systems for which the system organization and behavior are reasonably well understood.
EXPERT OPINION *Example: Use of experts in 'cause and effect diagramming'*	**Strength**: provides an organizing framework for more empirical analyses. **Weakness**: scores negatively on a number of CEA criteria.

Table 1 Summary of methods for addressing cumulative impacts (Cont'd)

PROGRAMMING MODELS *Example: Linear programming*	Linear programming is a tool that identifies resource allocations (solutions) which are feasible given specified environmental and other conditions (constraints), and then selects some 'optional' allocation based on a specified decision rule (objective function). **Strength**: offers a potential planning approach to investigate and manage cumulative environmental problems. **Weakness**: application in CEA would be a novel departure from typical socio-economic applications
LAND SUITABILITY EVALUATION *Example: 'Land disturbance target'*	The essence of this method is to select an indicator of environmental quality and to establish an allowable target or threshold for this indicator, which is then used as decision criteria to evaluate the cumulative effects of existing and future developments within an area. **Strength**: particularly suitable as a planning tool to evaluate and manage cumulative effects at the local and regional levels. **Weakness**: only a single activity or sole indicator of environmental change (e.g., erodibility); data-requirements dependent on a time limited historical record; an assumption that past land use trends and environmental responses are continued into the future.
PROCESS GUIDELINES	One approach consists of three main steps: Step one involves a decision tree diagram beginning with a series of directional questions to establish whether a CEA is needed for a particular problem. Major considerations include the type, size and number of projects, and spatial and temporal scales of anticipated effects. Step two requires a decision between two possible approaches to the analysis of cumulative effects, depending on the type identified in step one. Ex ante analysis is applied to identify and analyze cumulative environmental change in the future. Post analysis is implemented when cumulative effects are currently observable, but causality and origin are not known. Step three involves evaluation of development scenarios, assessment of the acceptability of future states of the environment, and appraisal of management options. Interdisciplinary expertise, 'affected publics' and workshops are an inherent part of this step. **Strength**: satisfactorily meets most relevant CEA criteria; suited as an organizing framework within which to carry out a comprehensive CEA, including the selection and application of more rigorous methods and techniques. **Weakness**: lacks specificity.

Table 2 Additional methods for analyzing cumulative effects

METHODS	DESCRIPTION	STRENGTHS	WEAKNESSES
Interviews Questionn-aires, and Panels	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	Flexible Can deal with subjective information	Cannot quantify Comparison of alternatives is subjective
Checklists	Help identify potential cumulative effects by providing a list of common or likely effects and juxtaposing multiple actions and resources. Checklists are potentially dangerous if used 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
Matrices	Use a 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 in the matrix 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
Networks and System Diagrams	Excellent method for delineating the cause-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 impacts on other resources.	Facilitate conceptualization Addresses cause-effect relationships Identify indirect effects	No likelihood for secondary effects Problem of comparable units Do not address space or time
Modeling	Powerful technique for quantifying the cause-effect relationships leading to cumulative effects. Modeling 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
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 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

Table 2 Additional methods for analyzing cumulative effects (Cont'd)

METHODS	DESCRIPTION	STRENGTHS	WEAKNESSES
Overlay Mapping and GIS	Incorporates 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
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 impact in system context Addresses time factors	Rarely can measure capacity May be multiple thresholds Requisite regional data are often absent
Economic Impact Analysis	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 (i) establishing the region of influence, (ii) modeling the economic impacts, and (iii) determining the significance of the impacts. 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
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

- Methods are typically reviewed as a group without distinctions of purpose (i.e., cumulative effects identification or prediction or quantification), specificity (i.e., generic methods or methods for a type of project, or specific resource or environmental media), or category of effects (i.e., biophysical or socio-economic. Such distinctions would aid in the development of appropriate comparisons between methods.
- Reviewed methods are often listed without examples of their application in CEA studies. Thus it may not be possible to judge between actual versus potential applications of the methods.

As is the case for EIA methods, there is no single CEA method that meets all of the desirable criteria, nor can a CEA depend on one method for meeting all study needs. Accordingly, a CEA study should typically involve the use of several types of methods for different purposes. Based on the assumption that selection of methods is a component of every CEA study, the question then shifts to deciding what approaches might be used to accomplish such selections. Examples include: (i) an approach based upon professional judgment only; (ii) an approach based upon systematic but qualitative comparisons of different methods for usage for different purposes; or (iii) an approach involving quantitative comparisons of different methods arrayed against a series of weighted decision criteria.

PREDICTION METHODS FOR CUMULATIVE EFFECTS

The methods available for predicting type and extent of cumulative impacts range from scoping to the use of quantitative modeling. Observations on these and other types of cumulative effects prediction methods are:

- Energy balances and mass balances can be useful prediction tools.
- Stress-response modeling refers to a general framework that can be used to predict the response of environmental systems to perturbations.
- The 'societal growth induction' capability of the proposed project may also need to be addressed in CEA. Growth induction refers to the fact that the introduction of certain activities can accelerate or decelerate the rate of development of new activities. Thus certain activities may have a precedent-setting effect in stimulating even greater development than previously anticipated.
- IMPLAN is an economic input-output model developed by the US Forest Service for estimating the effects of their various actions on employment, income, population, and other parameters at the county level and any higher aggregate affected area. It can also be used to examine cumulative socio-economic effects resulting from many types of development actions.
- Bounding analyses refer to simplified quantitative analyses that incorporate conservative assumptions and analytical techniques to ensure that the potential impacts of proposed

actions are not underestimated. The 'bounds' could be selected so as to represent 'best case' and 'worst case' conditions. Such quantitative analyses can be useful for both project-level and strategic impact studies, and for CEAs within these studies. Bounding analysis can be useful when: an impact is expected to be insignificant; when considering the generic impacts of a category of action; in the preparation of programmatic strategic environmental assessments (SEA); and for accident analyses and assessments for low-probability, high-consequence events.

- Eight methods involving indices or quantitative modeling have been developed for watershed cumulative effects occurring in California and the Pacific Northwest region of the United States.

Monitoring of Cumulative Effects

Monitoring of cumulative effects has been proposed in some cases, for example, a monitoring program for the Niagara Escarpment Plan area in southern Ontario, Canada. The area is a designated United Nations Biosphere Reserve, and monitoring in this context is defined as the repetitive measurement of indicators that will enable a better understanding of spatial and temporal changes in environmental quality.

The following generic steps are associated with developing a CEA monitoring program:

1. Establish management goals
2. Identify the ecological (i.e., natural, social, cultural) units for the monitoring program
3. Develop a monitoring framework
4. Select indicators and parameters or targets to be measured
5. Decide on sampling frequency, locations, etc.
6. Select measures that can be used to determine the significance of data collected (e.g., environmental standards and guidelines)
7. Collect the data
8. Manage and interpret the data
9. Report and use the information to assess and modify goals and objectives, environmental management practices and the monitoring system itself.