CONCEPTUAL MODELS, MATRICES, NETWORKS, AND ADAPTIVE MANAGEMENT – EMERGING METHODS FOR CEA[a]

by

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ABSTRACT

CEA can be aided by the use of an expanded set of methods. Four examples include conceptual models, modified interaction matrices, networks, and adaptive management (AM) processes. Conceptual models range from summarized scientific knowledge to graphical depictions of environmental resources, their interrelationships, and potential changes resulting from multiple actions and stressors. Modified matrices and networks can be used to address connections between proposed actions, other actions and identified VECs. Step-wise approaches for developing modified matrices and networks are also described. The AM process, which can be used to reduce uncertainties and inform the science of CEA, is thoroughly described in a corollary paper. Accordingly, and based upon concepts and case studies involving conceptual models, matrices, and networks, it can be noted that there are numerous examples of these three types of methods being used in CEA studies. The examples could be directly used in other studies or appropriately modified to meet specific site and study needs. Documentation of the rationale for the selected methods, as well as their assumptions and key features, can facilitate the aggregation of best practices approaches. The included case studies, and their usage of these three types of methods, represent extensions of the use of similar tools for addressing the direct and indirect effects of singular proposed actions via the EIA process. Finally, as the practice of CEA matures, it can be expected that continuing creativity will lead to still additional modifications and improvements in conceptual models, matrices, and networks.

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[a] Presented at Assessing and Managing Cumulative Environmental Effects, Special Topic Meeting, International Association for Impact Assessment, November 6-9, 2008, Calgary, Alberta, Canada.

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INTRODUCTION

The professional practice of environmental impact assessment (EIA) has been supported by an expanding methodological (analytical) foundation since 1970. In an analogous manner, the professional practice of cumulative effects assessment (CEA) also needs such a methodological foundation. The CEA foundation has been expanding since the early practice of CEA beginning in the mid-1980s. It is interesting to note that the developing CEA foundation is comprised of both new methodologies as well as modifications of EIA-related methodologies (Canter, 1997 and 1999; and Canter and Kamath, 1995).

Two main purposes can be identified for using methods within CEA studies: (1) to facilitate the identification of cumulative effects; and (2) for usage in the descriptive (qualitative) or quantitative prediction of such effects. Identification methods can be useful in scoping for VECs (Valued Ecosystem Components) and anticipated effects; establishing spatial and temporal boundaries for the study; selecting VEC-related indicators of cumulative effects; determining what features to address in preparing a description of historical to current baseline conditions; and in communicating study results relative to cumulative effects. 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 achieving these two purposes can be incorporated within the decision-making phase of the study 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 (RFFAs) in the designated study area.

CATALOG OF GENERIC CEA METHODS

The Council on Environmental Quality (CEQ) handbook on CEA identified 11 types of useful methods, included examples in appendices, and summarized their strengths and weaknesses. Brief information on the 11 types was also provided, with the key features of each being (Council on Environmental Quality, 1997, pp. 56-57):

- Questionnaires, Interviews, and Panels – Useful for gathering the wide range of information on multiple actions and resources (VECs) 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 study area or region. These methodologies can be used in internal and external scoping and in the identification of cumulative effects – these uses are subsequently delineated by the code SI (scoping and identification).

- Checklists – Useful for identifying potential cumulative effects by providing a list of common or likely effects and juxtaposing multiple actions and VECs. Checklists can be dangerous for the analyst that uses them as a shortcut to thorough scoping and conceptualization of cumulative effects problems. These methodologies can be used for SI and for descriptively predicting (DP) cumulative effects.

- Matrices – Use a tabular format to organize and quantify the interactions between human activities and resources of concern. Matrices can also be used to combine the values in individual cells in the matrix to evaluate the cumulative effects of multiple actions on individual resources, ecosystems, and human communities (typically referred to as VECs). These methodologies can be used for SI and DP.

- Networks and System Diagrams – Useful for delineating the cause-and-effect relationships resulting in cumulative effects. Can be used to analyze the multiple, subsidiary effects of various actions, and trace indirect effects to resources that accumulate from direct impacts on other resources (VECs). These methodologies can be useful for SI, DP, and quantitative predictions (QP).

- Modeling – A potential powerful technique for quantifying the cause-and-effect relationships leading to cumulative effects. Modeling can take the form of mathematical equations describing cumulative processes such as soil erosion, the use of VEC-specific software, or an expert system that computes the effect of various project scenarios based on a program of logical decisions. There are numerous available mathematical models which can be useful for QP.

- Trends Analysis – This methodology can be used to assess the status of VECs over time and to develop graphical projections of past or future conditions. Changes in the occurrence or intensity of stressors (contributing effects from other actions) over the same time period can also be determined. Trends can help the analyst identify cumulative effects problems, establish appropriate environmental baselines, and project future cumulative effects. This category of methodologies can be used for both DP and QP.

- Overlay Mapping and GIS – These methods 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. These methodologies can be useful for SI, DP, and QP.

- Carrying Capacity Analysis (a special method) – 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. These methodologies can be useful for DP and QP, as well as the determination of the significance of cumulative effects.

- Ecosystem Analysis (a special method) – Ecosystem analysis explicitly addresses biodiversity and ecosystem sustainability. The ecosystem approach uses natural boundaries (such as watersheds and ecoregions) and applies 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 assessment. These special methodologies can be useful for DP and QP.

- Economic Impact Analysis (a special method) – This method is an important component of analyzing cumulative effects, because the economic wellbeing of a local community and region 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 impacts, and (3) determining the significance of the impacts. Economic models play an important role in these impact assessments and range from simple to sophisticated. These special methodologies can be useful for DP and QP.

- Social Impact Analysis (a special method) – 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 judgment, and simulation modeling. These special methodologies can be useful for DP and QP.

Selection Approaches for CEA Methods

A typical CEA study requires the selection of one or more methods to meet identified study needs. Accordingly, consideration needs to be given to certain approaches which could be used in such a selection process. For some CEA studies, the sponsoring agency (proponent) may specify the methods to be used; such methods may have been specifically developed for the types of projects conducted by the agency. For example, the Federal Highway Administration (FHWA) in the USA has developed several specific tools and methods (Caltrans, et al., 2005; and Stanley, 2006). Depending upon the type of study, such methods may be dictated by proponent best practices or by statutory requirements. At the other extreme, and perhaps more typical of CEA studies, is when the proponent does not specify any methods for usage with the presumption being that the professionals on the interdisciplinary team conducting the study will utilize appropriate methods depending upon the type of project, selection of VECs, and study parameters such as time and funding. All CEA studies require some methods selection, including those studies that have stipulations for the usage of particular methods due to statutory requirements. For example, it may be necessary to select one or more methods for impact identification related to a proposed coal-fired power plant, but then to utilize a specified air quality dispersion model for addressing the atmospheric dispersion of sulfur dioxide from the plant stacks and other elevated point sources in the study area.

Based on the assumption that selection of methods, either formally or informally, is a component of every impact study, the question then becomes focused on what approaches might be used to accomplish such selections. Three examples are an approach based upon professional judgment only, an approach based upon systematic but qualitative comparisons of different methods for usage for different purposes, and an approach involving detailed quantitative comparisons of different methods arrayed against a series of weighted decision criteria (factors).

Method selection based upon professional judgment is actually involved in all three approaches. For example, methods can be chosen based upon the professional knowledge and judgment of individuals on an interdisciplinary study team, or the collective judgment of the study team as a whole, regarding comparative features of available methods and their usage in the pertinent CEA study. In this regard, specific decision criteria for comparing methods may not be delineated, with choices probably being related to the familiarity and possible previous usage of methods by individuals on the team. On the other hand, decision criteria could be used to aid the selection process. Finally, it is important to note that professional judgment can relate to both substantive issues addressed by individual methods as well as their comparative ease of usage in terms of required data, time considerations, and budgetary limitations.

Comparison Criteria for Methods

Several sets of criteria for selection of CEA methods have been promulgated since the mid-1980s (Council on Environmental Quality, 1997; Irving, et al., 1986; Smit and Spaling, 1995; and Vestal, et al., 1995). Such criteria could aid in the evaluation of existing CEA methods. Further, they could be used as a basis for combining the features of multiple methods, or modifying existing EIA or CEA methods for usage in specific studies.

One example of desirable criteria (or features) for a CEA methodology was promulgated in 1986 (Irving, et al., 1986). The six criteria, which could be generally applied to each selected VEC within a study, included: (1) the methodology should specifically address multiple developments or land use practices; (2) it should incorporate scoping to facilitate the narrowing of the list of potential impacts and impacted species and resources; (3) it should be adaptable to allow for the large array of possible site-resource-impact combinations; (4) it should have flexible boundaries in time and space because significant cumulative effects may occur offsite (at least in the traditional sense) or over an extended time frame; (5) it should be able to aggregate or tally incremental and interactive effects to give an estimate of the overall total effect to which a species or resource is being exposed; and (6) it should allow for differential levels of resolution, that is, it should allow for a more general, extensive analysis of the cumulative effects of all relevant developments, projects, or land use practices while still allowing intensive site- and project-specific impact analysis.

SCOPE OF TOPICS

The emphasis herein will be on CEA-focused modifications of two of the above types of methods – matrices and networks. Further, two additional methods not included in the above list; i.e., conceptual models and adaptive management, will be described. These additional methods are being increasingly used in CEA studies, particularly in the current decade. Adaptive Management will only be briefly addressed because a companion Special Topic Meeting paper is available on the subject (Canter and Atkinson, 2008). Finally, lessons learned from this review will be articulated.

CONCEPTUAL MODELS (CMs) IN CEA

Conceptual models (CMs) are simply abstractions of reality created to express a general understanding of a more complex process or system (Fischenich, 2008). Accordingly, a CM represents a summary of known scientific and policy information about the components of an environmental or social system (ecosystem), the characteristics and interactions of the components, and the effects of societal actions on such characteristics and interactions. More specifically, a CM has been defined as a representation of relationships among natural forces and factors, and human activities (intended or not) that are believed to impact, influence, or lead to an ecological or target condition. The target condition – e.g., lake water quality, habitat, level of risk – is significant or valued, ecologically and publicly (Henderson and O’Neil, 2004). Finally, it should be noted that CMs can be developed for usage at regional or broad-scale levels, or at localized or small-scale levels.

The outputs from CMs are typically qualitative or descriptive narratives or graphic representations that demonstrate the causal relationships between natural forces and human activities that produce changes in human and ecological systems (Henderson and O'Neil, 2004). More specifically, the information summary from a CM can be presented in a picture model form, a (descriptive) word, sentence, or paragraph model form, a tabular or interactive matrix form, a questionnaire checklist, or via box-and-arrow diagrams (analogous to network diagrams or cause-and-effects linkages used in EIA and CEA practice) (Jorgensen and Bendoricchio, 2001). Scientifically sophisticated models can include CMs which depict energy system diagrams or nutrient cycling.

Figures 1 and 2 are depictions of CMs which could be used in EIA and CEA (Henderson and O'Neil, 2007a, pp. 3-4). Figure 1 was developed in response to a breach in a dike at a confined disposal facility (Cdf). This breach resulted in the uncontrolled discharge of contaminated sediments into a nearby stream. The discharge triggered concerns about the degradation of fish and wildlife by the identified pathways. Accordingly, this simple CM could be used to anticipate the potential aquatic ecosystem consequences from the breach, and for planning a stream restoration program.

Figure 2 illustrates how the above issue (contaminated sediments) could be addressed in conjunction with urbanization effects in the stream, including an increase in runoff and stream flows, introduction of more nutrients, and loss of riparian vegetation. Increased runoff may re-suspend the contaminated sediments and flush benthic invertebrates, thus moving them downstream into the area of a drinking water intake structure. This flushing, along with increased nutrients, could contribute to water quality changes at the intake, and raise concerns about the treated water quality and potential human health consequences. Finally, Figure 3 depicts a re-arranged conceptual model for addressing both sediment quality and water supply issues in a river system (Henderson and O'Neil, 2007a, p. 5). The information is organized in accordance with a standard vocabulary involving drivers, stressors, essential ecosystem characteristics (EECs), and endpoints. Although Figure 3 is simplified it would be useful for considering cumulative effects in a river system.

In addition to EIA and CEA applicabilities, various forms of CMs (pictures, word models, connector tables and matrices, etc.) have been used for several decades in human health risk assessment, ecological risk assessment, ecosystem analysis and management, and ecosystem restoration programs. Despite the more complex scientific and policy issues which can arise in conjunction with CEA, there is a growing realization that CMs can be a useful tool in planning and conducting such cumulative effects studies.

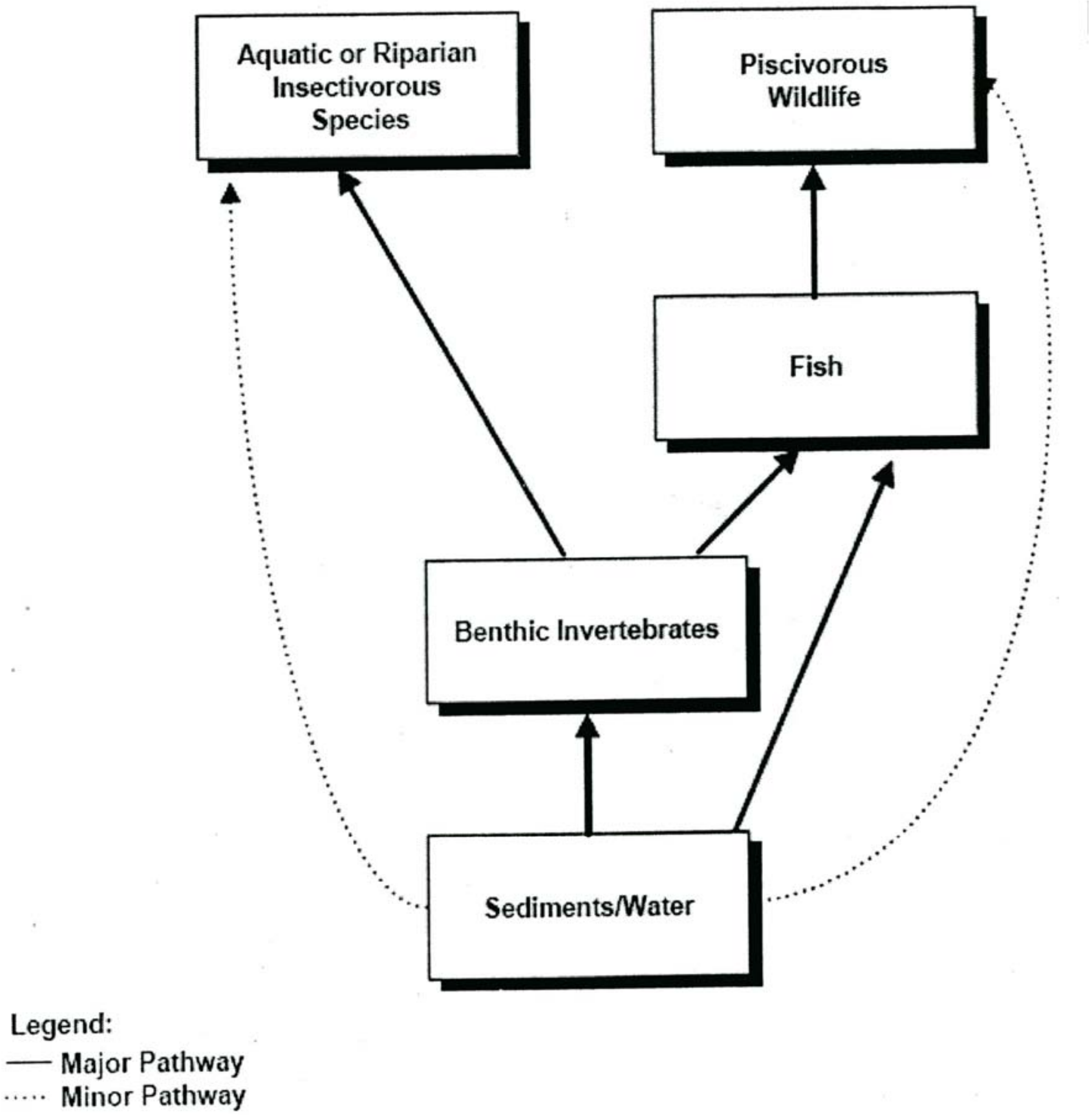


Figure 1: **New England District Model of Contaminated Sediment Uptake to Fish and Wildlife (Henderson and O'Neil, 2007a, p. 3)**

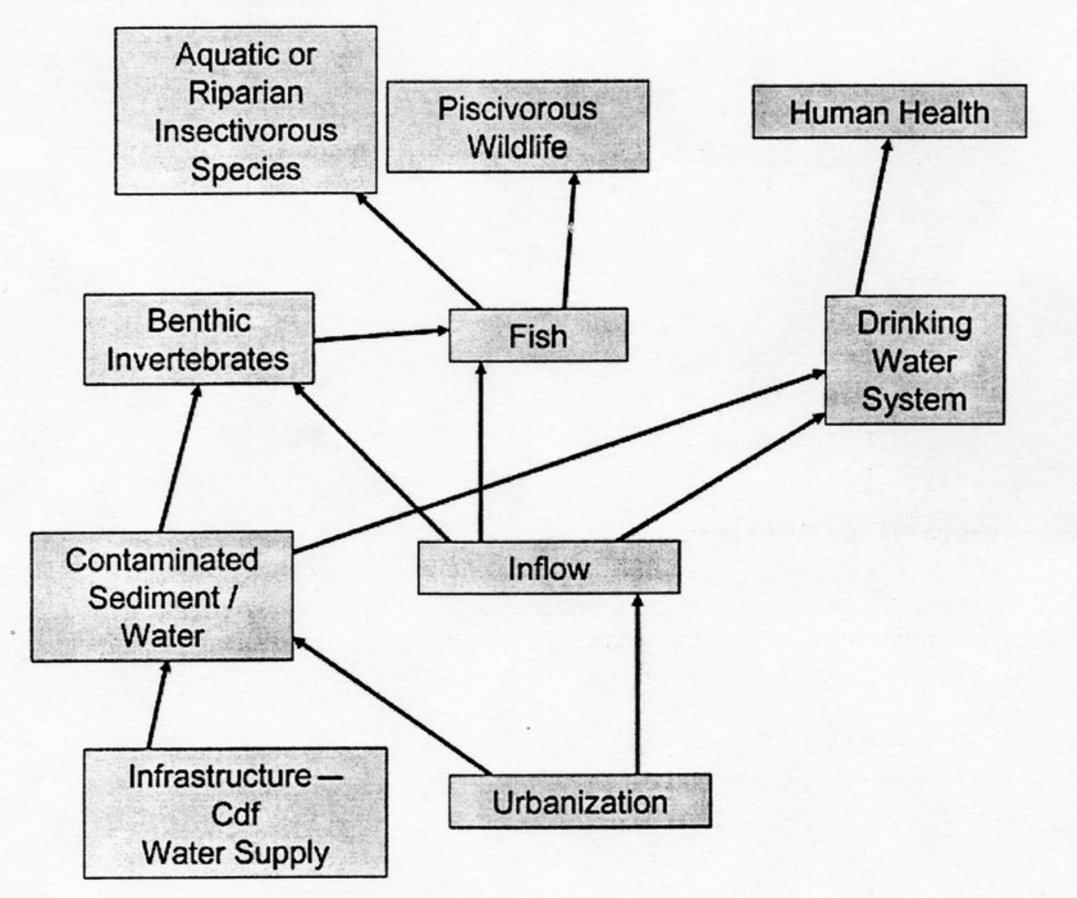
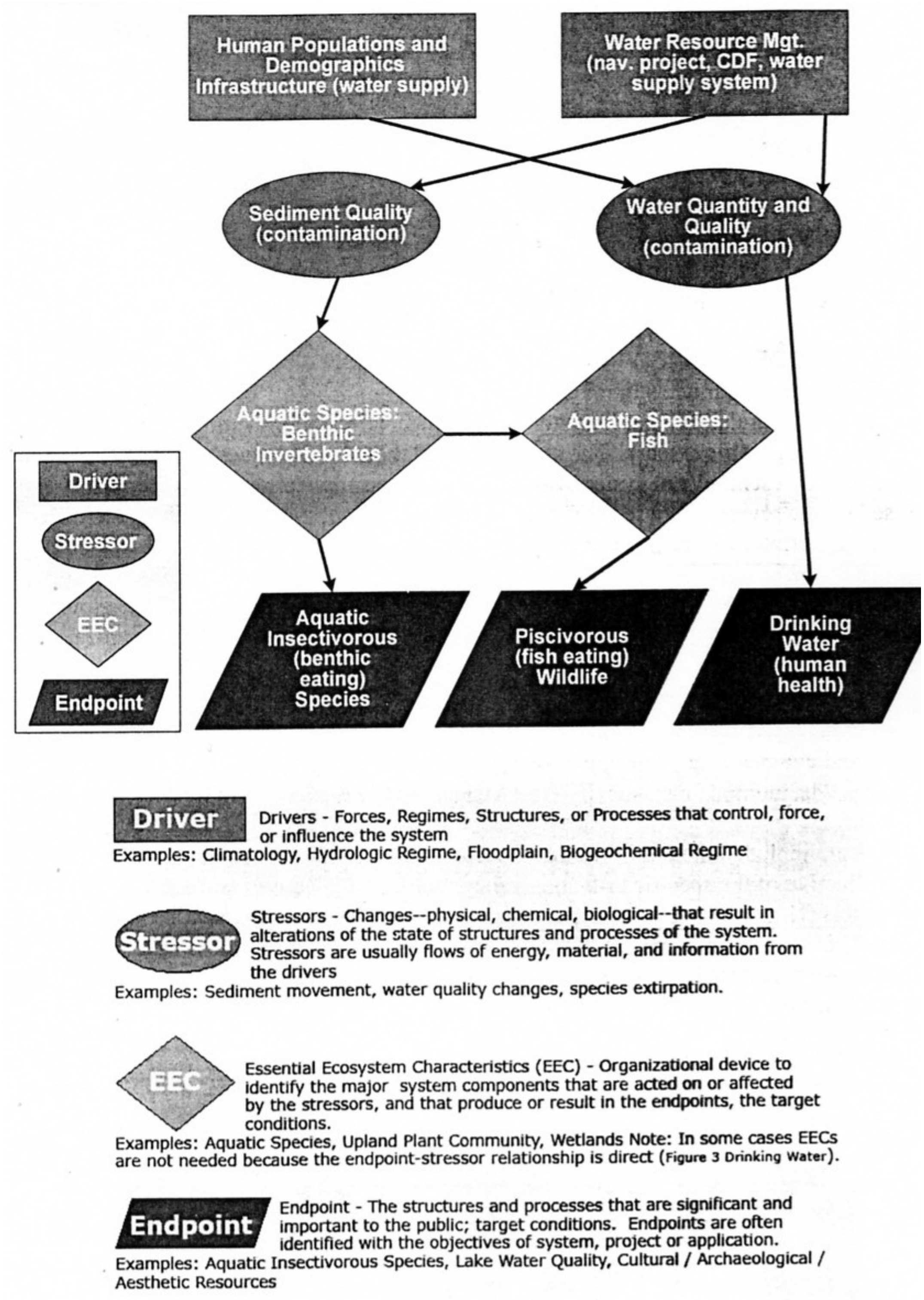


Figure 2: Water Supply Effects Added to the Contaminated Sediment Effects (Henderson and O'Neil, 2007a, p. 4)



Driver Drivers - Forces, Regimes, Structures, or Processes that control, force, or influence the system

Examples: Climatology, Hydrologic Regime, Floodplain, Biogeochemical Regime

Stressor Stressors - Changes--physical, chemical, biological--that result in alterations of the state of structures and processes of the system. Stressors are usually flows of energy, material, and information from the drivers

Examples: Sediment movement, water quality changes, species extirpation.

EEC Essential Ecosystem Characteristics (EEC) - Organizational device to identify the major system components that are acted on or affected by the stressors, and that produce or result in the endpoints, the target conditions.

Examples: Aquatic Species, Upland Plant Community, Wetlands Note: In some cases EECs are not needed because the endpoint-stressor relationship is direct (Figure 3 Drinking Water).

Endpoint Endpoint - The structures and processes that are significant and important to the public; target conditions. Endpoints are often identified with the objectives of system, project or application.

Examples: Aquatic Insectivorous Species, Lake Water Quality, Cultural / Archaeological / Aesthetic Resources

Figure 3: Conceptual Model of Contaminated Sediment-Water Supply Using D-S-EEC-E Formulation (Henderson and O'Neil, 2007a, p. 5)

Potential Uses of CMs In CEA

The potential uses of CMs in CEA include, but are not limited to, the following (National Park Service, 2008; National Park Service, undated; Henderson and O'Neil, 2004; and Patton and Mantione, 2008):

- To summarize and formalize current scientific and policy-related information related to pertinent environmental components, interactions between such components, and the anticipated direct, indirect, and cumulative effects of multiple societal actions within identified study spatial and temporal boundaries.

- To identify linkages of processes and effects across disciplinary boundaries.

- To contribute to communication among the staffs of proponent agencies or private section entities, regulatory and other government agencies, consultants, non-governmental organizations and the general public.

- To provide a scientific and policy basis for the identification of pertinent VECs and their associated indicators, the establishment of spatial and temporal boundaries for CEA studies, the designation of multiple actions contributing to common cumulative effects, the determination of the significance of such effects, and the development and evaluation of potential proposed action-related mitigation measures, and regional CEs management strategies.

- To enhance understanding of the response of VECs and their indicators to environmental stresses or changes resulting from past and present actions, and to inform predictions of the effects of future actions on such VECs and indicators.

- To facilitate the design and management of proposed projects or actions such that the promotion of environmental sustainability can be achieved.

- To aid the planning of follow-on monitoring and adaptive management (AM) programs which are designed to reduce uncertainties relative to cumulative effects. More specifically, lessons learned from the development and use of CMs for ecological monitoring programs include (National Park Service, 2008): (1) hierarchical sets of models can be useful for addressing both regional and local issues in CEA; (2) separate CMs may be needed to address plant or animal species and communities; (3) it can be time-consuming to develop scientifically-defensible and policy-consistent CMs; accordingly, collaborators with appropriate disciplinary expertise should be engaged as early as possible in development and sufficient time should be allowed for their revision; (4) at the more finite levels, models should include sufficient detail to link indicators to ecological processes and effects, and, where possible, to management actions; and (5) utilized CMs should be carefully described and definitions of key terms and phrases should be included in reporting.

- To provide an understandable foundation for the development of one or more quantitative models to address specific ecosystem processes and anticipated changes therein resulting from natural events and human intrusions.

- To serve as a useful tool to represent, communicate and analyze the structure, functions, and hierarchical relationships of the terrestrial, aquatic, and atmospheric systems affected by projects and actions promulgated by governmental agencies and the private sector.

Generic Steps in the Development of a CM

There are six generic steps related to the development of a CM (Henderson and O'Neil, 2004):

- Step 1 -- Identify the objectives and uses of the model. Examples of objectives include: (1) identify influence or cause-effect relationships; (2) communicate technical or complex issues to internal and external stakeholder groups; and (3) utilize system components to demonstrate processes and interactions, and to identify significant or critical attributes. Examples of potential uses of a model are (Henderson and O'Neil, 2004, p. 9):

    - Assessment and evaluation of changes to the system – range of natural variability; trends in model constituents, effects of planned management actions, alternatives, and scenarios; and use of the model as a simulation tool. Assessment and evaluation may support or disprove assumptions or hypotheses about the system, and the cause-and-effect relationships.

    - Providing an organizational framework for integration of input from multiple disciplines.

    - Evaluation of representative elements for significant direct, indirect, and cumulative effects on system resources and integrity, stress, and risk.

- Step 2 -- Delineate the spatial and temporal scales or boundaries of the model. Examples of questions which could be considered include (Henderson and O'Neil, 2004, pp. 11-13):

  - At what system level (local, regional, watershed, etc.) are we interested?

  - What are the requirements in the spatial extent of the system? For example, should the extent include all nearby actions contributing to cumulative effects on VECs; or should the extent address key environmental transport and fate pathways?

  - Is the system homogeneous or are there major natural or societal components or divisions of the system?

  - What are the limits to the applicability of the model; i.e., only within the specified spatial boundaries, or also to adjacent areas, or to other ecologically-similar areas?

  - Does the model address a single existing or hypothetical point in time or is the model to be used for evaluating past and future conditions?

- Step 3 -- Identify the structural components of the system. A useful approach for structural components is to consider four types of components – drivers, stressors, essential ecosystem characteristics, and endpoints. These terms are described as follows (Henderson and O'Neil, 2004, pp. 16-20):

  - Drivers are the natural and anthropogenic processes that cause ('force') changes in environmental conditions; i.e., drivers identify the source or cause of the stressors in conceptual models.

  - Stressors are the physical, chemical, and biological changes that result from natural and human-caused forces and effect other changes in ecosystem structure and/or function. Drivers can be considered first-order influences and stressors second-order influences in chains of cause and effect, where there are several links before the final effects on model endpoints. Stressors have associated time dimensions and usually can be quantified, e.g., nutrient loading rates. Stressors may affect a single resource or component, or the stressor may act on multiple ecosystem components, so that stressor effects may be limited or widespread.

  - Essential ecosystem characteristics (EECs) are system categories which depict major components acted on or through which the stressors act to cause or result in endpoints in the system. The organizing categories reflect or respond to the model domain, the process being used for development or construction of the model, and the resources of interest. Making decisions on EEC categories or the approach to use is dependent on the technical disciplines involved and knowledge and understanding of endpoints to be measured. Example system categories of EECs for the endpoints can include resources (habitat resources, water resources, land and terrestrial resources) of the location, site, or study area applicable to the conceptual model; and categories or classifications of resource types (e.g., via subregions). EECs can also include ecosystem structural and functional categories, such as individuals, populations, communities, or ecosystems; physical, chemical, and biological processes; “spheres” of processes—atmosphere, biosphere, hydrosphere, lithosphere, Sociocultural sphere, and metaprocesses (nutrient cycling, hydrologic cycling); and ecosystem patterns and processes, such as the following: patterns of landscape conditions, biotic conditions and chemical/ physical characteristics, and processes of hydrology/geomorphology, ecological processes, and natural disturbances.

  - Endpoints refer to ecosystem structures or functions that are considered ecologically significant and important to the public. Endpoints should be quantified and are often used in change assessment and monitoring. Each of the EECs could have one or more endpoints. Selecting an endpoint that is ecologically significant enables the model to be used to distinguish changes that are important ecologically or publicly from changes that have little ecological importance or that represent the natural variability of the system.

  - The endpoints identified in conceptual models may be broad, such as “native vegetation mosaic”, and as such measurement of the endpoint usually requires further specification. Often, for each endpoint or group of endpoints, another construct is needed to represent the endpoint measurement. These constructs are variously identified as assessment endpoints, performance measures, or indicators, depending on purposes, but all of them are indicators of output, or responses to natural and/or human-caused changes in the modeled system.

- <u>Step 4</u> -- Identify the sources of change in the system. The changes that occur in ecological systems are often represented in conceptual models as information transfers (as in management measures) and flows of energy and materials, including nutrients and contaminants, through the system’s structure. The system’s structure is often organized by functional level in the system (e.g., primary producer, herbivore, carnivore, decomposer). Natural and human developed processes, mechanisms, and pathways link changes in drivers to stressors and stressors to changes in EECs and to changes in endpoints (Henderson and O’Neil, 2004, p. 20).

- Step 5 -- Review the model. Most CMs are subject to periodic reviews and adjustments over both their development and usage phases. Such reviews could be conducted by the development and usage team, as well as by external peer reviewers. The following five questions could be considered in the review process (the first one is the primary question, with the last four being diagnostic in focus). The questions are (Henderson and O'Neil, 2004, p. 21):

  -- How well, effective, efficient, and unambiguously does the conceptual model fulfill its stated objectives and uses?

  -- Does the system appear complete, or is it lacking in some part?

  -- Can all of the relationships be verified to be consistent with existing science or logic?

  -- Are the relationships and linkages clear and not redundant or overlapping?

  -- Is the applicability (geographic, technical) appropriate, unclear, or overstated?

- Step 6 -- Implement the model. Model usage can involve the consideration of different drivers and stressors, and examination of the resultant endpoints. Examination of the results of such usage can be aided by the application of the following performance questions (Henderson and O'Neil, 2004, p. 24):

  -- Did the specification of drivers and stressors closely match the management measures or alternative components?

  -- Are there links or pathways of driver: stressor or endpoint: stressor relationships that were not affected? Is there a possibility the links are not important?

  -- Is there redundancy in the response of drivers, stressors, EECs, or endpoints? Does combining two or more make sense?

  -- Does the evaluation of endpoint changes make sense and provide decision-making or guidance capability?

Examples of Case Studies Involving the Use of CMs

CMs have been developed for a wide-range of uses. In some cases, the models exhibited direct usage in environmental planning and the preparation of NEPA compliance documents, including cumulative effects sections. In other cases, such models have been used for enhancing scientific understanding, monitoring and adaptive management, and general environmental management purposes, including the promotion of environmental sustainability. The following examples range from excerpts from specific studies to comprehensive reports containing detailed information, each of the examples either were or could be used in CEA. The case studies include the following:

- Fischenich (2008) – general discussion of usage of CMs for designing and evaluating U.S. Army Corps of Engineers ecological restoration projects.

- Gentile, et al. (2001) – usage of several CMs to illustrate linkages and test causal hypotheses for the environmental effects of potential ecosystem management actions being considered for sustainability enhancement in South Florida and Everglades systems.

- Gross (2003) – use of CMs for planning ecosystem monitoring programs for National Parks. Numerous visual depictions of conceptual models are included in Appendix IV.

- Henderson and O’Neil (2004) – excerpts of CMs are included on sustainable navigation on the Upper Mississippi River, a nutrient-based ecosystem model for Lake Okeechobee in the Florida Everglades, ecosystem monitoring in the Sierra Nevada National Forest, habitat evaluation along the Louisiana coastline, and ten major habitat types or communities along an 83-mile reach of Long Island in New York.

- Henderson and O’Neil (2007a) – excerpts of CMs are included on the consequences of contaminated sediments in aquatic ecosystems, and the influence of natural and anthropogenic sources of flows and contaminants in the Lower Brisbane River in Australia.

- Henderson and O’Neil (2007b) – several CMs for use by the Baltimore District of the U.S. Army Corps of Engineers in a watershed study of the middle Potomac River are described.

- King and Brown (2006) – a CM for assessing the aquatic ecosystem consequences of variable river flows in South Africa is described; emphasis is given to both quantitative and policy challenges related to model development.

- Lookingbill, et al. (2007) – the development of CMs for usage in hypothesis testing and monitoring for urban parks in the National Capital area is described along with their evaluation and usage in informing management decisions.

- Manley, et al. (2000) – an hierarchical, comprehensive, and ecosystem-processes CM for monitoring in the Sierra Nevada area of eastern and northeastern California is described, including the selection of attributes (indicators) based on their relationships to technical criteria and operational issues.

- Monz and Leung (2006) – a soil disturbance stressor model related to visitor usage in parks operated by the National Park Service is described in relation to both its development and usage in monitoring of vital signs indicators of visitor impacts.

- Napier (2006) – this detailed report describes alternative conceptual models for addressing key processes in radionuclide transport in the biosphere. There are a number of important features and processes that all terrestrial biosphere models must address: these include radionuclide behavior in soils, interception of deposition onto vegetation, weathering of intercepted material from plant surfaces, foliar absorption and translocation within plants to other vegetative structures, uptake from soil by plant roots, and transfer from plants to animals and animal products. This type of information is directly useful in formulating inputs to radioecological and food-chain models used in performance assessments and predictions of environmental impacts. This food-chain pathway information could be used to assess the radiation dose to persons in the reference biosphere (e.g., persons who live and work in an area potentially affected by radionuclide releases) of waste disposal facilities and decommissioning sites.

- Panel … (2001) – This National Research Council book reviews various processes through which CMs of flow and transport in the fractured vadose zone are developed, tested, refined, and reviewed. Some key conclusions are that the development of the CM is the most important part of the modeling process. The CM is the foundation of the quantitative, mathematical representation of the field site (i.e., the mathematical model), which in turn is the basis for the computer code used for simulation. Further, the context in which a CM is developed constrains the range of its applicability. Accordingly, a CM is by necessity a simplification of the real system, and the degree of simplification must be appropriate for the problem (issue) being addressed.

- Thomas (2001) – several examples of CMs which can be used for planning long-term ecological modeling on National Park Service lands are summarized. They include a model for current anthropogenic stressors of terrestrial prairie ecosystems, a model of core biotic and abiotic relationships of such ecosystems, models of community-level interactions and population dynamics of a plant species, an overall holistic model for the program, and a model related to monitoring feedback as an enhancement to management decisions.

- Zaldivar (2006) – this report assesses different types of coastal ecosystem models, e.g., population models, ecosystem models, chemical fate and transport models, bioaccumulation models and food web exposure models, and evaluates how an integrated fate and effect model should be developed to consider the occurrence of points at which there is an abrupt change in an ecosystem quality produced by a small change in an environmental driver. The main objective is to focus on preventing dramatic state changes in ecosystems and determine critical pollutant loads. Two case examples are addressed – a stage-based population model and a continuous food-web model that simulates a mesocosm experiment with the fast addition of a contaminant.

Reviewing CMs

While there are no certification procedures for CMs, the utilization of review criteria could be useful as a final check on model completeness and information communication. To illustrate, the U.S. Army Corps of Engineers has developed a list of questions for reviewing models in relation to the presentation, scientific bases, and forcing functions and uncontrollable factors. The comprehensive list of questions include (Fischenich, 2008, pp. 13-14):

- Presentation

    (1) Is the CM accurate, at the appropriate level of detail, and easily understood? Does the CM make effective use of various presentation types (i.e., is there a narrative component that refers to the graphical component for clarity)? Is the CM del figure (if used) well-designed and clearly presented? What changes would improve its clarity?

    (2) Is the source of the information used to support the linkages described in the model (e.g., published literature, workshop reports, expert opinion) provided? Is the importance of each linkage identified? Are the certainty and predictability of the linkage described and supported by citations as appropriate?

    (3) Does the model adequately and efficiently describe the important drivers, linkages, and outcomes related to the dynamics of the ecosystem? Does the model include extraneous information? Among the critical drivers and linkages identified that dictate function, does the model provide quantitative (or qualitative) information that can be used to evaluate the relative influence of each parameter on this outcome variable? Are any measures of certainty (confidence intervals, discussion of scientific consensus, etc.) that can be

ascribed to each parameter provided within the model? Does the CM indicate the effects, sensitivity, and direction of effects relative to changes in individual drivers? Does the CM identify the critical temporal and spatial junctures where the ecosystem elements are most important to species recovery and sustainability? Does the CM also highlight the possible limiting factors?

(4) If the model includes narrative and graphical components, can an individual knowledgeable in the field use the graphic without the narrative? Is the format easy to understand? Does the narrative adequately support the dynamics of the ecosystem element shown in the graphic?

- Scientific support, information gaps and scientific uncertainties

(1) Does the CM appropriately identify the assumptions, areas of disagreement, and gaps in the state of knowledge? Does the conceptual model accurately describe what is known about this ecosystem element, and how certain scientists are that the system performs or behaves in the manner described in the ecosystem?

(2) Does the CM identify monitoring or research needs that can help address uncertainties or data gaps? What should be added or changed to address uncertainties and how these uncertainties will be addressed in the future?

- Forcing functions and uncontrollable factors

(1) Does the CM allow for evaluation of the dynamic nature of the ecosystem element, including the role of uncontrolled drivers (e.g., local and global weather patterns)?

(2) Does the CM allow for evaluation of the nature of long-term population trends and the extent and source of variability in those trends?

Lessons Learned

Based upon the above information, three key lessons can be identified. First, CMs are not: (a) the truth – they are simplified depictions of reality; (b) final – they provide a flexible framework that evolves as understanding of the ecosystem increases; nor (c) comprehensive – they focus only upon those "parts" of an ecosystem deemed relevant while ignoring other important (but not immediately germane) elements (Fischenich, 2008). Second, it should be noted that "All models are wrong, but some are useful" (Box, 1979). Finally, EIA and

CEA practitioners routinely use CMs, although they may not actually use that specific term.

INTERACTION MATRICES IN CEA

Interaction matrices were one of the earliest types of methodologies developed for usage in impact studies. For example, in 1971, Leopold, et al. promulgated a simple interaction matrix for usage across the range of actions conducted by the U.S. Geological Survey (Leopold, et al, 1971). The “Leopold matrix” displayed project actions or activities along one axis (typically the x-axis), with appropriate environmental factors listed along the other axis (y-axis) of the matrix. When a given action or activity was expected to cause a change in an environmental factor, this was noted at the intersection point in the matrix and further described in terms of separate or combined magnitude and importance considerations.

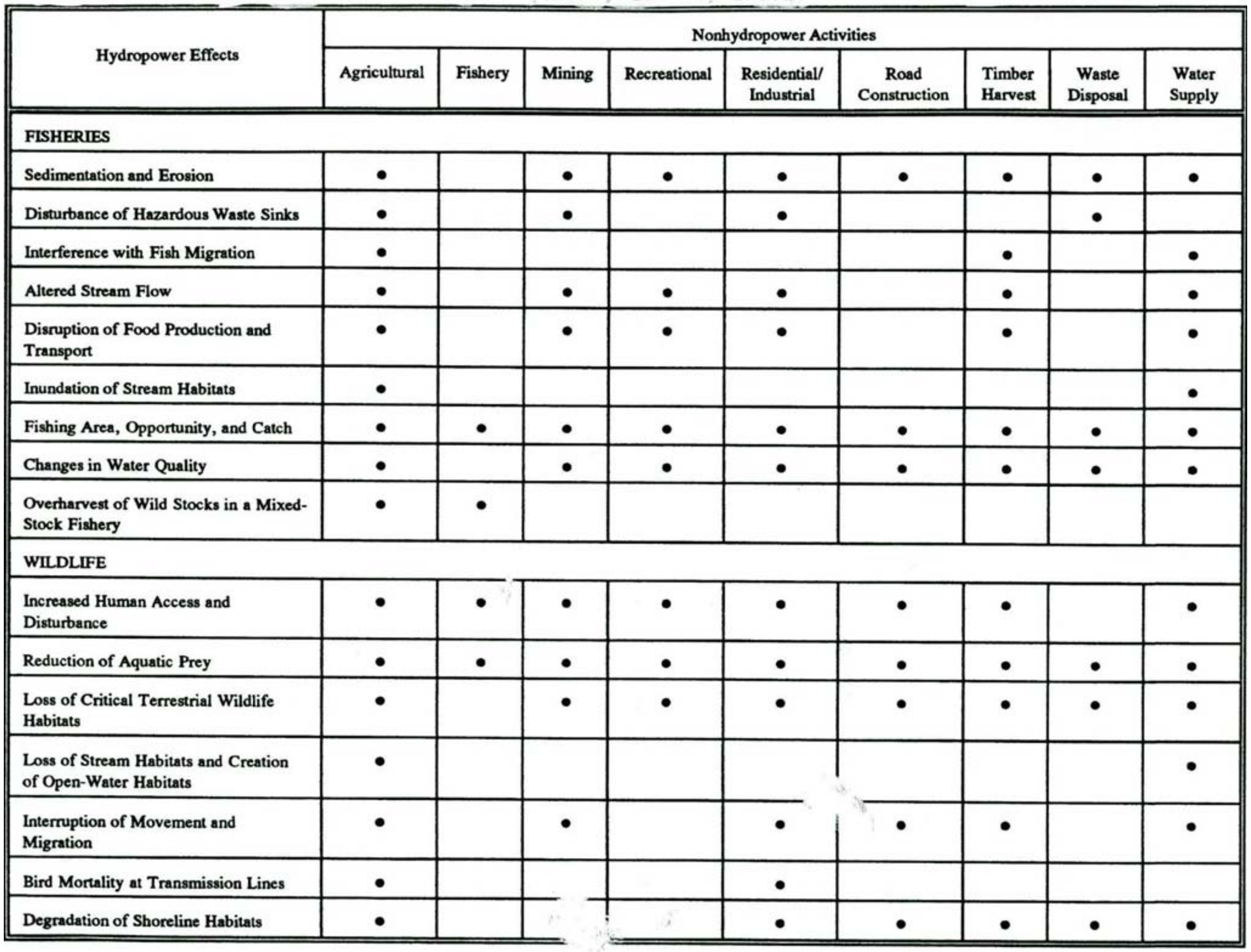
Many variations in the Leopold matrix have occurred over the four decades of EIA practice. Arguably, matrices have been the most widely used methodology in EIA practice. Further, they can be easily modified to address the type of project and utilized in CEA. To illustrate matrix modifications and their usage, seven examples will be noted herein along with the generic steps involved in the development of a CEA matrix. The section will conclude with a subsection on observations about CEA matrices.

Examples of CEA Matrices

An early example of a CEA-related matrix depicted the fish and wildlife effects of small (less than 10 MW) hydropower projects in the Columbia River Basin in the USA, along with similar effects on these resources from non-hydropower activities in the Basin. The matrix is in Table 1 (Stull, et al., 1987). The black dots in the matrix cells denote that the listed non-hydropower activities can also contribute to the effects listed in the Hydropower Effects column. Various dot sizes could have been used to denote relative contributions to the listed effects. It would also be useful to change the title of the left-hand column to “Effects”, and then include a new adjacent column entitled “Small Hydropower Projects”. The new column would include dots for each cell.

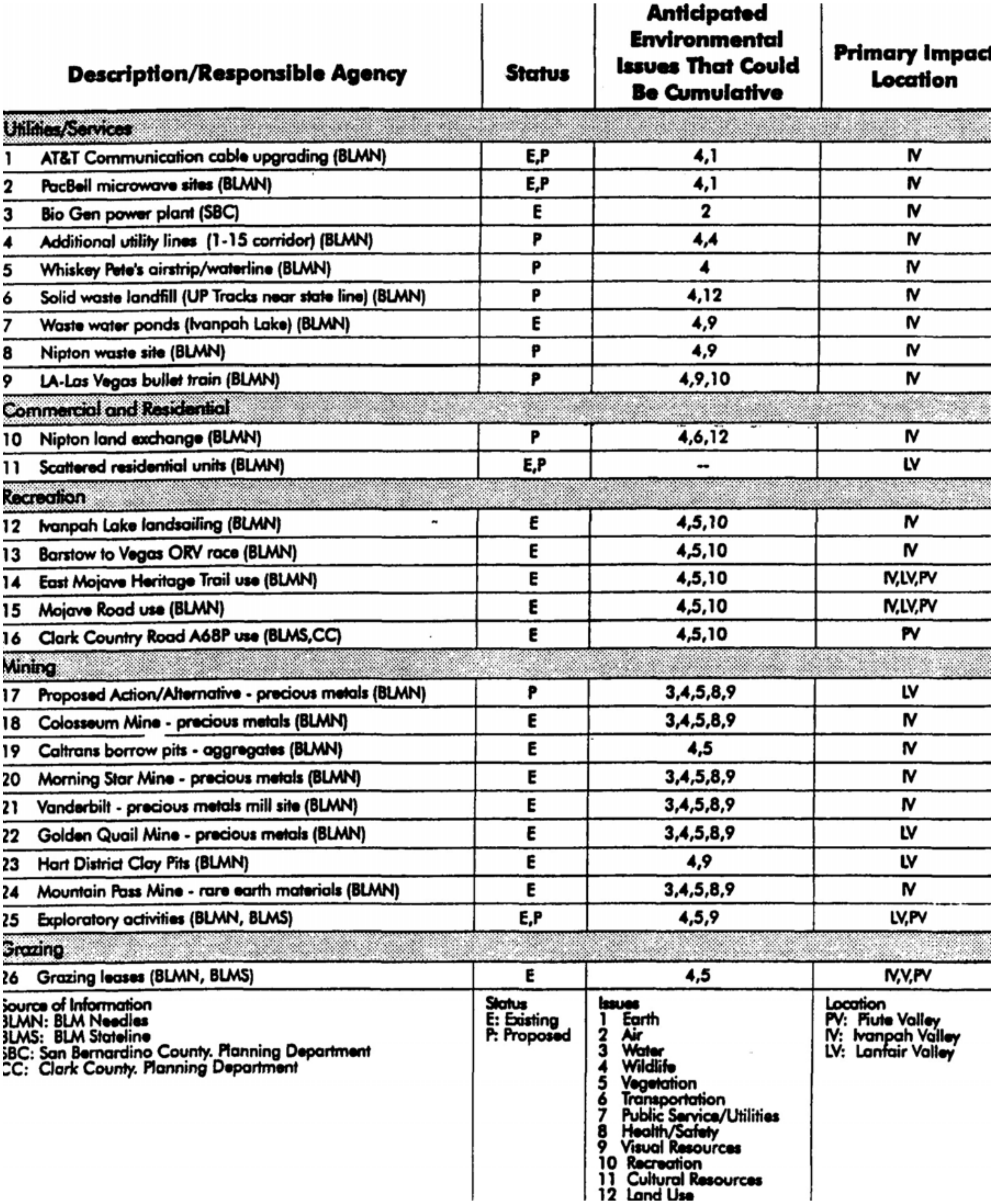
Another early example is shown in Table 2. This matrix table displays the effects of other existing and proposed activities that could affect the same 12 issues (resources or VECs) that were anticipated to be affected by the Castle Mining Project in southern California (Council on Environmental Quality, 1997, p. 28). This matrix could be improved via the addition of a row for the proposed project, division of the two status conditions (existing and proposed) into finite time categories, delineation of indicators for the 12 VECs, and the support of study area project locational maps for the time categories.

Table 1: Effects of Hydropower on Fish and Wildlife that also Occur from Other Activities in the Columbia River Basin (Stull, et al., 1987)



Hydropower Effects	Nonhydropower Activities								
	Agricultural	Fishery	Mining	Recreational	Residential/ Industrial	Road Construction	Timber Harvest	Waste Disposal	Water Supply
FISHERIES									
Sedimentation and Erosion	●		●	●	●	●	●	●	●
Disturbance of Hazardous Waste Sinks	●		●		●			●	
Interference with Fish Migration	●						●		●
Altered Stream Flow	●		●	●	●		●		●
Disruption of Food Production and Transport	●		●	●	●		●		●
Inundation of Stream Habitats	●								●
Fishing Area, Opportunity, and Catch	●	●	●	●	●	●	●	●	●
Changes in Water Quality	●		●	●	●	●	●	●	●
Overharvest of Wild Stocks in a Mixed-Stock Fishery	●	●							
WILDLIFE									
Increased Human Access and Disturbance	●	●	●	●	●	●	●		●
Reduction of Aquatic Prey	●	●	●	●	●	●	●	●	●
Loss of Critical Terrestrial Wildlife Habitats	●		●	●	●	●	●	●	●
Loss of Stream Habitats and Creation of Open-Water Habitats	●								●
Interruption of Movement and Migration	●		●		●	●	●		●
Bird Mortality at Transmission Lines	●				●				
Degradation of Shoreline Habitats	●				●	●	●	●	●

Table 2: Other Activities (existing and proposed) that May Cumulatively Affect Resources of Concern for the Castle Mountain Mining Project (Council on Environmental Quality, 1997, p. 28)



Description/Responsible Agency	Status	Anticipated Environmental Issues That Could Be Cumulative	Primary Impact Location
Utilities/Services			
1 AT&T Communication cable upgrading (BLMN)	E,P	4,1	IV
2 PacBell microwave sites (BLMN)	E,P	4,1	IV
3 Bio Gen power plant (SBC)	E	2	IV
4 Additional utility lines (1-15 corridor) (BLMN)	P	4,4	IV
5 Whiskey Pete's airstrip/waterline (BLMN)	P	4	IV
6 Solid waste landfill (UP Tracks near state line) (BLMN)	P	4,12	IV
7 Waste water ponds (Ivanpah Lake) (BLMN)	E	4,9	IV
8 Nipton waste site (BLMN)	P	4,9	IV
9 LA-Las Vegas bullet train (BLMN)	P	4,9,10	IV
Commercial and Residential			
10 Nipton land exchange (BLMN)	P	4,6,12	IV
11 Scattered residential units (BLMN)	E,P	--	LV
Recreation			
12 Ivanpah Lake landsailing (BLMN)	E	4,5,10	IV
13 Barstow to Vegas ORV race (BLMN)	E	4,5,10	IV
14 East Mojave Heritage Trail use (BLMN)	E	4,5,10	IV,LV,PV
15 Mojave Road use (BLMN)	E	4,5,10	IV,LV,PV
16 Clark Country Road A68P use (BLMS,CC)	E	4,5,10	PV
Mining			
17 Proposed Action/Alternative - precious metals (BLMN)	P	3,4,5,8,9	LV
18 Colosseum Mine - precious metals (BLMN)	E	3,4,5,8,9	IV
19 Caltrans borrow pits - aggregates (BLMN)	E	4,5	IV
20 Morning Star Mine - precious metals (BLMN)	E	3,4,5,8,9	IV
21 Vanderbilt - precious metals mill site (BLMN)	E	3,4,5,8,9	IV
22 Golden Quail Mine - precious metals (BLMN)	E	3,4,5,8,9	LV
23 Hart District Clay Pits (BLMN)	E	4,9	LV
24 Mountain Pass Mine - rare earth materials (BLMN)	E	3,4,5,8,9	IV
25 Exploratory activities (BLMN, BLMS)	E,P	4,5,9	LV,PV
Grazing			
26 Grazing leases (BLMN, BLMS)	E	4,5	IV,V,PV

Source of Information	Status	Issues	Location
BLMN: BLM Needles BLMS: BLM Stateline SBC: San Bernardino County. Planning Department CC: Clark County. Planning Department	E: Existing P: Proposed	1 Earth 2 Air 3 Water 4 Wildlife 5 Vegetation 6 Transportation 7 Public Service/Utilities 8 Health/Safety 9 Visual Resources 10 Recreation 11 Cultural Resources 12 Land Use	PV: Piute Valley IV: Ivanpah Valley LV: Lanfair Valley

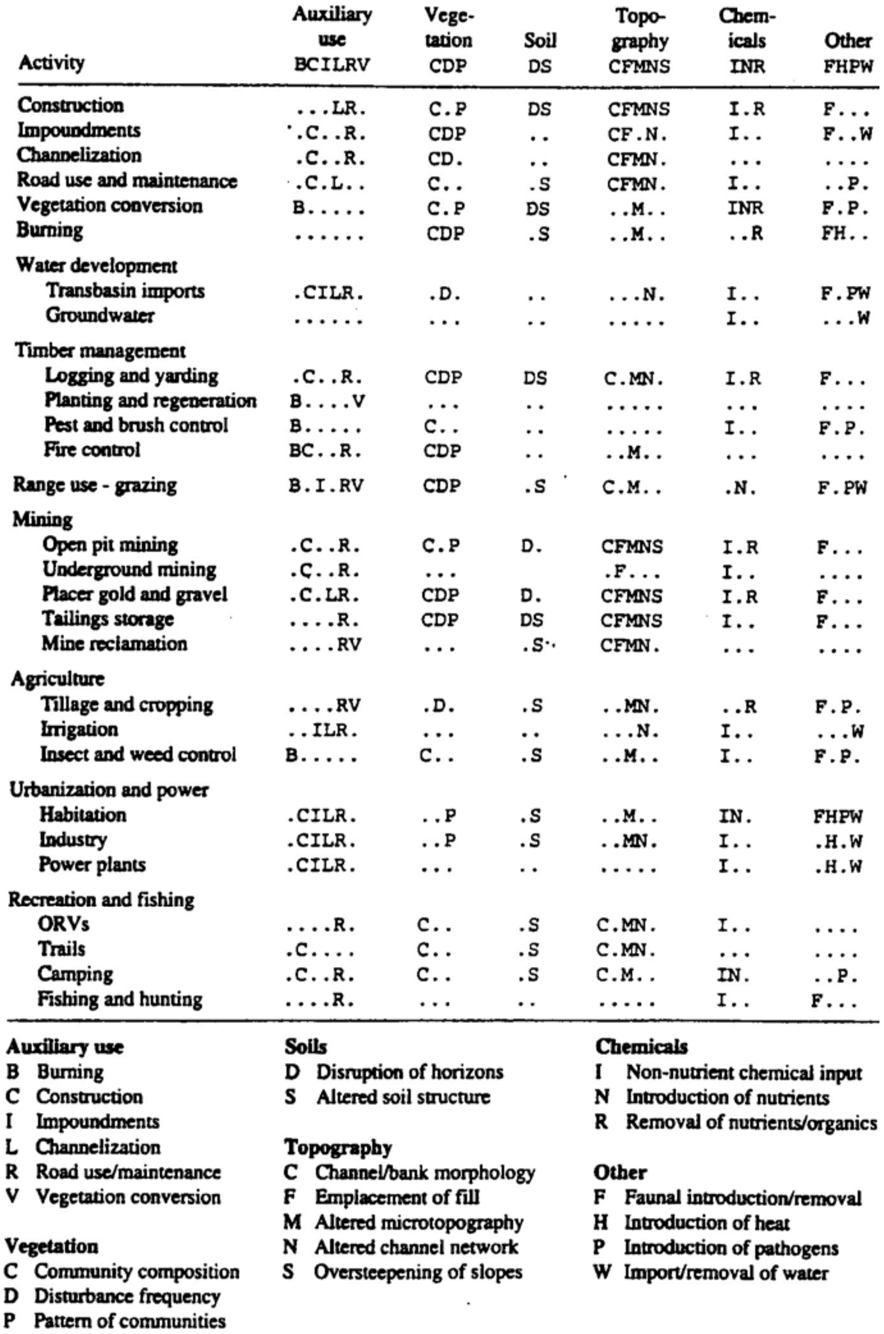
Watershed-based planning and management is being increasingly used in the USA. As a consequence, there is a growing need to address cumulative watershed effects for many larger-scale, regional studies. A useful reference document, which includes several CMs, matrices, networks, and indexing and quantitative models has been produced by the U.S. Forest Service (Reid, 1993). The report summarizes information on changes in watershed and ecosystem functions and processes that can arise from multiple land-use activities. Consideration of these changes from a holistic perspective provides the basis for analyses of cumulative watershed effects (CWEs). The land-use activities that are addressed include roads, impoundments and water development, timber management, grazing, mining, agriculture, urbanization, flood control and navigation, and recreation and fishing. Finally, eight methods for evaluating potential CWEs are described, including three procedures for calculating values of indices, several analytical procedures, and a checklist of issues for consideration.

Table 3 is a matrix related to the direct effects of selected land-use activities on watershed properties (or characteristics or features) (Reid, 1993, p. 52). The left column lists a variety of activities (actions or types of projects) in a watershed. The auxiliary use column delineates typical related components of a given activity. For example, open pit mining includes both construction (C) and road use/maintenance (R). Examination of the auxiliary use column reveals that many common components can result from the listed activities. The five right-most columns in Table 3 refer to common effects on five properties – vegetation, soils, topography, introduction of chemicals, and other. For each property, from two to five typical effects are identified by assigned codes. However, one note of caution would be that the same letter code, for example, C, has been used for several typical effects. To illustrate, C is used in two of the five right-most columns – it represents effects on community composition under vegetation, and effects on channel/bank morphology under topography. Finally, even though some code letters are used multiple times, Table 3 contains such a wealth of CEA-related information that the codes could be easily changed to reduce confusion.

Table 4 is a matrix which displays the consequences of changes in watershed properties (and their indicators or parameters) from Table 3 on five watershed processes (runoff, sediment, organic material, chemicals, and heat) (Reid, 1993, p. 56). The left column is comprised of the five watershed properties and effects from Table 3 (the five right-most columns and their associated codes). The cells in Table 4 are populated by letter codes denoting process changes resulting from the effect displayed in the left column. Again, multiple uses of the same letter codes for different processes should be noted, along with the fact that they can be easily modified.

CEA matrices have also been used in Canadian practice. For example, the following concepts and uses have been noted (Hegmann, et al., 1999, p. 23):

Table 3: Potential Direct Effects of Selected Land-Use Activities on Watershed Properties (Reid, 1993, p. 52)



Activity	Auxiliary use BCILRV	Vegetation CDP	Soil DS	Topography CFMNS	Chemicals INR	Other FHPW
Construction	...LR.	C.P	DS	CFMNS	I.R	F...
Impoundments	.C..R.	CDP	..	CF.N.	I..	F..W
Channelization	.C..R.	CD.	..	CFMN.	...	....
Road use and maintenance	.C.L..	C..	.S	CFMN.	I..	..P.
Vegetation conversion	B.....	C.P	DS	..M..	INR	F.P.
Burning	......	CDP	.S	..M..	..R	FH..
Water development						
Transbasin imports	.CILR.	.D.	..	...N.	I..	F.PW
Groundwater	......	...	..	.....	I..	...W
Timber management						
Logging and yarding	.C..R.	CDP	DS	C.MN.	I.R	F...
Planting and regeneration	B....V	...	..	.....	...	....
Pest and brush control	B.....	C..	..	.....	I..	F.P.
Fire control	BC..R.	CDP	..	..M..	...	....
Range use - grazing	B.I.RV	CDP	.S	C.M..	.N.	F.PW
Mining						
Open pit mining	.C..R.	C.P	D.	CFMNS	I.R	F...
Underground mining	.C..R.	...		.F...	I..	....
Placer gold and gravel	.C.LR.	CDP	D.	CFMNS	I.R	F...
Tailings storage	....R.	CDP	DS	CFMNS	I..	F...
Mine reclamation	....RV	...	.S	CFMN.	...	....
Agriculture						
Tillage and cropping	....RV	.D.	.S	..MN.	..R	F.P.
Irrigation	..ILR.	...	..	...N.	I..	...W
Insect and weed control	B.....	C..	.S	..M..	I..	F.P.
Urbanization and power						
Habitation	.CILR.	..P	.S	..M..	IN.	FHPW
Industry	.CILR.	..P	.S	..MN.	I..	.H.W
Power plants	.CILR.	...	..	.....	I..	.H.W
Recreation and fishing						
ORVs	....R.	C..	.S	C.MN.	I..	....
Trails	.C....	C..	.S	C.MN.	...	....
Camping	.C..R.	C..	.S	C.M..	IN.	..P.
Fishing and hunting	....R.	...	..	.....	I..	F...

Auxiliary use
B Burning
C Construction
I Impoundments
L Channelization
R Road use/maintenance
V Vegetation conversion

Vegetation
C Community composition
D Disturbance frequency
P Pattern of communities

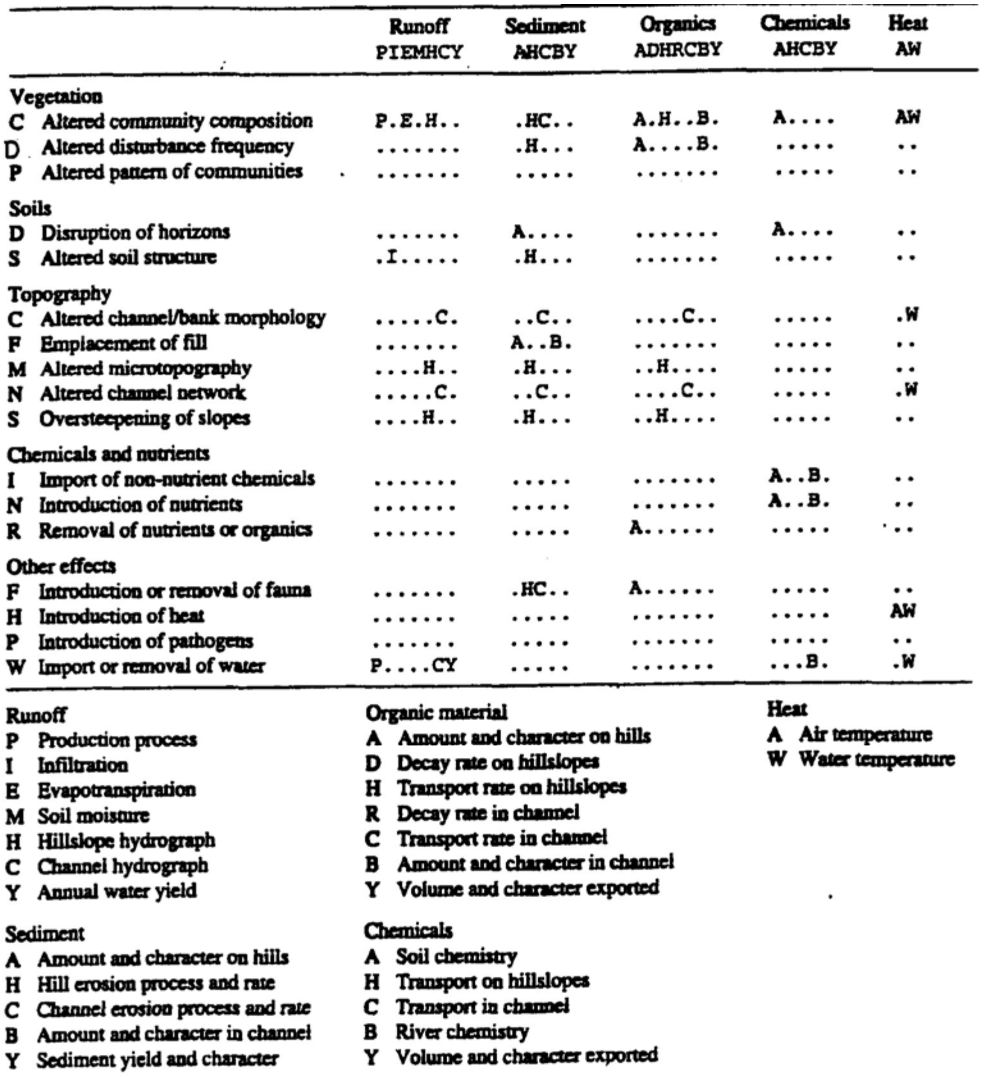
Soils
D Disruption of horizons
S Altered soil structure

Topography
C Channel/bank morphology
F Emplacement of fill
M Altered microtopography
N Altered channel network
S Oversteepening of slopes

Chemicals
I Non-nutrient chemical input
N Introduction of nutrients
R Removal of nutrients/organics

Other
F Faunal introduction/removal
H Introduction of heat
P Introduction of pathogens
W Import/removal of water

Table 4: Effects of Altered Environmental Parameters on Watershed Processes (Reid, 1993, p. 56)



	Runoff PIEMHCY	Sediment AHCBY	Organics ADHRCBY	Chemicals AHCBY	Heat AW
Vegetation					
C Altered community composition	P.E.H..	.HC..	A.H..B.	A....	AW
D Altered disturbance frequency	....	.H...	A....B.	.....	..
P Altered pattern of communities	....	.....	....	.....	..
Soils					
D Disruption of horizons	....	A....	....	A....	..
S Altered soil structure	.I.....	.H...	....	.....	..
Topography					
C Altered channel/bank morphology	.....C.	..C..	....C..	.....	.W
F Emplacement of fill	....	A..B.	....	.....	..
M Altered microtopography	....H..	.H...	..H....	.....	..
N Altered channel network	.....C.	..C..	....C..	.....	.W
S Oversteepening of slopes	....H..	.H...	..H....	.....	..
Chemicals and nutrients					
I Import of non-nutrient chemicals	....	.....	....	A..B.	..
N Introduction of nutrients	....	.....	....	A..B.	..
R Removal of nutrients or organics	....	.....	A......	.....	..
Other effects					
F Introduction or removal of fauna	....	.HC..	A......	.....	..
H Introduction of heat	....	.....	....	.....	AW
P Introduction of pathogens	....	.....	....	.....	..
W Import or removal of water	P....CY	.....	....	...B.	.W

Runoff
P Production process
I Infiltration
E Evapotranspiration
M Soil moisture
H Hillslope hydrograph
C Channel hydrograph
Y Annual water yield

Sediment
A Amount and character on hills
H Hill erosion process and rate
C Channel erosion process and rate
B Amount and character in channel
Y Sediment yield and character

Organic material
A Amount and character on hills
D Decay rate on hillslopes
H Transport rate on hillslopes
R Decay rate in channel
C Transport rate in channel
B Amount and character in channel
Y Volume and character exported

Chemicals
A Soil chemistry
H Transport on hillslopes
C Transport in channel
B River chemistry
Y Volume and character exported

Heat
A Air temperature
W Water temperature

> “An interaction matrix is a tabulation of the relationship between two quantities. Matrices are often used to identify the likelihood of whether an action may effect a certain environmental component or to present the ranking of various effect attributes (e.g., duration, magnitude) for various VECs. Matrices are an example of one tool that can be used during scoping exercises to identify the potentially “strongest” cause-effect relationships, and later to concisely summarize the results of an assessment. Matrices, however, only show the conclusions made about interactions, and cannot themselves reveal the underlying assumptions, data and calculations that led to the result shown; matrices are a simplistic representation of complex relationships. Matrices should, therefore, be accompanied by a detailed explanation as to how the interactions and rankings were derived (e.g., in a “decision record”).”

Three Canadian examples will be briefly noted. First, in a CEA study of the Trans Canada Highway, the potential degrees of interaction between various regional actions and VECs was determined. Sixteen actions were identified within the study area, and the effects of each action on 10 environmental and social VECs were ranked from negligible to low to moderate to high (Hegmann, et al., 1999, p. 25). The 16 actions were listed in the left column of the CEA matrix, and the 10 VECs were displayed in 10 columns to the right. The matrix cells were populated with codes (- for negligible, L for low, M for moderate, and H for high). Descriptions of the scientific and policy rationale for each cell’s assignment were also included in the text.

The second Canadian example involves CEA matrices for examining the effects of existing and proposed actions in and around Kluane National Park Reserve (Hegmann, et al, 1999, p. 25). Several key wildlife VECs were included, with one example being for grizzly bear. A specific CEA matrix for the grizzly bear included a left column comprised of nine existing actions and nine future actions. Seven additional columns highlighted potential effects on grizzly bear in terms of habitat loss, fragmentation, alienation, obstruction, mortality, removals, and an “overall” composite. Six categories of effects were used to populate the cells – “blank”=no effect; L=low probability of occurrence or magnitude of effect (on reproductive capacity of species or productive capacity of habitat) probably acceptable; M=moderate or possibly significant effect; H=high probability of occurrence or magnitude of effect probably unacceptable (e.g., population recovery may never occur or may occur in the long-term). A ranking option for a positive effect (+) was also provided. Again, descriptions of the scientific and policy rationale for each cell’s assignment, and the overall composite, were included in the text.

The final Canadian example includes the use of CEA matrices for analysis and evaluation of cumulative effects resulting from 12 hydropower projects proposed by Hydro-Quebec between 1999 and 2005 (Berube, 2007). The following 15 VECs were considered in the initial planning of each CEA study – fish species, mercury in fish, moose, bird species, wetlands, river banks, heritage, landscape, recreational/tourism, air, water, soil, health, navigation, and land use. Through scoping, from one to five of the 15 VECs were deemed appropriate for a given CEA study. Then, Hydro-Quebec used bi-dimensional tables (simple interaction matrices) to list and briefly describe the effects of all past, present and future actions on selected VECs. For example, from a detailed study associated with the Pikauba River regulation dam (Berube, 2007, p. 105), the complete matrix table, which was several pages long, listed pertinent past, present and future actions in the left column, with five additional columns noting the pertinent VECs (river banks, navigable waters, brook trout, moose, and wetlands). The cells in the table were populated with brief descriptive statements relating the actions to the VECs.

Detailed Example for Waterway Navigation

In a CEA study related to navigation infrastructure improvements on the 981-mile long Ohio River in the midwestern part of the USA, specific attention was given to the identification and analyses of the contributions of reasonably foreseeable future actions (RFFAs) to cumulative effects on selected VECs. The RFFAs, which also included similar past and present actions, were defined as (Canter and Rieger, 2005, p. 7):

> Actions identified by analysis of formal plans and proposals by public and private entities that have primary (direct) or secondary (indirect) impacts on VECs associated with the Ohio River. RFFAs also include potential actions that are beyond mere speculation when incorporated in plans or documents by credible private or public entities. RFFAs may also include events forecasted by trends, probable occurrences, policies, regulations, or other credible data that may have bearing on the VECs.

The original perception of the CPT (Central Planning Team) for the study was that one “overall matrix” could be developed. The overall matrix would have included all the identified RFFAs and the VECs and their subcomponents (indicators) together. However, due to expediency relative to matrix completion, it was recognized that individual matrices would be needed for 12 pre-identified VECs. For the three VECs with multiple components (Aquatic Ecological Resources, Riparian/Floodplain Ecological Resources, and Threatened/ Endangered /Protected Species), additional matrix columns were envisioned. However, it was soon recognized that matrices focused on single subcomponents (indicators) within VECs, or single VECs themselves, would be more useable. As a result, 22 matrices were used; the listing is in the left column of Table 5. Table 5 also indicates that several committees were involved in the preparation and review of the matrices (Canter and Rieger, p. 15).

Table 5: Summary of Process Features Related to Completion of the RFFA Matrices (Canter and Rieger, 2005, p. 15)

VEC	Preparation of Matrix	Review and Summarization of Matrix
AER – Water Quality/Sediment Qual	CPTC	CPT
AER – Fish	ERTC	CPT
AER – Mussels	IWGC (Note 1)	CPT
Air Quality	CPTC	CPT
RFER – Terrestrial Habitat	IWGC	CPT
RFER – Islands	IWGC	CPT
RFER – Wetlands	IWGC	CPT
RFER – Soils and Geology	IWGC	CPT
RFER – Floodplain Hydrology	IWGC	CPT
T/E/P Species – Fish	IWGC	CPT
T/E/P Species – Mussels	IWGC	CPT
T/E/P Species – Mammals	IWGC	CPT
T/E/P Species – Birds	IWGC	CPT
T/E/P Species - Plants	IWGC	CPT
Aesthetic Resources	CPTC	CPT
Noise	CPTC	CPT
Human Health and Safety	CPTC	CPT
Land Use	CPTC	CPT
Transportation and Traffic	CPTC	CPT
Socioeconomic Resources	CPTC	CPT
Cultural Resources	CPTC	CPT
Recreation	CPTC	CPT

Notes:

CPTC = central planning team committee (3-4 members)
CPT = central planning team
IWGC = interagency working group committee (3-4 members)
Note 1 = it was assumed that the T/E/P Species-Mussels RFFA Matrix is applicable to AER-Mussels
AER = aquatic ecological resources
RFER = riparian/floodplain ecological resources
T/E/P Species = threatened/endangered/protected species

Table 6 displays the first page only of a 5-page RFFA cumulative effects matrix used for the water and sediment quality VEC. The 87 identified types of RFFAs were divided into six categories: (1) navigation investment actions; (2) other Corps actions; (3) “but for” actions; (4) actions by others (could occur regardless of the Ohio River navigation system); (5) natural disasters; and (6) regulatory environment. “But for” actions refer to those actions by others which would not occur except for the existence and maintenance of the Ohio River navigation system. Natural disasters are included since floods, droughts, severe storms, and/or earthquakes can have major influences on many of the VECs and subcomponents. Definitions for each of the listed types of RFFAs were included in an appendix to the CEA report. Under the ORMSS (Ohio River Mainstem Systems Study), only “navigation investments actions” were evaluated programmatically for federal action. Finally, it should be noted that many of the RFFAs represented continuations of past and present actions.

The second column in Table 6 relates to sources of information that were the basis for the listed RFFA. Sources included plans, permits, census data, other EAs (environmental assessments) and EISs, surveys, map and/or navigation chart (Navchart) analyses, trends analysis data (TAD), and professional opinion. A summary of the types of utilized sources was included in an appendix to the CEA report.

The next three columns in Table 6 highlight relative characteristics of the listed RFFAs. The following definitions relate to the “codes” which were used for each of the characteristics:

(1) Time Period-short, medium and long-term. Short-term is the initial 10-year period from the point of completion of the CEA study (2005) and is based upon the probability of occurrence, availability of information, status of funding, and other factors. The medium time frame is from 10 to 25 years beyond 2005. The long-term period is 25 to 55 years. The date of 55 years is based on the economic analysis period for the navigation investment plan (to 2060).

(2) Occurrence Probability - high, medium, and low. High denotes substantial information exists and funding is already in place (already “on the books”). Medium denotes some information is available, and some funding possibilities exist. Low denotes minimal information and no identified funding or proponent.

(3) Location on River- Three reaches of the River were routinely used (upper, middle, or lower); the upper reach was from Pittsburgh to approximately Huntington, West Virginia; the middle reach was from Huntington, to Louisville, Kentucky; and the lower reach was from Louisville to Cairo.

Table 6: Portion of RFFA Matrix for Water and Sediment Quality (Canter and Rieger, 2005, p. 17)

RFFA	Sources	Time Period	Occurrence Probability	Location on River	Water Quality	Sediment Quality	Importance
Navigation Investment Actions							
Lock Extensions/New Locks/Replacement or Rehabilitation	Corps planning (districts); ORNIM study outputs						
L&D operation and maintenance	Corps O&M records, J.T. Myers & Greenup Locks Improvements EIS						
Non-structural navigation improvements	Examples from: Upper Mississippi -Illinois Waterway report, national park studies.						
Dam replacement and rehabilitation	(Category added by review team)						
Other Corps Actions							
Channel dredging/dredged material disposal	Corps (districts), J.T. Myers & Greenup Locks Improvements EIS						
Navigation aids - Construction and O&M	Corps historic records, trends related to GPS, 1980 Corps O&M EIS						
Flood damage reduction projects							
levees/floodwalls	EAs and EISs from individual communities, Corps O&M records, ERP projects list						
dry dams, other projects off mainstem	EISs in Corps planning offices (districts), projects planned on tributaries						
channel modifications	Point Pleasant project, projects planned on tributaries						
nonstructural measures (e.g. relocation)	FEMA, flood relocation reports, Corps planning, Mill Creek project						
Emergency streambank stabilization (Sec. 14)	Corps planning & operations (districts)						
Modification of Corps structures for env. improvements (Sec. 1135)	Corps planning & operations (districts)						

The final three columns relate to the effects on the VEC or sub-component thereof, and the overall importance of the RFFAs regarding cumulative effects. The key display information in the two VEC-related columns was associated with whether the RFFA exhibits negative or positive effects. Descriptive rationale for this determination was entered in “smart cells” as follows. The RFFA matrices were provided to each committee as Microsoft® Excel spreadsheets. The “insert comment” function was used to access a detailed definition of each RFFA. Committee members were able to read each definition by moving their cursor over the RFFA cell. The committee was also encouraged to insert comments to expand upon coded entries. This proved most useful when the team was describing the effects on the VEC or subcomponent, and rating the relative importance of the RFFA’s impact. In so doing, the issues or values most important in the formulation of their entries were identified.

The final column in Table 6 is entitled “Importance”. In this case, the committee assigned an “importance rating” to all RFFAs identified as having effects. The rating code was H (high importance), M (medium importance), or L (low importance). Again, notes were added to the respective “smart cells” in the Importance column to denote the rationale used. Some things that were considered included: (1) the relative contribution of the RFFA to the cumulative effects; (2) the spatial and temporal extent of the anticipated effects; (3) the level of knowledge regarding the affected VEC or subcomponent, and the effects themselves, and (4) the possibilities for cost-effectively mitigating the negative effects. Although use of the comments function was optional, committees often provided comments for all of their high and medium importance entries.

The final results from the matrix analyses are depicted in Table 7 (the first page of a 3-page table) for the High and Medium ranked RFFAs (Canter and Rieger, 2005, p. 19). The shading codes in the table denote importance (darker is higher importance), and the “+ and – signs” denote positive or negative impacts. Detailed information which provides the bases for these codes was incorporated in the “smart cells” of the individual matrices.

To summarize the RFFA matrix approach, the following lessons were identified relative to the value and uses of RFFA matrices in the ORMSS CEA study:

- The RFFA matrix is a valuable tool that facilitated a systematic process for considering and evaluating RFFAs in a CEA study. For example, in traditional project-level impact studies, there is a tendency to consider the effects of the project in isolation. CEA requires the consideration of the effects of multiple past, present, and future actions. RFFA matrices force the users to consider multiple future actions that may impact a given VEC or subcomponents. Further, completed RFFA matrices provide a documented basis for “scoping” RFFAs and determining which should be

Table 7: Portion of RFFAs Ranked High and Medium and their Effects by VEC (Canter and Rieger, 2005, p. 19)

RFFA	WQ & SQ	Fish	Mussels	Riparian	Health & Safety	Recreation	Air	Transportation & Traffic	Cultural	Socioeconomics
Navigation Investment Actions										
Lock Extensions/New Locks/Replacement or Rehabilitation		░ -	▓ -	░ -	▓ +	░ +	░ -	▓ +	▓ -	H/M +
L&D operation and maintenance	░ -	░ -	▓ -		░ +	░ +		░ +	▓ -	
Non-structural navigation improvements		▓ +	▓		▓ +	░ +	░ +	░ +		
Dam replacement and rehabilitation		▓ -	▓ -	▓ -	░ +	░ +		H/M+	▓ -	
Other Corps Actions										
Channel dredging/dredged material disposal	▓ -	▓ -	▓ -		░	░ -			░ -	
Navigation aids - Construction and O&M			░		░ +					
Flood damage reduction projects										
levees/floodwalls		▓ -		▓ -	▓ +	░ -			▓ -	░ +
dry dams, other projects off mainstem	░ -	░ -	░	░ -	░ +	░ +		░ +	▓	
channel modifications		░ -	▓ -	░ -	░ +				░	
nonstructural measures (e.g. relocation)		▓ +	▓ +	░ +		░ +			▓	
Emergency streambank stabilization (Sec. 14)		░ -	▓ -		░ +					
Modification of Corps structures for environmental improvements (Sec. 1135)		▓ +	▓ +	▓ +		░ +			░ -	
Environmental restoration of aquatic ecosystems (Sec. 206)		▓ +	▓ +	▓ +		░ +			░	
Recreation facilities - Construction and O&M					░ +	▓ +		░ -	▓	░ +
Key to shading/symbols:										
Indicates high importance ranking	▓									
Indicates high-medium ranking	H/M									
Indicates medium importance ranking	░									
Effect on resource is primarily positive	+									
Effect on resource is primarily negative	-									
No symbol for mixed + and - impacts										

No shading indicates the RFFA is of low importance ranking or was not ranked.

addressed in a more detailed manner. In addition, due to the similarity of actions over time along the Ohio River mainstem, matrices for past and other present actions were also derived.

- Information extracted from completed RFFAs can be utilized to summarize a number of key points related to a CEA study. Examples of such information include expected time periods wherein given RFFAs are expected to occur; their occurrence probabilities; the locations or settings on or along the River wherein the given RFFAs are expected to occur; the RFFAs with anticipated negative effects, positive effects, and combinations thereof; and the importance categories for the RFFAs. Further, a composite picture of the effects of a given RFFA across all VECs can be drawn from an analysis of each of the 22 matrices.

- The RFFA matrix was used as an initial step in delineating the relative contributions of individual RFFAs to the overall cumulative effects. For example, RFFAs rated as having high importance would be expected to contribute more to the cumulative effects on a VEC than RFFAs rated as low importance. In certain cases, more detailed data gathering and analysis efforts were conducted to quantify (approximate) the relative contributions of an RFFA to the cumulative effects on a VEC.

- The majority of the RFFAs in the first five categories (4 in navigation investment actions, 13 in other Corps actions, 19 in “but for” actions, 26 in actions by others, and 4 in natural disasters) represent continuations of past and present actions. However, from an historical perspective, different actions were initiated in different time periods in the past. Therefore, effects information from the completed RFFA matrices were applied, as appropriate, to historical time periods and present actions, and utilized to qualitatively summarize the effects of past and current actions on the VECs.

- Information from the RFFA matrices was used to examine the relationship between cumulative effects on a VEC or subcomponent (indicator) thereof, and the environmental sustainability (ES) of that VEC.

- Necessary VEC sustainability needs and monitoring programs can be developed for “not sustainable” or “marginally sustainable” VECs or subcomponents determined to have significant cumulative effects. Such needs and monitoring can be focused on the indicators and the potential contributions of RFFAs identified as being in the high and medium importance categories. Further, mitigation measures can be identified for key RFFAs, thus forming an initial basis for interagency discussions related to appropriate mitigation and adaptive management strategies for specific VECs.

Developing Interaction Matrices for CEA

The steps for CEA matrix development, which can be patterned after common steps for addressing direct and indirect effects (Canter, 1996, p. 78), include the following:

- Step 1 – List all anticipated project actions and group them according to temporal phase such as construction, operation, and post-operation. Note: project refers to the proposed action or preferred alternative. If cumulative effects are to be compared for a suite of alternatives, including the proposed action, then a temporally-related list of actions for each alternative would need to be developed. The list (or lists) would typically comprise the x-axes (columns) in a simple CEA interaction matrix.

- Step 2 – List environmental factors in appropriate categories. One categorization could be resources, ecosystems, and human communities; while another approach could involve physical and chemical components, biological and ecological components, historical and archeological components, and social and socio-economic components. A particularly relevant approach would be to list selected VECs and their indicators. Such VECs and indicators would typically comprise the y-axes (rows) in a simple CEA interaction matrix. Further, the VECs and indicators could be based on various spatial boundaries within the CEA study area; for example – local area and regional area, sub-watershed and watershed area, and/or upstream, site, and downstream area.

- Step 3 – Decide on an impact rating scheme to be used within the x-y cells in the matrix. The scheme could be based on color codes, circles or squares of various size, and numbers or letter codes. The components of the chosen scheme should be defined; with such definitions facilitating a consistent approach for matrix completion.

- Step 4 – Add additional columns (x-axis) to the matrix to reflect the contributions of past, present, and reasonably foreseeable future actions (RFFAs) to cumulative effects on the VECs and their indicators. The past actions could be grouped into several time categories (e.g., more than 20 years ago, from 10-19 years ago, and from 0-9 years ago) and listed in columns to the left of the project actions. The present actions (those under concurrent development with the project action) could also be listed in columns to the immediate left of the project actions. The RFFAs could be listed in columns to the right of the proposed action. Future time categories could also be considered as appropriate. The x-y cells associated with other actions should also be completed, as appropriate, using the chosen impact rating scheme from Step 3.

- Step 5 –Complete the CEA interaction matrix and prepare a systematic description of the matrix, the key rationale for the x-y cells, and an overall summary of the results. Definitions and explanations of the columns and rows in the matrix should be included in the text of the study report or an appendix. A matrix could be completed by an EIA/CEA professional, a CEA study team, or a group of subject matter experts focused on selected VECs. The summary should identify the most important relative contributors to cumulative effects across the range of VECs, as well as the key contributors to effects on specific VECs and their sustainability.

Summary Observations on Matrices

Based upon the above examples of CEA-related matrices and other experiences in using matrices in impact studies, the following observations can be made about the usage of this methodology:

- It is critical to carefully define the spatial boundaries associated with each of the VECs and their indicators; further, it is necessary to describe the temporal phases and specific actions associated with the proposed project; and the impact rating or summarization scales used in the matrix.

- A matrix should be considered a tool for purposes of analysis of cumulative effects, with the key need being to clearly state the rationale utilized for the impact ratings or codes assigned to a given temporal phase and project action, and a given spatial boundary and VEC/indicator.

- The development of one or more preliminary CEA matrices can be a useful technique in discussing a proposed action and its potential direct, indirect, and cumulative effects. This can be helpful in the early stages of a study to assist each team member in understanding the implications of the project and developing necessary plans for more-extensive studies on particular VECs and the contributed effects from multiple actions.

- The interpretation of cumulative impact ratings should be carefully considered, particularly when realizing that there may be large differences in spatial boundaries, as well as temporal phases, for the VECs and actions in a given setting.

- Interaction matrices can be useful for delineating the impacts of the first and second or multiple phases of a two-phase or multi-phase project; the cumulative impacts of a project when considered relative to other past, present, and RFF actions in the area; and the potential positive effects of mitigation measures. Creative codes can be used in the matrix to delineate this information.

- Impact quantification and comparisons to relevant standards can provide a valuable basis for the assignment of impact ratings to different project and other actions on VECs and their indicators.

- Color codes can be used to display and communicate information on anticipated impacts. For example, beneficial cumulative impacts could be shown by using green or shades of green; whereas, detrimental or adverse effects could be depicted with red or shades of red. Impact matrices can be used with the incorporation of number or letter codes in specific cells. For example, circles of varying size could be used to denote ranges of cumulative impacts. Matrices can also be completed via the use of bulleted descriptive information.

- One of the concerns relative to interaction matrices is that project actions and/or VECs are artificially separated, when they should be considered together. It is possible to use footnotes in a matrix to identify groups of actions, VECs, and/or impacts which should be considered together. This would also allow the delineation of interrelationships between VECs.

- Usage of an interaction matrix forces the consideration of actions and impacts related to a proposed project within the context of other related actions and their contributing impacts.

Finally, while the above observations are focused on CEA, similar observations have been made regarding the usage of matrices for addressing the direct and indirect effects of single projects (Canter, 1996, pp. 79-81).

NETWORKS IN CEA

“Networks” refers to methodologies which integrate impact causes and consequences through identifying interrelationships between causal actions and the impacted environmental factors, including those representing secondary and tertiary effects. A typical presentation involves drawing “connector lines” between actions and factors (VECs) which can be affected.

Network analyses can be useful for identifying anticipated direct, indirect, and cumulative effects associated with potential projects. Networks can also aid in organizing the discussion of anticipated project impacts as well as impacts associated with other past, present, and future actions. Simplified network displays can also be useful in communicating information about a CEA study to interested stakeholder groups. Further, networks can be promulgated as output from the development of CMs. The primary limitation of the network approach can be the minimal information provided on the technical aspects of impact prediction and the means for comparatively evaluating the impacts of alternatives. In addition, networks can quickly become visually complicated (Canter, 1996, p. 81).

This section includes two brief illustrations of networks used in CEA studies. Further, the generic steps associated with the development of a CEA network will also be described.

Brief Examples of Networks

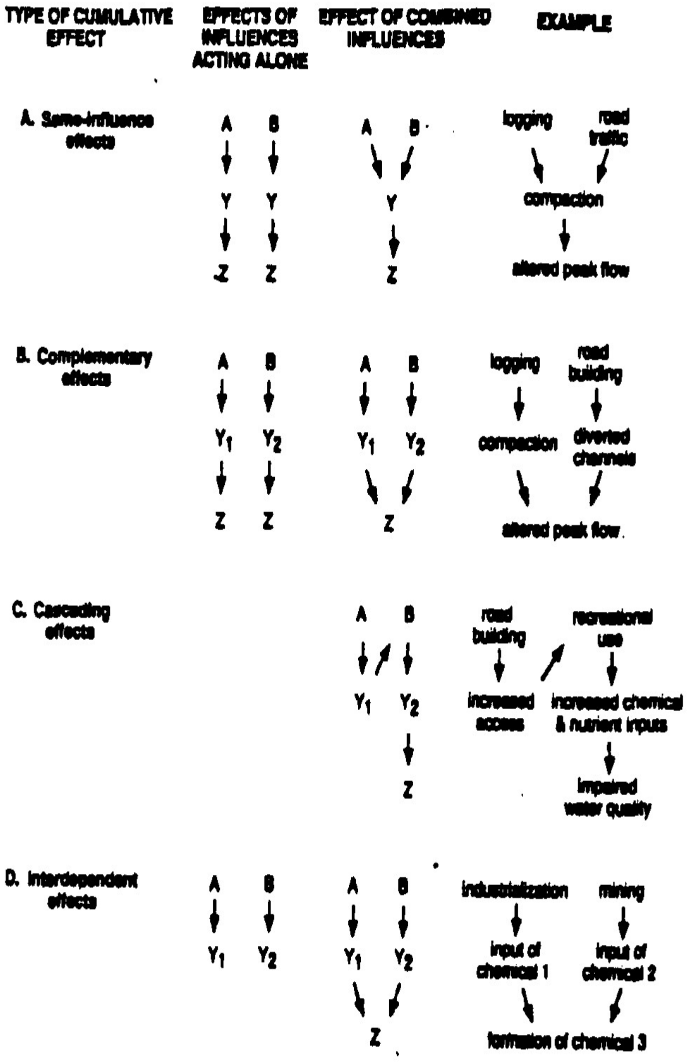
Networks do not have to be visually complicated. For example, Figure 4 displays four types of cumulative effects which could be related to activities A and B (Reid, 1993, p. 20). In this case, and assuming that activity A is an existing project in a watershed, while activity B is a proposed project, the cumulative effects concepts can be readily displayed. Modification of these simple networks would be necessary in watersheds with multiple past, current, and future projects that could contribute to cumulative effects on selected VECs.

To serve as a second example, a cause-effect network for identifying the cumulative effects of coastal zone development projects in Australia is in Figure 5 (Court, Wright, and Guthrie, 1994). This network displays relationships between causes of environmental change, resultant perturbations, and primary and secondary impacts. The “causes” column reflects various land uses and development projects in the coastal zone. Their timing (past, present, or future) could be delineated. The column entitled perturbation generally reflects resources, ecosystems, or human communities (i.e., VECs). Stated differently, the second column can generally be seen as a listing of identified VECs (e.g., national parks); however, actions such as commercial fishing and offshore mining are also included. The column entitled primary impact is analogous to direct impacts from the causes and perturbations, as appropriate. The secondary impact column is reflective of the consequences of the primary impacts (secondary impacts are often referred to as indirect effects). Finally, it should be noted that the primary impact column could be used to delineate the continuing causes and perturbations (move from right to left in Figure 5.

Even though only two examples of CEA networks are described herein, it should be readily apparent that such networks can be useful prior to, during, and following a public scoping process. For example, potential common effects on VECs from multiple types of actions can be identified; further, networks can aid in identifying actions that do not contribute to common effects on particular VECs. This information can then aid CEA study planning, the analysis of cumulative effects, documentation of the study process, and the development of local mitigation and regional cumulative effects management programs.

Developing Networks for CEA

The steps for CEA network development, which can be patterned after common steps for addressing direct and indirect effects, include the following:



Note: A and B are activities, Y is an environmental parameter, and Z is an impact.

Figure 4: Combinations of Activities that Can Cause Cumulative Effects in Watersheds (Reid, 1993, p. 20)

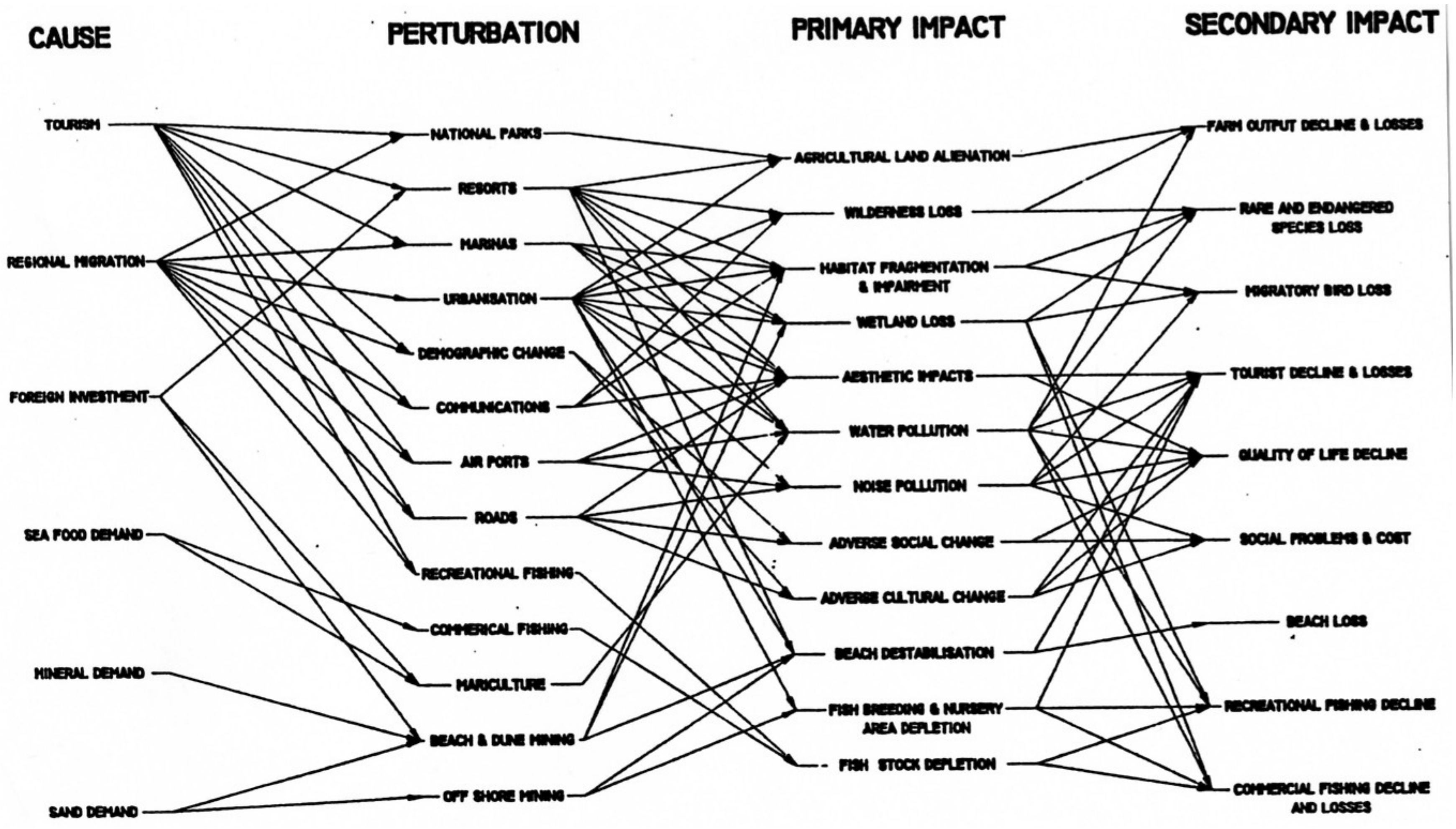


Figure 5: **Cause-Effect Network for Development Projects in the Coastal Zone of Australia (Court, Wright, and Guthrie, 1994)**

- Step 1 – Vertically list all anticipated project actions and group them according to temporal phase such as construction, operation, and post-operation. Note: project refers to the proposed action or preferred alternative. If cumulative effects are to be compared for a suite of alternatives, including the proposed action, then a temporally-related list of actions for each alternative would need to be developed, and separate networks would be needed for each alternative. The list (or lists) would typically be on the y-axis (in rows) in a simple CEA network.

- Step 2 – Vertically list, to the right of the actions list, environmental factors in appropriate categories. One categorization could be resources, ecosystems, and human communities; while another approach could involve physical and chemical components, biological and ecological components, historical and archeological components, and social and socio-economic components. A particularly relevant approach would be to list selected VECs and their associated indicators. Such VECs and indicators would typically be on the y-axes (rows) in a simple network depiction. Further, the VECs and indicators could be organized in accordance with various spatial boundaries within the CEA study area; for example – local area and regional area, various land uses, and protected ecological resources.

- Step 3 – As appropriate, draw connector lines (arrows) between each project action and each VEC/indicator that would be subject to the action's effects. While not required for network usage, the relative thickness of the arrows could denote relative contributions to the effects on VECs/indicators. A thicker arrow could be used to denote a greater relative contribution to cumulative effects; a normal thickness arrow could denote a moderate contribution, while a dashed arrow could depict a minor contribution.

- Step 4 – In the original left column, add additional vertical lists of past, present, and future actions which could contribute to cumulative effects on the VECs and their indicators. These additional lists could be added either above or below the above-noted vertical list of project actions (Step 1). In effect, the composite vertical lists in the left-hand column could be used to depict several time categories. For example, past actions could be grouped into several time categories (e.g., more than 20 years ago, from 10-19 years ago, and from 0-9 years ago) and listed either above or below the project actions. The present actions (those under concurrent development with the project action) could also be listed either immediately above or below the project actions. The RFFAs could be listed at the top or bottom of the column containing the list of project actions, depending upon whether the time considerations are increasing or decreasing above or below the project actions. Future time categories could also be considered and utilized as appropriate. Following the listing of all other actions (past, present, and future), they should also be connected via arrows to appropriate VECs/indicators noted in Step 2 above. Again, different thicknesses for the arrows could be utilized to denote relative contributions. It should be recognized that when all actions are considered, the connecting arrows could overlap in multiple ways. Accordingly, and in order for simplification, it may be desirable to develop separate networks for specific VECs and their associated indicators.

- Step 5 –Complete the CEA network and prepare a systematic description of the network, the key rationale for the arrows, and overall summary of the results. Definitions and explanations of all actions and VECs/indicators should be included in the report text or an appendix. A network could be completed by an EIA/CEA professional, a CEA study team, or a group of subject matter experts focused on selected VECs. The summary should identify the most important relative contributors to cumulative effects across the range of VECs, as well as the key contributors to effects on specific VECs and their sustainability.

ADAPTIVE MANAGEMENT IN CEA

Adaptive management (AM) is an emerging method which has usefulness in reducing numerous uncertainties associated with CEA, and in informing decision makers regarding the effectiveness of both local mitigation of cumulative effects and regional management of such effects resulting from multiple actions within defined spatial and temporal boundaries. Key elements related to AM include: (1) management objectives for identified VECs related to biophysical, ecological, cultural, and social/socioeconomics features of the study area; (2) multiple strategies for managing the selected VECs to achieve or enhance sustainability conditions; (3) separate or collaborative monitoring programs to evaluate the effectiveness of the strategies in meeting the identified objectives; (4) one to several models of the relevant environmental and economic systems to aid AM planners and related decision makers in their considerations and analyses; (5) an integrated decision-making process wherein monitoring results are considered, choices for subsequent actions are made, and their consequences evaluated; and (6) a pro-active information dissemination program involving various stakeholders, groups, and governmental agencies.

Although only briefly described herein, AM can be viewed as an emerging post-EIS method which can be used to inform current and future studies focused on CEA. Detailed information on AM planning, processes, and case studies was included in a corollary paper in the IAIA’s 2008 Special Topic Meeting on Cumulative Effects Assessment and Management (Canter and Atkinson, 2008).

LESSONS LEARNED

Based upon the above information related to concepts and case studies involving conceptual models, matrices, and networks, the following lessons can be noted:

- There are numerous examples of these three types of methods being used in CEA studies. The examples could be directly used in other studies or appropriately modified to meet specific site and study needs.

- Documentation of the rationale for the selected methods, as well as their assumptions and key features, can facilitate the aggregation of best practices approaches.

- The included case studies, and their usage of these three types of methods, represent extensions of the use of similar tools for addressing the direct and indirect effects of singular proposed actions via the EIA process.

- As the practice of CEA matures, it can be expected that continuing creativity will lead to still additional modifications and improvements in conceptual models, matrices, and networks.

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