Ecological Benefits Assessment Strategic Plan

United States Environmental Protection Agency
Washington, DC 20460

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List of Acronyms

ACE	Army Corps of Engineers
BCA	benefit-cost analysis
CO	carbon monoxide
CWA	Clean Water Act
DOI	Department of the Interior
EERS	Environmental Economics Research Strategy
EPA	Environmental Protection Agency
ERA	ecological risk assessment
GIS	geographic information system
NCEA	National Center for Environmental Assessment
NCEE	National Center for Environmental Economics
NCER	National Center for Environmental Research
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Research Laboratory
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOx	nitrogen oxides
NRC	National Research Council
OAR	Office of Air and Radiation
OAQPS	Office of Air Quality Planning and Standards
OERR	Office of Emergency and Remedial Response
OPEI	Office of Policy, Economics and Innovation
OPP	Office of Pesticide Programs
OPPT	Office of Pollution Prevention and Toxics
OPPTS	Office of Prevention, Pesticides and Toxic Substances
ORD	Office of Research and Development
OSP	Office of Science Policy
OST	Office of Science and Technology
OSW	Office of Solid Waste
OSWER	Office of Solid Waste and Emergency Response
OW	Office of Water
OWOW	Office of Wetlands, Oceans, and Watersheds
RFF	Resources For the Future
RP	revealed preference
SAB	Science Advisory board
SP	stated preference

USDA	United States Department of Agriculture
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VOC	volatile organic compound
WTA	willingness to accept
WTP	willingness to pay

Executive Summary

[TBD]

1 Introduction

The U.S. Environmental Protection Agency (EPA) continually strives to use the best available methods and data to assess the impacts of its policies. In 2000, the Agency published its *Guidelines for Preparing Economic Analyses* (USEPA 2000a), an update and expansion of its 1983 *Guidelines for Performing Regulatory Impact Analyses* (USEPA 1983). The revised *Guidelines* provides assistance to analysts conducting economic analyses of environmental policies and incorporates recent advances in theoretical and applied work in environmental economics. However, as acknowledged in the *Guidelines*, the current state of the science is sometimes insufficient to accurately assess many of the foreseeable impacts of Agency actions, or to value those impacts in monetary terms for comparison with the expected costs of the actions.

One category of benefits that is especially difficult to quantify and value is "ecological benefits," which includes a wide variety of environmental improvements that directly or indirectly contribute to human well-being. Human health benefits also can be difficult to quantify and value, but the Agency has more experience in that area. In the face of increasingly complex and difficult tradeoffs inherent in environmental protection, the Agency recognizes a strong need to improve its ability to assess ecological benefits to ensure comprehensive benefit-cost assessments to inform Agency decision-making.

In 2002, EPA published *A Framework for the Economic Assessment of Ecological Benefits* (USEPA 2002b) to provide guidance on the process of economically valuing ecological benefits. The *Framework* recommends that economists integrate their efforts with Agency ecologists following a process consistent with EPA's 1998 *Guidelines for Ecological Risk Assessment* (USEPA 1998a). Implementation of the *Framework*, however, requires appropriate methods, models, and data, which are lacking for many types of ecological benefits. The lack of such tools is not surprising for several reasons. Historically, the Agency has acted on fairly clear environmental problems that were of significant importance to human health or had obvious implications for broader environmental conditions. For many policy decisions regarding environmental protection in the past, measuring environmental benefits, especially in monetary terms, has not been considered necessary. Where such analyses are needed, there are substantial technical difficulties associated with quantifying and valuing ecological benefits because of the complexity of the ecosystems and economic systems involved and with characterizing individuals' preferences for non-marketed goods and services. Efforts to overcome current limitations in the state of the practice for any given assessment can be very labor and data intensive, and Agency resources – in the form of staff time, expertise, and money – that can be dedicated to any given assessment are limited. Finally, owing to historical aspects of EPA's development, meaningful collaboration between economists and ecologists needed to comprehensively assess ecological benefits has been relatively rare at the Agency.

This Strategic Plan provides the next step needed to implement the process described in the *Framework* for comprehensively valuing the ecological benefits of EPA's actions on a routine basis. The Plan identifies the primary gaps in understanding, methods, models, and data that currently limit the Agency's ability to perform economic assessments of ecological benefits. The Plan also recommends areas for future research, methods development, and other activities that could help fill the gaps, and specifies actions needed at an institutional level to ensure implementation of the Plan.

1.1 Objectives of Strategic Plan

This Strategic Plan provides a roadmap to guide Agency-wide investment in the development of the methods, models, and data needed to advance EPA's ability to assess the net ecological benefits of its actions. It recognizes that Agency actions can have both positive and negative effects on ecosystems, and that public policy decision-makers must balance both the public and private advantages and disadvantages of EPA's actions. The Plan also recognizes that the issues and decisions facing EPA today are far more complex and potentially costly to the regulated community and to EPA than in the past, and that those decisions need to be supported with comprehensive and rigorous analyses. Consequently, it is increasingly important that the Agency be able to monetize the advantages and disadvantages of its decisions in order to provide a common metric that is well understood by both policymakers and the public. However, it also is evident that current and near-term limits to our understanding of ecological and economic systems make it technically impossible to value all ecological effects in monetary terms. Thus, the Agency also seeks to improve its ability to quantify ecological effects in non-monetary terms to support decision-making in other ways, such as comparing the cost effectiveness of alternative actions. In this Strategic Plan, the term "ecological benefits assessments" refers to both the quantification of relevant ecological effects, and, when possible, the valuation of those effects in monetary terms.

The overall goal of this Strategic Plan is to improve the Agency's ability to identify, quantify, and value the ecological impacts of its actions in order to improve decision-making and better communicate the results. The specific objectives of the Plan in meeting this goal are:

- to clearly describe the major technical and scientific gaps that prevent the Agency from conducting rigorous and comprehensive ecological impact assessments, so that researchers within and outside EPA know what research is needed and how to tailor their work to meet the Agency's needs;

- to suggest areas for focus of Agency-wide investments in data collection, development of analytical tools, and applied research to ensure that a critical mass of Agency resources is targeted to the areas of greatest need regarding ecological benefits assessment;

- to specify activities to foster increased collaboration and coordination between the Agency's ecologists, economists, and other analysts in conducting ecological benefits assessments; and

- to propose institutional mechanisms that will allow adaptive implementation of this Strategic Plan, including periodic adjustments of the Plan to reflect events and progress in the state of knowledge.

1.2 The Role of Benefits Assessment in Agency Decision-making

When developing regulations, EPA attempts to estimate both the benefits to those who will be made better off by the regulations and the costs imposed on those whose activities are constrained by the regulations. In other words, the Agency attempts to estimate net benefits to society as a whole. Benefit-cost analysis is an economic tool that allows decision-makers to compare the desirable and undesirable effects a proposed policy or action (Arrow et al. 1996). An *ex ante* analysis allows decision-makers to quantify the net benefits of different policy options in order to determine which will be most effective given the limited resources available to address environmental problems. *Ex-post* analyses can be used to quantify the net benefits that actually resulted from an action to determine whether the action was successful, to learn from any unintended consequences, and to assess whether further action is needed.

In general, the disadvantages of regulations are easier to document than benefits, especially when regulations impose direct costs to readily identified or concentrated segments of society, such as an increase in production costs. When the expected benefits of a policy are obvious, there may be little debate over the appropriate course of action. However, some benefits may be indirect or widely distributed across the population, or there may be little agreement about the value of those benefits. In these situations, quantifying and monetizing, even if benefits are captured incompletely, can play a vital role in determining the best course of action, in communicating the rationale for taking action, and in building consensus by providing information about the advantages and disadvantages of the alternatives.

Where environmental goals have been "pre-specified", as per Congressional mandates in enabling legislation, the economic analysis might not need to monetize the benefits associated with those pre-specified goals. Instead, the effects of alternative policy options can be quantified, but not valued, to determine which policies can meet the pre-specified environmental goals at the lowest costs. However, current trends in environmental legislation are moving away from pre-specified goals, where cost-effectiveness analyses can suffice, toward requirements for benefit-cost analysis in establishing environmental goals when implementing statutes.

1.3 Assessment of Ecological Benefits

Broadly speaking, ecological benefits are any improvements in human well-being, whether material or subjective, whether direct or indirect, that result from changes in ecosystems, including ecological functions or processes (see Text Box 1). Ecological benefits flow from changes in the provision of ecosystem goods and services that result from environmental management actions (see Text Box 1). The basis for assessing the benefits of an Agency action is determining how the action affects the flow of these goods and services. The assessment of ecological benefits is thus distinct from the assessment of ecological risks, which is a process to determine the likelihood of an "adverse" ecological effect and its magnitude (USEPA 1998a), but not its impact on ecosystem services. This Strategic Plan is concerned primarily with valuing the changes in ecosystem services that result from EPA actions. Assessing the total value of all types of ecosystem services, which may be helpful as a means to prioritize services for protection, might use similar techniques, but is not the goal of this document.

Note that in this document, ecological benefits refers to the *net* ecological benefits of an EPA action, considering any negative as well as positive changes in ecological goods and services that might result. In the remainder of this document, ecological goods (e.g., fibers, foods) are subsumed in the concept of ecosystem services.

Text Box 1. Definition of ecological benefits and related terminology, adapted from Freeman (2003), Daily (1997, 2000) and Whigham (1997).

Ecological functions or processes – the characteristic actions or activities of ecosystems.
Example: the uptake of nitrogen from soil by vegetation.

Ecosystem services –

- ecological functions or processes that enhance human well-being by providing materials or conditions that sustain or fulfill human life.
  Example 1 : the production by an estuary of seafood harvested for human consumption.
  Example 2 : where excess nutrients have diminished an estuary's seafood production, as well as its recreational and aesthetic quality, the uptake of nitrogen by riparian and wetland vegetation in the watershed..
- ecosystem attributes from which people derive amenities, such as serenity, beauty and cultural inspiration, and recreational opportunities.
  Example: the autumn foliage in a mixed, temperate forest on a complex landscape, which people currently enjoy or would enjoy viewing.
- the preservation by ecosystems of the potential to sustain or fulfill human life in ways that are as yet unrecognized.
  Example: the maintenance by diverse ecosystems of a reservoir of biologically active chemical compounds whose uses as pharmaceuticals might be determined in the future.

Ecological benefits – in general, these are any improvements in human well-being that are derived from ecosystem services. In this document, however, the term refers specifically to those improvements in human well-being that are derived from *changes in* ecosystem services resulting from (or expected to result from) environmental management actions. Further, since changes in human well-being are often difficult to measure or estimate, changes in ecosystem services – that is, changes in ecological functions or other attributes – are also considered to be ecological benefits as long as the relationship to well-being is evident.

Examples:

- The contributions to human well-being of actions to protect or restore riparian and wetland vegetation, such as increased seafood production and improved recreational and aesthetic quality.
- The contributions to human well-being of actions to reduce concentrations of airborne particulate matter, such as the enhanced aesthetic qualities of the surrounding landscape.
- The potential for future improvements in human well-being resulting from actions to preserve species whose pharmaceutical uses might be recognized and developed in the future.

Finally, note that the definition of ecological benefits used in this Plan is specifically those improvements in human well-being that are derived from *changes in* ecosystem services resulting from EPA actions (Text Box 1).

1.4 Organization of This Document

The remainder of the Strategic Plan is organized in five main sections. Section 2 describes the nature of the challenge facing EPA and provides background on previous and ongoing activities intended to help improve EPA's capabilities in assessing ecological benefits. Section 3 describes the current state of the practice for assessing ecological benefits at EPA as well as an integrated process, which together provide a conceptual roadmap for the future – where we are and where we want to go. Section 4, which is the heart of the Strategic Plan, provides a roadmap to guide the Agency's investments in research to fill the major knowledge gaps and to deal with institutional barriers that currently impede the Agency's ability to assess ecological benefits. Section 4 also describes specific areas for short-term and mid–to-long-term research and process changes designed to fill the existing knowledge gaps and to overcome the current institutional barriers. Section 5 provides recommendations for implementing this Plan. [References are provided in Section 6 OR we may want to include references at the end of each chapter; decision can be postponed for now].

More information on EPA's current capabilities and needs in the area of ecological benefits assessment, as determined during an Agency-wide information gathering exercise and a follow-up survey conducted to support the Strategic Plan, is presented in Appendix A. A list of information sources relevant to economic assessments of ecological benefits that were identified during the development of this plan is provided Appendix B.

2 Background

This Strategic Plan builds on the Agency's previous efforts to advance its capabilities in assessing ecological benefits. Over several years, EPA, other federal agencies, and a number of non-governmental organizations have participated in collaborative research efforts designed to improve the state of the art in this area, including original research, workshops and symposia, case studies, meetings between organizations, and efforts to develop guidance for agency staff. Furthermore, there are a variety of ongoing efforts, both inside and outside of EPA, progressing in this area. However, much work remains to be done. This Strategic Plan is intended to supplement these past and ongoing efforts and to accelerate development of specific methods, models, and data to improve the Agency's ability to assess ecological benefits.

This section first describes in more detail the nature of the challenge of assessing ecological benefits, and then describes previous and ongoing activities aimed at improving economic assessment of ecological changes.

2.1 Nature of the Challenge

In the past, EPA's efforts to provide monetary measures of the economic effects of EPA's actions have mostly been limited to measuring human health effects. In some rare cases, however, EPA has attempted to evaluate the benefits of its actions on the flow of ecosystem services. For example, EPA's 1987 *Economic Impact Analysis of Effluent Limitations Guidelines and Standards for the OCPSF [Organic Chemicals, Plastics, and Synthetic Fibers] Industry* included monetized estimates of improvements along a water quality index intended to encompass effects on aquatic ecosystem health, commercial fishing, and the number of stream segments expected to meet water quality criteria (Caulkins and Sessions 1997; Raucher 1987; USEPA 1987a,b,c). The 1987 analysis of the *Montreal Protocol on Substances that Deplete the Ozone Layer* included estimates of crop damage from UV-B radiation and ground-level ozone and increases in commercial fish harvest (Hammit 1997). The economic analysis of the *Great Lakes Water Quality Guidance* included estimates of increases in recreational and commercial fishing, non-consumptive wildlife-related recreation, and "non-use" ecological benefits (Castillo et al. 1997; USEPA 1995). More recently, in its analysis for the *Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations*, EPA monetized improvements in recreational benefits, commercial fish harvests, and reduced fish kills (USEPA 2001c). For analysis of *The Benefits and Costs of the Clean Air Act, 1990 to 2010, EPA Report to Congress*, EPA monetized improvements in visibility for recreational use of national parks, increases in recreational fishing, and increases in commercial timber and agricultural productivity (USEPA 1999a).

The ecosystem goods and services that have been valued in these assessments, however, represent a small subset of the types of goods and services generally recognized as being supported by well functioning ecosystems. Examples from the larger universe of well recognized ecological benefits are listed in Table 1, and are categorized according to the types of benefits to human welfare that they provide: market or non-market, and direct-use, indirect-use, or non-use. Assessing this broad range of potential ecological benefits is challenging for several reasons, including limitations in the current state of ecological knowledge and the practice of ecological risk assessment, limitations in the current state of economic knowledge and the practice of economic benefits assessment, technical challenges to integrating ecological and economic models, and historical and practical impediments resulting from institutional characteristics of the Agency.

First, the current state of ecological knowledge and the state of the practice of ecological risk assessment set some limits on ecological benefits assessments. Although scientific understanding of ecological systems has advanced significantly in recent years, many gaps and uncertainties remain. For example, the Agency has made great strides in identifying acute, lethal impacts of various stressors on individuals of certain species, but models and data describing sublethal and reproductive impacts of various stressors on individuals, and how those effects translate into effects on populations, communities, and ecosystems, are limited or absent. Furthermore, given the complexity of ecological systems, it is difficult to identify the wide variety of ecological changes that might cascade through various ecological interactions. Developing the needed understanding, data, and methods will require continued, basic ecological research over the medium to long term.

Second, the current state of economic knowledge and the practice of economic assessment also set limits on ecological benefits assessments. Even when ecologists can quantify the ecological impacts of an action, economists may still find it difficult to estimate the value of those impacts in dollar terms for the purpose of benefit-cost analysis. The "use values" of some ecosystem services, such as those that influence recreational activities or that support the harvest of commercial fish species or forestry products, can be measured relatively easily using fairly well developed economic

Table 1. Types of ecological benefits categorized by benefits type[a]

Benefit Category		Explanation	Examples
Market		Generally relate to primary products that can be bought or sold as factors of production or final consumption products	• Food and water sources: drinking water, commercial fish, game fish • Building materials: timber • Fuel: biomass, fuelwood, timber • Clothing: furbearing mammals • Medicines: nature-derived pharmaceuticals
Non-market	Direct use	Directly sought and used or enjoyed by society; include both consumptive uses and non-consumptive uses	•Consumptive recreational: fishing, hunting •Non-consumptive recreational: boating, swimming, camping, sunbathing, walking, climbing, birdwatching, sightseeing, enjoyment of visual amenities
	Indirect use	Indirectly benefit society; may be valued because they support off-site ecological resources or maintain the biological and/or biochemical processes required for life support	• Maintenance of biodiversity • Maintenance and protection of habitat • Pollination of crops and natural vegetation • Dispersal of seeds • Protection of property from floods and weather extremes • Water supply (e.g., groundwater recharge) • Energy and nutrient exchange
	Non-use	Benefit does not depend on current use or indirect benefits; individuals might value the resource without ever intending to use it or have a sense of environmental stewardship; includes bequest value, existence value, philanthropic value, and cultural/historic value	• Perpetuation of an endangered species • Wilderness areas set-aside for future generations

[a]Adapted from USEPA 2000c, 2002b; Principe 1995; and Daily et al. 1997

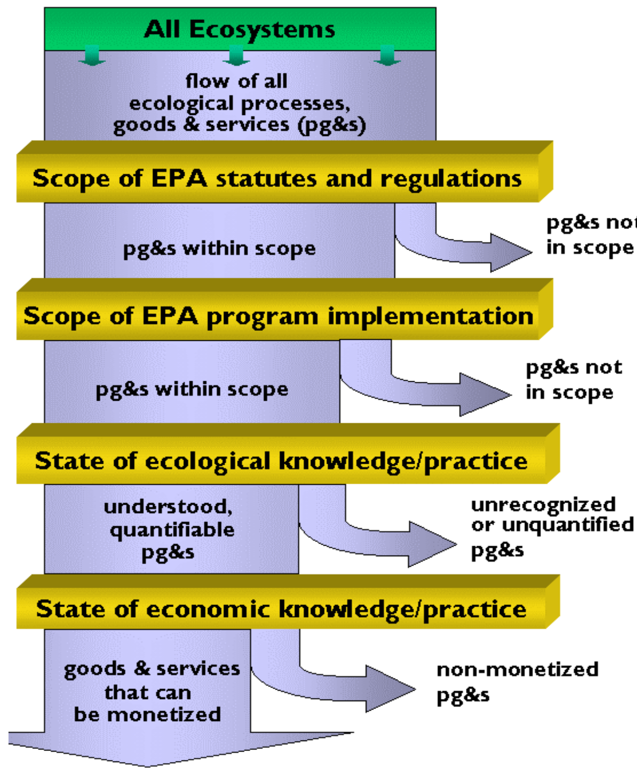
methods based on people's observed behavior. Economists have also developed methods to estimate "indirect-use" and "non-use values" of ecosystem services; however, those methods are subject to more controversy because they rely on responses to survey questions that ask people how they would behave in hypothetical situations. Such benefits may add up to a significant fraction of the total benefits expected from an EPA action. Improving EPA's use of currently available methods for valuing the expected impacts of Agency actions will require more resources devoted to the application of these methods and to the collection of relevant data. The development of new approaches for estimating the values of ecological impacts, particularly indirect use values and non-use values, will require continued basic economic research.

Apart from limitations of ecology and economics in their own right, there are challenges to integrating the models generally used by the two disciplines in conducting an integrated ecological benefits assessment as recommended by the *Framework* (USEPA 2002b). These challenges include identifying the most relevant endpoints from both ecological and economic perspectives, defining the linkages between ecological and economic endpoints, and integrating the temporal and spatial scales of the analyses. To date, Agency ecologists and economic analysts have limited experience in collaborating on integrated assessments.

Finally, the institutional history and organization of the Agency itself has not been conducive to advancing ecological benefits assessment as part of the Agency's decision-making processes. Historically, assessing ecological benefits has not been a major focus of the Agency and, therefore, the resources expended on conducting or improving such assessments have been limited. Moreover, the structural organization of the Agency tends to isolate ecologists and economists in different offices addressing different issues. To date there has not been an overall coordinated plan for the Agency to follow to systematically build its capabilities in this area, nor has there been an oversight entity at the Agency to ensure a sustained effort

Note that the state of the art of assessing ecological benefits is only one factor influencing how well valuable ecosystem services are actually maintained in the United States. Other factors such as legislative, institutional, and state of the knowledge also affect the extent to which EPA and other federal agencies can protect ecological goods and services. Figure 1 illustrates the measurement of regulatory efficacy as a flow of ecological processes, goods, and services and indicates that the flow can be diminished as some types of ecological benefits fall outside the scope of particular Agency actions or are not well understood. Those potential losses are depicted as flow diversions in the figure. There are opportunities for EPA to address these factors, to help maintain and protect the net flow of ecosystem services not only by making improvements in the Agency's ability to value ecological benefits, but also by taking strategic actions that 'minimize the diversions' in the scope of its regulations and program implementation. However, the focus of this Strategic Plan is on advancing the state of the knowledge and practice of ecological and economic benefit assessments and facilitating coordinated and integrated conduct of ecological benefits assessments during regulation development and program implementation at the Agency.

Figure 1: Factors affecting the maintenance of ecosystem benefits, represented as a flow with diversions. The degree to which flow is sustained at all stages influences the amount of goods and services that remain available for EPA's benefits assessment process to address and protect.



2.2 EPA-related Past Efforts

In 1981, the President issued Executive Order 12291, which directed federal agencies to assess the costs, benefits, and economic impacts of their major regulations and established a formal review process by the Office of Management and Budget (OMB).[1] To assist Agency analysts in meeting OMB requirements, EPA issued *Guidelines for Performing Regulatory Impact Analysis* (USEPA 1983), which provided a brief description of what was required for assessing costs, benefits, and economic impacts of its policies and actions. The *RIA Guidelines* were updated in 1991 with several appendices including the *Analysis of Benefits*, which provided general recommendations on methods of estimating benefits in

[1]For readers interested in a more comprehensive and detailed history of economic analyses of rules and policies, see Morgenstern (1997).

several categories, including human health; agriculture, fisheries, and silviculture; materials; recreation; aesthetics; and ecosystems. For the latter category, the *RIA Guidelines* acknowledged that "estimating the benefits (or damages averted) of environmental regulations that affect ecosystems is perhaps the most complex problem in benefits analysis" (pg A-19). The *RIA Guidelines* further noted that many ecosystem service flows may not be apparent, are difficult to understand, and are difficult to measure with conventional economic methods (pg A-20) (USEPA 1991).

Some offices within EPA developed more detailed guidance to help staff conduct economic valuations of at least some ecological changes. For example, in 1990, the Office of Marine and Estuarine Protection and the Office of Policy, Planning and Evaluation published *The Economics of Improved Estuarine Water Quality: An NEP Manual for Measuring Benefits* (USEPA 1990b). That manual provides guidance on monetizing ecological benefits, but only for those benefits for which monetary valuation techniques were already fairly well developed at the time (i.e., swimming, fishing, and boating and commercial fishing benefits). At the same time, the Office of Policy Analysis was arguing for the development of techniques capable of estimating economic values for a far wider range of ecosystem services, including many that are typically overlooked such as pest and disease control, pollination, microclimate control, and nutrient cycling (USEPA 1990c; draft final report *Ecosystem Services and Their Valuation*).

In its 1990 precedent-setting report *Reducing Risk: Setting Priorities and Strategies for Environmental Protection*, the EPA Science Advisory Board (SAB) stated that the value of natural ecosystems was inadequately considered in setting priorities at EPA and insufficient for EPA decision-making in general (USEPA 1990a). The SAB identified two key problems: (1) the focus of current economic models on structural attributes of ecosystems and not ecosystem functions and relationships, and (2) the fact that current ecological models generally do not describe the "services" of ecosystems. In that report, the SAB recommended that EPA "develop improved analytical methods to value natural resources and to account for long-term environmental effects in its economic analyses."

To assist the Agency in responding to SAB's observations and recommendations, the Office of Policy, Planning, and Evaluation established an Ecosystem Valuation Forum in 1990. A key purpose of the Forum was also to assist EPA "in overcoming piecemeal approaches to incorporating ecosystem values into a benefit/cost framework" at the Agency (Brody and Kealy 1995, pg 67). Its objectives were to improve existing methods as well as to develop new methods for valuing ecosystem services. During

1991 and 1992, the Forum met in a series of public workshops and identified many challenges to valuing ecosystem services, including the limited understanding of the many complex relationships between ecosystems and human well-being. The outcome of this effort was published in a special issue of *Ecological Economics* (1995, Vol. 14) and recommended that economists and ecologists collaborate on additional case studies as a next step in the process of improving ecological benefits assessments. Because the Forum was established by a single Office, changing priorities and reorganizations led to the discontinuation of the Forum.

Meanwhile, requirements for the analysis of social benefits and costs for significant regulatory actions were reaffirmed in 1992 with the issuance of Executive Order 12866 on regulatory planning and review. In addition to those requirements, economic assessments are also called for under various administrative statues (e.g. *Unfunded Mandates Reform Act of 1995*). Recognizing the importance of high quality economic analysis, OMB released its *Guidelines to Standardize Measures of Costs and Benefits and the Format of Accounting Statements* in 2000 (or *OMB Guidelines*; USOMB 2000).

EPA also recognized that careful economic analysis is an important component of the design of environmental policies. In order to keep pace with this increased emphasis on economic analysis, EPA significantly updated and revised the *RIA Guidelines*, publishing the new *Guidelines for Preparing Economic Analyses* in 2000 (USEPA 2000a). The *EA Guidelines* reflects the advancements in techniques for benefits estimation, different economic models for assessing costs and other effects, and the greatly expanded data sources and related guidance materials developed since 1983. With respect to ecological benefits, the *EA Guidelines* provide a categorization scheme according to how directly benefits are experienced by the public and how the benefits relate to the private good/public good continuum. That categorization helps analysts to identify which monetary valuation techniques might be applicable. The *EA Guidelines* assume that the necessary quantitative information on changes in ecological condition, processes, and service flows can be provided by the ecological risk assessors. As noted in Section 2.1 and as will be discussed in Section 4, however, that assumption overestimates the current state of the science of ecology.

In 2000, the SAB published *Toward Integrated Environmental Decision-making*, a follow-up report to *Reducing Risk*, which provided a conceptual vison for "the next step" in environmental protection for the United States (USEPA 2000b). The report described some important considerations for public environmental decision-making, and the need for broad participation in the decision-making process. The SAB recommended that "[w]hen evaluating risk reduction options, EPA should strive to weigh the full range of advantages and disadvantages, both those measured in dollars as costs and benefits and those for which there may not be a comprehensive dollar measure, such as sustainability and equity"(pg 39, Recommendation 5). The SAB further recommended that "EPA should seek and develop methods to characterize public values and incorporate those values into goal-setting and decision-making" (pg 40, Recommendation 6). Those recommendations highlighted the increasing perception that current economic assessment practices at the Agency do not incorporate the full range of effects that decision-makers may want to consider.

In 2001, EPA cosponsored a public workshop with the SAB titled *Understanding Public Values and Attitudes Related to Ecological Risk Management*, which brought together experts from ecology and four behavioral sciences – economics, psychology, decision science, and anthropology – to consider a specific case study (USEPA 2001b). The case study chosen for evaluation was nitrogen deposition in Tampa Bay, because both the valuation of ecosystem services was needed and the physical data necessary to carry out this valuation already existed. The centerpiece of the workshop was a series of presentations on research proposals to assess public environmental values associated with the Bay. The workshop represented a highly successful beginning step in implementing one of the suggestions in the SAB report *Toward Integrated Environmental Decision Making* – to create a forum for open discussion on the topic of natural resource valuation. This Strategic Plan proposes to pattern several of its short- to mid-term project activities after this model.

Starting in 1996, EPA's Science Policy Council convened an Ecological Benefit Assessment Workgroup to develop *A Framework for the Assessment of Ecological Benefits*, released in February 2002 (USEPA 2002b). The *Framework* outlines a process by which ecological risk assessors and economic analysts can conduct and coordinate their assessments. The steps of an economic benefits analysis, as identified in the *EA Guidelines*, are matched and integrated with the steps of an ecological risk assessment as outlined in EPA's (1998a) *Guidelines for Ecological Risk Assessment*. The *Framework* provides a process for conducting assessments of ecological benefits assuming that the necessary methods, models, and data are available. However, since many gaps exist in the state of knowledge and in available tools, implementation of the *Framework* requires development of tools to overcome the gaps. The purpose of this Strategic Plan is to provide a roadmap for developing those tools so that the Agency can operationalize the process set forth in the *Framework*.

Other federal agencies similarly have been addressing the challenge of assigning economic values to ecological benefits (e.g., NMFS 2000; USACE 1995, 1996; USDA 1999, 2002; USDOE 1995; USFWS 1985, 1995). In July, 2001, the U..S. Army Corps of Engineers (ACE) sponsored a workshop *Improving Environmental Benefits Estimation*, which included representatives from EPA and several other federal agencies. The workshop was part of their overall strategy for improving environmental benefits estimation in their assessments of ecological restoration and multipurpose ACE projects. One of ACE's goals in holding the interagency workshop was to encourage mutli-agency participation in and buy-off on the strategy that ACE is actively engaged in developing to improve its ability to conduct cost-efficiency and benefit-cost evaluations. ACE has developed a white paper, *Improving Environmental Benefits Analysis*, articulating its strategy (USACE 2003); however, it recently has suspended work on that strategy to focus on short-term solutions for their evaluation needs (e.g., guidance for current assessments). US ACE recognizes that many of the ecological valuation benefits that they see will require long-term research efforts and policy development.

The difficulty in quantifying and valuing ecological benefits has recently been reiterated by OMB in its revised guidelines for regulatory analysis (*Informing Regulatory Decisions: 2003 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local and Tribal Entities*; USOMB 2003).

2.3 Ongoing EPA Efforts

There are currently a number of activities and initiatives aimed at improving valuation of ecological benefits underway at EPA which recognize the technical challenges to progress in this area. The SAB has just convened a *Panel on Valuing the Protection of Ecological Systems and Services*. The purpose of the Panel is "to provide advice to strengthen the EPA's approaches for assessing the costs and benefits of actions designed to protect ecological systems and services, to identify research needs to improve how ecological resources are valued, and to support decision making to protect ecological resources."[2]

EPA's National Center for Environmental Research (NCER) and the National Center for Environmental Economics (NCEE) have developed and recently released a

[2] http://www.epa.gov/sab/panels/vpesspanel.html

draft *Environmental Economics Research Strategy* (EERS).[3] The EERS identifies EPA's highest priority research needs in environmental economics, describes the short- and long-term research objectives for each need, describes the resources and tools needed to achieve these objectives, and suggests a time frame for meeting the objectives. This strategy was developed in cooperation with EPA's program and regional offices. Interviews conducted to identify top priorities for the EERS indicated that the areas with the greatest research needs at EPA include human health and ecological benefits valuation, environmental (compliance) behavior and decision-making, market mechanisms and incentives, and benefits of environmental information disclosure. The EERS addresses each of those top research priorities with the exception of ecological benefits valuation. That topic is the subject of this Strategic Plan.

Through its STAR grant program, ORD's National Center for Environmental Research (NCER) is continuing to support research in *Decisionmaking and Valuation for Environmental Policy*, as well as a number of other areas that have the potential to advance methods and data for conducting ecological benefits assessment.[4] A partial list of these other research categories includes *Ecological Indicators*, *Ecosystem Indicators*, *Water and Watersheds.* This Strategic Plan is intended to assist ORD in defining key research areas related to ecological benefits valuation and in evaluating proposals submitted to the program.

NCEE and OW, in conjunction with the US Department of Agriculture and the Department of the Army, are cosponsoring a National Research Council (NRC) project on *Assessing and Valuing Aquatic Resources*.[5] The NRC committee of academic experts is charged with evaluating methods for assessing services and the associated economic values of aquatic and related terrestrial ecosystems. The project focus is on identifying and assessing existing economic methods to quantitatively determine the intrinsic value of these ecosystems in support of improved environmental decision-making, including situations where ecosystem services can be only partially valued. The committee charge includes several key questions, including:

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[3] http://es.epa.gov/ncer/events/news/2003/06_23_03a.html

[4] http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/research.search/rpt/abs/type/3

[5] http://www.nationalacademies.org/webcr.nsf/

- What is the relationship between ecosystem services and the more widely studied ecosystem functions?

- For a broad array of ecosystem types, what services can be defined, how can they be measured, and is the knowledge of these services sufficient to support an assessment of their value to society?

- What lessons can be learned from a comparative review of past attempts to value ecosystem services? Particularly, are there significant differences between eastern and western U.S. perspectives on these issues?

- What kinds of research or syntheses would most rapidly advance the ability of natural resource managers and decision-makers to recognize, measure, and value ecosystem services?

- Considering existing limitations, error, and bias in the understanding and measurement of aquatic ecosystem values, how can available information best be used to improve the quality of natural resource planning, management, and regulation?

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These ongoing efforts illustrate that valuation of ecological benefits, economic or otherwise, although extremely difficult technically, is considered to be very important to the benefit-cost assessments conducted in support of regulatory and policy development. Both EPA's SAB and the National Academy of Sciences are actively working to provide advice, leverage existing information, and identify research needs to enable adequate consideration of ecological benefits in environmental decision-making. Ecological benefits assessment comprises a component of the EPA NCEE, NCER, and ORD environmental economics research concerns.

2.4 Focus and Success of This Effort

The past and ongoing efforts also reveal that the general approach to building the Agency's capabilities to assess ecological benefits could be improved. Overall, the activities undertaken to date have generally been initiated separately, with expectations for follow-on activities and procedures for implementing recommendations of completed activities largely undocumented. Moreover, despite the fact that the need for improved capabilities in ecological benefits valuation crosses many program offices, an EPA-wide forum for addressing that need has not yet been established. Due to shifting Agency priorities and reorganization of the single sponsoring EPA office, the Ecosystem Valuation Forum was short-lived, and therefore could not serve to guide the Agency along a sustained and organized effort.

This Strategic Plan is intended to redress these problems by (1) describing the major scientific and technical gaps in ecological and economic understanding and tools; (2) laying out a roadmap for Agency-wide investments to an *organized* and *sustained* series of short- and medium-to-long term projects that will steadily improve the Agency's ability to identify, quantify, value, and communicate the ecological benefits of its actions and decisions; (3) laying out a series of activities that will provide ecological and economic analysts experience in collaborating on assessments; and (4) developing an implementation plan for the Strategy that will ensure its continuation despite changing priorities. This Plan distinguishes itself from previous and current efforts by focusing its scope on the practice of ecological benefits assessment at EPA and by suggesting activities and institutional changes that will lead to Agency-wide coordination and joint investments in models, methods, and data to estimate the ecosystem benefits of Agency actions.

3 Linking Ecological and Economic Assessments

Making informed choices between alternative environmental policies or management options requires, at the very least, a way to predict the likely effects of each option on the ecological endpoints of concern. Ideally we would also have the means of determining the relative desirability, or "value," of those effects on the ecosystems (Text Box 2). Ultimately, expressing those values in a common metric, dollars for example, can help decision-makers choose between alternative policy options that may have a range of negative or positive effects on many environmental endpoints.

> **Text Box 2. The Concept of Value**
>
> Value can be split conceptually into two distinct types: value may be "intrinsic" in the sense that entities have value exclusive of their relationship to humans, and value may be "instrumental", meaning it arises from the ability of an entity to achieve a human purpose (e.g., recreate) (Mazzotta and Kline 1995). Instrumental values can be aggregated and compared, at least in theory, so they are the basis of Agency decisions and actions.

In this section, we describe some of the key difficulties analysts face when attempting to assess ecological benefits in the context of economic analyses at EPA. We first describe the current state of the practice of ecological assessment and economic assessment at EPA, which are generally pursued independently for reasons described below. We then describe the ecological benefits assessment process, as recommended in the EPA 2002(b) *Framework*, in which ecological and economic analysts collaborate to integrate ecological and economic inputs and models. This section provides the context for Section 4, which discusses some of the specific barriers that stand between the current practice and the integrated process outlined in the *Framework,* and some key areas for tool development and institutional changes at the Agency that can help move the Agency toward a more fully integrated assessment of ecological benefits.

3.1 Current State of the Practice

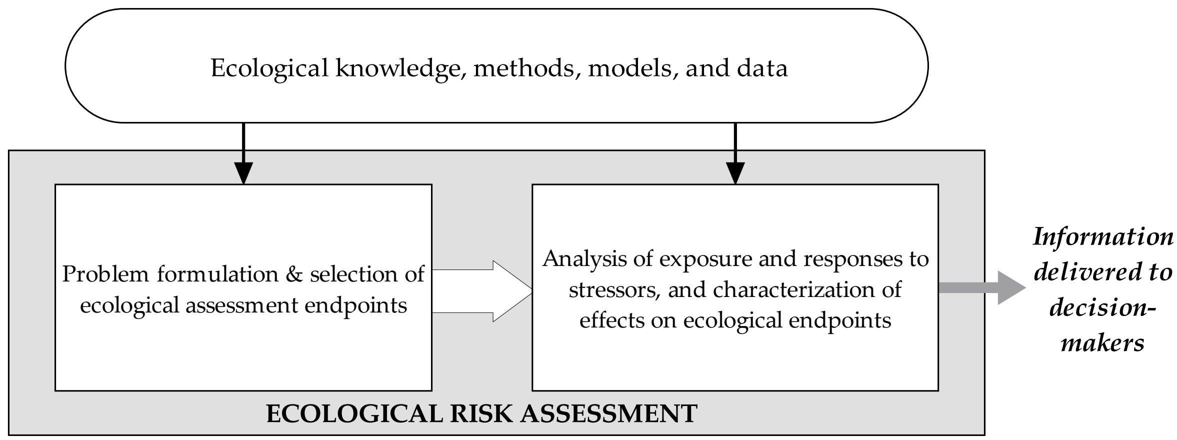
The Agency has made substantial progress in providing guidance and tools for conducting economic benefits assessments and ecological assessments over the past few decades (see Section 2.2 and USEPA 2000a *Guidelines for Preparing Economic Analyses* and USEPA 1998a *Guidelines for Ecological Risk Assessment;* many program-specific guidelines also have been developed). However, the need to thoroughly integrate ecological and economic assessments at the beginning of a regulatory impact analyses (or related programmatic evaluation) has only recently been articulated in the *Framework* document (USEPA 2002b). This section examines the current state of the practice of ecological risk assessment and economic benefits assessment and describes why the two practices have been conducted largely independently of each other at the Agency.

3.1.1 Ecological Assessments

Ecological assessments at EPA take many forms depending on the legislative mandates and decisions that they support. These include prospective risk assessments to evaluate environmental management options (e.g., for a given waste site or registration of a pesticide) and retrospective assessments of ecological impacts to diagnose their causes. These also include assessments of ecological and toxicological responses to stressor exposures to support development of environmental criteria, and assessments of environment monitoring data to document the condition of the nation's ecosystems. In conducting ecological assessments, the Agency generally follows the principles and approach communicated in EPA's 1998 *Guidelines for Ecological Risk Assessment* (USEPA 1998a).

In conjunction with other scientific information, such as economic assessments and engineering studies, ecological risk assessments (ERAs) play an important role in Agency decisions. Figure 2 shows a stylized representation of the ERA process. This figure has been simplified from the representation in the *Guidelines for Ecological Risk Assessment* (USEPA 1998a) to focus on the key similarities and differences between the ERA process and the economic benefits assessment process depicted later in Figure 3. The gray box contains the simplified stages of the assessment itself, with ecological knowledge, methods, models, and data, as depicted in the rounded box on the outside, informing each stage as depicted by the arrows. With input from EPA risk managers and stakeholders, and with reference to risk management goals, the first step is problem formulation. During this phase of an ERA, risk assessors evaluate the context and scope of the assessment, alternative management options under consideration, and likely stressors and exposure pathways, and then build a conceptual model of the environmental problem. It is during this up front evaluation that *assessment endpoints* (USEPA 1998a) – those endpoints that represent the ecological entities and attributes of concern (e.g., sustainability of a trout population, "health" of an aquatic community as indicated by species composition and abundance) – are selected. Another product of problem formulation is the risk assessment analysis plan, which also specifies the

Figure 2. Stylized representation of a standard ecological risk assessment



measurement endpoints (USEPA 1998a), those ecological attributes that can be measured and that will be used to infer or predict changes in the assessment endpoints. Problem formulation sets the course and activities for the remainder of the assessment.

The remainder of an ERA involves analysis of exposures and ecological effects and characterization of risks. Analysis of exposure involves an evaluation of the magnitude of co-occurrence of stressors and the ecological receptors over time and space. Analysis of ecological effects involves development of exposure-response profiles that describe the likely responses of receptors to such exposures. If the management goal is to protect against adverse effects, risk assessment may need only identify a "safe level", that is a threshold of exposure above which adverse effects might occur but below which no effects are expected. In such cases, a full description of an exposure-response curve is not needed. In essence, this is the approach EPA currently uses to establish ambient water quality criteria and cleanup goals for Superfund sites. Risk characterization integrates the exposure and effects assessments to estimate the likelihood of an adverse effect in the ecological assessment endpoints. Ideally, these estimates are in the form of bounded probabilities; however, because of available data, estimates often are comparisons of the predicted exposure levels against benchmarks representing thresholds for adverse effects. Ecological risks are communicated to the decision-makers together with interpretation of the significance of the risks, i.e., with judgment about the ecological importance of the effects on assessment endpoints.

For many EPA programs for which ecological risk assessment plays a key role in decision-making, economic valuation of ecological changes historically has not been needed. This is because the goals of many environmental protection statutes are or specified as preventing adverse environmental impacts. For example, the Clean Air Act is intended to protect and enhance the quality of the nation's air resources. The goal of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Other statutes are intended to prevent "unreasonable" adverse effects in the environment taking into account economic, social, and environmental costs and benefits. Examples include the Federal Insecticide, Fungicide, and Rodenticide Act, which addresses the use of pesticides, and the Toxic Substances Control Act, which covers the manufacture and use of new chemicals. Even for these statutes, emphasis is placed on ensuring that environmental concentrations do not exceed what might be considered safe levels wherever possible. Given the general mandate of preventing "adverse" effects, it has usually not been necessary to predict the types, magnitude, or extent of ecosystem changes that might occur if the "threshold" concentration for effects is exceeded. Where alternatives actions to achieve the same goal (e.g., of reducing environmental contamination to levels below the "threshold for adverse effects") are considered, cost-effectiveness in achieving the management goal can be evaluated without attempting to monetize benefits. Thus, most ERAs conducted at EPA to date have not provided estimates of changes in ecosystem processes that would be needed as inputs to economic analyses of benefits (i.e., to estimate changes in ecosystem goods and services). Note that many of the non-market indirect-use and non-use categories of services noted in Table 2 are particularly difficult to characterize and quantify, and ERAs generally do not include those endpoints when assessing thresholds for effects. Thus, those types of ecological benefits tend to be overlooked in both economic and ecological assessments. For this reason, Principe (1995) termed these "neglected" benefits.

In addition to ecological assessments to evaluate potential outcomes of specific Agency actions, another major focus of ecological assessment at the Agency is to use monitoring data to evaluate current condition and trends in our nation's ecosystems. This information can be used to assist in assessing the effectiveness of Agency programs overall in achieving environmental improvements, to identify emerging environmental issues, to document changes in ecosystem condition due to stressors beyond immediate Agency influence (e.g., changes in land-use), and to specify the baseline conditions against which the Agency should evaluate the results of its actions. These evaluations also are intended to support prioritization of areas and ecosystems for protection via enforcement actions and voluntary programs. EPA's Environmental Monitoring and

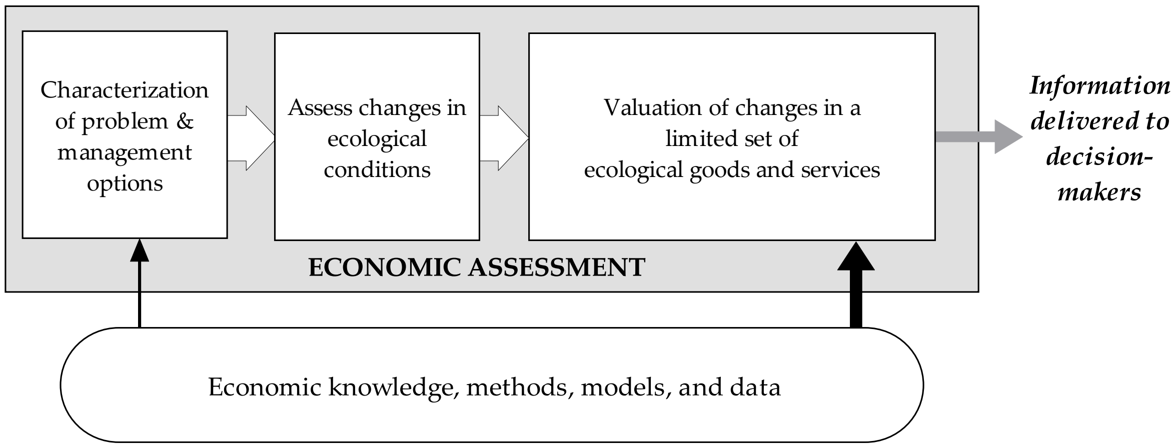
Assessment Program (EMAP) is a long-term research effort to enable condition and trend assessments of aquatic ecosystems across the United States with a known statistical confidence (USEPA 2002e). A variety of physical, chemical, and biological measures at specified sampling locations can be used to develop indicators of the condition of the aquatic ecosystems. An example of a biological indicator is the Index of Biotic Integrity (IBI; Karr 1981), which is a metric developed from several measures of the characteristics of a fish or benthic aquatic community (e.g., number of species, species abundance, presence of sensitive species). As yet, however, indicators of ecological condition have not been used to evaluate conditions and trends in the flow of ecosystem goods and services.

3.1.2 Economic Benefits Assessments

Economic analyses at EPA can take a variety of forms, depending on legislative mandates, the type of environmental issues being addressed, and the type of benefits in question. Most of these analyses apply the results of existing studies to new policy contexts, a practice generally referred to as "benefit transfer" (USEPA 2000a). Figure 3 provides a stylized representation of a standard economic benefits assessment, as currently practiced at EPA. The first step of the assessment is to characterize the problem and identify the alternative management options to be analyzed. Next, changes in ecological conditions are assessed. However, the set of ecological changes that are considered may not be comprehensive. Predictions are sometimes made on the basis of expert opinion, or the results of limited observational studies or ecological modeling. Because this portion of the assessment may not be comprehensive, the final benefit estimate may capture only a portion of the total benefits. Furthermore, if this second step of the assessment is not based on the best ecological methods and data available, then even the estimate of the (possibly unknown) portion of the total benefits that is captured may not be considered reliable.

In the third step of the assessment, the changes in ecological conditions predicted in the second step are valued using one or more economic valuation methods. Economists generally attempt to estimate the value of ecological goods and services based on what people are willing to give up to increase ecological services, or by what people are willing to accept in compensation for reductions in ecological service flows. Because money is used as the medium of exchange for so many goods and services that people buy and sell on a regular basis, economists generally estimate values in terms of dollars. That is, economists attempt to estimate people's willingness to pay (WTP) for improvements in environmental quality or willingness to accept (WTA) compensation

Figure 3. Stylized representation of a standard economic benefits assessment



for damages to the environment in dollar terms. The main approaches for estimating these values can be put into three categories: market-based methods, revealed preference methods, and stated preference methods.

In cases where ecosystem changes affect commercial activities (e.g., agriculture or commercial fishing), market-based valuation methods can be used to estimate the net increase or decrease of consumer and producer well-being. In the simplest cases, increases in commercial production can be valued at the price observed in the market. More detailed analyses may consider how changes in supply of the good in question might affect prices and how gains and losses are distributed between producers and consumers. For example, in commercial fisheries, the increase in harvest depends on the size of the fish populations, the harvesting methods used, and regulatory issues such as limits on the total fish catch. EPA has performed benefits assessments that include changes in ecosystem goods or services whose values are captured through markets. One example is the *National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs); Final Rule* (USEPA 2003a).

Revealed preference methods can be used to value ecosystem services that, though not bought or sold directly, are associated with goods or services traded in markets. Three revealed preference methods that can be used in this context are: "recreation demand models," "hedonic price models," and the "production function approach." Recreation demand models use data on observed (or self-reported) behavior to determine the value of environmental attributes that support outdoor recreational activities. For example, expenditures individuals incur to visit a park reflect the value they place on the park's environmental amenities. Such models have been widely used to estimate values for ecosystem services (Bockstael et al. 1989, Kaoru et al. 1995), and EPA has supported these research efforts. However, the application of these models to EPA benefits assessments has been limited to a few actions under the Clean Water Act.

Hedonic price models are typically used to measure the implicit prices of house and neighborhood characteristics, such as the number of bedrooms and the proximity to public transportation. These models can also be used measure the implicit values of aesthetic environmental amenities near the home (Geoghegan et al. 1997, Opaluch et al. 1999). This approach has been used less frequently than recreation demand models to value ecosystem services.

Another type of revealed preference method, sometimes referred to as the "production function approach," can be used to value ecosystem goods and services by treating them as inputs to production processes used to generate marketed goods or services (Barbier 2000, Bell 1998). Examples include pollination, which affects agricultural productivity, and aquifer recharge, which affects the provision of drinking water. Changes in these ecosystem services will affect the productivity or the costs of other inputs to the relevant production processes. Ultimately, changes in these ecosystem services should be reflected in the prices or quantities supplied of the final goods (e.g. agricultural output or drinking water).

These methods are not used frequently in economic benefits assessments at EPA partly because the data requirements for conducting original studies are substantial. Another reason these methods have not been more widely applied at EPA is that there are often few existing revealed preference studies appropriate for benefit transfer. The environmental attributes valued in existing studies may not be the same as those affected by proposed EPA actions.

While revealed preference methods rely on actual behavior, stated preference methods elicit people's WTP or WTA from surveys that describe hypothetical situations. For example, survey respondents may be asked how much they would be willing to pay to be able to boat, fish, or swim in a lake where water quality problems currently prohibit such activities, but might be achievable given various efforts at clean-up. One significant advantage of stated over revealed preference methods is that they allow the researcher to specifically define the environmental change to be valued, rather than relying on actual variation in ecological conditions. This feature can be used to reduce some of the uncertainty regarding the degree to which individuals recognize, and therefore incorporate into their behavior, differences in ecosystem services. This feature also allows the researcher to tailor the definition of changes in ecosystem services to relate more directly to anticipated policy impacts. The design of stated preference surveys, however, requires considerable care to ensure the results will be relevant to the environmental policies at issue (McFadden 1994). Other criticisms include the hypothetical nature of the surveys and the inherent difficulties in evaluating whether respondents answer survey questions in a thoughtful and truthful manner (Diamond and Hausman 1994). It may be difficult to know how accurate or reliable stated preference value estimates are, since individuals are never faced with paying the amount that they say a particular environmental attribute is worth (Arrow et al. 1993, Loomis et al. 1994, Kemp and Maxwell 1993).

Because non-use values, such as existence value, by definition have no association to any observable functioning market, the only means by which to value them is through stated preference methods. The only way estimate the non-use value for protecting an endangered species, for example, may be a survey that asks respondents how much they would be willing to pay to increase the likelihood that the species survives over a given period of time. In light of their unique ability to estimate non-use values, and despite their shortcomings, stated preference methods have been supported by EPA and used in some benefits assessments (e.g., Carson and Mitchell 1984). Nevertheless, non-use benefits still often remain unvalued in the Agency's economic assessments of ecological benefits.

EPA generally does not carry out original stated preference research to support regulatory analyses because of the time and expense involved. It is difficult to apply existing stated preference results because the environmental attributes valued in existing studies may not be the same as those affected by proposed EPA actions.

In the broadest sense, the goal of an economic assessment of ecological benefits is to predict the changes in people's well-being that result from changes in ecosystem services. When possible, economists attempt to estimate benefits in monetary terms, using one or more of the approaches mentioned above. However, when data or methodological limitations preclude a comprehensive and reliable dollar estimate of ecological benefits, these benefits can be expressed quantitatively, i.e., in biophysical measurements, or even qualitatively. A comprehensive benefits assessment may include all three types of representations. Quantitative estimates can be used to help rank alternatives by their benefit-cost ratios. For example, if one of the principal ecological benefits from management options designed to improve water quality were "increases in fish abundance," then the option expected to yield the largest increase in total fish biomass per dollar might be preferred, all else equal. When not even a quantitative assessment of ecological benefits is possible, qualitative descriptions of the potential benefits can be useful. For example, if the primary linkages between the management actions under consideration and a number of important ecological services can be described clearly and concisely, the assessment may provide decision-makers with a better understanding of the potential ecological benefits or costs of those actions. However, estimating benefits in dollar terms enables an assortment of distinct benefits to be combined and weighed against the costs of an action for a more transparent and easily communicated assessment.

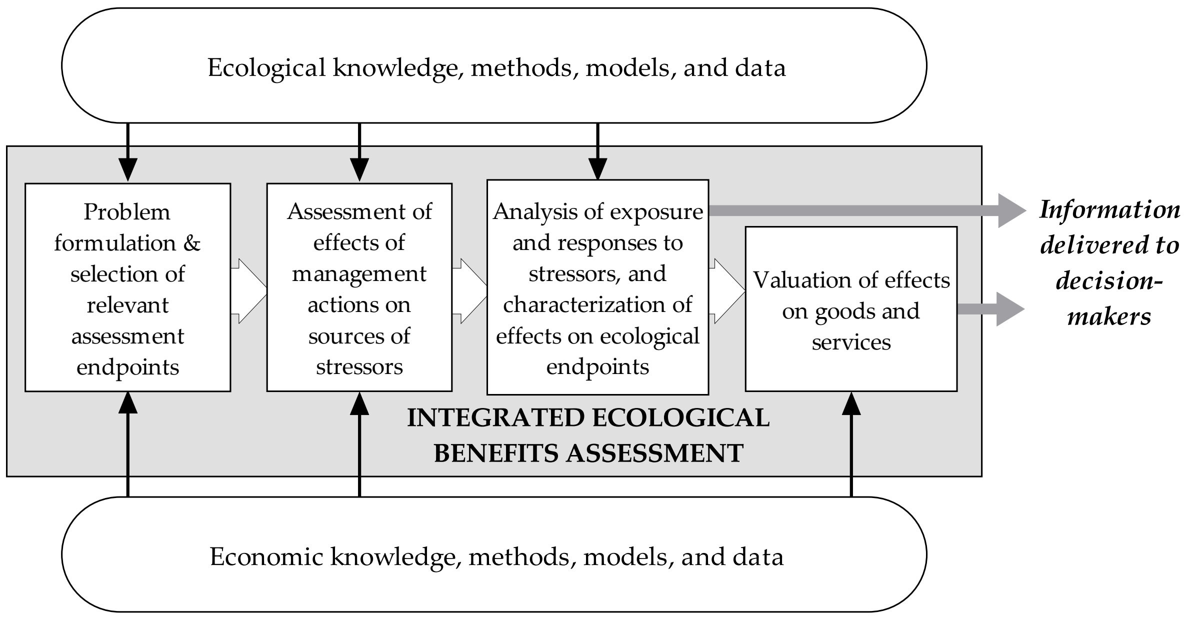
3.1.3 Implications for Integrated Ecological and Economic Assessments

In the past, for non-market ecological benefits assessments, economists have tended to evaluate the "standard" recreational use benefits (e.g., swimming, boating, fishing), which do not need information on how ecological processes might be changed by an Agency action; instead, those benefits can be assessed using data that directly relate use to chemical/physical measures of water quality. For other types of ecological benefits (e.g., indirect-use), the *EA Guidelines* assumed that estimates of ecological changes that might be needed as inputs to the economics benefits assessments are or can be provided by the ecological risk assessors; however, that assumption has turned out to be premature. Many Agency ecological risk assessments are conducted to identify a threshold level of stress that, if exceeded, might cause adverse ecological effects; thus, ecological risk assessors generally do not specify or quantify changes in ecosystem processes that might occur when the stress exceeds that threshold. When they do evaluate impacts that might occur, they tend to focus on structural changes (e.g., population size, species richness) rather than on flows of ecosystem services. Thus, much of the information and many of the tools required to implement the *EA Guidelines* and the *Framework* have yet to be developed.

3.2 Towards an Integrated Ecological Benefits Assessment Process

Figure 4 portrays the stages of an integrated ecological benefits assessment and highlights the contributions of ecology and economics. Arrows from the rounded boxes

Figure 4. Stylized representation of an integrated ecological benefits assessment



on the outside illustrate the major steps at which ecological and economic understanding are incorporated in the assessment. As indicated by the arrows, the assessment is a collaborative process in which the economic and ecological analysts integrate their understanding, methods, and data in planning the assessment, as suggested in *A Framework for the Economic Analysis of Ecological Benefits* (USEPA 2002b). Note that while the primary responsibility of valuation lies with the economists, ecologists have responsibilities to review the results to ensure that all information has been correctly interpreted and to communicate with decision makers.

An integrated ecological benefits assessment should begin by characterizing the problem and selecting relevant ecological endpoints around which the assessment will be structured. Both ecologists and economists should contribute to this phase of the assessment to ensure that the most appropriate combination of analytical tools and data are used and to ensure that the most relevant ecological endpoints are identified. The assessment should target ecological endpoints that reflect the goals of the Agency action as well as endpoints that relate to ecosystem services that directly support human well-being. These will be the endpoints most relevant to society in general, and to the policy goals in particular. In fact, the objectives of the policy will largely identify the endpoints of concern, although other endpoints should be considered, especially those that my be inadvertently harmed. Ecologists and economists should collaborate to identify the endpoints and prioritize those where ecological changes will most affect the value to society. Given resource limitations, it is likely that only certain endpoints can be fully assessed.

After the problem is characterized and the endpoints are selected, the next stage in the process is to assess the effects of the management action(s) under consideration on the sources of stressors (where "management action" refers to any Agency rule, program, or project designed to ameliorate one or more known or suspected sources of stress to the environment). This stage could require input from ecologists and others because it may involve assessing how particular technologies will perform under a variety of natural conditions. This stage could also require input from economists because it may involve assessing how individuals and firms will respond to new information, regulations, or incentives.

The next stage in the benefits assessment process is to assess how the ecological endpoints respond to the changes (generally reductions) in stressors brought about by the management actions. This chain may be quite extensive, beginning with a determination of how reduced exposure changes risks of mortality or morbidity to individual members of a species and translating that into population-level measures of abundance or reproduction/replacement rates. On the other hand, it may be as simple as determining the impact on indexes of ecological conditions, such as water quality, that can be directly related to recreational activities. The methodological and data requirements at this stage are largely the domain of ecology and other natural sciences. At the end of this stage in the process, the effects on relevant ecological endpoints have been quantified. These quantified effects can then be compared across management options, as would be the case in a typical ERA, or combined with estimates of economic costs in a cost-effectiveness analysis.

The final stage in the benefits assessment process is to value the changes in the ecological endpoints. This step involves estimating the tradeoffs people are willing to make for environmental protection. The methodological and data requirements at this stage are largely the domain of environmental economics. At the end of this stage in the process, the quantified effects on relevant ecological endpoints have effectively been combined into a single, monetized measure of value, which can then be compared directly to the estimated economic costs of the management actions under consideration.

Although it is fairly easy to specify the process by which analysts might accomplish an integrated and comprehensive ecological benefits assessment, there are several problems associated with its actual implementation, as described in the next section.

[Note: Sections 4 and 5 are not included in this draft.]

6 References

[Note: Some of these references below are not cited in Sections 1 through 3; rather they are cited in Section 4, which is still under development.]

Arrow, K., S. Solow, P.Portney, E. Leamer, R. Radner and H. Shuman. 1993. Report of NOAA Panel on Contingent Valuation. *Federal Register* 58:4016-4614.

Arrow, K.J., M.L. Cropper, G.C. Eads, R.H. Hahn, L.B. Lave, R.G. Noll, P.R. Portney, M. Russell, R. Schmalensee, V.K. Smith., and R.N. Stavins. 1996. Is there a role for benefit-cost analysis in environmental, health, and safety regulation? *Science* 272: 221-222.

Barbier, E.B. 1994. Valuing environmental functions: tropical wetlands. *Land Economics* 70(2): 153-173.

Barbier, E.B. 2000. Valuing the environment as input: review of applications to mangrove-fishery linkages. *Ecological Economics* 35: 47-61.

Bell, F.W. 1998. The state of nature as an input into the production function. *Journal of Economic Research* 3(1): 1-20.

Brody, M.S., and M.J. Kealy. 1995. Foreward to *Issues in Ecosystem Valuation: Improving Information for Decision Making*. Report of the Ecosystem Valuation Forum to the U.S. Environmental Protection Agency. Special Issues of *Ecological Economics* 14: 67-70.

Bingham, G., B. Richard, M. Brody, D. Bromley, E. Clark, W. Cooper, R. Costanza, T. Hale, G. Hayden, S. Kellert, R. Norgaard, B. Norton, J. Payne, C. Russell, and G. Suter. 1995. Issues in ecosystem valuation: improving information for decision making. *Ecological Economics* 14: 73-90.

Bockstael, N.E., K.E. McConnell, and I.E. Strand. 1989. Measuring the benefits of improvements in water quality: the Chesapeake Bay. *Marine Resource Economics* 6:1-18.

Carson, R.T., and R.C. Mitchell. 1993. The value of clean water: the public's willingness to pay for boatable, fishable, and swimmable quality water." *Water Resources Research* 29(7): 2445-2454.

Castillo, E.T., M.L. Morris, and R. S. Raucher. 1997. Great Lakes water quality guidance. In: R.D. Morgenstern (ed.), *Economic Analyses at EPA: Assessing Regulatory Impact*. Washington DC: Resources for the Future.

Caulkins, P., and S. Sessions. 1997. Water pollution and the organic chemicals industry. In: R.D. Morgenstern (ed.), *Economic Analyses at EPA: Assessing Regulatory Impact*. Washington DC: Resources for the Future.

Crocker, T.D. 1995. Ecosystem functions, economics, and the ability to function. In: J.W. Milon and J.F. Shogren (eds.), *Integrating Economic and Ecological Indicators: Practical Methods for Environmental Policy Analysis*. Westport, CT: Praeger; pp. 27-42.

Daily, G.C., S. Alexander, P.R. Ehrlich, L. Goulder, J. Lubchenco, P.A. Matson, H.A. Mooney, S. Postel, S. H. Shneider, D. Tilman, and G.M. Woodwell. 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. Ecological Society of America, *Issues in Ecology*, Number 2, Spring. Available from: http://esa.sdsc.edu/daily.htm

Daily, G.C. 1997. Introduction: what are ecosystem services? In: G.C. Daily (ed.), *Natures Services: Societal Dependence on Natural Ecosystems*. Washington, DC: Island Press.

Diamond, P.A., and J.A. Hausman. 1994. Contingent valuation: is some number better than no number? *Journal of Economic Perspectives* 8(4): 45-64.

Freeman, A.M. III. 2003. *The Measurement of Environmental and Resource Values: Theory and Methods.* 2nd Edition. Washington, DC: Resources for the Future.

Geoghegan, J., L. Wainger, and N. Boackstael. 1997. Spatial landscape indices in a hedonic framework: an ecological analysis using GIS. *Ecological Economics* 23: 251-264.

Goulder, L.H., and D. Kennedy. 1997. Valuing ecosystem services: philosophical bases and empirical methods. In: G. Daily (ed.), *Nature's Services*. Washington, DC: Island Press; pp. 23-48.

Hammit, J.K. 1997. Stratospheric-ozone depletion. In: R.D. Morgenstern (ed.), *Economic Analyses at EPA: Assessing Regulatory Impact.* Washington DC: Resources for the Future.

Kaoru, Y., V. Kerry Smith, and J.L. Liu. 1995. Using random utility models to estimate the recreational value of estuarine resources." *American Journal of Agricultural Economics* 77: 141-151.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6: 21-27.

Kemp, M., and C. Maxwell. 1993. Exploring a budget context for contingent valuation, In: J. Hausman (ed.), *Contingent Valuation: A Critical Assessment*. New York, NY: North Holland; pp. 217-270.

Loomis, J., A. Gonzalez-Caban, and R. Gregory. 1994. Do reminders of substitutes and budget constraints influence contingent valuation estimates? *Land Economics* 70: 499-506.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H.Evans, M. Clout, and F. Bazzar. 2000 Biotic invasions: causes, epidemiology, global consequences and control. *Issues in Ecology* 5(Spring). Washington, DC: Ecological Society of America; 20 pp.

Mazzotta, M., and J. Kline. 1995. Environmental philosophy and the concept of non-use value. *Land Economics* 71(2): 244-249.

McFadden, D. 1994. Contingent valuation and social choice. *American Journal of Agricultural Economics* 76: 689-708.

Morgenstern, R.D. (ed.). 1997. *Economic Analyses at EPA. Assessing Regulatory Impact.* Washington, DC: Resources for the Future.

NMFS (National Marine Fisheries Services). 2000. *Guidelines for Economic Analysis of Fishery Management Actions*. Silver Spring, MD: Office of Sustainable Fisheries. August.

NRC (National Research Council). 1993. *Pesticides in the Diets of Infants and Children*. Washington, DC: National Academy Press.

NRC (National Research Council). 1994. *Science and Judgment in Risk Assessment*. Washington, DC: National Academy Press.

NRC (National Research Council). 2000. *Ecological Indicators for the Nation*. Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments, Washington, DC: National Academy Press.

NRC (National Research Council). 2002. *Estimating the Public Health Benefits of Proposed Air Regulations.* Washington, DC: National Academy Press.

NRC (National Research Council). 2003. *Assessing and Valuing the Services of Aquatic Ecosystems.* Water Science and Technology Board. Project WSTB-U-00-02-A. Available from: http://www4.nas.edu/webcr.nsf/ProjectScopeDisplay/WSTB-U-00-02-A

Opaluch, J., T. Grigalunas, J. Diamantides, M. Mazzotta, and R. Johnston. 1999. *Recreational and Resource Economic Values for the Peconic Estuary System.* Report prepared for the Peconic Estuary Program, Suffolk County Department of Health Services, Riverhead, NY, by Economic Analysis, Inc.

PCCRARM (Presidential/Congressional Commission on Risk Assessment and Risk Management). 1997. *Risk Asseessment and Risk Management in Regulatory Decision-Making*. Washington, DC: Government Printing Office.

Principe, P.P. 1995. Ecological benefits assessment: A policy-oriented alternative to regional ecological risk assessment. *Human and Ecological Risk Assessment* 1(4):423-435.

Raucher, R. 1987. *A Summary of the Benefit-Cost Analyses of the Final Effluent Limitations Guidelines for the Organic Chemicals, Plastics, and Synthetic Fibers Industry*. Energy and Resources Consultants, Inc. (as cited in Caulkins and Sessions 1997).

Reid, W., N. Ash, E. Bennett, P. Kumar, M. Lee, N. Lucas, H. Simons, V. Thompson, and M. Zurek. *Millenneium Ecosystem Assessment: Millennium Ecosystem Assessment Methods.* MA Secretariat, ICLARM Office, Penang, Malaysia. October 18, 2002. Available from: http://www.millenniumassessment.org

The Heinz Center (The H. John Heinz III Center for Science, Economics and the Environment). 2002. *State of the Nation's Ecosystems*. Cambridge, UK: Cambridge University Press. Available from: http://www.heinzctr.org/ecosystems

USACE (U.S. Army Corps of Engineers). 1991. *Economic Valuation of Wetland Functions and Values: Literature Review.* Engineer Research and Development Center (Luzar, E.J., and C. Gan). TA7 W343.W4.L8.

USACE (U.S. Army Corps of Engineers). 1995. *Review of Monetary and Nonmonetary Valuation of Environmental Investments*. Alexandria, VA: Water Resources Support Center, Institute for Water Resources and Vicksburg, MS: Waterways Experiment Station. February. IWR Report 95-R-2. Available from: http://www.iwr.usace.army.mil/iwr/pdf/95r02.pdf

USACE (U.S. Army Corps of Engineers). 1996. *Monetary Measurement of Environmental Goods and Services: Framework and Summary of Techniques for Corps Planners*. Alexandria, VA: Water Resources Support Center, Institute for Water Resources and Vicksburg, MS: Waterways Experiment Station. November. IWR Report 96-R-24. Available from: http://www.iwr.usace.army.mil/iwr/pdf/96r24.pdf

USACE (U.S. Army Corps of Engineers). 2003. Draft Report on *Improving Environmental Benefits Analysis*. Alexandria, VA: Institute for Water Resources.

USDA (U.S. Department of Agriculture). 1999. *Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP.* Washington, DC: Economic Research Service (ERS). Agricultural Economics Report No. 778. Available from: http://www.ers.usda.gov/publications/aer778/

USDA (U.S. Department of Agriculture). 2002. Part 610 Conservation Planning: National Resource Economics Handbook. Washington, DC: Natural Resources Conservation Service (NRCS). April. Available from: http://waterhome.tamu.edu/NRCSdata/tech.html

USDOE (U.S. Department of Energy). 1995. *Valuation of Ecological Resources*. Prepared by the Pacific Northwest Laboratory, Battelle Memorial Institute, for USDOE. April. PNL-10533.

USEPA (U.S. Environmental Protection Agency). 1983. *Guidelines for Performing Regulatory Impact Analysis*. Washington, DC: Office of Policy, Planning and Evaluation. December. EPA-230-84-003.

USEPA (U.S. Environmental Protection Agency). 1985. *Guidelines for Deriving Numeric National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*. Washington, DC: Office of Water. PB85-227049.

USEPA (U.S. Environmental Protection Agency). 1987a. *Development Document for Effluent Limitations Guidelines and Standards for the OCPSF Point Source Category* (Volumes 1 and 2). Washington, DC: Office of Water. EPA 440/1-87-009a and b. NTIS PB88-171335.

USEPA (U.S. Environmental Protection Agency). 1987b. *Economic Impact Analysis of Effluent Limitations Guidelines and Standards for the OCPSF Industry*. Washington, DC: Office of Water. EPA 440/2-87-009. NTIS PB89-11430.

USEPA (U.S. Environmental Protection Agency). 1987c. *Regulatory Impact Analysis of the Effluent Guidelines Regulation for the OCPSF Industry*. Washington, DC: Office of Water.

USEPA (U.S. Environmental Protection Agency). 1990a. *Reducing Risk: Setting Priorities and Strategies for Environmental Protection*. Washington, DC: Science Advisory Board.

USEPA (U.S. Environmental Protection Agency). 1990b. *The Economics of Improved Estuarine Water Quality: An NEP Manual for Measuring Benefits.* Washington, DC: Office of Marine and Estuarine Protection and Office of Policy, Planning, and Evaluation. September. EPA 503/5-90-001.

USEPA (U.S. Environmental Protection Agency). 1990c. *Ecosystem Services and Their Valuation*. Draft Final Report. Prepared by RCG/Hagler, Bailly, Inc., for the Office of Policy Analysis. February 7.

USEPA (U.S. Environmental Protection Agency). 1991. *Guidelines for Performing Regulatory Impact Analysis*. Washington, DC: Office of Policy, Planning and Evaluation. December. EPA-230-84-003. 1983 *Guidelines* reprinted with Appendices in March 1991.

USEPA (U.S. Environmental Protection Agency). 1992. *Ecological Risk Assessment Framework.* Washington, DC: Risk Assessment Forum. February. EPA/630/R-92/001.

USEPA (U.S. Environmental Protection Agency). 1993. *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents*. Washington, DC: Office of Federal Activities.

USEPA (U.S. Environmental Protection Agency). 1995. *Revised Assessment of Compliance Costs Resulting from Implementation fo the Final Great Lakes Water Quality Guidance.* Washington, DC: Office of Water. EPA-820-95-010.

USEPA (U.S. Environmental Protection Agency). 1997a. *Priorities for Ecological Protection: An Initial List and Discussion Document for EPA* (Discussion Document). Washington, DC: Office of Research and Development. January. EPA/600/S-97/002.

USEPA (U.S. Environmental Protection Agency). 1997b. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. Interim Final*. Washington, DC: Office of Solid Waste and Emergency Response. EPA 540-R-97-006. Available from: http://www.epa.gov/superfund/programs/risk/ecorisk/ecorisk.htm

USEPA (U.S. Environmental Protection Agency). 1998a. *Guidelines for Ecological Risk Assessment*. Washington, DC: Risk Assessment Forum. April. EPA/630/R-95/002F. Available from: http://www.epa.gov/ncea/ecorsk.htm

USEPA (U.S. Environmental Protection Agency). 1998b. *An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas*. Washington, DC: Office of Research and Development. EPA/600/R-97/130. Available from: http://www.epa.gov/emap/html/atlas.html

USEPA (U.S. Environmental Protection Agency). 1998c. *Communicating the Condition of Terrestrial Ecosystems: A Focused Investigation of Terrestrial Ecosystem Health Indicators.* Prepared by ICF Incorporated for the Office of Policy, Washington, DC. July.

USEPA (U.S. Environmental Protection Agency). 1999a. *The Benefits and Costs of the Clean Air Act, 1990 to 2010, EPA Report to Congress*. Research Triangle Park, NC: Office of Air and Radiation and Office of Policy. November. EPA-410-R-99-001.

USEPA (U.S. Environmental Protection Agency). 1999b. *Issuance of Final Guidance: Ecological Risk Assessment and Risk Management Principles for Superfund*. Washington, DC: Office of Solid Waste and Emergency Response. OSWER Directive 9825.7-28P. Available from http://www.epa.gov/superfund/programs/risk/ecorisk/final99.pdf

USEPA (U.S. Environmental Protection Agency). 1999c. [Obtain from Sharon Hayes.]

USEPA (U.S. Environmental Protection Agency). 2000a. *Guidelines for Preparing Economic Analyses*. Washington, DC: Office of the Administrator. September. EPA 240-R-00-003. Available from: http://epa.gov/osp/spc/feaeb3.pdf

USEPA (U.S. Environmental Protection Agency). 2000b. *Toward Integrated Environmental Decision-making*. Washington, DC: Sciene Advisory Board. August. EPA-SAB-EC-00-11. Available from: http://www.epa.gov/sab/pdf/ecirp011.pdf

USEPA (U.S. Environmental Protection Agency). 2000c. *Assessing the Neglected Ecological Benefits of Watershed Management Practices*. Prepared by ICF Incorporated for the Office of Water, Assessment and Watershed Protection Division. April.

USEPA (U.S. Environmental Protection Agency). 2000d. *Supplementary guidance for Conducting Health Risk Assessment of Chemical Mixtures*. Washington, DC: Risk Assessment Forum.

USEPA (U.S. Environmental Protection Agency). 2001a. [Draft: Do Not Cite or Quote - need to determine likely publication date.] *Planning for Ecological Risk Assessment: Developing Management Objectives* (External Review Draft). Washington, DC: Risk Assessment Forum and Office of Research and Development. June. EPA/630/R-01/001A.

USEPA (U.S. Environmental Protection Agency). 2001b. *Understanding Public Values and Attitudes Related to Ecological Risk Management*. Washington, DC: Science Advisory Board. September. EPA-SAB-EC-WKSP-01-001. Available from: http://www.epa.gov/science1/ (under "Reports," then "Fisal Year 2001”).

USEPA (U.S. Environmental Protection Agency). 2001c. *Environmental and Economic Benefit Analysis of Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations.* Washington, DC: Office of Water. January. EPA-821-R-01-002.

USEPA (U.S. Environmental Protection Agency). 2002a. [Draft: Do Not Cite or Quote - need to determine likely publication date.] *Generic Assessment Endpoints for Ecological Risk Assessments* (External Review Draft). Washington, DC: Risk Assessment Forum. EPA/630/P-02/004A. October. Available from: http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=54923

USEPA (U.S. Environmental Protection Agency). 2002b. *A Framework for the Economic Assessment of Ecological Benefits.* Washington, DC: Office of Science Policy, Social Sciences Discussion Workgroup. February. Available from: http://epa.gov/osp/spc/feaeb3.pdf

USEPA (U.S. Environmental Protection Agency). 2002c. *A Framework for Assessing and Reporting on Ecological Condition*. Washington, DC: Science Advisory Board. September. EPA-SAB-EPEC-02-009A. Available from: http://epa.gov/sab.

USEPA (U.S. Environmental Protection Agency). 2002d. *Generic Assessment Endpoints for Ecological Risk Assessments.* External Review Draft. Washington, DC: Risk Assessment Forum. October. EPA/630/P-02/004A. Available from: http://epa.gov/ncea/raf

USEPA (U.S. Environmental Protection Agency). 2002e. *Research Strategy: Environmental Monitoring and Assessment Program.* Research Triangle Park, NC: Office of Research and Development, National Health and Environmental Effects Research Laboratory. July. EPA 620/R-02/002. Available from: http://www.epa.gov/emap/html/pubs/docs/resdocs/EMAP_Research_Strategy.pdf

USEPA (U.S. Environmental Protection Agency). 2002f. *Draft Action Plan: Development of a Framework for Metals Assessment and Guidance for Charcterizing and Ranking Metals*, External Review Draft. Washington, DC: Office of Research and Development. June. EPA/630/P-02/003A.

USEPA (U.S. Environmental Protection Agency). 2003a. *National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs); Final Rule.* Washington, DC: Office of Water. Available from: http://cfpub.epa.gov/npdes/afo/cafofinalrule.cfm

USEPA (U.S. Environmental Protection Agency). 2003b. *Framework for Cumulative Risk Assessment*. Washington, DC: Risk Assessment Forum. May. EPA/630/P–02/001F.

USFWS (U.S. Fish and Wildlife Service). 1985. Human Use and Economic Evaluation (HUEE). Washington, DC: U.S. Department of the Interior, FWS, Division of Ecological Services. 104 ESM.

USFWS (U.S. Fish and Wildlife Service). 1995. *A Manual for Conducting Natural Resource Damage Assessment: The Role of Economics.* Washington, DC: U.S. Department of the Interior, FWS, Division of Economics. Available from: http://policy.fws.gov/NRDAIndex.html

USOMB (U.S. Office of Management and Budget). 2000. *Guidelines to Standardize Measures of Costs and Benefits and the Format of Accounting Statements.* Washington, DC. OMB Memorandum M-00-08, March 22.

USOMB (U.S. Office of Management and Budget). 2003. *Informing Regulatory Decisions: 2003 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local and Tribal Entities* Available from: http://www.whitehouse.gov/omb/inforeg/2003_cost-ben_final_rpt.pdf

van Woerden, J. 2003. *Data Issues of Global Environmental Reporting: Experiences from GEO*-2000. UNEP/DEIA&EW/TR.99-3. 2003. Nairobi, Kenya, United Nations Environment Program.

Walmsley,J.J. 2002. Framework for measuring sustainable development in catchment systems. *Environmental Management* 29: 195-206.

Whigham , D.F. 1997. Ecosystem functions and ecosystem values. In: R.D. Simpson and N.L. Christensen, Jr. (eds.), *Ecosystem Function and Human Activities: Reconciling Economics and Ecology.* New York, NY: Chapman and Hall Publishers; pp. 225-239.

Wilson, M.A., and S.R. Carpenter. 1999. Economic valuation of freshwater ecosystem services in the United States: 1971-1997. *Ecological Applications* 9(3): 772-783.