ERDC/EL TR-13-17

US Army Corps of Engineers®
Engineer Research and Development Center

ERDC
INNOVATIVE SOLUTIONS for a safer, better world

Ecosystem Management and Restoration Research Program

Incorporating Ecosystem Goods and Services in Environmental Planning

A Literature Review of Definitions, Classification and Operational Approaches

David J. Tazik, Janet Cushing, Elizabeth Murray, and Lisa Wainger

August 2013

Approved for public release; distribution is unlimited.

Environmental Laboratory

Ecosystem Management and Restoration
Research Program

ERDC/EL TR-13-17
August 2013

Incorporating Ecosystem Goods and Services in Environmental Planning

A Literature Review of Definitions, Classification and Operational Approaches

David J. Tazik

NEON, Inc.
1685 38th St., Ste. 100
Boulder, CO 80301
Formerly of
Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road, Vicksburg, MS 39180-6199
Vicksburg, MS 39180-6199

Janet Cushing

Institute for Water Resources
7701 Telegraph Rd.
Alexandria, VA 22315-3868

Elizabeth O. Murray

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road, Vicksburg, MS 39180-6199
Vicksburg, MS 39180-6199

Lisa Wainger

University of Maryland Center for Environmental Studies
Chesapeake Biological Laboratory
PO Box 38
Solomons, MD 20688-0038

Final report

Abstract

This paper reviews historical development of Ecosystem Goods and Services (EGS) concepts and the range of definitions, conceptual models, classification schemes and operational approaches that have been put forth in the literature. The intent is to lay the foundation for development of a framework that the U.S. Army Corps of Engineers (the Corps) can use to incorporate consideration of ecosystem goods and services in water resource project planning and management, and identify any research needs to accommodate that goal. While the notion of ecosystem goods and services benefiting humans is not new, it has become increasingly formalized for consideration in environmental policy analysis and is closely tied to concepts in ecosystem-based management of natural resources. Despite this, no single conceptual model or classification system has been accepted, because the particular purpose, circumstance and decision context will dictate the most appropriate definitions and models to apply. This review and the corresponding technical note (Murray et al. 2013) are the first products in a series of reports for the Ecosystem Goods and Services Project. Subsequent related products researching policies, data and tools, interagency coordination and an assessment framework are in process, and will be released over the next several years.

Contents

Figures and Tables

Figures

Tables

Preface

This is the first of a series of reports planned by a multi-year Work Unit concerning Incorporating Ecosystem Goods and Services in Environmental Planning. The Work Unit was sponsored by the Ecosystem Management and Restoration Research Program and was jointly managed by the Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), and the U.S. Army Corps of Engineers Institute for Water Resources (IWR). Dr. Dave Tazik was co-Principle Investigator and primary author of this report when he was with the Ecosystem Evaluation and Engineering Division, EL, ERDC, and the work was continued by his co-authors after he left the Corps.

The purposes of the Work Unit are to investigate the potential for using ecosystem goods and services in Corps planning; to investigate the current state of the field, including its relevant tools and policies; and ultimately to develop a practical framework that could allow USACE Districts to analyze ecosystem goods and services in planning and alternatives evaluation for Corps projects, thereby strengthening agency decision-making as it relates to maximizing the benefits humans derive from functioning ecosystems. The Work Unit has been divided into several tasks, listed below. This report is one of two products of the first task, and constitutes a literature review of key concepts and best practices relating to the field of Ecosystem Goods and Services and how they might be applied to the Corps' Civil Works planning process. It provides background information for the much more condensed and Corps-specific technical note being published concurrently.

All of the tasks of the Work Unit are listed below:

- Principles & Best Practices: A technical note and longer technical report will explore the prevalent definitions, classifications, history and conceptual models relating to ecosystem goods and services, and will propose working definitions and conceptual models that are appropriate for Corps use, along with implications for the Corps planning process.
- Policy Review & Analysis: This report will review and analyze USACE authority, policy and guidance that either supports or impedes the

integration of ecosystem goods and services information. The report will also review the policies and practices of other agencies using ecosystem service-based approaches.

- Review of Data & Analytical Tools: A database will be created to catalogue data sources, analytical tools and models with the potential to support EGS considerations in Corps planning. A synthesis report will describe strengths and weaknesses and offer example applications.
- Case Study Retrospective: A report will describe previous and current Corps efforts to address ecosystem goods and services in the planning process. The same report will also summarize successes and lessons learned so that such knowledge may be incorporated into the proposed framework.
- Analytical Framework and Guidelines: Ultimately, the research described above will inform the development of a framework and guidelines that could be used by Corps Districts to analyze ecosystem goods and services in the planning process.

The Co-Principle Investigators of this Work Unit are Elizabeth Murray and Janet Cushing. Figures and tables in this report that were taken from the literature are cited as appropriate. Other figures were created by the authors.

This report is published by ERDC under the Ecosystem Management and Restoration Research Program (EMRRP). The USACE Proponent for the EMRRP Program is Rennie Sherman. The Technical Director is Dr. Al Cofrancesco, and the Program Manager is Glenn Rhett of the ERDC EL. Technical Peer review comments were received and incorporated from several people within and outside ERDC: Bruce Pruit, Charles Theiling, Kelly Keefe, Brian Harper (Galveston District), Chris Behrens, Shawn Komlos, Bernard Hargrave, Susan Durden, Lynn Martin, Richard Cole, Bruce Carlson, and Dave Tipple. The report was also sent to members of the Work Unit Project Delivery Team (PDT) and Headquarters for review. The report was prepared under the general supervision of Patrick O'Brien, Chief, Wetlands and Coastal Ecology Branch; Dr. Ed Russo, Chief, Ecosystem Evaluation and Engineering Division, EL; Dr. Beth Fleming, Director, EL.

Cover photo by Darryl Clark, US Fish & Wildlife Service, of the Coastal Wetlands, Planning, Protection, and Restoration Program's South White Lake Shoreline Restoration project (ME-22) - US Army Corps of

Engineers, New Orleans District- Project Federal Sponsor, State of Louisiana - Project Local Sponsor.

At the time of publication of this report, COL Kevin J. Wilson was Commander of ERDC. Dr. Jeffery P. Holland was Director.

This technical report should be cited as follows:

Tazik, D., J. Cushing, E. O. Murray, L. Wainger. 2013. *Incorporating ecosystem goods and services in environmental planning – A literature review of definitions, classification and operational approaches*. ERDC/EL TR-13-17 . Vicksburg, MS: US Army Engineer Research and Development Center.

1 Introduction

Overview

There has been interest for several decades in assessing the benefits that humans derive from naturally functioning ecosystems and the benefits provided by ecosystem restoration actions. Despite this interest and a fair amount of academic and agency research, limited progress has been made toward systematically and explicitly incorporating ecosystem goods and services (EGS) into U.S. Army Corps of Engineers (the Corps) water resource management planning and decision-making. This paper reviews historical development of relevant concepts and the range of definitions, conceptual models, classification schemes, and operational approaches that have been put forth. The authors' intent is to lay the foundation for development of a framework that the U.S. Army Corps of Engineers (Corps) can use to incorporate consideration of ecosystem goods and services in water resource project planning and management, and identify any research needs to accommodate that goal. While the notion of ecosystem goods and services benefiting humans is not entirely new, it has become increasingly formalized for consideration in environmental policy analysis and is closely tied to concepts in ecosystem-based management of natural resources. A number of definitions for ecosystem goods and services have been proposed and all are clearly rooted in the human welfare benefits provided by healthy, naturally functioning ecosystems. However, no single conceptual model or classification system has been accepted, because the particular purpose, circumstance and decision context will dictate the most appropriate definitions and models to apply. This review and the corresponding technical note (Murray et al. 2013) are the first products in a series of reports for the Ecosystem Goods and Services Project. Subsequent related products researching policies, data and tools, interagency coordination, and an assessment framework are in process, and will be released over the next several years.

Objective

The objective of this report is to explore the history, definitions, conceptual models, classification schemes, and operational approaches of ecosystem services as an initial step in the development of a framework for incorporating ecosystems services in Corps planning. This is not meant to be a comprehensive treatment; the reader is referred to several excellent sources of information noted within this report. However, here the authors provide an overview of several important issues in the literature and ideas that have emerged in the evolution of the ecosystem services concept. This review is paired with a shorter technical note on the subject (Murray et al. 2013). That tech note covers much of the material, but does not include the broader literature review; rather, it addresses the considerations most pertinent for developing a viable ecosystem goods and services assessment framework for the Corps. This report provides the background and supporting information for that more concise technical note. The authors' intent is to use both this technical report and the technical note as a basis to inform (1) Corps project planning and (2) an approach to future research and development in support of the Corps Planning Community of Practice.

These two publications are the first in a series investigating the potential for incorporating ecosystem goods and services analysis into Corps planning. Several of the issues raised in this technical report will be explored further in future products in this research. Those future research products examine relevant Corps policies and authorities, published EGS tools and models, and case studies of previous attempts at conducting EGS assessments. The culmination of these efforts will be a framework intended to guide the incorporation of ecosystem goods and services assessment into Corps planning. This technical report is one of the first steps in raising — and then addressing — the many issues involved in applying ecosystem goods and services assessment to decision making.

Scope

This literature review is part of a series of publications produced to advance the Corps' capabilities in incorporating ecosystem goods and services into Corps planning. It focuses on historical background, definitions, conceptual models, and classification schemes. In this and future reports on this topic, key principles will be identified and described that are intended to help integrate sound science, policy and practice. This report is not intended to provide definitive guidelines; rather, it is intended to lay the foundation for future research and development in support of practical guidelines for incorporating ecosystem service considerations in Corps planning. Although the authors ultimately plan to address the potential role of ecosystem goods and services in all Corps missions, initial emphasis is on issues most relevant to ecosystem restoration planning and natural resource management: recognition of potential services; identification of relationships to human welfare; characterization and quantification of the reliability, resiliency, and sustainability of service provisions.

Background

Interest in ecosystem services in environmental management has increased and evolved over the past several decades. There has been an increasing awareness of and an interest in exploring the benefits and values that we humans derive from ecosystems, and how we can use the concept to improve our ability to make wise environmental policy choices. Significant reviews have been completed during this period. Notable among these is a compendium of papers edited by Gretchen Daily (1997) that reviews economic issues, a range of major ecosystem services, services associated with major biomes and a series of case studies. Costanza et al. (1997a) further demonstrated the potential extraordinary value of ecosystem services by compiling a wide range of research that attached monetary values to ecosystem goods and services. While that report's estimate of $33 trillion in annual global value is appealing, the calculation is not considered robust because it does not consider how value varies with relative abundance of the service nor other factors that determine value (Toman 1998, Bockstael et al. 2000). Turner et al. (2008) describe the variety of economic methods that are used to value ecosystem services and create values relevant for local decision-making. However, Balmford et al. (2002) demonstrated from a literature review that the monetizable value of the flow of ecosystem goods and services from undisturbed lands rarely exceeds the monetary values in developed uses. Thus, they revealed some of the limitations to using monetary values of ecosystem goods and services — given our current understanding and tools — to justify their preservation.

The first comprehensive review of the status of ecosystem services on a global scale was completed under the Millennium Ecological Assessment in 2005 (MA 2005), which found that over half of the world's major ecosystem services are in a state of decline. The National Research Council (NRC 2005) provided a review focused on aquatic ecosystems and illustrated analytical techniques that can be applied in environmental decision-making. Recently, Kareiva et al. (2011) published a compendium of papers illustrating theory and practice in ecosystem services modeling changes in response to resource management decisions. The compendium reveals that the state of the science has progressed but still lacks universally applicable models.

The concept of ecosystem services has been accepted by governments worldwide and used qualitatively by the UN Environment Programme for over a decade (UNDP et al. 2000, UNEP 2006, Boelee 2011). The extent to which ecosystem service concepts have advanced in the U.S. is illustrated by the emphasis placed on ecosystem service evaluations by several federal agencies, including the U.S. Environmental Protection Agency (EPA 2009), the U.S. Department of Agriculture (Ribaudo et al. 2008), the U.S. Department of the Interior (2011), the U.S. Fish and Wildlife Service (Ingraham and Foster 2008), U.S. Geological Survey (Gleason et al. 2008), and the Department of Defense (Keysar and Goran 2008). The White House Council on Environmental Quality has taken up the banner as well (CEQ 2009), as has the President's Council of Advisors on Science and Technology (PCAST 2011).[1] Federal capabilities to address ecosystem services are quite extensive and would benefit from a focused strategy and consistent guidance on ecosystem service measurements and monitoring (Scarlett and Boyd 2011).

Evaluation of ecosystem services holds promise for more clearly illustrating a wide range of impacts when balancing competing demands on our natural resources, or "natural capital," as it is often referred to in the ecosystem services literature. Quantifying the change in ecosystem service outputs that result from human actions is one way to more explicitly assess the direct and indirect impacts of our policy decisions on human welfare. Furthermore, doing so may permit a more transparent trade-off analysis or balancing among competing resource demands.

Despite this growing interest in ecosystem goods and services, limited progress has been made toward explicitly and systematically incorporating ecosystem goods and services in environmental planning and in water resource management planning and decision-making in particular. The development of assessment, monitoring and forecasting capabilities has been constrained by an incomplete understanding and description of the links between ecosystem structure and functions and the benefits derived by human society; the lack of market prices and direct behavioral links to all potential goods and services; and the lack of integration between the ecological and economic disciplines (NRC 2005).

[1] Appendix C within the PCAST report lists a number of on-going federally sponsored ecosystem services valuation projects.

Although the concept of ecosystem services is not new (Mooney and Ehrlich 1997), there has been a particular emphasis in more recent years on the means to explicitly account for and quantify those services, the benefits that humans derive from them, and the extent to which they are valued in monetary and nonmonetary terms. The intent is to use ecosystem service assessments to more directly and substantively contribute to environmental policy decisions.

For the Corps, the concept of accounting for the effects of proposed plans, including effects on ecosystem functions and services during project planning, is rooted in public welfare benefits provided by such government activities – very similar to the concepts behind ecosystem services. It is a major theme throughout the Planning Guidance Notebook (PGN). [1] Some notable attempts have been made to evaluate the links between ecosystem restoration outputs and services of value to humans (Shabman 1994, Cole et al. 1996, Stakhiv et al. 2003, Fischenich 2011, Shabman and Scodari 2012), and NEPA documentation requires that a broad range of impacts and benefits are addressed. Nonetheless, explicit accounting for effects on ecosystem goods and services *per se* has never been a Corps planning requirement, and efforts to consistently, completely, and reliably quantify ecosystem functions and the values of related services during water resources planning studies have realized only limited success.

Consequently, ecosystem services have become a prominent topic of discussion and interest within the Corps in recent years; the result being that some ecosystem restoration project teams are investigating the use of ecosystem services for plan evaluation. Compensatory mitigation of impacts to aquatic resources for Corps permits under section 404 of the Clean Water Act now has language regarding the need to mitigate where it is most likely to replace lost services (33 CFR Parts 325 and 332, Ruhl et al. 2009). Incorporating an ecosystem services evaluation would require improved capabilities to assess ecosystem services in the Corps and other natural resource planning agencies. More recently, the Report to the President on Sustaining Environmental Capital: Protecting Society and the Economy, from the President's Council of Advisors on Science and Technology (PCAST 2011), highlighted the need for federal agencies to develop ways to account for ecosystem services.

[1] Engineer Regulation 1105-2-100, 22 April 2000 – "The conceptual basis for evaluating nonmonetized NER (National Ecosystem Restoration) benefits is society's value toward the increase in ecosystem services."

In response to these multiple calls to address ecosystem services, the Corps has initiated a research and development effort to explore the challenges and opportunities for incorporating ecosystem service considerations in project planning and to recommend analytical tools, techniques and potential guidelines for the Corps planning community of practice. This technical report and its corresponding technical note (Murray et al. 2013) are the first in a series of reports that will address this topic.

2 Definitions of Ecosystem Goods and Services

Concepts regarding ecosystems services have emerged from the ecological and economics communities somewhat independently, although there have been recent attempts to integrate the two in the emerging field of ecological economics. In its review of the topic, the Natural Research Council ("NRC" 2005) found that ecosystem services had yet to become a well-established field of study, and that future advancements in the area were dependent on further integration of ecology and economics. The NRC also specifically notes that definitions of ecosystem goods and services must match across ecological and economic studies in order to properly integrate the two disciplines. Others also have noted the need for a standard definition (Boyd and Banzaf 2006). Further review of recent definitions, descriptions and classification schemes seems appropriate as a prelude to discussing assessments, valuations and applications.

Several definitions and descriptions of Ecosystem Services can be found in Table 1. These definitions represent a range of recent thinking on the matter. In evaluating these varying definitions, a number of issues arise that should be addressed prior to settling on a definition that might be most applicable in the Corps' planning process. A treatment of some of these issues follows.

Goods vs. Services

Goods, which are tangible or material items such as food, fiber and other raw material, are often lumped with services, which are derived from ongoing processes such as water purification and waste assimilation, for convenience (Costanza et al. 1997a; NRC 2005). However, when developing ecosystem service accounting, it can be important to be maintain this distinction (e.g., Boyd and Banzaf 2006, 2007; Brown et al. 2007).

Human Well-Being

Common to all definitions of ecosystem goods and services is the idea that an ecosystem output is not a good or service unless it contributes to human well-being. Well-being is broadly defined to include financial, health, and social aspects of the condition. Some ecosystem outputs directly affect

Table 1. Definitions of Ecosystem Services found in the literature.

"Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. They maintain biodiversity and the production of *ecosystem goods*, such as seafood, forage, timber, biomass fuels, natural fiber, and many pharmaceuticals, industrial products, and their precursors." Furthermore, "In addition to the production of goods, ecosystem services are the actual life-support functions, such as cleansing, recycling, and renewal, and they confer many intangible aesthetic and cultural benefits as well." (Daily 1997)
Ecosystem goods and services "…represent the benefits that human populations derive, directly or indirectly, from ecosystem functions. For simplicity, we will refer to ecosystem goods and services together as ecosystem services." Here, ecosystem functions "…refer variously to the habitat, biological or system properties or process of ecosystems. Also in a more economic parlance, "Ecosystem services consist of flows of materials, energy and information from natural capital stocks which combine with manufactured and human capital services to produce human welfare." (Costanza et al. 1997a)
In regard to wetlands, ecosystem services are "the beneficial outcomes that result from wetland functions (e.g., better fishing and hunting, cleaner water, better views, and reduced human health risks and ecological risks). These require some interaction with, or at least some appreciation by, humans." Service outputs can be physically measured, and a wetlands functional capacity can be estimated without regard to ethical or subjective considerations of worth. (King et al. 2000)
"Ecosystem services are the benefits people obtain from ecosystems. These include *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services." Importantly, "…human well-being is assumed to include basic material for a good life, health, good social relations, security, and freedom of choice and action." Furthermore, "The conceptual framework … posits that people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being… At the same time, social, economic, and cultural factors unrelated to ecosystems alter the human condition, and many natural forces influence ecosystems." This approach "…emphasizes the linkages between ecosystems and human well-being, [and] it recognizes that the actions people take that influence ecosystems result not just from concern about human well-being but also from considerations of the intrinsic value of species and ecosystems. Intrinsic value is the value of something in and for itself, irrespective of its utility for someone else." (MA 2005)
"Ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well being…. This deceptively innocuous verbal definition is in fact quite constraining and has important properties from the standpoint of welfare measurement…. it signifies that services are end-products of nature. The distinction between end-products and intermediate products is fundamental to welfare accounting. If intermediate and final goods are not distinguished, the value of intermediate goods is double-counted because the value of intermediate goods is embodied in the value of final goods." Another distinction is that "…they are components. This means that services are things or characteristics, not functions or processes. Ecosystem components include resources such as surface water, oceans, vegetation types, and species. Ecosystem processes and functions are the biological, chemical, and physical interactions between ecosystem components." (Boyd and Banzhaf 2006, 2007)
Ecosystem goods and services generally are "…the flows from an ecosystem that are of relatively immediate benefit to humans and occur naturally." They result "…from ecosystem structure and processes. *Ecosystem structure* refers to the abiotic and biotic components of an ecosystem and the ecological connections between these components. *Ecosystem process* refers to the cycles and interactions among those abiotic and biotic components, which produce ecosystem goods and services." Also, "…goods and services…derive from more than the 'ecosystem.' Indeed, they include nonrenewable resources that accumulated through geological processes that took millions of years, as well as services that involve global hydrologic and climatic systems." (Brown et al. 2007)
"Ecosystem services are the direct or indirect contributions that ecosystems make to the well-being of human populations. Ecosystem processes and functions contribute to the provision of ecosystem services, but they are not synonymous with ecosystem services. Ecosystem process and functions describe biophysical relationships that exist whether or not humans benefit from them. These relationships generate ecosystem services only if they contribute to human well-being, defined broadly to include both physical well-being and psychological gratification. Thus, ecosystem services cannot be defined independently of human values." (EPA 2009)
Ecosystem services "…*are the aspects of ecosystems utilized (actively or passively) to produce human well-being.* The key points are that 1) services must be ecological phenomena and 2) that [sic] they do not have to be directly utilized. Defined this way, ecosystem services include ecosystem organization or structure as well as processes and/or functions if they are consumed or utilized by humanity either directly or indirectly…. The functions or processes become services if there are humans that benefit from them. Without human beneficiaries they are not services." (Fischer et al. 2009)
"Ecosystem services are results of ecosystem processes that confer benefits on human society." (President's Council of Advisors on Science and Technology (PCAST) 2011)

welfare (e.g., food provision), while others indirectly affect welfare (e.g., carbon sequestration that indirectly moderates risk from climatic hazards, among other benefits).

Intermediate vs. Final Goods and Services

Imprecision in characterizing ecosystem services can be overlooked when the intent is to communicate in a general way. However, when quantifying outcomes used to compare projects in the Corps' planning process, it becomes important to be more analytically exacting. Boyd and Banzhaf (2007) make this point by distinguishing between intermediate and final goods and services. Intermediate goods and services are inputs or raw materials for the goods and services that are easily recognized as valuable. Intermediate services (e.g., water purification) can sometimes be directly valued but, more often, are inputs into the final goods and services (e.g., safe drinking water, recreational fishing opportunities, and preservation of valued ecosystems) — or the outputs — directly used and valued by people. In order to reduce the risk of double-counting costs or benefits, final goods and services are preferred for quantitative analysis, as explained further in Boyd and Banzhaf (2007).

Structures, Functions, and Processes vs. Goods and Services

As is evident in Table 1, services are sometimes considered to include ecological structure, processes, and functions (see glossary). This mixing of biophysical metrics that are only recognizable as important to scientists (e.g., denitrification) with metrics that represent outcomes used by the public (e.g., recreational fishing) tends to convolute the measurement of ecosystem goods and services. As will be illustrated in one or more of the conceptual models below, ecosystem goods and services are usefully viewed as benefits that derive from sufficiently functional ecosystems in a given location. The authors distinguish ecological structures, functions or processes from services, by defining the former as characteristics of the status and dynamics of ecosystems that are inputs to beneficial outcomes. For instance, nutrient cycling is a process or function that is the product of several other processes — fixation, mineralization, nitrification, denitrification. On the other hand, ecosystem services are the result of multiple structural and functional qualities that produce goods and services enjoyed by or benefitting people and society, such as clean drinking water. The key distinction is that ecosystem services require use or appreciation by people. While it is sometimes necessary to use structure and processes as proxies for ecosystem goods and services, the mixing and matching of these different types of metrics can lead to double counting of benefits and obscure the beneficial outcomes.

Benefits and Value

Just as a change in an ecosystem state does not necessarily change the state of an ecosystem service, a change in ecosystem service does not necessarily lead to a human benefit with value. A change in the supply of goods and services may not adversely affect human well-being (i.e., have economic value), if people are unaffected by or willing and able to adapt to that change (e.g., by substituting a different good or service). An economic benefits assessment will consider such factors in assessing the value of a change. A simple example is that levees are substitutes for natural flood risk mitigation, therefore, a change in water holding capacity (e.g., by a wetland) in an area behind a levee, may not result in a change in benefits because it has no effect on flood risk, though other services may be provided.

Value is not a quantification of the service; rather, it is a quantification of the worth of the benefit derived from a change in an ecosystem. The two can be distinguished in the following sense. Natural pollination of crops can be an intermediate ecosystem service and the benefits could be many, including enhanced yield of one or more agricultural crops. The value of the enhanced yield benefit would be the marginal contribution to profit of having some quantity of natural pollination service (Goulder and Kennedy 2011). In other words, there is a definable change in the quantity of a good or service flow (extent or quality of pollination service available), a quantifiable change in the benefit (marginal increase in crop production), and a change in value (increased profit as a result of the pollination). Benefits result from services; values can be placed on the benefits received by people.

When goods and services are directly used and appreciated by people, monetization approaches tend to be most effective at capturing value. However, many services are not bought and sold in markets and people are not able to say how much they value some beneficial outcomes, thereby creating challenges to monetization. Therefore, to broadly encompass the social welfare effects of ecosystem service changes, non-monetary metrics are often used as proxies for some of the more indirect effects of ecosystem processes on well-being. To serve as proxies for social welfare, the metric must be justified by demonstrating that an increase or decrease in the metric can reasonably be associated with an increase or decrease in welfare of some sort (e.g., change in risk of harm), even if the benefit cannot be quantified (Wainger and Boyd 2009).

Use, Non-Use, Passive Use

"Use" goods and services are those that include direct (usually on-site) and indirect (usually off-site) uses now or in the future. "Direct use" goods and services can be consumptive (e.g., mushroom harvesting) or non-consumptive (e.g., bird-watching). "Indirect use" services are provided to users who are not actively using an ecosystem but still benefit from its goods or services, such as when wetlands provide flood protection to distant homes. Reserving the opportunity to use a good or service in the future is currently referred to as "option (use) value," although it was formerly lumped under non-use or passive use services (Freeman 2003). "Non-use" (also known as "passive use") goods and services are those associated with preserving a resource without the intent to tangibly use or enjoy the good or service. This category also includes benefits derived from preserving a good or service for the benefit of others in the current or future generation(s). These non-use services are typically referred to as existence, altruistic, and bequest values (Turner et al. 2008, Smith 1987).

Passive use is an alternative wording coined in a court ruling that specified the kinds of natural resource damages that Department of Interior agencies are required to consider. That ruling states, "Option and existence values may represent 'passive' use, but they nonetheless reflect utility derived by humans from a resource, and thus, prima facie, ought to be included in a damage assessment." (880 F.2d 432, D.C. Circuit Court, 1989).

These concepts, as well as consideration of classification approaches detailed below, will help prevent the Corps from double counting or confounding the calculations of ecosystem goods and services during project planning. They will become critical to the operationalization of any ecosystem goods and services assessment.

3 Ecosystem Services – A Brief Historical Context

Humanity has, of course, depended upon the goods and services provided by nature throughout our history. Advancements in technology and our rapidly evolved ability to extract or husband nature's goods and services has contributed to the rise and advancement of civilization over the past 13,000 years. The extent to which advances in human civilization have been dependent upon environmental circumstances is documented (Diamond 1997), as is the collapse of human societies that overreached local ecological carrying capacities (Diamond 2005). Our unique ability to develop technological solutions to environmental constraints has been a hallmark of our biological and cultural evolution (Simon 1981, Simon 1996, Taylor 2010). It also has led to ecosystem degradation on a wide scale (MA 2005 among others). A fundamental tenet underlying and an impetus to applying ecosystem service concepts is that we are unlikely to be able to substitute technology for many vital services that we largely take for granted and that where it is possible it may be risky, uneconomical or unethical to do so.

The origins of the concept of goods and services derived from natural systems have been traced at least to Plato (Krutilla 1967, Daily 1997, Mooney and Ehrlich 1997). Within the American tradition, there are clear roots in the writings and activities of George Perkins Marsh, John Muir, Gifford Pinchot, Fredrick Law Olmstead, Aldo Leopold, and Paul Sears, among others, representing both conservationist (wise use) and preservationist (nonconsumptive use) perspectives (Merchant 2007). It is also evident in the American conservation movement of the later 19th and early 20th century that witnessed establishment of the nation's National Parks[1]

[1] Under the National Park Act of 1916, parks were set aside to "…conserve the scenery and natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." The national controversy over the Hetch Hetchy Dam in Yosemite National Park represents an early conflict between competing "ecosystem services" in the American experience; i.e., preservation of the nonconsumptive values of the park versus the public water supply that could be wrought from the Hetch Hetchy Valley.

and National Forests,[1] and the environmental movement that sprang forth in the 1960s and 1970s leading to several landmarks in environmental legislation (Thompson 2008). Several notable conservation programs that address ecosystem services in intent if not in name include The Conservation Reserve Program under the Farm Bill, the National Wetland Mitigation Plan under the Clean Water Act, and conservation banking under the Endangered Species Act.

Historically, various terms have been used to describe the concept, including "environmental services" (SCEP 1970), "nature's services" (Westman 1977) and "ecosystem services" (Ehrlich and Ehrlich 1981). The notion of quantifying the value of these services in order to inform environmental policy and management decisions appears to have been first posited by Westman (1977). An exploration of concepts in ecosystem services requires a partnership between ecology and economics (NRC 2005). Although the two disciplines have developed in large part independently, there are obvious linkages that offer promise of fruitful evolution in collaboration. The discipline of ecology has possessed an underlying socio-economic character in several phases of its development as illustrated in Table 2. The fields of environmental and natural resource economics have been developing tools over many decades that serve as the foundation of ecosystem service valuation. While natural assets were historically treated by economists only as inputs into production, environmental economics adopted the approach that such assets are a special form of capital that generates flows of goods and services and those assets can be either depleted or accumulated (Barbier 2008, 2009). In addition to valuation tools, the fields of environmental and resource economics have developed methods for balancing costs and benefits of preserving or restoring ecosystem services and seeking tools that minimize costs using market-based incentives. In the early to mid-1900s, some of the first applications of cost-benefit analysis to what might today be called ecosystem services were in the field of water management (Eckstein 1958, Krutilla and Eckstein 1958

[1] The Forest Reserve Act of 1891 arose out of concern for watershed protection to prevent flooding and soil erosion, to preserve the nation's forests and wildlife, and to reserve the forests for democratic development; it was used to create the national forest system. Subsequently, the Forest Management Act (Organic) of 1897 was enacted to "…improve and protect the forest within the reservation or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States." See Merchant (2007). Although the sustained yield policies of the Forest Service have come under some criticism, they represent an early recognition of the value of sustainability of what we might now call important goods and services such as forest production, water supply, water quality, and soil stability – and the need to balance competing demands on valuable natural resources that are important to sustaining a democratic society.

Table 2. Summary of the historic approaches to the study of ecology in the United States; based largely on Merchant 2007 (see also Worster 1977).

Phase	Description	Social Perspective	Representative Works
Haeckel	Investigation of the economy of nature. The whole science of the relationship of organisms to the environment. Early connection to concepts in evolution.	Introduced the Greek term *oikos* linked to both ecology (study of the household) and economics (management of the household).	Haeckel 1866, 1873, 1879, Forbes 1888
Human Ecology	Studied the surroundings of human beings and the effects on human living conditions.	Humans were viewed as part of nature, and fresh air and clean water were considered a necessity of human health.	Richards 1907
Organismic Approach / Clemensian Ecology	Elaborated on the theories of community organization, succession and development. Clements viewed the climax formation of plant communities as an organic entity.	Humans were considered separate from nature, but nature was viewed as possessing certain moral principles that might guide and heal human society. Humans could and should develop the scientific and ethical tools to learn form and heal nature.	Clements 1916; Clements and Shelford 1939; Allee et al. 1949; Leopold 1949
Economic Approach	Organisms responded to the environment individually according to their needs. Incorporated thermodynamics in the study of ecological systems.	Supported a strong quantitative approach to ecology and resource management with the goal of maximizing ecosystem productivity for human benefit.	Gleason 1926, 1939; Tansley 1935; Lindeman 1942; Elton 1966 Watt 1962, 1968
Homeostatic/ Equilibrium Approach	Integrated the human, organismic and economic approaches to ecology to argue for a balance of nature approach that provided the scientific underpinnings of the environmental movement.	Humans were viewed as the primary sources of disturbance and degradation. Built on the idea of *oikos* and the land ethic – we can and should be wise managers of the landscape. This formed a basis for the modern environmental movement.	Odum 1953
Chaos Theory/ Disequilibrium Approach	Re-introduced Gleasonian view of individualism. Moved to an understanding of the much larger role of natural disturbance regimes and patch dynamics in ecosystems	Recognized nature as often unpredictable and disorderly. Humans will have to work with nature to restore it. Emphasized the extent to which human society is dependent on and must be prepared to adapt to changing environmental conditions.	Gleason 1926, 1939; May 1976; Pickett and White 1985; Bodkin 1992

and McKean 1958 as cited in Pearce 2002). Through this work, practical guidelines were established for testing whether overall social well-being was improved by water resource decisions by considering whether benefits of a given project exceeded costs and whether the value that accrued to beneficiaries was sufficient to compensate any who were harmed.

Further, the field of environmental economics advanced methods for harnessing market forces for managing environmental outcomes. One of the first major successes of such an approach was the use of tradable air pollution credits to reduce the costs of complying with air quality regulations (Stavins 2005). Natural resource taxes, cap and trade programs, and mitigation and offset programs — which today form the basis of innovative ecosystem services management — are all outgrowths of early environmental economic work that revealed how using market forces can lower costs of achieving pollution targets (see Tietenberg and Lewis 2008 for further details).

The emergence of a new field of study called Ecological Economics generated a more systems-based understanding of the relationships between ecology and economics (Costanza 1989, Costanza et al 1997b, Daly and Cobb 1989). It was established under the premise that environmental and resource economics centered primarily on the value of extractable resources from natural systems and lacked the consideration of ecosystem dynamics that would be necessary to produce multiple environmental benefits simultaneously through management choices. Basic ecology, on the other hand, tended to focus on energy flow, production, diversity, biogeochemical cycling and other functions pertaining to interactions among organisms and their environment without considering the connection to human needs or wants. A merger of the two was needed to promote a more holistic view of their interactions and mutual dependencies.

Concepts in environmental policy have evolved in parallel as well. For example, while the perspective of resource management during the first half of the 20th century was narrowly focused on specific resource development and sustained yield, it progressively broadened to incorporate the sustainability of all potential ecological resources as the public became increasingly troubled by the costs of mounting pollution and environmental degradation to present and future generations. During this latter period, the dialogue evolved from strictly regulatory compliance with environmental law – environmental impact assessment, clean water and wetlands protection, clean air and endangered species protection – to broader issues in conservation of biodiversity and ecosystem-based management. Endangered species protection, in particular, moved the focus from single issues and species toward a management paradigm that integrated human and natural environments into a managed landscape. Ecosystem-based management is intended to incorporate explicit consideration of the interacting social, economic and ecological elements that together contribute to human environmental well-being (e.g., Christiansen et al. 1996, Brussard et al 1998, Lackey 1998, Szaro et al. 1998). This would seem to have set the stage for a new phase of socio-environmental analysis reliant upon an understanding of how ecosystems provide valuable direct and indirect benefits to human social, economic and political welfare. It might also serve as a basis for reconsidering our current environmental regulatory framework (Thompson 2008).

In the more recent discourse on ecosystems services, the underlying thesis is clearly stated by Costanza et al. (1997a), "Because ecosystem services are not fully 'captured' in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions." Although ecosystem services are, by definition, essential to human life and well-being, "… modern urban life obscures their existence" (Daily 1997, p7). At their biophysical root, ecosystem services are generated and sustained by a complex of natural cycles that have been billions of years in the making (Daily 1997). For all practical purposes, we are wholly dependent upon the continuation of these cycles for our very existence (Daily 1997, Costanza et al. 1997a). Although we have derived benefits from these processes and functions for millennia without major disruptions, recent pervasive impacts now cause significant disruptions at local through global scales (MA 2005). Conclusions drawn from these early explorations of ecosystem service concepts follow (see Daily 1997):

1. Our knowledge of how services operate is poor; it is also difficult to substitute technology for these services
2. Their total value is high – many trillions of dollars
3. Marginal values can be quite high in some cases; their marginal value will likely increase over time
4. Safeguarding ecosystem services is a wise investment

The first comprehensive assessment of the state of the earth's ecosystems and the service derived from them was completed under the Millennium Ecosystem Assessment (MA 2005). The MA reported that over half of the major ecosystem services examined (15 of 24) were being degraded and used unsustainably, with some having the potential to exhibit accelerating and abrupt changes. In summary, they found the following:

- Humans have changed ecosystems more rapidly and extensively over the past 50 years than in any comparable period of time in human history, resulting in a substantial loss of biological diversity.
- While these changes have contributed to substantial net gains in human well-being and economic development, growing costs have resulted in the form of the degradation of many ecosystem services.
- The degradation of ecosystem services could grow significantly worse during the first half of this century.

- While options do exist to conserve or enhance specific services, significant changes in policies, institutions, and practices will be needed to reverse ecosystem degradation while meeting increasing demands for their services.

The National Research Council completed a comprehensive evaluation of the current state of knowledge about the value and valuation of aquatic ecosystem services in 2005 (NRC 2005). Their study focused on analytical issues that will be particularly important as models and analytical tools are developed and applied in the context of integrated water resource management by the Corps and others. Several premises were put forth that are not dissimilar to the above. Fundamentally, ecosystems produce ecosystem goods and services that are valued by humans. Many people value the existence of aquatic ecosystems for their own sake, or for the role they play in ensuring the preservation of species whose existence is perceived as important. The authors also reinforce the notion that understanding the links between human systems and ecosystems requires integration of economics and ecology. While our knowledge about ecosystems, the services they provide, and how people value those services is imperfect, the current state of economic and ecological modeling and analysis allows for estimation of at least some of the values people place on changes in ecosystem services. Importantly, several research needs were identified, including the following:

1. Advances in Ecological Knowledge:

    a. The potential of various aquatic ecosystems to provide goods and services may involve mapping and other documentation to show how eco-outputs relate to service and benefit flows
    b. The effect of changes in ecosystem structure and function on the provision of goods and services
    c. Spatial and temporal thresholds for various ecosystems
    d. Accounting for uncertainties resulting from ecological dynamics and nonlinearity

2. Advances in Valuation Methods:

    a. The range of goods and services to which valuation methods can be applied, recognize advantages and constraints of available methods
    b. Contingent valuation methods, particularly with respect to nonuse values

c. Methods to address uncertainty in valuation studies

3. Bridging the Ecology and Economics of Ecosystem Goods and Services:

   a. Better align ecological and socio-economic conceptions of ecosystem goods and services and their attending value
   b. Develop methods that incorporate modeling of integrated ecological-economic systems

4. Case Studies: Review or develop case studies to serve as examples that can be used more generally

A recent major contribution to the dialogue has come from the Natural Capital Project,[1] which has developed and made available a collection of practical models for ecosystem services that are intended to inform resource management decisions (Kareiva et al. 2011). A key difference between these models and some earlier attempts to value ecosystem services is that they attempt to incorporate both supply of and demand for ecosystem services to understand how changes may be valued for a better understanding of tradeoffs.

In many ways, the idea that ecosystem goods and services are not receiving adequate consideration in policy and management decisions is not new. Recognition of environmental externalities — those arising from private development, public resource development, and market failures when it comes to public goods — is foundational in the economics literature, environmental legislation, and environmental planning, as it has been practiced in the United States for many decades. However, the most recent discourse on ecosystem goods and services takes a decidedly broader and more comprehensive view. It is consonant with ecosystem-based management, moving away from single-issue environmentalism; it incorporates the disequilibrium approach to ecology (Table 2) and the need to manage with natural processes and dynamics; it helps to further merge the disciplines of ecology and economics; and it attempts to capture the full range of human welfare benefits and values (i.e., total economic value as described in NRC 2005) that flow from natural systems behaving naturally.

[1] http://naturalcapitalproject.org

In another extensive review of the state of ecosystem services, Cox and Searle (2009) aptly made several conclusions:

- The ecosystem services field is in the proof-of-concept stage and will advance only with clearer science, well-defined beneficiaries, and solid governance.
- Efforts to develop the needed science are increasing within academia and the government.
- Widespread adoption will require public education, leadership and policy reform.
- Evaluating ecosystem services has the potential to help achieve conservation beyond traditional methods, particularly in otherwise highly constrained populated areas of the world.
- Momentum is building.

As the Corps considers implementing ecosystem goods and services assessment into its planning process, understanding this history will help illuminate where this evolving field has shown strengths, where uncertainties remain, and where continued research and investigations might be needed to fully implement quantitative assessment.

4 Classification of Ecosystem Services

A number of classifications of ecosystem goods and services have been proffered (Daily 1997, Postel and Carpenter 1997, Ewel 1997, Peterson and Lubchenco 1997, de Groot et al. 2002, MA 2005, Farber et al. 2006, Wallace 2007). Several of the earlier examples are presented in NRC (2005). However, there is no broad consensus on a comprehensive list (NRC 2005), and no single classification scheme will be useful in all situations (Costanza 2008, Fisher et al. 2009). Costanza (2008) suggested three possible classifiers – 1) type of good or service; 2) spatial characteristics of the service; and 3) economic characteristics of the service – excludability and rivalness. Fisher et al. (2009) identified key characteristics to be captured and types of classifiers to be used. These will be discussed further below.

One of the most oft-cited classification schemes is that reported in the Millennium Ecological Assessment (MA 2005). The main features are illustrated in Figure 1 and captured in more detail in Table 3. This classification scheme is based somewhat on that presented by de Groot et al. (2002) and is representative of classifications commonly reported in the literature (e.g., Wallace 2007). While it is useful for some purposes, it does not, in its complete form, provide a rigorous basis for environmental analysis and decision-making in an operational sense for two primary reasons: 1) the system confounds the measurement of intermediate and final goods, thereby promoting double counting and other problems; and 2) because many of the services, as defined, cannot be represented in terms of changes in human welfare and therefore they are difficult to use in decisions requiring priority setting or trade-offs (Boyd and Banzhaf 2006, Wallace 2007, Fisher et al. 2009).

Others have examined classification from the standpoint of use in valuation. For example, de Groot et al. (2002) categorized services according to the valuation measures that were used by Costanza et al. (1997a) in their valuation study. A simplified version of this is presented in Table 4. Similar information is provided by NRC (2005; Table 4-2 therein), Turner et al. (2008; Table 5.1 therein) and Goulder and Kennedy (2011; Table 2.1 therein).

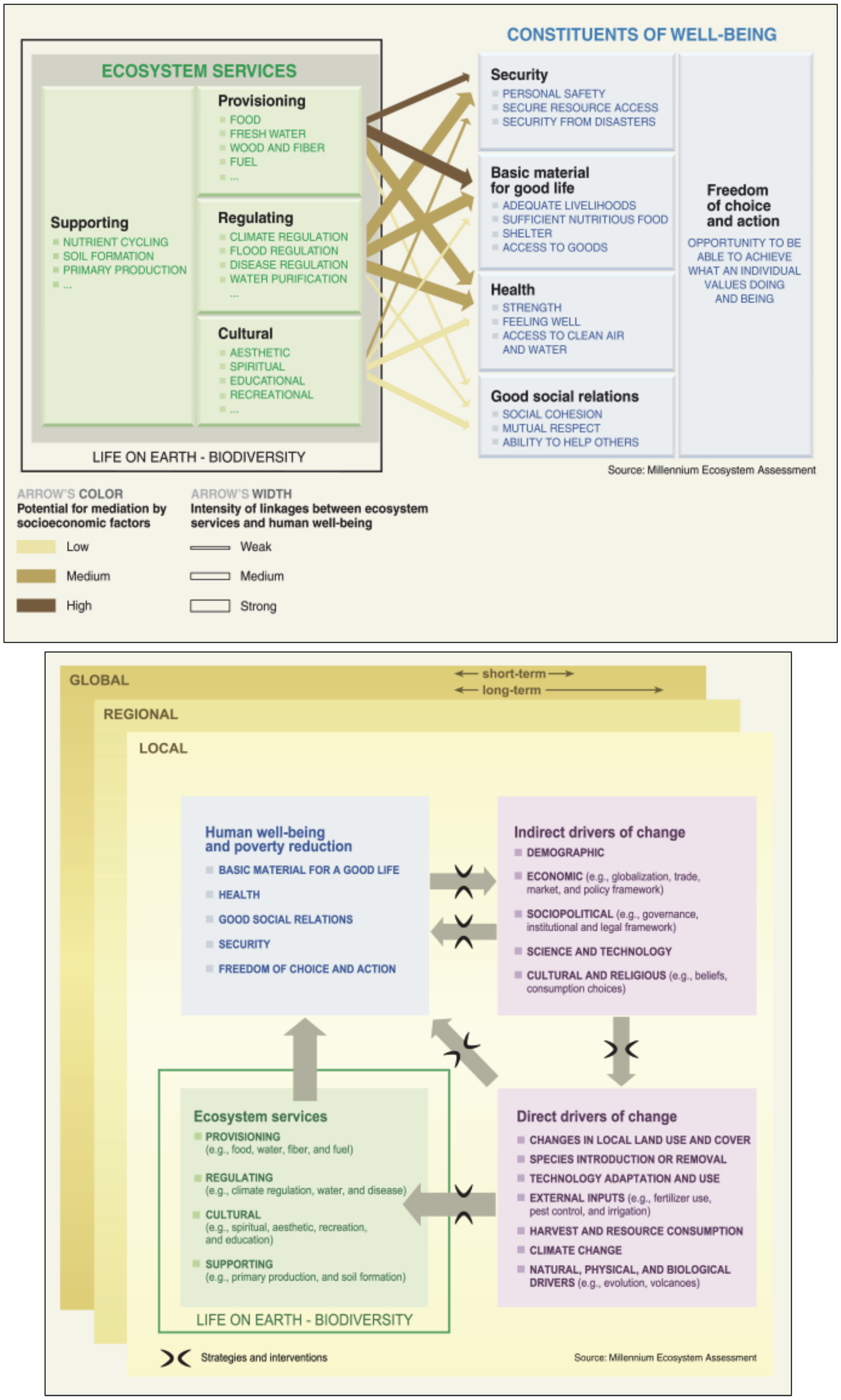

Figure 1. Illustration of the linkages between ecosystem services and human well-being (from MA 2005).

Table 3. Categories of ecosystem services based on Millennium Ecosystem Assessment (MA 2005).

Type of Service	Service
Provisioning	Food—crops, livestock, fisheries, aquaculture, wild plant and animal products Fiber—timber, textiles, wood fuel Genetic resources Bio-chemicals, natural medicines, etc. Ornamental resources Fresh water
Regulating	Air quality regulation Climate regulation—global, regional and local Water regulation Erosion regulation Disease regulation Pest regulation Pollination
Cultural	Cultural diversity Spiritual and religious values Recreation and eco-tourism Aesthetic values Knowledge systems Educational values
Supporting	Soil formation Photosynthesis Primary production Nutrient cycling Water cycling

Recognizing that ecosystem goods and services, and their classification, are most useful when viewed in the context of specific policy and management decisions that need to be made, Fisher et al. (2009) explored the characteristics of ecosystem services and how these relate to various classifiers. Their organizing framework is shown in Figure 2, which ties together definitions, characteristics and decision/policy context as a basis for specifying a meaningful and appropriate classification system. Thus, different agencies with different policies and purposes might address EGS in different ways, utilizing different classification systems. The characteristics of ecosystems and ecosystem services relevant in this approach are briefly described below (see Fisher et al. 2009 for more in-depth discussion). Note that they are not entirely independent and do interact with one another to a significant degree.

Table 4. Classification by valuation approach. (Modified from de Groot et al. 2002)

Ecosystem Functions (and associated goods and services)	Direct Market Pricing	Indirect Market Pricing			Contingent Valuation
		Replacement Cost	Travel Cost	Hedonic Pricing	
Regulation Functions					
Gas Regulation		o			o
Climate Regulation		o			o
Disturbance Regulation		X		o	X
Water Regulation	o	o		o	o
Water Supply	X	X	o	o	o
Soil Retention		X		o	o
Soil Formation		o			o
Nutrient Cycling		X			o
Waste Treatment		X		o	X
Pollination	o	X			o
Biological Control	o	X			o
Habitat Functions					
Refugium Function	X	o		o	X
Nursery Function	X	o		o	o
Production Functions					
Food	X	o			o
Raw Materials	X	o			o
Genetic Resources	X	o			o
Medicinal Resources	X	o			o
Ornamental Resources	X	o		o	o
Information Functions					
Aesthetic		o	o	X	o
Recreation and Tourism	X	o	X	o	X
Cultural and Artistic	o		o	o	X
Spiritual and Historic			o	o	X
Science and Education	X		o		o

X = frequently used method; o = could be used, but typically is not

Rival and Excludable Goods

Goods and services, can generally be classified by the degree to which they are, in economic terms, *rival* and *excludable*, which is important in determining the most appropriate and feasible means of provision and financing and the level of government intervention in allocations (see also Brown et al 2007, Costanza 2008). A *rival* good or service when consumed by one person reduces the amount of that good or service available for another person. A *nonrival* good or service consumed by one does not reduce the

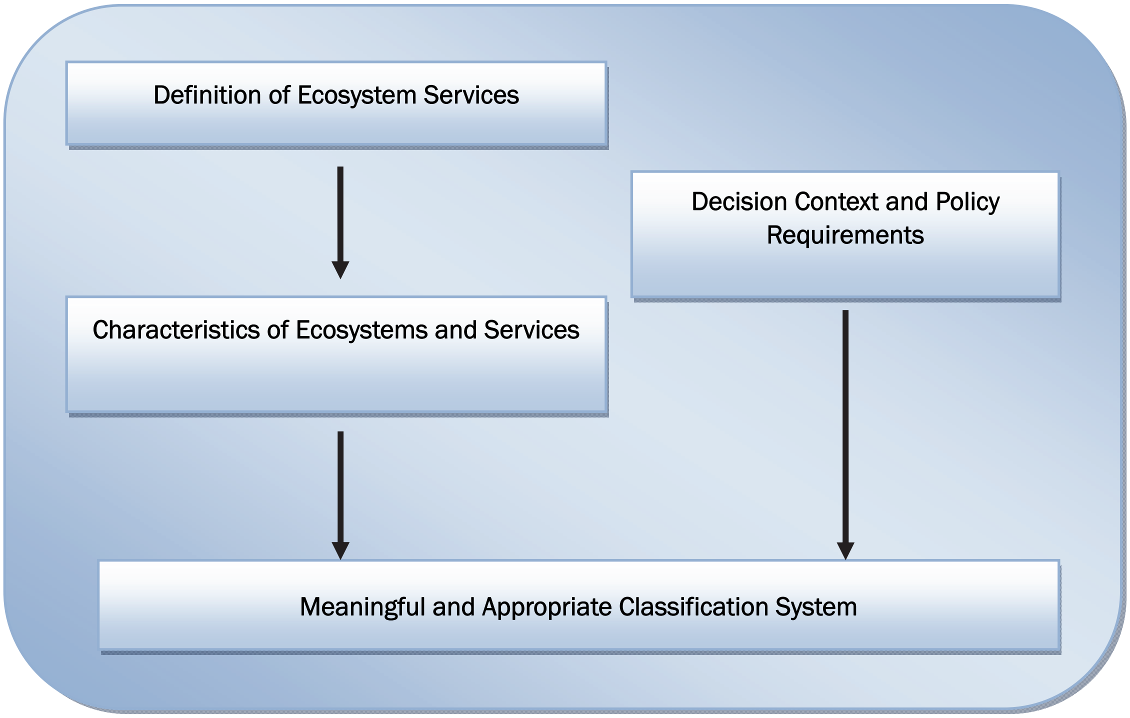

Figure 2. Illustrates that an appropriate and meaningful classification of ecosystem services will require a clear definition of ecosystem services, understanding their key characteristics and the decision context in which the ecosystem service concept will be used (modified from Fisher et al. 2009).

amount available for another. An *excludable* good or service can be controlled by one party to the exclusion of others. A *nonexcludable* good or service is one for which others cannot be excluded, even if they do not pay for it. Ecosystem goods and services, even when they are public goods, can hold any combination of these characteristics. See Table 5 for further illustration and examples. These distinctions are not hard and fast, as there may be goods and services that fall on a gradient between types. Also, classification of any given service may depend on the quantity of the good or service available, the amount that is being used at any one time (i.e., whether congestion is possible), and governance of the resource (i.e., the restriction of spatial and temporal access to or use of the resource).

Competing vs. Complementary Ecosystem Services and Joint Production

While many ecosystem services can be produced simultaneously from a natural system (e.g., undisturbed forests may easily provide drinking water purification, climate regulation, hunting and fishing opportunities, etc.) the ability to assess tradeoffs of different resource use and management depends on comparing the social importance or value of *competing*

Table 5. Classification by rivalness and excludability (based largely on Brown et al. 2007; see also Costanza 2008, and Fisher et al. 2009).

	Excludable	Non-Excludable
Rival	*Private Good* – A conventional market good – e.g., an apple. Includes most Provisioning Services *Nonrenewable goods from contained deposits (fossil fuel, minerals)* *Renewable goods from harvested contained ecosystems (fish, wildlife, trees, fuel wood, edible plants)* *Consumptive recreation opportunities on contained properties (hunting and fishing)* *Nonconsumptive recreation opportunities on congested, contained properties (hiking, viewing)* *Service outputs contained within property ownership(maintenance of soil fertility on a farm)*	*Open Access/Common Pool Resource* – e.g., deep sea fishery (classic *tragedy of the commons*). Includes some Provisioning Services *Renewable goods from harvested uncontained ecosystems (fish, wildlife, trees, fuel wood, edible plants)* *Consumptive recreation opportunities on contained properties (hunting and fishing)* *Nonconsumptive recreation opportunities on congested, uncontained properties (hiking, viewing)* *Service outputs contained within property ownership but realized in the quality of rival goods (erosion control, natural water storage, waste assimilation)* *Natural animal and plant pest control and pollination services*
Non-Rival	*Toll or Club Good* – e.g., Information from nature that can be patented *Nonconsumptive recreation opportunities (hiking, viewing) on uncongested, contained properties*	*Pure Public Good* – UV Protection from the atmosphere. Includes most Regulatory and Cultural Services *Nonconsumptive recreation opportunities (hiking, viewing) on uncongested, uncontained properties* *Maintenance of regional precipitation patterns* *Temperature maintenance via carbon storage* *UV protection* *Ambient air purification* *Natural water storage as it lowers probability of floods and droughts*

services. Similar to rival goods, competing services may be completely mutually exclusive, (e.g., competing needs of some protected species) or partially competing (e.g., carbon sequestration and biodiversity cannot be simultaneously maximized in some systems, Nelson et al. 2008). (See Daily 1997 and NRC 2005 for more examples). When ecosystem goods and services compete, the *joint production* of a bundle of goods and services can be used to maximize outcomes of restoration projects or management strategies. This fundamental characteristic of synchronism or antagonism among services has rather important implications for accounting – e.g., the problem of weighing synergies and trade-offs in ecosystem management.

Spatial and Temporal Dynamism

Ecosystem goods and services vary over space and time with respect to their production and the values enjoyed by humans. While soil formation provides services that can be used where they are produced, ecosystem services (including soil formation) provide carbon sequestration benefits at a global scale. Similarly, watershed protection at higher elevations provides water quality benefits to those using water in the lowlands, which is part of the intent of the Clean Water Act. Ecosystem support for species at local risk of global extinction contributes to biodiversity maintenance benefits both nationally and globally. Annual and decadal cycles in temperature, precipitation and water delivery (e.g., el Niño), as well as natural succession changes in ecosystems, lead to temporal fluxes in associated services. For example, carbon sequestration service varies widely over different stages of ecosystem succession. Shifting demographics and preferences may alter perceived benefits and values over time as well. Costanza (2008) provides a spatio-temporal classification using the ecosystem services listed in his earlier work (Costanza et al. 1997a; Table 6). (See also King et al. 2000; Table 6 therein.)

Table 6. Classification based on spatial characteristics (from Costanza 2008).

Global Non-Proximal—benefits all irrespective of the location of the ecosystem where they are produced
Climate regulation
Carbon sequestration
Carbon storage
Local Proximal—depends on the spatial proximity of the ecosystem relative the human beneficiaries
Disturbance regulation / storm protection
Water treatment
Pollination
Biological control
Habitat / refugia
Directional Flow Related—flow from point of production to point of use – an “upstream to downstream” effect
Water regulation / flood protection
Water supply
Sediment regulation / erosion control
Nutrient regulation
In situ—produced and enjoyed at the same location
Soil formation
Food production / non-timber forest products
Raw materials
User Movement Related—depends on flow of people to unique natural features
Genetic resources
Recreation potential
Cultural / aesthetic

Complexity

Ecosystems are inherently complex – they exhibit nonlinear behavior, feedbacks, hysteretic and threshold effects, perturbations and time lags. In addition, we possess incomplete knowledge of ecological dynamics and often are unable to accurately forecast system response (i.e., changes in structure, function and services) to management actions. Some services are more amenable to measurement and monitoring than others – while we can measure primary productivity via remote sensing, we are hard-pressed to quantify waste assimilation. Divining the role of biodiversity in ecosystem functioning and delivery of ecosystem services is particularly problematic (Naeem et al. 2012, Tilman 1997, Duarte 2000, Kremen 2005, Kremen and Ostfeld 2005, Balvanera et al. 2006). The NRC (2005) report states that "In the face of this apparent conundrum [*sic*] the practical solution to the need to complete an assessment of ecosystem function and/or provision of services is to proceed with caution." Exactly what proceeding with caution means must be interpreted within the decision context by considering what is at risk and the willingness of stakeholders to bear that risk.

Benefit Dependence

Appreciation of an ecosystem service is dependent on the benefits that accrue to human well-being, and the extent to which we understand and use our ingenuity to derive such benefits (NRC 2005). This requires that we understand the biophysical underpinnings of any service or collection of services we wish to manage toward, as well as the chain of processes, functions, and intermediate services that lead to services we value directly. For example, water regulation can serve as an intermediate service to a final service; namely, provision of clean water. While we value the latter, we need to understand the processes that support the former. Furthermore, where fish production is the service desired, provision of clean water becomes an intermediate service; understanding the water quality to fish production function then becomes key. Wallace (2007) also recognized the means versus ends dilemma in his treatment of the subject, and the topic is covered in more detail by Boyd and Banzhaf (2007). The problem is further complicated upon realization that different individuals and stakeholder groups perceive services and value services differently. This leads to conflicts within and across spatial scales and to gaps in the conservation of those ecosystem services for which knowledge of their benefits is not fully appreciated. Clearly, a trade-off analysis requires the fullest possible understanding of these service/benefit dependencies as well as the underlying biophysical processes that support them.

In summary, the intended purpose and decision context, viewed in light of the above characteristics, will largely determine the utility of any proposed classification scheme – different schemes are required for different needs. Fisher et al. (2009) provide a nice treatment of this issue, which is summarized in Table 7. They illustrate that the purpose of a classification scheme may be to 1) satisfy the need to communicate our understanding of the value of ecosystem services; 2) assess the value of ecosystem services; 3) manage across landscapes; and 4) meet public policy goals and social equity considerations. They also recognize that there may be multiple objectives requiring a multi-criteria assessment. Again, the classification scheme developed and used will depend upon the types of policy and management decisions that need to be made and the characteristics of ecosystems and associated services to be considered. Different agencies will design their EGS classification and assessments in accordance with their own mandates, authorities and purposes (e.g., education, regulation, resource conservation, restoration investment). The approach or classification developed by one agency, therefore, is not necessarily consistent with the authorities or purposes of another; consequently, the approach may not translate to the decision context of a different agency.

Table 7. Summary of the purposes for which an ecosystem services classification might be developed and applied (based largely on Fisher et al. 2009).

Decision Context	Description	Characteristics	Classification Approach	Example
Understanding & Education	Promotes understanding and educates the public about the services and benefits that results from healthy, functioning ecosystems	Complexity Public-Private Good Aspects	Divides services into bundles and illustrates the relationships to each other and to human well-being.	MA 2005
Cost-Benefit Analysis or Natural Resource Damage Assessment	Where the goal of classification is economic valuation of ecosystem services. Avoids double counting unlike the MA classification—e.g., nutrient cycling and water flow regulation both contribute to usable water for recreation; it would be inappropriate to count both. It should help determine which benefits are amenable to monetization and which are not.	Complexity Benefit Dependence	Divides services into intermediate and final services and shows relationships to benefits	NAS 2012 Turner et al. 2008
Landscape Management (including wetland mitigation or permitting decisions)	Where it is important to manage the flow of services across the landscape—water regulation services from watershed protection upstream, benefiting users downstream	Spatio-Temporal Dynamics Public-Private Good Aspects Benefit Dependence	Describes relationship between where service production occurs and where the benefits are realized.	Costanza 2008; Boyd and Wainger 2003
Public Policy and Social Equity	Addresses economic externalities and distributional issues. One person's timber harvest is another's lost hunting opportunity. Impacts often disproportionally affect the disenfranchised. Provides information on the extent to which human needs and valued benefits are being met in a given spatial context.	Spatio-Temporal Dynamics Public-Private Good Aspect Benefit Dependence	Starts with basic needs (e.g., adequate resources) and other categories of human benefits; then link to services, then to processes.	Wallace 2007

5 Linking Ecosystems to Human Welfare

Ecosystem service-based evaluation in environmental planning and assessment are not a substitute or alternative to ecologically based approaches — full consideration of relevant biophysical factors is a prerequisite. Ecosystem structure and function are dynamic, such that service outputs and their values will vary spatially and temporally, both across and within ecosystems. As such, the ecological system must be fully considered in the environmental analysis of any project. A sound conceptual model of the interacting ecological and socio-economic aspects of the system is a good place to start. Multiple conceptual models linking ecosystems to human welfare can be found in the literature. The models vary in their emphasis on different elements of the relationships between ecosystems and services, whether it be ecological complexity or economic concepts. For instance, a useful conceptual model is presented in Figure 3 that illustrates the linkages between ecosystem structure and function, goods and services, human values, and actions (from NRC 2005). There are four issues to note here. First, ecosystem goods and services form a bridge between ecosystem structure and function and human values; they are a way of translating the outputs of naturally functioning ecosystems into benefits that humans place value on. Second, the explicit link between ecosystem structure and function to values is intended to illustrate that the mere existence and functioning of these elements can be and often are valued by humans in their own right, irrespective of any specific good or service produced. Third, total economic value (TEV) captured in the lower set of boxes incorporates use and nonuse values – use values include both consumptive and non-consumptive use values. Finally, public and private ecosystem use and protective actions are taken based on human values, which, in turn, influence the state of the ecosystem. The implication here is that the more we are able to capture and quantify the value humans place on ecosystem goods and services, the more efficient will be our policy decisions. A corollary to this is that the more we understand ecosystem structure and function and the production functions that yield goods and services, the more certainty we will have in our estimates of value.

The Millennium Ecological Assessment's conceptual model (see Figure 1) illustrates the relationships between groups of bundled services and human well-being (MA 2005). The two elements in this figure illustrate

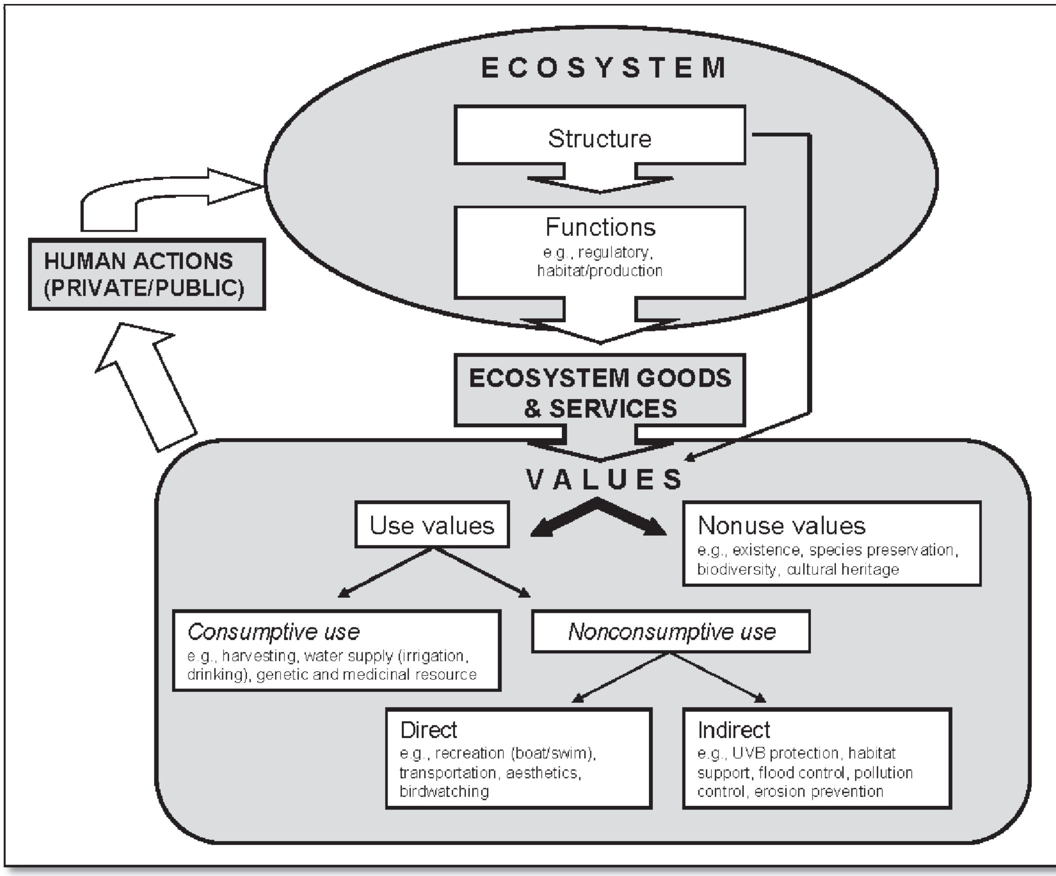

Figure 3. Ecosystem services conceptual model – connections between ecosystem structure and function, goods and services, human actions and values (From NRC 2005). Values illustrated capture Total Economic Value.

the interaction between ecosystems, human welfare, our socio-economic and political constructs, and impacts on the environment that, in turn, affect ecosystem structure and function. This is a good heuristic view and quite useful as an educational tool.

A third conceptual model (Figure 4) explicitly illustrates the important point that ecosystem services also interact with one another (Bennett et al. 2009). Few studies exist that have assessed the interaction among multiple ecosystem services. A holistic treatment of goods and services should consider the effects of drivers of those goods and services <u>and</u> the relationships among the goods and services.

One of the important Corps missions is ecosystem restoration and mitigation of environmental impacts from other missions, such as navigation infrastructure development and flood risk management. Figure 5 addresses this by illustrating ecosystem services in the context of ecosystem

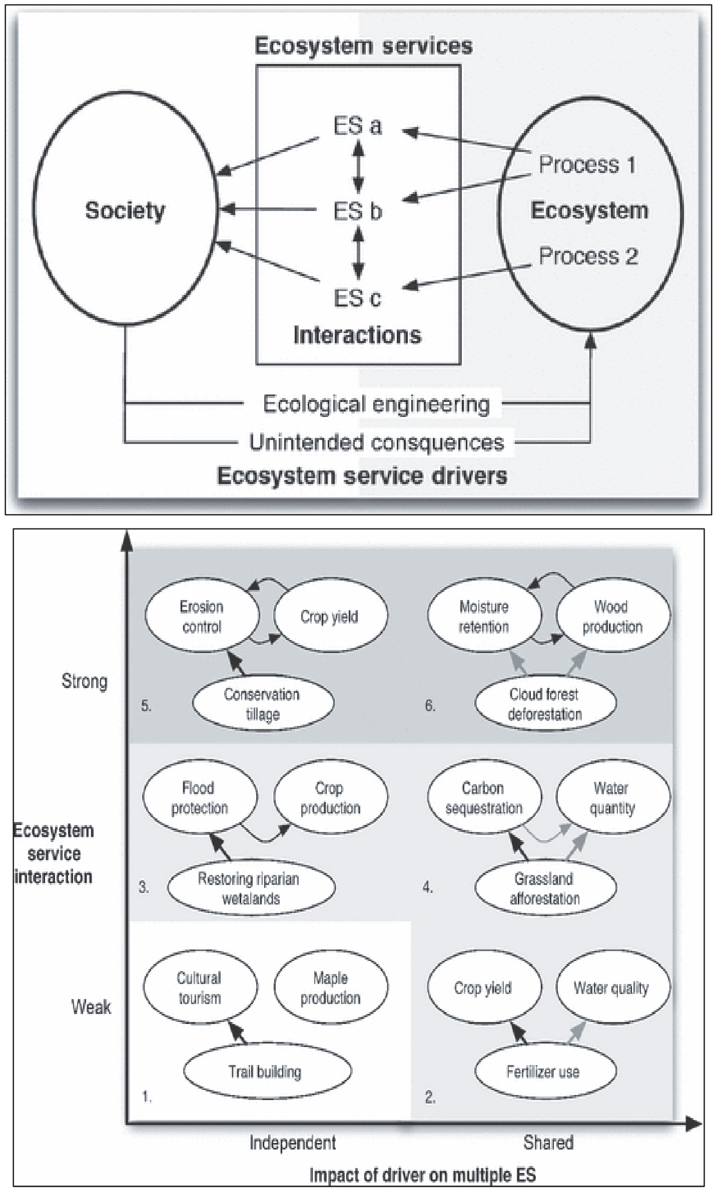

Figure 4. (a) Illustrates the interactive relationship among ecosystems services. (b) Illustrates the relationship between ecosystem service interactions and the impact that drivers have on those interactive relationships. The supply of ecosystems services can be related either due to interactions between ecosystem services, or due to responding to the same driver of change. Black arrows indicate a positive effect and grey a negative effect (from Bennett et al. 2009).

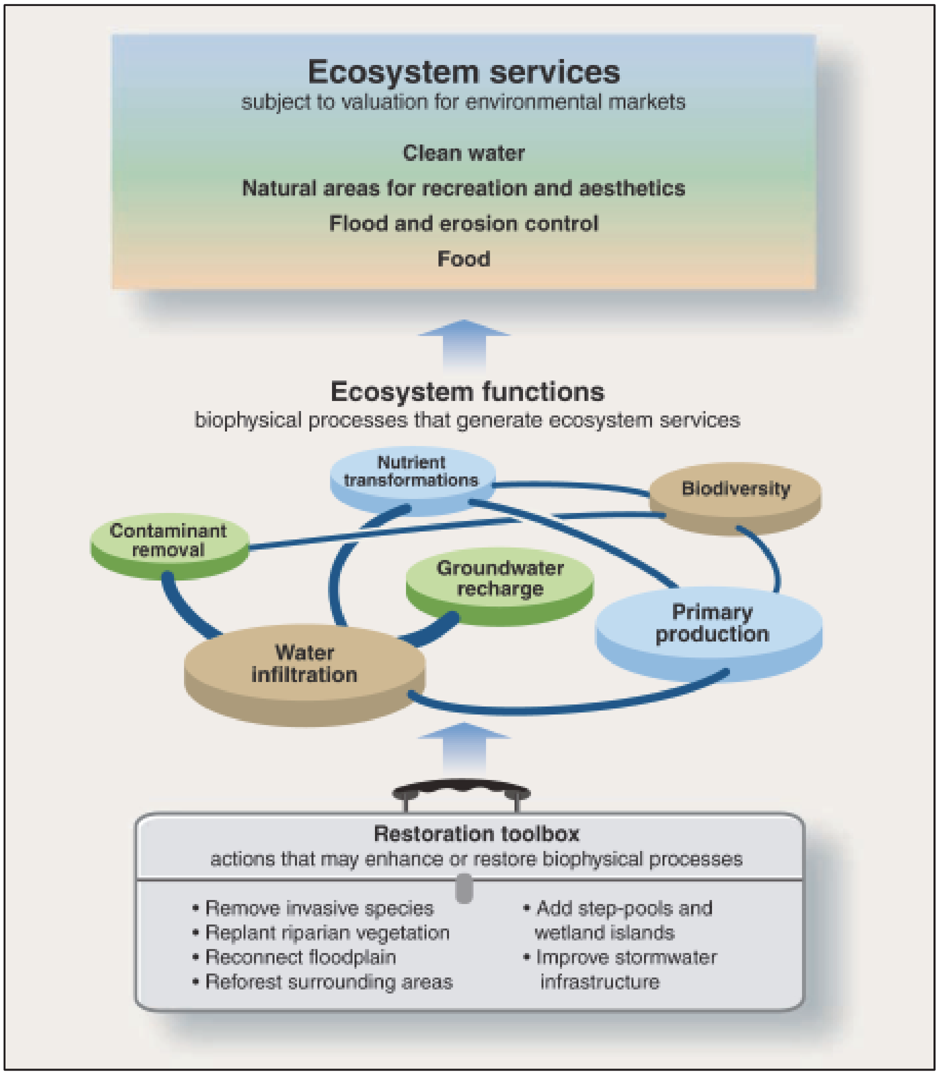

Figure 5. Illustrates the role of ecosystem restoration in improving delivery of ecosystems services (from Palmer and Filoso 2009).

restoration and mitigation. The point here is that restoration and mitigation impacts on ecosystem services are to be mediated indirectly through the effects of these activities on ecosystem functions and processes, not merely structure. Where Figure 3 emphasizes components of value and Figure 1 the connection between service bundles and human benefits, Figure 5 emphasizes the need to focus first and foremost on biophysical processes (e.g., microbial removal of excess dissolved nitrogen, the uptake of metals by plants, or the infiltration of rainwater into soils) that underlie the output of ecosystem goods and services (Palmer and Filoso 2009).

The interaction of these processes with structural and compositional features of the ecosystem and surrounding landscape collectively yield ecosystem functions or ecological processes. The services themselves (e.g., clean water) or the functions that support that service (e.g., denitrification) must be measured. As noted by Palmer and Filoso (2009), in many cases, we are only now identifying the most relevant ecological processes. Another useful conceptual model is provided by Stakhiv et al. (2003), which illustrates the flow of services from process and function to human benefits and values (Figure 6).

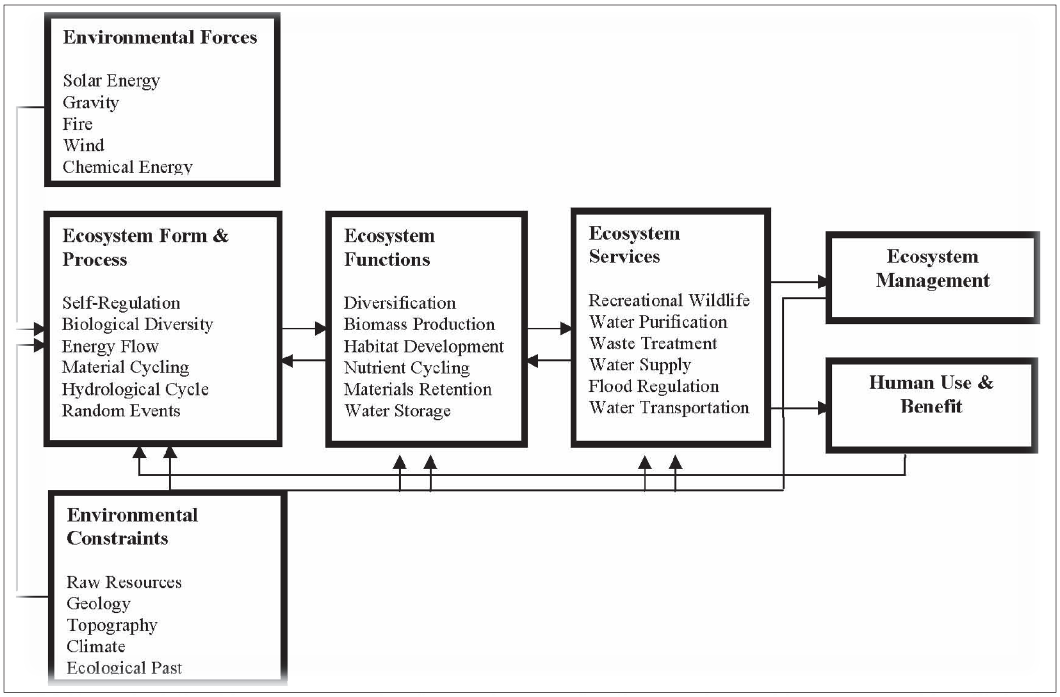

Figure 6. A conceptual model of ecosystem goods and services (from Stakhiv et al. 2003).

A discussion of conceptual models for ecosystem services would not be complete without touching on the economic concepts of value, valuation and measuring social benefits. A fuller treatment of these topics is available elsewhere (King and Mazotta 2000, NRC 2005, Wainger and Boyd 2009), and will be reserved for another technical report. However, a brief discussion is in order here to add context.

Value is the way humans represent the importance or desirability of something, and *valuation* is the process by which value may be assigned or determined. It is indeed possible to monetize many ecosystem services, including both use and non-use values (see Figure 3). The Corps can use a variety of prior work to inform the development of EGS assessment measures and their application to decision-making. For example, an EPA report (EPA SAB CVPESS 2009) stated, "In assessing and reporting value, EPA should also be as transparent and explicit as possible as to what methods it has used, why it chose the methods that it has used, the assumptions underlying the methods, and the limits of the methods. " The report stresses the need for comprehensiveness of effects, where possible, and a discussion of the limitations of the approach where it is not. Similar guidance is offered by OMB Circular A-4 (2003), which promotes evaluation that monetizes, quantifies, or describes all important effects, rather than limiting the evaluation to only those effects that can be monetized.

Much of the prior recommendations on valuing EGS stresses the importance of linking cause and effect as part of the benefits assessment and acknowledges the many challenges of monetizing EGS changes (NRC 2005, EPA SAB CVPESS 2009, OMB 2003). Environmental economic tools that are widely used in ecosystem services valuation include revealed and stated preference approaches, which are techniques for capturing values of goods and services that are not traded in markets and would otherwise be impossible to quantify. Revealed preference approaches use techniques, such as travel cost and hedonic pricing, to estimate the value of goods and services based on how people spend time and money (See Bockstael and McConnell 2007 for more detail). Travel cost models are used to value changes in recreational ecosystem services, such as fishing opportunities, based on how much time and expense people are willing to invest in to visit a site. Similarly, hedonic pricing is used to value the contribution of natural systems and their environmental qualities to a marketed good. For example, people are willing to pay a premium for a house with amenities, such as a view of a salt marsh or better air quality. Stated preference approaches directly query people about their preferences and willingness to pay for ecosystem services and are the only techniques available to value services that people do not explicitly use. Unfortunately, the application of these methods is often not performed in a robust manner, and the results have often been criticized (NAS 2005). Further, though there are multiple techniques available for non-market valuation, there is no single technique that is most appropriate in all circumstances (NAS 2005), and challenges are associated with all of these approaches.

Another common means of determining monetary value of services is "benefit transfer," the application of a value determined in one location to a project in another. However, assessments done within one policy context (regulation, damage assessment, etc.) or location may not be readily transferable to another due to a mismatch of environmental, social, or legal conditions (Ready and Navrud 2005). Further, the differences between the underlying assumptions of studies might be lost as values from multiple studies are combined to find an average value. Thus, classification and purpose of the original assessment must be an underlying consideration if attempting to use benefit transfer methods for assigning monetary values.

However, nonmonetary, economically based measures of relative services can be robustly applied to compare the cost-effectiveness of alternatives and are used routinely in decision making. For example, "deaths avoided" is a non-monetary benefit metric used to decide whether to install traffic signals. Given the public-good nature of ecosystem services, nonmonetary measures may be necessary to capture a broad array of many welfare concerns, since only a subset of welfare impacts can be monetized.

Ecosystem services valuation include revealed and stated preference approaches, which are techniques for capturing values of goods and services that are not traded in markets and would otherwise be impossible to quantify. Revealed preference approaches use techniques, such as travel cost and hedonic pricing, to estimate the value of goods and services based on how people spend time and money (See Bockstael and McConnell 2007 for more detail). Travel cost models are used to value changes in recreational ecosystem services, such as fishing opportunities, based on how much people are willing to invest in time and expense to visit a site. Similarly, hedonic pricing is used to value the contribution of natural systems and their environmental qualities to a marketed good. For example, people are willing to pay a premium for a house with amenities, such as a view of a salt marsh or better air quality. Stated preference approaches directly query people about their preferences and willingness to pay for ecosystem services and are the only techniques available to value services that people do not explicitly use. As the Corps pursues assessing ecosystem services, a variety of valuation methods may be required for different services of interest.

Economic alternatives to monetization include approaches such as the Wetland Value Index (King et al. 2000, Wainger et al. 2001), Ecosystem Benefit Indicators (Boyd and Wainger 2003), and Ecological Service Index (Banzhaf and Boyd 2005). Metrics or indices used to reflect potential benefits are similar to ecological indicators that are in widespread use in decision-making. The main difference is that benefit indicators are more likely to consider use or potential for use of services and the risk of disrupt-tion to service flows (e.g., consider the longevity of a tidal wetland in an area of sea level rise). However, most ecological and benefit indicators have not been vetted for their reliability in representing social benefits and many cannot be readily compared across locations because they are typically scaled to conditions within a study area. Techniques such as multi-criteria decision analyses, which are based on economic utility theory, are available to combine benefit indicators in order to consider multiple objectives (Linkov et al. 2004, Kiker et al. 2005). As a whole, these techniques are not a panacea and must be applied with a certain rigor in order to avoid bias and minimize subjectivity.

Whether the value indicators are monetary or nonmonetary, several key principles need to be recognized for project planning purposes. First, valuation tools are intended to be applied in a marginal analysis. Typically, we are not interested in the economic value of the entire ecosystem, but rather with the *change* in value that results from a management action or policy decision. Second, the value of a *single* ecosystem service should not be confused with the total value of the change, which has far more than one dimension. Although focusing on a single service may, in some cases, be useful in evaluating policy and management alternatives, it will represent only a partial value at best (NRC 2005). Third, public benefits can increase, decrease or remain unchanged in response to change in an ecosystem state. A change in the quantity or quality of a good or service may not measurably affect human welfare, if there is little demand for that good or service.[1] In the end, the choice of service or bundle of services and the analytical approach must be driven by the decision that needs to be made for a given project.

A conceptual framework for linking components of nature to human welfare benefits based on these ideas is portrayed in Figure 7, which is useful whether monetary or nonmonetary approaches are implemented. Here *natural features* are characteristics of natural systems that are readily observed such as vegetation. *Ecological production functions* are the biophysical processes that generate ecological endpoints, which measure capacity to supply final or intermediate ecosystem goods and services. *Economic demand functions* account for human preferences given con-

[1] This differs from traditional environmental assessments, which focus more simply on the change in quantity and quality of environmental resources without explicit consideration of demand. For example, in ecosystem restoration, alternative restoration plans are often compared based on the extent to which outcomes conform to undisturbed reference conditions. This is useful when the targets of restoration are species or conditions that are to be protected from human use (e.g., endangered species habitat). It is less useful when improved human access for resource use is the project goal (e.g., wildlife viewing areas and greenway development in urban settings).

siderations of access, scarcity or substitutability, and reliability. Where *complementary goods and services* are important, their interrelationships would impact the economic demand function. Resultant benefits are valued in the final step in either monetary terms or as benefit indicators. *Social values* influence both the choice of ecological endpoints and the direct use of human preferences in demand characterization.

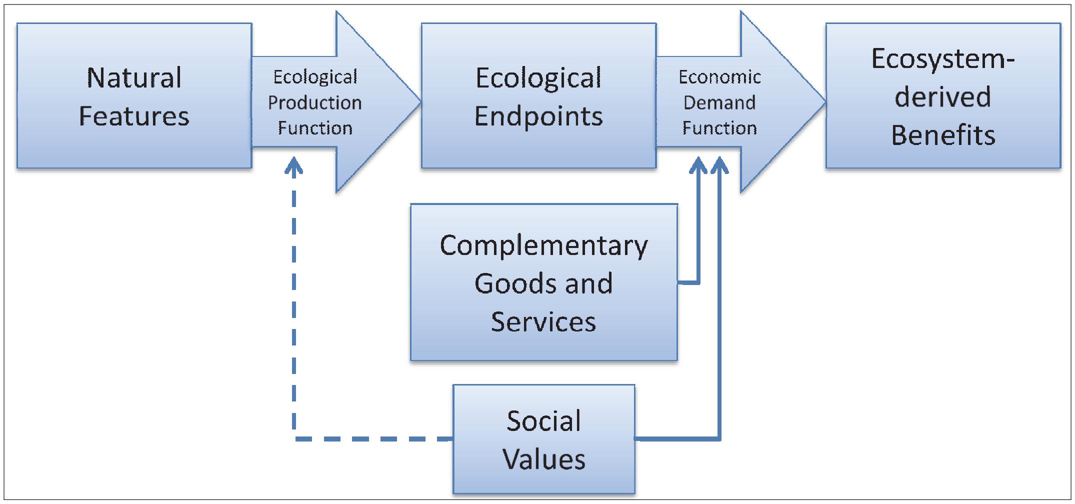

Figure 7. Analysis framework of benefits derived from natural systems. See text for further information. Modified after Wainger and Boyd (2009).

This final conceptual model provides a useful operational framework. It separates and maintains the integrity of the ecological and economic elements while clearly illustrating the operational linkage between these two phases of the analysis. It also helps to clearly specify measures appropriate at each point in the analysis, reveal assumptions and uncertainties, and communicate effectively with stakeholders. If crafted properly, the ecological endpoints themselves can serve as reasonable proxies in economic valuation.

6 Operationalizing Ecosystem Goods and Services Considerations in Environmental Decision-Making

The critical issue at this juncture is to move from a diverse suite of definitions, conceptual models, and generalized classification schemes to an operational model for linking healthy functioning ecosystems to human well-being. The model should serve as a basis for making efficient and transparent environmental policy and management decisions. Fortunately, progress is being made in this regard as the state of the science and ecological economics have evolved in recent years. Here the authors introduce several selected approaches that have been proposed in the last decade or so with the intent of being representative rather than exhaustive. Available data, analytical tools and models will be treated in more detail in a separate technical report.

Analytical Framework and Modeling Considerations

An example of a straightforward analytical framework for estimating the economic effects of ecosystem restoration and management actions is illustrated in Figure 8. Using this framework, Wainger and Mazzotta (2011) describe a multiple step process to evaluate changes in social welfare that results from human actions affecting the environment. Application of this and similar analytical frameworks requires many considerations, which are described in detail by Wainger and Mazzotta (2011). In addition, NRC (2005) addresses the capabilities that need to be developed in order to implement such a framework for ecosystem services analysis.

First, there must be a clear understanding of the purpose, scope and geographic scale of the valuation exercise. Significant data and information gaps then must be identified and addressed based on the purpose, scope, and scale (NRC 2005). For instance, if the purpose of the EGS assessment is to differentiate among different restoration activities at a particular site, a high level of precision may be necessary, resulting in significant data requirements. If, instead, the purpose is to compare the potential EGS outputs at restoration sites across multiple watersheds, differentiation might require less precision and data, due to the number of inherent differences between the watersheds, and larger potential differences in

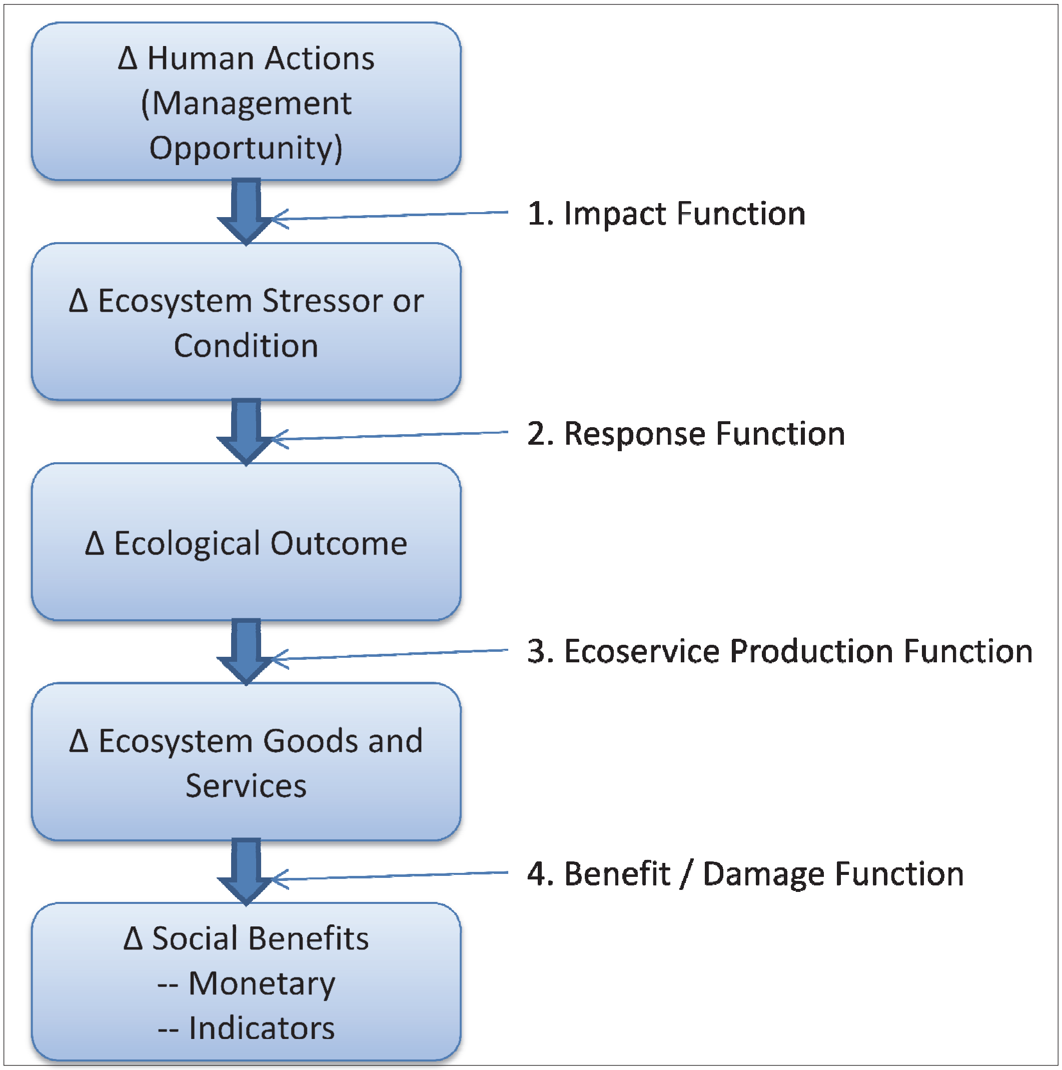

Figure 8. A Framework for Estimating Economic Benefits of Ecosystem Restoration And Management (modified based on Wainger and Mazzotta 2011).

services produced across them. Likewise, some ecosystem functions (e.g., floodwater retention) are more easily measured at a watershed scale than a site scale (NRC 2005). It is important to be clear about what is known and not known about the underlying ecological structure, functions and dynamic processes in order to forecast outcomes of different policy and management options; these will inform the *Impact and Response Functions* (Steps 1 and 2, Figure 8). The *Impact Function* defines the expected effect of a human action or behavior on ecosystem conditions and stressors. For example, how might a change in dam operation affect flow regime? The *Response Function* estimates the expected changes in ecological outcomes when conditions and stressors change. How might the change in flow regime affect fish movement and productivity downstream? Significant data and information gaps must be identified and addressed (NRC 2005).

The ecosystem services of importance to the Corps and partners must be determined. This might be done via a coarse level ecosystem-based matrix, similar to the one developed for the Gulf of Mexico (Yoskowitz et al. 2010). Sixteen coastal and marine geo-environments and the list of ecosystem services associated with each in the Gulf of Mexico were identified through expert elicitation (Table 8). The group went further to prioritize key services for each geo-environment with the idea of focusing on those top services in subsequent evaluation. A similar matrix could be developed as part of the scoping portion of a Corps framework to help planning teams identify important services. If incorporated, a few issues of concern would need to be addressed. In this example, both intermediate and final services are included, which complicates accounting. In addition, the criteria for prioritizing ecosystem services are not provided, and it is not clear whether multiple viewpoints were considered. However, with more diligent separation of services, and better transparency, such an approach could aid planning teams in scoping EGS for an assessment.

The *Ecoservice Production Function* (Step3, Figure 8) determines whether services are produced. Does the change determined by the *Response Function* result in greater recreational opportunities such as boating and fishing? Finally, the social welfare value of the change in services is quantified via a *Benefit/Damage Function*. This function processes how people and their well-being are affected by the change. Note that this function can be monetized or captured as non-monetized indicators. If outputs are *not* being monetized through a benefits/damage function, the results of the Ecoservice Production Function may be a satisfactory proxy to represent benefits if qualitative considerations of demand and alternatives are considered. For instance, rather than merely using an Index of Biotic Integrity (IBI) or Habitat Suitability Index (HSI) showing general ecological lift, these metrics might be combined with data addressing thresholds for a species of interest. An increase in vegetation cover from 5 to 20 percent is of little benefit if the vegetation needed for nesting success of a species of interest is 50 percent. But that same amount of lift could be a large benefit if the shift in vegetation cover is from 45 to 60 percent. Thus, translating the ecological lift into its likely contribution to a benefit of interest cannot be assumed to be linear. As another example, rather than using a metric showing how much floodwater has been retained by volume, the change in area (and affected infrastructure) flooded would be a metric that more closely addressed the service provided.

Table 8. Geo-Environments of the Gulf of Mexico and Associated Ecosystem Services (only priority services are listed; from Yoskowitz et al. 2010)

Oyster Reef Food Water Quality Biological Interactions Hazard Moderation	Coral Reefs Recreational Opportunities Aesthetics and Existence Biological Interactions
Freshwater Submersed Aquatic Vegetation Biological Interactions Water Quality Recreational Opportunities Nutrient Balance	Non-Freshwater Submersed Aquatic Vegetation Food Biological Interactions Water Quality
Saline Marsh Biological Interactions Hazard Moderation Recreational Opportunities	Brackish Marsh Nutrient Balance Biological Interactions Soil and Sediment Balance
Freshwater Marsh Nutrient Balance Biological Interactions Hazard Moderation	Macroalgae Biological Interactions Nutrient Balance Food
Swamp/Bottomland Hardwood Hazard Moderation Nutrient Balance Water Quality	Dunes/Beaches Hazard Moderation Aesthetic and Existence Soil and Sediment Balance
Forested Coastal Ridge Recreational Opportunities Hazard Moderation Soil and Sediment Balance	Intertidal-Sand/Mud Soil and Sediment Balance Biological Interactions Recreational Opportunities
Subtidal-Sand/Mud Biological Interactions Nutrient Balance Soil and Sediment Balance Raw Materials	Open Water Food Recreational Opportunities Climate Regulation
Offshore-Shoals and Banks Recreational Opportunities Food Biological Interactions	Mangroves Biological Interactions Hazard Moderation Soil and Sediment Balance

The valuation of that infrastructure would be the step addressed by the benefits function, which would be used to calculate demand for a service by location and the infrastructure's ability to substitute or adapt to a change in the quality or quantity of a service through standard economic modeling approaches (e.g., Turner et al. 2008). The outputs of any of these economic approaches would be monetary units of consumer surplus, producer surplus, or similar metric.

Table 9. A spectrum of modeling complexity (derived from Wainger and Mazzotta 2011 and Swannack et. al. 2012).

Model Type	Description	Examples
Land Use/Cover Classification	Ecological impacts, outcomes and services are simply associated with different land uses and land cover types.	Geo-environments and associated ecosystem services (Yoskowitz et al. 2010 – see Table 8 above)
Conceptual	Represents the system of interest qualitatively, usually as a diagram that shows the important variables and how those variables are related to each other (e.g., qualitative relationships between drivers, stressors and effects).	Several (Fischenich 2008); Southwest Coastal Louisiana (Fischenich and Barnes in preparation)
Analytical	Specifies a generalized mathematical relationship between variables usually written as difference or differential equations.	Equation for exponential population growth: $N = e^{r(t-c)}$
Index	Ecological outcomes and services are evaluated based on a series of indicators weighed according to their biophysical and/or socio-economic importance.	Habitat Suitability Index (USFWS 1980) Hydrogeomorphic Functional Capacity Index (Smith et al. 1995)
Empirical Models	The relationship between ecological outcomes and services are described statistically or empirically based on site-specific data.	Fish habitat models (Killgore et al. 2008)
Simulation / Process-based Models	A complex of models that mathematically relates a myriad of ecosystem features, fluxes, activities and stressors to assess possible ecological impacts and outcomes. The intent is to capture real world processes and systems (e.g., quantitative relationships between drivers, stressors and effects).	Chesapeake Bay Eutrophication Model (Cerco and Noel 2004)

The *Ecoservice Production Function* and *Benefit/Damage Function* (Steps 3 & 4, Figure 8) will require specific ecological and economic information for the analysis. The planning team will need to determine whether it can obtain the relevant biophysical data and information, as well as have available the right economic evaluation tools and approaches. In some cases, these may need to be developed. Important sources of uncertainty in the data affecting the outcomes should be identified and managed. This might involve Monte Carlo simulations of variation within some documented range of outcome possibilities as well as the prescription of adaptive management procedures.

Available tools and techniques to model and evaluate the ecosystem *Response Functions* range in complexity from simple qualitative models to more complex data-driven models (Table 9). Economically based landscape indicators can also range widely from simple statistical models to highly sophisticated simulation models. The particular tools or techniques used depends in large measure on the questions being asked and resources available. The models applied need not be any more complex than the size, scope and complexity of problem addressed.[1] For example, if the goal of a

[1] See Swannack et al. (2012) for detailed guidance on selection and development of ecological models

particular restoration project were to increase the stock of waterfowl, it might suffice to know the amount of relevant wetland habitat restored under various restoration alternatives and the qualitative relationship between wetland attributes and waterfowl numbers at some specified time of the year (e.g., HEP models or Murray et al. 2009). On the other hand, understanding the effect of changing land use practices on nutrient loadings and the risk of harmful algal blooms at the scale of the Chesapeake Bay may necessitate a far more complex model (e.g., Cerco and Noel 2004). Limitations on the availability of needed data and information, and the cost and complexity of acquiring any missing data and information, may limit which services are included in the analysis or how explicitly services can be measured.

The last two steps in the framework above, determining the change in ecosystem service levels and the value to humans associated with that change, require consideration of economic principles such as scarcity and demand. The value associated with an ecosystem is not based on the ecological state and outputs alone – i.e., *Impact and Response Functions*. This may seem obvious given the definition and discussion of value above. Yet, historically, ecological assessments (e.g., assessing restoration alternatives) have largely relied on ecological parameters without explicit assessment for the ultimate social values produced. Moving into the realm of ecosystem service evaluation based on economic principles requires a broader contextual analysis.

The Wetland Value Index (WVI) proposed by King and colleagues (2000), and later extended by Wainger et al. (2001), utilizes wetland functional capacity indices from the hydrogeomorphic (HGM) approach to wetlands evaluation as a basis for valuation. Here, wetlands are considered "factories" of multiple beneficial services, the outputs of which depend upon inherent functional capacity and geographic circumstance of the wetland site. It includes a consideration of on-site functional capacity of the wetland, combined with an off-site assessment of various landscape considerations (Figure 9). The later point is critical; the characteristics of the surrounding landscape — including proximity to and use by people — are considered key determinants in the levels and values of the services rendered by a given wetland site as are the risks of disruption to service flows.[1]

[1] For example, wetland functions and services that are moved to a different location will have benefits and values that vary in accord with a change in one or more landscape, risk and demographic factors in the new setting. Also, benefits perceived as positive at one geographic scale (better trout fishing downstream) may have a negative impact at another (more mosquitoes in the upstream wetland).

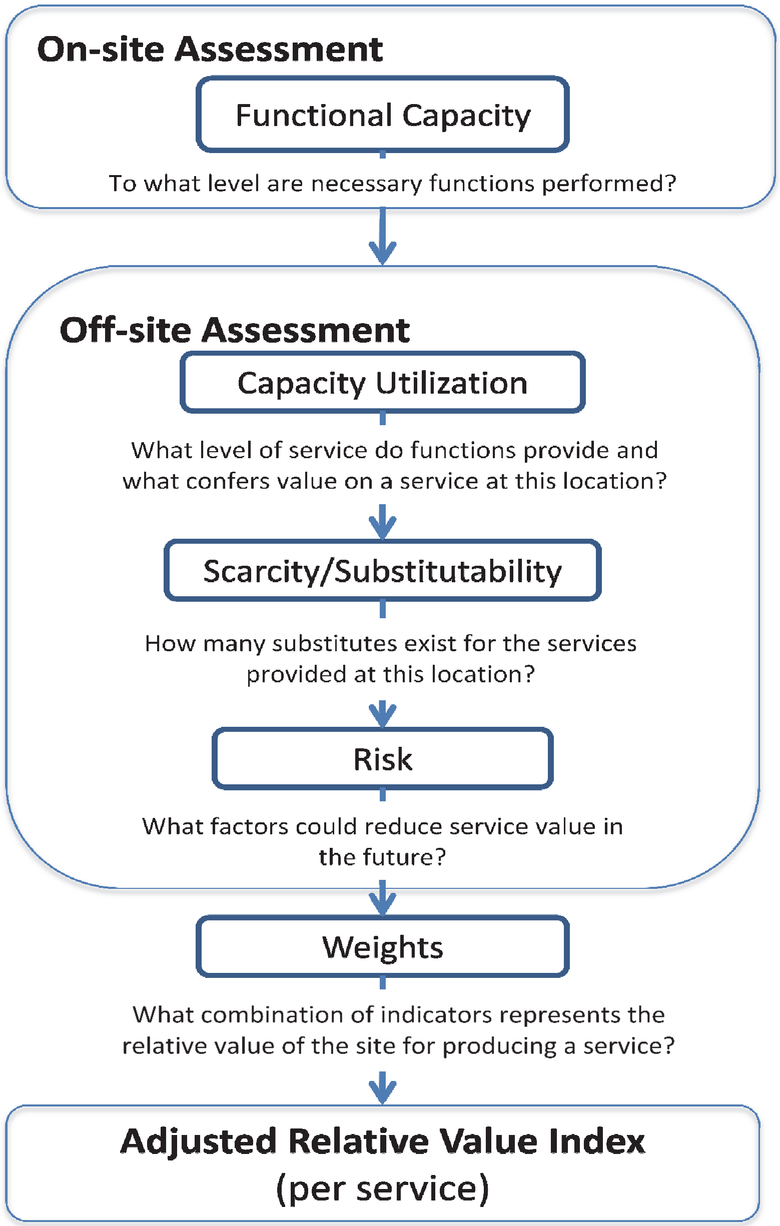

Figure 9. Steps in Wetland Value Indicator Development (modified based on Wainger et al. 2001)

In their further development and extension of this concept, Boyd and Wainger (2002, 2003) described five major, valuation-based landscape indicators that can be employed to assess off-site features that affect ecosystem service production and value: landscape advantage, scarcity, complementary inputs, risks and changed future conditions, and income and equity considerations. Using this method, these authors were able to demonstrate how readily available, GIS-based landscape information could be used successfully to evaluate the importance of wetlands at particular locations and infer value from landscape characteristics. Boyd and Wainger

(2002, 2003) cautioned against simplistic aggregation of indices across indicators and multiple services. First, while a single aggregate index is attractive to decision-makers, much important information can be lost. Second, the manner in which indices are mathematically aggregated is important (summation versus multiplication, geometric versus arithmetic means, weighting, etc.) and it is not always clear which approach is best. Finally, there can be large uncertainties with respect to the relationship between indicators and actual services – these relationships may be linear, convex, concave or non-monotonic. Despite these concerns, the approach detailed by Boyd and Wainger (2002, 2003) offers an alternative to more time-consuming and costly econometric analyses that may not be required by policy nor warranted by the nature and scope of the problem and the funding available for planning and analysis.

A simplified Hydrogeomorphic (HGM) approach was also used by Turner and colleagues (2008) as a foundation for ecological evaluation and economic valuation of multifunctional wetlands in the United Kingdom. One factor that weighs heavily in favor of this approach is that under the HGM method, wetlands are taken as the unit of assessment, not the individual services. In this way, the overall health and integrity of the system is appraised. Though the technique involved both intermediate and final services, they did tie wetland functions as defined in HGM to human well-being.

The Corps' Institute for Water Resources (IWR) sponsored an early attempt at a comprehensive analytical framework in 1996 (Cole et al. 1996). They sought to address a fundamental question: What are the possible changes in the ecosystem that may result from Corps environmental mitigation and restoration projects? And: What outputs and services do these changes provide society? They recognized early on the notion of intermediate services in noting that intermediate ecological outputs serve as inputs for other processes and for the ultimate outcomes (i.e., perceived human benefits). One premise of their effort was based on recognition of the inadequacies of Habitat Evaluation (HEP)-based methods (USFWS 1980), which, surprisingly, are still relied upon to this day to a greater extent than one might have presumed.[1] Cole and colleagues (1996) emphasized the need for a "more robust" accounting of benefits as a basis for justifying federal expenditures on environmental mitigation and restoration. They also

[1] While maintenance of habitat can be viewed as one beneficial output of a functioning ecosystem, it represents only one type of intermediate service.

cautioned that inappropriate decisions might result if one did not fully appreciate the complex relationships between ecosystem processes, integrity and resulting human services.

The approach they took was to identify specific Corps activities, list the potential direct and indirect effects of those activities on the ecosystem and then make a tie to socio-economic impacts. The report was intended as a guide for Corps project planning teams. It provides an extensive list of impacts to consider in the plan formulation and justification process. Useful information is also provided on fundamental concepts in ecology and economics.

A fairly complex but accessible series of tables is laid out in the report along with procedures for using the tables. The general concept is illustrated in Figure 10. Specific Corps actions are linked to potential ecological inputs and outputs, which are, in turn, linked to specific services. The utility of this is that it puts the concept squarely in the context of the Corps project planning process. Although it may appear to be prescriptive, it is only intended as one guide by which to identify and evaluate potential outcomes and it has not been updated to include new knowledge. The reader is referred to the original report to examine the details of the tables – information is provided therein on specific services, metrics, and techniques by which to value the service outputs.

It was also recognized that not all services need or should be considered in any given study. In most cases, project planners would be expected to pick a subset of relevant service. Criteria proposed to guide selection include: legal relevance, demand and limited supply, stakeholder interest, ability to use the service in distinguishing project alternatives, and availability and accessibility of data.

The history, varied definitions, methods and models, and the work by IWR and others lead to conclusions that are specific to the Corps. In the next section the authors suggest a definition and explore how the Corps may incorporate ecosystem goods and services in planning for restoration and mitigation projects.

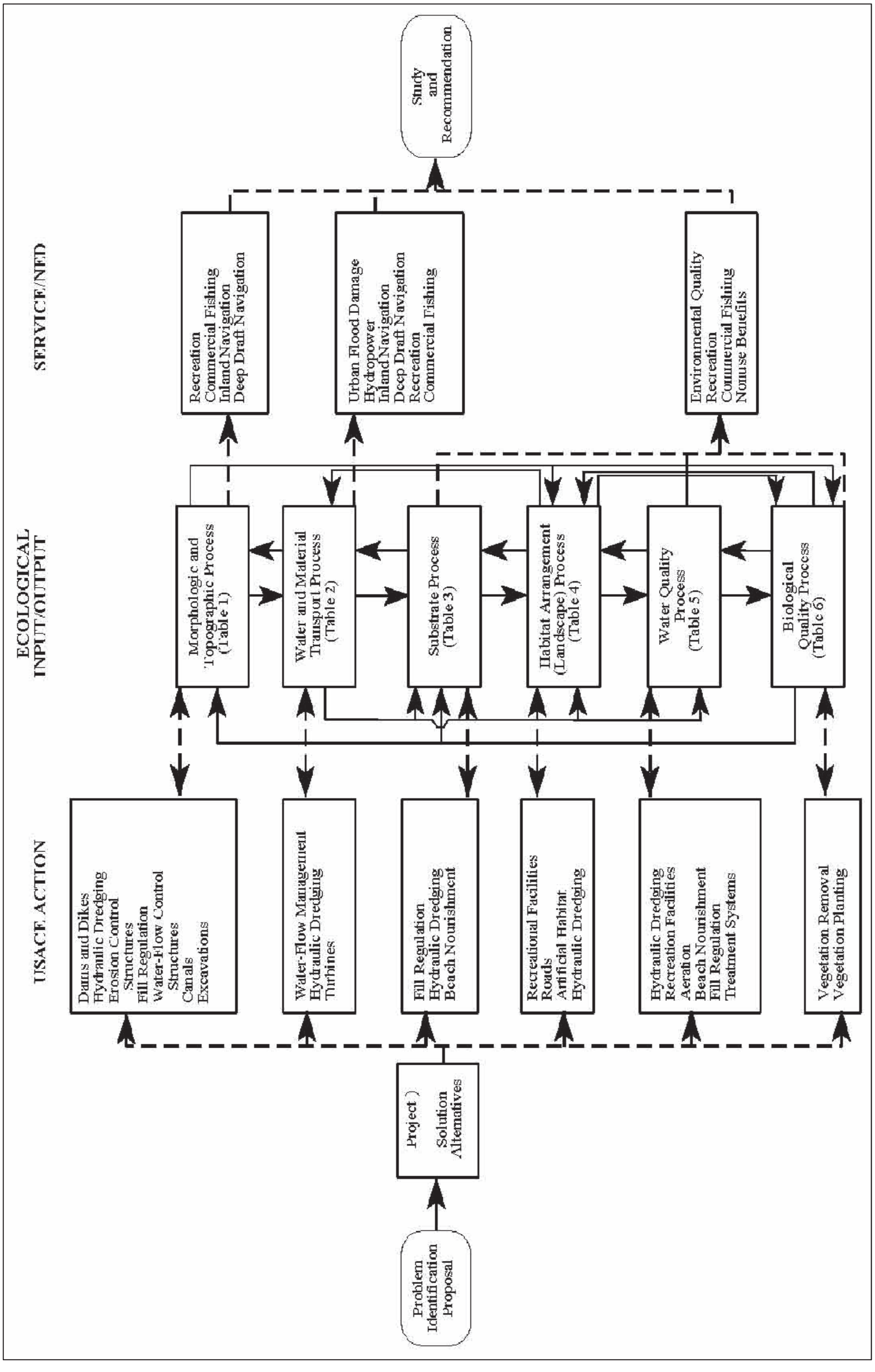

Figure 10. The process for evaluating human service outputs from Corps projects (from Cole et al. 1996).

7 Implications for the Corps: Incorporating Ecosystem Goods and Services in Corps Planning

The Corps' mission in water resource development has evolved as the needs of the Nation have changed over time. Historically, the Corps was called upon to provide for water-borne navigation and then flood control services for the economic benefit of the Nation. In consonance with the environmental movement and attendant environmental laws and regulations in the latter half of the 20th century, the Corps and its sister agencies have and continue to strive to balance economic and environmental goals and objectives. Increasingly, competing water uses must strike a balance to provide multiple benefits, including economic security, environmental health, social well-being, and public safety. As the Corps and the Nation tackle the next generation of water resources infrastructure and environmental challenges, consideration of ecosystem services may play an expanding role in evaluating alternatives at policy, program and project levels.

As noted above, the concept of ecosystem services is not new to the Corps. By policy, the Corps' water resource development and management mission is carried out in the public interest and with the intent to ensure the economic and environmental well-being of the Nation. The ecosystem service concepts presented above are largely consistent with the Corps water resources mission, and provide a useful basis upon which to explicitly connect the Corps' environmental activities to the host of benefits that derive from sound ecosystem restoration and management. The section below focuses on the implications of the above discussion regarding definition, classification, and operationalization for Corps planning.

Definitions of Ecosystem Services

The choice of definition used for the term "ecosystem services" has implications for how the Corps would use an ecosystem services framework for civil works planning. Any guidelines or policy that might be developed should be explicit as to the definition so that a common lexicon is used among planning teams, reviewers, and decision-makers. As stated earlier in the document, the authors recommend distinguishing between goods and services, for accounting and communication purposes.

The precise language used by the Corps to define ecosystem goods and service may need to await further policy discussions along with a full consideration of the federal/public interest that is being served and the manner in which analyses are to be carried out. Provisionally, the authors provide this general definition, which is similar to that used by the MA (2005).

> *Ecosystem goods and services are socially valued aspects or outputs of ecosystems that depend on self-regulating or managed ecosystem structures and processes.*

This definition is largely consistent with the spirit and intent of definitions presented in the literature, but uses more specific language appropriate for applied use by the Corps. In order to reduce the risk of double-counting of benefits, final goods and services are preferred for quantitative assessments, as recommended by Boyd and Banzhaf (2007). In addition, the uncertainties inherent in ecosystem service calculations increases as the service is further removed from direct human usage; thus, while noting the indirect ecosystem services is helpful from a public communications standpoint, the authors recommend changes in benefits from direct goods and services. Overall, this definition incorporates the Corps' definition of ecosystem restoration, which is to restore significant ecosystem structure and dynamic processes that have been degraded. The intent here is to emphasize the need for naturally functioning systems as a basis for ensuring a sustainable flow of goods and services. However, we acknowledge that a certain level of management may be necessary in some environments.

Classification of Ecosystem Services

Earlier in this paper, the authors presented several different classification systems that have been developed for ecosystem services. The purpose of a classification system in this case is to help organize ecosystem services so that planners can attribute and assess the services attained or impacted by implementing project alternatives. Previous attempts, as reviewed in this document, provide a good foundation upon which to build. The classification framework is needed to promote consistency and should aid in a *practical, comprehensive assessment* of goods and services produced, to the degree that the state of knowledge permits, and in identification of the best approaches to quantification of potential changes in benefits and relative values (monetary or nonmonetary, as appropriate). Ideally, the EGS selected for assessment will allow for more objective, complete, and consistent evaluation of investment options and their potential effects on society. This information could be used both at the project and programmatic levels to supplement the evaluation of resource significance (USACE 2000, IWR 1997, Tazik 2012, USACE 2010). Significance criteria include institutional, public, and technical significance as a means to determine whether a resource is protected by law, of interest to the public, or scientifically important.

The classification scheme provided in the Millennium Ecological Assessment (2005) is a commonly applied framework that provides a recognizable and relatively simple way to describe the types of goods and services that might be of interest to a broad set of stakeholders. However, it has limitations for analyzing changes in benefits associated with Corps projects. A primary concern with operationalizing the system is that it can easily lead to double-counting of the same benefits, due to the fact that it includes both intermediate and final services. In particular, *supporting services,* which are recognized as inputs into other services (Figure 1), are often accounted for in parallel to other types of services, without considering the overlap of benefits.

While many ecosystem services can be produced simultaneously from a natural system (e.g., undisturbed forests may easily provide drinking water purification, climate regulation, hunting and fishing opportunities, etc.) the ability to assess trade-offs of different resource use and management depends on comparing the social importance or value of *competing* services (see Daily 1997 and NRC 2005 for examples). Competing services may be completely mutually exclusive or partially competing. *Joint production* occurs when a bundle of complementary or partially complementary goods and services are produced for a given restoration project or management strategy. When services are not completely complementary, enhancing one service can come at the expense of other services (See Daily 1997 and NRC 2005 for examples). Any classifications system used by the Corps would need to help planners identify competing and complementary services, so joint production could be adequately addressed.

In its assessment of different classifications, the NRC (2005) report noted that services should also be considered in terms of temporal and spatial scale. Ecosystem goods and services vary over space and time with respect to their production and the values enjoyed by humans. While soil formation provides services that can be used where they are produced, carbon sequestration benefits provide services at a global scale. Further, carbon sequestration service varies widely over different stages of ecosystem succession, creating changes in rates through time. The value of services will also respond to shifts in preferences over time (Costanza 2008, King et al. 2000, Table 6 therein). This aspect of scale is particularly important for Corps projects, which vary in terms of project area and also typically have planning horizons of 50 years. As a result, the beneficiaries of Corps projects may be distant from the project both in space and time.

A potential starting point for developing a classification of ecosystem services for Corps planning purposes would be to organize ecosystem services using considerations important to the Corps:

1. Service-providing habitats
2. P&G accounts: National Economic Development, Environmental Quality, Regional Economic Development, and Other Social Effects
3. Spatial/temporal scale (both at which the service is produced as well as valued)
4. Corps mission area(s)

Each of these may be relevant at different stages of an analysis. For instance, initial screening during Step 1 of the Planning process (Identifying Problems and Opportunities) might consist of qualitatively addressing the services associated with different ecosystems types. These qualitative assessments could be expanded using conceptual models to make the case for significance of the resource and restoration plan by linking specific management actions with subsequent changes in ecosystem outputs and ecoservice outcomes. Thus, the conceptual models clarify why selecting metrics represent beneficial outcomes and help "tell the story" of why the restoration would be beneficial to the public. Such a use of EGS could be accomplished using a classification that focuses on final goods and services but uses intermediate services — as needed — to provide a more comprehensive assessment of potential benefits from basic life-support services.

However, in later steps, the project delivery team might conduct a detailed quantitative assessment on a subset of services that are particularly important to the project purpose(s), federal interest, local sponsor, etc.

The project delivery team would also assess the changes in service outputs over the duration of the planning horizon. Such quantitative assessment would require stricter adherence to the use of final services, to avoid double counting.

In addition, any classification scheme that is developed for use by the Corps should display the relationship between the final good or service and the intermediate service(s) from which they are derived. This is important so that planners can deal with the complexities of trade-off analyses and reduce or avoid potential double-counting of benefits. Developed properly, the classification scheme should help to identify the goods and services of interest during characterization of problems, opportunities, objectives, and constraints, and aid in the production of a conceptual model for the system under investigation; in so doing, planners can quickly recognize deficits in particular goods and services, as well as risks associated with depletion or disruption of goods and services provisioning. Finally, a useful classification scheme would likely allow for classification of goods and services in terms of the four Principle and Guidelines accounts (National Economic Development "NED," Environmental Quality "EQ," Regional Economic Development "RED," Other Social Effects "OSE") and the Multiple Objective module of the SMART Planning guide (reflecting national accrual or redistribution of Economic, Environmental, Social effects). Further discussion of Corps classification will be the subject of future reports within this ecosystem goods and services project.

Operationalizing Ecosystem Services Assessment

As noted earlier in this paper, having a checklist or general guidelines is a useful first step for the Corps to consider ecosystem goods and services, but is not sufficient for evaluating the potential goods and services that are produced by various alternatives. An analytical framework that goes through the steps of ecosystem service evaluation and comparison, like the one presented in Wainger and Mazzotta (2011), could provide utility to Corps planners in fuller accounting of benefits and costs of their alternatives.

A framework that would provide such utility should possess the following characteristics and illustrate the following conditions:

- Risk and uncertainty. As with other components of the project, this framework should reflect the consideration and documentation of the uncertainties associated with ecosystem services production at each step identified in the conceptual model. The framework should also reflect the risks; use of a risk register, either as one register for all aspects of the project, or developing a separate register for consideration of ecosystem services, is recommended. Documenting such risks may help project planners select ecosystem goods and services for accounting purposes that are most robust.
- Transparency. The framework should be developed so that the assumptions, weighting of criteria, and trade-offs among services, would be clearly laid out so that decision-makers and the public are fully informed of how plans are selected.
- Distinctiveness. In order to be useful in plan formulation or alternatives analysis, a framework and associated tools must allow users/planners to detect the differences between alternatives and each alternative's ability to produce the services of interest. If they cannot, ecosystem goods and services may still be useful for producing a full accounting of services provided by an alternative selected via traditional means.

8 Conclusion

The Corps' mission in water resource development has evolved as the needs of the Nation have changed over time. Historically, the Corps was called upon to provide for water-borne navigation and then flood control services for the economic benefit of the Nation. In consonance with the environmental movement and attendant environmental laws and regulations in the latter half of the 20th century, the Corps and its sister agencies have and continue to strive to balance economic and environmental goals and objectives. Increasingly, competing water uses must strike a balance to provide multiple benefits, including economic security, environmental health, social well-being, and public safety. As the Corps and the Nation tackle the next generation of water resources infrastructure and environmental challenges, consideration of ecosystem services may play an expanding role in evaluating alternatives at policy, program and project levels. The ecosystem service concepts presented in this document are largely consistent with the Corps' water resources mission, and provide a useful basis upon which to explicitly connect the Corps' environmental activities to the host of benefits that derive from sound ecosystem restoration and management.

The ecosystem service concept is an overarching idea that *potentially* illustrates the value to society of a broad range of ecosystem processes, structures, and functions. The notion is not new to environmental planning and management within the federal sector. However, it has evolved in recent decades to become more formalized. By seeking to integrate humans in the managed landscape, it is a good complement to holistic or ecosystem-based approaches to natural resource management.

The significance of ecosystem services assessment lies both in its ability to quantify change relative to human welfare, an appropriate role for federal investments, and to effectively communicate physical manifestation or environmental change in a manner that permits people to understand the change in terms of human welfare.

The authors conclude this technical report with several principles that are most relevant to Corps projects, based on a thorough review of the field of ecosystem services and the authors' understanding of the Corps' planning process.

Ecosystem goods and services are socially valued aspects or outputs of ecosystems that depend on self-regulating or managed ecosystem (e.g., Mississippi River) structures and processes. A distinction is made between the ecological outputs of natural systems (e.g., plant diversity), and the goods and services that the system might provide.

An evaluation of ecosystem goods and services can be an important input to environmental decision-making. The existing planning process addresses some considerations captured by EGS through the determination of significance of the resources being restored, as well as the consideration of ancillary benefits. In addition, NEPA evaluates many of the environmental changes that will or could occur with project implementation. However, NEPA outputs are rarely integrated with significance criteria to create a unified method of comparing the relative importance of environmental changes for project options. Further, the significance criteria do not address a full range of EGS issues since they are generally aimed at non-use EGS.

The EGS assessment process aims to integrate the identification and use of relevant EGS changes in project formulation and evaluation and provide a more comprehensive assessment of effects of the selected plan. By developing and applying the proposed conceptual models, an EGS assessment can promote project designs that produce the highest level of overall benefits and can be used to report benefits consistently across projects. The approach expands upon NEPA outcomes by incorporating the social importance of environmental changes for both use and non-use services. Such results can help to frame the project outcomes in a way that will be meaningful not only to decision makers, but their partners and the public.

The fundamental principles of good planning currently used by the Corps would also apply to EGS assessment. The first step in the Corps' six step planning process is to identify and define the problems, opportunities and objectives. If the intent is to address ecosystem services, then one must have identified the problems and opportunities associated with goods and services early on in the planning process. This would typically be illustrated during formulation of the conceptual model.

Ecosystem restoration and mitigation may be justified and planned under current policies based on ecological considerations alone, and reasonable alternatives can be identified and evaluated based on ecological criteria. However, if problems and opportunities include ecosystem goods and services, it would be necessary to identify the relevant goods and services and clearly relate those to anticipated ecological outputs. This implies that goods and services would be characterized, inventoried and forecasted to inform the formulation process rather than accounted for as an afterthought when the project is completed.

Currently, accurate evaluation and forecast of ecosystem goods and services is limited in two important ways. First, there are uncertainties in accurately forecasting ecological responses to restoration and management actions. Second, there are few production functions available by which biophysical changes may be translated into changes to the goods and services delivered by ecosystems. As such, qualitative techniques and conceptual models may be required to assess changes, but they can be created in such a way as to incorporate the best available science, be transparent in their methods, and be impartial in the processing that calculates EGS.

The interconnectedness of ecosystem goods and services (joint production) makes it difficult to evaluate and study only one without simultaneously considering others. Ecosystem service analysis will have the same challenges as other project analysis approaches for representing complex system dynamics, including feedbacks and interactions. However, the accounting of multiple key services can be a tractable approach to understanding conflicts and synergies among various types of services that result from Corps activities. The most highly valued services and/or the services with the greatest changes may provide sufficient information to inform decisions, particularly if they include services that partially or wholly conflict with each other, which will clarify trade-offs of project choices.

Ecosystem value depends, at least in part, on the extent to which people understand the contribution of that resource and associated goods and services to their well-being. Service benefits may be inferred using benefit indicators or quantified in monetary terms to represent the social value that projects provide NRC (2005) and can serve to demonstrate cost-efficiency or return on investment. Changes in benefits can only be measured by considering how people use and value EGS and whether a change in a good or service is important to their welfare. The monetary values produced from an EGS analysis will not represent the total value of the ecosystem; rather, they will represent the increment of social value due to the project for the bundle of services measured. The ability to quantify or monetize a range of ecosystem services may be especially useful in the evaluation of multipurpose projects that are seeking to meet a range of goals.

Finally, the consideration of ecosystem services allows the project team and decision-maker to be more fully informed about the outcomes (both the increase and loss of particular goods and services) of the project. Even given the uncertainties of various production functions and inability to fully characterize all EGS, the information derived from an EGS analysis may help the project team to use a systems approach that embodies the over-arching strategy of the Civil Works Strategic Plan (USACE 2011) of integrated water resources management. It is not always necessary to monetize ecosystem services to communicate project value to society. However, metrics used to measure outcomes will be most effective if they resonate with a broad set of people. Use of an ecosystem services framework also provides a means to communicate with decision-makers about how a project fits into national priorities. Therefore, the more comprehensively effects can be captured, the more effectively decision-makers can understand their return on investment. Future products of the Ecosystem Services Work Unit will describe the stages of the proposed framework in greater detail, as well as assess existing models/tools to help project teams conduct the analyses for those stages.

References

Allee, W. C., A. E. Emerson, O. Park, T. Park, and K. P. Schmidt. 1949. *Principles of animal ecology*. Philadelphia, PA: W. B. Saunders.

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R. E. Green, M. Jenkins, et al. 2002. Economic reasons for conserving wild nature. *Science* 297 (5583): 950 – 953.

Balvanera, P., A. B. Pfisterer, N. Buchmann, J. S. He, T. Nakashizuka, D. Raffaelli and B. Schmid. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters* 9: 1146–1156.

Banzhaf, S. and J. Boyd 2005. The Architecture and Measurement of an Ecosystem Services Index. Resources for the Future (RFF) Discussion Paper (DP) 05-22.

Barbier, E. B. 2008. Ecosystems as natural assets. *Foundations and Trends in Microeconomics* 4(8):611-681.

Barbier, E. B. 2009. Ecosystem service trade-offs. In *Ecosystem-based management for the oceans*, ed. K. L. McLeod and H. M. Leslie, 129-144. Washington, DC: Island Press.

Bennett, E. M., G.D. Peterson, and L. J. Gordon. 2009. Understanding relationships among multiple ecosystem services. *Ecology Letters* 12: 1-11.

Bockstael, N. E., A. M. Freeman, R. J. Kopp, P. R. Portney, and V. K. Smith. 2000. On Measuring Economic Values for Nature. *Environ. Sci. Technol.* 34 (8): 1384–1389.

Bockstael, N. E., and K. E. McConnell. 2007. *Environmental and resource valuation with revealed preferences*. Dordrecht, The Netherlands: Springer.

Bodkin, D. B. 1992. *Discordant harmonies: A new ecology for the 21st century*. USA: Oxford University Press.

Boelee E (ed) 2011. *Ecosystems for water and food security*. Nairobi: United Nations Environment Programme; Colombo: International Water Management Institute.

Boyd, J. and S. Banzaff. 2007. What are ecosystem services? *Ecological Economics* 63(2-3):616-626.

Boyd, J., and S. Banzaff. 2006. What are ecosystem services? The need for standardized environmental accounting units. Resources for the Future Discussion Paper RFF DP 06-02.

Boyd, J. and L.A. Wainger, 2002. Landscape indicators of ecosystem service benefits. *American Journal of Agricultural Economics* 84(5):1371-1378.

Boyd, J. and L. A. Wainger. 2003. Measuring ecosystem service benefits: *The use of landscape analysis to evaluate environmental trades and compensation*. Resources for the Future, Discussion Paper 02-63. April 2003. http://www.rff.org/disc_papers/PDF_files/0263.pdf

Brown, T. C., J. C. Bergstrom and J. B. Loomis. 2007. Defining, valuing, and providing ecosystem goods and services. *Natural Resources Journal* 47:329-376.

Brussard, P. F., M. J. Reed, and T. C. Richard. 1998. Ecosystem management: What is it really? *Landscape and Urban Planning* 40: 9-20.

Cerco, C., and Noel, M. 2004. Process-based primary production modeling in Chesapeake Bay Marine Ecology. Progress Series 282 pp: 45-58.

Christensen, N. L., A. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Moodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. *Ecological Applications* 6:665-691.

Clements, F. E. 1916. Plant Succession: An analysis of the development of vegetation. Washington, DC: Carnegie Institution.

Clements, F. E and V.E. Shelford. 1939. *Bio-ecology*. New York, NY: Wiley.

Cole, R. A., J. B. Loomis, T. D. Feather, and D. T. Capan. 1996. *Linkages between Environmental Outputs and Human Services*. Institute for Water Resources (IWR) Report 96-R-4.

Costanza R. 1989. What is ecological economics? *Ecological Economics* 1:1-7.

Costanza R., R. d'Arge, R de Groot,S. Farber,M Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, M. van den Belt. 1997a. The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.

Costanza, R., Cumberland, J. H., Daly, H., Goodland, R., Norgaard, R. B. 1997b. *An Introduction to Ecological Economics*, Boca Raton, FL: St. Lucie Press and International Society for Ecological Economics.

Costanza, R. 2008. Ecosystem services: multiple classification systems are needed. *Biological Conservation* 141:350-352.

Council on Environmental Quality (CEQ). 2009. *Proposed national objectives, principles and standards for water and related resources implementation studies*. Office of the President.

Cox, S. and B. Searle. 2009. *The state of ecosystem services*. Boston, MA: The Bridgespan Group, Inc.

Daily, G. (ed.). 1997. *Nature's services: Societal eependence on natural ecosystems*. Washington, DC: Island Press.

Daly, H.E. and J.B. Cobb. 1989. *For the common good: Redirecting the economy toward community, the environment, and a sustainable future*. Boston, MA: Beacon.

de Groot, R. S., M. A. Wilson and R. M. J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41:393-408.

Department of the Interior (DOI). 2011. *The Department of the Interior's economic contributions*. Washington, DC: U.S. Department of the Interior.

Diamond, J. 1997. *Guns, germs and steel: The fates of human societies*. New York, NY: Norton.

Diamond, J. 2005. *Collapse: How societies choose to succeed or fail*. New York, NY: Viking Penguin.

Duarte, C. M. 2000. Marine biodiversity and ecosystem services: an elusive link. *J. Exp. Mar. Biol. Ecol.* 250 (2000) 117–131.

Eckstein O. 1958. *Water resource development: the economics of project evaluation*. Cambridge, MA: Harvard Univ. Press.

Ehlrich, P. and A. Ehlrich. 1981. *Extinction: The causes and consequences of the disappearance of species*. New York, NY: Random House.

Elton, C. 1966. *The patterns of animal ecology*. New York, NY: Wiley.

Environmental Protection Agency (EPA). 2009. *Valuing the protection of ecological systems and services: A report of the EPA science advisory board*. EPA-SAB-09-012. Washington, DC: Office of the Administrator, EPA.

Ewel, K. C. 1997. Water quality improvement by wetlands. In *Natures Services: Societal Dependence on Natural Ecosystems*. Washington DC: Island Press.

Farber, S., R. Costanza, D. L. Childers, J. Erickson, K. Gross, M. Grove, C. S. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren, M. Wilson. 2006. Linking ecology and economics for ecosystem management. *Bioscience* 56(2):121-133.

Fischenich, C. 2008. The Application of Conceptual Models to Ecosystem Restoration. EMRRP-EBA-01. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Fischenich, J. C. 2011. Stream restoration benefits. In *Stream restoration in dynamic fluvial systems: Scientific approaches, analyses, and tools***.** A**.** Simon, S.J. Bennett, and J.M. Castro eds. AGU Geophysical Monograph Series, Volume 194, 2011.

Fischenich, J.C. and T. Barnes. Southwest coastal Louisiana conceptual ecosystem model: A case study. EBA Technical Notes Collection (in preparation). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Fisher, B., R. K. Turner, and P Morling. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68:643-653.

Freeman, A. M. 2003. *The measurement of environmental and resource values: Theory and methods*. Washington, DC: RFF Press.

Gleason, H. A. 1926. The individualistic concept of the plant association. *Bull. Torey Botanical Club* 53:7-26.

Gleason, H. A. 1939. The individualistic concept of the plant association. *American Midland Naturalist* 21: 92-110.

Gleason, R. A., Laubhan, M. K., and Euliss, N. H., Jr., eds., 2008, Ecosystem services derived from wetland conservation practices in the United States Prairie Pothole Region with an emphasis on the U.S. Department of Agriculture Conservation Reserve and Wetlands Reserve Programs: U.S. Geological Professional Paper 1745.

Goulder, L. H. and D. Kennedy. 2011. Interpreting and estimating the value of ecosystem services. In *Kareiva* et al. 2011. *Natural capital: Theory and practice of mapping ecosystem services*. New York: Oxford University Press.

Haeckel, E. 1866. *Generelle Morphologie der Organismen: Allgemeine Grundzuge der organiischen Formen-Wissenschaft, mechanisch begrundet durch die von Charles Darwin reformierte Descendenz-Theorie*. 2 vols, Reimer, Berlin.

Haeckel, E. 1876 [1873]. The History of Creation, or Development of the earth and its Inhabitants by the Action of Natural Causes. [Translation] London, UK: Henry S. King.

Haeckel, E. 1879. *The evolution of man: A popular exposition of the principle points of human ontogeny and phylogeny*. New York, NY: D. Appleton.

Headquarters, USACE. 2000. Planning Guidance Notebook. Engineer Regulation 1105-2-100. http://planning.usace.army.mil/toolbox/library/ERs/entire.pdf

______. 2010. *Corps of Engineers Civil Works direct program development guidance*. USACE Engineering Circular 11-2 199. http://140.194.76.129/publications/eng-circulars/ec11-2-199/entire.pdf

______. 2011. Sustainable solutions to America's water resources needs. Department of the Army Corps of Engineers Civil Works Strategic Plan 2011–2015. http://www.usace.army.mil/Portals/2/docs/civilworks/news/2011-15_cw%20stratplan.pdf

Ingraham, M. W. and S. G. Foster. 2008. The value of ecosystem services provided by the U.S. National Wildlife Refuge System in the contiguous U.S. *Ecological Economics* 67(4): 608-618.

IWR. 1997. Resource significance protocol for environmental project planning. IWR Report #97-R-4. http://www.iwr.usace.army.mil/docs/iwrreports/97r04.pdf

Kareiva, P., H. Tallis, T. H. Ricketts, G. C. Daily, and S. Polasky. 2011. *Natural capital: Theory and practice of mapping ecosystem services*. New York, NY: Oxford University Press.

Keysar, E. and W. Goran. 2008. *Provision of ecosystem services through market-based approaches: Department of Defense applications*. ERDC-CERL SR-08-4. Champaign, IL: U.S. Army Engineer Research and Development Center.

Kiker, G. A., T. S. Bridges, A. Varghese, T. P. Seeger, I. Linkov. 2005. Application of multicriteria decision analysis in environmental decision making. *Integrated Environmental Assessment and Management* 1(2): 95-108.

Killgore, K. J., Hoover, J. J., and Murphy, C. E. 2008. *Library of habitat models to evaluate benefits of aquatic restoration projects on fishes*. EMRRP Technical Notes Collection. ERDC TN-EMRRP-ER-10. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

King, D. M. and M. Mazotta. 2000. Ecosystem valuation: Descriptions and illustration of tools and methods for non-economists. http://www.ecosystemvaluation.org

King, D. M., L. A. Wainger, C. C. Bartoldus, and J. S. Wakeley. 2000. *Expanding wetland assessment procedures: Linking indices of wetland function with services and values*. ERDC/EL TR-00-17. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Kremen, C. 2005. Managing ecosystem services: What do we need to know about their ecology? *Ecology Letters* 8: 468–479.

Kremen, C. and R. S. Ostfeld. 2005. A call to ecologists: Measuring, analyzing and managing ecosystem services. *Frontiers in Ecology and the Environment* 3(10): 540-548

Krutilla, J.V. 1967. Conservation Reconsidered. *American Economic Review* 57:777–86.

Krutilla J and O. Eckstein. 1958. *Multipurpose river development*. Baltimore, MD: Johns Hopkins Univ. Press.

Lackey, R.T. 1998. Seven pillars of ecosystem management. *Landscape and Urban Planning* 40: 21-30.

Leopold, A. 1949. *A Sand County Almanac*. New York, NY: Oxford University Press.

Lindeman, R.L. 1942. The trophic-dynamic aspect of ecology. *Ecology* 23:399-418.

Linkov, I., A. Varghese, S. Jamil G. T.P. Seager, G. Kiker and T. Bridges. 2004. Multi-Criteria decision analysis: A framework or structuring remedial decisions at contaminated sites. In *Comparative risk assessment and environmental decision making,* ed. I. Linkov, and A.B. Ramadan, Norwell, MA: Kluwer Academic Publishers.

May, R. M. 1976. Simple mathematical models with very complicated dynamics. *Nature* 261:459-467.

McKean R. 1958. *Efficiency in government through systems analysis*. NewYork, NY: Wiley.

Millennium Ecosystem Assessment (MA). 2005. *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.

Merchant, C. 2007. *American environmental history: An introduction*. New York, NY: Columbia University Press.

Mooney, H. A. and P. R. Ehrlich. 1997. *Ecosystem services: A fragmentary history*. (in Daily 1997)

Murray, B., A. Jenkins, R. Kramer, and S. P. Faulkner. 2009. Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. Nicholas Institute, Duke University NI 9:02.

Murray, E. O., J. A. Cushing, L. A. Wainger, and D.J. Tazik. 2013. *Incorporating ecosystem goods and services in environmental planning—definitions, classification, and operational approaches*. ERDC/EMRRP TN-ER-18. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Naeem, S., J. Emmett Duffy, and E. Zavaleta. 2012. The functions of biological diversity in an age of extinction. *Science* 336 (6087) (June 15): 1401–1406.

National Research Council (NRC). 2005. *Valuing ecosystem services: Toward better environmental decision-making*. Washington, DC: The National Academic Press.

National Academy of Sciences (NAS) Committee on the Effects of the Deepwater Horizon Mississippi Canyon-252 Oil Spill On Ecosystem Services in the Gulf Of Mexico. 2012. *Approaches for Ecosystem Services Valuation for the Gulf of Mexico After the Deepwater Horizon Oil Spill: Interim Report*. Washington, DC: National Academies Press. http://www.nap.edu/catalog.php?record_id=13141.

Nelson, E., S. Polasky, D. J. Lewis, A. J. Plantinga, E. Lonsdorf, D. White, D. Bael, and J. J. Lawler. 2008. Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. *Proceedings of the National Academy of Sciences* 105:9471-9476.

Odum, E. P. 1953. *Fundamentals of ecology*. Philadelphia, PA: W. B. Saunders.

Palmer, M. A. and S. Filoso. 2009. Restoration of ecosystem services for environmental markets. *Science* 325:575-575.

Pearce, D. 2002. An intellectual history of environmental economics. *Annual Review of Energy & the Environment* 27:57.

Peterson, C. H. and J. Lubchenco. 1997. Marine ecosystem services, pp. 177-194 in Daily 1997.

Pickett, S. T. A. and White, P.S. 1985. *The ecology of natural distrubance and patch dynamics*. Orlando, FL: Academic Press.

Postel, S. L. and S. Carpenter. 1997. Freshwater ecosystem services, pp. 195-214 in Daily 1997.

President's Council of Advisors on Science and Technology (PCAST). 2011. *Sustaining environmental capital: Protecting society and the economy*. Washington, DC: Report to the President.

Ready, R., and S. Navrud. 2005. Benefit transfer - The quick, the dirty, and the ugly? *Choices: The Magazine of Food, Farm & Resource Issues* 20:195–199.

Ribaudo, M., L. Hansen, D. Hellerstein, and C. Greene. 2008. The Use of Markets to Increase Private Investment *in Environmental Stewardship*. USDA Economic Research Report No. 64.

Richards, E. S. 1907. *Sanitation in daily life*. Whitcomb and Borrows, Boston. Citation in Merchant 2007.

Ruhl, J.B., J. Salzman, I.Goodman. 2009. Implementing the new ecosystem services mandate of the Section 404 compensatory mitigation program—a catalyst for advancing science and policy. *Stetson Law Review* 38(251):251.

Scarlett, L. and J. Boyd. 2011. *Ecosystem Services: Quantification, Policy Applications, and Current Federal Capabilities*. RFF DP 11-12. Washington, DC: Resources for the Future.

Study of Critical Environmental Problems (SCEP). 1970. *Man's impact on the global environment*. Cambridge, MA: MIT Press.

Shabman, L. 1994. *Environmental activities in Corps of Engineers water resources programs: Charting a new direction*. IWR Policy Study 93-PS-1. Washington, DC: U.S. Army Corps of Engineers,Water Resources Support Center.

Simon, J. L. 1981. *The ultimate resource*. Princeton, NJ: Princeton University Press.

Simon, J. L. 1996. *The ultimate resource 2*. Princeton, NJ: Princeton University Press.

Smith, V. K. 1987. Nonuse values in benefit cost analysis. *Southern Economic Journal* 54 (1): 19–26.

Smith, R. D., Ammann, A., Bartoldus, C., and Brinson, M. M. 1995. An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. Technical Report WRP-DE-9. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Stakhiv, E., R. Cole, P. Scodari, and L. Martin. 2003. *Improving Environmental Benefits Analysis in Ecosystem Restoration Planning*. IWR Report 03-PS-3. Alexandria, VA: U.S. Army Corps of Engineers.

Stavins, R.N. 2005. Lessons learned from SO2 Allowance Trading. *Choices: The Magazine of Food, Farm & Resource Issues* 20 (1): 53-57.

Swannack, T. M., J. C. Fischenich and D. J. Tazik. 2012. *Ecological modeling guide for ecosystem restoration and management*. ERDC/EL TR-12-7. Vicksburg, MS: U.S. Army Research and Development Center.

Szaro, R., Sexton, W.T., and Malone C.R. 1998. The emergence of ecosystem management as a tool for meeting people's needs and sustaining ecosystems. *Landscape and Urban Planning* 40: 1-7.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. *Ecology* 16(3): 284-307.

Taylor, T. 2010. *The artificial ape: How technology changed the course of human evolution*. New York, NY: Palgrave MacMillan.

Tazik, D. 2012. Evaluating Protocols to Quantify the Significance of Aquatic Ecosystems at Regional and National Scales: Proceedings of a Workshop, Cambridge, MA, 20-22 July 2011. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Thompson, Jr., B. H. 2008. Ecosystem services and natural capital: Preconceiving environmental management. *NYU Environmental Law Journal* 17:460-489

Tietenberg, T., and L. Lewis. 2008. *Environmental and Natural Resource Economics*. 8th ed. Addison Wesley.

Tilman, D., 1997. Biodiversity and ecosystem functioning. In: *Nature's services: Societal dependence on natural ecosystems*, ed. G.C. Daily, 93-112. Washington, DC: Island Press.

Toman, M., 1998. Why not to calculate the value of the world's ecosystem services and natural capital. *Ecological Economics* 25(1): 57-60.

Turner, R. K., S. Georgiou, and B. Fischer. 2008. *Valuing ecosystem services: The case of multi-functional wetlands*. London, UK: Earthscan.

UNDP, UNEP, World Bank, WRI. 2000. World Resources 2000–2001: People and ecosystems: The fraying web of life. Washington DC: World Resources Institute, United Nations Development Programme, United Nations Environment Programme, World Bank.

UNEP. 2006. Marine and coastal ecosystems and human wellbeing: A synthesis report based on the findings of the Millennium Ecosystem Assessment. Nairobi: United Nations Environment Program.

USEPA, SAB CVPESS. 2009. Valuing the Protection of Ecological Systems and Services: A Report of the EPA Science Advisory Board. EPA-SAB-09-012.

U.S. Fish and Wildlife Service (USFWS). 1980. Ecological services manual: ESM 101, Habitat as a basis for environmental assessment; ESM 102, Habitat evaluation procedures (HEP); ESM 103, Standards for the development of habitat suitability index models; ESM 104, Human use and economic evaluation (HUEE). Washington, DC: Division of Ecological Services, U.S. Fish and Wildlife Service, Dept. of the Interior.

US Office of Management and Budget. 2003. Circular A-4. Subject: Regulatory Analysis. Retrieved from http://www.whitehouse.gov/omb/memoranda_m03-21.

Wainger, L. A. and J. Boyd. 2009. Valuing ecosystem services. In *Ecosystem-based management for the oceans, ed*. K. L. McLeod and H. M. Leslie, 92-111. Washington, DC: Island Press.

Wainger, L., and M. Mazzotta. 2011. Realizing the potential of ecosystem services: A framework for relating ecological changes to economic benefits. *Environmental Management* 48 (4): 710–733.

Wainger, L. A., D. M. King, J. Salzman and J. Boyd. 2001. Wetland value indicators for scoring mitigation trades. Stanford Environmental Law Journal 20(2):413-478.

Wallace, K. J. 2007. Classification of ecosystem services: problems and solutions. *Biological Conservation* 139:235-246.

Watt, K. E. F. 1962. Use of mathematics in ecology. *Annual Review of Entomology* 7: 243-260.

Watt, K. E. F. 1968. Ecology and resource management: A quantitative approach. New York, NY: MacGraw-Hill.

Westman, W.E. 1977. How much are nature's services worth? *Science* 197:960-964.

Worster, D. 1977. *Natures Economy: The Roots of Ecology*. San Francisco, CA: Sierra Club Books.

Yoskowitz, D., C. Santos, B. Allee, C. Carollo, J. Henderson, S. Jordan and J. Ritchie. 2010. In *Proceedings of the Gulf of Mexico Ecosystem Services Workshop, 16-18 June 2010, Bay St. Louis, Mississippi*. Corpus Christi, TX: Harte Research Center Institute for Gulf of Mexico Studies, Texas A&M University. http://www.northerngulfinstitute.org/publications/docs/2010/10/8736eservicesproceedings1.pdf

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)*** August 2013	**2. REPORT TYPE** Final report	**3. DATES COVERED** ***(From - To)***
4. TITLE AND SUBTITLE Incorporating Ecosystem Goods and Services in Environmental Planning. A Literature Review of Definitions, Classification and Operational Approaches		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) David J. Tazik, Janet Cushing, Elizabeth Murray, and Lisa Wainger		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center Environmental Laboratory 3909 Halls Ferry Road, Vicksburg, MS 39180-6199		**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/EL TR-13-17
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Headquarters, U.S. Army Corps of Engineers Washington, DC 20314-1000		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This paper reviews historical development of Ecosystem Goods and Services (EGS) concepts and the range of definitions, conceptual models, classification schemes and operational approaches that have been put forth in the literature. The intent is to lay the foundation for development of a framework that the U.S. Army Corps of Engineers (the Corps) can use to incorporate consideration of ecosystem goods and services in water resource project planning and management, and identify any research needs to accommodate that goal. While the notion of ecosystem goods and services benefiting humans is not new, it has become increasingly formalized for consideration in environmental policy analysis and is closely tied to concepts in ecosystem-based management of natural resources. Despite this, no single conceptual model or classification system has been accepted, because the particular purpose, circumstance and decision context will dictate the most appropriate definitions and models to apply. This review and the corresponding technical note (Murray et al. 2013) are the first products in a series of reports for the Ecosystem Goods and Services Project. Subsequent related products researching policies, data and tools, interagency coordination and an assessment framework are in process, and will be released over the next several years.

15. SUBJECT TERMS Ecosystem Goods and Services   Ecosystem Restoration Planning

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** ***(include area code)***
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		75	