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Incorporating Ecosystem Goods and Services in Environmental Planning – Definitions, Classification and Operational Approaches

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Overview: There has been interest for several decades in assessing the benefits that humans derive from naturally functioning ecosystems. 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. It is closely tied to concepts in ecosystem-based management of natural resources. The authors' intent in this technical note is to lay the foundation for 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; the authors also seek to identify any research needs to accommodate that goal. This technical note and the corresponding literature review and report are the first products in a series of publications for the Incorporating Ecosystem Goods and Services (EGS) in Environmental Planning Work Unit. Subsequent related products researching policies, data and tools, interagency coordination and an assessment framework are in progress, and will be released over the next few years.

Objective

The objective of this technical note is to explore the challenges and opportunities for incorporating EGS considerations in project planning. These considerations are particularly important for ecological restoration projects; additionally, there is potential for application to all Corps Civil Works business lines. This technical note offers a brief review of the state of the science of EGS and highlights the types of analytical tools, techniques, and considerations that would be needed within a Corps planning community of practice. This publication complements a detailed technical report that provides a more thorough discussion of the concepts, historical development, and alternative perspectives on evaluation methods. The two publications are the first in a series dedicated to investigating the potential for incorporating ecosystem goods and services analysis into Corps planning. Several of the issues raised in this technical note will be explored further in future products addressing this research. Those future research products will 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 EGS assessment into Corps planning. This technical note is only the first step in (raising and then) addressing the many issues involved in applying ecosystem goods and services to decision-making.

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Scope

This and future publications generated from the Work Unit will describe key principles which researchers leading this interdisciplinary project will use to integrate sound science, policy, and practice for well-grounded EGS assessment. These principles and the integration process are crucial for formulating strategies to accurately quantify and report ecosystem goods and services affected by Corps environmental projects. Although the authors ultimately plan to address the potential role of ecosystem goods and services in all Corps missions, initial emphasis will be 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.

Introduction

Interest in considering ecosystem goods and services in environmental management has increased and evolved over the past two decades. There has been an increasing awareness that humans derive many types of benefits from ecosystems. The literature indicates that understanding how benefits are derived from natural systems could improve our ability to make wise choices. Significant reviews have been completed during this period to illuminate linkages between ecosystems and derived benefits and suggest values of identified benefits (Daily 1997, Costanza et al. 1997, Turner et al. 2008). However, development of assessment 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).

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 developed a classification scheme and used it to suggest 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 of ecosystem service concepts and methods that illustrated analytical techniques and described a foundation for economic benefits assessment. Recently, Kareiva et al. (2011) published a compendium of papers illustrating theory and practice in modeling changes in ecosystem services that can result from resource management decisions. The compendium reveals that the state of the science has progressed but still lacks universally applicable models.

Ecosystem services are not foreign to the Corps. Prior efforts have evaluated 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 environmental or water resources planning studies have realized only limited success.

Within the Corps, ecosystem services have become such a sufficiently prominent topic of discussion that some ecosystem restoration project teams are investigating the use of ecosystem services for plan evaluation. Compensatory mitigation for impacts to aquatic resources subject to Corps permitting actions pursuant to section 404 of the Clean Water Act now includes discussion and consideration of services that might be altered as a result of a regulated action (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.

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 note and its corresponding report (Tazik et al. 2013) are the first in a series of reports that will address this topic. The implications for the Corps efforts conclude each section below.

Definitions of Ecosystem Goods and Services

Ecosystem goods and services are not consistently defined in the literature or in common use (Boyd and Banzaf 2007, NRC 2005, Tazik et al. 2013), at least in part because concepts regarding ecosystems services have emerged from the ecological and economics communities somewhat independently. Researchers have noted the need for a standard definition (Boyd and Banzaf 2007, NRC 2005).

The choice of definition used for the term "ecosystem services" has implications for how the Corps would use ecosystem services assessment for civil works planning. Thus, 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. This definition is also suited to the Corps' ecosystem restoration mission, which is to restore significant ecosystem structure and dynamic processes that have been degraded, a demand typically expressed in law. The intent is to emphasize the need for naturally functioning systems as a basis for ensuring a sustainable flow of goods and services. However, the authors acknowledge that a certain level of management may be necessary in some environments.

Within the definition of ecosystem goods and services, there are two major groupings that have different methods of measurement: *use* (e.g., commercial fishing, bird-watching) and *non-use* or passive use (e.g., existence value) goods and services. Use services are goods and services that are directly or indirectly used; thus people can often reveal their values for these goods through their behavior, such as when they pay more for a house with view of a natural vista. For goods and services that are used, monetization approaches can be effective at conveying value, particularly when people have good information about the services that they are using (e.g., outdoor recreational services). However, many services are either poorly understood (e.g., flood risk mitigation from forests) or only appreciated and not directly used. Therefore, their behavior does not provide evidence of value and valuation must rely on having people state their preferences for these goods and services. Since people can have difficulty expressing how much they value some ecosystem products or characteristics, such non-use services pose challenges to monetization. Consequently, to broadly encompass the social welfare effects of ecosystem service changes, non-monetary metrics (e.g., natural units) 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 effect cannot be quantified (Wainger and Boyd 2009).

Concepts underlying the definitions of ecosystem goods and services are more fully explained in the technical report (Tazik et al. 2013), but some important considerations are discussed below.

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 well-being. Some ecosystem outputs directly affect 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 versus Final Goods and Services: Imprecision in characterizing ecosystem services can be overlooked where 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 intermediate versus final goods and services as those that 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 final goods and services (e.g., safe drinking water, recreational fishing opportunities, and preservation of valued ecosystems) that are the outputs directly used and valued by people. In order to reduce the risk of double-counting of benefits, final goods and services are preferred for representing benefits, as explained further in Boyd and Banzhaf (2007).

Structures, Functions, and Processes vs. Goods and Services: Ecological structures, functions or processes are characteristics of the status and dynamics of an ecosystem. Ecosystem goods and services, on the other hand, require use (direct or indirect) or demand (revealed or stated) by people. For instance, nutrient cycling is a process or function that contributes to the final ecosystem service, provision of clean drinking water. While it is sometimes necessary to use structure and function as proxies when quantifying ecosystem goods and services, the mixing and matching of these different types of metrics can easily lead to double counting of benefits and obscure the demonstration and communication of beneficial outcomes. Corps planning will need to distinguish these metrics to avoid double counting of benefits.

Benefits and Value: Just as a change in an ecosystem state does not necessarily change the state of an ecosystem service, a change in an ecosystem service does not necessarily lead to a human benefit with value. A change in the supply of goods and services may not affect human well-being (i.e., have economic value), if people are unaffected by or willing and able to adapt to a change in supply of a service (e.g., by substituting a different good or service). Thus, value is not a quantification of the service, but rather a quantification of the *worth* of the benefit derived from a change in an ecosystem. For example, providing more public hunting areas increases the service area, but if hunters already had preferred areas in which to hunt, and no increase in hunting occurs, it would not be a benefit to hunters. The Corps will need to consider issues of demand in order to accurately measure ecosystem goods and services across project alternatives.

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 distant homes are afforded flood protection by wetlands. 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 the act of 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).

Classification of Ecosystem Services

A number of classifications of ecosystem goods and services have been proffered (Daily 1997 introduction, 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 regarding a comprehensive list (NRC 2005), and no single classification scheme will be useful in all situations (Costanza 2008, Fisher et al. 2009).

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 1. It is based somewhat on the classification presented by de Groot et al. (2002) and is representative of classifications commonly reported in the literature (e.g., Wallace 2007). It includes supporting services, defined as inputs to other types of services (Figure 1), and while the classification 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 tradeoffs (Boyd and Banzhaf 2007, Wallace 2007, Fisher et al. 2009).

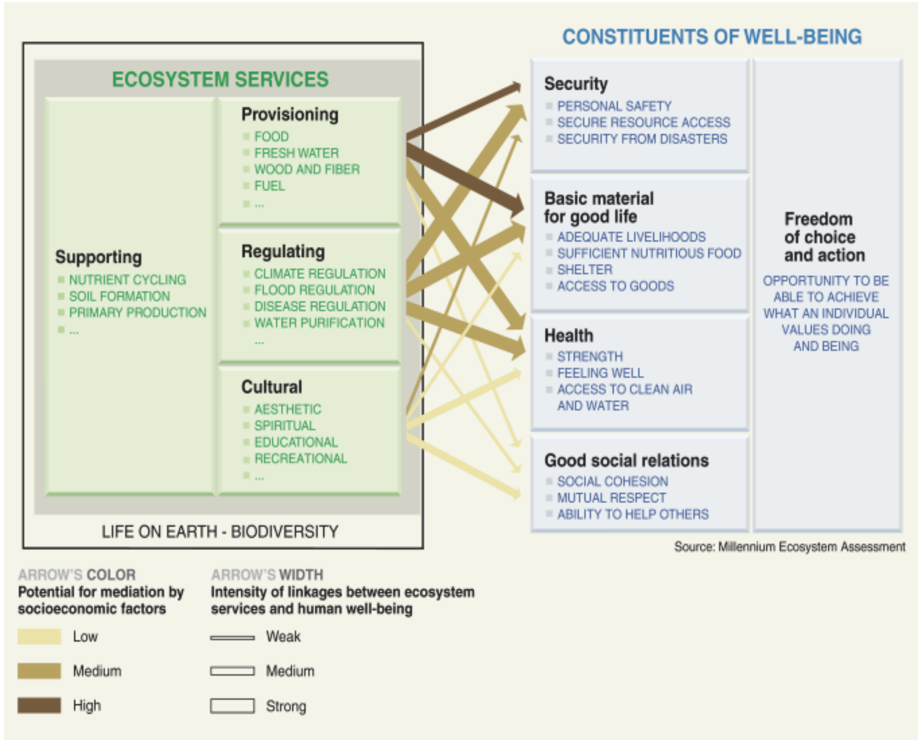

Figure 1. Illustration of the linkages between ecosystem services and human welfare (from MA 2005).

Table 1. 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. Table 2 shows that different project characteristics and decision/policy context may serve 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. Many of the specific classifications presented in Table 2 are described in more detail in the technical report developed with this note (Tazik et al. 2013). 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 2. Summary of the purposes for which an ecosystem services classification might be developed and applied (based largely on Fischer et al. 2009).

Decision Context	Description	Characteristics	Classification Approach	Example
Understanding & Education	Promotes understanding and educate the public about the services and benefits that result from healthy, functioning ecosystems	Complexity Public-Private Good Aspects	Divides services into bundles and illustrates the relationships to one another 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 down stream	Spatio-temporal dynamics Public-Private Good Aspects Benefit Dependence	Describes the relationship between where service production occurs and where the benefits are realized.	Costanza 2008; Boyd and Wainger 2002
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 meet 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 links to services, then to processes.	Wallace 2007

Implications of Ecosystem Services Classification within the Corps

The purpose of a classification system by the Corps would be to help organize ecosystem services so that planners can attribute and assess the benefits attained or impacted by implementing project alternatives. Previous attempts, as reviewed in the accompanying technical report (Tazik et al. 2013), provide a good foundation upon which to build. A 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 effects 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 (MA 2005), described in the Introduction of this paper, is commonly applied but has limitations for analyzing benefits or impacts of Corps projects. A primary concern with operationalizing the MA system in Corps planning 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. For instance, supporting services are often accounted for in parallel to other types of services, without considering the overlap of benefits, since supporting services are inputs to other services such as provisioning and regulating.

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*** services (see Daily 1997 and NRC 2005 for examples). Competing services may be completely mutually exclusive, (e.g., between competing needs of different protected species) or partially competing (e.g., carbon sequestration and biodiversity cannot be simultaneously maximized in some systems, Nelson et al. 2008). *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, demand, and the values enjoyed by humans. For example, 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 have planning horizons typically 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 Corps:

a. Service-providing habitats
b. P&G accounts: National Economic Development, Environmental Quality, Regional Economic Development, and Other Social Effects
c. Spatial/temporal scale (both at which the service is produced as well as valued)
d. 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 ecosystem 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 represents 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. This undertaking would also involve assessing 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 (NED, EQ, RED, 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 EGS project.

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, and are described in the technical report (Tazik et al. 2013) associated with this technical note (e.g., NRC 2005, MA 2005, Bennett et al. 2009, Stakhiv et al. 2003). Rather than detailing those various approaches here, the authors offer a general operational framework that draws on the literature, but is honed to the Corps' ecosystem restoration efforts.

The proposed model includes stages of analysis and their functions (Figure 2). The four numbered boxes in the figure represent the stages of analysis, and are described below. Between each stage is a *function* which uses output from one compartment to create the input for the next. The numbered stages and lettered function steps are described below.

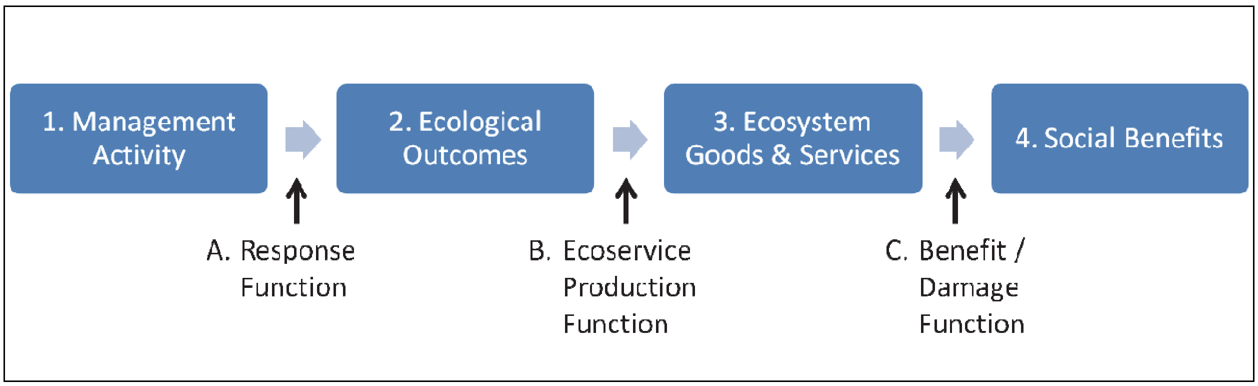

Figure 2. Ecosystem services conceptual model -- connections between human management activities, ecosystem structure and function, goods and services, and social benefits or costs.

1. **Management Activity**. This stage identifies human actions that act to enhance or degrade ecosystem structure or function.

   A. **Response Function**. A conceptual or quantitative model that estimates the effect of the management activity in terms of an ecological outcome (degradation or improvement). These models are often called stressor-response or recovery-response functions. Example: If evaluating the effect of bank stabilization on delivery of fine sediments to gravel beds that are used for salmonid spawning, the *response function* establishes whether the necessary natural conditions exist to produce an ecosystem service (e.g., spawning success) and whether the service would be improved by the activity.

2. **Ecological Outcome**. This stage of the analysis looks for meaningful change in ecological structure or process. This is typically assessed using biophysical metrics,

measured at environmentally relevant temporal and spatial scales, that directly capture changes in outcomes of relevance to people (e.g., salmonid spawning success, probability of harmful algal blooms, frequency of property flooding, population of significant species, hydrogeomorphic functional assessment models).

B. **Ecoservice Production Function**. A qualitative or quantitative model that establishes whether potential services are likely to be produced through interactions of people with the ecosystem. For example, recreational fishing services might be measuring by establishing that 1) anglers have access via onsite piers or nearby boat ramps; 2) the service is of local interest because of the number of fishing licenses sold in the area; and 3) demand is likely because existing sites are congested and this site is sufficiently close to population centers. For non-use services, this function will demonstrate existence of beneficiaries and whether the restoration contributes to the flow of the service as it is valued by people. For example, it may assess contributions to potential long-term viability of a bird species that is known to be of interest to birders or considered a species of concern by a government agency or NGO.

3. **Ecosystem Goods and Services.** This stage of the analysis evaluates socially valued aspects or outputs of ecosystems that depend on self-regulating or managed ecosystem structures and processes.

C. **Benefits/Damage Function**. A model that estimates how a change in ecosystem goods and services may affect human welfare. 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.

The valuation of that infrastructure would be the step addressed by the benefits function, which would consider demand for a service by location and the 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.

4. **Social Benefits.** The final result is a measure of human welfare that represents the social benefit of the change in ecosystem service, either in terms of monetary or non-monetary metrics.

For each of these stages, but particularly for the first stage (Management Activity), the project team should consider the study area in the context of the watershed in which it resides, and explicitly state the planning assumptions and constraints (e.g., planning horizon, future land use changes, statutory/legislative requirements, partnering agency actions). This general framework separates and maintains the integrity of the ecological and economic elements while illustrating the operational linkages management effects on ecology and resulting ecosystem goods and services.

While Figure 2 outlines the steps and framework of an ecosystem service analysis, it doesn't capture the complexity that is generally present at each step. Figure 3 illustrates the first three steps in a more detailed way. Restoration and mitigation impacts on ecosystem services are mediated indirectly through the direct effects of these activities on ecosystem functions and processes, which are interrelated and contain feedbacks. Figure 3 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). Missing from Figure 3 is the last step in the assessment steps: taking ecosystem goods and services as input and assessing social benefits via valuation or other functions.

While the Framework report, which is currently in development, will elucidate that step in detail, one of the most frequently confused concepts of an ecosystem services framework should be addressed here: differentiating between ecological indicators and social values. Ecological indicators represent measurable aspects of ecosystem structure or processes: for example, habitat units, spawning success, sediment retention. *Value* is the way humans represent the importance or desirability of something. It is indeed possible to monetize many ecosystem services, including both use and non-use values using multiple techniques. 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 stress the importance of linking cause and effect as part of the benefits assessment and acknowledge 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

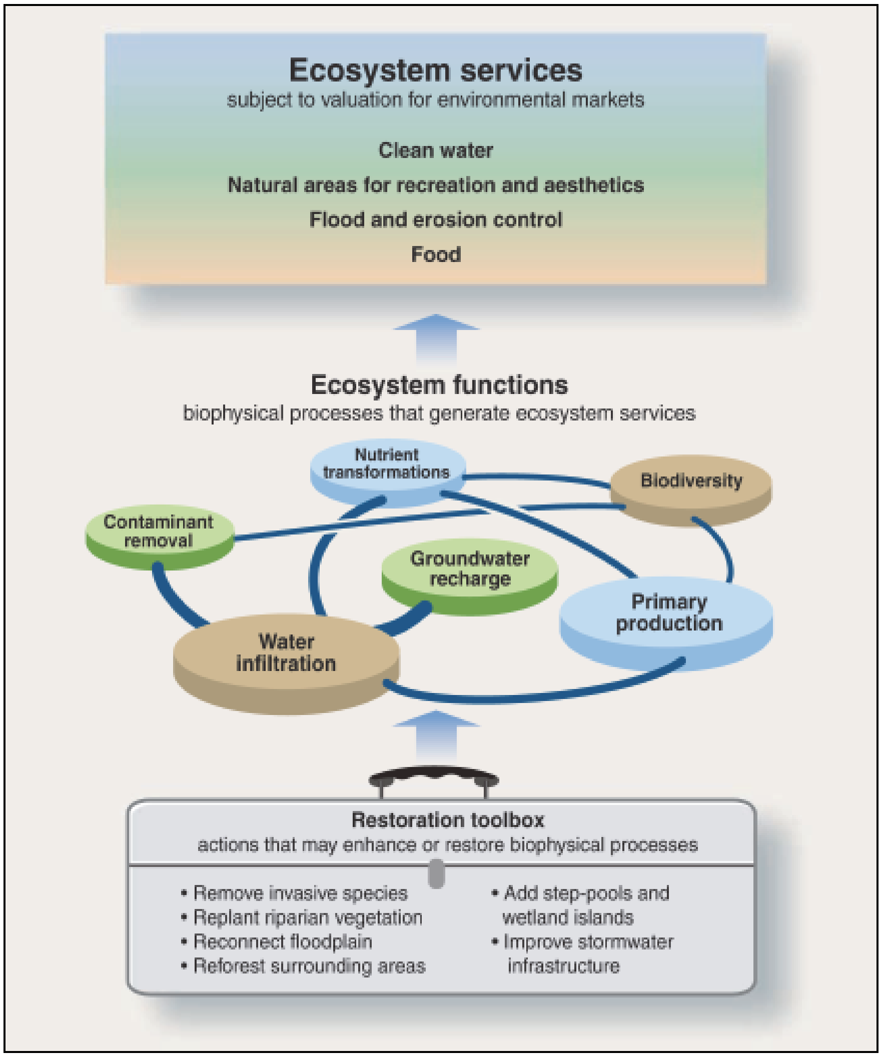

Figure 3. Illustrates the role of ecosystem restoration in enhance ecosystems services (from Palmer and Filoso 2009, used with permission).

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. 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.

Operationalizing Ecosystem Goods and Service Consideration in Environmental Decision-making

Figure 2 offers a straightforward analytic framework for estimating the economic effects of ecosystem restoration and management actions. It is very similar to the framework used by Wainger and Mazzotta (2011) to describe a multiple step process to evaluate changes in social welfare that result 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. Here, the authors highlight some of the most important considerations for the Corps.

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 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 Response Function (Step A, Figure 2).

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. 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 and Benefit/Damage Function (Steps B & C, Figure 2) will require specific ecological and economic information for the analysis. The planning team will need to determine if 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 conceptual models to more complex data-driven models (Table 3). Economically based landscape indicators can also range widely from simple statistical models to highly sophisticated simulation models. The particular tools or techniques used depend 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 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 in how explicitly services can be measured.

The value associated with an ecosystem is not based on the ecological state and outputs alone - i.e., 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 et al. (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

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

Table 3. A Spectrum of Modeling Complexity (derived from Wainger and Mazzota 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)
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)

capacity of the wetland, combined with an off-site assessment of various landscape considerations. The later point is critical - the characteristics of the surrounding landscape, including proximity to and use by people are considered as 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]

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: 1) landscape advantage; 2) scarcity; 3) complementary inputs; 4) risks and changed future conditions; and 5) income and equity considerations. Using this method, these authors were able to demonstrate how readily available, GIS-based landscape information could be used 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 has implications for how services are being represented and whether values are double-counted. Finally, there can be large uncertainties with respect to the relationship between indicators and actual services – these relationships may be linear, convex, concave or even more complex. Despite these concerns, thoughtful approaches to index creation can mitigate these challenges and a service indicator approach 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 project.

[1] For example, wetland functions and services that are moved to a different location will have benefits and values that vary in accordance 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).

A simplified Hydrogeomorphic (HGM) approach was also used by Turner et al. (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 wellbeing.

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?" Cole et al. (1996) emphasized the need for a "more robust" accounting of benefits as a basis for justifying federal expenditures on environmental mitigation and restoration than that afforded by Habitat Evaluation (HEP)-based methods (USFWS 1980). They also cautioned that inappropriate decisions might result if one did not fully appreciate the complex relationships between ecosystem processes, integrity and resulting human services.

They 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 services. 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.

Operationalizing Ecosystem Services in a Corps Planning context

As noted above, having a list of general guidelines, such as those offered by the NRC (2005), 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 in a manner compatible with the existing Corps planning process could provide utility to Corps planners in fuller accounting of benefits and costs of their alternatives.

A framework that would provide such utility should comprise the following aspects:

- Incorporation of risk and uncertainty. As with other components of a project, this framework should reflect the consideration and documentation of the uncertainties associated with ecosystem services production at each step identified in Figure 2, as well as the risks; use of a risk register, either as one component of the overall project risk register, or as a separate register for consideration of ecosystem services only, is recommended.
- 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.
- Ability to differentiate among alternatives. In order to be useful, a framework and associated tools must be able to detect differences among alternatives in their ability to deliver the services of interest.

Developing such a framework is the subject of a complementary report within this ecosystem service project.

Concluding Comments - 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. 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.

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.

This technical note is concluded with several principles that the authors believe are most relevant to Corps projects, based on a thorough review of the field of ecosystem services and an 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 aimed only 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 (Figure 2), 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, constraints, 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 implies that goods and services would be characterized, inventoried and forecasted in 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.

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 tradeoffs 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. But 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, but rather 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 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.

Other Information

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