LINKAGES BETWEEN ENVIRONMENTAL OUTPUTS AND HUMAN SERVICES

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PREFACE

This study was conducted as part of the Evaluation of Environmental Investments Research Program (EEIRP). The EEIRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). It is jointly assigned to the U.S. Army Engineer Water Resources Support Center (WRSC), Institute for Water Resources (IWR), and the U.S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL). Mr. William J. Hansen of IWR is the Program Manager and Mr. H. Roger Hamilton is the WES Manager. Program Monitors during this study were Mr. John W. Bellinger and Mr. K. Brad Fowler, HQUSACE. The Field Review Group members that provided overall Program direction and their District of Division affiliations were: Mr. David Carney, New Orleans; Mr. Larry M. Kilgo, Lower Mississippi Valley; Mr. Richard Gorton, Omaha; Mr. Bruce D. Carlson, St. Paul; Mr. Glendon L. Coffee, Mobile; Ms. Susan E. Durden, Savannah; Mr. Scott Miner, San Francisco; Mr. Robert F. Scott, Fort Worth; Mr. Clifford J. Kidd, Baltimore; Mr. Edwin J. Woodruff, North Pacific; and Dr. Michael Passmore, Walla Walla. The work was conducted under the Monetary and Other Valuation Techniques Work Unit of EEIRP. Mr. Gerald D. Stedge of IWR is the Principal Investigator.

The work was performed by Planning and Management Consultants, Ltd. (PMCL), under Task Order 0013, Contract No. DACW72-94-D-0003. Dr. Richard A. Cole of New Mexico State University and Dr. John B. Loomis of Colorado State University were the authors in collaboration with Dr. Timothy D. Feather and Mr. Donald T. Capan of PMCL.

This report contains a series of tables which link ecosystem outputs to human services and goods. As such, they are quite detailed and may be difficult for the reader to digest. In an effort to make the tables more accessible, and thus more useful within the planning process, IWR is currently investigating the feasibility of producing on-line hypertext versions of the tables.

The report was prepared under the general supervision at IWR of Mr. Michael R. Krouse, Chief, Technical Analysis and Research Division; and Mr. Kyle E. Schilling, Director, IWR; and at EL of Mr. H. Roger Hamilton, Chief, RAB; Dr. Robert M. Engler, Chief, NRD; and Dr. John W. Keeley, Director, EL.

At the time of publication of this report, Mr. Kyle E. Schilling was Acting Director of WRSC and Dr. Robert W. Whalin was Director of WES. Commander of WES was COL Bruce K. Howard, EN.

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I. INTRODUCTION

BACKGROUND

A critical part of planning for environmental restoration projects is assessing the impacts of alternative plans. There are many dimensions to this assessment that are critical to formulating the most appropriate (socially, environmentally, etc.) alternative plan. Among these aspects are two foundational elements that require evaluation: the ecologic impacts and the resultant socioeconomic effects. Ecology and economics are academic disciplines in their own right and are supported by vast literatures. Each has displayed varying degrees of success in pragmatic application, such as what is required for U.S. Army Corps of Engineers (Corps or USACE) environmental plan formulation. Building a bridge between these two disciplines, ecology and economics, in support of environmental plan formulation is the aim of this study.

The Corps civil works mission is to support national economic development. This necessarily brings economics into the analytical picture for project justification and plan formulation. Projects that produce benefits that outweigh costs of construction and maintenance have traditionally been viewed favorably in the Corps and Congress. Although there has been considerable debate in academic circles about the potential measures of benefit-cost analysis, the Corps and other agencies have generally found it both useful and appropriate for making investment and management decisions.

Complications arise when project outputs are not readily measurable in monetary terms, which is a very common situation for environmental restoration projects. The benefits associated with environmental improvement often cannot readily be measured)or more specifically, there are no standard methods used by Corps planners to place economic values on improvements to the environment. Although traditional Corps projects, such as flood control and navigation, are readily supported through Corps-developed analytical techniques for benefits calculations, suitable technical support is lacking in the case of environmental projects, which is one of the chief motivations of the Corps Evaluation of Environmental Investments Research Program (EEIRP).

The EEIRP is an aggressive research effort set out by the Corps Institute for Water Resources and Waterways Experiment Station to develop analytical methods and models to determine objectives, measure outputs, and analyze cost-effectiveness in support of an evaluation framework for environmental investment decisions. The formal direction of the EEIRP is to develop analytical tools to assist planners, managers, and regulators in addressing the following two questions, referred to as the "site" and "portfolio" questions, respectively:

(1) How can the Corps determine whether the recommended action from a range of alternatives is the most desirable in terms of the environmental objective being addressed?

(2) How should the Corps allocate limited resources among many “most desirable” environmental investment decisions?

These questions are underlain by many issues of ecology and economics. These two disciplines provide essential theoretical platforms for addressing the site and portfolio questions, and elements of ecology and economics can be seen in almost all the EEIRP work units shown in Table I-1.

TABLE I-1

EEIRP WORK UNITS

- Determining and Describing Environmental Significance
- Determining Objectives and Measuring Outputs
- Objective Evaluation of Cultural Resources
- Engineering Environmental Investments
- Cost-Effectiveness Analysis Techniques
- Monetary and Other Valuation Techniques
- Incorporating Risk and Uncertainty into Environmental Evaluation
- Environmental Databases and Information Management
- Evaluation Framework

This research was conducted under the EEIRP work unit Monetary and Other Valuation Techniques. The objectives of this work unit are:

- To identify relevant socioeconomic use and nonuse values associated with environmental projects

- To improve the linkages between environmental output measures and necessary inputs for socioeconomic evaluation

- To develop, test, and provide guidance with regard to monetary and nonmonetary evaluation techniques

- To develop a greater understanding of the decision processes of USACE project stakeholders.

PROJECT SCOPE AND INTENT

The present study focuses on the linkage improvement objective shown above for the Monetary and Other Valuation Techniques work unit. Publications resulting from research conducted within this work unit, (Russell 1992; Feather et al. 1995) cover many of the important foundational elements of the ecology-economics linkage challenge. The ultimate goal of the EEIRP is to produce "how-to" manuals that can aid Corps planners involved with development of environmental projects.

This study creates linkages based upon contemporary biological and economic thinking and serves as an entree into the procedures manuals. The specific research question addressed in this report is:

> *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?*

Forging an understanding of the effectiveness, both biological and sociological, of Corps environmental improvements is critical to effective planning. Without an ability to predict the effectiveness of management actions, the Corps is severely limited in making decisions for allocating funds among proposed projects. For water management decisions, outcome prediction is based on the understanding of systematic cause-and-effect relations defined by physical, chemical, biological, and sociological processes, once appropriate input information is made available. Ecological and management processes generate intermediate ecological outputs, which serve as inputs for other processes and for the ultimate outcome, which is typically human benefit.

Environmental restoration is a relatively recent addition to the well-established Corps civil works mission. The Corps uses its resources to respond to those local project proposals that best serve the national interest. To successfully pursue this mission, the Corps must be able to link the ecological outputs of environmental management to human services and benefits provided at the local and national levels. The intent of this report is to identify categories of ecological outputs that might result from projects developed anywhere under Corps authority and to illustrate how those outputs provide human services and benefits in general form. This report does not address project-specific details for design features. Rather, it provides a checklist of outputs and services that can be considered at the project level, thus guiding the development of site-specific information.

In terms of the Corps environmental plan formulation process (see Figure I-1), this study directly supports the fourth step, *estimate effects of alternatives*. The tools and methods identified in this report are important to other elements of the process, especially *compare alternatives*. Some of the theoretical perspectives provided in this report, particularly the ecological systems approach, could also be very useful in the earlier plan formulation steps such as *problem definition* and *objective formulation*.

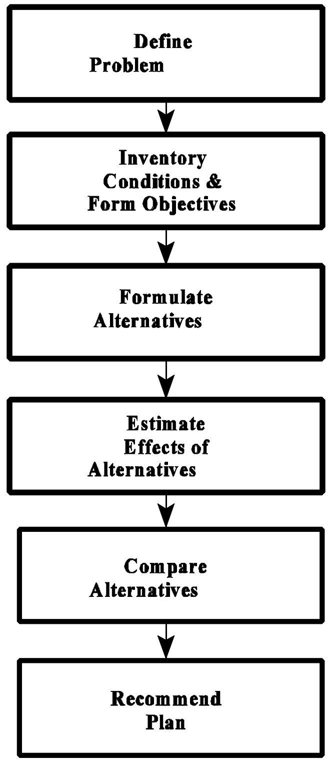


FIGURE I-1
PLAN FORMULATION STEPS

STUDY APPROACH AND PHILOSOPHY

Few studies prior to the present have undertaken such an aggressive effort toward bridging the gap between ecology and economics. However, each discipline has addressed this interdisciplinary challenge in some forum. For example, economics offers several journals such as *Environmental and Resource Economics*. In Feather et al. (1995) academicians representing the fields of ecology, economics, engineering, and psychology offered their perspectives on Corps evaluation challenges for environmental projects:

> While no agency, academic discipline, or research entity can claim the "right answer" to the environmental restoration challenge, the Corps seeks to uncover, organize, and build upon the foundations of existing approaches to better understand which can reasonably be used and is open to well-established recommendations on an approach to the problem.

This study utilizes an interdisciplinary approach but with a sharp focus on the central element of the challenge, the link between ecological effects and socioeconomic impacts. Russell et al.

(1992), which offered an environmental valuation research agenda, made strong suggestions for a clearer link between ecological and economic impacts. This study responds directly to the recommendations offered in Feather et al. (1995):

> The panel of experts shared their diverse perspectives on the services and outputs that ecosystems provide to society and how they could be addressed in the environmental decision process. The lists of outputs developed by the expert panel members, while providing an excellent starting point for future research, are not uniform enough to permit the development of guidance on monetary valuation and nonmonetary evaluation protocols. Thus, it is recommended that a hierarchical structured list of ecosystem outputs and services that might arise from possible Corps mitigation and restoration projects be developed.

In this vein, a research team, led by an applied biologist and supported closely by a resource economist, began developing a list of ecosystem and socioeconomic outputs resulting from Corps restoration endeavors. At a critical juncture of the project, the research team was given access to an interagency team of environmental practitioners to gain perspectives and insights on the direction of the product. Along with commentary on specific details of the preliminary products, the interagency team offered counsel as to how this product and its descendant products could be used in the planning process.

Identification of the basis for portrayal of ecosystems that could readily link to economic analysis while maintaining integrity to the biology community received a great deal of attention. Compromises had to be made to accommodate the pragmatic draw of the intended research tools. For example, describing an ecosystem in a static form such as tables was considered less than optimal from the biological perspective because of the numerous interrelationships and dynamic nature of an ecosystem. However, in light of the need for pragmatic inputs for further analysis and review, ecosystem specificity was reduced, and tables were created that form the basis of this research product. Other important ideological positions were formed that set the stage for the resultant products and are discussed below.

Systems Approach to Defining Environmental Outputs

Ecological outputs from management activities are typically diverse, often unexpected, and more numerous than can be cost-effectively monitored. Ecological outputs include many different physical, chemical, and biological manifestations of ecosystem processes; most prominently, the abundance and renewal rates of desired species, sequestering and export of various water transported materials, and biological integrity of ecosystems. Targeting the most appropriate outcome categories and the most desirable output levels for decision criteria is a prerequisite for the most effective management. There is an effort currently being conducted through the EEIRP's Determining Objectives and Measuring Outputs work unit that identifies important environmental parameters for project planning and available models that can be used to measure the parameters.

Criteria targeted by past water-based environmental policy analyses have emphasized specific material or species outputs, or select groups of outputs, such as suspended sediment, salinity, oxygen, heat, food, endangered species, waterfowl, and sport fish. Policy analyses relied on indices that link habitat conditions to water-quality status or individual-species status, often through model predictions of habitat suitability or more generic indicators of habitat quality. More recently, policy has inclined toward a more holistic and diffuse view, seeking criteria more representative of diverse ecosystem functions and their sustainability. Ecosystem functions include those processes that directly affect human welfare as well as those that indirectly affect future human welfare by sustaining future ecosystem functions.

Present practice in the Corps relies heavily on the use of HEP-based (habitat evaluation procedures) techniques for describing the environmental status of the project at hand, mainly because they are readily available and widely used. Feather and Capan (1995) describe the present planning perspective based on case studies of ten Corps environmental projects:

> HEP has been applied many times to describe the outputs of a wetland of an environmental region, and the model has also been revised quite often or adapted for a particular case. Despite the popularity of these models, there is general agreement that they do not adequately represent the environmental system affected by the proposed project.

The results of this study provide more opportunities for identifying potential ecological and socioeconomic impacts of a project. This, in turn, gives additional information to support and/or provide a better explanation of HEP results as part of project evaluation. A more robust accounting of the impacts of restoration projects could garner added support from project partners that often possess a range of perspectives to be accommodated in the proposed project. It could lead toward closer examination of project alternatives and better project design.

The previous narrow focus on species-centered production quotas (e.g., trees harvested, waterfowl use days, sport-fish catch rates), models, and indices has widened to encompass indices of ecosystem diversity and integrity. Ecosystem integrity suggests wholeness needed to sustain diverse ecological outputs, some of which have no present use value. Ecosystem integrity and organism health are often treated as analogous concepts, but the concept of ecosystem health can imply "superorganism" attributes without scientific foundation. Therefore, the term is avoided here. To the extent that functional wholeness sustains a full set of future output options, the concept of ecosystem integrity probably incorporates the primary concern associated with the concept of ecosystem health (see Ryder 1990). Evaluation procedures have responded to a limited extent to contemporary need for better indices of ecosystem integrity. HEP, for example, has been modified to incorporate broader measures of wetlands condition than indicated by a single species (Adamus et al. 1991; Schroeder et al. 1993). Yet the complexity of ecosystem processes and integrity mostly remains beyond capture in existing indices. *Those wishing to link ecological outputs to human services need an appreciation for that complexity to avoid promoting inappropriate decisions.*

Systems Interaction Between Ecology and Economics

One intent of this report is to illustrate how indicators of ecosystem functions, such as species diversity and biological integrity, are conceptually related to specific ecological outputs and economic outcomes. This discussion is intended to facilitate a more integrated systems approach to understanding the links that exist between ecological outputs and human services. Some of this discussion is presented in Chapter II; detailed discussion is presented in the Appendix. The goal is to develop a tool, in table format, that would impart the systems nature of links as well as list the ecological outputs and human services of concern.

From a management perspective, an important advantage of water quality and habitat suitability indices is their identification of input parameters that can be targeted as measurable ecological outputs resulting from environmental restoration, impact, or mitigation. Such simple indices, however, do not always appear logically connected to ecosystem processes, other important outputs, or water management tactics. This is especially applicable to decision makers who are only broadly familiar with the specialized sciences that constitute the field of environmental science. Thus the reason for this present study, as stated earlier, is to develop an ecosystem basis for the selection of ecological outputs relevant to water management decision making and to connect those outputs to human services and economic value, most often through indirect effects.

REPORT CONTENTS AND STRUCTURE

The general model that is followed in this study takes typical Corps restoration activities, identifies possible effects (both direct and indirect) on the ecosystem resulting from the Corps action, then ties socioeconomic impacts (e.g., NED benefit categories) to each ecosystem effect. The report can guide the Corps planning team in developing an extensive list of impacts to pursue in the plan formulation and justification process. Factors such as planning budget, political setting, funding authority, and local preferences will influence the ultimate choice of project outputs that the planning team will fully develop.

The contents of the report converge on a set of tables in Chapter III that provide a cross-referencing between Corps-influenced input for environmental restoration projects, their potential ecological effects, and the associated human services. Corps input is the management approach used to effect a physical change in an ecosystem. The outputs and benefits of a management approach do not always result from a direct action, such as taking steps that control erosion that indirectly benefits substrate in an aquatic community. The detailed structure and content of the tables are described in Chapter III. Also provided in Chapter III are the procedures for using the tables, which are supported by an illustrative example.

Chapter II serves as theoretical background to the tables in Chapter III. It is essentially a primer on systems ecology and economics. The first part of the chapter covers the general principles of ecosystems and highlights features that have important implications to Corps restoration planning. Interaction among water resource types in a watershed system is discussed. The rest of Chapter II describes the basic principles of economics and some of the related application issues in defining value of ecosystem goods and services. Both sections in Chapter II are laced with technical terms and jargon that the authors have attempted to define. Entire books are written on each of these chapters (many of which are referenced) thus presenting the challenge of surfacing the right combination of terms and concepts. Readers are encouraged to spend time studying Chapter II. This will appropriately allow one to understand and employ the linkage tables efficiently and will promote a fuller understanding of the tables' inherent strengths and limitations.

The Appendix provides important foundational material for the ecological principles advanced in Chapter II. Critical topics such as energetics, diversity, and ecosystems size are technically described and the implications of Corps management is highlighted. A Glossary has been provided for the explanation of technical terms.

II. BASIC PRINCIPLES OF ECOLOGICAL SYSTEMS AND ENVIRONMENTAL ECONOMICS

The model and tables provided in Chapter III are the ultimate product of this research effort and represent a matured version of many important ecological and economic ideas. The tables (III-7 through III-12), while useful to the casual reader, provide significantly more utility to the planner that has a reasonable grasp of the theoretical concepts supporting the tables.

Chapter II is dedicated to providing important ecological and economic concepts. Basic ecosystem interactions are defined, including human influences. Energy and material flows that convert ecosystems are described. A section dedicated to large-scale interaction and related watershed processes is provided.

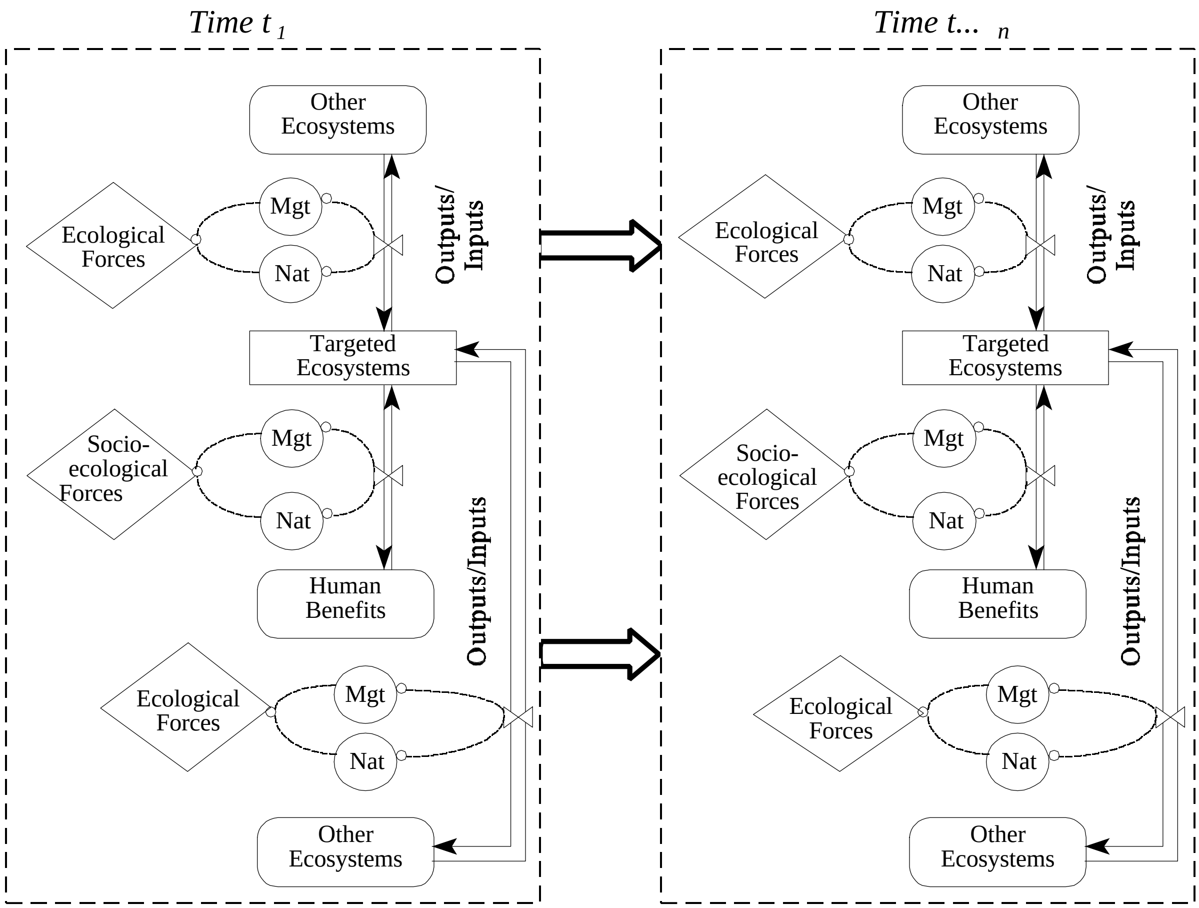
The concepts behind translating environmental restoration impacts from ecological effects to valued socioeconomic goods and services are the subject of the second half of Chapter II. The field of economics provides numerous tools and conceptual frameworks for addressing valuation issues. This section reviews selected economic concepts and discusses their importance as related to ecosystem goods and services. A detailed and involved discussion of advanced ecosystem topics is provided in the Appendix.

BASIC ECOSYSTEM INTERACTIONS

System Characterization

Figure II-1 demonstrates basic ecosystem interactions, incorporating management strategies as well as other human impacts, and Figure II-2 places these general interactions into more concrete water resource terms. The symbols used in the flowcharts are defined below and are described in more detail by Grant (1986). In Figures II-1 and II-2, targeted ecosystems, in which potential projects are situated, are manageable states (state variables are in rectangles) that vary through time and culminate at some future planning endpoint according to planning needs. The appropriate fineness of the time step used in analysis depends on prediction purposes and data availability. The targeted ecosystems in Figure II-1 include a large set of unidentified subsystems, each of which functions based on energy and material inputs from other ecosystems.

A newly constructed reservoir, for example (Figure II-2), includes many subsystems, each of which is an ecosystem. Major ecosystem divisions often are defined by habitat, natural communities, and the role of humans in the system. The new reservoir may develop subsystems of marshes, swamps, pelagic plankton, and tributary streams. Within each system a unique natural community develops and changes over time. Individual marshes around the reservoir margin may be separated by large expanses of pelagic habitat, yet be routinely interconnected through fish and waterfowl movement and through exchange of water-transported nutrients and



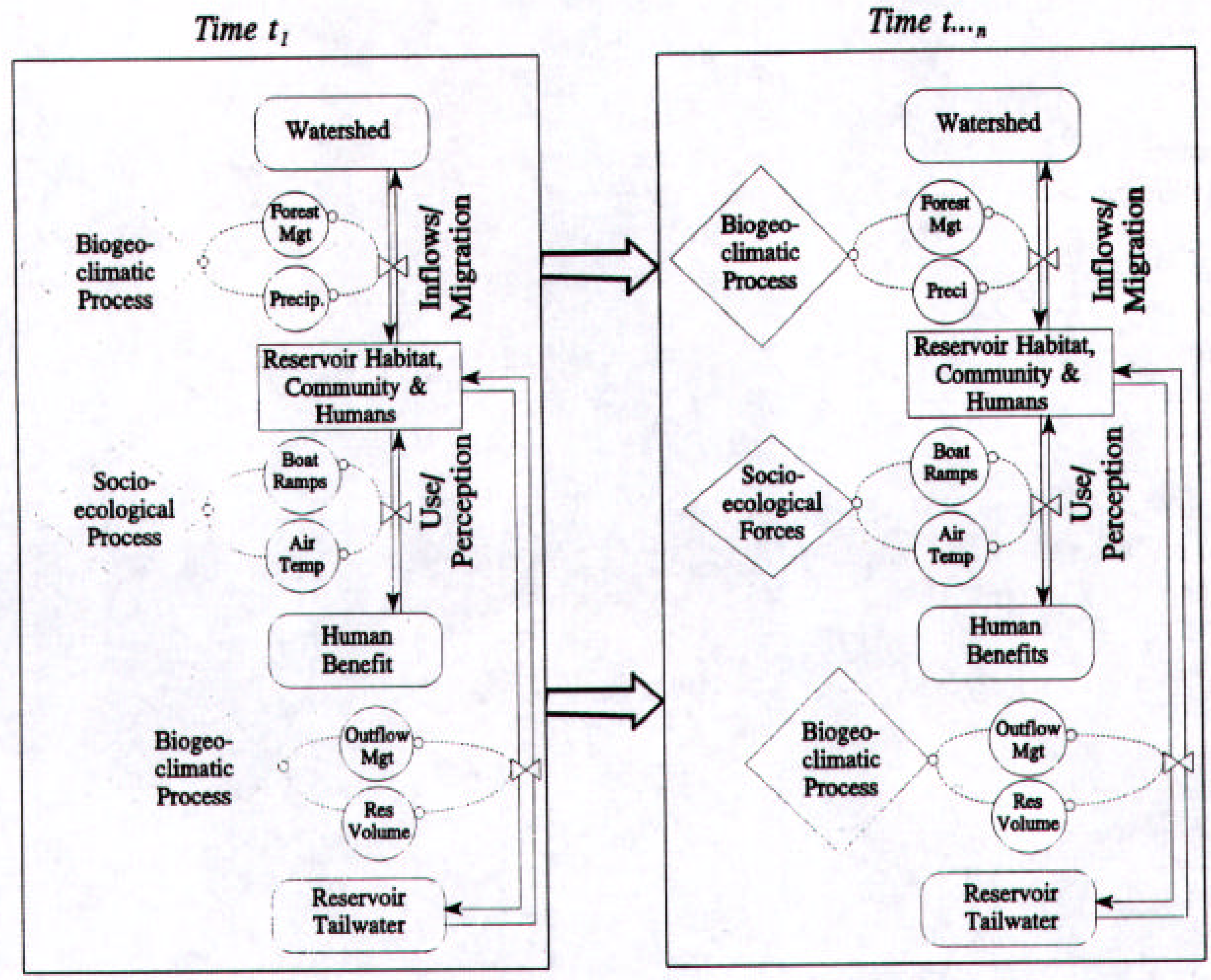
1. Elliptical symbols indicate either sources or sinks for materials, including human use. Rectangles indicate state variables, which export and trap materials that sustain or threaten ecological functions. Diamonds indicate driving variables, which export material flows at control points (bow ties on the flow lines). Driving variables are modified by augmentation variables in the circles (mgt = management variables; nat = natural variables). The two large boxes defined by dashed lines enclose ecosystem states at some initial time and some terminal time.

FIGURE II-1
GENERAL PATHWAYS[1] BY WHICH MATERIALS ARE TRANSPORTED AMONG ECOSYSTEMS, INCLUDING ECOSYSTEMS TARGETED BY PROJECT CONSIDERATION

organic matter. As water levels change in that reservoir, the extent of each subsystem community also will change, usually in nonlinear ways, as will the intensities of interactions among the communities. Targeted populations can serve to identify ecosystem dimensions, which will differ depending on whether the population is composed of mallards, largemouth bass, cypress, or otherwise.

Energy and Material Flow

Energy and material flows connect ecosystems. In Figure II-1, materials move from "source" ecosystems to the targeted ecosystem and from the targeted ecosystem to "sink" ecosystems (sources and sinks are symbolized by ellipses or rectangles with rounded ends). Material transport by water



1. Symbols are as identified in Figure II-1.

FIGURE II-2
GENERAL PATHWAYS[1] IDENTIFIED IN FIGURE II-1 APPLIED TO A RESERVOIR-BASED SYSTEM TARGETED FOR PROJECT CONSIDERATION

is the main process by which materials are moved to, from, and through ecosystems. Although much transport remains inobvious within biological processes, fluvial transport is more evident and more directly affected by Corps activity.

Ecological Control of Flow Rates

Ecological forces drive rates of material flows among ecosystems, such as material output from the reservoir watershed, control of reservoir inputs of nutrients, sediments, and contaminants (diamond symbols are driving variables in Figures II-1 and II-2). Depending on the dimensions of the chosen ecosystems, ecological forces, or "drivers" (diamond shapes), may have profound to negligible impacts on ecosystem functions. The driving variables control transport rates and transformations of materials moving among ecosystems, signified by the dashed-line ties to control points (bow-tie shapes) along the material and energy flow routes between state variables and material sinks.

Ecological forces controlling material and energy flows are expressed in numerous forms, indicated collectively here by natural process and management process categories. The circles in Figures II-1 and II-2 represent specific expressions of driving variables. Forest management, for example, influences the amount of water taken up by trees and diverted back to the atmosphere rather than contributing to water volume in a down-slope reservoir. In thorough representation of a real system, many specific expressions of driving variables need to be considered for both positive and negative effects on desired outcomes. Changes induced by ecological controls include natural factors determining watershed integrity (e.g., vegetation, slope, soil types), material transport (e.g., discharge, turbulence, riparian integrity), and management factors (e.g., forest, range, urban-industrial, and river channel management). Subsystem inputs and outputs are differentially affected by natural and managed processes. For example, management that maximizes bass production and abundance is not likely to be optimum for cypress or mallards. While wetland management hundreds of miles away can critically influence mallards, it will minimally affect bass and cypress, other than through waterfowl impacts.

Management Impact Considerations

Although management intends to guide ecological forces toward desired ecosystem outputs, less desirable or undesirable side effects also result in most situations, offsetting to some extent the intended benefit. Positive effects of habitat development for waterfowl typically will negatively affect other wildlife that contribute positively to regional and national welfare. The Corps manages water resources mostly by controlling topography, that is, the shapes of basins, channels, and watersheds. Topographic slope is an especially important driving variable that is managed by the Corps because it defines the effect of gravity on water and material transport through a watershed and throughout basins and channels. Because many Corps projects shape fundamental ecological forces, project ramifications frequently are diverse, complex, and difficult to identify. The Corps has direct or indirect effects wherever driving variables occur in Figures II-1 to II-2.

Source ecosystems and sink ecosystems lie beyond project ecosystem boundaries. The degree to which source and sink ecosystems are "externalized" during problem analysis influences prediction of ecological outputs from the targeted ecosystem. Watersheds, for example (Figure II-2), export organic matter (output), which contains potential food energy (input) for downstream consumers (detritivores) in targeted reservoir ecosystems. Rates of watershed output are a function of terrestrial production, consumption, decomposition, erosion, and intermediate entrapment rates (e.g., depression storage, floodplain storage). Thus the extent to which watershed outputs provide inputs to pelagic ecosystems in a new reservoir (the target ecosystem) depends on the extent that intermediate ecosystems operate to sequester, modify, or generate materials and potential energy. Dimensions between ecosystems are as important as the dimensions within watersheds in determining transport process and rate. Although water is a main avenue by which materials are transported, other pathways may be important, including animal migration and aerial transport.

Management of targeted ecosystems produces ecological outputs that have both positive and negative outcomes in the form of social service and benefit. Ecosystems include human users and consumers, who affect ecological outputs as much if not more than other ecosystem elements. Humans benefit from both natural and managed processes, depending on their demand for the output and output scarcity. Demand is a key driving variable that depends on human perception of need. The extent to which people collectively perceive benefit also contributes to determining the extent to which they continue to support management policies.

Impact of Human Use

Rates of resource use by people also directly influence functions of a targeted ecosystem. Most obviously, consumptive use of ecological outputs, such as fish and waterfowl species, has a direct impact on the abundance and production of those populations. While nonconsumptive use also contributes to determining natural and ecological processes, it may have a direct affect on the targeted ecosystems. For example, catch-and-release fisheries increase fish mortality even though no fish are consumed by humans in the process. When a policy decision is made to protect a particular species, for whatever reason, including nonuse values, there may often be effects (both positive and negative) on other species.

Ecosystem Context of Water Resource Interactions

Use of the tables in Chapter III for identifying ecological linkages to human services should encourage a wider ecosystem perspective of project dimensions than might otherwise be considered. Further appreciation of large-scale ecosystem interactions may help table users to understand table content. The following section employs the systems perspectives presented earlier and discusses the interaction between types of water resources in a watershed context. This type of systems thinking is directly applicable to the Corps watershed planning philosophy.

Watershed Processes

Projects often are characterized in terms of their water resource category. However, projects may have numerous off-site effects, or projects may perform with varying success, depending on how they are impacted by off-site processes. Broader awareness of large-scale cumulative processes resulting from past water management activity also may aid definition of the "most desirable" environmental investments via restoration projects. The most common ties among projects and off-site conditions are watershed processes (Figure II-3). Project ecological outputs are various, including intended and unintended outputs both on and off the project site. Deciding the location of project development goes a long way in determining the extent to which ecological outputs occur off site in other water resource areas. The tables need to be used while considering links to off-site conditions.

Project position along watershed gradients signals potential for off-site impacts, which may either bolster or diminish the benefits derived from on-site outputs. The force of gravity operating on water and material running over a slope is a primary determinant of ecological output displacement. Wind and tide also are critical forces for material transport and off-site consequences of project activity such as, most obviously, sediment displacement.

The general watershed relationship of the six basic water resource categories are schematically shown in Figure II-3. Among these categories, wetlands probably are most diverse and the most diffusely positioned in the watershed. Each of the other water resource categories often have unique wetland associations, which add to the variety of water resource attributes. Maximization of project environmental benefits both on and off site depends on understanding watershed-based and other environmental connections. It also depends on recognition of more specific water resource attributes than are illustrated here. But project planners should be aware of watershed relationships and the secondary role of wind and tides in transporting project effects to distant water resource areas.

Although Corps project activities rarely incorporate whole watersheds, all projects influence watersheds draining to the project water body or to other locations. The watershed is the primal water resource, the source of all down-slope water except for on-site precipitation or pumped water. Watershed flows include both surface and groundwater. Subsurface water emerges at springs and seeps, which initiate and sustain rivers and diverse wetlands. These wetlands may be extensive but often form little more than pocket marshes and bogs. Wetlands may drain at the surface to other water resource areas, or they may recharge groundwaters, which remain in place or drain through subsurface routes, emerging somewhere down slope. The form and amounts of material transport to down-slope locations greatly depend on the extent and speed that water moves over erosive surfaces and through filtering substrates.

Riverine systems include river channels and floodplains. In upper, steeper watersheds, floodplains usually are narrow or nonexistent. Many of the smallest riverine systems have ephemeral or intermittent runoff, especially in arid watersheds. Wetlands associated with upper-watershed riverine systems most usually form the natural or artificial damming of streamflows or diversions into natural depressions or excavations. Beaver activity is a common source of upper-watershed wetlands associated with riverine systems. In arid areas, earthen stock tanks are the human-built equivalent. Because groundwater is limited or transitory in narrow valleys, such wetlands are sustained by riverine flow or by precipitation where it exceeds or equals evapotranspiration. Wetland character therefore much depends on the quality of river water, especially the amount of suspended sediment and its nutrient and contaminant content. Many upper watershed wetlands have been filled or altered by tributary-quality changes, especially in areas with high human population density.

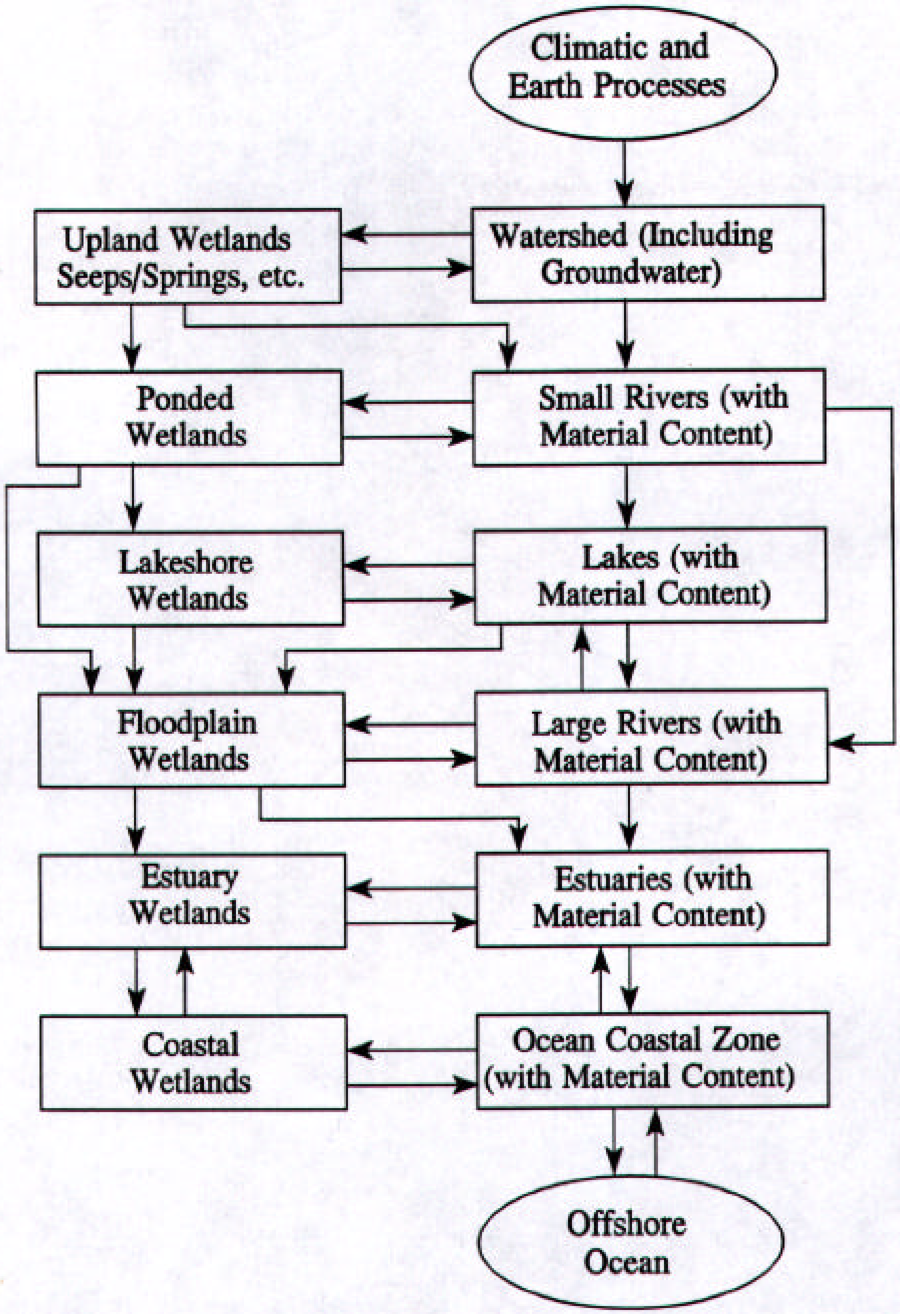


FIGURE II-3
GENERAL RELATIONSHIPS[1,2] EXISTING AMONG CORPS WATER RESOURCE CATEGORIES USED IN THE LINKAGE TABLES

1. Flow lines represent water and transported materials.
2. This figure emphasizes the interconnections among water resource categories and the potential for numerous and often remote off-site impacts, especially as projects accumulate in effect.

Lakes occur wherever a basin is formed with a surrounding watershed. Although small lakes often are common in upper watersheds, especially where postglacial activity occurred, large lakes are more likely to form downslope in wide valleys as a consequence of natural glacial, tectonic, riverine, or coastal impoundment processes. Artificial lakes show similar size distributions because watershed area, valley width, and slope are fundamental determinants of potential impoundment size. Wetlands often are associated with lake margins, much depending on basin slope. Shore marshes, swamps, and bogs are most extensive in flat terrain. Riverine marshes may drain directly to lake and shore marshes, especially in flat topography. Steep-walled canyon reservoirs are least likely to form marsh habitat, especially where water levels fluctuate dramatically during the growing season. Artificial lakes typically drain via the surface into riverine systems, although many natural lakes are sustained and drained via groundwater flowages, including many floodplain lakes (see Cole 1994; Wetzel 1983).

River channels and floodplain width typically increase as watershed area increases. Floodplain alluvium can hold extensive groundwater aquifers, which sustain lakes and wetlands during periods of low river flow. River flooding also is a water source for floodplain lakes but may be more important for sediment and nutrient loading and flushing dynamics. Temporary connections between river and floodplain water bodies facilitate life-cycle requirements for numerous species requiring riverine backwater conditions. Wide floodplains typically harbor the greatest diversity of wetland and lake communities, partly because of different river connection patterns. River-flooded lakes, marshes, and swamps on floodplains acquire different structure and ecological processes than do depressions filled mostly by groundwater. Widespread construction of large impoundments, navigation structures, and levees have profoundly altered floodplain relationships between rivers and floodplain lakes and wetlands.

Rivers empty into estuaries, which are defined primarily by tidal forces and somewhat predictable periodicity in salinity over the estuarine bottom. Wind and river flow also are important mixing influences. The extent that wetlands form around estuaries depends mostly on the slope of surrounding topography, estuarine widening of the river channel, and sediment load. Wetlands usually develop most extensively in wide estuary basins in flat coastal plains served by rivers with high sediment load. Coastal erosion and deposition form barrier beaches that contribute to estuarine wetland development by protecting estuaries from coastal storms. Riverine wetlands may drain on the surface or through groundwater directly to estuarine wetlands, or they may drain back to the river before reaching the estuary.

Estuaries empty into oceans, but because of tidal and coastal currents, points of entry often are indistinct. Development of barrier beaches, especially on flat coastal plains, greatly modifies and extends estuarine systems behind the beaches. Riverine material load is a major source of barrier-beach deposits in addition to oceanic sources. Development of intracoastal canal systems for boat traffic has linked many previously separate estuarine areas, creating new circulation patterns and different wetland configurations in association with estuaries behind barrier beaches. Mixing rates and amounts of salt water and freshwater and waters with different sediment loads contribute in barrier beaches often profoundly change estuarine mixing patterns and associated community patterns.

Ocean shore deposition and erosion dynamics maintain barrier beaches. Beach material supply is critical, as is the integrity of coastal vegetation, once established. Vegetation stabilizes dunes and resists breaching during major storm events. Storm patterns are variable, thus barrier beach processes are dynamic, and a certain amount of instability in estuarine and coastal communities is to be expected. Engineering modifications also have altered material transport from watersheds and probably have affected natural beach nourishment rate and estuarine water quality.

Project-by-project water resource modification has had cumulative impacts, especially on water quality and sediment erosion, transport, and deposition dynamics. This cumulative effect has been most evident in large river floodplains, estuaries, and barrier beaches, where physical and chemical changes have resulted in significant biological changes. The vast majority of sediments supplying river floodplains, estuaries, and coastal beaches depends on river contributions (Pethic 1984). Watershed and river-flow modifications have significantly altered that process. In the past, each engineered project, taken alone, had what appeared to be negligible off-site effects. The collective impact of water resource engineering in the U.S. and elsewhere has been impressive. Impoundment development retained sediment, resulting in down-slope diminishment of sediment loads, significantly so in floodplains and estuaries of some watersheds. Evaporation surface has increased, increasing estuarine salinity in some locations. Changes in estuarine circulation patterns have altered salinity distributions. Channelization has routed sediment loads through estuarine deltas to offshore ocean depths and some estuarine marshes are eroding partly as a consequence. These physical and chemical changes have been accompanied by extensive biological change. These large-scale alterations of past ecological processes remain poorly defined.

Cross-Watershed Processes

Processes other than watershed can influence project effectiveness. Animal migration is important, especially for projects managed for migratory birds or projects that could be affected by migratory bird use. The ecosystem context in those cases is the flyway used by the birds and the availability of alternative flyway sites in the general vicinity of the project. Similarly, for migratory fish species that complete their life cycles both in watersheds and in oceans, the top-down impact of commercial fishing and other oceanic change interacts with watershed and river management processes to determine ultimate fishery status.

Human users, like birds and fish, also move among project sites and across watershed boundaries. This may be due to changes in site qualities or a perceived need for something different. The dynamic in human use created by substitute sites can result in user impacts on the site qualities generated as ecological outputs, such as population densities of fish, birds, and other animals. The availability of site substitutes also influences the net benefit derived from project development. Where numerous high-quality substitute sites are available in the vicinity of a project, the benefits of a new site are less likely to be utilized than where substitutes are scarce or of poor quality.

Airsheds may influence material transfer, especially with respect to various contaminants found in automobile, industrial, and other aerial exhausts. Although this form of input to projects usually plays a minor role, it can be critical in certain situations.

ECONOMIC VALUES OF ECOSYSTEM SERVICES AND INDICATORS OF THE DEMAND FOR ECOSYSTEM SERVICES

Services of Ecosystems

Ecosystems generate multiple categories of valuable services to humans: (1) direct use values, (2) indirect use values, (3) option values for future use, (4) nonuse or existence/bequest values, and (5) cultural significance to native peoples.

Restoration of ecosystems and their functions will often increase the quantity or quality of environmental services valued by humans. Restoration of water-based ecosystems such as lakes, rivers, wetlands, and estuaries often contribute to one or more of the above services to humans. The tables shown in Chapter III link the restoration measures undertaken by the USACE to specific human services that fall under one or more of these service categories.

The *direct use values* resulting from USACE restoration projects include:

(1) Contribution to increasing the quantity of commercially valuable organisms (Table III-12, finfish, some invertebrates such as shellfish)

(2) Increase in the supply or quality of recreation opportunities such as swimming and various types of boating (see Tables III-7 through III-12), recreational fishing (Table III-12), as well as bird viewing and waterfowl hunting (Table III-12)

(3) Increasing the supply of clean water for municipal and industrial (M&I) purposes (Table III-7, III-11), navigation (Table III-7), irrigation (Table III-11), and hydropower (Table III-7)

Second, ecosystem restoration provides *indirect use values* by performing services that become inputs to production of fish and wildlife that are of direct value further up the food chain. Wetlands, for example, also provide natural filtering, nutrient uptake, and detoxification of pollutants that would otherwise flow into watercourses and would require expensive human-constructed treatment plants. Those ecosystems may supply valuable services at lower costs. Restoration of ecosystems may reduce costly damages that might arise to houses (Table III-7) or infrastructure such as highways, water supply canals, and pipes.

Third, restoration of ecosystems may have an *option value* to people. Some people may wish to visit these areas or view the unique wildlife that live there in the future, even if they do not now. Thus, they may be willing to pay to maintain these areas so they could visit them in the future. Option values also accrue to decisions involving restoration of endangered species habitats. Increasing the probability that a particular threatened and endangered (T&E) species survives into the future provides that option to the future (Table III-12).

Fourth, there are also significant *off-site or nonuse values* to many members of the public from simply knowing that a particular ecosystem and their service flow exists *(existence value)* or knowing that future generations will have this ecosystem in a restored condition (*bequest values*). These values appear to be of public importance for T&E species (see Table III-12) and wetlands (Loomis et al., 1990).

Fifth, ecosystems may also have *cultural significance to native peoples*. Many natural areas may be of religious or cultural importance as ceremonial sites (e.g., bathing rituals, fishing sites, collecting sites), or the natural products produced by a wetland may be used in religious ceremonies or for subsistence purposes (e.g., particular plants or animals).

Supply and Demand for Ecosystem Services

Environmental restoration projects can potentially increase the quantity (amount, duration, areal extent) and quality (i.e., improve the timing or reduce variability) of ecosystem services discussed above. One way to think of environmental restoration is that it augments the supply of some ecological services.

But for these services to have the types of economic values described below, there must be a demand for these services. The first question to ask is, demanded by whom? A *biocentric* view would suggest that if plants or animals benefit from an increase in oxygen in the water, then this is sufficient. Several of the ecological outputs are measured in units that suggest a biocentric view. Many measures described in the tables (Chapter III), such as biological processes or outputs related to different dimensions of substrate (Table III-7) or water quality (see Table III-11 oxygen, pH, etc.), are first and foremost of biocentric value, since they contribute to a particular ecosystem function or functions. Biodiversity and the ecological integrity of an ecosystem are outputs and services of natural systems (see Table III-12) and therefore have a biocentric value.

Restoration of ecosystems to increase the diversity of plants, fish, and wildlife may make a significant contribution to biodiversity of an area in at least one of two ways: (1) high direct on-site diversity and (2) being a critical habitat component to support a particular life stage for a wide variety of fish and wildlife at other areas (e.g., downstream).

In addition, some of these ecosystem functions are inputs to other ecosystem functions that can eventually be traced to a human use of the environment. Tracing the ecological effect to humans provides an *anthropocentric* viewpoint. This view suggests that if something is to have an economic value to society, it must be possible to connect a human demand to the ecological effect. That is, is there a human demand to hunt the additional waterfowl, to view the additional birds, to swim in the improved water quality, etc. The linkage can be <u>indirect</u> as well. For example, humans may not care if the soil toxicity is reduced such that it is safe for pocket gophers. However, if we consider the food-chain effects, we recognize that pocket gophers may be a major part of the red-tailed hawk's diet, and people do enjoy viewing the hawks. In this way, there is a human demand for clean soil and pocket gophers, indirectly through the food chain. In some cases, there is a human demand to know that the natural functions have been restored to an area such that it will now support native plants, fish, and wildlife even though the person currently does not visit the area. That is, there may be an option demand to visit the restored area in the future or simply an existence demand to know the restored area exists as habitat or performs ecological functions. Finally, individuals today may have a bequest demand to leave a restored ecological system in this specific area to future generations of residents there.

Nonetheless, it is important for the analyst to look at the demand for the new services created relative to existing supply of those services. Restoration of additional habitat may at some point saturate the "market" for the associated human services, and each new project simply redistributes the same fixed amount of use. The Corps has seen this phenomenon with regard to some recreation projects in some reservoir-rich regions of the U.S. It should be noted that restoration may have the potential to increase the quality of recreation use (e.g., increased catch rates, greater viewing diversity).

The importance of there being a demand for the additional supply of ecological and human services created by the restoration project is illustrated in Figure II-4, panels A and B. Panel A illustrated the case where there is a demand for both the current supply and the augmented supply. This might illustrate the case of wetlands for waterfowl hunting and viewing in a particular area. A restoration project that increases the quality or quantity of wetlands, will be translated into an increase in the supply of hunting and viewing days. Specifically, a substantial increase in wetlands might allow for issuing of more waterfowl hunting permits or allow more viewing blinds to be constructed to accommodate more bird watchers. This is illustrated by a rightward shift in the supply curve from Supply-current to Supply-restored. The additional benefits created are equal to area *B* in panel A. As will be explained in more detail below, area *B* is the willingness to pay for the added trips or visitors. The additional travel costs and management costs of accommodating the additional visitors must be subtracted to arrive at net benefits or National Economic Development (NED) benefits. Panel B illustrates the case where there is already an abundance of high-quality groundwater supply to meet all economic demands and there is no overdrafting of the aquifer. As such, there is no current or direct economic value of increases in groundwater recharge from the restoration project. That is, while wetland restoration provides additional bird-viewing opportunities for which there is a demand, the groundwater recharge service has no current or direct economic value today. Benefits with and without the increase in supply are the same, area *A* in Figure II-4, panel B. An analogy may help the reader understand the logic of this conclusion. If you own a stadium that has never sold out and is not expected to do so in the foreseeable future, what is the economic return of adding more seating capacity? There probably is none. The same logic applies to supplying more of an environmental service for which current and projected demand is already met.

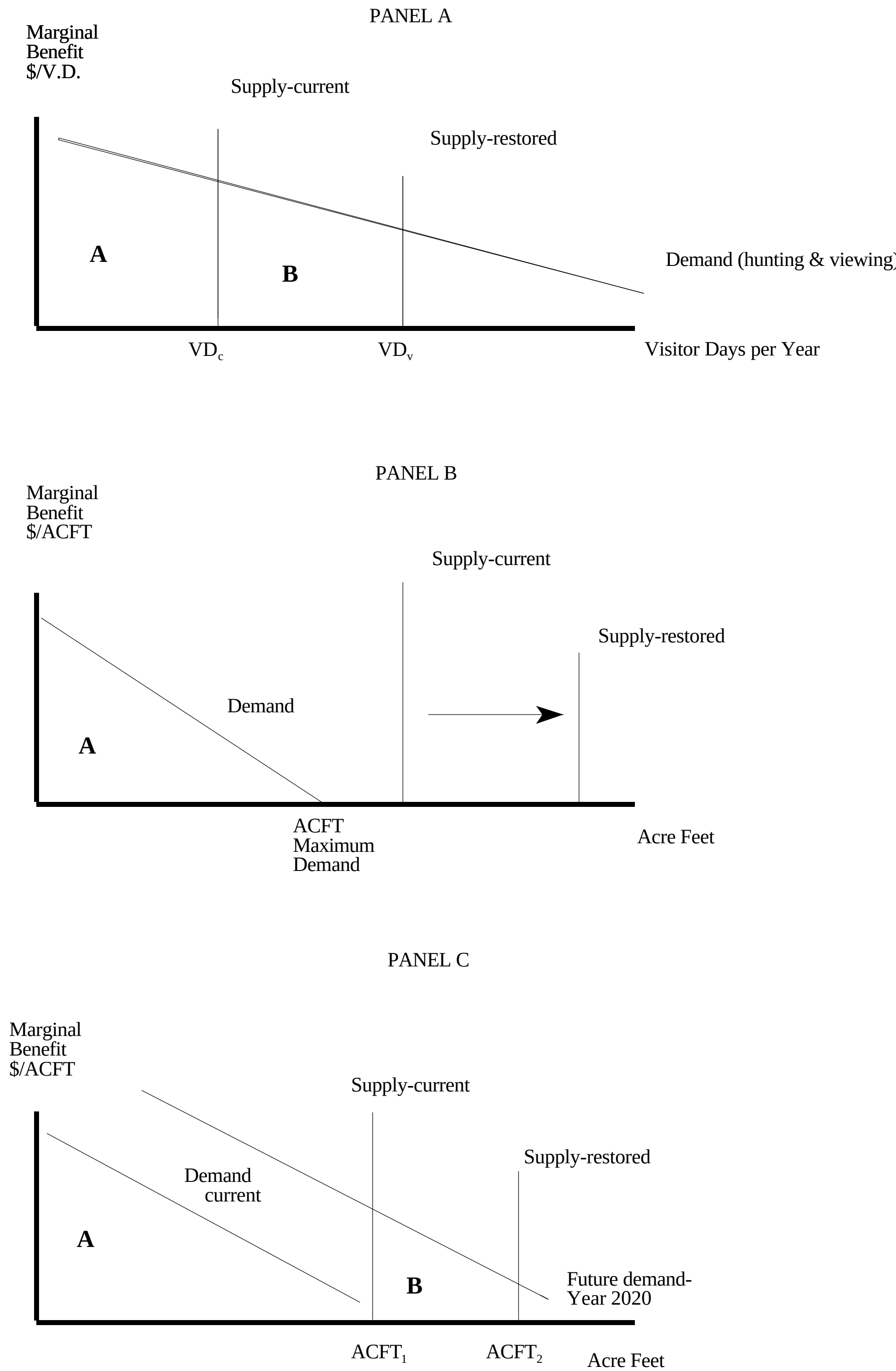


FIGURE II-4

SUPPLY-DEMAND CURVES REGARDING ENVIRONMENTAL RESTORATION OPPORTUNITIES

As shown in panel C, future demand might increase to the point where there will be a demand in the year 2020 for additional output created by the project. In this case, there will be benefits (area *B* in panel C), but these benefits must be discounted from the 25-year period before they are received. At the current water resource rate of 7.75 percent, one dollar's worth of benefits received 25 years from now is worth about twenty-five cents today.

When attempting to determine if human demand for ecosystem services or outputs exists, the planner should consider the following:

(1) *Public access to the on-site or off-site resources.* For the human <u>use</u> benefits (nonuse benefits are discussed below) to be realized, people must be able to see the restored area, wildlife that live or migrate in and out of the area, or receive other off-site effects such as improved water quality. This human use may include residents who live adjacent to the area, i.e., homeowners. In addition, public access for visitors who want to come and view, fish, hike, swim, etc., at the site is another way in which human use might occur. It is possible that some of the human use can occur downstream of the restored area, whereby cleaner water is obtained at downstream city water supplies of downstream rivers and lakes. In addition, birds that nest in the restored area may be seen flying around the general area where people live. In any case, some connection to people in the area is necessary for use benefits to be realized. Nonuse benefits are discussed below in item 7.

(2) *Regional presence of high demand for the targeted resource.* This may be a high absolute level of use or a high use per acre. A wetland may attract 10,000 visitors a year, but other wetlands of similar size in the state may only have 1,000 visitors per year. Thus on a per acre basis, there is a high demand for this type of recreation in this area relative to other areas. Assembling background information on use of the study site relative to *substitute sites* offering similar services will help document whether there is a demand for the additional supply created by environmental restoration. It is important to separately account for net new use at the restored site versus simply a redistribution of use from existing sites to the restored sites. Another common indicator of high demand for a specific restoration site may be a high incidence of field trips to the area by conservation organizations.

(3) *Periodic shortages of resource*. Evidence of demand for the newly restored resource can be documented if there is past evidence of frequent shortages. It would be important to document, for example, an environmental restoration project that provides additional clean water in areas where a combination of drought and polluted water have resulted in water shortages or water use restrictions. Increasing instream flows at times of the year when water flows are low would reduce the scarcity of instream recreation opportunities. The percentage of a site or area capacity that is utilized might be another indicator of demand. If capacity is nearly used on most weekends, then one would expect future demand to outstrip the available supply.

(4) *Legal mandates for services including environmental laws and standards*. In many cases the scarcity and demand for the environmental outputs are documented by mandates. For example, water quality is below the legal standard, a species is listed by the state as one of special concern, or executive orders exists, such as those pertaining to "no net loss" of wetlands. In other cases, relating the project's contribution to larger-scale plans such as the North American Waterfowl Management Plan and associated Flyway Plans and Joint Ventures will show that a project contributes to meeting a larger societal need. These are political manifestations of societal demand for these outputs.

(5) *Stakeholder willingness to contribute funding.* If the environmental services provided by a site are of economic value to members of a community or result in significant cost savings to a community, the community should be able to express that significance by making its cost share a high priority. Of course, it is important to be aware of local tax limitation laws or requirements of "super majorities" to pass tax increases or bond referendums that often mask the fact that there is substantial (even if not majority) demand for a project. Also, city, county, state, and nonprofit group monetary or in-kind contributions may be taken as an indicator of demand for the project services.

(6) *Potential of the restored environment to be used for environmental education*. Many areas have large school district demand for nearby accessible natural areas to be used for environmental education at all levels. Documentation of this may be performed by contacting the school districts environmental education coordinator or nearby schoolteachers to gauge their interest in using such an area. However, it is important to ascertain the advantages of the newly restored area as compared with any existing areas already used by the school district.

(7) *Nonuse or existence values for the specific natural resource at this particular location*. Planners should note whether the restored site would provide or enhance populations of regionally unique plants or animals or natural features not found in the region. Nonuse values might be demonstrated in newspaper articles about the specific resource at this site or local television coverage of the resource, etc.

Nonmarket Economic Values

Renewable natural resources in particular and ecosystems in general provide many services to human beings that are of direct economic value. Some of these services are priced in competitive markets, and therefore the price paid for the service reflects the economic value of that service. However, many services of ecosystems listed above are not traded in markets. In some cases, this absence of markets is a social choice. For example, in the U.S. free-ranging wildlife is regarded as a public trust, where the government regulates harvesting. For various political and administrative reasons, governments usually do not establish competitive markets for wildlife. Absence of markets does not mean absence of economic value. As discussed below, market simulation approaches can be used to estimate the value of wildlife recreation and wetland recreation in the absence of markets.

Other ecosystem services listed above have no markets because there is no technically feasible means to charge the recipients for the services they receive. For example, the benefits from knowing a particular species exists and will be available for future generations can be enjoyed without paying. If a person does not make a donation to the government or an environmental group, as long as others do so and the ecosystem is protected, the nonpayers can still benefit from knowing these ecosystems exist (even though they do not have the satisfaction of knowing they contributed to their survival). For existence and bequest services, the simulated market approach, discussed below, must be relied on to obtain an estimate of the value received by nonvisiting households.

NED Measures of the Economic Value of Ecosystem Services

The U.S. Water Resources Council (1983) requires that NED benefits be measured in terms of net willingness to pay (WTP). Net WTP is the amount the user (e.g., visitor, homeowner) would pay, over and above their own cost, to obtain some improvement. The improvement might be cleaner water, greater diversity of birds, less odor, greater instream flow, etc. The WTP can also reflect a cost savings to society. For example, the cost savings to a reservoir owner from less sediment in the water can be the reduced water treatment cost or the reduced cost from less frequent dredging of a reservoir. Flood damages avoided by homeowners is another type of NED benefit that reflects landowner's WTP to avoid losses.

Measuring as many of the NED benefits as practical can contribute to determining the optimal scale or size of an individual restoration project as well as selecting among different restoration projects. However, most restoration projects do not require a complete NED or benefit-cost analysis. Oftentimes determining which scale of restoration project or which restoration project provides desired outputs (e.g., habitat units, waterfowl populations) at a reasonable level of costs per unit is sufficient to guide the decision process.

Many of the direct service benefits of ecosystems can often be valued using market prices (net of harvesting costs) such as the dockside price of fish or pelts. In some cases, we must disentangle the price of housing near restored ecosystems to arrive at the ecosystem's contribution. This approach is known as the hedonic property value method. For recreational hunting or viewing, we can rely on the fact that many visitors must pay a price in travel costs and travel time. While the amount spent is <u>not</u> a direct measure of the value of viewing or hunting (expenditures are a measure of cost to the visitor, not benefits), the variations in travel costs incurred and associated number of visits taken do allow the analyst to trace out a demand curve for recreation at the wetland. From this demand curve, the WTP over and above the costs can be calculated. This approach is known as the travel cost method (TCM). Details of this method are provided in NED manuals developed by the Corps Institute for Water Resources (Vincent, Moser, and Hansen 1986).

For indirect service benefits provided by ecosystems, one can value the services by looking at either the products created or the cost of providing this service using nonnatural means. For example, groundwater recharge can be valued if one knows the acre-feet of water delivered to the aquifer by a wetland and a price per acre-foot of groundwater reserve (i.e., value of water in the ground before pumping costs are incurred). If, for example, flood protection and water-quality filtering are services that would have to be provided in absence of the wetland, then the cost savings of using the wetland instead of structural flood control features (such as dams or water treatment plants) is an economic benefit of maintaining the wetland. This approach is sometimes called the replacement cost method. It must be used appropriately, otherwise ludicrously large benefit estimates can result. For example, a wetland may be trapping and detoxifying heavy metals and preventing them from reaching a watercourse. It might cost $150 million dollars to build and operate an equivalent treatment plant. But the damages from the heavy metal entering the watercourse in terms of reduced fish and shellfish production and higher cancer rates might only be $5 million a year. It would be misleading to say the wetland has a value of $150 million because it would cost this much to build a treatment plant. Given the magnitude of the costs and the relatively small size of the damages, the treatment plant and the wetland value would be equal to the $5 million loss to society that would result if the wetland were not there.

Option, existence, and bequest values can be valued using a contingent valuation method (CVM) survey that estimates maximum WTP through questioning individuals. These surveys are illustrated in a case study of the San Joaquin Valley wetlands preservation and protection (Loomis et al. 1990). While the WTP question can be asked in numerous ways, one useful approach is to ask if individuals would vote in favor of a specific wetland program that would involve specific acreage, etc., at a given price (with the price varying across respondents). By calculating the percent of people that would pay each price, a demand curve can be statistically estimated and WTP calculated. This WTP reflects all the motivations people have to pay and frequently reflects option, existence, and bequest values.

CVM can be criticized on several grounds. First, respondents must be given adequate information about service flows from ecosystems so they can rationally estimate their WTP. A more fundamental question is whether people would actually pay the dollar amounts they state in the survey. There is some evidence that CVM responses are valid measures of WTP for environmental services such as air quality (Brookshire et al. 1982). However, the more unfamiliar one is with an environmental resource, the greater the potential for discrepancy between stated and actual WTP, often a factor of 2:1. While carefully designed CVM surveys can often provide far more precision than order-of-magnitude estimates of nonmarket values, even order-of-magnitude estimates can be useful for many policy decisions. Frequently, there are good cost estimates but no estimates of the benefits. Since nearly all the population of an area can enjoy the existence and bequest values from maintaining ecosystems, even small values per household ($10-$30) produce large aggregate estimates of benefits. Past analyses that ignored these values and relied solely on commercial and recreation values were misleading and incomplete. It is usually better to have a good approximation of the total value than to have a precise estimate of just a partial measure.

SUMMARY

The examination of ecosystem processes from a systems perspective requires careful and extensive consideration of its components, including energy and material flows. (An extensive discussion of these components and function can be found in the Appendix.) This is especially important regarding management approaches, because an alternative often will have additional indirect effects beyond its intended benefit or services. The benefits and services of ecosystems are of value to humans. A large variety of these services can be measured using market prices, replacement costs, simulated demand curves for recreation, and simulated markets using the contingent valuation method. While there will frequently be values of ecosystems that may not be captured in a human-based valuation method, the quantifiable economic values often exceed the sum of financial values and recreation values alone.

Cooperation of ecologists and economist can expand the types of values that can be quantified in future surveys and analyses. The tables in Chapter III have been designed to accommodate both the important ecological and the socioeconomic aspects of environmental planning, namely ecological outputs and their related socioeconomic benefits and services. It should be recognized, however, that this in no way suggests all restoration benefits be presented in monetary form. Although the tables in Chapter III present an extensive accounting of socioeconomic benefits, they do not accommodate all the benefit categories that a project can provide. There are many benefit categories that are not readily characterized by existing or simulated markets and are therefore portrayed in qualitative form.

III. ECOSYSTEMS-BASED SERVICES FOR PLAN FORMULATION

The preceding chapters set the initial ecological and socioeconomic foundations for the development of the tables in this chapter. This chapter will focus on the table contents and how to apply them to environmental restoration planning efforts.

TABLE PURPOSE IN PLANNING PROCESS

This chapter presents a set of tables designed to aid identification of links between ecological output and human services. Despite much conceptual advancement over the past half century, quantitative understanding of ecosystem processes remains rudimentary. Although much more can be learned through further research and model development, water managers must rely on present understanding to make the decisions demanded of them while they encourage research and development of better decision-making tools. Figure III-1 illustrates how the information presented in each table fits into the plan formulation process, starting with the identification of Corps project alternatives and culminating in project recommendations. The tables provided as a planning tool in this chapter should be viewed as an intermediate step in the development of more sophisticated planning tools and not as the ultimate management tool.

From the proceeding analysis several criteria were developed for table structure and content, with the ultimate intent that the tables fully represent links between management processes, ecological outputs, and human services.

- The tables should reflect the interactive dynamics of ecosystems processes that link ecological outputs with human services.
- The tables should incorporate human actions and needs as integral parts of ecosystem processes that are among the criteria used to assess ecosystem integrity.
- The tables need to include ecosystem inputs that are important determinants of ecological outputs and are influenced by Corps management activity.
- The tables need to include important direct and indirect linkages between ecological inputs, ecological outputs, and human services, even when numerous ecologic interactions occur between management cause and ultimate service effect.

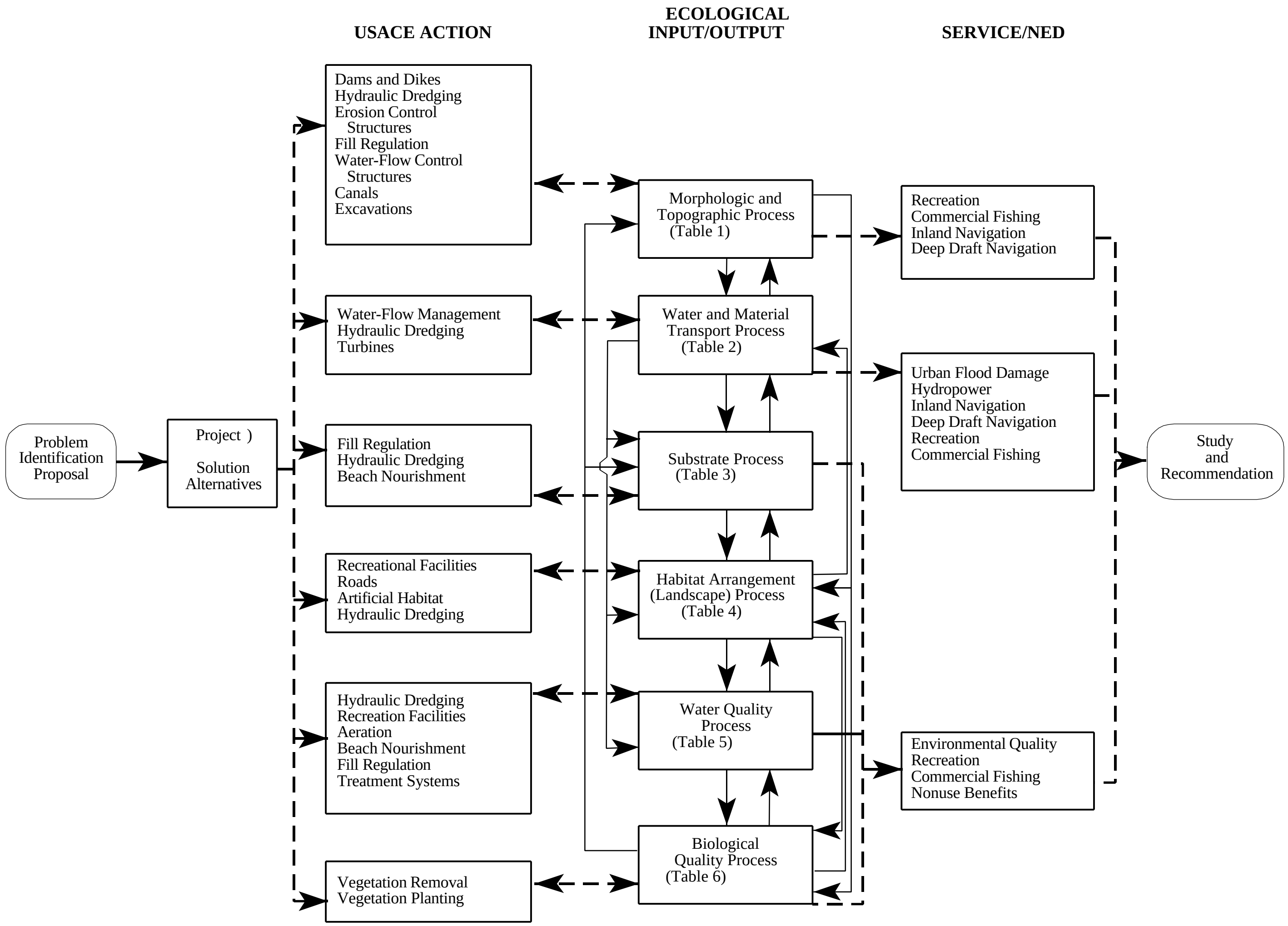


FIGURE III-1
RELATIONS BETWEEN ECOLOGICAL OUTPUT CATEGORIES[1,2] EITHER DIRECTLY OR INDIRECTLY INFLUENCED BY CORPS MANAGEMENT

1. Flow lines represent information, material and energy connections.
2. Each category under ecological input/output is the base of a table summarizing the ecological outputs and services that could be affected by project realization.

- The tables need to account for both positive and negative consequences of management actions on linkages between ecological outputs and human services to properly assess management effectiveness.

- The tables need to provide a checklist for both intended and unintended management effects on ecological outputs, including numerous "side effects" that tend to be overlooked or discounted as insignificant in the planning process.

- The tables need to account for complex branching and feedbacks among ecosystem-output responses to management inputs.

- The tables need to signal the possibility of remote, off-site impacts that could have positive or negative cumulative effects with respect to national economic development.

Meeting these criteria resulted in the detailed tables found in Tables III-7 through III-12. For introductory purposes, the information contained in the 39 pages of Tables III-7 through III-12 has been collapsed into a simple cross-referenced listing in the form of Tables III-1 through III-6.

Tables III-1 through III-6 provide the user with a general assessment of which human service categories are associated with a particular ecological impact. These tables can also quickly indicate which ecological inputs influence a given human service category.

Tables III-7 through III-12 identify ecological outputs and dependent human services. When ecological outputs are directly linked to human services, those services are immediately identified in the tables, and information is provided about benefit form and whether the service is positively or negatively affected by the ecological output. Some ecological outputs enhance service benefits, while others diminish benefits. When the effect of ecological output on human service is indirect, the table reader is directed to another table where the secondary outputs may have direct links to services. Although many human services are directly affected by Corps management, most effects are indirect.

The conception of potential projects starts with the identification of a restoration need, which may be provided through a number of alternative management actions (see Figure III-1). Often, a proposal not only identifies need but also suggests at least some management alternatives such as building a dike or dam, eliminating existing water control structures, redistributing bottom sediments, adding mechanical oxygenation, planting marsh plants, or harvesting aquatic weeds. Planners are expected to evaluate the need and the various management alternatives to determine which is the most cost-effective in providing for the need. Each of the alternative proposal actions indirectly and directly generates environmental changes, which are categorized in the six tables as Morphology and Topography, Water and Material Transport, Substrate, Habitat Arrangement (Landscape Process), Water Quality, and Biological Quality.

TABLE III-1
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHIC PROCESS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement**	**Water Quality (Tbl 5)**	**Bio Process/Quality**	**Aesthetics**	**Recreation**	**Property Value**	**Flood Control**	**Sediment Control**	**Water Supply**	**Hydroelectric**	**Groundwater Recharge**
SURFACE AREA														
Total use area								●						
Aesthetic							●							
Total area of productive habitat						●								
AREA FLUCTUATION														
Concentration and dilution effect						●								
Fluctuation of use base	●						●	●						
Shore protection					●	●				●				
VOLUME														
Storage capacity										●	●	●		
Total material and energy content					●	●								

TABLE III-1 (Continued)
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHIC PROCESS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement**	**Water Quality (Tbl 5)**	**Bio Process/Quality**	**Aesthetics**	**Recreation**	**Property Value**	**Flood Control**	**Sediment Control**	**Water Supply**	**Hydroelectric**	**Groundwater Recharge**
Concentration and dilution					●	●								
Water discharge sustainability		●				●		●						
Oxygen load and concentration					●	●								
Thermal load					●	●								
Material loads	●			●	●	●								
Hydraulic impacts		●		●										
DEPTH														
Clearance to bottom					●	●		●						
Particle resuspension					●	●								
Vertical mixing		●												
Tailwater discharge depth					●	●							●	

TABLE III-1 (Continued)
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY
WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHIC PROCESS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement**	**Water Quality (Tbl 5)**	**Bio Process/Quality**	**Aesthetics**	**Recreation**	**Property Value**	**Flood Control**	**Sediment Control**	**Water Supply**	**Hydroelectric**	**Groundwater Recharge**
AREA-DEPTH RATIO														
Evapotranspiration	●				●									
FETCH														
Turbulent mixing		●												
SLOPE														
Basin slope	●				●	●	●	●						
Channel slope	●		●	●	●	●	●	●		●	●		●	
Watershed slope		●												
SHORELINE LENGTH														
Organic detritus supply					●	●								
Shade					●	●		●						

TABLE III-1 (Continued)
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY
WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHIC PROCESS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement**	**Water Quality (Tbl 5)**	**Bio Process/Quality**	**Aesthetics**	**Recreation**	**Property Value**	**Flood Control**	**Sediment Control**	**Water Supply**	**Hydroelectric**	**Groundwater Recharge**
Terrestrial organism water use						•								
Shore erosion						•	•	•		•				
SHORELINE DEVELOPMENT														
Ratio of shoreline length to water area		•	•	•	•	•	•							
CHANNEL FORM														
Wetted Perimeter	•	•				•								
Meander radius, length and amplitude	•	•		•			•	•						
Stream Braidedness			•			•								
FLOODPLAIN FORM														
Floodplain storage capacity		•	•	•						•				•

TABLE III-1 (Continued)
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY
WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHIC PROCESS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement**	**Water Quality (Tbl 5)**	**Bio Process/Quality**	**Aesthetics**	**Recreation**	**Property Value**	**Flood Control**	**Sediment Control**	**Water Supply**	**Hydroelectric**	**Groundwater Recharge**
WATERSHED FORM														
Impenetrable surface		●		●		●								●
Depression storage		●		●	●	●								●

TABLE III-2
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY WATER AND MATERIAL TRANSPORT PROCESS INCLUDING USACE IMPACT ON ECOSYSTEM TRANSPORT PROCESS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality (Tbl 5)**	**Bio Process/Quality (Tbl 6)**	**Flood Control**	**Recreation**
DISCHARGE								
Watershed discharge and load			•		•	•		
Waterbody discharge and load	•		•		•	•	•	
Hydraulic retention			•		•	•		
Channel discharge and load	•				•	•	•	•
CURRENT, TURBULENCE & WAVE HEIGHT								
Surface turbulence and wave height	•		•		•	•		•
Vertical and horizontal mixing				•	•			
Erosion, transport and deposition dynamics	•		•	•	•	•		

TABLE III-3
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY SUBSTRATE INCLUDING THE USACE IMPACTS ON SUBSTRATE

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality (Tbl 5)**	**Bio Process/Quality (Tbl 6)**	**Aesthetics**	**Construction Support**	**Recreation**
SUBSTRATE PARTICLE STRUCTURE									
Substrate particle size	●				●	●	●		
Particle density		●			●	●			
Particle shape		●			●	●			
Particle roughness and abrasiveness		●			●	●			
Particle aggregation		●			●	●			
Particle stability		●				●		●	
Particle compaction		●				●		●	
SUBSTRATE CHEMISTRY									
Organic content	●	●			●	●	●		●
Nutrient content					●	●			
Toxic contaminant content					●	●			
Solubility		●			●	●			
SUBSTRATE ORIENTATION AND DEVELOPMENT									
Within habitat vertical development	●	●		●	●	●	●		
Between habitat vertical development	●	●		●	●	●	●		

TABLE III-4
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY HABITAT ARRANGEMENT AND LANDSCAPE PROCESS INCLUDING USACE IMPACTS ON LANDSCAPE

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality**	**Bio Process/Quality (Tbl 6)**	**Aesthetics**	**Atmospheric humidification**	**Recreation**	**Property Value**
HABITAT PATCHINESS										
Within habitat						●	●			
Regional habitat						●				
Edge development						●	●			
HABITAT CONNECTIONS										
Intra-habitat conn.						●	●			
Inter-habitat conn.						●	●			
Air-water Interface		●				●		●		
HABITAT DIVERSITY										
Within-habitat divers.						●	●			
Between-habitat divers.						●	●			
Habitat Interspersion						●				
HUMAN HABITAT										
Foot, road & parking		●	●	●	●	●	●		●	●
Boat ramps		●	●				●		●	●
Docks, marinas, promenades		●	●	●			●		●	●
Sanitary facilities					●	●	●		●	

TABLE III-4 (Continued)
ECOLOGICAL OUTCOMES AND SERVICES DIRECTLY AFFECTED BY HABITAT ARRANGEMENT AND LANDSCAPE PROCESS INCLUDING USACE IMPACTS ON LANDSCAPE

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality**	**Bio Process/Quality (Tbl 6)**	**Aesthetics**	**Atmospheric humidification**	**Recreation**	**Property Value**
Campgrounds, picnic grounds, rest stops		●	●	●		●			●	
Tennis courts, bridle paths, golf course...			●	●					●	●
Recreation regulation			●		●	●			●	●

TABLE III-5
ECOLOGICAL OUTCOME AND SERVICES DIRECTLY AFFECTED BY
WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material Transfer (Tbl 2)**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality (Tbl 5)**	**Bio Process/Quality (Tbl 6)**	**Aesthetics**	**Recreation**	**Turbidity**	**Water Contamination**	**Damage to Equipment**	**Water Supply**	**Ecosystem Integrity Index**	**Industrial**	**Thermal Load Capacity**	**Agricultureal Benefit**
SUSPENDED PARTICULATE MATTER																
Total Suspended solids					●	●	●	●	●	●	●					
Suspended organic solids					●	●				●						
Suspended color					●		●			●						
Suspended inorganic nutrients					●	●										
Suspended toxic material						●				●						
Ratio of inorganic and organic suspended solids						●										
Suspended inorganic complexes					●	●										

TABLE III-5 (Continued)
ECOLOGICAL OUTCOME AND SERVICES DIRECTLY AFFECTED BY
WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material Transfer (Tbl 2)**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality (Tbl 5)**	**Bio Process/Quality (Tbl 6)**	**Aesthetics**	**Recreation**	**Turbidity**	**Water Contamination**	**Damage to Equipment**	**Water Supply**	**Ecosystem Integrity Index**	**Industrial**	**Thermal Load Capacity**	**Agricultureal Benefit**
Suspended organic complexes					•	•										
DISSOLVED MATTER																
Dissolved organic matter					•	•										
Water color					•		•					•				
TDS											•	•				•
Salinity						•		•			•	•				•
Hydrogen ions					•	•					•					
Oxygen					•	•					•		•			
Nitrogen gas						•					•					
Dissolved inorganic nutrients						•										•
Ionic ratios						•						•				

TABLE III-5 (Continued)
ECOLOGICAL OUTCOME AND SERVICES DIRECTLY AFFECTED BY
WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material Transfer (Tbl 2)**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality (Tbl 5)**	**Bio Process/Quality (Tbl 6)**	**Aesthetics**	**Recreation**	**Turbidity**	**Water Contamination**	**Damage to Equipment**	**Water Supply**	**Ecosystem Integrity Index**	**Industrial**	**Thermal Load Capacity**	**Agricultureal Benefit**
Biogeochemical elements					●									●		
Hardness										●			●	●		
Dissolved toxic materials						●				●			●			
ELECTROMAGNETIC																
Light transmission					●	●	●									
Temperature	●	●				●		●						●	●	
Reduction-oxidation					●											

TABLE III-6
ECOLOGICAL OUTPUTS AND SERVICES DIRECTLY AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES

ECOLOGICAL INPUTS *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material Transfer (Tbl 2)**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality (Tbl 5)**	**Bio Process/Quality (Tbl 6)**	**Building Materials**	**Grazing Forage**	**Aesthetics**	**Health Threats**	**Commercial Harvest**	**Recreational Harvest**	**Ecological Indicators**	**Endangered Species**	**Nuisance Species**	**Recreation**	**Depredation**	**Property Damage**	**Watchable Species**	**Species Richness/Abundance**	**Stratification**	**Genetic Information**	**Biotic Integrity**	**Material Retention/Export**	**Production/Respiration**	**Biogeochemical Cycling Rate**	**Solar Energy Capture**	**Trophic Level Efficiency**	**Foodweb Complexity**	**Algal Suspended Solids**
POPULATION PRODUCTION PROCESS																														
Terrestrial macrophytes				●			●	●	●																					
Decomposer populations					●																									
Pathogen populations										●																				
Aquatic macrophytes											●	●	●	●	●	●														
Planktonic algae											●	●	●		●	●														
Fin-fish populations										●	●	●	●	●			●		●											
Invertebrate populations										●	●	●	●	●	●			●	●											
Reptile & amphibian populations										●	●	●	●	●	●		●		●											

TABLE III-6 (Continued)
ECOLOGICAL OUTPUTS AND SERVICES DIRECTLY AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES

ECOLOGICAL INPUTS / *Ecological Outputs*	**Morphology (Tbl 1)**	**Water & Material Transfer (Tbl 2)**	**Substrate (Tbl 3)**	**Habitat Arrangement (Tbl 4)**	**Water Quality (Tbl 5)**	**Bio Process/Quality (Tbl 6)**	**Building Materials**	**Grazing Forage**	**Aesthetics**	**Health Threats**	**Commercial Harvest**	**Recreational Harvest**	**Ecological Indicators**	**Endangered Species**	**Nuisance Species**	**Recreation**	**Depredation**	**Property Damage**	**Watchable Species**	**Species Richness/Abundance**	**Stratification**	**Genetic Information**	**Biotic Integrity**	**Material Retention/Export**	**Production/Respiration**	**Biogeochemical Cycling Rate**	**Solar Energy Capture**	**Trophic Level Efficiency**	**Foodweb Complexity**	**Algal Suspended Solids**
Bird populations										●		●	●	●	●		●		●											
Mammal populations										●	●	●		●	●		●		●											
COMMUNITY PROCESS																														
Biodiversity																				●	●	●								
Biological integrity													●										●	●	●	●	●	●	●	
Community metabolism			●	●	●																									●

TABLE III-7

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHIC PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Resource Surface Area[15]	Total use area: usable surface for various activities. [acres, ha, km, miles]	beach swimming	visitor days	Willingness to pay (WTP)		+				+
		tubing	visitor days	WTP			+			
		snorkeling	visitor days	WTP		+	+			+
		scuba	visitor days	WTP		+				+
		non-motor rafting, canoeing, kayaking	visitor days	WTP		+	+	+	+	+
		sail boating	visitor days	WTP		+	+		+	+
		small outboard-motor and air boats	visitor days	WTP		+	+	+	+	+
		inboard recreational craft	visitor days	WTP		+	+		+	+
		commercial craft	$	income		+	+		+	+
		various land uses including commercial, recreational and cultural-natural heritage.	visitor days, $ property foregone	WTP, income, appraisal value foregone	-	-	-	-	-	-
	Aesthetic: sense of space and horizon [%, degrees of view]	pleasing environment	$ property, visitor days	property value, WTP	+-	+-	+-	+-	+-	+-
	Total area of productive habitat [acres, ha]	*indirect effect biological processes*	*See Table III-12 outputs for the range of possible impacts on human services. Most population and community processes are expressed per unit area, but require conversion to total abundance and other total measures by multiplying by project surface area.*							

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Resource Area Fluctuation[16]	Concentration and dilution effect [range of acres, ha]	*indirect effect via consistency of biological processes*	*See Table III-12 outputs for details. Surface area fluctuation concentrates and dilutes biological processes, altering ecological functions and human services. As consistency decreases benefits usually decrease.*							
	Fluctuation of use base	*boating*	*See this Table outputs on usable surface area for more detail. Consistency of useable space is an independent factor determining average utility. Benefits increase with consistency.*							
		swimming	*See this Table outputs on usable surface area for more detail. Consistency of useable space is an independent factor determining average utility. Benefits increase with consistency.*							
		aesthetics consistency	visitor days, $ property	WTP, income	+-	+-	+-	+-	+-	+-
	Shore protection [shore miles (km, m), acres (ha)]	property protection	developed area	damages avoided		+	+	+	+	+
		indirect effect via biological processes	*See Table III-12 outputs for detail. Numerous shore-oriented population and community processes are affected by barrier-beach and other shorezone integrity. As shorezone integrity increases biotic integrity usually increases, but individual populations may decrease.*							
		indirect effect via water quality	*See Table III-11 outputs for detail. Numerous chemical and physical attributes are determined by the integrity of barrier-beach and other shorezone conditions. Output-benefit relations are complex.*							
Volume[17]	Storage capacity [acre-ft, and m^3]	flood control	flood damage	damages avoided		+	+	+	+	
		sediment control	sediment load	damages avoided	+	+		+		
		water supply upon demand	supply consistency	WTP, income		+				
	Total material and energy content [Kg, Kcal]	*indirect effect via biological process*	*See Table III-12 outputs for detail. Total organismic volumes are determined by concentration and total habitat volume. Mixed benefit effects as biomass increases, depending on desirability of populations and their water quality side effects.*							
		indirect effect via water quality	*See Table III-11 outputs for detail. Total material and energy amounts are determined by concentration and volume. Total oxygen, for example, determines BOD and COD that can be assimilated; total heat content determines cooling water potential. Mixed benefits depending on material desirability.*							

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Volume (cont.)	Concentration and dilution [kg, Kcal]	*indirect effect via biological process*	*See Table III-12 outputs for detail. Population concentrations and dependant rate functions are affected by volumetric fluctuations. Output-benefits relations are complex, depending on individual population composition and side effects (e.g., eutrophication).*							
		indirect effect via water quality	*See Table III-11 outputs for detail. Virtually all water quality measures are diluted or concentrated by relative proportions of source-water inflows. Complex output-benefit relations depending on material composition, distribution and amount.*							
	Water discharge sustainability [m³/sec, ft³]	downstream recreation and commercial navigation needs.	visitor days, $ property	WTP, income		+	+		+	
		indirect effect via instream flows supporting biological processes	*See Table III-10 and Table III-12 outputs for details. Biological processes in flowing waters depend fundamentally on water supply rate (discharge). While instream production benefits may increase with optimum instream flow, regional benefits may decrease.*							
	Oxygen load and concentration [mg/liter]	*indirect and off-site effect via downstream biological processes*	*See Table III-12 for output detail. Oxygen is a basic life requirement and rate regulator for virtually all macroorganisms. Production-related benefits usually increase when oxygen is supplied enough to satisfy most populations.*							
		indirect effect via off-site downstream water quality	*See Table III-11 for output detail. Oxygen is a primary determinant of reduction-oxidation environments and the form and distribution of many elements and their compounds. It also determines the amount of BOD and COD that may be assimilated as waste.*							
	Thermal load [Kcal, BTU]	*indirect and off-site effect via downstream biological process*	*See Table III-12 for output details. Heat concentration, temperature, is a basic determinant of life process rate. Complex output and benefits relationships.*							
		indirect and off-site effect via downstream water quality	*See Table III-11 for output details. Temperature influences chemical reaction rates and indirectly determines heat assimilation and industrial cooling capacities.*							
	Material loads [mg/liter]	*indirect and off-site affect via downstream biological process*	*See Table III-12 for output details. A variety of nutrient, toxic and other materials influence biological process rates. Also living organisms are transported downstream with various effects on downstream communities.*							
		indirect and off-site effect via downstream water quality	*See Table III-11 for output details. Downstream water quality is fundamentally determined by upstream input.*							
		indirect and off-site effect via downstream habitat arrangements	*See Table III-10 for output details. Downstream habitats are basically determined by sediment and nutrient supply from upstream sources.*							

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Volume (cont.)	Material loads (cont.) [mg/liter]	*indirect and off-site effect via downstream channel shape*	*See other Table III-7 outputs for details. Upstream material load is a basic determinant of channel shape and dynamics.*							
	Hydraulic attributes [m^3/sec, ft^3/sec]	*indirect and off-site effect via downstream morphologic process*	*See other Table III-8 outputs for details. Discharge and other water and material transport attributes combine with material supply to determine downstream morphologic process.*							
		indirect and off-site effect via downstream habitat arrangements and landscape processes	*See Table III-10 outputs for detail. Material supply and water and material transport attributes are the major determinants of habitat arrangement and diversification in downstream environments.*							
Depth[18]	Clearance to bottom [meters, feet, fathoms]	*boating*	*See this Table, Surface area, for more detail. Channel depth and flow rates are primary determinants of navigation type.*							
		swimming	*See this Table, surface area, for more detail. Channel depth and flow rates are primary determinants of swimming use by type.*							
		indirect effect via biological processes	*See Table III-12 for output details. Depth is a determinant of population distribution for numerous species.*							
		indirect effect via water quality	*See Table III-11 for output details. Depth of pure water determines light transmission and heat distribution.*							
	Particle resuspension [mg/liter]	*indirect effect via biological process*	*See Table III-12 for output details. Depth determines the extent that surface generated mixing influences sediment stability and resuspension, thus influences biological distributions and nutrition.*							
		indirect effect via water quality	*See Table III-11 for output details. Because of surface generated mixing, depth to sediments greatly determines water quality attributes.*							
	Vertical mixing [water density variation, tracers]	*indirect effect via water and material transport*	*See Table III-8 for output details. Depth affects mixing effectiveness, turbulence and flow velocity, and erosion, transport and deposition.*							
	Tailwater discharge depth [feet, meters]	*indirect and off-site effect via tailwater biological processes*	*See Table III-12 for output details. Because depth is a major factor determining organism distribution in lakes, it also contributes to determining biological properties of water released to downstream environments.*							

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Depth (cont.)	Tailwater discharge depth (cont.)	*indirect and off-site effect via tailwater water quality*	*See Table III-11 for output details. Because depth is a major factor determining mixing rates generated by surface phenomena, it contributes to determining water quality variation in depth profiles.*							
	[feet, meters]	hydroelectric	Kwatts	alternative cost savings		+	+			
Water Area-depth Ratio[19]	Evapotranspiration	*indirect effect via water quality*	*See Table III-11 for output details. Evapotranspiration concentrates materials of all kinds and influences salinity and constituents greatly in some areas, and affects temperature.*							
		indirect effect via morphologic typographic process	*See other outputs from Table III-7. Evapotranspiration influences volumes, surface areas and depths.*							
Fetch [20]	Turbulent mixing [epilimnetic depth, formulae]	*indirect effect via water and material transport*	*See Table III-8 for more detail. Wind acting on the fetch is the main mixing force for waters not moved by gravity.*							
Slope[21]	Lake basin slope [%, degrees]	*boating*	*See this Table, surface area, for more detail. Rates of depth change, slope, are important determinants of boating suitability and safety.*							
		swimming	*See this Table, surface area, for more detail. Rates of depth change, slope, are important determinants of swimming suitability and safety.*							
		indirect effect via biological process	*See Table III-12 for more output detail. Distributions and movements of many larger organisms are related to slope, which is an indicator of the proximity of different habitats.*							
		aesthetics of waterbody and adjacent shore	visitor days, $ property	WTP, income, appraisals, insurance	+-	+-	+-	+-	+-	+-
		indirect effect via water quality	*See Table III-11 for more details. Locations of intakes and outlets, in part determined by slope, also affect water quality.*							
	Channel slope	*indirect effect via biological process*	*See Table III-12 for more output detail. Distributions and movements of many stream organisms are related to slope.*							
		boating	*See this Table, surface area, for more detail. Rates of depth change are important determinants of boating utility.*							
		swimming	*See this Table, surface area, for more detail. Rates of depth change are important determinants of swimming utility.*							

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Slope (cont.)	Channel slope (cont)	*indirect effect via water quality*	*Slope determines locations of water intakes and outlets, in part determining water quality*							
		hydropower generation (head)	Kwatts	alternative cost savings				+		
		flood control	flood damage	damages avoided			–		–	
		indirect effect via water and material transport	*See this Table, storage capacity and Tables III-9, III-10, III-11 and III=12 for more detail. Erosion and deposition are major dynamics affecting virtually all water-based ecological outputs.*							
		aesthetics of waterbody and adjacent shore	visitor days, $ property	WTP, income, appraisals,			+		+	
	Watershed slope [%, degree]	*indirect effect via water and material transport*	*See Table III-8 for more detail. Watershed slope is a variable determining runoff depth and shear stress on watershed substrates.*							
Shoreline Length[22]	Organic detritus supply [km, miles riparian cover]	*indirect effect via biological process*	*See Table III-12 for detailed output. Many aquatic organisms are influenced by the riparian input of organic matter used as foods.*							
		indirect effect via water quality	*See Table III-11 for detailed output. Water quality is influenced by riparian material inputs.*							
	Riparian shade	*indirect effect via biological process*	*See Table III-12 for detailed output. Shade is a cover for many organisms.*							
		indirect effect via water quality	*See Table III-11 for detailed output. Shade determines amounts of subsurface light and temperature.*							
		shore recreation	visitor days, $ property	WTP, income, appraisal		+	+	+	+	+
	Terrestrial organism water use [km, miles of shore]	*indirect effect via biological process*	*See Table III-12 for detailed output. Proximity of water to terrestrial environments provides many organisms with necessary water, food or cover.*							
	Shore erosion	*indirect effect via biological process*	*See Table III-12 for detailed output. Many aquatic and terrestrial riparian organisms are affected by erosion and deposition process.*							
		shoreline property	$ property value	damage avoided		_	_	_	_	_

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Shoreline Length (cont.)	Shore erosion (cont.)	shore recreation	visitor days	WTP, protection costs		–	–	–	–	–
		aesthetics	visitor days	WTP		_	_	_	_	_
Shoreline Irregularity[23]	Ratio of shoreline length to water area [miles/acres, km/ha]	aesthetics	visitor days, $ property	WTP, income		+	+	+	+	+
		indirect effect via biological process	*See Table III-12 for more detail. Rates and effectiveness of many riparian-organism interactions are related to this ratio.*							
		indirect effect via water and material transport	*See Table III-8. Erosion and deposition is much affected by the open water available for wind and gravity driven currents to operate without energy dissipation.*							
Channel Form[24]	Wetted Perimeter [m^2, acres]	*indirect effect via water and material transport*	*See Table III-8 for more detail. Wetted perimeter controls depth, velocity and width interactions as discharge changes.*							
		indirect effect via biological process	*See Table III-12 and this Table, surface area. Wetted perimeter is a truer measure of benthic surface for life processes than mapped surface area.*							
		indirect effect via morphologic process	*See this Table under depth, hydraulic retention, and surface area. Increased wetted perimeter increases depth, surface area and hydraulic retention.*							
	Sinuosity (meander radius, and length) [m, ft]	*indirect effect via water and material transport*	*See Table III-8 for more detail. Meander radius, length and amplitude controls depth, velocity and width interactions and the probability of floodplain flooding*							
		aesthetics	visitor days, $ property	WTP, income			+-		+	
		indirect effect via habitat arrangement and landscape process	*See Table III-10 for more detail. Meander radius predicts variation in flowing habitats, such as riffle and pool relationships and ratios.*							
		indirect effect via morphologic process	*See this Table under depth, hydraulic retention, and surface area. Increased meander radius is associated with increased depth, surface area, hydraulic retention and floodplain flooding.*							
		boating	*See this Table under surface area for more detail. Increased meander radius increases the distance travel between two points on a river system thus requires more time and costs.*							
	Stream braidedness [channel #]	aesthetics	visitor days, $ property	WTP, income, appraisal			+-			
		Indirect effect via habitat arrangement and landscape processes	*See Table III-10 for detail. Braiding creates a network of channels and islands which results in habitat patchiness and habitat instability.*							

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Floodplain Form[25]	Floodplain storage capacity [acre-ft, m^3]	flood impacts on adjacent floodplain	flood damage, visitor days	damage avoided			+	+	+	
		downstream flood impacts	flood damage and visitor days	damage avoided		-	-	-	-	
		indirect effect via substrate	*See Table III-9 for detail. Floodplain storage capacity alters substrate suitability for plant and animal colonization and growth in riparian communities.*							
		indirect effect via habitat arrangement and landscape process	*See Table III-10 for detail. Floodplain development increases habitat diversity, often enhancing the integrity of scarce ecosystems.*							
		direct effect and indirect effect via groundwater recharge	*See Table III-8 for detail. Recharge sustains predictable downslope streamflow, lake and wetland supply.*							
			water supply	WTP, income, appraisals			+	+		
Watershed Form[26]	Impermeable surface [acres, ha]	*indirect effect via biological process*	*See Table III-12 for detail. Most effect is on suitable substrate for vegetation development. Biological production benefits are decreased by increasing impenetrable surface.*							
		indirect effect via water and material transport	*See Table III-8 for detail. Impenetrable surface determines proportions of surface and groundwater runoff. It typically increases runoff depth and material erosion from erodible watershed surface.*							
		indirect effect via water quality	*See Table III-12 for detail. Amounts and forms (suspended or dissolved) of eroded materials determining water quality are determined by proportion of ground and surface runoff.*							
		indirect effect via habitat arrangement and landscape process	*See Table III-10 for detail. Variation in watershed penetrability and depth to ground water are basic determinants of habitat arrangement and diversity. The amount, arrangement and degree of impenetrability interact to determine some optimum habitat condition in watershed and downslope water bodies, will not be maximum when all watershed surface is maximally penetrable.*							
		direct and indirect effect via groundwater recharge	*See Table III-8 for detail. Groundwater sustains downslope flows into rivers, lakes and wetlands.*							
			water supply	WTP, income appraisal	-					

TABLE III-7 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATERSHED, BASIN, AND CHANNEL MORPHOLOGICAL AND TOPOGRAPHICAL PROCESS[1]

Corps-Influenced Ecological Input[2]	Ecologic Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Watershed Form (cont.)	Depression storage [acre ft, m^3]	*indirect effect via biological process*	*See Table III-12 for range of impacts possible. Depression storage determines different watershed soil moisture, temporary ponding, and dependent biological processes.*							
		indirect effect via water & material transport	*See Table III-8 for detail. Increased depression storage decreases runoff depth and velocity, thus decreases net watershed erosion.*							
		indirect effect via water quality	*See Table III-11 for detail. Depression storage increases retention of surface materials and usually encourages a greater proportion of dissolved material runoff.*							
		indirect effect via habitat arrangement and landscape process	*See Table III-10 for detail. Large depressions in watersheds greatly contribute to habitat variation and arrangements in the watershed and adjacent water bodies.*							
		indirect and direct effect via groundwater recharge	*See Table III-8 for detail. Groundwater sustains stable downslope river flows, and elevations in lakes and wetlands.*							
			water supply	WTP, income, appraisal	+					

1. Morphologic topographic process is directly affected by Corps activities, usually by creating basins and channels through building barriers, dredging and filling.
2. Ecological input variables effecting ecological outputs vary with project. Input variables are either directly or indirectly influenced by Corps management decisions. Project effectiveness is evaluated by examining the collective effects of all Corps influenced inputs.
3. Ecological outputs are physical, chemical and biological responses to natural or human-caused changes in the environment.
4. Human services are the social functions performed by the ecological output.
5. The more common measures of human services are provided for each category; project services may vary from the most common measures.
6. The form of benefit provided by the human service. Only the most prominent forms of benefit are provided.
7. Human demand for the service will be unique for each project and needs to uniquely evaluated. Considerations for estimating demand include:
   a. Regional presence of high demand of the targeted resources in total or per unit area.
   b. Periodic shortages of resource availability or access, for example, when visitors are turned away from use areas on weekends or water rationing.
   c. Legal mandates for services including environmental laws and standards.
   d. Stakeholder willingness to contribute funding to project development.
   e. Potential for use in environmental education.
   f. Specific non-use value for a particular natural resource, which can be found at very few locations, including the project location.
8. Major water resource divisions are identified here. A plus, minus, or both indicates the usual relationship between ecological output and benefit) whether it is positive or negative as ecological output increases. Where no value is provided, the service for that category is considered minor or non-existent, although specific project conditions may be exceptional.
9. The watershed category includes all projects contributing surface and subsurface (groundwater input) as well as downslope watershed influenced by the project.
10. The lake category includes all inland waters occupying basins, either temporary or permanent, with a level surface; they may be natural or artificial, including those formed by dams and dikes, and by dredging. Morphology and water and material transport characteristics physically determine more specific lake categories for each project.

11. The river category includes all flows occupying channels and generated on a slope by gravity, temporary or permanent; they may be natural or artificial, including excavated and otherwise engineered water conveyances.
12. The wetland category includes all areas in which soils are temporarily to permanently flooded inland and coastal sites and often support, or could support, indicator plant growth. These are highly variable in form and include marshes, swamps, and bogs in various forms. Wetland types are usually defined by their proximity to other water resources, such as estuarine marshes and riverine bottomlands.
13. The estuary category includes all water bodies where marine and inland waters converge, are affected by tides, and often, but not necessarily, vary in salt content.
14. Oceanic coastal areas occur where undiluted ocean water meets shore, thus lie beyond the obvious effect of inland water runoff.
15. Resource surface area usually is managed by damming or otherwise changing water depth.
16. Area fluctuation is managed mainly through placement of impoundments and operation of water and sediment control structures such as dams, dikes, and levees, or by mechanical movement of sediment.
17. Volume is managed mostly through placement of impoundments, operation of water-control structures and via dredging and filling.
18. Depth is managed primarily through placement and operation of impoundments and other water-control structures, and through dredging and filling activities.
19. The area-depth ratio is managed by control structure placement and operations and by dredging and filling effects on basin shapes (area-volume-depth relationships).
20. Fetch is managed by placement and management of water control structures.
21. Slope is managed mostly by the placement of water control structures and their operation, but also through dredging and filling activity.
22. Shoreline length is managed water-level and discharge control, beach nourishment, dredging.
23. Shoreline irregularity is managed through water-level control, dredging and filling.
24. Channel form is managed by control of water and material discharge, river control structure construction and operation, and dredging or other artificial channel development.
25. Floodplain form is managed by water-level control, discharge control of water and material, depression filling or excavation and construction and operation of dikes and levees.
26. Watershed form is managed mostly by vegetation management and management of the impermeable surface.

TABLE III-8

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATER AND MATERIAL TRANSPORT PROCESS INCLUDING USACE IMPACT ON ECOSYSTEM TRANSPORT PROCESS[27]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Discharge[28]	Watershed discharge and load [m^3, ft^3, kg, tonnes]	*indirect effect via biological process*	*See Table III-12 for detailed output. Discharge and load haves indirect effects on virtually all biological process via effects of depth, velocity and abrasion by transported material*							
		indirect effect via water quality	*See Table III-11 for detailed output. Discharge and load determine water quality.*							
		indirect effect via substrate	*See Table III-9 for details. Watershed discharge determines watershed topography with other factors.*							
	Waterbody discharge and load [m^3, ft^3, kg, tonnes]	*indirect and off-site effect via biological process downstream*	*See Table III-12 for detailed output. Discharge and load have indirect effects on all biological process via effects on water quality, depth, velocity and abrasion by transported material.*							
		indirect effect via morphologic process	*See Table III-7 for details. Waterbody discharge determines the depth, surface area, volume and other morphologic processes of the water body and downstream channel discharge.*							
		indirect and off-site effect via downstream substrate	*See Table III-9 for detailed output. Discharge and load have indirect effects on substrate composition, stability, and consolidation.*							
		indirect and off-site effect via water quality downstream	*See Table III-11 for detailed output. Discharge affects on load determine water quality.*							
		flooding both upstream and downstream	area affected, visitor days, property $	WTP, income, appraisal, insurance	-	-	-	-	-	-
	Hydraulic retention [discharge/volume (days)]	*indirect effect via biological process*	*See Table III-12 for detailed output. Major effects are on flushing of water body/inhabitants downstream.*							
		indirect effect via substrate	*See Table III-9 for detailed output. Hydraulic retention influences sedimentation accumulation rate.*							
		indirect effect via water quality	*See Table III-11 for detailed output. Hydraulic retention influences sedimentation rate of particulate materials.*							

TABLE III-8 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATER AND MATERIAL TRANSPORT PROCESS INCLUDING USACE IMPACT ON ECOSYSTEM TRANSPORT PROCESS[27]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Discharge (cont.)	Channel discharge and load [m^3, ft^3, kg, tonnes]	*indirect effect via biological process*	*See Table III-12 for detailed output. Discharge and load determine biological qualities, mainly through effects on velocity and abrasion.*							
		indirect effect via morphologic process	*See Table III-7 for detailed output. Channel discharge determines with other factors, width, depth, and other morphology.*							
		indirect effect via water quality	*See Table III-11 for detailed output. Discharge and load interact to determine concentrations of most water quality variables.*							
		flooding	area & property affected, visitor days,	WTP, income, appraisal, insurance	-	-	-	-	-	-
		boating	*See Table III-7, surface area, for detailed types. Discharge determines velocity and depth of channel*							
		swimming	*See Table III-7, surface area, for detailed types. Discharge determines velocity and depth.*							
Current, Turbulence & Wave Height[29]	Surface turbulence and wave height [cm/sec, m, ft, tracers]	*boating*	*See Table III-7, surface area, for detailed types. Turbulence determines resistance to a subsidy for boat velocity and control.*							
		swimming	*See Table III-7, surface area, for detailed types. Turbulence determines resistance to or subsidy to swimming velocity and reduces control.*							
		indirect effect via biological process	*See Table III-12 for detailed outputs. Turbulence determines habitat and stability, swimming resistance, and planktonic suspension.*							
		indirect effect via water quality	*See Table III-11 for detailed outputs. Turbulence determines gas exchange rates between air and water, and entrainment of atmospheric gasses.*							
		indirect effect via substrate	*See Table III-9 for detailed outputs. Turbulence determines substrate stability and erosion rates in part.*							
	Vertical and horizontal mixing	*indirect effect via biological process*	*See Table III-10 for detailed outputs. Turbulence determines homogeneity of aquatic habitats. Variation in turbulence contributes importantly to habitat variation.*							
		indirect effect via water quality	*See Table III-11 for details. Turbulence determines relative homogeneity of dissolved and suspended matter throughout the habitat.*							

TABLE III-8 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY WATER AND MATERIAL TRANSPORT PROCESS INCLUDING USACE IMPACT ON ECOSYSTEM TRANSPORT PROCESS[27]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Current, Turbulence & Wave Height (cont.)	Erosion, transport and deposition dynamics [kg/m², mg/l]	*indirect effect via substrate*	*See Table III-9 for details. Erosion and deposition are major determinants of substrate condition depend on transport capacity of waterbodies.*							
		indirect effect via water quality	*See Table III-11 for details. Transport capacity determines form (suspended or dissolved) and amounts of materials in the water column.*							
		indirect effect via morphologic process	*See Table III-7. Degradation and aggradation are major forces shaping basins and channels.*							
		indirect effect via biological process	*See Table III-12 for detail. Forces affect ability of organisms to sustain position and to obtain food and cover resources.*							
		indirect effect via habitat arrangement and process	*See Table III-10 for detail. Erosion and deposition are major forces shaping the arrangements of habitats within waterbodies and adjacent riparian and watershed areas.*							

1. Morphologic topographic process is directly affected by Corps activities, usually by creating basins and channels through building barriers, dredging and filling.
2. Ecological input variables effecting ecological outputs vary with project. Input variables are either directly or indirectly influenced by Corps management decisions. Project effectiveness is evaluated by examining the collective effects of all Corps influenced inputs.
3. Ecological outputs are physical, chemical and biological responses to natural or human-caused changes in the environment.
4. Human services are the social functions performed by the ecological output.
5. The more common measures of human services are provided for each category; project services may vary from the most common measures.
6. The form of benefit provided by the human service. Only the most prominent forms of benefit are provided.
7. Human demand for the service will be unique for each project and needs to uniquely evaluated. Considerations for estimating demand include:
   a. Regional presence of high demand of the targeted resources in total or per unit area.
   b. Periodic shortages of resource availability or access, for example, when visitors are turned away from use areas on weekends or water rationing.
   c. Legal mandates for services including environmental laws and standards.
   d. Stakeholder willingness to contribute funding to project development.
   e. Potential for use in environmental education.
   f. Specific non-use value for a particular natural resource, which can be found at very few locations, including the project location.
8. Major water resource divisions are identified here. A plus, minus, or both indicates the usual relationship between ecological output and benefit)whether it is positive or negative as ecological output increases. Where no value is provided, the service for that category is considered minor or non-existent, although specific project conditions may be exceptional.
9. The watershed category includes all projects contributing surface and subsurface (groundwater input) as well as downslope watershed influenced by the project.
10. The lake category includes all inland waters occupying basins, either temporary or permanent, with a level surface; they may be natural or artificial, including those formed by dams and dikes, and by dredging. Morphology and water and material transport characteristics physically determine more specific lake categories for each project.
11. The river category includes all flows occupying channels and generated on a slope by gravity, temporary or permanent; they may be natural or artificial, including excavated and otherwise engineered water conveyances.
12. The wetland category includes all areas in which soils are temporarily to permanently flooded inland and coastal sites and often support, or could support, indicator plant growth. These are highly variable in form and include marshes, swamps, and bogs in various forms. Wetland types are usually defined by their proximity to other water resources, such as estuarine marshes and riverine bottomlands.
13. The estuary category includes all water bodies where marine and inland waters converge, are affected by tides, and often, but not necessarily, vary in salt content.
14. Oceanic coastal areas occur where undiluted ocean water meets shore, thus lie beyond the obvious effect of inland water runoff.
27. Water and material transport includes all those attributes of discharge, current, and turbulence that determine erosion, load transport, and deposition of materials.
28. Discharge is managed by watershed management and operation of water control structures.
29. Currents and turbulence are managed primarily through management of discharge, channel form and placement of wing-dams, sediment islands, groins and other barriers.

TABLE III-9

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY SUBSTRATE INCLUDING THE USACE IMPACTS ON SUBSTRATE[30]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Substrate Particle Structure[31]	Substrate particle size [mm]	*indirect effect via biological process*	*See Table III-12 for details. Substrate particle size determines rooting, burrowing and other utility of substrate resources, and contributes greatly to population and community processes.*							
		indirect effect via water quality	*See Table III-11 for details. Substrate particle size determines interstitial space development, water mixing in the substrate, and active particle surface area for release and absorption of materials determining water chemistry.*							
		aesthetics (e.g., emergent marsh, submerged rock and vegetation)	visitor days, $ property	WTP, income, appraisals	+-	+-	+-	+-	+-	+-
		swimming	*See Table III-7, surface area, for more detail. Particle size determines suitability for many swimming activities.*							
		morphology	*See Table III-7, wettable perimeter, for more detail. Particle size on the bottom surface determines wettable perimeter.*							
	Particle density [Wt/volume]	*indirect effect via biological process*	*See Table III-12 for more detail. Density affects rooting, burrowing and other biological activity influencing relative resource utility.*							
		indirect effect via water and material transport	*See Table III-8 for more details. Particle density influences the erosion capacity of water flow with a specified shear stress and the deposition of particles transport capability changes.*							
		indirect effect via water quality	*See Table III-11 for more details. Density contributes to likelihood of transport and inclusion in suspended material measures of water quality.*							
	Particle shape [descriptive]	*indirect effect via biological process*	*See Table III-12 for more details. Particle shape determines ratio of surface area to volume and attachment space as well as corridors for movement through habitats.*							
		indirect effect via water and material transport	*See Table III-8 for more detail. Particle shape determines substrate anchoring and erosion resistance; elongate particles are more likely to become anchored than spherical particles.*							
		indirect effect via water quality	*See Table III-11 for more detail. High ratio of surface area to volume increases substrate solubility and the probability of incorporation into the water column as suspended material.*							
	Substrate particle roughness and abrasiveness [descriptive]	*indirect effect via biological process*	*See Table III-12 for more detail. Particle roughness determines abrasiveness to organisms where they come in close contact and habitat suitability.*							
		indirect effect via water and material transport	*See Table III-8 for more detail. Variation from smooth surface increases resistance to erosion forces and increases transportability once eroded.*							

TABLE III-9 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY SUBSTRATE INCLUDING THE USACE IMPACTS ON SUBSTRATE[30]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Particle Structure (cont.)	Substrate particle roughness and abrasiveness (cont.) [descriptive]	*indirect effect via water quality*	*See Table III-11 for more detail. Roughness increases surface area for chemical erosion.*							
	Substrate particle aggregation [descriptive]	*indirect effect via biological process*	*See Table III-12 for more detail. Aggregation, as formed by clay cohesion and root growth, affects resource utility by different populations.*							
		indirect effect via water and material transport	*See Table III-8 for more detail. Aggregation increases mass resistant to erosive displacement.*							
		indirect effect via water quality	*See Table III-11 for more detail. Aggregation affects solubility through surface-volume relationships and interstitial extent.*							
	Substrate particle stability [movement/time]	*indirect effect via biological process*	*See Table III-12 for more detail. Substrate stability determines the reliability of substrate as support and cover for all species.*							
		indirect and direct effect via construction support	*property $, highways, sewerage, etc*	*income, WTP*	+	+	+	+	+	+
			See Table III-8 for detail. Substrate stability determines erosion.							
	Substrate particle compaction [weight/volume corrected for particle density]	*indirect effect via biological process*	*See Table III-12 for detail. Substrate compaction affects root growth, burrowing and other biological process.*							
		construction support in floodplains and watersheds	property $, highways, sewerage, etc	income, WTP	+		+			
		indirect effect via water and material transport	*See Table III-8 for detail. Compaction determines substrate erosion.*							
Substrate Chemistry[32]	Organic-matter content [fraction, mg/Kg]	aesthetics	visitor days, $ property	WTP, income, appraisals	+-	+-	+-	+-	+-	+-
		swimming	*See Table III-7, surface area, for more detail. Organic content affects the substrate suitability for wading etc.*							

TABLE III-9 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY SUBSTRATE INCLUDING THE USACE IMPACTS ON SUBSTRATE[30]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Substrate Chemistry (cont.)	Organic-matter content (cont.) [fraction, mg/Kg]	*indirect effect via biological process*	*See Table III-12 for detail. A base for benthic detritus feeders and food chains.*							
		indirect effect via water and material transport	*See Table III-8 for detail. Living and dead roots and branches and other litter add stability to substrates and erosion resistance.*							
		indirect effect via water quality	*See Table III-11 for details. Absorbs many nutrient, toxic and other materials depending on reduction-oxidation state. Exerts oxygen demand on water in and above the sediment, thus greatly influencing reduction-oxidation environment. Also affects carbon dioxide, carbonic acid and hydrogen ion concentration, also influencing reduction-oxidation environment.*							
	Nutrient content [mg/l, mg/kg]	*indirect effect via biological process*	*See Table III-12 for details. Important for root uptake.*							
		indirect effect via water quality	*See Table III-11 for details. Determines in part the amount of soluble nutrient transferred to interstitial water and water column.*							
	Toxic contaminant content	*indirect effect via biological process*	*See Table III-12 for details. Toxic material uptake and impacts important for benthic organisms.*							
		indirect effect via water quality	*See Table III-11 for details. Toxic materials, depending on solubility and transport, are transferred to interstitial water and water column.*							
	Material solubility [weight loss rate]	*indirect effect via biological process*	*See Table III-12 for details. Solubility is critical for root uptake of nutrients as a consequence of their impact on reduction-oxidation environment. Determined greatly by the amount of carbonate and other soluble material in the substrate particles.*							
		indirect effect via water and material transport	*See Table III-8 for details. Soluble matter is more readily transported.*							
		indirect effect via water quality	*See Table III-11 for details. Substrate solubility is a basic determinant of interstitial water quality and transfer to the water quality.*							
Substrate Orientation and Development[33]	Within-habitat vertical development [m, ft]	*indirect effect via biological process*	*See Table III-12 for details. Provides physical diversity for food and cover and influences hydraulic energetics to trap sediments and associated organics. Major factor for determining ecological pathways and diversity.*							
		indirect effect via morphologic process	*See Table III-7 for details. Horizontal development of structure influences channel and basin shapes, directly and indirectly through water and material transport.*							
		indirect effect water and material transport	*See Table III-8 for details. Structural development changes flow patterns and energies.*							

TABLE III-9 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY SUBSTRATE INCLUDING THE USACE IMPACTS ON SUBSTRATE[30]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Service or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Substrate Orientation and Development (cont.)	Within habitat vertical development (cont.) [m, ft]	*indirect effect via habitat arrangement and landscape process*	*See Table III-10 for details. Structural development changes habitat arrangements.*							
		indirect effect via water quality	*See Table III-11 and this Table above for details. Structural development creates greater absorption surface and sequestering and release of nutrient and toxic materials depending on reduction-oxidation and transport environments.*							
		aesthetics--as created by spacial diversification of shape and color in submerged marshes etc.	visitor days, $ property	WTP, income, appraisal	+	+	+	+	+	+
	Between-habitat vertical development	*indirect effect via biological process*	*See Table III-12 for details. Structural development increases surface amount and diversity of physical niches for population resource utility. Vertical development creates movement corridors for many organisms using both aquatic and terrestrial environments.*							
		morphometric aetonographic process	*See Table III-7 for details. Structural development alters channel and basin shape and associated dimensions.*							
		indirect effect via water and material transport	*See Table III-8 for details. Structural development alters substrate resistance to erosion and hydraulic energetics operating on substrates.*							
		indirect effect via water quality	*See Table III-11 for details. High surface area: volume ratio provides much absorption surface for sequestering various toxic and nutrient materials.*							
		indirect effect via habitat arrangement and landscape process	*See Table III-10 for more detail. Creates connections between quite different environments resulting in a diverse physical space such as in marshes and swamps.*							
		aesthetics--as affected by spacial diversification in emergent marshes etc.	visitor days, $ property	WTP, income, appraisal	+	+	+	+	+	+

1. Morphologic topographic process is directly affected by Corps activities, usually by creating basins and channels through building barriers, dredging and filling.
2. Ecological input variables effecting ecological outputs vary with project. Input variables are either directly or indirectly influenced by Corps management decisions. Project effectiveness is evaluated by examining the collective effects of all Corps influenced inputs.
3. Ecological outputs are physical, chemical and biological responses to natural or human-caused changes in the environment.

4. Human services are the social functions performed by the ecological output.
5. The more common measures of human services are provided for each category; project services may vary from the most common measures.
6. The form of benefit provided by the human service. Only the most prominent forms of benefit are provided.
7. Human demand for the service will be unique for each project and needs to uniquely evaluated. Considerations for estimating demand include:
   a. Regional presence of high demand of the targeted resources in total or per unit area.
   b. Periodic shortages of resource availability or access, for example, when visitors are turned away from use areas on weekends or water rationing.
   c. Legal mandates for services including environmental laws and standards.
   d. Stakeholder willingness to contribute funding to project development.
   e. Potential for use in environmental education.
   f. Specific non-use value for a particular natural resource, which can be found at very few locations, including the project location.
8. Major water resource divisions are identified here. A plus, minus, or both indicates the usual relationship between ecological output and benefit)whether it is positive or negative as ecological output increases. Where no value is provided, the service for that category is considered minor or non-existent, although specific project conditions may be exceptional.
9. The watershed category includes all projects contributing surface and subsurface (groundwater input) as well as downslope watershed influenced by the project.
10. The lake category includes all inland waters occupying basins, either temporary or permanent, with a level surface; they may be natural or artificial, including those formed by dams and dikes, and by dredging. Morphology and water and material transport characteristics physically determine more specific lake categories for each project.
11. The river category includes all flows occupying channels and generated on a slope by gravity, temporary or permanent; they may be natural or artificial, including excavated and otherwise engineered water conveyances.
12. The wetland category includes all areas in which soils are temporarily to permanently flooded inland and coastal sites and often support, or could support, indicator plant growth. These are highly variable in form and include marshes, swamps, and bogs in various forms. Wetland types are usually defined by their proximity to other water resources, such as estuarine marshes and riverine bottomlands.
13. The estuary category includes all water bodies where marine and inland waters converge, are affected by tides, and often, but not necessarily, vary in salt content.
14. Oceanic coastal areas occur where undiluted ocean water meets shore, thus lie beyond the obvious effect of inland water runoff.
30. Substrate includes all solid surfaces and their subsurface composition in watersheds and waterbodies.
31. Substrate particle structure is managed by dredging, filling, and beach nourishment.
32. Substrate chemistry is managed mostly through morphologic process and material transport process, and by dredging, filling and beach nourishment.
33. Substrate orientation and development is managed by structural modification through placement of water control structures and artificial habitat, and indirectly through encouragement of ecological succession.

TABLE III-10

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY HABITAT ARRANGEMENT AND LANDSCAPE PROCESS INCLUDING USACE IMPACTS ON LANDSCAPE[34]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Habitat Patchiness[35]	Within-project habitat patchiness [landscape ecology formulas]	*indirect effect via biological process*	*See Table III-12 for range of possible impacts. Habitat fragmentation within boundaries causes insufficient habitat element sizes for supporting desired species or fragmentation encourages undesirable species.*							
		aesthetics	visitor days, $ property	WTP, income, appraisal	+-	+-	+-	+-	+-	+-
	Regional habitat patchiness	*indirect effect via biological process*	*See Table III-12 for range of possible impacts. Habitat fragmentation may be reduced or increased depending on project placement and development with respect to relevant regional habitat distribution. Affects size and separation of habitat islands in other habitat matrix, including, most obviously, terrestrial islands in water bodies.*							
	Edge development	*indirect effect via biological process*	*See Table III-12 for detail. Unique habitat conditions usually develop where two dissimilar habitats abut and are occupied by unique species which interact with species occupying centers of the two habitats.*							
		aesthetics	visitor days, $ property	WTP, income, appraisal	+	+	+	+	+	+
Corridors (Habitat Connections)[36]	Intra-habitat connections	aesthetics	visitor days, $ property	WTP, income, appraisal	+-	+-	+-	+-	+-	+-
		indirect effect via biological process	*See Table III-12 for details. Critical for species with diverse habitat needs to complete life cycle. For example, emergent plants act as travel corridors for emerging aquatic insects.*							
	Inter-habitat connections	*indirect effect via biological process*	*See Table III-12 for details. Connections among similar habitats or habitats required for different life stages affect the viability of many populations. Most obvious examples are connecting channels among open waters of wetlands, among channels in a braided stream, or among lakes.*							
		aesthetics	visitor days, $ property	WTP, income, appraisal	+-	+-	+-	+-	+-	+-
	Air-water interface [acres, ha]	atmospheric humidification	relative humidity	cooling costs, WTP	+-	+-	+-	+-	+-	+-

TABLE III-10 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY HABITAT ARRANGEMENT AND LANDSCAPE PROCESS INCLUDING USACE IMPACTS ON LANDSCAPE[34]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Corridors (Habitat Connections) (cont.)	Air-water interface (cont.) [acres, ha]	*indirect effect via water and material transport*	*See Table III-8, currents and turbulence. Operation of wind over the surface generates turbulence.*							
		indirect effect via water quality	*See Table III-11, especially oxygen and H+. Air-water interface determines gas exchange, which influences a number of water quality parameters.*							
Habitat Diversity[37]	Within-habitat diversity [landscape ecology formulas]	*indirect effect via biological process*	*See Table III-12 for details. Spacial diversity is a major determinant of the potential species diversity that may occur within habitats.*							
		aesthetics	visitor days, $ property	WTP, income, appraisal	+	+	+	+	+	+
	Between-habitat diversity	*indirect effect via biological process*	*See Table III-12 for details. Regional habitat diversity is a major determinant of the regional species diversity that can occur.*							
		aesthetics	visitor days, $ property	WTP, income, appraisal	+	+	+	+	+	+
	Habitat interspersion	*indirect effect via biological process*	*See Table III-12 for detail. The interspersion of habitat determines distance that must be crossed for species that require more than one habitat to complete life cycle.*							
Human Habitat (Access, facilities and other human density)[38]	Foot, road, and parking access [acres, miles]	recreation	visitor days	WTP	+	+	+	+	+	+
		property value	$	income, appraisals	+-	+-	+-	+-	+-	+-
		aesthetics	visitor days	WPT	+-	+-	+-	+-	+-	+-
		indirect effect via water and material transport	*See Table III-8 for details. Water diversion, site erosion and other erosion occurs at roads and other structures.*							
		indirect effect via substrate	*See Table III-9. Roads alter watershed and floodplain substrate attributes.*							
		indirect effect via habitat arrangement	*See this Table, especially habitat connectivity and edge. roads create corridors and barriers between habitats. roads also create edge and fragment habitats.*							
		indirect effect via morphologic process	*See Table III-7, watershed form and impermeability. Roads and other structures increase impermeability.*							

TABLE III-10 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY HABITAT ARRANGEMENT AND LANDSCAPE PROCESS INCLUDING USACE IMPACTS ON LANDSCAPE[34]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Human Habitat (Access, facilities and other human density) (cont.)	Foot, road, and parking access (cont.) [acres, miles]	*indirect effect via water quality*	*See Table III-11. Road use adds exhaust, tire-rubber and other contaminants to air and water.*							
		indirect effect via biological quality	*See Table III-12. Roads result in disturbances with direct impacts on mortality, growth and natality for local life forms.*							
	Boat ramps [numbers, lanes, feet]	recreation	visitor days	WTP		+	+	+	+	+
		property value	$	income, appraisals		+-	+-	+-	+-	+-
		aesthetics	visitor days	WTP		+-	+-	+-	+-	+-
		indirect effect via water and material transport	*See Table III-8. Ramps can decrease or increase erosion, depending on construction.*							
		indirect effect via substrate	*See Table III-9. Ramps locally alter substrates.*							
	Docks, marinas, promenades [number, slips]	recreation use	visitor days	WTP		+	+	+	+	+
		property value	$	income, appraisal		+	+	+	+	+
		aesthetics	visitor days, property $	WTP, income, appraisals		+-	+-	+-	+-	+-
		indirect effect via water and material transport	*See Table III-8. Docks and marinas and promenades alter shore currents and erosion process.*							
		indirect effect via substrate	*See Table III-9. Docks and marinas alter substrate form and orientation*							
		indirect effect via habitat arrangement and landscape process	*See Table III-10. Docks and marinas alter habitat arrangements, especially related to light and currents.*							
	Sanitary facilities (toilets, showers, drinking water, fish cleaning stations, garbage receptacles) [number of units]	recreation	visitor days	WTP		+	+	+	+	+
		aesthetics	visitor days	WTP						

TABLE III-10 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY HABITAT ARRANGEMENT AND LANDSCAPE PROCESS INCLUDING USACE IMPACTS ON LANDSCAPE[34]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Human Habitat (Access, facilities and other human density) (cont.)	Sanitary facilities (toilets, showers, drinking water, fish cleaning stations, garbage receptacles) (cont.) [number of units]	*indirect effect via water quality*	*See Table III-11. Many water quality factors are affected by the adequacy and function of sanitary facilities.*							
		indirect effect via biological quality	*See Table III-12, especially nuisance and watchable wildlife. One animal's garbage is another animal's free lunch.*							
	Campgrounds, picnic grounds, rest stops [number of units]	recreation	visitor days	WTP	+	+	+	+	+	+
		indirect effect via water and material transport	*See Table III-8. Erosion usually increased in the construction process but may be reduced ultimately.*							
		indirect effect via substrate	*See Table III-9. Floodplain and watershed substrates altered.*							
		indirect effect via habitat arrangement and landscape process	*See this Table. Habitat connectivity, edge and fragmentation are affected.*							
		indirect effect via biological quality	*See Table III-12. Plant community modification, nuisance and watchable wildlife interactions altered.*							
	Tennis courts, bridle paths, golf courses, sports fields	recreation use	visitor days	WTP	+-	+	+	+	+	+
		property value	$	income, appraisals	+-	+-	+-	+-	+-	+-
		indirect effect via substrate	*See Table III-9. Modified amount of permeable surface.*							
		indirect effect via habitat arrangement and ecological process	*See Table III-10. Modifies habitat connection, fragmentation, and edge.*							

TABLE III-10 (Continued)

ECOLOGICAL OUTCOMES AND SERVICES AFFECTED BY HABITAT ARRANGEMENT AND LANDSCAPE PROCESS INCLUDING USACE IMPACTS ON LANDSCAPE[34]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relations[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Human Habitat (Access, facilities and other human density) (cont.)	Recreation regulation [visitor days]	recreation	visitor days	WTP	+-	+-	+-	+-	+-	+-
		property value	$	income, appraisals	+-	+	+	+	+	+
		indirect effect via substrate	*See Table III-9. People trample things, increase compaction and modify permeability.*							
		indirect effect via water quality	*See Table III-11. Water quality is affected by intensity of water use by swimmers, boaters and others.*							
		indirect effect via biological quality	*See Table III-12. Biological attributes are altered by direct affects on organism abundance and numerous indirect affects.*							

1. Morphologic topographic process is directly affected by Corps activities, usually by creating basins and channels through building barriers, dredging and filling.
2. Ecological input variables effecting ecological outputs vary with project. Input variables are either directly or indirectly influenced by Corps management decisions. Project effectiveness is evaluated by examining the collective effects of all Corps influenced inputs.
3. Ecological outputs are physical, chemical and biological responses to natural or human-caused changes in the environment.
4. Human services are the social functions performed by the ecological output.
5. The more common measures of human services are provided for each category; project services may vary from the most common measures.
6 The form of benefit provided by the human service. Only the most prominent forms of benefit are provided.
7. Human demand for the service will be unique for each project and needs to uniquely evaluated. Considerations for estimating demand include:
   a. Regional presence of high demand of the targeted resources in total or per unit area.
   b. Periodic shortages of resource availability or access, for example, when visitors are turned away from use areas on weekends or water rationing.
   c. Legal mandates for services including environmental laws and standards.
   d. Stakeholder willingness to contribute funding to project development.
   e. Potential for use in environmental education.
   f. Specific non-use value for a particular natural resource, which can be found at very few locations, including the project location.
8. Major water resource divisions are identified here. A plus, minus, or both indicates the usual relationship between ecological output and benefit)whether it is positive or negative as ecological output increases. Where no value is provided, the service for that category is considered minor or non-existent, although specific project conditions may be exceptional.
9. The watershed category includes all projects contributing surface and subsurface (groundwater input) as well as downslope watershed influenced by the project.
10. The lake category includes all inland waters occupying basins, either temporary or permanent, with a level surface; they may be natural or artificial, including those formed by dams and dikes, and by dredging. Morphology and water and material transport characteristics physically determine more specific lake categories for each project.
11. The river category includes all flows occupying channels and generated on a slope by gravity, temporary or permanent; they may be natural or artificial, including excavated and otherwise engineered water conveyances.
12. The wetland category includes all areas in which soils are temporarily to permanently flooded inland and coastal sites and often support, or could support, indicator plant growth. These are highly variable in form and include marshes, swamps, and bogs in various forms. Wetland types are usually defined by their proximity to other water resources, such as estuarine marshes and riverine bottomlands.
13. The estuary category includes all water bodies where marine and inland waters converge, are affected by tides, and often, but not necessarily, vary in salt content.
14. Oceanic coastal areas occur where undiluted ocean water meets shore, thus lie beyond the obvious effect of inland water runoff.
34. Habitat arrangement and landscape process is the relative location and dimensions of habitat types in a defined geographical space and the movements of materials and energy among habitats.
35. Habitat patchiness is managed primarily through original placement of water management structures and their subsequent operation and the control of water depth above and below ground.

36. Habitat connections (corridors) are managed through project location and control of depths, slopes and sedimentation process through dredging, dredge material deposition, and water control structures.
37. Habitat diversity is managed mostly through project location; and control of depth, slope and distributions of sediment, and introduction and planting and removal of appropriate species.
38. Human habitat is managed by developing structures that facilitate or discourage human use including roads, trails, ramps, docks, sanitary facilities, campgrounds and fenced off or otherwise closed areas.

TABLE III-11

ECOLOGICAL OUTCOME AND SERVICE AFFECTED BY WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS[39]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services[4]	Measure[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Suspended Particulate Matter[40]	Total suspended solids [mg/l, sighting, touch]	*indirect effect via biological process*	*See Table III-12 for more detail. It acts diversely to influence food suitability, other habitat suitability and human use. Also, when settled in high quantity, suffocates eggs and sensitive benthic organisms.*							
		turbidity	turbidity units	standard--index for suspend-ed solids		+	+	+	+	+
		indirect effect via light transmission	*See this Table, light transmission. Suspended solids reflect light and decrease penetration.*							
		general drinking and food processing contaminant--grittiness, possibly toxic	mg/liter	standards, treatment costs		-	-	-		
		abrasion causes machinery and transport system damage	mg/liter	standards, treatment costs		-	-	-	-	-
		recreational boating	visitor days	WTP		-	-	-	-	-
		swimming	visitor days	WTP		-	-	-	-	-
		aesthetics	visitor days, & property	WTP, income, appraisal		-	-	-	-	-
	Organic suspended solids	*indirect effect via biological process*	*See Table III-12 for detail. Organic matter in suspension is used by numerous suspension feeding organisms such as most zooplankton and many benthic invertebrates. Also acts as a substrate for microorganisms, some of which are important food resources for many organisms, while others are disease organisms.*							
		domestic water contaminant	mg/liter	standards, treatment costs		-	-	-		
			taste	standards, treatment costs		-	-	-		

TABLE III-11 (Continued)

ECOLOGICAL OUTCOME AND SERVICE AFFECTED BY WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS[39]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Suspended Particulate Matter (cont.)	Organic suspended solids (cont.)	domestic water contaminant (cont)	odor	standards, treatment costs		-	-	-		
		indirect effect via Biological Oxygen Demand (BOD)	*See Oxygen in this Table. Consumption and decay exerts an oxygen demand that contributes to oxygen depletion.*							
	Suspended color [color units]	*indirect effect via light transmission*	*See light transmission in this Table. Color in suspended matter absorbs light and decreases transmission depth.*							
		domestic water use	color	standard, treatment costs		-	-	-	-	
		indirect effect via suspended solids	*See total suspended solids in this Table.*							
		aesthetics	appearance, visitor days	WTP		-	-	-	-	
	Suspended inorganic nutrients [mg/l]	*indirect effect via biological process*	*See Table III-12, primary producers, for details. Influences the availability of nutrients for photosynthesis and may be available for uptake in this form. Especially important nutrients are phosphorus, nitrogen and iron.*							
		indirect effect via dissolved nutrient source.	*See dissolved nutrients this Table. A reservoir for potentially dissolved nutrients.*							
	Suspended toxic material	*indirect effect via biological process*	*See Table III-12 for details. Consumed toxic compounds have important biological consequences.*							
		domestic and livestock water use	mg/liter of toxic material	treatment costs, standards		-	-	-	-	
	Ratio of inorganic and organic suspended solids [ratio]	*indirect effect via biological process*	*See Table III-12 for detail. Dilution of food quality for suspension feeding organisms, such as most zooplankton and many bottom organisms like clams and oysters.*							

TABLE III-11 (Continued)

ECOLOGICAL OUTCOME AND SERVICE AFFECTED BY WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS[39]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Suspended Particulate Matter (cont.)	Suspended inorganic complexes [mg/l]	*indirect effect via biological process*	*See Table III-12, and nutrients and toxins in this Table for detail. Affects the availability of nutrients and toxins for uptake in soluble form. Complexes of precipitates and absorbed dissolved nutrients, toxic metals, and other materials occur in suspension and in sediment with variable availability for uptake by living organisms, often depending on the reduction-oxidation environment. May be important in sequestering materials that would otherwise go into solution.*							
		indirect effect via dissolved nutrient	*See dissolved nutrients this Table for more detail.*							
		indirect effect via dissolved toxin	*See dissolved toxins in this Table for more detail.*							
	Suspended organic complexes	*indirect effect via biological process*	*See Table III-12, and nutrients and toxins in this Table for detail. Organic complexes, often with inorganic elements, affect nutrient and toxin availability.*							
		indirect effect via nutrient availability	*See dissolved nutrients in this Table for more detail.*							
		indirect effect via toxin availability	*See dissolved toxins in this Table for more detail*							
Dissolved Matter[41]	Dissolved organic matter	*indirect effect via biological process*	*See Table III-12 for more details. Dissolved organics form aggregates with bacteria that may be consumed by suspension feeders. Some protists appear to absorb them directly. Certain dissolved organics are required nutrients for certain algae.*							
		indirect effect via Biological Oxygen Demand (BOD)	*See this Table for oxygen. Dissolved organics decay and exert oxygen demand.*							
	Water color [color units]	*indirect effect via light transmission*	*See light transmission in this Table. Dissolved organic pigments absorb light, often staining the water tea or coffee color in bogs and black-water streams.*							
		aesthetics--reaction to water color is often negative	visitor days, $ property	WTP, income		-	-	-	-	
		domestic water supply	color units	standard, treatment cost, health cost		-	-	-		

TABLE III-11 (Continued)

ECOLOGICAL OUTCOME AND SERVICE AFFECTED BY WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS[39]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Dissolved Matter (cont.)	Total dissolved solids (TDS) [mg/liter]	equipment maintenance (corrosion)	mg/liter	standards, treatment & maintenance cost		-	-	-	-	-
		domestic supply	mg/liter	standard, treatment & health cost		-	-	-		
		agricultural crop supply	mg/liter	standard, treatment cost, lost income		-	-	-		
	Salinity [ppt]	*indirect effect via biological process*	*See Table III-12 for detail. It determines habitat suitability based on species osmoregulatory requirements including humans, pets and livestock use.*							
		equipment corrosion costs--metal corrosion rates and reduced decay rates of wood	ppt	standard treatment & maintenance cost		+-	+-	+-		
		agricultural water-decreases crop growth or lethal	ppt	standard, income lost		-	-	-		
		domestic and livestock water	ppt	standard, treatment cost		-	-	-		
		swimming and related recreation	ppt	WTP shower costs,		-	-	-	+-	+-
	Hydrogen ions (acidity) [pH]	*indirect effect via biological process*	*See Table III-12 for more detail. Acidity is a major variable determining habitat suitability, especially in freshwater habitats.*							
		equipment maintenance (corrosion)	equipment maintenance	costs		-	-	-		

TABLE III-11 (Continued)

ECOLOGICAL OUTCOME AND SERVICE AFFECTED BY WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS[39]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Dissolved Matter (cont.)	Hydrogen ions (acidity) (cont.) [pH]	*indirect effect via reduction-oxidation*	*See in this Table. This is an important variable determining the reduction-oxidation environment*							
	Oxygen [mg/l]	*indirect effect via biological process*	*See Table III-12 for more detail. All consumer organisms and many decomposers require oxygen for metabolism. It is an important metabolic rate regulator at low concentrations and a major determinant of habitat suitability where it varies from saturation. to oxygen deficits.*							
		reduction-oxidation	*See reduction-oxidation, this Table. It is an important determinant of the oxidation-reduction environment.*							
		equipment maintenance (corrosion and cavitation effects)	replacement and cleaning rates	maintenance cost		-	-	-	-	-
		ecosystem integrity index	mg/liter	saves investigation costs	+	+	+	+	+	+
	Nitrogen gas [mg/l]	*indirect effect via biological process*	*See Table III-12 for more detail. As fish and other organisms move to surface from a supersaturated environment the bubbles expand. Nitrogen gas can become a nutrient source for certain noxious bluegreen bacteria.*							
		industrial cavitation effects	replacement and cleaning rates	maintenance cost		-	-	-	-	-
	Dissolved inorganic nutrients	*indirect effect via biological process*	*As nutrient availability increases total production increases but often causes undesirable side effects because of excessive organic loading by primary producers (eutrophication); excessive to the extent that oxygen demand from plant decay is offset by oxygenation of habitats from the atmosphere and downward mixing.*							
		agriculture benefits from high nutrient concentration	crop production	income, food prices		+	+	+		

TABLE III-11 (Continued)

ECOLOGICAL OUTCOME AND SERVICE AFFECTED BY WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS[39]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Dissolved Matter (cont.)	Ionic ratios	*biological process*	*See Table III-12 for details. Ionic ratios are important determinants of plant habitat suitability and also affect consumers. Contributes to determining noxious algae. Important reason why many marine species cannot survive in certain inland environments of similar salinity.*							
		livestock water suitability in part determined by proportion of sulfates in salts	livestock production	income, food prices		-	-	-		
	Biogeochemical elements	precipitates of iron, calcium and other compounds for industrial and domestic uses	cleaning effect, maintenance	standards, cost		-	-	-	-	-
		indirect effect via nutrient	*See this Table, nutrients. Helps determine nutrient availability.*							
		indirect effect via toxic material	*See this Table, toxins. Helps determine toxin availability.*							
	Hardness	domestic and industrial water- decreases surfactant action and creates scale	cleaning effect, maintenance	standard, cost		-	-	-	-	-
		binds and precipitates toxic materials	reduced treatment need	cost savings		+	+	+	+	+
	Dissolved toxic materials	*indirect effect via biological process*	*See Table III-12 for detail. Differential toxicity causes many changes in ecological pathways.*							
		domestic and livestock water	mg/l	standards, treatment cost, lost income	-	-	-	-	-	-
		possible ecosystems integrity measures, e.g., mercury	index	investigation cost savings	-	-	-	-	-	-
Electromagnetic Process[42]	Light transmission [watts, lumens]	*indirect effect via biological process*	*See Table III-12 for detail. Light transmission is a basic determinant of primary production process and food web interactions, as well as a measure of water quality.*							
		indirect effect via temperature	*See temperature, this Table. Light is primary source of heat and temperature distribution, although mixing depth, residence time and turbulence are more important.*							

TABLE III-11 (Continued)

ECOLOGICAL OUTCOME AND SERVICE AFFECTED BY WATER AND SEDIMENT QUALITY INCLUDING USACE IMPACTS ON QUALITY FACTORS[39]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measure[5]	Benefit Form[6, 7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Electromagnetic Process (cont.)	Light transmission (cont.) [watts, lumens]	aesthetics	visitor days, property $	WTP, income		+	+	+	+	+
	Temperature [C^0, F^0]	*indirect effect via biological process*	*See Table III-12 for detail. Temperature is a basic determinant of metabolic rates, production rates and foodweb pathways.*							
		thermal load capacity for wasting heat	BTU, ice accumulation	income, electric cost		-	-	-	-	-
		industrial cooling capacity	BTU	income, electric cost		-	-	-	-	-
		swimming	*See Table III-7 for detailed activities. Effects visitor days; nearby property values.*							
		boating/navigation	*See Table III-7 for detailed activities. Ice impedes boat use.*							
		indirect effect via water and material transport	*See Table III-8 for detailed activities. Temperature is a variable determining density and viscosity, which, in turn, influence material transport capacity.*							
	Reduction-oxidation [redox potential, volts]	*indirect effect via nutrients*	*See this Table nutrients.Reduction-oxidation determines the solubility of many nutrient and toxic elements, and affects the absorption of dissolved matter to suspended or sedimented matter.*							
		indirect effect via toxins	*See this Table, toxic materials. Reduction-oxidation determines solubility and ability of organic substrates to sequester toxins.*							
		indirect effect via biogeochemistry	*See this Table, biogeochemistry. Reduction-oxidation determines solubility and forms of many compounds important in nutrient cycles and spirals, such as nitrogen, phosphorus, iron and sulfur.*							

1. Morphologic topographic process is directly affected by Corps activities, usually by creating basins and channels through building barriers, dredging and filling.
2. Ecological input variables effecting ecological outputs vary with project. Input variables are either directly or indirectly influenced by Corps management decisions. Project effectiveness is evaluated by examining the collective effects of all Corps influenced inputs.
3. Ecological outputs are physical, chemical and biological responses to natural or human-caused changes in the environment.
4. Human services are the social functions performed by the ecological output.
5. The more common measures of human services are provided for each category; project services may vary from the most common measures.
6. The form of benefit provided by the human service. Only the most prominent forms of benefit are provided.

7. Human demand for the service will be unique for each project and needs to uniquely evaluated. Considerations for estimating demand include:
   a. Regional presence of high demand of the targeted resources in total or per unit area.
   b. Periodic shortages of resource availability or access, for example, when visitors are turned away from use areas on weekends or water rationing.
   c. Legal mandates for services including environmental laws and standards.
   d. Stakeholder willingness to contribute funding to project development.
   e. Potential for use in environmental education.
   f. Specific non-use value for a particular natural resource, which can be found at very few locations, including the project location.
8. Major water resource divisions are identified here. A plus, minus, or both indicates the usual relationship between ecological output and benefit) whether it is positive or negative as ecological output increases. Where no value is provided, the service for that category is considered minor or non-existent, although specific project conditions may be exceptional.
9. The watershed category includes all projects contributing surface and subsurface (groundwater input) as well as downslope watershed influenced by the project.
10. The lake category includes all inland waters occupying basins, either temporary or permanent, with a level surface; they may be natural or artificial, including those formed by dams and dikes, and by dredging. Morphology and water and material transport characteristics physically determine more specific lake categories for each project.
11. The river category includes all flows occupying channels and generated on a slope by gravity, temporary or permanent; they may be natural or artificial, including excavated and otherwise engineered water conveyances.
12. The wetland category includes all areas in which soils are temporarily to permanently flooded inland and coastal sites and often support, or could support, indicator plant growth. These are highly variable in form and include marshes, swamps, and bogs in various forms. Wetland types are usually defined by their proximity to other water resources, such as estuarine marshes and riverine bottomlands.
13. The estuary category includes all water bodies where marine and inland waters converge, are affected by tides, and often, but not necessarily, vary in salt content.
14. Oceanic coastal areas occur where undiluted ocean water meets shore, thus lie beyond the obvious effect of inland water runoff.
39. Water quality includes suspended and dissolved matter in the water column and in sediment interstices, typically in small enough form to be easily sampled in 1 to 10 liter water samplers. It also includes electromagnetic properties associated with light, heat, and reduction-oxidation voltages.
40. Suspended particulate matter is managed mostly indirectly through watershed and water-control management, but also through dredging operations.
41. Dissolved matter is managed mostly indirectly by watershed management, dredging activity, and water-structure control of amounts of water from different sources and evaporation surfaces, but also through fertilization, liming, aeration and other direct chemical or physical means.
42. Electromagnetic processes; light, heat and redox potential; are managed mostly indirectly via morphologic and material transport process, dredging activity, riparian vegetation management and water mixing process.

TABLE III-12

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Population Production Process[44]	Terrestrial macrophytes [Board ft, cords, animal units, bales, diversity and arrangement of form, landscape formulae, area covered, Kg/ha]	building material, paper	$	income	+	+		+		
		grazing forage, hay	$	income	+	+		+		
		aesthetic	visitor days, $	W-T-P, income, appraisals	+	+		+		
		indirect effect via habitat arrangement and landscape process	*See Table III-10 for more detail. Terrestrial habitat arrangement with aquatic habitats. Important influences on population abundances and distributions.*							
		indirect effect via morphologic process	*See Table III-7. Forest and range modify the waterbed, flood plain and channel form.*							
		indirect effect via water quality	*See Table III-11. The biomass and growth of waterbed vegetation team and exports nutrients, toxic containments and other material.*							
	Decomposer populations [#/ml]	*indirect effect via water quality*	*See Table III-11 for more detail, especially about nutrients and oxygen. Decomposers play an indispensable role in recycling, and also exert biological oxygen demand.*							
		commercial harvest	$	income		+-	+-	+-	+-	+-
		recreational harvest and other use	visitor days	W-T-P		+	+	+	+	+
		ecological indicators	index	index cost savings		+	+	+	+	+
	Pathogen populations [#/ml]	health	presence/ absence	standards, treatment costs	-	-	-	-	-	-
		commercial harvest	$	income		-	-	-	-	-
		recreational harvest and other use	visitor days	W-T-P		-	-	-	-	-
		ecological indicators	index	index cost savings		+	+	+	+	+
	Aquatic macrophytes [kg/ha, kg/ha/yr, relative #, area covered, landscape formulae]	Fishing	visitor days	WTP		+-	+-	+-	+-	+-
		commercial harvest	$	income		+-	+-	+-	+-	+-
		recreational harvest and other use	visitor days	W-T-P		+-	+-	+-	+-	+-

TABLE III-12 (Continued)

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Population Production Process (cont.)	Aquatic macrophytes (cont.) [kg/ha, kg/ha/yr, relative #, area covered, landscape formulae]	ecological indicators	index	index cost savings		+	+	+	+	+
		endangered species	ESA (law	non-use values and income lost		+	+	+	+	+
		nuisance species	visitor days, $	income lost, W-T-P		-	-	-	-	-
		swimming, boating, etc.	visitor days, $	income lost, W-T-P		-	-	-	-	-
		indirect effect via morphologic process	*See Table III-7. As plants grow they alter basin morphology, such as the amount of open water in habitat.*							
		indirect effect via substrate	*See Table III-9. Aquatic plants act as substrate for many organisms and alter other substrate as they grow.*							
		indirect effect via habitat arrangement and landscape process	*See Table III-10. Colonization by aquatic macrophytes greatly alter the arrangement of habitats and indirectly affects many species.*							
		indirect effect via water quality	*See Table III-11. Vegetation growth both team and mobilize nutrient, contaminants and other nature.*							
	Planktonic algae [kg/ha, kg/ha/yr, relative #]	Fishing	visitor days	WTP		+-	+-	+-	+-	+-
		commercial harvest	$	income		+-	+-	+-	+-	+-
		recreational harvest and other use	visitor days	W-T-P		+-	+-	+-	+-	+-
		ecological indicators	index	index cost savings		+	+	+	+	+
		nuisance species	visitor days	income lost, W-T-P		-	-	-	-	-
		swimming, boating, etc.	visitor days	income lost, W-T-p		-	-	+-	-	-
		algal suspended solids	numbers	standards, treatment cost	-	-	-	-	-	-

TABLE III-12 (Continued)

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Population Production Process (cont.)	Planktonic algae (cont.) [kg/ha, kg/ha/yr, relative #]	algal suspended solids (cont.)	taste	standards, treatment cost	-	-	-	-	-	-
			odor	standards, treatment cost	-	-	-	-	-	-
	Fish populations (excluding "shellfish") [kg/gear, kg/ha, #/h, relative #, sightings of threatening species (e.g., sharks), total #	commercial harvest	$	income		+	+	+	+	+
		recreational catch, harvest and other use	visitor days, yearly yield	willingness to pay, cost savings		+	+	+	+	+
		ecological indicators	presence/ absence	index, cost savings		+	+	+	+	+
		health hazard	incidents	use & income foregone, control costs		+-	+-	+-	+-	+-
		depredation	incidents	use, income foregone, control costs		+-	+-	+-	+-	+-
		watchable wildlife	visitor days	willingness to pay, cost savings		+	+	+	+	+
		endangered species	ESA (law)	non-use values, income foregone, option value		+	+	+	+	+
	Invertebrate populations (including "shellfish") [kg/ha,#/ha, #/gear, relative #, sightings of threatening species (e.g., jellyfish), incident rate]	commercial harvest	$	income	+	+	+	+	+	+
		recreational harvest	visitor days, yearly yield	willingness to pay, cost savings	+	+	+	+	+	+
		ecological indicators	presence/ absence	index, cost savings	+	+	+	+	+	+

TABLE III-12 (Continued)

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Population Production Process (cont.)	Invertebrate populations (including "shellfish") (cont.) [kg/ha,#/ha, #/gear, relative #, sightings of threatening species (e.g., jellyfish), incident rate]	health hazards	incidents	use, income foregone	+-	+-	+-	+-	+-	+-
		property damage	incidents	replacement, maintenance,insurance costs	+-	+-	+-	+-	+-	+-
		nuisance	discomfort level	use, income foregone	+-	+-	+-	+-	+-	+-
		endangered species	ESA (law), presence-absence	use, income foregone, option value	+	+	+	+	+	+
		watchable wildlife	visitor days	willingness to pay	+	+	+	+	+	+
	Reptile & amphibian populations [#/ha, relative #]	commercial harvest	$	income	+	+	+	+	+	+
		recreational harvest	visitor days	willingness to pay, cost savings	+	+	+	+	+	+
		depredation	incidents	replacement & protection cost	+-	+-	+-	+-	+-	+-
		nuisance/health	incidents	use, income & property value foregone	+-	+-	+-	+-	+-	+-
		endangered species	(ESA) law, presence-absence	non-use values , income & property value foregone	+	+	+	+	+	+
		ecological indicator	presence/ absence	index, cost savings	+	+	+	+	+	+
		watchable species	visitor days	willingness to pay	+	+	+	+	+	+

TABLE III-12 (Continued)

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Population Production Process (cont.)	Bird populations [relative #, #/ha, use-days]	waterfowl hunting	visitor days	willingness to pay	+	+	+	+	+	+
		upland bird hunting	visitor days	willingness to pay	+	+	+	+	+	+
		watchable water birds	visitor days	willingness to pay	+	+	+	+	+	+
		watchable riparian & upland birds	visitor days	willingness to pay	+	+	+	+	+	+
		endangered species	ESA (law) presence/ absence	non-use values , income & property value foregone	+	+	+	+	+	+
		ecological indicators	presence/absence	index, cost savings	+	+	+	+	+	+
		nuisance/health	incident rates	use, income foregone, control costs	+-	+-	+-	+-	+-	+-
		depredation	incident rates	use, income foregone, control costs	+-	+-	+-	+-	+-	+-
	Mammal populations [#/ha, relative #]	recreational harvest	visitor days	willingness to pay	+	+	+	+	+	+
		furs	$	income	+	+	+	+	+	+
		watchable species	visitor days	willingness to pay	+	+	+	+	+	+
		endangered species	ESA (law), presence-absence	non-use values foregone use, income, option values	+	+	+	+	+	+
		depredation	incident rate	foregone use, income, property value	+-	+-	+-	+-	+-	+-

TABLE III-12 (Continued)

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Population Production Process (cont.)	Mammal populations (cont.) [#/ha, relative #]	health/nuisance	incident rate	foregone use, income, property value	+-	+-	+-	+-	+-	+-
Community Process[45]	Biodiversity [species #, species/ha, formulae, wt/species formulas, # of strata, cover/stratum, DNA]	species richness	index	option values, education, research, saves investigation cost	+	+	+	+	+	+
		species abundance evenness	index	option values, education, research, saves investigation cost	+	+	+	+	+	+
		biological stratification	index	option values, education, research, saves investigation cost	+	+	+	+	+	+
		genetic information	index	option values, education, research, saves investigation cost	+	+	+	+	+	+
	Biological Integrity [formulae, kg, tonnes, relative #, grams carbon, Kcal, range of concentrations or loads, range of kg/m^2/year, kg/m^2/yr, flux, efficiency, interaction counts]	material retention	index	option values, education, research, saves investigation cost	+	+	+	+	+	+
		ecosystem indicator species	index	option values, education, research, saves investigation cost	+	+	+	+	+	+

TABLE III-12 (Continued)

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Community Process (cont.)	Biological Integrity (cont.) [formulae, kg, tonnes, relative #, grams carbon, Kcal, range of concentrations or loads, range of $kg/m^2/year$, $kg/m^2/yr$, flux, efficiency, interaction counts]	production/respiration (P/R)	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+
		material export stability	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+-
		production stability	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+-
		production level	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+-
		biogeochemical cycling rate	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+-
		efficiency of solar energy capture	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+-

TABLE III-12 (Continued)

ECOLOGICAL OUTPUTS AND SERVICES AFFECTED BY BIOLOGICAL QUALITIES, INCLUDING USACE IMPACT ON BIOLOGICAL QUALITIES[43]

Corps-Influenced Ecological Input[2]	Ecological Output[3]	Human Services or Precursor Effect on Service[4]	Measures[5]	Benefit Form[6,7]	Resource Output-Benefit Relation[8]					
					WS[9]	L[10]	R[11]	W[12]	E[13]	C[14]
Community Process (cont.)	Biological Integrity (cont.) [formulae, kg, tonnes, relative #, grams carbon, Kcal, range of concentrations or loads, range of kg/m²/year, kg/m²/yr, flux, efficiency, interaction counts]	trophic level efficiency	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+-
		foodweb complexity/support	index	option values, education, research, saves investigation cost	+-	+-	+-	+-	+-	+-
		Indirect effects on water quality	*See Table III-11. Oxygen, pH, nutrients, toxins, and other water quality measures are indicators of biological integrity.*							
	Community metabolism [mg/liter, pH]	*indirect effect via substrate*	*See Table III-9. Many aspects of substrate structure are affected by organism behavior, death, and decay.*							
		indirect effect via water quality	*See Table III-11, suspended and dissolved organic matter. The relative amounts depend on effectiveness of community respiration.*							
			See Table III-11, suspended and dissolved nutrients. Community respiration substantially determines nutrient distribution.							
			See Table III-11, oxygen. Community respiration generates and consumes oxygen.							
			See Table III-11, hydrogen ions. Respiration alters the carbonic acid content via its affect on carbon dioxide and pH.							

1. Morphologic topographic process is directly affected by Corps activities, usually by creating basins and channels through building barriers, dredging and filling.
2. Ecological input variables effecting ecological outputs vary with project. Input variables are either directly or indirectly influenced by Corps management decisions. Project effectiveness is evaluated by examining the collective effects of all Corps influenced inputs.
3. Ecological outputs are physical, chemical and biological responses to natural or human-caused changes in the environment.
4. Human services are the social functions performed by the ecological output.
5. The more common measures of human services are provided for each category; project services may vary from the most common measures.
6. The form of benefit provided by the human service. Only the most prominent forms of benefit are provided.
7. Human demand for the service will be unique for each project and needs to uniquely evaluated. Considerations for estimating demand include:
   a. Regional presence of high demand of the targeted resources in total or per unit area.
   b. Periodic shortages of resource availability or access, for example, when visitors are turned away from use areas on weekends or water rationing.
   c. Legal mandates for services including environmental laws and standards.
   d. Stakeholder willingness to contribute funding to project development.
   e. Potential for use in environmental education.
   f. Specific non-use value for a particular natural resource, which can be found at very few locations, including the project location.
8. Major water resource divisions are identified here. A plus, minus, or both indicates the usual relationship between ecological output and benefit)whether it is positive or negative as ecological output increases.
9. The watershed category includes all projects contributing surface and subsurface (groundwater input) as well as downslope watershed influenced by the project.
10. The lake category includes all inland waters occupying basins, either temporary or permanent, with a level surface; they may be natural or artificial, including those formed by dams and dikes, and by dredging. Morphology and water and material transport characteristics physically determine more specific lake categories for each project.
11. The river category includes all flows occupying channels and generated on a slope by gravity, temporary or permanent; they may be natural or artificial, including excavated and otherwise engineered water conveyances.

12. The wetland category includes all areas in which soils are temporarily to permanently flooded inland and coastal sites and often support, or could support, indicator plant growth. These are highly variable in form and include marshes, swamps, and bogs in various forms. Wetland types are usually defined by their proximity to other water resources, such as estuarine marshes and riverine bottomlands.
13. The estuary category includes all water bodies where marine and inland waters converge, are affected by tides, and often, but not necessarily, vary in salt content.
14. Oceanic coastal areas occur where undiluted ocean water meets shore, thus lie beyond the obvious effect of inland water runoff.
43. Biological qualities include all manifestations of biological process.
44. Population production process is managed mostly indirectly through management of physical habitat and less often through introduction (including planting), removal (including forest and range use), and stocking of living organisms.
45. Community production process is managed mostly through alteration of the physical ecosystem and less often through introduction and removal of organisms.

Many project solutions require changing water surface area, volume, and depth. These changes act as ecosystem inputs, which induce sequences of ecological outputs, one output acting as an input for generating the next output. Increased water surface area, for example, directly increases the use area for boating and swimming while indirectly decreasing the use area for various land uses. But the larger impact may be the indirect effect on wildlife-based recreation via changes in the total area of productive habitat provided as surface area changes. Thus morphological change, in Table III-7, affects biological quality, in Table III-12, and the table reader is directed to Table III-12 to find the direct effects of biological processes on recreational use. The link between morphology and biological quality is illustrated in Figure III-1.

The chain of important effects continues, however, because of ecological successional processes, creating a feedback from biological quality to morphology and topography (Figure III-1). When the depths of a newly constructed wetland area are first shaped according to project design specifications, different types of plants are expected to take root depending on the depth. The shape of the basin in time is expected to support an ecosystem with patches of herbaceous marsh, open water, and woody swamp as plants colonize (or are planted) and grow. The growth modifies ecosystem morphology, which, in turn, changes site suitability for a succession of new species and life stages.

As shown in Figure III-1, many feedbacks occur in real ecosystems and in the suite of tables. The extent feedback occurs depends on project dimensions in space and time and the rate of change induced per unit area. Many projects designed to restore environmental qualities that provide desired human services can take decades, even centuries, to have their ultimate effect.

It is possible in using Tables III-7 through III-12 to go on in an endless cycle of feedback loops. In real ecosystems, and in ecosystem process models, material and energy pathways eventually decay to a point of no service-significant effect. An important weakness of this tabular approach is the lack of quantification that signals significance level. Planners using the tables must use their judgment and the inputs of disciplinary specialists to decide when they have looped through enough indirect effects.

Tables III-1 through III-12 are intended to be a general planning guide toward more specific identification of intended and unintended project outcomes. The main intent of Tables III-1 through III-12 is to help planners pose the right questions for interdisciplinary examination in site-specific study. Input and output links identified in Tables III-1 through III-12 as possible project issues will rarely be sufficient without further organized study at the project level. As shown in Figure III-1, once detailed studies are completed, recommendations are made to decision makers.

ORGANIZATION AND SUMMARY OF TABLES

Tables III-7 through III-12 are the central feature of this report, where the linkage between ecological and socioeconomic impacts is actually formed. The logic and philosophy of the tables are discussed throughout this report and appendix. The following sections describe first the constituency of the tables, their structure, and general contextual information concerning the entries in the individual tables. This is followed by a discussion of the important role of feedback and indirect effects that overlay the series of tables. Critical terms are defined in the Glossary, and footnotes are found at the end of each table that expand on terms and ideas presented.

Table Structure and Sequence

Information in the set of six tables (Tables III-7 through III-12) is arranged from left to right with the first column on the left identifying the ecological input category. This ecological input is altered by natural or managed events to generate ecological outputs and associated measurements listed in the second column. The third column lists the types of human services or ecological precursors (which leads to another table) affected by ecological outputs. The fourth and fifth columns list the benefit measure and form, respectively, for each entry. Services and benefits may be positive or negative as ecological outputs increase. Many ecological outputs generate a mix of positive and negative impacts, and there are many exceptions to the general case shown in the final six columns of the tables. These last six columns are reserved for the type of relationship between ecological output and service, positive or negative, for each of the major water resource categories (**W**ater**S**hed, **L**ake, **R**iver, **W**etland, **E**stuary, **C**oastal).

Morphology, Table III-7

The hierarchial nature of the impacts of Corps projects on the ecosystem (e.g., direct morphological changes and resultant indirect effects) as illustrated in Figure III-1 are reflected in the sequencing of Tables III-7 through III-12. The table for morphological and topographic process begins the sequence of tables because Corps activities modify foremost the morphology of watersheds, basins, and channels, causing a chain of subsequent ecological outputs. The Corps shapes topographic features by excavating (mostly dredging) and by building structures designed to contain, redirect, and exclude water flow. Such structures include dams, dikes, wing dams, levees, revetments, breakwaters, groins, canals, pipes, penstocks, diversion dams, locks, etc. Structures usually are designed to exclude, divert, or contain water or sediment to meet project objectives. In the process, Corps projects develop depths, slopes, volumes, surface areas, and shoreline lengths and configurations, which collectively impart a water resource with much of its ecological character. By way of its affect on watershed, basin, and channel morphology, the Corps indirectly influences ecological outputs and related services in the remaining five table categories.

Water and Material Transport, Table III-8

Water and material transport, slope and depth work interactively to generate erosive discharges and material transport capacity, once water is supplied by precipitation and runoff. Erosion, transport, and deposition reshape channel and basin morphology and influence substrate, habitat arrangement, and water quality. Morphology and water and material transport interact to influence biological quality. Biological populations respond diversely to depth, current, erosion, sediment suspension, and sediment deposition.

Substrate,Table III-9, and Habitat Arrangement, Table III-10

Substrate form and stability are defined by the types and productivities of colonizing plants, animals, and decomposer organisms that are present. Habitat arrangement, including habitat diversity, is fundamentally determined by spatial variation in water depth, current, and substrate condition. To the extent that depths and current patterns can be engineered, the Corps has potential control over habitat patterns both locally and regionally.

Water Quality, Table III-11, and Biological Quality, Table III-12

Managed habitat patterns also indirectly influence water quality, which diversely impacts biological colonization of habitats. A Corps project that targets water quality and biological habitats might call for very specific engineering action such as mechanical aeration of a project site, site fertilization, or tree planting in riparian zones. These types of management activities have very specific impacts on selected aspects of an ecosystem, usually more so than the general activities included in the earlier tables in the series.

Indirect Effects and Feedback

Although the Corps may directly affect ecological outputs in any of the six categories, many of the effects are indirect. Whenever indirect effects occur, the table reader is guided to another table where the effects are direct. Most Corps actions, for example, directly influence physical environment and indirectly influence the water quality and biological properties of ecosystems. Because Corps activities usually impact fundamental habitat qualities, they usually have widespread impacts on water and biological quality. Both synergistic and antagonistic interactions can result, creating unexpected outcomes. Many biological impacts of Corps activities do not fully manifest for years, or even decades, following management actions. Yet these ultimate impacts may have the greatest ultimate effect on services provided by ecological functions.

Feedback occurs commonly throughout this system of table categories. In fact, feedback is such a common feature of ecosystem function that the number of feedbacks is a useful indicator of ecosystem complexity. An example of how feedback could occur is as follows. Photosynthesis and decomposition are elemental functions affecting dissolved oxygen, pH, reduction-oxidation, and the availability of nutrients and toxic materials feeding back to affect subsequent biological processes. For example, organic production is a major determinant of light transmission through air and water. In water, both biomass and dissolved organic byproducts produce color, which absorbs light and decreases light transmission and, in turn, feeds back to affect future organic production.

One of the disadvantages of a qualitative approach to system process, as used in Tables III-7 to III-12, is the difficulty in deciding how far to follow feedback effects. As in the real world, it is possible for readers to find themselves in a never-ending cycle of feedbacks. The readers must use their own judgment and expert input to decide how far they should take feedback pathways through the tables.

APPLICATION ISSUES FOR PLANNING

Basic Steps

The first requirement of a planner using the tables and other information in this report is to organize a list of ways in which management-action alternatives are likely to impact the ecological outputs and human services. This list of impacts should be grouped according to the six major table categories of ecological inputs for determining ecological outputs and services. Tables III-1 through III-6 provide an overview of the interrelationships in the more detailed tables (III-7 through III-12). Thus, Tables III-1 through III-6 are a good starting point to make sure that certain ecological effects are not overlooked. Reviewing the categories in the first column of each table will help in this listing process, but typically a project will have some relatively fine management ideas that have been created by local agencies, interest groups, the Corps, or other federal resource agencies familiar with the site.

Once management inputs are identified, the ecological outputs for each input can be reviewed. If the ecological outputs directly affect the form of service or benefit, they will be identified in the same row of the table. The likelihood of a positive or negative relationship of the effect for each of the major water resource categories also is identified in the same row. In many cases the relationship will be indirect, and the table user will be directed to see another table or a section within a table. When another table is identified, the user should expect the indirect effects to be complex and diverse, often influencing most ecological inputs and outputs in the table. Because morphology is so generally influential, any project change in morphology will have diverse and numerous indirect effects.

More specific management will have a much more narrowed effect. If for example, management is directed at surface agitation in order to oxygenate water, the user can search out those specific impacts, such as surface turbulence and water mixing in Table III-7 (Water and Material Transport) and oxygen in Table III-11 (Water Quality), to track through impacts on ecological outputs and services. Alternatively, a management approach may focus directly on aquatic plant enhancement or removal, and the table user would enter Table III-12 (Biological Quality).

Refining List of Service Categories for Analysis

The tables can be used as a checklist to identify nearly all of the potential human services and associated benefits associated with different restoration actions. The use of this checklist approach helps to ensure that interconnections and unfamiliar or unusual effects will not be overlooked. However, oftentimes there will be several dozen human services with many measures of benefits, such as visitor days, acre-feet of water, specific fish and wildlife species, etc. As shown in Figure III-2, the planners can think of this as a list of <u>candidate</u> services that may be chosen for in-depth evaluation across restoration alternatives or scales of restoration efforts. Only a subset of these candidate variables may be measured, depending on their economic and political importance as well as available data, models, budget, time, and relevance to various stakeholders (including those providing the cost-share money).

A screening process should be used to determine which of the potentially affected human services and associated benefit measures to carry forward in the restoration planning process. This is based on the following criteria:

(1) *Is the variable of legal importance?* Certain air and water pollutants or plant and animal species have laws governing minimum and maximum levels. As such, these variables must often be measured for each alternative.

(2) *What is the demand for the service?* For the human service to provide an economic benefit to society, there must be demand in the form of current use levels exceeding resource capacity that cause a lack of local availability of a resource, rationing, shortages, or legal requirements for production. (See Chapter II for details on demand factors.)

(3) *Is this human service or benefit of great interest to one or more stakeholders?* For example, if bird viewing in newly created wetlands is a high-priority human service to a cost-sharing agency, then this should be carried to criterion #5 for final evaluation of its feasibility for use in the study.

(4) *Is the relative importance of the human service measurable across different restoration alternatives or different sizes of the restoration project?* While some human services such as existence value may be important, our inability to measure it with enough resolution to determine how it varies with different-size restorations may make it a less useful variable for comparing different scales of restoration.

RESULTS OF APPLYING **TABLES III-7 THROUGH III-12 TO RESTORATION PROJECT**
CANDIDATE LIST OF HUMAN SERVICE (HS) AND BENEFIT FORM (BF)
(HS_1&BF_1) (HS_2&BF_2), (HS_3&BF_3), (HS_4&BF_4), (HS_5&BF_5), (HS_6&BF_6), ... (HS_n&BF_n)
Screening Criteria
1. Is there a legal requirement to evaluate this human service? YES NO? (If YES, carry forward to final list, otherwise, go to #2)
2. Is there a demand for added amounts of this human service? YES NO? (If YES, carry forward to #4, if NO go to #3)
3. Is this human service critical to one of the stakeholders? YES NO? (If YES, carry forward to #5, if NO drop out)
4. Can meaningful differences in the level of human services be measured across different restoration alternatives or scale of the project? YES NO? (If YES, go to #5, if NO drop out)
5. Are data available to measure this human service/benefit or is there sufficient time or budget to collect such data? YES NO? (If NO, then variable drops out, if YES, carry forward to final list)
Example Final List: (HS_2&BF_2) (HS_5&BF_5) (HS_6&BF_6)
4444444444444444444444444444444444444444444444

FIGURE III-2

CRITERIA FOR SELECTION OF CANDIDATE SERVICES FOR VALUATION OF RESTORATION EFFORTS

(5) *Are data available to measure this human service and benefit, or is there sufficiently time or money available to collect such data?* If data or resources are unavailable to determine benefits, the service should not be further examined.

If planners use the criteria shown in Figure III-2, only a subset of the potentially affected human services may get carried forward for detailed analysis as a result of the screening process. But the tables do provide a systematic way to identify the candidate list of human services associated with environmental restoration without overlooking ones that a particular planner may not have encountered because of the type of ecosystem under study. There could be a situation where human services meet criteria #1 through #5, but may be overlooked if the tables are not evaluated first. In the example in Figure III-2, it might be (HS_2&BF_2), (HS_5&BF_5), and (HS_6&BF_6) that meet all of the criteria. However, without the initial Tables III-7 through III-12, one of these important human services might have been overlooked.

Illustrative Application of Linkage Tables

In the following example, selected input-output-service combinations are traced to illustrate the series of decisions that could be made in determining an appropriate set of human service categories deserving further analysis for ecosystem project planning and justification. This hypothetical example walks the reader through the decision points, via Tables III-7 through III-12, that could bring the planning team from a proposed environmental management action to a set of selected benefit categories pertinent to further analysis. In a straightforward sense, the illustrative example shows the reader how an operational linkage between ecosystem impacts and human services could be made. Additionally, this illustrative exercise demonstrates that the tables provide an opportunity for thinking through the environmental impacts. That is, the tables organize information to facilitate decisions that could be made by the environmental planning team. Although attempts have been made to present realistic planning situation decisions, the reader should take careful note that the illustrative example is purely hypothetical.

The next section describes the planning context that would be served by this linkage approach to environmental planning. Following a brief description of the physical and developmental contexts of the hypothetical restoration site, a discussion of the possible path through Tables III-7 through III-12 and the selection of candidate ecosystem outputs and human services are provided. After the candidate list is produced, the steps for applying the human demand screening criteria in Figure III-2 are followed and reasons for further analysis (yes or no) are summarized.

Planning Setting

The linkage tables and associated methodology described in this chapter are most applicable for the reconnaissance and early feasibility planning stages involving environmental impact. For restoration projects, the initial idea at a given site typically is brought to the attention of the Corps by a local interest. In some cases, the project is developed under a regional planning effort (e.g., watershed plan). For this example, the restoration project was part of a long-term consideration by the Corps in close cooperation with the state in which it was located.

Once the proposed restoration activity is on the table, the restoration planning team would cooperatively work through the tables. Two keys to successful application of the tables for restoration planning are 1) an interdisciplinary team working through the tables and 2) team members with sophisticated knowledge of the subject ecosystem. The tables were designed to guide the expertise of the planning team, to facilitate more effective communication between disciplines, and to promote a more robust examination of restoration impacts and benefits. A typical planning team would consist of a biologist/environmental scientist, economist, planner, and engineer. These team members should have a working knowledge of the subject ecosystem and would, in most cases, include the Corps study manager and selected technical staff. Some situations may call for technical staff from prominent resource agencies affected by the project to join the planning team (e.g., if the site is near a USFWS wildlife refuge, it may be advantageous to have the expertise of the refuge manager as part of the team working through the tables).

Hypothetical Site and Project Description

The illustrative example is a restoration project for a small tidal lake that is part of a riverine system. The lake and the river are tributaries to an estuary that were greatly modified as the watershed was urbanized. The lake was modified by the installation of tidal gates, by sedimentation, by contamination of sediments by urban runoff, and by changes in its connection to the river and migratory aquatic species associated with the estuary. The lake level fluctuates with the surge and ebb of the estuary tide. A proposal to improve habitat in the lake, primarily for migratory species in the estuary, was the redistribution of sediment by hydraulic dredging to support a network of marsh and tidal-flow channels. Thus, the focus for this illustrative example is on the impacts of dredging for restoration purposes.

Candidate Ecosystem Outputs and Human Services

Based on the proposed management action, hydraulic dredging, Figure III-1 indicates that every table in the series except for biological quality (Table III-12) would be directly influenced. The six tables can be accessed in any order, although starting with Table III-7 is recommended because it is affected by most Corps management actions and because changes in morphology and topography usually cause additional ecological and other changes in aquatic ecosystems.

The direct and indirect impacts of hypothetical dredging activities are listed in Tables III-13 and III-14, respectively. First, the example covers all of the direct impacts (Table III-13) and proceeds through each of the elements in the tables accordingly. Then, each of the indirect impacts are traced through the appropriate tables (summarized in Table III-14). All candidate human service entries are provided for each ecological output that is deemed appropriate. This constitutes the candidate services inventory as shown in the left-hand section of Tables III-13 and III-14. The entire set of candidate human services are further scrutinized through the demand screening procedure shown on the right-hand section of the tables. A description of the demand screening procedure that summarizes the candidate services inventory follows this section.

Entering Table III-7, we encounter **resource surface area** first (note all table entries are shown in boldface text). It is a major variable among ecological inputs altered by the proposed

TABLE III-13

ILLUSTRATIVE EXAMPLE: DIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY				SERVICE DEMAND ANALYSIS					
Table Reference	**Dredging-Influenced Ecosystem Input**	**Dredging-Influenced Ecosystem Output**	**Candidate Human Service**	**Screening Criteria**					**Carry Forward**
				1	**2**	**3**	**4**	**5**	
Watershed, Basin, and Channel and Topographical Process (Table III-7)	dredging will increase water resource surface area	total use area increases	beach swimming	N	Y	--	N	--	N
			tubing	N	Y	--	N	--	N
			snorkeling	N	Y	--	N	--	N
			scuba	N	Y	--	N	--	N
			non-motor rafting, canoeing, kayaking	N	Y	--	Y	Y	Y
			sail boating	N	Y	--	N	--	N
			small outboard-motor and air boats	N	Y	--	Y	Y	Y
			inboard recreational craft	N	Y	--	N	--	N
			commercial craft	N	Y	--	N	--	N
			various land uses including commercial, recreational and cultural-natural heritage	N	Y	--	N	--	N
		aesthetic sense of space and horizon	pleasing environment	N	Y	--	Y	Y	Y
	resource surface area fluctuation should decrease with increased volume dredged	fluctuation of use base	boating	N	Y	--	Y	Y	Y
			swimming	N	Y	--	N	--	N
			aesthetics consistency	N	Y	--	Y	Y	Y

TABLE III-13 (Continued)

ILLUSTRATIVE EXAMPLE: DIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY				SERVICE DEMAND ANALYSIS					
Table Reference	**Dredging-Influenced Ecosystem Input**	**Dredging-Influenced Ecosystem Output**	**Candidate Human Service**	**Screening Criteria**					**Carry Forward**
				1	**2**	**3**	**4**	**5**	
Watershed, Basin, and Channel and Topographical Process (Table III-7) (cont.)	resource surface area fluctuation should decrease with increased volume dredged (cont.)	shore protection	property protection	N	N	N	--	--	N
	volume holding water will increase from dredging	storage capacity will increase	flood control	Y	--	--	--	--	Y
			sediment control	N	Y	--	N	--	N
			water supply upon demand	N	N	N	--	--	N
		water discharge sustainability should increase as volume dredged increases	downstream recreation and commercial navigation needs	N	Y	--	N	--	N
	depth will increase from dredging	clearance to bottom will increase	boating	N	Y	--	Y	Y	Y
			swimming	N	Y	--	N	--	N
		tailwater discharge depth for hydroelectric production is not a consideration here	hydroelectric	N	N	N	--	--	N
	slope would be increased by dredging	lake basin slope would increase	boating	N	Y	--	Y	Y	Y
			swimming	N	Y	--	N	--	N
			aesthetics of waterbody and adjacent shore	N	Y	--	Y	Y	Y
		channel slope	boating	N	Y	--	Y	Y	Y

TABLE III-13 (Continued)

ILLUSTRATIVE EXAMPLE: DIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY				SERVICE DEMAND ANALYSIS					
Table Reference	**Dredging-Influenced Ecosystem Input**	**Dredging-Influenced Ecosystem Output**	**Candidate Human Service**	**Screening Criteria**					**Carry Forward**
				1	**2**	**3**	**4**	**5**	
Watershed, Basin, and Channel and Topographical Process (Table III-7) (cont.)	slope would be increased by dredging (cont.)	channel slope (cont.)	swimming	N	Y	--	N	--	N
			hydropower generation (head)	N	N	N	--	--	N
			flood control	Y	--	--	--	--	Y
			aesthetics of waterbody and adjacent shore	N	Y	--	Y	Y	Y
	shoreline length is likely to be increased by dredging designed to create wetlands	riparian shade may increase depending on proximity to trees	shore recreation	N	Y	--	N	--	N
		shoreline erosion often increases as shoreline length increases but should be controlled by wetland protection	shoreline property	N	N	N	--	--	N
			shore recreation	N	Y	--	N	--	N
			aesthetics	N	Y	--	Y	Y	Y
	shoreline irregularity should be increased by dredging in a pattern suitable for wetland creation	the ratio of shoreline length to water area should increase	aesthetics	N	Y	--	Y	Y	Y
	channel form is changed by dredging	the sinuosity of tidal creeks in the wetland could be increased over time	aesthetics	N	Y	--	Y	Y	Y
			boating	N	Y	--	Y	Y	Y
	floodplain form is altered by dredging	floodplain storage capacity for water and sediment should increase at the site	flood impacts on adjacent floodplain	Y	--	--	--	--	Y
			downstream flood impacts	Y	--	--	--	--	Y

TABLE III-13 (Continued)

ILLUSTRATIVE EXAMPLE: DIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY				SERVICE DEMAND ANALYSIS					
Table Reference	**Dredging-Influenced Ecosystem Input**	**Dredging-Influenced Ecosystem Output**	**Candidate Human Service**	**Screening Criteria**					**Carry Forward**
				1	**2**	**3**	**4**	**5**	
Watershed, Basin, and Channel and Topographical Process (Table III-7) (cont.)	floodplain form is altered by dredging (cont.)	floodplain storage capacity for water and sediment should increase at the site (cont.)	direct effect and indirect effect via groundwater recharge	N	N	N	--	--	N
				--	--	--	--	--	N
	watershed form should not be measurably affected by this project	not applicable	not applicable	--	--	--	--	--	N
Water and Material Transport Process (Table III-8)	dredging directly affects watershed and material transport only temporarily	not applicable	not applicable	--	--	--	--	--	N
Substrate (Table III-9)	substrate particle structure is altered by dredging	substrate particle size could be altered by dredging depending on specific conditions at the site	aesthetics (e.g., emergent marsh, submerged rock and vegetation)	N	Y	--	Y	Y	Y
		substrate particle stability may be altered by dredging--usually stability decreases	direct effect via construction support	N	N	N	--	--	N
		substrate particle compaction usually decreases	construction support in floodplains and watersheds	N	N	N	--	--	N
	substrate chemistry	organic matter content would not be expected to change	not applicable	--	--	--	--	--	N
		nutrient content would not be expected to change	not applicable	--	--	--	--	--	N

TABLE III-13 (Continued)

ILLUSTRATIVE EXAMPLE: DIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY				SERVICE DEMAND ANALYSIS					
Table Reference	**Dredging-Influenced Ecosystem Input**	**Dredging-Influenced Ecosystem Output**	**Candidate Human Service**	**Screening Criteria**					**Carry Forward**
				1	**2**	**3**	**4**	**5**	
Substrate (Table III-9) (cont.)	substrate orientation and development	within-habitat vertical development such as a mix of steep-sided and gradual slopes, are likely to result from planned wetland development during dredging	aesthetics--as created by spatial diversification of shape and color in submerged marshes etc.	N	Y	--	Y	Y	Y
		between-habitat vertical development is likely to result from placement of dredge material above and below the water line	aesthetics-as affected by spatial diversification in emergent marshes etc.	N	Y	--	Y	Y	Y
Landscape Process (Table III-10)	habitat patchiness	within habitat patchiness is likely to be increased by proper contouring of the wetlands bottom habitat during dredging	aesthetics	N	Y	--	Y	Y	Y
		habitat edge development should be increased during wetland development	aesthetics	N	Y	--	Y	Y	Y
	habitat connections and corridors	intrahabitat connections that link similar habitats are likely to be fostered by dredging to create wetlands	aesthetics	N	Y	--	Y	Y	Y
		interhabitat connections between different habitat types will be increased as habitat edge development increases	aesthetics	N	Y	--	Y	Y	Y

TABLE III-13 (Continued)

ILLUSTRATIVE EXAMPLE: DIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY				SERVICE DEMAND ANALYSIS					
Table Reference	**Dredging-Influenced Ecosystem Input**	**Dredging-Influenced Ecosystem Output**	**Candidate Human Service**	**Screening Criteria**					**Carry Forward**
				1	**2**	**3**	**4**	**5**	
Landscape Process (Table III-10) (cont.)	habitat connections and corridors (cont.)	air-water interface will not be impacted significantly	not applicable	--	--	--	--	--	N
	habitat diversity can be reduced or increased by dredging patterns	within habitat diversity may be affected by spatial variety created while dredging	aesthetics	N	Y	--	Y	Y	Y
		between habitat diversity such as the mix of water, short vegetation and tall vegetation, can be encouraged by dredging designed to develop wetlands	aesthetics	N	Y	--	Y	Y	Y
	human habitat is not part of the design of the proposed dredging activity	not applicable	not applicable	--	--	--	--	--	N
Water and Sediment Quality (Table III-11)	all direct impacts will only be temporary during actual dredging activity	not applicable	not applicable	--	--	--	--	--	N

TABLE III-14

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Resource Surface Area	total area of productive habitat is increased by dredging	*Biological Qualities (Table III-12)*	population production processes usually are increased when more habitat area is increased	forest and range populations will not be affected by dredging	not applicable	--	--	--	--	--	N
				pathogen populations usually are not affected by dredging	not applicable	--	--	--	--	--	N
				aquatic macrophyte extent is determined by area of suitable habitat	fishing	N	Y	--	Y	Y	Y
					commercial harvest	N	Y	--	N	--	N
					recreational harvest and other use	N	Y	--	Y	Y	Y
					ecological indicators	N	Y	--	N	--	N
					endangered species	Y	--	--	--	--	Y
					nuisance species	N	Y	--	N	--	N
					swimming, boating, etc.	N	Y	--	Y	Y	Y
				planktonic algae will increase in proportion to the areal increase in habitat	fishing	N	Y	--	Y	Y	Y
					commercial harvest	N	Y	--	N	--	N
					recreational harvest and other use	N	Y	--	Y	Y	Y
					ecological indicators	N	Y	--	Y	Y	Y

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Resource Surface Area (cont.)	total area of productive habitat is increased by dredging (cont.)	*Biological Qualities (Table III-12) (cont.)*	population production processes usually are increased when more habitat area is increased (cont.)	planktonic algae will increase in proportion to the areal increase in habitat (cont.)	nuisance species	N	Y	--	Y	Y	Y
					swimming, boating, etc.	N	Y	--	Y	Y	Y
					suspended solids	N	N	N	--	--	N
				fish populations will increase in proportion to areal increase of habitat	commercial harvest	N	Y	--	N	--	N
					recreational catch, harvest and other use	N	Y	--	Y	Y	Y
					ecological indicators	N	Y	--	N	--	N
					health hazard	Y	--	--	--	--	Y
					depredation	N	N	N	--	--	N
					watchable wildlife	N	Y	--	Y	Y	Y
					endangered species	Y	--	--	--	--	Y
				invertebrate populations will increase in proportion to areal increase of habitat	commercial harvest	N	Y	--	N	--	N
					recreational harvest	N	Y	--	Y	Y	Y
					ecological indicators	N	Y	--	N	--	N
					health hazards	Y	--	--	--	--	Y
					property damage	N	N	N	--	--	--
					nuisance	N	Y	--	N	--	N
					endangered species	Y	--	--	--	--	Y

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Resource Surface Area (cont.)	total area of productive habitat is increased by dredging (cont.)	*Biological Qualities (Table III-12) (cont.)*	population production processes usually are increased when more habitat area is increased (cont.)	invertebrate populations will increase in proportion to areal increase of habitat (cont.)	watchable species	N	Y	--	Y	Y	Y
				certain reptiles and amphibians should increase while others may decrease slightly	commercial harvest	N	Y	--	N	--	N
					recreational harvest	N	Y	--	Y	Y	Y
					depredation	N	N	N	--	--	N
					nuisance/health	Y	--	--	--	--	Y
					endangered species	Y	--	--	--	--	Y
					ecological indicator	N	Y	--	N	--	N
					watchable species	N	Y	--	Y	Y	Y
				certain bird populations should increase as dredged area increases	waterfowl hunting	N	Y	--	Y	Y	Y
					upland bird hunting	N	Y	--	N	--	N
					watchable water birds	N	Y	--	Y	Y	Y
					watchable riparian & upland birds	N	Y	--	N	--	N
					endangered species	Y	--	--	--	--	Y
					ecological indicators	N	Y	--	N	--	N
					nuisance/health	Y	--	--	--	--	Y

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria 1	2	3	4	5	Carry Forward
Resource Surface Area (cont.)	total area of productive habitat is increased by dredging (cont.)	*Biological Qualities (Table III-12) (cont.)*	population production processes usually are increased when more habitat area is increased (cont.)	certain bird populations should increase as dredged area increases (cont.)	depredation	N	Y	--	N	--	Y
				certain mammalian populations should increase as dredged area increases	recreational harvest	N	Y	--	Y	Y	Y
					furs	N	Y	--	N	--	N
					watchable species	N	Y	--	Y	Y	Y
					endangered species	Y	--	--	--	--	Y
					depredation	N	Y	--	N	--	Y
					health/nuisance	Y	--	--	--	--	Y
			community process associated with dredged habitat should increase	biodiversity should increase because the dredged area adds different habitat to the region	species richness	N	Y	--	Y	N	N
					species abundance evenness	N	Y	--	Y	N	N
					biological stratification	N	Y	--	Y	N	N
					genetic information	N	Y	--	Y	N	N
				biological integrity should increase to the extent that a condition closer to original ecosystem attributes is created by dredging	material retention	N	Y	--	N	--	N
					ecosystem indicator species	N	Y	--	N	--	N
					production/ respiration (P/R)	N	Y	--	N	--	N

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Resource Surface Area (cont.)	total area of productive habitat is increased by dredging (cont.)	*Biological Qualities (Table III-12) (cont.)*	community process associated with dredged habitat should increase (cont.)	biological integrity should increase to the extent that a condition closer to original ecosystem attributes is created by dredging (cont.)	material export stability	N	Y	--	N	--	N
					production stability	N	Y	--	N	--	N
					production level	N	Y	--	N	--	N
					biogeochemical cycling rate	N	Y	--	N	--	N
					efficiency of solar energy capture	N	Y	--	N	--	N
					trophic level efficiency	N	Y	--	N	--	N
					foodweb complexity/ support	N	Y	--	N	--	N
Resource Area Fluctuation	concentration and dilution effect	*Biological Qualities (Table III-12)*	population production process	populations are affected only temporarily in the category	not applicable	--	--	--	--	--	--
	shore protection should increase as fluctuation increases		population production process and community process will be affected	most population and community process is affected by shore protection at this site	*(see outputs and candidate service analysis for productive habitat entry)	*	*	*	*	*	*

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Resource Area Fluctuation (cont.)	shore protection should increase as fluctuation increases (cont.)	*Water and Sediment Quality (Table III-11)*	suspended particulate matter should decrease as shore protection increases	total suspended solids should decrease with decreased shore erosion	turbidity	N	Y	--	N	--	N
					general drinking and food processing contaminant -- grittiness, possibly toxic	N	N	N	--	--	N
					abrasion causes machinery and transport system damage	N	N	N	--	--	N
					recreational boating	N	Y	--	Y	Y	Y
					swimming	N	Y	--	N	--	N
					aesthetics	N	Y	--	Y	Y	Y
				organic suspended solids	domestic water contaminant	N	N	N	--	--	N
				suspended color will change to a more natural color	domestic water use	N	N	N	--	--	N
					aesthetics	N	Y	--	Y	Y	Y
				suspended toxic materials should decrease following dredging	domestic and livestock water contaminant	N	N	N	--	--	N
			dissolved matter may increase slightly as shore erosion decreases	water color may be affected	aesthetics	N	Y	--	Y	Y	Y
					domestic water supply	N	N	N	--	--	N

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Volume	total material and energy content will increase as dredged volume increases	*Biological Qualities (Table III-12)*	population production processes and community processes will be slightly effected downstream from the site	all population and community processes present in the newly dredged habitat will expand in proportion to the additional volume dredged	*(see outputs and candidate service analysis for productive habitat entry)	*	*	*	*	*	*
	concentration and dilution effects will be minor and temporary		biological quality will be supported in proportion to increased loads	living and non-living material concentrations will temporarily decrease	not applicable	--	--	--	--	--	--
			water quality factors will be temporarily and slightly effected by volumetric expansion	living and non-living material concentrations will temporarily decrease	not applicable	--	--	--	--	--	--
	water discharge sustainability will be increased a slight amount		population production processes and community processes will be slightly effected downstream from the site	a small flow augmentation will result in an insignificant positive effect on the esturarine ecosystem	not applicable	--	--	--	--	--	--

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Volume (cont.)	oxygen load, thermal load, and material load, will increase in proportion to increased aquatic volume at the site	*Biological Qualities (Table III-12) (cont.)*	biological quality will be supported in proportion to increased loads	most chemical and biological process supported by loads will increase in proportion	*(see outputs and candidate service analysis for productive habitat entry)	*	*	*	*	*	*
			water quality will be supported in proportion to increased loads	most chemical and biological process supported by loads will increase in proportion	*(see outputs and candidate service analysis for productive habitat entry)	*	*	*	*	*	*
Depth	depth variables will be little affected at the site or are irrelevant	not applicable	not applicable	not applicable	not applicable	--	--	--	--	--	--
Water area-depth ratio	evapotranspiration will not be affected by dredging at this humid site	not applicable	not applicable	not applicable	not applicable	--	--	--	--	--	--
Fetch	although slightly affected, turbulent mixing would be insignificant	not applicable	not applicable	not applicable	not applicable	--	--	--	--	--	--

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria 1	2	3	4	5	Carry Forward
Slope	lake basin slope	*Biological Qualities (Table III-12)*	population production process	aquatic macrophytes are likely to increase with slope changes	fishing	N	Y	--	Y	Y	Y
					commercial harvest	N	N	N	--	--	N
					recreational harvest and other use	N	Y	--	Y	Y	Y
					ecological indicators	N	Y	--	N	--	N
					endangered species	Y	--	--	--	--	Y
					nuisance species	N	Y	--	N	--	N
					swimming, boating, etc.	N	Y	--	Y	Y	Y
Shoreline length	organic detritus supply should increase at the site	*Biological Qualities (Table III-12)*	population production process	some fish and invertebrates	commercial harvest	N	N	N	--	--	N
					recreational catch, harvest and other use	N	Y	--	Y	Y	Y
					ecological indicators	N	Y	--	N	--	N
					health hazard	Y	--	--	--	--	Y
					depredation	N	N	N	--	--	N
					watchable wildlife	N	Y	--	Y	Y	Y
					endangered species	Y	--	--	--	--	Y
					property damage	N	N	N	--	--	N
					nuisance	N	Y	--	N	--	N

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Shoreline length (cont.)	organic detritus supply should increase at the site (cont.)	*Water and Sediment Quality (Table III-11)*	suspended particulate matter	organic suspended solids should increase, but would be insignificant	not applicable	--	--	--	--	--	--
	riparian shade	not applicable	at this site, riparian shade is a minor issue	not applicable	not applicable	--	--	--	--	--	--
	terrestrial organism water use	*Biological Qualities (Table III-12)*	population production process	numerous reptiles and amphibians, birds should be favored by dredging design	commercial harvest	N	N	N	--	--	N
					recreational harvest	N	Y	--	Y	Y	Y
					depredation	N	N	N	--	--	N
					nuisance/health	Y	--	--	--	--	Y
					endangered species	Y	--	--	--	--	Y
					ecological indicator	N	Y	--	N	--	N
					watchable species	N	Y	--	Y	Y	Y
					waterfowl hunting	N	Y	--	Y	Y	Y
					upland bird hunting	N	Y	--	N	--	N
					watchable water birds	N	Y	--	Y	Y	Y
					watchable riparian & upland birds	N	Y	--	Y	Y	Y
	shore erosion		population production process	net erosion effects should be minimal at this site	not applicable	--	--	--	--	--	--

TABLE III-14 (Continued)

ILLUSTRATIVE EXAMPLE: INDIRECT ECOSYSTEM IMPACTS AND CANDIDATE HUMAN SERVICES

CANDIDATE SERVICES INVENTORY						SERVICE DEMAND ANALYSIS					
Dredging-Influenced Ecosystem Input	**Direct Ecological Outputs with Indirect Effects**	**Table Reference**	**Factors Indirectly Affected by Dredging**	**Dredging-Influenced Ecological Output**	**Candidate Human Service**	Screening Criteria					Carry Forward
						1	2	3	4	5	
Shoreline irregularity	ratio of shoreline length to water area	*Biological Qualities (Table III-12) (cont.)*	population production process and community process	numerous aquatic and terrestrial organisms are affected	*(see outputs and candidate service analysis for productive habitat entry)	*	*	*	*	*	*
		Water and Sediment Quality (Table III-11)	pattern of contours dredged will impact water and sediment quality	suspended particulate matter will be altered--very slightly decreased depending on pattern dredged	not applicable	--	--	--	--	--	--
	floodplain storage capacity	*Substrate (Table III-9)*	substrate particle structure	substrate particle size	aesthetics	N	Y	--	Y	Y	Y
				substrate compaction	construction support in floodplains and watershed	N	N	N	--	--	N

management actions. Varying the resource surface area would increase **total use area** for a variety of possible recreational uses such as **beach swimming** and **tubing**. **Aesthetic** human services are also of concern. The expanse of open water, marsh, and forest, and its juxtaposition with the urban environment are likely to affect aesthetic sensibility. **Productive habitat area** is another variable linked to surface area; however, support of **biological processes** is only indirectly linked to human services. Indirect human services are addressed below after all direct effects are reviewed.

The remaining direct impacts are summarized in Table III-13. Many of the impacts are deferred to analysis under indirect impacts. All of the potential direct impact entries from Table III-8, which describe water and material transport, were deemed insignificant and therefore were not applicable for further analysis. The significant direct impacts from dredging on water and sediment quality (Table III-11) would be only temporary, occurring during the actual dredging activity, and were therefore excluded from further analysis.

After the analysis of the direct impacts, the restoration team could retrace the tables and follow through the indirect impacts. The indirect impacts and candidate services are shown in Table III-14. Because of the complex interrelationships between elements of the ecosystem, examination of indirect impacts can be an intense undertaking. It is up to the planning team to decide the appropriate number of iterations that should be followed in examining the indirect impacts. For the illustrative example, the first generation of indirect impacts originating from Table III-7 is shown.

The first reference to a relevant indirect effect from Table III-7 is found under **resource surface area** and the entry called **total area of productive output**. The precursor effect that is referenced directs the planning team to Table III-12, which describes potential impacts on **biological processes**.   At Table III-12, the first ecological input category considered is **population production processes**. Following through to the ecological output column reveals **forest and range populations**. For the illustrative case of dredging activities, this output category would not be affected, and therefore no further analysis on that family of impacts is needed. Similarly, **pathogen populations** are typically not impacted by dredging activities and therefore would not be applicable for further analysis. **Decomposer populations** may indirectly impact **water quality**. The project team would follow through on **water quality** impacts, but for the case of the illustrative example, only the first generation of indirect impacts is being described.   The next category of direct ecological outputs to consider is **aquatic macrophytes**, which would probably be enhanced by the dredging activity. Several associated human service impacts could be influenced, including **recreation and commercial fishing**. The remaining indirect impacts are summarized in Table III-14.

Screening Criteria for Further Analysis

The results of the inventory identified several candidate human service categories, some of which surface multiple times (e.g., aesthetics). Given restoration priorities, study project budgets, and available time/data, it may not be practical or feasible to quantify and/or monetize all of these human services. To determine which candidate services might be carried forward for further analysis during plan formulation, the planning team would apply the criteria in Figure III-2. The illustrative example is continued with the analysis of demand for services that is summarized in the right side of Tables III-13 and III-14. Each of the five criteria is considered and assigned a *yes* or *no* response according to the conditions of the illustrative example.

Looking at the first entry in Table III-13, the candidate human service is **beach swimming**. The service demand analysis first addresses the issue of whether it is a legal requirement for beach swimming to be evaluated. The answer is no, there is not a legal reason to evaluate beach swimming. The next criterion asks if there is demand for added amounts of this service, which in this case there is, given the close proximity to an urban area where beach swimming would be used by families. Answering yes to the second criterion, then moves us to the fourth, which asks if meaningful differences in human service can be measured given the proposed restoration alternatives. The answer here is no because the dredging will provide better conditions for wildlife but will not improve the quality of the water to point that would support beach swimming. Therefore, the **beach swimming** human service would not be carried forward for further analysis.

Each candidate human service listed in Tables III-13 and III-14 is evaluated in similar manner. In situations where judgments on a certain criterion are not needed, a double dash is provided. There are a few cases in Table III-14 where the candidate service inventory revealed the same set of candidate human services as an earlier output. In this case, reference is made to the earlier entry and asterisks are shown in the service demand analysis columns. The trends for each criterion are described below, and then the remaining set of human service categories suggested for further analysis are summarized.

Legal. A review of human service and benefit measures in Tables III-14 and III-15 suggests that very few legally require analysis. Of all the candidate human service categories, only **endangered species**, **flood control**, and **health hazards** require legal consideration. Endangered species require analysis according to federal law. According to state laws, any modifications to the watershed, including restoration activities, need to be evaluated in terms of impacts on flood potential. Lastly, the county health department pays particular attention to water resource activities especially along the lines of increased health threats. Each of these is automatically carried forward. Although water resource activities may not be significantly impacted by the proposed project, an assessment stating the magnitude of impacts (small or large) is required.

Demand. Most of the candidate services offered by the dredging activities are demanded, especially the recreation, aesthetic, and wildlife-type services. Thus, most of the responses to the second criterion are yes. Demand for biodiversity and ecological integrity in the county is evidenced by articles about natural area restoration in the local newspaper as well as volunteer efforts to clean up nearby streams to improve habitat for fish and wildlife. Volunteers, a local fundraiser, and contribution by local businesses to provide money and materials needed are being organized for another nearby area. This documents the demand for biological integrity and diversity, since native species are being restored in these areas. There is a demand for freshwater fishing sites close to urban areas. The fish and game agency is attempting to hold "take a kid fishing days" to encourage children and teenagers to fish. Existing areas for freshwater fishing are often quite crowded on weekends, decreasing the quality of the fishing experience. While there are currently adequate opportunities for bird viewing, this is a rapidly growing segment of outdoor recreation, and this location may soon run out of sites to see wading and shore birds.

A few of the candidate services are not in demand at this particular site, such as **water supply** (residential, commercial, agricultural) and **hydroelectric power**. Another service that is not in demand is **property protection**, because the site is zoned for no development and therefore has no residential or commercial properties threatened. Another potential service that is provided by **improved substrate conditions** is for construction. However, it is not applicable because limited construction and use of heavy equipment are planned around the site.

Importance of Stakeholders. This demand criterion provides an opportunity to accommodate human services that might be critical to a particular stakeholder while not displaying a firm case for added demand (second criterion). Most of the entries in the third criterion are left blank because an affirmative response to the second criterion moves the demand analysis to the fourth criterion. The remaining human service categories evaluated under this criterion were assigned no because they were not of particular importance to any stakeholder. For example, **water supply** was assigned no to this criterion because it is not an issue. When a human service category is assigned no under this criterion, it is no longer considered for further analysis.

Determination of Meaningful Differences Across Alternatives. While there are many human service categories that will be impacted by the proposed dredging, the magnitude of impact in many cases cannot be meaningfully measured. Although there is demand for many of the active water-based recreation activities, such as **swimming** and **tubing** in this region, presently there is none, and the proposed dredging activities will not improve the resource enough to allow for significantly more water-contact recreation. Therefore, many of the candidate human service categories are assigned a no at this step. Some **boating** activities and **recreational fishing** will be improved by the project; however, **commercial fishing** will not be impacted significantly. All categories of **aesthetics** and **watchable wildlife** will be enhanced. Any human service categories assigned a no for this criterion would not be further analyzed.

Data Availability. Of the candidate human service categories that made it to this final criterion, the final issue of data availability must be addressed. The importance of **aesthetics**, **fishing**, **boating**, and **hunting** could be assessed through a brief survey of potential users of the site. However, the most likely source of valuation data will be through the existing literature.
For example, willingness to pay (WTP) for additional visitor days of fishing and higher catch rates can be obtained from the 1990 National Survey of Fishing, Hunting, and Wildlife Recreation. For bird viewing, the Corps will, in cooperation with the Audubon Society and Ducks Unlimited, conduct on-site surveys of current bird-viewing areas and ask visitors about their interest in using the newly restored area and their WTP per day. Biodiversity will be retained in index form, but nonuse values will not be monetized because neither the money nor the time is available to perform a contingent valuation survey.

In summary, many potential human services could be impacted by the proposed dredging activity. In this case, about fifteen pages of candidate human service categories were distilled to a handful of critical human service categories that could be realistically pursued. For legal reasons, impacts on endangered species, health hazards, and flood control must be assessed. The values of fishing, hunting, boating, wildlife watching, and aesthetics could form a substantial argument for project justification. This would give the restoration planning team some insights and direction for further valuation analysis. As the planning activities unfold, other factors may be discovered that would cause the restoration team to revisit the tables.

Final Thoughts on Application

As planners move through the entries in the tables, they will encounter a list of direct and indirect effects that may possibly result from proposed management actions. In the process, they will encounter feedbacks representing complex systems interactions. The complexity will grow with the time and space dimensions included in the project. The intent in this table complexity is to encourage planners to analyze several steps further than they might if they simply looked at a list of direct linkages between ecological outputs and human services. At what point should table readers break the feedback cycle? There is no pat answer of course, but at some point ecologically informed readers will no longer be able to identify meaningful change.

This method of identifying meaningful links between ecological outputs and human services will have served its purpose well if it encourages deeper questioning of management alternatives than would otherwise have occurred. For complex environmental restoration projects or any other project involving environmental impacts, this method will be served best by an interdisciplinary team of engineers, ecologists, economists, and other special disciplines. This method should become increasingly useful as it is used for more and more projects and users become more familiar with its strengths and weaknesses. It will be enhanced further if it is modified to add meaningful dimension and to delete trivia. The results of certain projects at least should be rigorously monitored to identify which ecological links to human services actually materialized and why, as advocated in principles of adaptive management (Walters 1986).

CLOSING DISCUSSION

The goal of this research effort was to provide a hierarchical list that Corps planners could use to support the examination of economic and ecological impacts associated with proposed environmental restoration projects. Tables III-7 through III-12 support that goal. If utilized by the Corps planning community, these tables will make an immediate impact on environmental plan formulation by offering a more comprehensive profile of ecological and economic impact categories. The tables provide more than 180 entries of ecosystem effects and human service linkages associated with typical Corps environmental restoration projects. This listing alone provides a useful starting point for a Corps planner charged with project formulation and evaluation.

Although the linkage tables are important products of this research, an equally important contribution to the field of environmental evaluation is the process that produced them. Freeing an ecologist and economist from their disciplinary constraints proved profitable. Attempts at ecological-economic linkage typically produce models that require data that may never exist. The research team was able to keep a practical perspective and produce tables as readily available tools that can almost immediately support planning efforts. While the tables deserve further testing and review, the tools therein are readily available in most instances.

Users of the tables will find them complex and somewhat cumbersome to handle. The complexities of environmental systems made this inevitable. Although the tables are logical in their present form, the general structure of the tables begs for formatting in hypertext. This computer technology (which is very common to WINDOWS computer users) allows for information retrieval at specified locations in the document. Thus, the user, instead of going to an entry in the table and then directed to go elsewhere, would have all these data available in a "point and click" fashion without having to go through several pages of tables. Information found in the footnotes and Glossary could also be nested in hypertext fashion.

The information that has been compiled as a result of this research effort should not be viewed as the final compilation for use by field planners. Instead, the information needs to be treated as part of a "living document," one that can incorporate new information as it is developed. As techniques improve and new outputs and services are identified, the tables will evolve. One possible addition in the short term could be the inclusion of the ecological model inventory that is being conducted under the *Objectives and Outputs* work unit in EEIRP by Waterways Experiment Station. These models could be listed in a column in the tables alongside the appropriate ecological output entry. (These could even be more accessible to the user in hypertext format.) This continued refinement and enhancement should involve review from field personnel in both the Corps and other agencies involved in environmental planning and evaluation. Interagency support during this process is vital, because it provides the needed validation and improvement of the results from these tables.

GLOSSARY

Allochthony (allochthonous) transport of material or energy from its site of formation to the site of concern.

Basin slope see **Slope**.

Biodiversity the amount of differentiation away from a state of biological monotony. Maximum diversity occurs when each element encountered is different from all other elements, and the least diversity occurs when all elements are identical. Diversity may be expressed in terms of species (and other taxonomic divisions), habitat, genes, structures, and ecosystems.

Biogeochemistry study of chemical transformations and pathways through biotic and abiotic process in ecosystems.

Biological biotic integrity wholeness or completeness of biological elements and functions needed to sustain system processes indefinitely. System size ranges from individual tissues in organisms to the largest of ecosystems--the biosphere. Biosystems with high integrity have all of those elements necessary to perform all functions indefinitely. Sometimes used synonymously with "health" as in **ecosystem health**.

Braided stream a stream that separates into numerous channels, which often are unstable and shift locations.

Capacity the maximum load that can be transported by a current or stream.

Channel a naturally eroded or artificially constructed course for running water, wider and deeper than the streamflow except during flood.

Channel slope see **Slope**.

Color pigment in water that absorbs light, usually associated with organic compounds. It is responsible for coffee- or tea-colored staining of water in many aquatic habitats, most notably bogs.

Community an aggregation of different species populations in the same space and time frame. It is the collective-living part of an ecosystem.

Consumers organisms (usually animals) that ingest (eat) foods and secrete enzymes to internal surfaces where foods are dissolved and assimilated. They usually develop large body sizes to hold the internal high-surface area needed for digestion and assimilation.

Corridor (habitat connection) connections linking similar habitat patches.

Current the movement of water within a lake or stream along discrete lines of travel.

Decomposers organisms that secrete enzymes to external surfaces where food substrates are digested (dissolved) and then assimilated. They usually have very high ratios of body surface area and volume, and many are very small (however, the largest organisms on earth are decomposers--soil fungi).

Deposition amount of suspended and dissolved material deposited by physical and chemical processes.

Depression storage water or material storage capacity in watershed depressions, including depressions already partially filled with water, such as impoundments.

Depth the distance from top to bottom of a water body or an aquifer, often expressed as a mean, or the depth from the surface to some specified point, such as a water discharge level.

Discharge is the flow rate of water through a cross-sectional area of stream channel, penstock, weir, canal, or other structure.

Dissolved matter in water that will never settle out in its present chemical form and is usually defined as that matter that passes a 0.45 micron filter.

Ecological (trophic-level) efficiency the energy captured at one trophic level divided by the energy captured at the next lowest trophic level.

Ecological indicator a physical, chemical or biological index to the integrity of ecological functions in a community or ecosystem, such as presence of a unique species, variation of oxygen from atmospheric saturation, or water level dynamics.

Ecosystem an organized interaction of physical, chemical, and biological processes into predictable manifestations and arrangements of energy and matter in diverse biological forms (see Evans 1956).

Ecosystem health see **Biological integrity**.

Ecosystem inputs environmental variables, including human causes, that affect ecosystem processes and usually result in altered ecological outputs from those ecosystems. Plant nutrients are basic ecological inputs for most ecosystems.

Ecosystem outputs physical, chemical, and biological responses to natural or human-caused changes in ecosystem processes. Outputs usually become inputs for other processes. Input of plant nutrients, for example, generates plant-growth output, which becomes input for herbivore growth, and so on.

Edge development extent of interface that develops between adjoining habitats. Irregular edges are more developed than regular edges.

Electromagnetic process pertains to radiation and electrons.

Epilimnion the wind-mixed surface stratum of a lake, which is superimposed over a hypolimnion. Vertically well-mixed waters do not form strata (do not stratify).

Erosion amount of substrate material displaced by physical or chemical processes.

Evapotranspiration total water lost through surface evaporation and plant transpiration.

Fetch is the longest distance over which wind operates to mix a water body.

Floodplain the valley bottom adjacent to water bodies, created in part by flood sediments (alluvium) and subject to further flooding.

Floodplain storage capacity maximum amount of water and/or material that can be stored in a floodplain.

Flow velocity is the net rate of current or streamflow in one direction.

Form physical appearance of a channel, watershed, or basin.

Habitat the unique combination of physical, chemical, and biological properties that support a specific assemblage of organisms.

Habitat arrangement alignment and interspersion of different habitats in physical space.

Habitat connections see **Corridor**.

Hardness equivalent to the amount of calcium and magnesium concentration, which is most responsible for reducing soap suds in wash water, and interacts with nutrients and contaminants to modify their biological impacts.

Heterotrophy nutrition is derived by decomposers and consumers from organic matter originally produced through photosynthesis or chemosynthesis.

Human services the anthropocentric functions performed by ecological outputs.

Hydraulic retention a measure of the volume displacement rate of water from a lake basin through its point of discharge.

Impenetrable surface that surface in a watershed that sheds all water at the surface, and no water infiltrates to subsurface flows or storage.

Interspersion extent to which all habitats within a specified area come in contact with each other.

Landscape ecology branch of ecology that treats ecosystem interactions at a geographical scale.
Load amount of material or energy (**thermal load**) carried in a lake or river.

Loading rate at which a water body takes on materials, usually expressed per unit area (e.g., Kg/hectare/year).

Macrophytes large vascular plants and algae in contrast with microscopic algae.

Matrix (habitat) the dominating habitat in a region.

Meander length of a full meander cycle, usually expressed as a mean.

Meander radius deviation of a stream meander from a straight-line path, usually expressed as a mean.

Morphologic processes those processes that shape watershed and floodplain, lake basin and river channel topography.

Nutrients the elements required for life. Phosphorus, nitrogen, iron, and carbon are among those most likely to be in short supply and limit growth in aquatic ecosystems.

Patchiness extent to which habitats of the same kind becomes dispersed into isolated "islands" or patches.

P/B the ratio of production and biomass, usually on an annual basis.

pH logarithmic expression of hydrogen ion concentration in which the concentration is highest when the pH is lowest (acid) and the pH of pure water is 7.0.

Population an assemblage of genetically similar organisms, which are geographically distributed so that members have potential for reproductive, genetic, or other interaction.

Primary producers organisms that generate organic matter from inorganic matter through photosynthesis (the vast majority of production) or through chemosynthesis.

Production amount of matter or potential energy generated over some specified time period (productivity is production rate), including that biological matter (biomass) or potential energy that died and was decomposed or consumed. Population production is the biomass produced by a population. Community production is the biomass produced by a community.

Reduction-oxidation a measure of the net electrical state in a solution. It contributes importantly to chemical reaction rates and chemical compound solubility in water.

Riparian stream-side habitat usually regulated by floodplain groundwater.

Salinity total concentration of dissolved, ionized inorganic matter in water.

Shear stress the forces exerted on a channel or lake bottom by flow.

Shellfish crustacean or molluscan species differentiated from true vertebrate fishes.

Shoreline irregularity the degree to which terrestrial and aquatic environments are interspersed at the edge of a water body.

Shoreline length the length of the interface between terrestrial and aquatic habitats.

Slope "rise over the run." **Basin slope** is the mean slope of a watershed (or simply watershed slope) basin or lake basin. **Channel slope** is the longitudinal gradient along a stream channel.

Storage capacity the volumetric capacity of a basin for water sediment or other storage.

Substrate material underlying the surface environment: usually soil, sediment, wood, plants, or rock.

Substrate development a process of substrate change mostly through ecological succession.

Substrate orientation vertical to horizontal aspect of substrate surfaces.

Surface area the geographical amount of watershed, water body, or other ecosystem measure at its surface.

Suspended solids the material suspended in the water, usually defined as larger than can pass through a 0.45 micron filter.

Tailwater river discharge from a dam.

Thermal load see **Load**.

Total dissolved solids (TDS) total amount of dissolved matter contained in a volume of water and includes all inorganic ions composing salinity and all other dissolved matter.

Transport the carriage of materials in solution, suspension, and floatation.

Transport capacity the maximum load that can be carried by a given water body under prevailing conditions

Turbulence chaotic flow, moving in all directions and effectively mixing water and materials.

Volume the water or other habitat volume held in a basin or channel.

Watershed the total surface area overlying substrate, acting as a catchment for, and potential delivery of, water to a water body via surface and subsurface flows.

Wave height diameter of wave circulation, indicated by the distance between the trough and the crest of a wave cycle.

Wetted perimeter actual bottom surface that comes in contact with water along a flow cross-section.

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APPENDIX

ECOSYSTEM PROCESSES UNDERLYING ECOLOGICAL OUTPUTS

UNDERLYING ECOLOGICAL OUTPUTS

This report has, to this point, presented basic information regarding the development and use of interdisciplinary tables for environmental restoration planning efforts. This appendix provides an in-depth examination of the ecological processes that affect ecosystems. It is intended to enhance understanding of the interactions that occur in the ecological outputs included in Tables III-7 through III-12.

ECOSYSTEM ENERGETICS AND MATERIAL FLOW

Energy Transformation and Biological Production

An extensive theoretical basis for gauging ecosystem integrity has developed over the last half-century starting with Lindeman's (1942) seminal work on energy and material flow through ecosystems. It is founded in the conceptual understanding of energy and material resource partitioning among diverse populations. An ultimate aim is understanding how energy is captured and directed through ecological processes into diverse biological outputs, such as production and biomass of individual species populations. The principles of ecosystem energetics and material transformation can help clarify connections among resource management decisions, physical-chemical inputs, ecological outputs, and benefit outcomes. Discussion of this theory illustrates why certain physical, chemical, and biological properties are among the more inclusive indices of ecological conditions indicating ecosystem integrity. Some basic discussions are presented in Odum (1971, 1983), Whittaker (1975), and Ricklefs (1979). More advanced discussions are presented by O'Neill et al. (1986) and King (1993).

Within ecosystems, material inputs are derived from watershed, airshed, and migratory processes (Figure A-1). Energy is transformed from solar and geochemical sources primarily by photosynthesis (chemosynthesis is relatively rare in most systems). Consumer and decomposers derive their energy heterotrophically from the assimilation of food materials initially created by photosynthesis or chemosynthesis in the first trophic level. This energy transformation is the basis of so called energy pyramids in which energy content is greatest in solar and geochemical sources and diminishes with transformation in each successive trophic level (Figure A-1).

Trophic Levels

Energy transmission through ecosystems is substantially less than 100 percent efficient in preserving biological production at each transformation level in the food web. The number

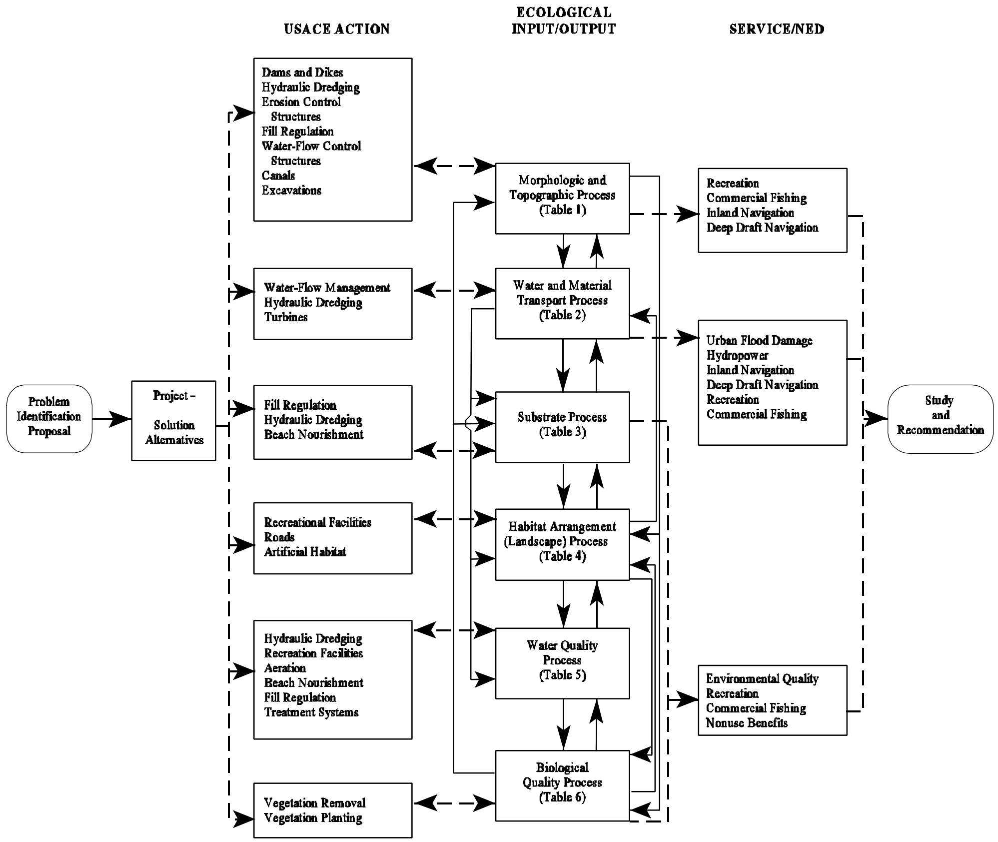


FIGURE A-1
ENERGY AND MATERIAL FLOW PATHWAYS[1] BY WHICH KINETIC AND POTENTIAL ENERGY ORIGINATES AND IS TRANSPORTED, TRANSFORMED, AND PARTITIONED AMONG LIFE FORMS BEFORE IT LEAVES THE ECOSYSTEM[2]

1. Symbols are as in Figure II-1. N=nutrient, L=light, T=temperature, F=flushing rate, SS=suspended solids, O=oxygen, b=bottom substrate, S=salinity, and Sp=species. All variables are exemplary only.
2. Resource partitioning occurs among trophic levels and within trophic levels, depending on factors that regulate efficiencies at each trophic level and at each guild and species within each trophic level.

of energy transformations preceding the one occurring as an organism eats, places that feeding action in a specific trophic level. Thus an omnivore eating plants falls in the second trophic level (herbivore level) at that instant, but falls into the third level when it eats an herbivore. Many species participate in more than one trophic level, depending on adaptational range, life stage, time of year, and opportunity. An accurate determination of the annual mean trophic-level position for an omnivore can be an intermediate value, such as 2.3. The sum of all energy transformations within a trophic level is used to determine the trophic-level efficiency.

As energy cascades though trophic levels, a portion is sequestered in biochemical energy with potential for kinetic expression. The energy is captured with carbon-based compounds in which carbon, hydrogen, and oxygen form the bulk of the biomass formed. Carbon is the most common measure used to represent ecosystem material flow. In the process, however, many other required and nonrequired elements are sequestered, including scarce nutrients and toxic materials. For special applications, material flow is measured with a limiting nutrient or a toxic element. Examples of research defining this process in aquatic environments include Lindeman (1942), Odum (1957), and Teale (1962).

The biomass developed from radiant and chemical energy provides potential for sequestering various materials in a harmless and beneficial state or mobilizing them into pathways leading to harmful impacts. The capacity for material storage extends beyond life processes to physical uptake by leaf litter, humus, and derivative clays. Understanding of mechanisms that determine storage and release is useful for managing the concentration of both desirable and undesirable materials. Whereas much storage is temporary and a part of ecosystem processes, permanent storage is a sink for materials.

A common measure of a consumer trophic-level efficiency is its net production divided by the net production of the supporting trophic level (e.g., herbivore production/primary production). Past ecological theory proposed that consumer trophic-level efficiency averaged about 10 percent as energy passed through successive consumer levels from primary producers (i.e., herbivores, carnivores, and top carnivores). Many studies over the decades indicate that this trophic-level efficiency varies widely among ecosystems and possibly among trophic levels. It most usually varies between 5 and 15 percent. Some of this variation undoubtedly is due to sampling error. Some is likely, however, because of differential environmental resistances to energy flow through consumer communities. Because food webs eventually run out of the energy needed to sustain an identifiable trophic level, food-chain length varies among environments with different energy inputs and environmental resistances to energy flow. Kozlovsky (1968) thoroughly discusses ecological efficiencies and problems encountered in attempts to identify trends. Trophic-level efficiency is one measure of the ecological efficiency with which natural communities transform solar energy into community production of consumer trophic levels.

Trophic-Process Indicators of Environmental Stress

The consequences of variation in outputs regarding trophic efficiency can be profound for predicting the production and abundance of many functionally similar groups (guilds) or predicting individual species populations, especially in the carnivore trophic levels (Table A-1). The degree of variation developed within trophic levels as average trophic-level efficiency changes is magnified with increasing trophic level. Whereas herbivores, using 1,000 g C/M^2/year of primary production, evidence a 3x variation among the examples of 5 percent and 15 percent efficiency in Table A-1, third-level carnivores evidence about 25x variation. Uppermost levels are more sensitive indicators of changes in trophic-level dynamics as a consequence of environmental change. Therefore top carnivores make sensitive indicators of loss in ecosystem integrity, especially if species richness is judged to be an important ecological output. Their welfare depends on underlying efficiency of trophic interactions within the ecosystem as well as the interaction with other species. Top carnivores are frequently among the first species to disappear as an ecosystem loses integrity under stress. Simple models of single-species response to habitat change are more likely to go awry for carnivores than for species lower in the food web because of the numerous food-web factors involved in addition to habitat attributes.

TABLE A-1
HYPOTHETICAL LEVELS OF PRODUCTION (g C/M^2/year) IN EACH TROPHIC LEVEL, ASSUMING DIFFERENT CONSUMER TROPHIC-LEVEL EFFICIENCIES AND PHOTOSYNTHETIC EFFICIENCIES

	Trophic-Level Efficiencies					
Trophic Level	0.5%	5%	10%	15%	15%	Variable %[1]
Primary producer	1,000	1,000	1,000	1,000	10	1,000
Herbivore	5	50	100	150	1.5	100
1° Carnivore	0.25	5	10	22.5	0.23	5
2° Carnivore	0.02	0.25	1	3.38	0.03	0.75
3° Carnivore	0.00	0.02	0.1	0.51	0.00	0.08

1. Herbivore efficiency is 10%.
 1° Carnivore efficiency is 5%.
 2° Carnivore efficiency is 15%.
 3° Carnivore efficiency is 10%.

Mean size of consumer species also increases with increased trophic level because of the advantage size lends in most predator-prey interactions. Humans, of course, are relatively large omnivores with a significant portion of their consumption in carnivore categories. They tend to choose large prey, and perhaps not coincidentally, they tend to value large consumer organisms more highly than small ones. A somewhat simplistic popular emphasis on protecting large endangered consumer species is apparent in the facetious assignment by some to a new taxonomic category, "charismatic megafauna." The average size of species targeted for consideration in judging habitat suitability is larger than the average consumer. Their position in the food web, at least at certain life stages, also is higher than the average trophic position. This implies that for many targeted species, habitat models using physical-chemical measures often are less reliable than they may be for the smaller organisms, which in general occupy lower positions in the food web. There are, of course, numerous exceptions to the general rule.

Dramatically stressed ecosystems provide the best evidence that food-chain length varies with stress and that consumer efficiency varies significantly from 10 percent, depending on rate-regulation processes. Low consumer efficiencies are commonly encountered in aquatic environments that experience low oxygen concentrations. Only anaerobic decomposers can function significantly in situations such as deoxygenated hypolimnia or poorly mixed rivers and bays receiving organic wastes with high biological oxygen demand. In such circumstances consumer efficiencies approach zero as long as oxygen remains too low for consumers to function. To exemplify such extremes in Table A-1, where consumer efficiency was dropped to 0.5 percent, virtually all carnivore production ceased. Other examples of stressful environments include those with harmful toxicity levels, extremely hot environments, and extremely saline environments.

What may be stressful for one trophic level may not be stressful for another. Toxic materials are often specific for consumers and primary producers, for example. Even though primary producers cannot function in prolonged darkness, many consumers do well, and consumer efficiency is much less limited by prolonged darkness than by anoxia. Hot springs can have high primary production and low consumer trophic-level efficiency because of different primary producer and consumer tolerances to high temperature. The mixed reactions of ecosystem component species and guilds to stress complicate energy pathway predictions and exemplify a limitation inherent in simple indices.

Grazing and Detritus-Based Foodwebs

In most sampled environments, the efficiency of primary production is less than that of consumer trophic levels. High seasonal or annual primary production values are about 2 percent of the total visible solar energy reaching an aquatic community (e.g., Brylinski 1980). These high-efficiency conditions typically occur in habitats with continuous and plentiful nutrient supply, low concentrations of inorganic suspended matter, low light-extinction rates (other than caused by primary producers, low inorganic suspended solids, warm (25°-30° C) temperatures, low flushing rates, absence of toxic materials, and, especially in shallow streams and shore zones, stable bottom substrates. A physiological maximum photosynthetic efficiency may approach 10 percent or more for short periods in natural environments (Dubinsky and Berman 1981). Primary production efficiency is critical because it establishes the basis for consumer production. When, as in Table A-1, the efficiency of primary production is low, even a high consumer efficiency may not be enough to sustain food-chain length. There are many examples of positive relationships between primary production and consumer production (Morgan et al. 1980; Oglesby 1977).

In situ primary production is not, however, the only source of organic matter available for consumers in most ecosystems. Two major consumer food-chain divisions are recognized: (1) the grazing chain based on herbivorous consumption of living and recently dead primary producers and (2) the detritus chain based on partially decomposed, dead primary producers. One of the major advances in understanding ecological energetics and processes was recognition of the role of allochthonous (from outside sources) detrital organic matter and decomposition in supporting consumer production and abundance. As shown in Figure A-1, watersheds are a source of allochthonous organic matter, both from nearby riparian sources and from diffuse watershed sources (Cole et al. 1990; Webster et al. 1979; Vannote et al. 1989). This allochthonous load contributes to the total pool of potential energy available to heterotrophic organisms, including specialized consumers.

Stress Factors Limiting Ecological Efficiency

Detritivores face a limiting condition not shared with herbivores: nitrogen and other nutrients are rapidly leached from dead organic matter. This makes detritus, before it is colonized by decomposers, rich in calories but nutritionally poor and inefficiently transformed into detritivore tissue. Colonization of detritus by bacteria and fungi increases detritivore efficiency because decomposers add nitrogen from the water to the detritus via their own protein content. Thus decomposers serve a dual role with respect to consumer populations, first as competitors for organic resources and second as nutritional sources that greatly augment the importance of detritivore food chains in many ecosystems (McDiffert 1970; Minshall 1980, Teale 1962; Mann 1988; Wetzel 1983). Although detritivore efficiency may approach that of herbivores, a significant part of the energy must go to maintenance of bacterial and fungal production.

The diversity and form of organic matter is important in determining efficiency. Large, woody, and acidic organic matter is more resistant to decomposition than small, nonwoody, and pH-neutral organic matter. Therefore, basic ecological outcomes of potential interest for predicting production amounts, levels, and species composition are related to the amount of acidic, woody material, usually from allochthonous sources. Ecosystems rich in such allochthonous organic matter and poor in calcarious alkaline compounds usually form acidic black-water rivers, swamps, or bogs as refractory dissolved organic matter accumulates (Wetzel 198; Cole 1994).

A relationship exists between the protein content in food and the efficiency with which trophic levels assimilate the food. Consumer assimilation efficiencies tend to be lowest for detritus not yet colonized by decomposers, higher for colonized detritus, higher still for fresh plant and algae, high for animal foods with extensive organic exoskeleton development, and highest of all for animal foods without such exoskeleton development. Generally speaking, top carnivores have the highest assimilation efficiencies, which decrease as trophic levels approach the primary producer level. However, metabolic maintenance costs also tend to increase with increased trophic level, partly because predators tend to be more active than prey (Kozlovsky 1968).

A maximum possible consumer trophic-level efficiency (measured in terms of net production) can be estimated from knowledge of consumption, assimilation, and respiration efficiency. In ecosystems where consumers manage to eat all food efficiently with none left over for decomposers, the trophic-level efficiency is A(1-R), where A is fraction of consumed food assimilated and R is the fractional amount of the assimilated food that goes to respiration. For top carnivores with efficiencies of 80 percent for assimilation and 60 percent for respiration, the maximum trophic-level efficiency is about 32 percent. The maximum appears to be similar but perhaps different for other trophic levels because assimilation efficiencies may change more with trophic level than will respiration efficiencies. Of course where detritus chains are important in ecosystems, the maximum consumer efficiency is likely to be lower because decomposers get a maintenance fraction. The relationship between decomposers and consumers remains an area of active ecological research in pursuit of improved understanding of trophic interactions.

A variety of factors act to reduce or constrain development of the theoretical maximum consumer efficiency in ecosystems by:

(1) Diverting more energy into respiratory maintenance

(2) Diverting potential energy resources into storage (e.g., bottom sediments)

(3) Exporting potential energy before it can be consumed or decomposed (e.g., estuary flushing to offshore waters)

Among those constraining factors several stand out, including temperature, flushing rates, inorganic sediments, oxygen concentration, substrate stability, light transmission, and nutritional quality. These are symbolized as augmentation variables (in circles in Figure A-1), which drive energy transformation. They also contribute to determining resource partitioning among species.

A major factor is water availability. In terrestrial ecosystems, availability of water usually is the key factor determining productivity and community composition. In those transitional environments between fully aquatic and fully terrestrial states, water-level fluctuation predominates among factors determining community composition and productivity.

Temperature affects most ecological rates of importance, including photosynthesis, consumption rate, assimilation rate, and respiration rate. Endothermy (internal body heat regulation) is less energy efficient than ectothermy (externally regulated body heat). Endotherms are less externally regulated by environmental temperature but are not independent of it. Ecosystems dominated by endotherms may be less efficient overall in generating biomass and diversity because they are less energy efficient than systems dominated by ectotherms. However, a disproportionate number of high-profile species are endotherms.

Flushing rates are determined by the relative discharge and volume relations of a water body. Small streams have very high flushing rates of organic matter compared with most larger water bodies. Flushing rate is affected by substrate structure and morphology that decreases velocity in the reach where sedimentation occurs. The ratio of low-velocity pools and high-velocity riffles is an index to this phenomenon. Flushing rates are remarkably high in many coastal environments where important retention mechanisms for organic matter are sessile filter- feeders such as barnacles and mussels. Tidal periodicity greatly modifies net flushing and makes the definition of ecosystem boundaries more difficult than where flushing rates are low.

Inorganic sediments are important either in suspended or deposited form. Large quantities of suspended or deposited sediment dilutes the concentration of organic matter and decreases consumption efficiencies for numerous organisms. As sediment increases, it reduces oxygen and other material transport into sediments, reduces light transmission, and increases abrasion wherever currents occur.

Oxygen in at least some minimal quantity is required for efficient metabolism by all consumers, some being much more tolerant of oxygen depression than others. Whereas oxygen rarely limits consumer production and diversity in terrestrial environments, it is scarcer in aquatic environments and often is reduced enough to be the most critical limiting factor in aquatic systems where insufficient reaeration by mixing occurs to compensate for high biological and chemical oxygen demand. Oxygen and other gas supersaturation can be intolerable as well (e.g., salmonid gas narcosis below deep-injection penstocks). Water depth creates pressure, which limits distribution of vascular plants and other organisms. Velocity and turbulence displace organisms, resist movement and relocation, and, with suspended solids, abrade tissue.

Other habitat factors have less diverse impacts. Substrate stability and penetrability are important for providing dependable support to many primary producers and consumers. Light transmission is important not only for photosynthetic production but for the control of rates of sight-based consumption. The appropriate proportion of nutrient in the appropriate form is important for determining caloric consumption efficiency for all trophic levels.

Other factors may be locally important. Toxic materials are among the more critical. Because toxins rarely have equal impact on all community members, they create pathway shifts and different efficiency changes among the trophic levels.

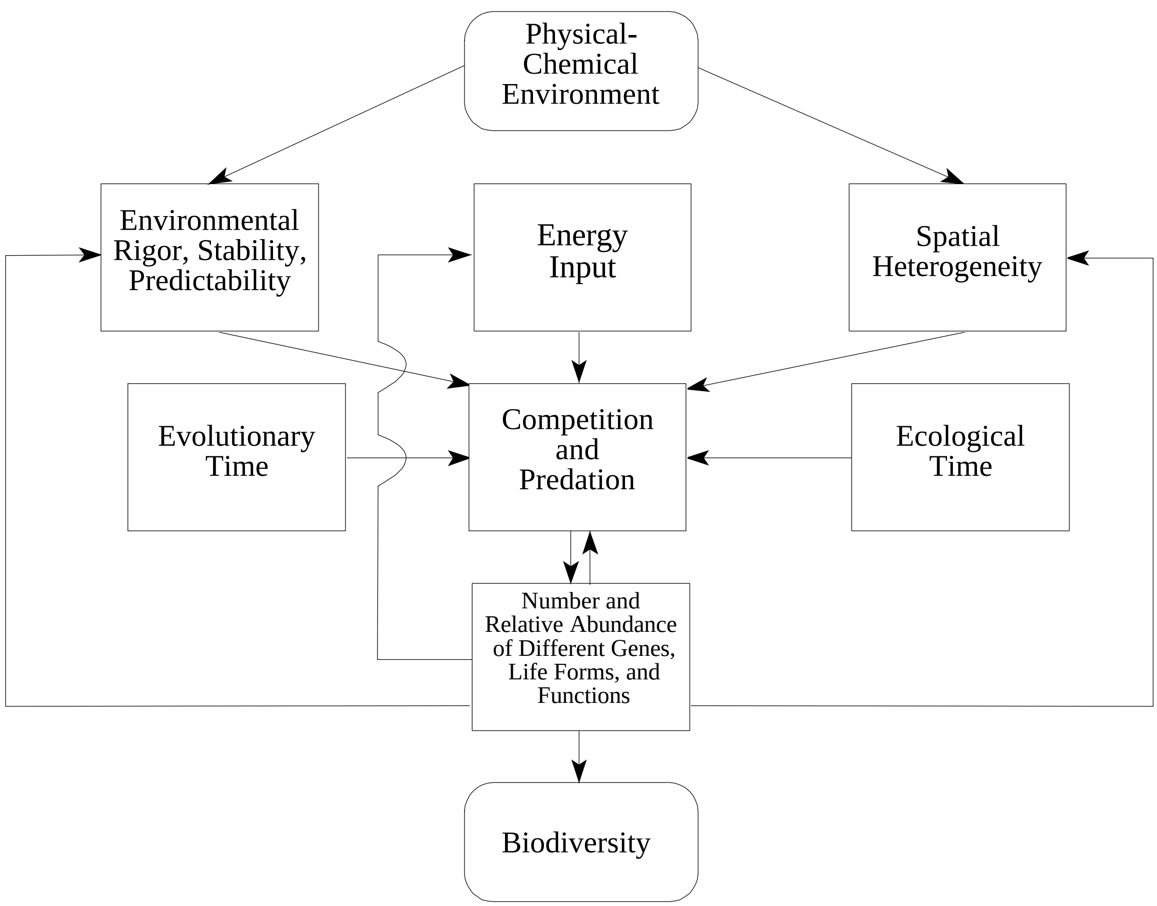
The morphology, or topography, of watersheds, lake basins, and stream channels indirectly influences the intensity and distribution of regulatory factors. Slope, or gradient, interacting with gravity determines rates of water movement, turbulence, and erosivity. Watershed, lake basin, and chemical shapes determine how much water values will be contained at what surface area and depth (above and below ground level). Morphological variables influence temperature, oxygen, light, velocity, turbulence, concentrations of toxic and nutrient materials, substrate penetrability and stability, and most other factors regulating the trophic-level efficiency and resource partitioning among species.

DIVERSITY

Factors Controlling Biodiversity

Diversity and energy flow are related through trophic resource-partitioning processes (Figure A-2). Nutritional energy is partitioned among functionally similar species (guilds) and then among species within guilds, based on differential adaptation of guilds and species to diverse attributes of the nutritional base and its environmental presentation (where and how food appears in the ecosystem). Guild categories are determined based on locomotory adaptation, categories of acceptable nutrition type and presentation, and other unique features held in common by member species.

Both consumer and decomposer guilds occur in each trophic level. One of the most important



1. All categories can and often are influenced by human activity including intended efforts.

FIGURE A-2

CATEGORIES OF FACTORS DETERMINING SPECIES DIVERSITY IN ANY ECOSYSTEM[1]

partitions in energy pathways occurs between consumers and decomposers because decomposers are rarely targeted as species of direct interest to humans, even though they are ecologically indispensable. Although decomposers frequently are treated as a single guild, they are sometimes split into bacteria and fungi or into obligate anaerobes, facultative anaerobes-aerobes, and obligate aerobes, based on their tolerance to oxygen and related conditions (Atlas and Bartha 1987).

Diversity is determined by many interacting variables, which are categorically represented in Figure II-4. Initially all environmental attributes stem from the physical-chemical environment from which biological process derives. This physical-chemical environment supplies raw energy, spatial variation (spatial heterogeneity), and environmental variation that supports and constrains biological diversification. The primary biological force acting to determine biodiversity is competition among life forms for limiting resources and predation on life forms in lower trophic levels. The biological engine for change is genetic mutation and recombination. Evolutionary process requires time. Newly formed ecosystems with unique attributes require evolutionary time to diversify. Some general references about biodiversity and related concepts include Paine (1966), Poulson and Culver (1969), Wilson (1992), Walker (1992), Jones and Lawton (1995), and Noss and Cooperrider (1994).

Many new environments, however, are similar to existing ecosystems, which can serve as a source for colonizing forms. Depending on intervening conditions between similar habitats and the adaptation of potentially colonizing forms, ecological time is required for the colonization process to take place. Disturbed environments are denied the ecological time required for colonization, often despite close proximity of similar ecosystems. Thus frequently disturbed environments usually are less diverse than more constant and otherwise similar ecosystems.

The process by which disturbed environments become recolonized and ecosystems evolve changed functions is linked with the concept of succession, especially in terrestrial ecology. As plants colonize sites, to form marsh or swamps, for example, the community undergoes biotic and abiotic transition. Species composition, structural dimension, and biodiversity change and generate abiotic changes in sediments, soils, water amounts, shade, nutrient availability, currents and other factors that determine habitat suitability. As succession proceeds, many feedback interactions occur to inhibit some populations while others flourish. Many animal and plant species are most abundant at one stage of succession, indicating that the success of some species depends on all critical stages of succession being available within the range of individual organisms. Terrestrial succession adjacent to water ultimately results in filling those aquatic systems with low hydraulic energies and water exchange rates, such as many wetlands.

The extent that diversity occurs within ecosystems depends on energy flow rate. Where energy flow rates are very low, regardless of habitat optimality otherwise, only so much diversification of tissue is possible because of limited nutrition. Cave communities provide a good example of such nutrition-limited systems, typified by low diversity and community production dependent on small quantities of allochthonous organics (Paulson and Culver 1969). Food-chain length and diversity within each trophic level is reduced as source energy diminishes. This energetics limitation also may contribute to observed decrease of species richness as one moves from equatorial environments to polar environments. Other factors, however, are locally more important than source energy availability in determining diversity within ecosystems.

The spatial heterogeneity determines distance and connectivity between ecosystems. Landscape features play an important role in determining ultimate diversity and form of the inhabiting community of a new site. New ecosystems, such as created with water impoundment, initially have low diversity, which increases with impoundment age as invading species successfully colonize the new site (MacArthur and Wilson 1967; Simberloff and Wilson 1969). The species invasion rate and subsequent diversification depends on the suitability of intermediate environments consisting of emigration routes from similar ecosystems. Intervening environments can be effective barriers to species colonization of new sites, but most environments are penetrable, given enough time. Depending on management foresight, connecting corridors and barriers can be created to encourage a specified diversity. Many floodplain systems are perturbed by floods, for example, and their diversity depends on flood severity, connections to similar systems, and the time that has passed since the last flood event.

The principles of emigration, invasion, colonization, habitat patchiness. and local extinction are reasonably well developed in island biogeography (MacArthur and Wilson 1967), landscape ecology (Forman and Godron 1986; Harris 1984; Naveh and Lieberman 1990), and evolutionary ecology (Meffe and Carroll 1994; Primack 1993), although they have yet to be extensively applied. Where similar ecosystems are densely represented in the landscape and are interconnected by similar habitat conditions, a new site can be rapidly colonized by most species. Where density and connectedness are extremely low, however, complete colonization by all potential community members may never occur. The size and linear extent of a new site also are important, because increased dimension is more likely to intercept emigrants from other ecosystems. Of course, humans have substantial ability to influence colonization and diversification process through accidental and intended introduction.

Colonization rate and organism size are correlated because small organisms are wind transported or otherwise transported more readily than large organisms. Top carnivores tend to arrive last on the scene. Because of predator-prey interactions, major changes in communities can occur when carnivores arrive, especially for old and highly isolated locations. This was most dramatically demonstrated in Lake Victoria, Africa, when Nile perch were introduced to a million-year-old lake community and eliminated much of the endemic diversity because this predator had not evolved with the prey species (Barel et al. 1991).

Spatial heterogeneity operates both among and within ecosystems. Those ecosystems composed of diverse habitats are likely to carry more species than ecosystems composed of one habitat type. Different habitat types support different guilds because of the different locomotion and nutritional possibilities provided by each habitat. Some habitats are physically more diverse than others (marsh verses mudflat) and may be expected to support a greater diversity of adaptations as a consequence.

Organism size, activity, and position among trophic levels, all of which are correlated, also are correlated with the size and spatial diversity of the targeted ecosystem. Whereas small organisms frequently complete their life cycle within one habitat type, larger organisms frequently require several habitat types to complete their life cycles. Most evident usually are differences between nursery habitats and those habitats routinely used by foraging adults. The juxtaposition, interspersion, and connectedness of such habitats are critical for determining ecosystem optimality for many of the largest organisms in the ecosystem. These large species typically are carnivorous at some point in their lives and frequently are among species targeted in environmental protection, mitigation, and enhancement programs. Most sportfish and waterfowl are examples. The newly emerging principles of landscape ecology are especially applicable to projects designed to increase species abundance with diverse habitat needs (Harris 1984).

Environmental rigor, stability, and predictability also regulate diversity, which tends to decrease as physical-chemical factors vary from the conditions under which life evolved. Thus life functions are most diverse where and when temperatures remain about 25° to 30° C. For consumers, diversity decreases as oxygen varies from saturated concentration and goes to zero as oxygen concentration approaches zero for an extended time. Diversity decreases as environmental abrasiveness and friction increases, as in systems with rapidly moving suspended or deposited sediment. Coastal beaches and sandy rivers are good examples. Perpetually dark systems are likely to be less diverse than illuminated systems. These rigorous environments require exceptionally long evolutionary time to diversify to the same extent as less rigorous environments.

A certain amount of environmental instability may enhance diversification process. Daily changes in light intensity enable diverse sight adaptations to persist in the same ecological space. Diversity is reduced, however, when instability results in extended periods of rigor, such as frozen winter conditions. Predictable but instable seasonal temperature change has fostered a diversity of insect species, each of which functions most actively at different times of the year. Insect diversity usually decreases when impoundments create relatively uniform downstream temperatures (Ward and Stanford 1979; Vannote et al. 1989). However, the instability of salinity in estuarine environments has long been recognized as an especially difficult condition for diversification, which is usually lower than in either freshwater or marine environments.

The predictability of environmental variation also is critical in determining adaptational effectiveness. Instability can be predictable, as is daily and seasonal change in illumination intensity. Instability also may be unpredictable, such as catastrophic geologic, climatic, or anthropogenic events. Streamflow variation provides a good example. While streamflow varies with somewhat predictable seasonal patterns in most stream channels, and many organisms are adapted to such pattern, catastrophic floods are far less predictable and more destructive because their infrequency precludes adaptation. Management that re-creates the somewhat predictable flow variation and floodplain flooding that favored unique adaptation will preserve that diversity, just as management to reduce extreme flood damage also can protect diversity. On the other hand, management that both eliminates seasonal variation and increases the likelihood of extreme flooding is likely to reduce ecosystem integrity and diversity.

The process of diversification itself fosters further diversification within habitats, but can reduce total diversity across habitats. As a new site becomes colonized by marsh and swamp plants, for example, the new physical structure developed by the community stabilizes and reduces hydraulic energies and environmental abrasiveness. Suspended solids settle and are held in place by the plants. The new community provides numerous physical-biological niches for which diverse species are adapted, which otherwise would not exist without preliminary diversification. The new community also entraps greater imported organic matter, thus increasing the organic base for consumer production and diversification.

Diversity, Ecological Efficiency, Stability, and Ecosystem Integrity

As predators and competitors continue to colonize a new site, some less adaptive species go extinct locally while diversity overall usually increases and ecological efficiency increases. Sometimes, however, invasion by a particularly influential or keystone species can reduce diversity and ecological efficiency. This happened when Nile perch, a large predator, was introduced into Lake Victoria (Barel et al. 1991). Depending on how long unique species have been isolated from new sources of predation and competition, as in many isolated aquatic habitats, processes that normally cause diversification can both locally and globally decrease diversity. It is no accident that many recent extinctions occurred on land islands or their aquatic equivalents as humans "colonized" them and overly exploited their resources. Zoogeographic study indicates this has been a common process in the evolution of ecosystem diversity. Humans are among a number of colonizing forms capable of reducing diversity and ecological efficiency, but with exceptional effectiveness.

All species are not equal in determining how diversity contributes to ecological efficiency, however. Keystone species can occur at any level and have disproportionate influence within the community (Paine 1966). Species with disproportionate influence are more likely to occur in communities with lower diversity or are recent invaders such as the Nile perch in Lake Victoria (Barel et al. 1991) or the sea lamprey in the upper Great Lakes (Regier and Hartman 1973). Diversification tends to diminish the influence of any one species and builds functional redundancy into the system. That redundancy tends to sustain stability in ecological processes such as total community production and other ecological outputs, but at a cost in production or other output associated with one or a few of the species.

Species in simpler communities have, to some extent, compensated for the lack of species redundancy by becoming more resilient in the face of ecosystem fluctuation and sustained change. These broadly adapted species have high reproductive potential when trophic opportunities arise. Therefore, simple communities may be nearly as stable and efficient as complex communities when the tolerances of any one of the few species present are not exceeded. Because of their relative abundance and renewal rates, many of the wild species most valued as food and sport are resilient species that do not compete well in more diverse communities. Thus, management conflicts can exist between those who wish to maximize diversity and those who wish to maximize more immediate user benefits.

Biodiversity and ecosystem integrity are not simply and consistently related. Biodiversity varies from low to high in wilderness ecosystems, depending on the factors limiting diversification in those systems. Thus, from a management standpoint, ecosystem integrity is meaningful with respect to potential biodiversity that could exist, given ecosystem limiting conditions and their manageability. Part of the complexity derives from the hierarchial nature of ecosystems. Low local biodiversity often promotes higher biosphere biodiversity because many unique forms cannot withstand competition in more diverse communities. Numerous islands and isolated water bodies have lost endemic species as new species invaded with the help of humans. Even though local biodiversity can increase as a consequence of new species invasions, the total number of species in all of the earth's ecosystems decreases as a consequence.

There is some evidence that biodiversity has fluctuated as new, competitively superior species invaded established communities. Humans are, of course, keystone among competitive species. The concept of ecosystem integrity depends on the extent to which human behavior is accepted as part of natural ecosystem processes. The extent to which human behavior that reduces biodiversity is accepted in part depends on the extent society justifies human welfare at the expense of future option values associated with lost biodiversity. A practical definition of ecosystem integrity accommodates the best of human culture while protecting important future options (see Regier 1993).

BIOMASS AND CASCADE THEORY

Top-Down and Bottom-Up Ecological Forces

The downward force (top-down) of consumption and the upward (bottom-up) force of habitat attributes combine to determine the species biomass and numbers in ecosystems. This recent area of ecology, cascade theory, is the basis of a form of aquatic ecosystem management referred to as biomanipulation (Carpenter 1988; Carpenter and Kitchell 1992; DeMelo et al. 1992; Jones 1986). Because people seem to value present biological abundance more than biological renewal rate (production, sustainability), quantification of production and biomass relations and the effects of consumption on those relationships are desirable for developing more predictive ecosystem management understanding.

Trophic cascade relationships between bottom-up habitat drivers and top-down consumption drivers are illustrated in Figure A-3. Bottom-up drivers of ecosystem processes can be viewed loosely as habitat determinants (including engineered habitat conditions) of ecosystem functions. In Figure A-3, the conditions driving habitat quality originate in the watershed and in basin and channel morphology and water transport properties. Top-down drivers are mostly caused by predators, including humans. Organisms do not have to actually eat prey to act as a top-down force. They can interfere with reproduction, growth, or other processes. In addition, certain species, including humans, can greatly modify habitats from various positions in food webs (e.g., bald cypress, grass carp, beaver, alligators).

Bottom-up forces typically influence lower trophic levels more strongly than top-down forces. Water management manipulates ecological forces that drive material flow rates among ecosystems, most obviously out of watersheds and upper-watershed aquatic habitats into lower-watershed aquatic ecosystems and oceanic systems. This relationship between watershed and aquatic ecosystems profoundly influences ecosystem attributes, especially once watershed process

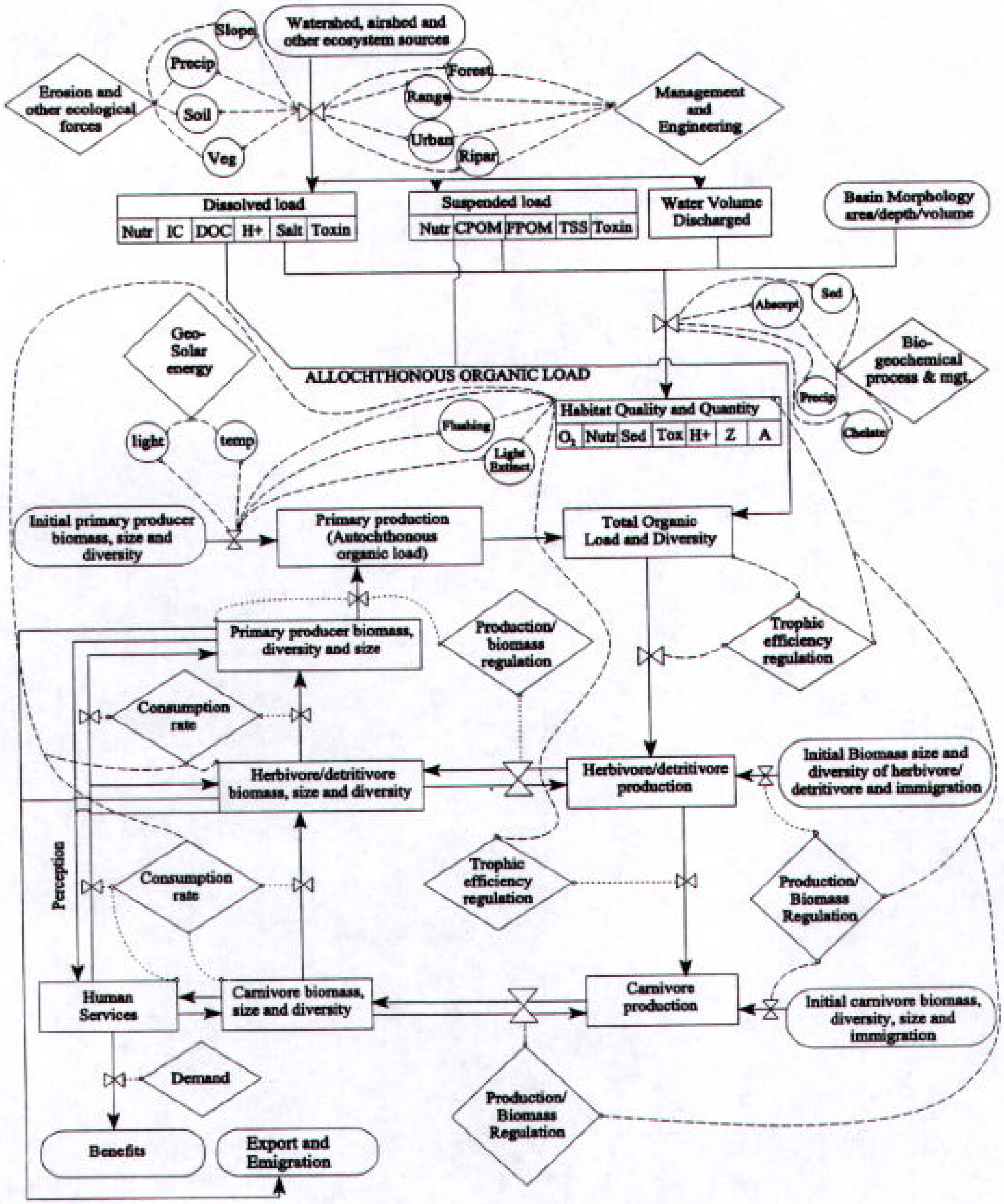


FIGURE A-3
INTERACTION BETWEEN BOTTOM-UP[1] AND TOP-DOWN[2] PROCESS IN DETERMINING BIOLOGICAL BIOMASS AND PRODUCTION WITHIN TROPHIC LEVELS[3]

1. Bottom-up process originates with off-site and on-site habitat conditions.
2. Top-down process originates with upper trophic-level influence on lower trophic levels, mostly through predation consumption rate.
3. Symbols are as in previous figures.

is integrated with solar energy influx and morphological conditions of channels and basins containing aquatic habitats. They collectively determine most of the physical-chemical concentration and intensities that regulate the efficiency with which physical-chemical energy is biologically "captured" by photosynthesis and transmitted through food webs to all species present. Although those physical-chemical attributes go far in determining production and biomass among populations, top-down effects often are substantial, especially in the upper trophic levels. The real top-down impact of humans in aquatic systems is most dramatically evidenced by the closure of numerous fisheries in recent decades.

Any complete predictive understanding of ecosystem management must start with initial conditions in the watershed, the channels and basins, the aquatic-based biotic communities, and proximal ecosystems. Such predictive understanding also must know the bottom-up and top-down ecological controls and how they respond to management. The initial diversity, biomass, and size structure of organisms need to be documented, both within the developed habitat and in surrounding ecosystem sources for colonizing species. In addition to controls within ecosystems, rates of emigration, invasion, and successful colonization from other ecosystem sources need to be accounted for.

The extent to which primary production is realized from initial biomass is determined by habitat quality, habitat quantity, and the grazing pressure of herbivores. Some important habitat factors symbolized in Figure A-3 represent a large array of possible factors depending on the ecosystem chosen for project consideration. Autochthonous primary production is augmented by allochthonous organic matter from terrestrial primary production (and other trophic levels in much smaller quantities). Habitat quality and quantity also influence the relationship that exists between biomass and production, the P/B ratio. An important determinant of P/B ratio is organism size, both within and among species, because size is an index for maximum growth rate possible when nutrition is nonlimiting. Small organisms typically grow faster than larger organisms when all nutritional requirements are filled (Peters 1983). See Peters (1983) for a thorough integration of the ecological importance of organism size.

Maximum population growth rate, however, is constrained by various habitat variables as they vary from optimum conditions. Extreme but tolerable low temperature, for example, profoundly limits ectothermic growth (fish, invertebrates, reptiles, and amphibians) and partially limits endothermic growth (birds, mammals). Depending on the system and species, any to all of the habitat factors described can constrain population growth through their effect on P/B ratio.

Management Implications of Cascade Theory

Ultimately, the biomass, numbers, form of diversity, and size of organisms greatly determine how humans relate to the community supported by ecosystem processes. This relationship is both ecological, through consumption and habitat modification, and psychological, as determined by perception of, and attitudes toward, community properties. The psychological process determines the extent that humans perceive benefit from the ecosystem and its management. Of course, the more humans can anticipate their needs from the community, their unplanned and planned impacts on the community, and the effects of other forces operating in the ecosystem, the more they can shape ecosystems to meet collective needs, including perceived need for long-term sustainability of diverse ecological outputs.

Those applied ecologists who emphasize the bottom-up management process have much to learn about ecosystem regulation, but may have more information available to them than those emphasizing top-down biomanipulation. Even though top-down management has existed as long as fish and game protection (millennia), the effects of top-down management on lower trophic levels have been scientifically documented only in the past few decades. Fish population manipulation has been shown to influence the biomass of both macrophytes and phytoplankton. Both theory and empirical results show that reduction of first-level carnivores allows herbivore abundance to increase and depress phytoplankton abundance--thus clarifying water and possibly reducing treatment costs by chemical or mechanical means.

Fisheries regulation usually disproportionately influences carnivores and indirectly may influence water-quality factors through ecologically transmitted effects. The extent of effect is variable and not entirely predictable. Generally, however, where water quality focuses on primary production dynamics, the ties between habitat regulation and primary production are clearer and more reliable than the tie between primary producers and upper trophic-level dynamics.

Recent ecological research in cascade ecology, if nothing else, demonstrates the complexity with which human actions can be transmitted through ecosystems to trophic levels and constituent species (e.g., see Carpenter et al. 1988). Although the impacts of both bottom-up and top-down influences diminish with the number of intermediary ecological interactions, the impact on human values may be disproportionate to ecosystem impacts. This is especially true of species in top carnivore levels, such as lake trout in the Laurentian Great Lakes or bald eagles in the continental United States. For lake trout, canal development modified habitat enough to allow entry of an effective predator, the sea lamprey, which interacted with commercial fishing to depress the lake trout population. For the bald eagle, bottom-up pesticide impacts interacted with top-down shooting. A list of endangered and threatened species reveals many that have reached their status because of the combined effects of bottom-up habitat change and top-down reduction.

IMPORTANCE OF ECOSYSTEM SIZE

Cumulative Management Effects

How big is an ecosystem? And how does the typical Corps project fit into that context? Practical management demands that limits be defined on project dimensions. At some point, project influence must diminish to inconsequential impacts. Yet history indicates that what appeared to be inconsequential off-project impacts have had important cumulative impacts, especially in wetlands, floodplains, estuaries, and barrier beaches. There is now a need to mitigate and recover from past cumulative effects through environmental restoration projects. The concept of ecosystem size is central to the concept of cumulative effect generated by material transport process in and out of project domains. As that concept becomes more generally recognized, the scale of the typical environmental restoration project is likely to increase.

The bounding of ecosystems for policy analysis is determined by human perspective and need more than by inherent ecological properties. Management outcomes usually identify the relevant ecological interactions to be incorporated into ecosystem perspective. Ecosystems are hierarchial assemblages of smaller systems within larger systems (O'Neill et al. 1986; King 1993). The dimensions of ecosystems range from subpopulation to global scale, depending on planning needs. Past management planning usually focused on certain subsystem outputs, such as specific vertebrate population abundance, and the intensity of management impacts radiated unevenly from those targeted systems inward to embedded subsystems and outward to enveloping supersystems.

An evolving perspective toward a more holistic concept of ecosystem integrity has increased the dimensions of relevant ecosystem processes and output (Regier 1993). For agencies concerned about total impact, useful criteria for bounding ecosystems must be defined as much by non-targeted ancillary outputs (side effects) as by the targeted outputs. These ancillary outputs may either augment or detract from the benefit intended from management. These side effects often take the form of off-site impacts beyond project boundaries.

An example of social problems that emerge when management outcomes are overly compartmentalized is the degradation of aquatic resources caused by overly erosive watershed practices, such as those intended to maximize agricultural production in the short run. Another less obvious example is the degradation of estuarine and coast resources as a consequence of engineering in the watersheds supplying nourishing sediment (Chapman 1973; Morgan 1973). The sum result of overly erosive watersheds and widespread development of sediment trapping impoundments is significant regional diminishment in the long-term benefit derived from reservoir construction.

Generally, as ecosystem size increases for targeted management outcomes and collateral nontargeted side effects, the intensity of interaction with other external ecosystems decreases. For example, when a lake alone is considered an ecosystem, many unexplained changes come about as a consequence of watershed processes. But when the lake and the watershed are integrated into a single ecosystem perspective, many of the previously mysterious processes become apparent and far fewer remain unexplained. When atmospheric or migratory processes are included within the ecosystem perspective, interactions with other external ecosystems may diminish to negligible levels.

Important Export Dynamics and Ecosystem Size

A truer measure of the extent that ecosystem size reduces interactions are measures of material import and export dynamics. Small systems with large ratios of material export to material retention may be equaled by very large systems with low ratios of material export to material retention.

Ecosystem dimensions typically are defined around those ecological factors that either constrain too much or too little the targeted ecological-output development. It is critical to assure that the identified ecological outputs are appropriate for intended management outcomes. When intermediate outputs are chosen as indices for the outputs of true concern, there is always a risk of index error. For example, habitat for a particular species may be the identified output, but "building it" may not automatically mean "they will come" if ecological factors elsewhere that constrain the population's ecosystem act to limit population use of the habitat. For example, building winter habitat for waterfowl that are limited by nesting habitat availability will do little to increase total bird abundance. Similarly, improving migration routes for migratory fishes may do little to increase abundance where marine fisheries go unregulated or spawning gravel remains embedded by sediments from overly erosive watersheds. Although the targeted corridor habitat may be effectively developed, the ultimate purpose remains unrealized and project value questioned.

Any index developed for predictive purposes must incorporate all of the relevant control factors for the expected project outcome. When they do not, either the outputs should be reconsidered or better indices sought. Meanwhile, decisions need to be made with the best information available, realizing there is always room for improvement.

Ecosystem dimensions also are defined to account for inputs and outputs that could alter interpretation of observed outputs. The most obvious example relates to estimates of habitat use as a measure of management outcome. Development of new habitat may result in high targeted population use rates mostly because populations are diverted from other habitats. Although a project habitat appears to produce 100,000-population use days, for example, the total use of all existing habitat may increase by only 10,000-population use days. To account for such possible misrepresentation of habitat "value," ecosystem perspective used in planning should include all alternative (substitute) habitats that may be used by the targeted populations.

ROLE OF MODELS

Numerous models have been developed to predict ecological outputs. These models may be useful planning tools depending on their applicability to specific project attributes. At the very least, models may help planners identify the critical input information needed to determine ecological output amount and form. Such models have been reviewed elsewhere in Corps reports, and the intent here is to show how some of the more commonly used models relate to the systems discussion developed here. Russell et al. (1992) identified several categories of ecological models that form a basis for model categories used here: population status, population dynamics, natural community process, natural ecosystems process, and natural-cultural ecosystems process.

Population Status Models

Population status models have enjoyed the most attention in past Corps planning, probably because they focus on habitat regulation of population performance, usually measured in terms of relative numbers, biomass, fecundity, productivity, or habitat use time. They are designed typically to estimate the optimum habitat configuration for maximum population performance. Many of the models have been developed as part of the habitat evaluation process (HEP) developed by the U.S. Fish and Wildlife Service in response to requests for environmental impact information and mitigation of environmental damage generated by federal projects (USFWS 1980, 1981; Shamberger et al. 1982; Bovee 1986). The main elements of HEP are habitat suitability indices (HSI) for high-profile species. These models are usually based on probability of population occurrence in habitats of various status. Certain fish, birds, and mammals have been most addressed with such models. Also, instream-flow analysis is based on the concept.

HEP models have dominated wildlife models for the past twenty-five years because they offer the advantages of simplicity, objective focus, and sponsorship by the lead wildlife agency in Federal government. They have, however, many limitations, some of which are no longer a function of the computing limitations and understanding of ecological processes that existed 25 years ago. Their biggest inherent limitation is single-species focus in an era when more holistic measures of ecosystem output are more desirable. Targeting more than one species for a project outcome requires an optimization process among the species management variables, a process that is unproven and risky but has potential with further research.

HEP was initiated in 1970, when most wildlife management revolved around some single high-profile species--the era of deer and black bass management. More recently, holistic natural community management outcomes have been superimposed on single-species management, such as management for greater species diversity and greater self-sustaining population regulation. Multiple species use and concerns have reoriented many management agencies to this community perspective, while their modeling approaches remained focused mostly on single-population issues. Some attempts to modify HEP and HSI to fit more of a community perspective have resulted in development of WET and certain other more holistic models (Adamus et al. 1987, 1991). Yet the modeling process for the most part remains experimental and unverified.

Population and Community Dynamics Models

Other specialized population models have been developed for different purposes and often under nonfederal control. Abundance models generate estimates of numbers, biomass, or population growth and productivity. A good example is the biomass estimation model of Kitchell et al. (1978). Other models focus on population viability and often blend habitat-based model structures with population dynamics. These have specific use for endangered species analysis and only limited generalized process has emerged from them.

Certain population biomass models are based on biological energetics (e.g., Kitchell et al. 1978). At a larger community level, a number of energetics or material-flow models have been developed. These are ecosystems models that track material and energy pathways from sources to sinks through production, biomass, and guilds or populations that constitute communities (e.g., Jorgensen et al. 1983; Odum 1983; Starfield and Blelock 1986; Chapra and Reckhow 1983). Some models are quite elaborate and include material recycling processes. Some models were first developed during the International Biological Program conducted in the 1970s and have since been refined and applied to a diversity of ecosystem conditions (e.g., McIntire and Colby 1978). An important element in such models is estimation of trophic-level and resource-partitioning efficiencies, as illustrated in Figure A-1. With further development, they may be used to evaluate management impact on ecosystem-wide processes and various holistic measures of biological integrity.

Most early versions were bottom-up models, which assumed that regulation of efficiency was entirely from habitat-based sources such as suspended sediment, nutrient, water color, flushing rates, and substrate stability. More recently, the top-down effect of predation has been modeled. So far, however, the top-down process has not been well integrated with the bottom-up process in comprehensive models despite the basic information to do so (Carpenter and Kitchell 1992). Effective management models, even if focused on the bottom-up process, much as the Corps is focused, cannot ignore interactions with agencies that manage the top-down process. In isolated instances, such as in grass carp introduction to control aquatic plants, the Corps may directly participate in top-down management.

Ecosystem Process Models

A number of models have been designed to analyze for the effects of ecological processes on ecosystem level outputs, such as sequestering of materials in ecosystem biomass and sediments (Mitsch and Gosselink 1986; Gosselink et al. 1990). Much work needs to be done, however, to interface management models with ecological process models in a way that Corps activities or other management activities can be superimposed to assess the impacts in terms of ecological output and their attendant human services and benefits.

Although there is great potential for developing comprehensive management models relevant to project activity of the Corps, there has been little concerted effort to do so. Few models have attempted to integrate natural and human-caused processes into management models with an ecosystems structure incorporated in the models and with both economic and ecological consequences. An example of such a model is a comprehensive management model developed for New Mexico sport fisheries (Cole et al. 1990, 1995). It is a practical applications model that incorporates a statewide perspective with watershed interactions, angler impacts on fisheries, and angler economic benefits derived from the fisheries. Although limited in management perspective, the approach taken in the New Mexico model can be extended to many other uses and over a larger geographical area.

A new area of model development is under way that addresses ecological processes at the landscape level. These models address the movement of materials, organisms. and energy among landscape elements and build on material transport models created to analyze atmospheric processes, water movement, and sediment and contaminants transport (Turner and Gardner 1991). The most useful models in the future will integrate landscape process, material transport, ecological energetics, habitat qualities, community production, population dynamics, human use and benefits, and management impact. Even though the elements are present, integration and development will require time and money and will be constrained by computer capacities and reliable information. Development of geographical information systems software in recent years has facilitated landscape process modeling.